# TWENTY-SEVENTH INTERNATIONAL CONGRESS ON LARGE DAMS
# VINGT-SEPTIÈME CONGRÈS INTERNATIONAL DES GRANDS BARRAGES

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# VINGT-SEPTIÈME CONGRÈS INTERNATIONAL DES GRANDS BARRAGES

27th May–3rd June 2022
MARSEILLE – FRANCE

# TRANSACTIONS

# COMPTES RENDUS

*Published by the*
*International Commission*
*On Large Dams*

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*Publiés par*
*la Commission Internationale*
*des Grands Barrages*

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CRC Press/Balkema is an imprint of the Taylor & Francis Group, an informa business


Typeset by MPS Limited, Chennai, India

Published by: CRC Press/Balkema
Schipholweg 107C, 2316 XC Leiden, The Netherlands
e-mail: enquiries@taylorandfrancis.com
www.routledge.com – www.taylorandfrancis.com

ISBN: 978-1-032-07848-9 (Hbk)
ISBN: 978-1-003-21180-8 (ebk)
DOI: 10.1201/9781003211808

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QUESTION 104

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## CONCRETE DAMS DESIGN INNOVATION AND PERFORMANCE

a. Innovations for arch dam analysis, design and construction; including RCC arch and arch- gravity dams.

b. Innovations for design, construction materials and placement methods, flood management during construction and performance of concrete dams, including RCC and cemented material dams.

c. Innovations for raising existing concrete dams.

d. Innovations for extremely high concrete dams.

e. Operational performance of concrete dams during the life cycle, including under extreme conditions.

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## INNOVATIONS DANS LA CONCEPTION ET LA PERFORMANCE DES BARRAGES EN BÉTON

a. Innovations pour l'analyse, la conception et la construction des barrages-voûtes; y compris les barrages-voûtes en BCR et les barrages poids-voûtes

b. Innovations relatives à la conception, au choix des matériaux, aux méthodes de mise en place, au contrôle des crues pendant la construction et performance des barrages en béton, y compris en BCR et en matériaux cimentés.

c. Innovations pour la surélévation des barrages en béton existants.

d. Innovations pour les barrages en béton de hauteur extrême.

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**SURVEILLANCE, INSTRUMENTATION, AUSCULTATION ET ACQUISITION DES DONNÉES**

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DES GRANDES BARRAGES
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VINGT SEPTIÈME CONGRÈS
DES GRANDES BARRAGES
*MARSEILLE, JUIN 2022*
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# CONTRIBUTION ON RESTORATION OD TAILINGS DAMS DAMAGED AT INITIAL PERIOD OF CONSTRUCTION (*)

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MACEDONIA

## SUMMARY

The similarities between the tailing dams and the embankment dams for water storage have contributed a great number of procedures and techniques in the design, construction and maintenance of the conventional dams, to be applied to tailings dams. However, the numerous reports of collapses of the tailing dams in the last three decades, all over the World, indicate that the safety in the phases of design and construction were not controlled with the same rigor and carefulness - as for the embankment dams. This fact, in part, results from the long-term construction of the tailings dams, where as a building material is used sand obtained by separating of the waste material from floatation process during the exploitation of the mine. In this paper are presented results from the research and insights of the tailings dam Sasa 4 of mine Sasa, Makedonska Kamenica, Republic of North Macedonia, damaged in the initial period of construction in September, 2020, in order

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* *Contribution à la restauration des barrages de stériles endommagés à la construction*

 DOI: 10.1201/9781003211808-60

to: (1) detect the reasons for damaging, (2) determine urgent measures for providing of the required stability of the tailings dam at elevation 910.0 m asl, (3) to define measures for landscaping of the surrounding terrain and upgrade of the structures and the equipment for restarting of the tailings dam by current elevation of dam crest at 910.0 m asl and (4) to foreseen measures for further safe service of the tailings and construction of the tailings dam, from current elevation of 910.0 m asl till final elevation at 952.0 m asl.

