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EDITORIAL - Preface to Volume 11 Issue 2 of the Scientific Journal of Civil Engineering (SJCE)

Vladimir Vitanov EDITOR - IN - CHIEF

Dear Readers,

The **S**cientific **J**ournal of **C**ivil **E**ngineering (SJCE) is an international, peer-reviewed, open-access journal that has been published bi-annually since December 2012. Since December 2021, SJCE has established its own website and implemented a fully digital submission, review, and publication process. For additional information about the online version of the Journal, please visit www.sjce.gf.ukim.edu.mk.

Our commitment at SJCE is to publish and disseminate high-quality and innovative scientific research in the broad field of engineering sciences. The journal is dedicated to advancing technical knowledge and promoting innovative engineering solutions in civil engineering, geotechnics, survey and geo-spatial engineering, environmental protection, construction management, and related areas.

We strive to offer the best platform for researchers to publish their work transparently and integrally through the open-access model, providing a forum for original papers addressing theoretical and practical aspects of civil engineering and related sub-topics.

As the Editor-in-Chief of the Scientific Journal of Civil Engineering, it gives me great pleasure to present to you the Second Issue of Volume 11, an open-subject edition featuring six scientific research papers that have successfully undergone the general review process of this journal.

These papers cover a range of advanced scientific topics. The first paper analyses static pile load testing to determine axial capacity, demonstrating minor deformations and employing numerical modelling for assessment the ultimate axial capacity of the pile. The second explores automatic building footprint extraction from LiDAR data. The third paper introduces a method to determine the rotational stiffness of welded connections between square columns and I-beams, comparing semi-rigid versus fully rigid connections in frame structures. The fourth paper examines challenges in providing displacement overview in composite steel-concrete frames, proposing a numerical solution, and comparing findings with EN 1994-1-1 recommendations. The fifth paper discusses causes of embankment dam failure, emphasizing overtopping as the most common reason, and analyses flood propagation at a cascade system of tailings dams, while the final paper outlines the characteristics of the Transverse Mercator projection and its applications, highlighting its advantages over the Gauss-Kruger projection.

I sincerely hope that the papers published in this issue will inspire further research in these fields. I extend my gratitude to all the authors for contributing to this issue, and I appreciate the detailed and timely evaluations provided by the reviewers. Finally, I wish to extend my heartfelt gratitude to the editorial office members who demonstrated remarkable enthusiasm and made significant contributions to this journal issue.

Best regards,

Vladimir Vitanov

Editor-in-Chief

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CONTENTS

PROPAGATION OF FLOOD WAVE CAUSED BY TAILINGS DAMS FAILURE

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Embankment dams' failure is often caused by overtopping during flood wave – caused by insufficient spillway capacity. Failure can also be caused by progressive seepage through the dam's body as a result of increased contact seepage alongside an internal manmade waterway. Other causes for dam failure, include: slope instability of embankment dams, damages in the dam body caused by earthquakes, liquefaction of earth dams under static and seismic action, and flood waves caused by earthquake – induced landslides into the reservoirs from the valley sides [1]. According to ICOLD, the most common reason for embankment dams' failure is overtopping – 30÷35% of all registered cases. During dam failure, as result of the immediate discharge of the impounded water in the reservoir – or impounded flotation tailings at tailings waste lagoon - in the downstream river valley, a catastrophic flood wave makes its hazardous way towards destruction. Normally, the time needed for the flood wave warning system to activate, is much shorter than the time needed for the formation of the flood wave caused by rainfall – runoff. Thereafter, depending on the location of the dam, a potential dam failure – especially in case of tailings dam failure – could result in catastrophic losses of human lives, destruction of agricultural land and long-term degradation of the environment. In this manner, as follows, results of 2D analysis for flood propagation at a cascade system of tailings dams Sasa 3-2 and Sasa 4 are analyzed. Both cascade dams are located in the northeast part of RN Macedonia, on river Saska. The analysis is conducted with the use of the software program HEC RAS.

Keywords: flood wave, dams, tailings, failure, 2D analysis, HEC RAS

1. INTRODUCTION

Tailings storage facilities (TSF) are a special type of structures comprised of a tailings dam and waste lagoon, built to store mud and waste tailings from mining technological process. During the service period of tailings storage facilities (TSF), flotation tailings with hydro transport (usually gravitational pulp line) is transported to the tailings dam crest. There, with hydro-cycloning, tailings separate into two fractions. With the coarser, or dry fraction (cycloned sand), the dam body is created, and the finer fraction (cyclone mud) is deposited in the waste lagoon.

