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2D-HEC-RAS MODELING OF THE FLOOD WAVE PROPAGATION DUE TO THE RTH FLOTATION DAM OVERTOPPING FAILURE

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Abstract

The earth dams, formed to create a storage space for mining waste disposal are called the flotation dams. Incidents at these dams are not uncommon, and as a result, the dam can ultimately collapse and form a flood wave. The simulation of a dam breach and flood wave propagation is aimed to determine the flooding boundaries and the time of arrival the flood wave to ensure the precautionary measures, alerts, and notifications. This study presents a 2D HEC-RAS model was used for the flood wave propagation. Attention will be focused on defining the input parameters when creating the model.

***Keywords**: HEC-RAS, flotation dam, flood wave*

1. INTRODUCTION

Flotation dams are essential in the processing and production of metals and very significant from the social urban and ecological aspect. However, on the other hand, they represent a significant potential danger due to the possibility of dam breaches and formation the flood waves. In such a case, the downstream population, environment, and infrastructure would be at risk. Determining the extent of the flood wave is crucial for assessing the flood risks and adequately planning the emergency responses. Modeling allows the identification of the most vulnerable areas, facilitating timely evacuation and protection of population. It also enables the assessment of potential damage to the infrastructure and natural resources.

The HEC-RAS program is most commonly used for the flood wave modeling today. It was developed by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers. The program enables the simulation of both steady and unsteady flow in the river channels and flood zones, which is crucial for the flood wave modeling. Both 1D and 2D modeling options are available. The 1D modeling uses the 1D Saint-Venant unsteady flow equations, while the 2D modeling uses the 2D Shallow Water Equations (Saint Venant Equations) or 2D Diffusion Wave Equations [2].

The 2D models can show how the flood wave spreads and behaves in different parts of the river system, including the role of floodplains and wider river areas. Additionally, an integration with the GIS tools allows for better analysis and visualization of the results, providing a significant advantage over the 1D models. Therefore, the use of 2D models in the flood wave propagation solutions has become a common approach.

2. STUDY AREA

The city of Bor, located in eastern Serbia, is one of the main centers of mining activities in the country. The flotation tailing dam in the area of the old open pit of the ore body "H" has been in operation work since 1985. It is located near the city center, about 500 meters east of the flotation facilities.

To ensure the continuity of flotation work and tailings disposal in RTB Bor, it is planned to raise the tailing dam RTH from the current crest elevation of 380 m altitude to the elevation of 390 m altitude. Accordingly, a flood wave model was created for the potential breach of the dam. The calculation covered the valley of the old Bor River channel to its confluence with the Krivelj River.

3. PROCESS OF A MODEL FORMATION IN THE PROGRAM HEC RAS

3.1 General

At the very beginning of model creation, a map of the area in .tif format was used, allowing the formation of the terrain using the RAS Mapper tool within the HEC-RAS 5.0.7 software package. Terrain processing is an essential part of a model preparation and depends on the data from the obtained map. It often involves manually adding culverts under bridges because when creating the terrain map, the bridge elevation is represented as the terrain elevation, causing water to be retained upstream. Processing can also involve adding or removing the certain objects, adjusting point elevations that have been processed through a detailed geodetic survey of the terrain, etc., all to form a more relevant model.

After that, the contours of tailings (geometries - Storage areas) and flood zones (geometries - 2D Flow areas) are defined. It is important to create a dense enough mesh for the flood zone, especially along the river course, otherwise, the model will be unstable. The next step is to establish the connection between the flood zone and tailings, i.e., to define the dam.

The tailing dams are built from tailings or earth material and differ from standard ones in shape as well. In this case, only the northeastern side is surrounded by the terrain (Visoki planir), while the rest of the storage space is bounded by an embankment approximately 2200 meters long. When defining the dam in the HEC-RAS model, it is sufficient to define a specific segment at the potential breach location instead of the entire length of embankment.

Feeding the model with necessary data is done on the basis of an analysis of topographic, hydrological, and hydraulic characteristics of the area, and defining the dimensions and formation of the breach.

3.2 Topographic Bases

In this case, an important topographic factor is a depression south of the tailings. In the event of a dam breach on its eastern or southern side, part of the flood wave would certainly be retained in this depression, making it crucial to determine the retention capacity of depression.

3.3 Hydrological Bases

From a hydrological perspective, it is important to determine the volume of flood wave, which in the case of tailings represents a two-phase fluid (water + tailings). Therefore, it is important to determine the amount of water and amount of material that will participate in the flood wave. Water arrives at the RTH tailing dump in two ways. The first is through the process, where for the needs of tailing transport by a pump pipeline, tailings are mixed with enough water and as a hydro-mixture reach the tailing dump. A pontoon pump station maintains the water level in the lake at the tailing dump, meaning the water volume in the lake during normal operation is constant. Therefore, water reaches the tailings naturally, i.e., from the atmospheric precipitation. When determining the volume from rainfall, data on the 100-year return period rainfall lasting 24 hours is used. The sum of volume from the rainfall and volume of the lake represents the liquid phase volume of the flood wave, which in this case is $749x10^3$ m^3.

Determining the solid phase is one of the most critical parameters of the flood wave. The volume of the solid phase largely depends on a dam height, assumptions about the elevation and dimensions of the breach, and type of tailings being disposed of. In this case, it was assumed that the solid phase would be mobilized in the amount of 83x10^3 m^3, representing about 10% of the two-phase fluid volume.

A flood wave of two-phase fluid has the greater flooding depths and slower propagation speed compared to a "clean water" flood wave. Therefore, the criterion was established that for marking the flood-prone areas, the results of calculations for water and tailings mixture wave (which gives the greater flooding depths) are used, while for notifying and alerting the population, the "clean water" wave (which has a higher propagation speed) is used.