## RÉSUMÉ

Les similitudes entre les barrages de stériles et les barrages en remblai pour le stockage de l'eau ont contribué à un grand nombre de procédures et de techniques dans la conception, la construction et l'entretien des barrages conventionnels, à appliquer aux barrages de stériles. Cependant, les nombreuses ruptures de barrages de stériles au cours des trois dernières décennies, partout dans le monde, indiquent que la sécurité dans les phases de conception et de construction n'a pas été contrôlée avec la même rigueur et la même prudence – que pour les barrages en remblai. Ce fait résulte en partie de la construction à long terme de ces barrages, où du sable obtenu en séparant les déchets du processus de flottation pendant l'exploitation de la mine est souvent utilisé comme matériau de construction. Dans cet article sont présentés les résultats de recherche et perspectives du barrage de résidus Sasa 4 de la mine Sasa, Makedonska Kamenica, République de Macédoine du Nord, endommagé pendant la phase initiale de construction en septembre 2020, afin de: (1) détecter les raisons des dommages, (2) déterminer des mesures urgentes pour assurer la stabilité requise du barrage à une altitude de 910 m, (3) définir des mesures d'aménagement paysager du terrain environnant et de modernisation des structures et de l'équipement pour le redémarrage du barrage de stériles par l'élévation actuelle de la crête du barrage à 910,0 m d'altitude et (4) aux mesures prévues pour une exploitation plus sûre et la construction du barrage depuis l'élévation actuelle de 910,0 m d'altitude jusqu'à l'élévation finale à 952,0 m d'altitude.

## 1. INTRODUCTION – SAFETY OF TAILINGS DAMS

The tailings dams are complex engineering structures, composed of starter dam, sand dam, waste lagoon, drainage system, water conveyors for taking out of the cleared water and structures for protection in case of inflow (external) water. The tailings dams, on one hand, due to the numerous structures of which are composed, should be inspected on great number of safety cases at static and dynamic loadings, similar as for conventional fill dams [1], [2], [3], and on other hand, due to the enormous volume of the waste lagoon, they are fill structures with highest potential hazard for the surrounding [4]. Due to the great importance of the tailings dams, one


Fig. 1
Location in Europe and map of Republic of North Macedonia
*Situation en Europe et carte de la République de Macédoine du Nord.*

of the ICOLD's Technical Committees specifically deals for such hydraulic structures - ICOLD Committee on Tailings dams and Waste Lagoons, that has published 10 Bulletins, [5], [6]. Due to the long construction period, the approach for conventional dams (for creation of water reservoirs) for confirmation of proper accomplishment of the hydraulic structures – with full supervision of the construction and control of the first reservoir filling, as well and the assessment of the dam's proper behaviour with construction parameters throughout comparation with monitoring data, at most cases is not applied fully in case of tailings dams. Unfortunately, such main difference between the conventional and tailings dams is amplified in case of technical solutions with combined construction method [7], [8] and in case of heightening [9], [10] thus providing increase of the deposit space of the tailings dams. The aims of the research of the tailings dam Sasa 4 of mine Sasa, Makedonska Kamenica, Republic of North Macedonia (fig. 1), damaged in the initial period of construction in September, 2020 are: (1) to detect the reasons for damaging of the tailings dam, occurred on 14 September, 2020; (2) to determine urgent measures for providing of the required stability of the tailings dam at elevation 910.0 masl; (3) to define measures for landscaping of the surrounding terrain and upgrade of the structures and the equipment for further service of the tailings with the required safety, for actual crest elevation of the dam at 910.0 masl, (4) to foreseen measures for further safe service of the tailings and construction of the tailings dam, from current elevation of 910.0 masl till final elevation at 952.0 masl.

## 2. TAILINGS DAM SASA 4 – BASIC PARAMETERS

In the past period of service of tailings dam of mine Sasa in M. Kamenica, they were intended for deposition of the flotation tailings obtained with the

Fig. 2
Tailings dam and waste lagoon Sasa 4, February, 2020
*Barrage de Tailing et lagune de déchets Sasa 4, février 2020*.

technological process of flotation of minerals lead and zinc. It was transported by hydraulic transport (gravity pulpline) all to the dam crest of active tailings no. 1, 2, 3-1, 3-2 and 4, from where by cycloning was separated in two fractions. The downstream dams were constructed by the coarser dry fraction (sand), while the fine liquid fraction was deposited in the waste lagoons. According to the current state of the tailings, tailings dam no. 4 is active, that will be created by construction of combined tailings dam no. 4, by final crest elevation of 952.0 masl and waste lagoon at maximal active level of 950.0 masl. During construction of the starter dam Sasa no.4 (fig. 2), certain modifications took place (compared to the Basic design from 2014); (1) covering by geosynthetic impermeable lining of: (a) river bed upstream of the starter dam, (b) valley abutments up to elevation 950.0 masl upstream of the sand dam and (c) downstream slope of dam no. 3-2 below elevation 950.0 masl; (2) replacement of the material in the starter dam (constructed up to elevation 905.0 masl), so that low permeable graphite shale was replaced by permeable tailings mine rock, due to the plan for lining of the upstream slope with geomembrane (that later was not installed). The appropriate mathematical model for as built state of dam Sasa no. 4, at final stage is displayed on Fig. 3.

