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Research paper

Construction of dams using the hydraulic fill method, discussion of the methodology of the Tailings Storage Facility Żelazny Most

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Abstract: The hydraulic fill method of erecting dams was characterized. The main assumptions and practical aspects of sand spigot were discussed on the example of the spigot of the dam body of the Żelazny Most Tailings Storage Facility (TSF). The advantages and disadvantages of the method are discussed, and the directions of attempts to implement pipelines rising along with sedimenting waste are presented, which are to reduce earthworks.

Keywords: hydraulic fill, Żelazny Most, tailings

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1. Introduction

Dams erected by the hydraulic fill method are defined as facilities in which the construction material is transported by pipelines in the form of a mixture of soil and water (pulp) or, more generally, as selective soil movement using a water jet.

The technology is mainly used to erect large-volume structures. In addition to the construction of dams, it is commonly used to build embankments for roads, airports, artificial islands, or to restore eroded coasts [1–3].

The paper discusses examples of such facilities in the world, detailed rules of operation of the Żelazny Most Tailings Storage Facility and the directions of its expansion and changes in operating solutions.

2. Examples of dams erect by the hydraulic fill

In the area of Glasgow, Montana, the Fort Peck Dam on the Missouri River was erected in the years 1933–1940 using the hydraulic fill method. It is the largest this type of dam in the United States. 62 m high and almost 6.5 km long, it forms a flood that feeds the turbines of the hydroelectric power plant. The washing technique was chosen due to the size of the dam. The material was dredged from the river below and above the dam, transported with a network of pipelines and filled the prepared fields [4].

The first hydraulic fill dam in Russia was the dam on the Ivankowo reservoir on the Volga. The reservoir called the Moscow Sea is one of the sources of drinking water for Moscow. The dam, 300 m long and 22.5 m high, was built of hydro-transported alluvial sands and sealed with a steel screen in the body [5]. Also the right dam on the Bracki reservoir in the Irkutsk region, which paves water for the needs of the largest hydroelectric power plant in the world at the time of commissioning, built for the 50th anniversary of the October Revolution was built using the spigottig method. 2965 m long and 36.5 m high, it was built of hydro-transported material from dredgers via pipelines of approximately 10 kilometers [6].

The Koronowo dam is located in the region of Bydgoszcz, in Pieczyska. It is an earth dam, 23.5 meters high and 340 meters long. It crossed the Brda River valley, creating Zalew Komorowski, built for the needs of a pumped storage power plant. The first construction project was developed in the years 1928–1932, but it was not implemented. The idea was revived after the war. Built in 1956–1960, the dam was rebuilt in 1976–1981 due to suffosion. The next corrective actions related to the piercings were performed in 2016. [7]. In the quoted article, this dam is described as "(...) the only earth filtration dam in Poland made with the silting method". But is it really the only dam made with the use of the hydraulic fill technique in Poland?

3. The biggest Tailing Storage Facility in the Europe

3.1. Main parameters

Tailings Storage Facility (OUOW) Żelazny Most it is the largest structure of this type in Europe and one of the largest in the world [8]. It is an above-level reservoir built in the valley of the Kalinówka watercourse with dams all around the perimeter built mainly by the method of spigoting the material supplied by hydrotransport. Currently, the ordinate of the dam crown is from 187.50 m up to 190 m above sea level and is constantly increased, while the adjacent area is located at an altitude of 110 m up to 150 m above sea level, which gives in the highest point the height of the dam 80 m. This makes the dam one of the highest in the country [9], and considering its length at the base of just over 16 km, it is certainly the longest. It should be emphasized here that the reservoir is mostly filled with post-flotation slurry, and only the top layer with a depth of about 3 m is water, but the slurry, due to its fine grain size, also accumulates significant amounts of water remaining largely in a liquid consistency.

The body of the dam, made of spigot material, mainly fine sand granulation, is not sealed. The free water table depression curve is lowered by annular drainage in the form of a filtration wall located in the upstream part of the body, and then classically by the basic drainage of the dam. The canopy is sealed with a layer of fine-grained waste collected in it, which also effectively reduces water filtration to drainage of the body (Fig. 1).