Currently, thousands of tailings dams worldwide contain billions of tons of waste material from mineral processing. TSFs should be constructed to achieve a safe, stable post – operational tailings pond [2] [3] and to contain the waste materials indefinitely [4]. Therefore, they are supposed to last forever, however, since 1960 there have been over 80 major TSFs failures reported around the world, with the last one reported on January 31st 2023 in Kearl oil sands mine, Alberta, Canada [5].

On January 25, 2019, tailings dam No. 1 of Vale's external link Córrego do Feijão iron ore mine near Brumadinho, Região Metropolitana de Belo Horizonte, Minas Gerais, Brazil, suddenly failed, releasing almost its complete holdings of 12 million cubic meters of tailings in a big burst. As a result, 267 people have been declared deceased and many others as missing [5].

On Aug. 4, 2014, the tailings dam of Imperial Metals Corp.'s Mount Polley copper and gold mine near Likely, British Columbia, Canada, failed, releasing 7.3 million m^3 of tailings, 10.6 million m^3 of water, and 6.5 million m^3 of interstitial water into the environment. The tailings flowed into adjacent Polley Lake and Quesnel Lake, snapping countless trees in its 50 m wide flow path [5].

2. CASE STUDY

Within the zinc and lead mining complex 'Sasa', located in the northeast part of RN Macedonia some 12km upstream from the city of Makedonska Kamenica, five cascade tailings storage facilities (TSFs) are formed: TSF Sasa 1 at 1035 masl, TSF Sasa 2 at 1015 masl, TSF Sasa 3-1 at 995 masl, TSF Sasa 3-2 at 978 masl and TSF Sasa 4 at 952 masl. The fifth TSF – TSF Sasa 4 – is currently in service period (Figure 1).

All TSFs are located in the riverbed of Saska river (also known as 'Kamenichka river'). The river itself has been permanently diverted by diversion tunnel under the right bank.

TSFs Sasa 1, 2 and 3-1 had been formed over 30 years ago and in the past period, their waste lagoons have mostly consolidated and hardened.

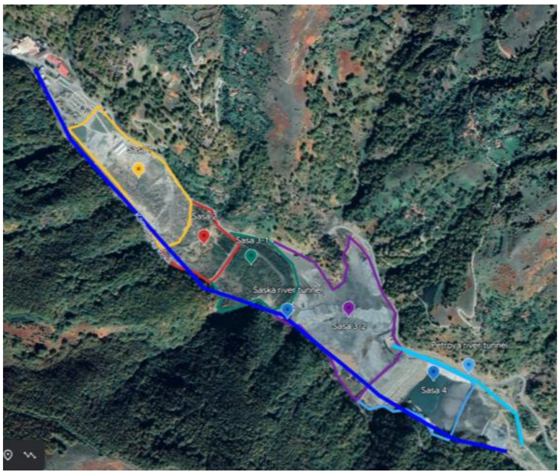

Figure 1. Layout configuration of all five TSFs in the zinc and lead mining complex 'Sasa'. The diversion tunnel for Saska river is under the right bank, whereas the tunnel for Petrova river is under the left bank. Source: Google Earth

TSF Sasa 3-1 is no longer in service since 2003, when an accident occurred with the drainage system. During this accident, a large crater was formed in the waste lagoon Sasa 3-1 (Figure 2), and mudflow propagated downstream in the river valley. The height of the flow was around 10m, and the flood wave reached 12km in length. It is assumed that some 70 000 – 100 000 m^3 of tailings was discharged in the river valley and subsequently in Kalimanci lake [4]. Today, two decades after the accident, downstream of TSF Sasa 3-1, the waste lagoon of Sasa 3-2 is located. It is assumed that the sand dam of Sasa 3-1 keeps the lagoon stable and the risk of mud propagation from Sasa 3-1 is minor [6].

Figure 2. Picture of the visible part of the crater formed in the lagoon of Sasa 3-1

Currently in operation stage is TSF Sasa 4, which is created with construction of a combined tailings dam, with crest elevation of 932.0 masl in October, 2022 (Figures 3 and 4). Designed crest elevation of the tailings dam Sasa 4 is 952.0 masl, with maximal waste lagoon elevation of 950.0 masl.

Figure 3. Downstream tailings dam Sasa 4, waste lagoon of Sasa 4, and upstream tailings dam Sasa 3-2. Picture dates from October, 2022

Figure 4. Downstream slope of tailings dam Sasa 4. Picture dates from October, 2022

Since tailings storage facilities pose major hazard for the downstream river valley, it is crucial to know the potential flood wave propagation area in order to minimize the damaging environmental and social impacts. Dam breach inundation studies are required to evaluate the potential impacts of hazards associated with TSF at all stages of design, whether the facility is proposed, operating or closed [7].

In this paper, the propagation of a potential flood wave caused by dam breach of TSFs Sasa 3-2 and Sasa 4 are analyzed and discussed. It is assumed that the upstream TSFs (Sasa 3-1, Sasa 2 and Sasa 1) no longer pose threat to the downstream valley.