During service period of tailings dam Sasa no. 4, in period February-September, 2020 was carried out technical monitoring for the tailings dam, the appurtenant structures and waste lagoon, according appropriate Design for tailings dam monitoring. The measured values from the monitoring process of tailings dam Sasa no. 4, such as: surface displacements in the dam obtained by survey methods, water levels in the piezometers, seepage discharge in the drainage system, quality of the drained water, visual inspection of the dam and the surrounding terrain, were systemized in appropriate monthly reports. Afterwards an assessment of the safety of tailings dam Sasa no. 4 was done, by comparation of the measured values from monitoring with calculated values by the mathematical models and permanently was confirmed the global stability of the maximal cross section of the dam.

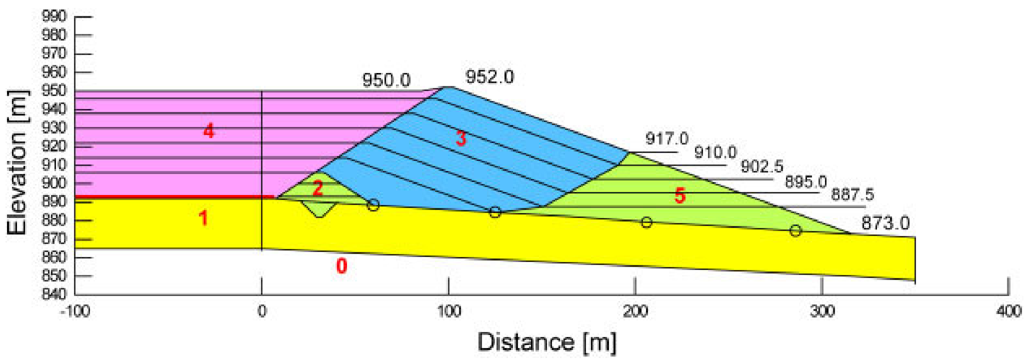


Fig. 3
Representative cross section of tailings dam no. 4, according to as built state, model with geomembrane in the riverbed.
*Coupe transversale représentative du barrage de résidus no. 4, selon l'état de construction, modèle avec géomembrane dans le lit de la rivière.*

| | | | |
|---|---|---|---|
| 0 | Rock foundation, | 0 | Fondation rocheuse |
| 1 | Deposit (variable depth) | 1 | Gisement (profondeur variable) |
| 2 | Starter (initial) dam (crest width b = 5.0 m, designed at elevation 906.0 m asl, constructed at 905.0 m asl) | 2 | Barrage de départ (initial) (largeur de crête b = 5,0 m, conçu à 906,0 m, construit à 905,0 m) |
| 3 | Sand dam (final crest elevation 952.0 m asl, crest width b = 5.0 m, profile axis X = 100 m) | 3 | Barrage de sable (élévation finale de la crête 952,0 m, largeur de la crête b = 5,0 m, X = 100 m) |
| 4 | Waste lagoon (maximal water level 950.0 m asl) | 4 | Lagune de déchets (niveau d'eau maximal 950,0 m d'altitude) |
| 5 | Downstream embankment of mine rock (crest elevation at 917.0 m asl) | 5 | Remblai en aval de la roche minière (élévation de la crête 917) |

## 3. DAMAGING OF THE TAILINGS DAM SASA NO. 4 IN INITIAL PERIOD OF CONSTRUCTION ON 14.9.2020

According to eye witness of the event, an employee in mine Sasa, morning on 14.9.2020, approximately at 05h45 started process of penetration of water from the waste lagoon at crest of sand dam Sasa no. 4 (constructed till elevation 910.0 masl) in nearby of the right valley bank. Rapidly, the water penetration became progressive, the tailings sand from the downstream slope in nearby of the right bank was taken away (fig. 4), the material became loose and the material from the upper zone settled, that enabled creation of opening in the zone of the maximal water level in the lagoon, till crest of the sand dam. Through the opening was discharged approximately 5,000 m3 of water from the waste lagoon, that was above the tailings silt in the lagoon (fig. 5) and due to the denivelation from the upper to lower water (approximately 23 m), the discharge developed high cinematic energy. Such energy was released by significant erosion in the downstream part of the tailings dam (fig. 6). The height of the opening from the crest to the dam toe is $H = 910.0 - 885.0 = 25.0$ m, bottom width of approximately 2.0 m, and in the crest 10.0 m, by average depth (transverse

Fig. 4
Damage in the right bank of the tailings dam, state on 14.9.2020
*Dommages en rive droite du barrage à résidus, état au 14.9.2020*.