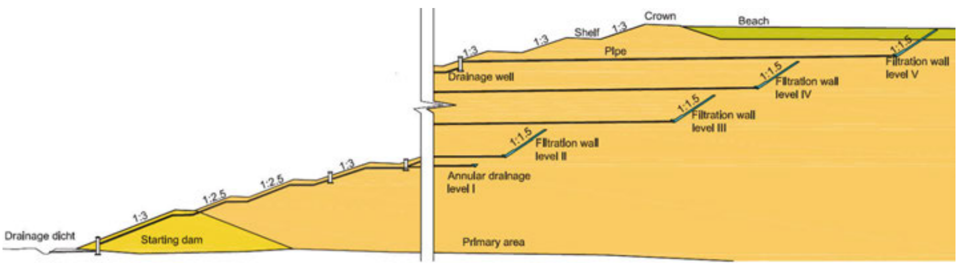

Fig. 1. The cross-section of the dam Żelazny Most TSF with filtration walls

Due to the size of the facility, its location in an urbanized area and importance in the main production line of KGHM Polska Miedź S.A. is one of the best monitored earth structures in the world. The geotechnical monitoring system includes, among others, about 2350 piezometers, 90 inclinometers, 440 points of the benchmark network, including many of these systems working as permanent automatic measurements [10].

The basic parameters of the facility for April 2021 are presented in the Table 1.

Table 1. Quantitative list of post-flotation waste and free water in the Żelazny Most TSF

Żelazny Most 01.04.2021				
Waste		Free water		
Dry mass [Mg]	Volume [m^3]	Volume [m^3]	Area [ha]	Perimeter [m]
1 097 479 530	669 462 513	5 070 482	450	10 000

3.2. Description of the depositing technology

The reservoir was created as a place for depositing waste from the flotation of copper ores, which, due to the construction of the deposit, constitutes up to 97% of the total material extracted. This waste is crushed and ground rock in the process of enrichment of copper ores. It is in the form of a suspension in saline technological water in the average proportion of 1 Mg of solid waste per 5 m^3 of water. Such suspension is pumped by centryfugal pumps into the network of pipelines leading to the crowns of Żelazny Most TSF. On the canopy, the sludge poured onto the beaches flows towards the center of the reservoir, leaving the coarsest grains in the form of sediment that causes an increase in the elevation of the beaches, and along with fine fractions goes to the reservoir in the central part of the facility. Here, the water is clarified by gravity, and then collected by towers is pumped back into production, closing the loop of the process water circuit, or as excess water is discharged outside the KGHM Polska Miedź S.A. process water system.

The ore mined in three mines is enriched in the flotation process in three branches. The waste discharged from them differs slightly from each other due to the differences in the processed ore. In terms of suitability for separating the material that can be incorporated into the dam body, the most important are the differences in the particle size composition. This criterion excludes waste discharged from the Ore Enrichment Plant Polkowice. The ore processed in it with a significant share of carbonates requires grinding to such fine fractions that, despite segregation during rafting on the beach, there is still too much dusty fraction in the deposited material, i.e. over 30% according to the current guidelines. Therefore, the slurry from this source is directed, bypassing the spigot, directly to the central part of the facility – to the canopy through a pipeline laid on the embankment running across the sedimentary beaches, called a point discharge, or a pier (Fig. 2a).

The other two sources i.e. slurry from Ore Enrichment Plant Rudna and Lubin are directed to spigotting to sedimentary beaches. Sludge with a density of 1.11 to 1.15 Mg/m^3, pumped with centrifugal pumps, which at a rock density of about 2.7 Mg means a ratio of 1 Mg dry mass to 5 m^3 of water, is poured on the crowns of the facility to the upstream side and flows down to the center of the object (Fig. 2b).

The crown of the building is divided into 26 sections constituting a DN 800 or DN 1000 pipeline separated with valves, with DN 200 outlets placed with a spacing of 15 to 20 m, regulated by valves. The streams are led through four working pipelines, so 4 out of 26 sections are simultaneously washed. The remaining ones constitute a reserve and are excluded from the use due to the required "rest" period after the spigotting, or constitute

(a) (b)

Fig. 2. Slurry deposition (a) pier, discharge point; (b) spigotting onto the beach

the front of construction works related to the continuous superstructure of the facility. The superstructure is due to the storage technology. The waste sedimenting on the beaches raises their elevation to a level slightly below the crown of the object, then the section is transferred to the superstructure, during which, from the material accumulated on the beach, machines form another 2.5 m increase of the dam crown, the sewage pipeline is re-laid on the raised crown and repeated is a spigot cycle. Less than two years is required to complete the process of lifting subsequent sections. Of course, this period results from the amount of segregated material on the beaches and is consistent with the growth of the inner, fine-grained canopy of the facility.