3. DESCRIPTION OF ANALYSES

In the following analyses, a simultaneous cascade dam failure is analyzed for both TSF Sasa 3-2 and Sasa 4, constructed up to their designed crest elevations – TSF Sasa 3-2 crest elevation at 978.0 masl, and TSF Sasa 4 crest elevation at 952.0 masl. Dam breach is presumed up to the crest of their respective initial dams – for Sasa 3-2 the final bottom elevation of the breach is 937.5 masl, and for Sasa 4 – 906 masl.

Storage areas for both Sasa 3-2 and Sasa 4 are defined through volume – elevation curves (Figures 5 and 6).

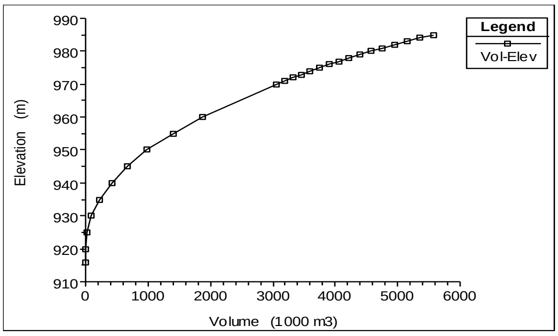

Figure 5. Volume – elevation curve for Sasa 3-2 TSF

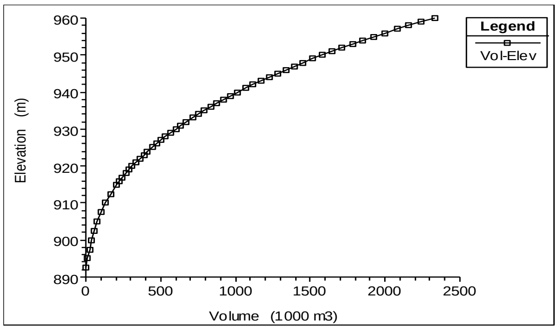

Figure 6. Volume – elevation curve for Sasa 4 TSF

Two scenarios were modelled and discussed.

First scenario assumes waste lagoons at normal operating levels, and dam failure in static conditions, with rainfall – runoff conditions equal to dry state. This scenario is a replica of a situation where an earthquake occurs, or, unfavorable seepage through the tailings dam is the failure cause [6].

The second scenario assumes dam failure caused by overtopping, with flood wave formed with rainfall – runoff from the upstream basin of Petrova and Saska river with probability of occurrence of for return period of T=10 000 years [6].

The analyses were conducted with application of program HEC RAS 6.3.1. Topographic bases were derived from Lidar maps, with pixel accuracy of 10x10m. The model was prepared for 2D analysis, with the use of RAS Mapper. The roughness coefficient is presumed to 0.06 for the whole inundation area, since major part of it is under natural grassland, woods and pastures.

Like most forensic studies, and all predictive, emergency-management simulations, the following models did not have in situ concentration measurements or rheological data. These parameters can be difficult to measure in controlled laboratory settings. They are practically impossible to measure directly during an event of this scale, which is unpredictable, dangerous, and includes clasts larger than any sampler. Therefore, the fluid is modelled as non – Newtonian, with parameters defined in respect to the Bingham plastic approach. This case study evaluated the model performance with the uncalibrated published parameters, reported for 'standard soil' in Julien (1995) [11] [12]. The volumetric concentration of the fluid is adopted at 60%, with yield strength defined through the exponential method with respect to the following coefficients: a = 0.005, b = 7.5 and B = 8 [11] [12]. A widely used formula to estimate the yield stress is the exponential formulation [13] [14] [15]:

$$\tau_y = a \cdot e^{b \cdot C_v} \qquad (1)$$

, where:

τ_y – yield stress,
a, b – Calibration coefficients,
C_v – Volumetric concentration.

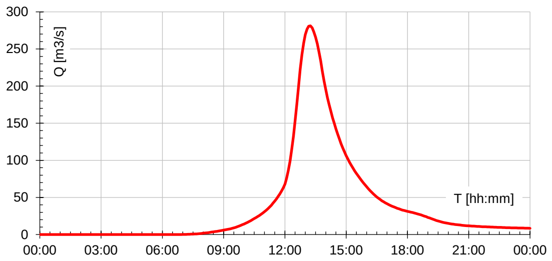

Figure 7. Hydrograph of flood wave for Saska river, with recurrence interval of T = 10 000 years, with max peak Q_{max} = 281.20 m^3/s