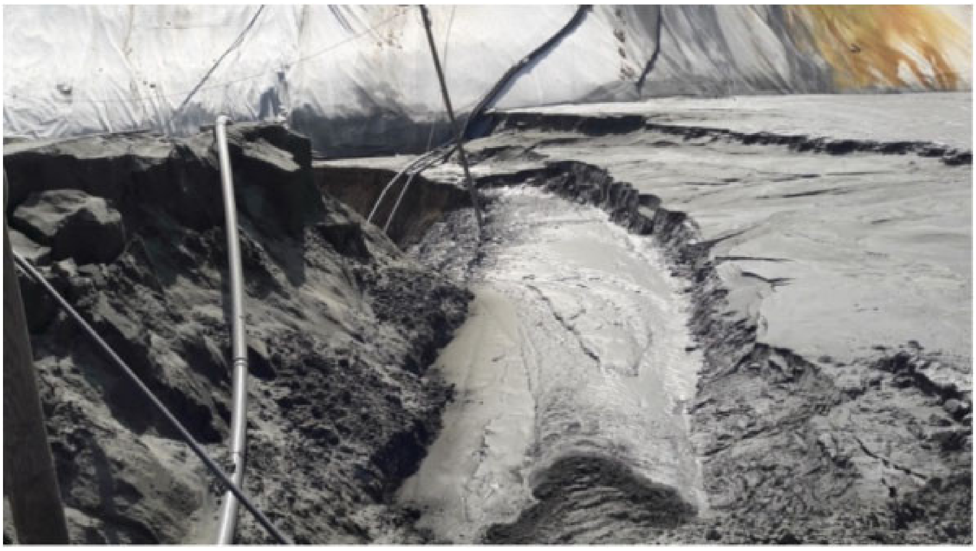

Fig. 5
Opening at dam crest where the discharge of the stored waste water took place
*Ouverture à la crête du barrage où a eu lieu l'évacuation des eaux usées stockées*.

to the original slope with inclination 1:2.7) of approximately 5.0 m. It is estimated that it was discharged approximately 3,000 m3 tailings sand from the dam body.

The mixture of water from the waste lagoon that leaked uncontrollably through the breach point in the upper zone in the right bank of the tailings dam and tailings sand of the downstream part of the dam has propagated downstream of the tailings

Fig. 6
Tailings sand that was taken away from the downstream body of the dam
*Sable de résidus qui a été enlevé du corps en aval du barrage*.

Fig. 7
Stopped erosion of the slope of tailings dam Sasa no. 4 on 14.9.2020
*Arrêt de l'érosion de la pente du barrage de résidus Sasa no. 4 le 14.9.2020*.

dam toe. Such mixture of water from the technological process (deposited in the lake) of approximately 8,000 m3, along with pure water downstream of the terminal structure of the diversion tunnel, has transported, spreaded and deposited on large section of Kamenicka river. As soon as the water level has lowered and equaled with elevation of sufficient length of the beach from tailings mud, directly upstream from the dam crest, the process of further impermissible seepage through the tailings dam and surface flow along the downstream zone of the dam has stopped, that enabled also and the dam erosion to be stopped (fig. 7).

## 4. REASONS FOR DAMAGING OF TAILINGS DAM SASA NO. 4

According to the event description from the staff of mine Sasa and terrain inspection conducted on 14.9.2020m it can be stated that there is no case of human error, equipment malfunction or systematic incorrect operation with tailings dam Sasa no. 4. It is obvious that tailings dam damaging is not caused by excessive inflow and overtopping of dam crest (at current elevation 910.0 masl) nor due to insufficient heightening from maximal water level to the dam crest. Namely, such heightening was constantly maintained above 2.0 m, as designed. At the same time, the damaging did not occur due to insufficient casual seepage strength or endangerment of the dam stability due to irregularly constructed geometry of the cross section. Confirmation for such statement is (1) geometry of the constructed part of the sand dam is according to the design documentation, by which is confirmed the static stability and (2) measured seepage pore pressures in the installed piezometers are in accordance with the expected values, and by regular visual monitoring of the drainage system there was no detected occurrence of turbidity of the seepage water in case of eventual process of mechanical erosion (suffusion).