The quantity and quality (graining) of the deposited material depends mainly on the composition of the slurry, but also on the slope of the beaches and the method of spigot. The slope of the beaches is related to the type of waste, but it can be to some extent regulated by the frequency of material intake for forming, followed by the flattening of the slope, the alternation of spigot, i.e. a change in the source of waste in a given section, and the direction from which a given section is supplied. The washing line is a discharge line along the way, operating at low pressure and relatively large outlets. This causes a significant difference in the flow rate between the first and last working outlet. This changes the working regime of the pipeline along its length and ultimately leads to differences in the grain size and density between the extreme outlets (Fig. 3).

By changing the direction of supply and regulating the number and expenditure of working outlets, it is possible to influence the shape of sedimentary beaches.

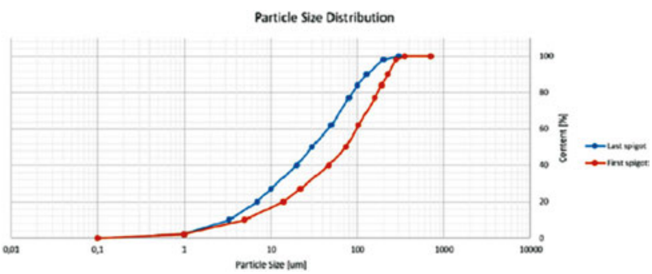

Fig. 3. Particle Size Distribution of first and last outlets

3.3. Detailed spigot guidelines

Detailed guidelines for the technology of washing waste onto the beaches are specified in the internal Operation Manual [11], which is the result of many decades of experience at the Żelazny Most TSF. It is adapted to the facility's growth cycle, production volume and facility size. It should be emphasized here that the active surface of the building has become a very sensitive element. Because each successive lifting of the crowns by 5 meters (two forming cycles) moves the crown of the dam to the inside by the width of the base of the built-up dam and the width of the ledge on the upstream side maintaining the average slope inclination and at the same time constituting communication routes on the dams. This method of superstructure is referred to as an upstream superstructure and allows for convenient development of air slope (downstream slope), but ultimately reduces the useful area of the object. Due to the decrease in this value, the superstructure cycle is shortened by successive ordinates and there is a change in the equilibrium between the growth of the inner and outer part of the object. The distance between the canopy and the body of water is shortened, and the influence of the sediments on the water quality in the body of water is increased. The Operation Manual allows to operate in a single section for up to three weeks. The limitation is mainly due to the prevention of over-irrigation of the dam body and overload of the annular drainage system. The body consists of well-drained fine sands, therefore the introduction of the slurry to the section causes large amounts of water to infiltrate deep into the beaches, where they end up on subsequent walls of annular drainages and are discharged through the system of wells to the dam ditches and further pumping stations surrounding the facility. Prolonged spigot could overload the drainage system and increase the upper limit of seepage (phreatic line), the level of which is regulated by this drainage. The second important aspect that determines the duration of the spigot is the parallelism of the increase in beaches. It is not possible to make significant differences in the elevation of the beaches in 26 sections because they constitute the border of the reservoir, which, in order to maintain the water above the tight layer of fine-grained waste and the supported work of water intakes, must remain in a specific position. Another guideline for transferring the sediment to other sections is the need to keep the beaches relatively humid, as this is the best protection against excessive wind blowing of fine particles from the beaches. Dehydrated beaches will create a source of dust, negatively affecting the surroundings. Construction works related to the renovation of the pipeline network, the formation of dams, the construction of subsequent stages of drainage, which often require changes in working systems, are also important. Combining all these variables into an efficient persuasion requires a lot of experience.