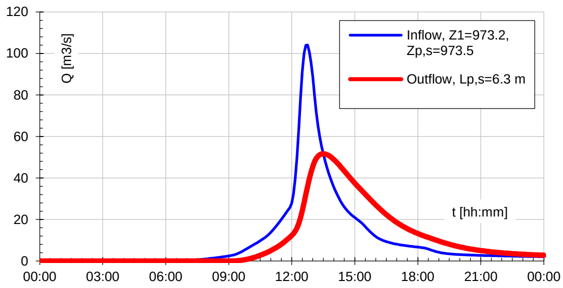

Figure 8. Hydrograph of flood wave for Petrova river, with recurrence interval of T = 10 000 years, inflow and outflow hydrograph

It should be noted that Saska river is completely diverted from the tailing facility location, and its flood wave (Figure 7) is expected to have effect in the riverbed downstream of the TSF Sasa 4, hereinafter it does not contribute to the rainfall – runoff input for any of the scenarios. Its hydrograph is entered as a boundary condition downstream of Sasa 4, and its influence increases the total flood wave effect in the downstream valley, however, it does not have effect on the dams' failure. On the other hand, the tributary of Saska river – river Petrova, enters the reservoir of TSF Sasa 3-2. For evacuation of the expected flood wave (Figure 8), a spillway with tunnel structure is designed in TSF Sasa 3-2 (Figure 9).

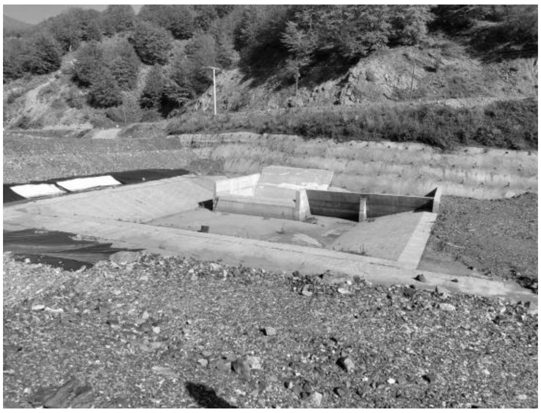

Figure 9. Spillway structure in TSF Sasa 3-2 for evacuation of flood wave from Petrova river

For the overtopping analyses, it is assumed that a trapezoid breach will occur (Figure 10), with top level of breach equal to dam crest elevation, and bottom level equal to the crest elevation of the initial dams respectively. The slopes of the trapezoid breach are assumed as V:H = 1:1, and final bottom width of 60m for TSF Sasa 3-2, and 40m for Sasa 4. The breach formation time is adopted as 24min.

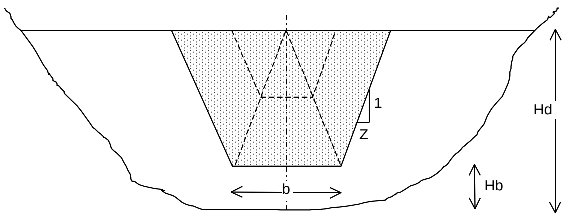

Figure 10. Representative scheme for the mathematical model for overtopping analyses

It is assumed that the failure starts on crest elevation with linear or non-linear progression towards the bottom of the trapezoid breach, where it reaches its final width. Breach flow is calculated with respect to Bernoulli equation for crest spillways.

4. RESULTS AND DISCUSSIONS

The area of interest is located between the TSF Sasa 3-2 as the most upstream point of the model, and the Kalimanci Lake as the most downstream point. Before entering the Kalimanci Lake, Saska river passes through the city of Makedonska Kamenica, and the analyses are greatly focused on determining the flood wave propagation in this zone.

Table 1. Both scenarios with the size of inundation area according to the output results

Scenarios	Inundation area [m^2]	Inundation area [km^2]
Scenario 1	2,110,199	2.11
Scenario 2	**2,137,100**	**2.14**

According to the output results for both scenarios, the second one is more hazardous – just as expected (Table 1). Its flood wave inundates 0.03 km^2 larger area than the first scenario (Figures 13 and 18). The difference between the results paints a picture where the flood wave caused by dam breach is much larger than the one formed by rainfall – runoff. As follows, results are given for both scenarios.