We are on opinion that initial leakage of water in zone of the dam crest in nearby of the right bank of valley is case of impermissible seepage. It cannot be described by established models for stationery and non-stationery seepage, based on principles of mechanics, but it can be explained by engineering logic. The impermissible seepage consists of paths of concentrated seepage that in case of progressive type can endanger stability of some parts or of the full embankment structure. It is caused by incidental occurrence of loose porous medium exposed at active action of the flow, due to design or construction errors or due to unfavorable natural ambient.

In this case, the occurrence of impermissible seepage is caused by superposition by number if influences, that according to the contribution can be divided in primary (significant) and secondary (ancillary). Primary for occurrence of the impermissible seepage are:

(1) Unfavorable hydraulic contact of the tailings sand (from the dam shell) with coefficient of permeability $k = 2 \times 10^{-6}$ m/s and geomembrane with coefficient of permeability $k = 10^{-12}$ m/s. It is a case of hydraulic contact of two materials that extremely differs by its permeability. This led to fully redirecting of the flow lines towards the les permeable material – tailings sand and it created initial contact seepage.

(2) Insufficient length of the beach from tailings mud, upstream of the upstream edge of the dam crest that conditioned close vicinity of the water from the waste lagoon to the dam sand. Such vicinity does not result with significant loss of water head of the seepage flow before the contact with the sand dam apropos it had maximal head along the exactly along the upstream slope of the sand dam.

Secondary reasons for occurrence of impermissible seepage are:

(1) Unfavorable natural configuration of the terrain above the dam crest, that in case of intensive rainfalls creates concentrated surface flow, directed exactly towards the dam crest or directly downstream of the dam. Such surface flow additionally weakens the contact of the dam with valley bank.
(2) Unfavorable mechanical contact of the tailings sand with geomembrane apropos smooth layer between the two materials with extremely different stiffness and reduced friction along the contact that facilitated downstream displacement of the sand grains in direction of the active force of the seepage flow.
(3) Great natural slope in the right bank of the valley, that conditioned “hanging” of the soft tailings material on the stiff rock foundation, that is manifested by unfavorable transfer of stresses and occurrence of loose (insufficiently compacted) earth, through which is eased hydraulic breach if exposed to seepage flow.
(3) Unfavorable natural configuration of the terrain by widening of the valley downstream of the sand dam and eased displacement in downstream direction at action of the hydrostatic pressure that conditioned the tailings sand not to be pressured in the contact with the rock in the bank but to be loosened, that additionally worsens the seepage through the dam.

It is stated that the dimensions of the created crater in the right bank of the dam, by variable width of 2m in the bottom up to 10 m in the crest, by average depth of approximately 5m, cannot endanger global safety of the embankment structure. Namely, it has crest length of approximately 100m, and the central section, with maximal height and it is of key importance for the global stability, and is at sufficient distance from the crater. But the crater muse be filled with ballast material as soon as possible, so that can be prevented its further expanding and widening.

## 5. URGENT MEASURES FOR PROVIDING OD REQUIRED STABILITY OF THE TAILINGS DAM SASA NO. 4, AT ELEVATION 910.0 MASL

The first stage of the damaging restoration of the tailings dam Sasa no. 4 regards the dam stability. Such stage is urgent and should be used current favorable weather conditions (without rainfalls) and the taken material in the right bank of the dam (tailings sand) to be replaced by appropriate local material, for which we emphasize following recommendations:

(1) The material should be non-coherent and by higher or equal strength and permeability, compared to the tailings sand. Most rational is to use tailings mine rock, available in mine Sasa and it will be used for the downstream prism of this combined dam (till elevation 917.0 masl), that is sufficiently investigated as material and by known geomechanical parameters.
(2) The material will be spreaded in horizontal layers by height of 50 cm, from the breach bottom (approximately at 885.0 masl) till starter dam crest at elevation

906.0 masl (or till elevation according the as built drawing). The material should be sufficiently compacted by available machinery of mine Sasa.

(3) During the spreading and compaction in layers of the mine rock, special care should be taken for employees safety and firstly the steep surfaces of the tailings sand (that are almost vertical), created by the accident, should be soften. Such vertical surfaces we believe that are in state of limit equilibrium and any moment (by small variation of the humidity) is possible occurrence of local instability and sliding on the steep slope.