3.4 Hydraulic Bases

In general, the hydraulic bases would consist of the measured water level lines for different flows on a river section to successfully calibrate and verify the results of calibrated numerical model. Due to a lack of recorded water level lines, it is not possible to calibrate the Manning's roughness coefficient values, as the roughness coefficient is usually a calibration factor. In this case, when the recorded water level lines are not available, the Manning's roughness values are determined by the field surveys and gaining insight into the riverbed characteristics, the degree of bank vegetation, and vegetation type. In this case, the estimated resistance value for the "clean water" scenario for the main riverbed is n=0.04 $m^{-1/3}s$, and inundations, n=0.06 $m^{-1/3}s$.

It should be noted that this is a necessary approximation, meaning that the spatial and temporal variability of resistance is neglected. This means that the change in roughness coefficient values along the watercourse and inundations and its dependence on flow or water level is not considered.

Regarding the flow resistances, it should be considered that these resistances also depend on the physical properties of the fluid. In the case of dense water and solid material mixtures - "two-phase fluid," the internal resistances increase with the proportion of the solid phase in mixture. The only way to consider the increase in the viscosity of this mixture is by adjusting the Manning's roughness coefficient. In this particular case, the estimated resistance coefficient values for the Bor River section should be multiplied by a factor of 1.5. Additionally, it was assumed that the increased Manning's coefficient values do not change spatially or temporally, resulting in the safety-oriented outcomes.

3.5 Defining the Breach Characteristics

Considering the large number of tailings dam failures, the International Commission on Large Dams (ICOLD) has conducted several studies to determine the causes of these incidents. Between 1915 and 2016, a total of 209 incidents were recorded. Excluding a group of 52 incidents for which the cause is unknown, the overtopping is the most common cause of the tailing dam incidents. This data was used to select the "Failure mode" in the Storage Area Connection Breach Data window.

Due to the length and construction characteristics of the earth-fill dams, their failure can only be partial and progressive, with the formation of a breach in the dam body. The cross-section of the breach is a trapezoidal or rectangular in shape. The width at the bottom, height, and rate of development of the breach are defined on the basis of data from historical dam breaches. In this case, a trapezoidal cross-section with the side slopes of 1:1, bottom width of 30 m, and a formation time of 15 minutes was adopted.

4. RESULTS

Based on the given input data, an unsteady flow calculation was carried out for both the clear water model and water-tailings mixture model. The calculation results produced a diagram of arrival the flood wave peak, shown in Figure 1 (blue line - mixture, orange line - clear water). It can be observed that as the distance from the breach increases, the difference in arrival time also increases. In the initial sections, this difference is negligible. At a distance of 5 km, this difference is about 0.15 hours, and at a distance of 9 km, the difference is almost 0.35 hours.

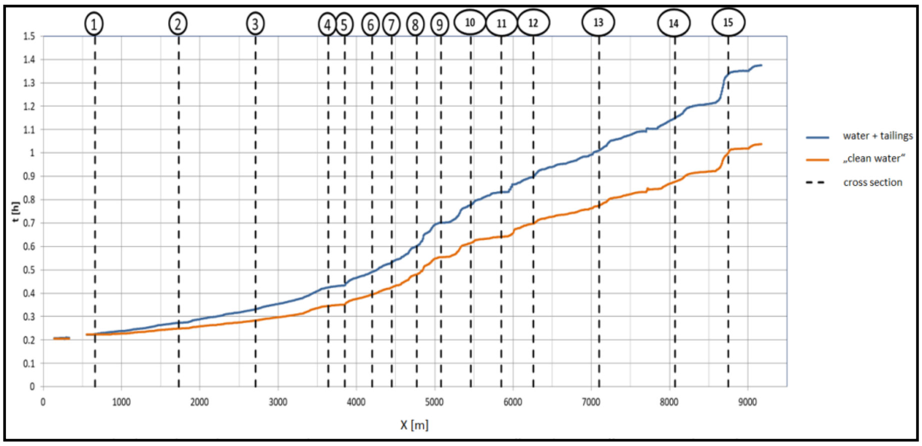

Figure 1. *Diagram of arrival the flood wave peak*

5. CONCLUSION

Modeling of the flood wave is necessary to identify the most vulnerable areas and plan adequate responses to emergency situations. The HEC-RAS program is particularly important in this context, enabling the precise simulations of a flood wave propagation, which is crucial for timely evacuation and protection of the population. The use of advanced 2D models provides a detailed analysis and visualization of possible consequences, significantly increasing safety and efficiency of planning responses to the potential accidents.

The detail and accuracy of input data are crucial for successful modeling. Topographic maps must be precisely defined to identify all key terrain features, such as depressions that can retain part of the flood wave. A quality DEM map allows the creation of a relevant terrain model in tools such as RAS Mapper. Hydrological inputs define the volume of a flood wave, while the hydraulic inputs are essential for determining the propagation speed and flood depths of the given flood wave.

It is important to carry out calculations for two models: the clear water model (Manning's coefficient determined on the basis of surveyed water level lines or field visits) for determining the propagation speed, and the two-phase fluid model (higher Manning's coefficient) for defining the flood zone.

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REFERENCES

[1] Supplementary Mining Design of Elevation the Flotation Tailing Dump RTH, MME Bor, 2023.

[2] I.R. Karim, Z.F. Hassan, H.H. Abdullah, I.A. Alwan, Civil Engineering Journal, 7(9) (2021) 1501-1514.

[3] K. Thygesen, E. Baker, P. Sevaldsen, C. Roche, Mine Tailings Storage: Safety is no Accident, 2017.