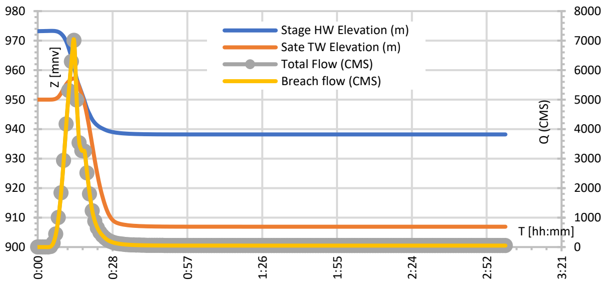

Figure 11. Hydrograph of water level and flood wave in the profile of TSF Sasa 3-2, for scenario 1

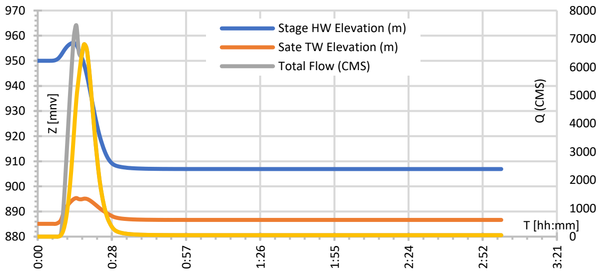

Figure 12. Hydrograph of water level and flood wave in the profile of TSF Sasa 3-2, for scenario 2

For scenario 1 (Figures 11 and 12), the maximal flow expected as breach flow at TSF Sasa 3-2 is Q_{max} = 7006 m^3/s, whereas at TSF Sasa 4 it is Q_{max} = 6652 m^3/s. The total breach flow at TSF Sasa 4 is Q = 7475 m^3/s. As the breach progresses downstream, combined with the flood wave of Petrova river and Saska river, its maximal value just downstream of TSF Sasa 4 is Q = 7609 m^3/s. The time difference between dam breaching of Sasa 3-2 and Sasa 4 is 5min.

The flood wave propagation time is 19min (Table 2), for 12km distance between the most upstream and most downstream profile (Figure 11). The water surface elevation in the city of Makedonska Kamenica reaches 558.0 masl before entering the city, and at the last profile before Kalimanci Lake, it reaches 521.0 masl. The maximal water depth of the flood wave coming through the city, is approximately 9m.

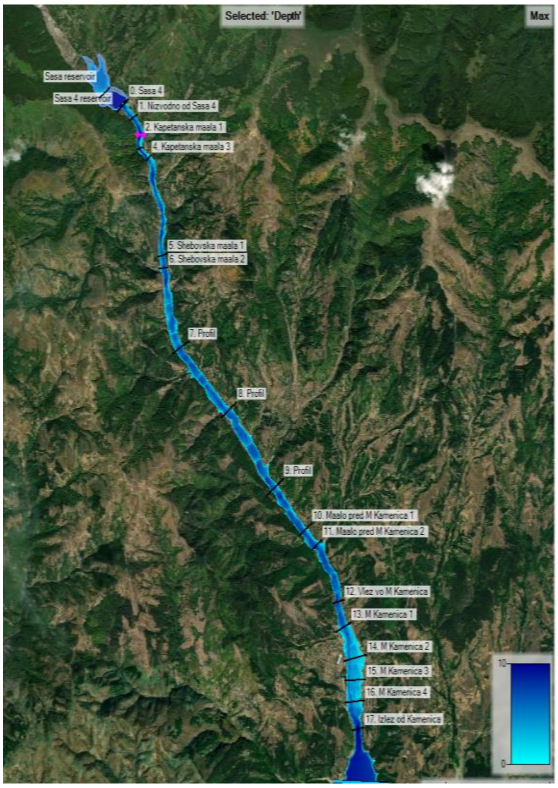

Figure 13. Flood mapping for scenario 1

In order to summarize the results from the conducted analyses, 18 profiles along the downstream riverbed were chosen where hydrodynamic parameters of the flow were observed (Table 2). Profiles located in the city of Makedonska Kamenica are profiles from no. 12 to no. 17.

Table 2. Profiles, maximal flow at each profile, time of flood wave propagation, as well as maximal elevation of water level at right and left riverbank for scenario 1.

Profile	Qmax	t	Elevation (L)	Elevation (R)
	m3/s	hh:mm	m asl	m asl
00=Sasa 4	3273.91	0:15	927.35	928.71
01=Nizvodno od Sasa 4	7609.07	0:15	879.32	880.77
02=Kapetanska maala 1	7472.84	0:15	868.13	868.00
03=Kapetanska maala 2	7278.86	0:15	857.17	857.81
04=Kapetanska maala 3	7382.81	0:16	844.51	844.82

05=Shebovska maala 1	7390.94	0:17	752.06	752.87
06=Shebovska maala 2	7287.58	0:17	743.71	743.66
07=Profil	7216.19	0:19	691.47	691.20
08=Profil	6969.92	0:21	649.08	649.99
09=Profil	6619.12	0:25	611.79	612.08
10=Maalo pred M Kamenica 1	6603.10	0:27	588.11	588.54
11=Maalo pred M Kamenica 2	6566.20	0:27	580.90	581.91
12=Vlez vo M Kamenica	6477.56	0:29	557.95	558.37
13=M Kamenica 1	6389.92	0:30	548.98	549.02
14=M Kamenica 2	6298.10	0:31	535.14	535.54
15=M Kamenica 3	6141.88	0:32	529.03	528.43
16=M Kamenica 4	5986.15	0:33	520.84	521.09
17=Izlez od Kamenica	5676.31	0:34	517.04	516.98