(4) During placement of the mine waste rock the continuity from the left to the right side of the created crater should be preserved, and by scale advancement in height. The greatest part from the dam opening should be filled with such material, so that till the final shaping of the geometry to be left approximately 1.0 m of thickness, that will be filled by tailings sand, by placement in sloped layers from the dam crest (as soon as the use of the tailings dam has commenced).

(5) Above elevation of the starter dam (according to as built drawing) in horizontal layers should be embedded tailings sand, by moderate compaction in the final 10 m with the contact in the valley right bank. Such embankment should be by crest elevation 910.0 masl, crest width 5.0. m, dispositioned in layout so that upstream slope of the sand dam is formed by slope 1:1.5, and on the downstream face slope less than 1:2 (in order to have satisfying temporary stability). Required downstream slope of 1:2.7 m in order to permanent safety to be provided, will be filled with tailings sand, by deposition in inclined layers from the dam crest (as soon as the use of the tailings dam has commenced).

(6) The tailings sand should be borrowed from the downstream slope of dam Sasa no. 4m, in section less than 10 m, that will be filled instantly by mine rock or from the crest of dam Sasa no. 4, that has great width (approximately 30 m), in zone of the downstream edge, by previously temporary removal of eventual layers of mine rock.

(7) At contact of the embankment from tailings sand and the right bank the three-layer geosynthetic lining to be removed (at least 2 m upstream from the contact of the sand dam with the terrain, and in zone of crest support (width of 5 m) the local material should be removed, at depth of 0.5 m or at level of rock foundation. Namely, such material was placed in order the unevenness to be leveled for installation of the geosynthetic lining. Such material is extremely permeable and it must be removed in trench by approximate dimensions of 5 m (in width as the dam crest width) and 0.5 m (depth in permeable local material or till rock foundation in the bank), at the contact of the dam crest with the terrain.

## 6. NECESSARY MEASUERS FOR PREPARATION OF THE TERRAIN, STRUCTURES AND EQUIPMENT FOR RESTARTING OF THE SERVICE OF TAILINGS DAM SASA NO. 4

The second stage of the restoration of the damaging of tailings dam Sasa no. 4 regards preparation of the terrain, civil engineering structures and equipment for restarting of the technological process and resumption with use of the tailings. The second stage from the restoration should take place upon completion of the first stage, and the necessary measures regards two aspects: hydraulic-civil engineering and mining-technological process. The measures from aspect of hydraulic-civil engineering are:

(1) If the tailings sand would rely on the diluvium, the natural slope material along the valley bank, then specified hydraulic and mechanic diversity would be reduced to a minimum, and due to the natural unevenness the contact would have higher passive friction force. Therefore, in the further use of the tailings dam and advancement from the current dam elevation of 910.0 masl till final elevation of 952.0 masl, the construction to be according to design documentation, prepared by recommendations for lining from the Commission form Ministry of Environment and Physical Planning. So, it is necessary removal of the geosynthetic lining on contact between tailings dam and natural ground. After that the surface material from organic substances (trees, roots, rock and etc.) in zone of the dam crest should be cleared out.

(2) Common practice in Dam engineering, upon serious damage of the dam body (as in case of damaging during construction of tailings dam Sasa no. 4) is to identify and apply additional measures for providing of greater stability. Therefore, the unfavorable hydraulic contact of the tailings mud (from the beach, upstream of the sand dam) and geotextile on which he is relied on should be taken in consideration. The geotextile is drainage material with much higher seepage coefficient, compared with tailings mud from the beach. It is a thin water conveyor between two isolators, geomembrane from below and tailings mud from above. Of course, the geotextile in this zone does not affect on the central seepage (in maximal cross section), that has dominant influence on the dam's global stability. But, the geotextile significantly affects the lateral seepage due to the reduction of the head of the lateral seepage flow through the beach from the tailings mud, in direction of the lagoon with waste water towards the sand dam and it can cause impermissible contact seepage. Therefore, we recommend that beside removal of the geo-synthetic lining on contact of tailings dam and natural ground, additional removal (upstream of such contact for 2 m) of the geotextile and the geomembrane, and only the geo-synthetic clay liner to be kept (that is easily adaptable on unevenness). Also, we recommend removal of at least 30 m upstream of the crest, as the beach from tailings mud is planned. Namely, the geotextile in such zone has no any useful function, because it has nothing to protect from the geomembrane due to filling of the waste lagoon with mud and waste water and not with rock-fill and concrete slabs with sharp edges.