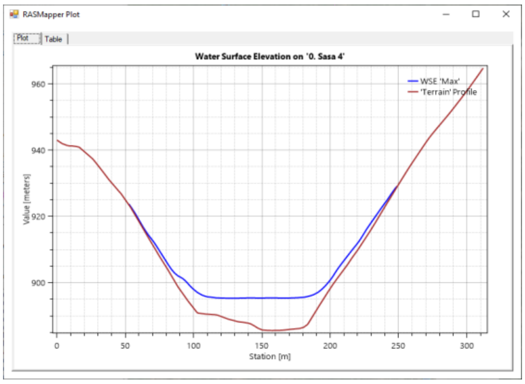

Figure 14. Water surface level at profile 00 – downstream of TSF Sasa 4, for scenario 1

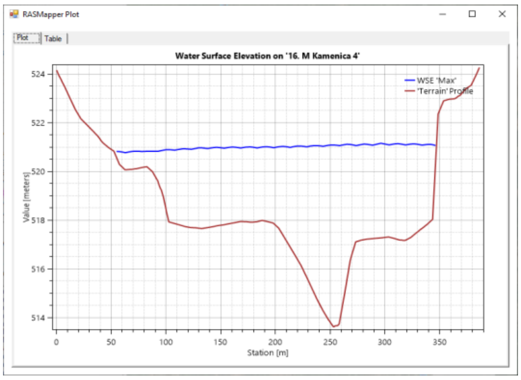

Figure 15. Water surface level at profile 16 – in the city of Makedonska Kamenica, for scenario 1

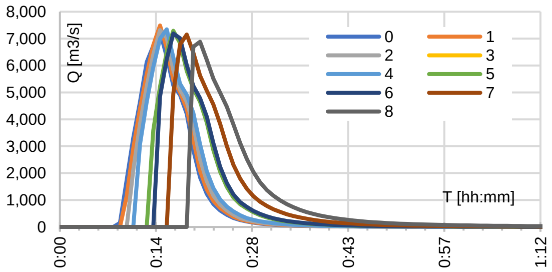

Figure 16. Hydrographs of flood wave propagation for profiles 0 – 9, for scenario 1

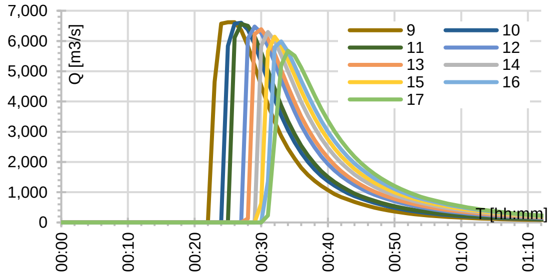

Figure 17. Hydrographs of flood wave propagation for profiles 10 – 17, for scenario 1

For scenario 2 (Figures 19 and 20), the maximal flow expected as breach flow at TSF Sasa 3-2 is Q_{max} = 7458 m^3/s, whereas at TSF Sasa 4 it is Q_{max} = 5684 m^3/s. The total breach flow at TSF Sasa 4 is Q = 7716 m^3/s. As the breach progresses downstream, combined with the flood wave of Petrova reka, its maximal value just downstream of TSF Sasa 4 is Q = 8271 m^3/s. The time difference between dam breaching of Sasa 3-2 and Sasa 4 is 5min.

The flood wave propagation time is 16min (Tab. 2), for 12km distance between the most upstream and most downstream profile (Figure 13). The water surface elevation in the city of Makedonska Kamenica reaches 558.0 masl before entering the city, and at the last profile before Kalimanci Lake, it reaches 521 masl. The maximal water depth of the flood wave coming through the city, is approximately 10m.

Maximal flow velocity during the flood wave is approximately 15 m/s, but not exceeding 10 m/s in the city of Makedonska Kamenica.

Table 3. Profiles, maximal flow at each profile, time of flood wave propagation, as well as maximal elevation of water level at right and left riverbank for scenario 2

Profile	Q_{max}	t	Elevation (L)	Elevation (R)
	m3/s	hh:mm	m asl	m asl
00=Sasa 4	7716.00	9:07	934.75	951.02
01=Nizvodno od Sasa 4	8271.40	9:07	879.82	881.52
02=Kapetanska maala 1	8287.69	9:07	868.54	868.39
03=Kapetanska maala 2	8200.69	9:07	858.03	858.18
04=Kapetanska maala 3	8096.28	9:07	844.63	844.99
05=Shebovska maala 1	8053.94	9:09	752.43	753.06
06=Shebovska maala 2	8110.41	9:09	744.15	744.04
07=Profil	7951.88	9:10	691.83	691.70
08=Profil	7779.89	9:12	649.52	650.51
09=Profil	7457.80	9:14	612.17	612.46
10=Maalo pred M Kamenica 1	7073.62	9:15	588.35	588.81
11=Maalo pred M Kamenica 2	6942.39	9:16	581.08	582.08
12=Vlez vo M Kamenica	6488.97	9:18	558.41	557.93
13=M Kamenica 1	6235.90	9:19	548.99	548.96
14=M Kamenica 2	6073.42	9:20	535.02	535.37

15=M Kamenica 3	5820.36	9:21	528.96	528.34
16=M Kamenica 4	5618.24	9:22	520.79	520.88
17=Izlez od Kamenica	5288.57	9:23	516.88	516.84

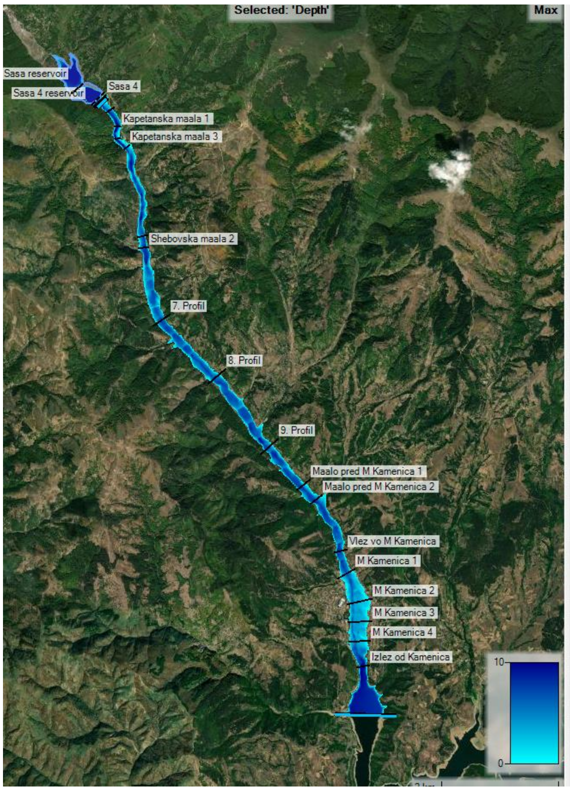

Figure 18. Flood mapping for scenario 2

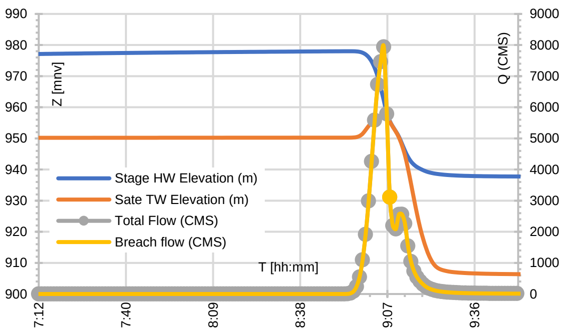

Figure 19. Hydrograph of water level and flood wave in the profile of TSF Sasa 3-2, for scenario 2

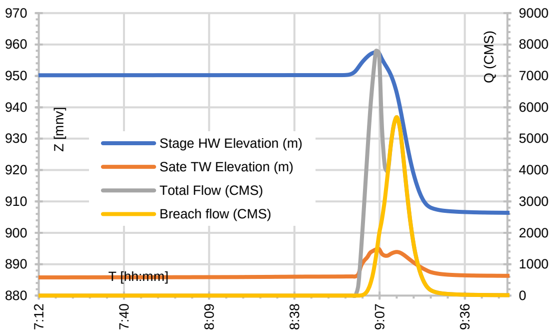

Figure 20. Hydrograph of water level and flood wave in the profile of TSF Sasa 4, for scenario 2

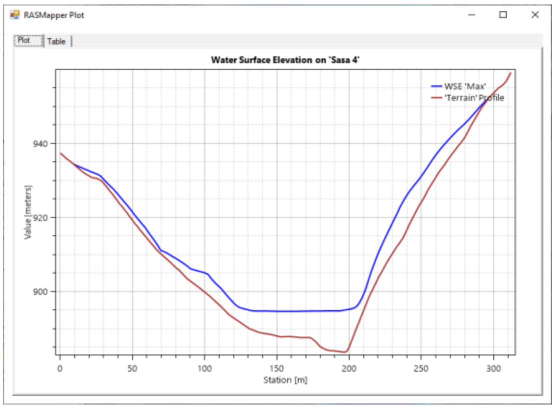

Figure 21. Water surface level at profile 00 – downstream of TSF Sasa 4, for scenario 2