(3) Intake pipe Ø200 mm to be installed through the steel shield, upstream at around 5 m of the joint of the spillway collector $D = 2.0$ m (horizontal tunnel according to the as built drawing) with the diversion tunnel of Kamenicka River. The steel shield to be constructed with height of 1.0 m, relied on steel sloped element (buttress) from the downstream side. The joints to be filled with permanently elastic putty. The sealing with the specified putty to be from the

upstream and the downstream side, and also at all joints apropos joint of steel with steel and steel with existing concrete lining.

(4) The upper edge of the intake pipe to be installed on the steel shield at height 0.2 m from the upper edge of the shield. Downstream of the intake pipe to be installed pipeline in the internal part of the tunnel, by leveling that will always be lower than the leveling of the opening in the steel partition. The pipeline will convey spillway water all to the existing reservoir (or previously to new temporary settling tank) by permanent pump station (for recirculation of the drained water for the need of the technological process). At the downstream ending of the pipeline two gates are to be installed, that will regulate spillway outflow whether it should be released in the river or in the settling tank and then in the reservoir. So, if it is estimated that the existing reservoir is with insufficient volume, in such case the water should be kept in the temporary settling tank.

(5) The location of the temporary settling tank should met following criteria: (a) not to obstruct construction of the downstream part of the combined tailings dam Sasa no. 4, (b) to be located in nearby of the exit structure of the diversion tunnel (in the right bank of the valley), (c) to be located in nearby of the existing reservoir, but on higher elevation, so the water can flow by gravity from the settling tank in to the reservoir, (d) to have eased access for water tank for occasional cleaning of the settling tank, (e) to be upstream from the terminal structure of the channel for Petrova Reka (in the left bank of the valley) and (f) the construction period of the settling tank to be reduced to minimum.

(6) One of the reasons for the impermissible seepage on 14.9.2020 and damaging in the right bank of tailings dam Sasa no. 4 is unfavorable natural configuration of the terrain above sand dam crest, that in case of intensive rainfalls creates concentrated surface flow, directed exactly towards the dam crest or directly downstream of the dam. Such surface flow additionally weakens contact of the dam with the valley bank and contributes for erosion of the deposited cycloned tailings sand. Therefore in the further course of the construction of the tailings dam it is necessary to be captured external surface water (occurred from intensive rainfalls), that gravitate towards the crest and the downstream slope of the dam. The tailings dam Sasa no. 4 is earth dam, but it is built in stages, simultaneously with filling of the waste lagoon apropos construction duration is equated with service of tailings dam. Therefore in case of tailings dams there is no possibility to be constructed durable protection channels in service stage of waste lagoon but, if required, are constructed temporary channels (by excavation in the valley banks), that are appropriate for some stage of construction of the tailings dam and method of construction advancement.

## 7. REQUIRED MEASURES FOR FURTHER SAFE SERVICE OF TAILINGS DAM SASA NO. 4 AND CONSTRUCTION OF TAILINS DAM FROM ELEVATION 910.0 MASL TO 952.0 MASL

Upon completion of the measures from the second stage of restoration of tailings dam Sasa no. 4, with which preconditions are acquired for restarting of the technological process for use of the tailings and further construction of tailings dam from elevation 910.0 m asl till final elevation of 952.0 m asl, in order to be provided satisfying safety level, we recommend required measures that regards two aspects hydraulic civil engineering and mining technological. The measures form hydraulic civil engineering aspects are the following:

(1) As it is progressed in height with the dam crest simultaneously to be removed geo-synthetic lining on contact of the tailings dam and the natural ground. Afterwards, to be cleared out surface material of organic substances (trees, roots, humus, rocks etc.) in dam crest zone and to be removed surface degraded material in depth of at least 50 cm.
(2) If the future technological process is realized by occasional outflow of non-cycloned tailings (by spigots) for creation of beach with slope 1:15 from the upstream edge of the dam in direction of waste lagoon and if there is no sufficient quantity of tailings sand, in such case in the crest should be placed layer of mine rock. The horizontal layer of mine rock to be with height of 50 cm by track transport and by moderate compaction with the available machinery of mine Sasa. In such case, due to the increased needs for maneuver for the track transport, the crest width to be increased to 6.0 m
(3) If the future technological process is realized only by cycloning, by increase of the number of cyclones from the current two to three cyclones, deployed on dam crest, in such case the water to be distanced from the crest at least 28.5 m, with estimation that slope of the beach from the cycloned mud is 1° or 1:57, the discharge of the overflow of the cyclones should be less than 1.5 m below the crest.
(4) The protective height in the lowermost part of the dam crest till the water level in the lagoon to be at least 2.0 m.
(5) In case when there is outflow of cleared water through the spillway openings, then the water in the pipeline downstream of the steel shield will be discharged directly in to the river (open only gate 1). In case of outflow of turbid water through the spillway openings (distributed in the collector of the right bank of the valley), in order to be provided required protective height from the water level till the dam crest, in such case the water will be discharged in the settling tank and afterwards in the reservoir (open only gate 2). Upon reaching the maximal level in the reservoir, the water will be recirculated in to the technological process (sprinklers) by pump station.
(6) The downstream body from mine rock, designed with final crest elevation of 917.0 masl, is to be constructed in 4 stages. With the stage construction, with crest width of 3.0 m and upstream slope 1:1.5, will be provided two functions. First, support of the inclined layers from the deposited tailings sand and second, providing of reserve volume. So, if in further period there is eventual taken out tailings material downstream of the dam site, in that case it will be retained and it will not propagate in the downstream river bed of Kamenicka River.
(7) The terrain in the zone above the crest should be inspected and improved permanently and always to be shaped so that eventual concentrated surface flow along the slope (in case of intensive rainfalls) to be redirected downstream of the downstream toe of the sand dam. If such is not possible, then to be

redirected towards the waste lagoon, at least 30 m upstream of the dam crest. However, it is not to be allowed ever again concentrated surface flow from the valley banks to be directed towards the crest and towards the downstream slope of the dam.

(8) The tailings sand along the crest surface of the sand dam to be compacted by the available machinery of mine Sasa, on sections with length of minimum 10 m, in nearby of the right and the left bank of the valley, that will reduce the eventual looseness of the deposited tailings sand and it will improve its seepage strength in critical zone for occurrence of impermissible contact seepage.

(9) The key for stability of the tailings dam is regular operation of the drainage system that consists of 4 drainage blankets embedded transversally on the valley. They are constructed in the river bed from filter material and lined with geotextile, in order to be prevented eventual plugging of the drainage material. Upon the accident, the upper geotextile of drainage blankets no. 3 and 4 is covered by sediment and it is plugged apropos it is not able to operate. Therefore, the upper part of the geotextile should be removed and replaced with new layer with same properties.

(10) On daily basis to be inspected occurrences of: (a) humidity along the surface of the downstream slope, (b) the surface craters, from eventual settlement of the material due to mechanical erosion in the dipper layers, (c) turbid water in the drainage system, as result of unfavorable seepage process and in case of such registered occurrences the tailings dam service should be stopped temporary.

(11) The future planning and designing of the protective channels, their construction apropos excavation in the valley banks, should fit the specific terrain conditions that will suit for the next state of construction of the tailings dam. Such temporary structures belong in maintenance of the hydraulic structures by the operator in service period of the tailings dam. We underline that in future are possible occasional erosion along the surface of the embankment structure, if in case of more intensive rainfalls are is created surface flow that will exceed the capacity of the protective channels. It is a case in the service period at permanent protective channels of conventional earth dams with water reservoir, so of course it is possible and for temporary protective channels at tailings dams with waste lagoons. Therefore there is visual auscultation during the service period of the dams, because they are civil engineering structures with active influence of the water. What matters is that the small surface damages should be timely detected and restored as soon as possible, that is obligation of the dam operator.

## 8. CONCLUSIONS

The unfavourable contact seepage in upper zone of the right bank of the dam conditioned progressive seepage in the right bank of the tailings dam Sasa no. 4, in initial period of construction, at elevation 910.0 masl in September, 2020. At action of the progressive seepage was developed process of taking out of sand grains from the dam body, loosening of the material and settlements under the loading of the upper layers. Cumulative settlement was maximal at the dam crest. As soon as the crest was on lower elevation to the water level in the lagoon, there was uncontrolled out flow of the stored water. The maximal kinetic energy was in the nearby of the downstream toe of the dam and caused material erosion and creation of crater. Afterwards the crater was deepened and got to the dam crest but by lowering of the water level till elevation of the tailings mud the surface flow and crater widening was stopped. Having in consideration the reasons for occurrence of unfavourable contact seepage and the scope of damaging of tailings dam Sasa no. 4, were adopted measures for restoration in two stages (urgent for providing dam stability and preparation for restarting of the tailings dam) and measures for further safe use of the tailings and construction of the tailings dam. The tailings dam Sasa no. 4 must not be in service before all measures from both stages of restoration are not completed in full.

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