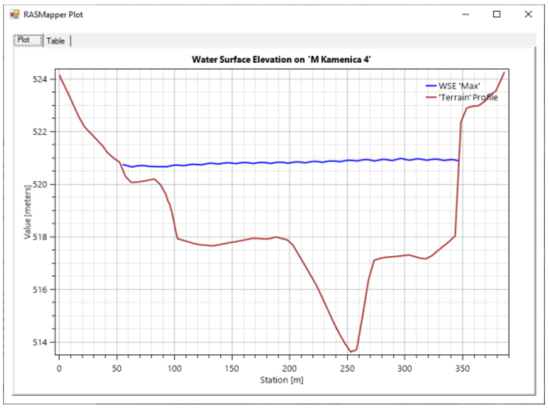

Figure 22. Water surface level at profile 16 – in the city of Makedonska Kamenica, for scenario 2

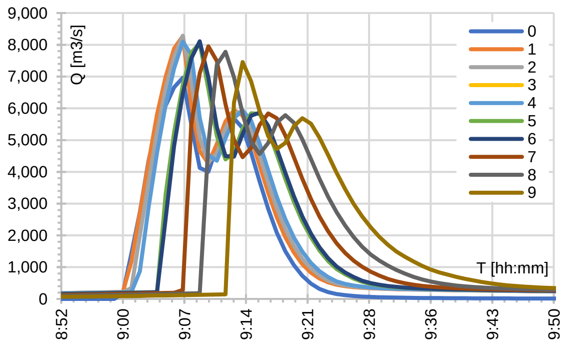

Figure 23. Hydrographs of flood wave propagation for profiles 0 – 9, for scenario 2

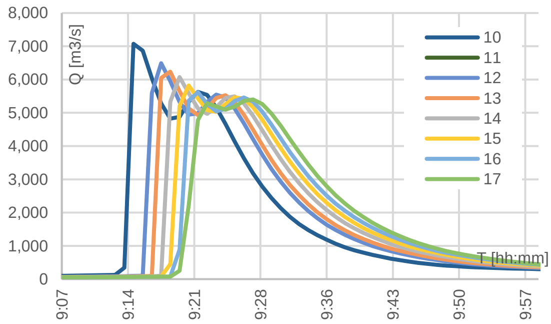

Figure 24. Hydrographs of flood wave propagation for profiles 10 – 17, for scenario 2

CONCLUSIONS

In order to evaluate the effect of breach flow of cascade dam failure, two different models are analyzed by application of plane (2D) HEC RAS software for the cascade system of tailings dams Sasa 3-2 and Sasa 4. Both tailings dams are part of the ore mining facility 'Sasa' located in east RN Macedonia.

Analyses were carried out by application of Lidar topographic maps, designed geometric characteristics of the TSFs and current geometric characteristics of the TSFs according to updated surveying.

Two scenarios were analyzed. First scenario assumes waste lagoons at normal operating levels, and dam failure in static conditions, with rainfall – runoff conditions equal to dry state. The second scenario assumes dam failure caused by overtopping, with flood wave formed with rainfall – runoff from the upstream basin of Petrova and Saska river with probability of reccurrence of 1 in 10 000 years.

For scenario 1, the maximal flow expected as breach flow at TSF Sasa 3-2 is Q_{max} = 7006 m^3/s, whereas at TSF Sasa 4 it is Q_{max} = 6652 m^3/s. The total breach flow at TSF Sasa 4 is Q = 7475 m^3/s. As the breach progresses downstream, combined with the flood wave of Petrova river and Saska river, its maximal value just downstream of TSF Sasa 4 is Q = 7609 m^3/s. The time difference between dam breaching of Sasa 3-2 and Sasa 4 is 5min.

For scenario 2, the maximal flow expected as breach flow at TSF Sasa 3-2 is Q_{max} = 7458 m^3/s, whereas at TSF Sasa 4 it is Q_{max} = 5684 m^3/s. The total breach flow at TSF Sasa 4 is Q = 7716 m^3/s. As the breach progresses downstream, combined with the flood wave of Petrova reka, its maximal value just downstream of TSF Sasa 4 is Q = 8271 m^3/s. The time difference between dam breaching of Sasa 3-2 and Sasa 4 is 5min.

It can be concluded that the effect of the flood wave caused by rainfall – runoff coming from the upstream basin of Petrova and Saska river is very minor compared to the flood wave caused by the cascade dams failure.

The alarming time between the initial breaching of the upstream Sasa 3-2 dam, and the arrival time of the flood wave in the city of Makedonska Kamenica, is very short – 15min for the second scenario which is the more hazardous one compared to scenario 1.

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