The required time of normalization ("rest") of the section follows after the spigot period i.e., the time for draining excess water from the body and normalizing the work of drainage systems in the area of the wash-up. This period is defined as equal to the spigot period, and in areas where the construction of the basement of dams is not very permeable, it is equal to twice the spigot period. This condition was of greater importance in the period when the dams were lower, so the waters infiltrated the native soil faster. The time of normalization after the washing period can be observed after changes in drainage expenditure or piezometer indications, if they are built in the area of the wash.

Observation of the work of annular drainages is an excellent tool for controlling the processes of spigotting and dams. By observing the expenses and the quality (cleanliness) of the water, it is possible to assess the correctness of the washing process and possible deviations from the permissible state. For this reason, there is an obligation to control annular drainages by employees controlling the spigot on each working shift in the area of the working section and to control the operation of all drainages once a week. The repeatability of these checks by the crew allows for quick detection of irregularities, e.g. blockage of a fragment of the drainage pipe network between the wells, flooding of excavations in the area of beaches, or excessive increase in expenditure in the area of the spigot. Drainage control in the washed area is carried out by a person assigned to a given section, each section to be spigot is supervised around the clock, and the scope of service includes, apart from the control of drainages, adjustment of the flow rate and sequence of working outlets, control of the flow direction through the beach and flow direction control, waste discharged from adjacent point discharges, if in operation. The staff also regulates the length of the outlet hoses, which on the one hand prevent the slope of the drainage dam from being washed away, and on the other hand cannot be flooded, choking the outflow. The hoses at the free end rest on wooden trestles so that they do not wash the outlet (Fig. 2b).

The operation by throttling specific outlets or turning them off maintains a steady increase in the elevation of the beaches and prevents the flow of slurry along the beaches to prevent the deposition of too fine material due to the too slow flow of waste into the reservoir.

The control of the supply direction is usually carried out between successive washing cycles, and only sporadically during a single cycle due to the time-consuming process of switching. The process of filling the beach between successive formations takes an average of 11 to 15 weeks and depends on the source of waste, the fall of the beaches, the vicinity of point discharges. Therefore, in each cycle between spigotting, it is possible to change the direction of the supply or the source of waste several times.

The differences between the material deposited at the beginning and the end of the section are presented below (Fig. 4), while the change in grain size along the length of the beach is shown in Fig. 5.

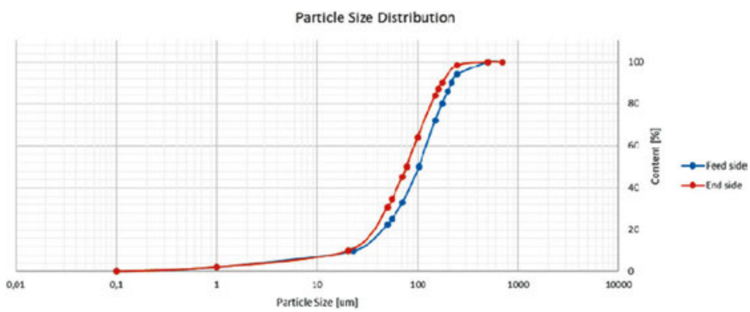

Fig. 4. Particle Size Distribution of beach material next to first and last spigot

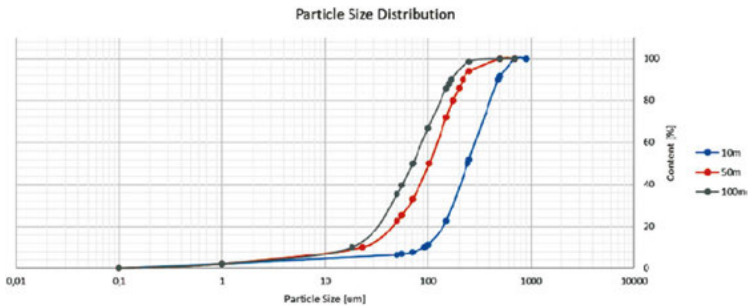

Fig. 5. Particle Size Distribution of beach material on the 10, 50 and 100 m from crest of dam

3.4. Hydraulic fill advantages and disadvantages

The main advantages of using hydrotransport and spigotting of the material delivered in this way include:

- Possibility to move and integrate significant earth masses with relatively little participation of machines and committed employees. KGHM Polska Miedź S.A. builds in about 2,300,000 Mg of dry mass of ground rock per month.
- The spigotting process ensures the compaction of the washed material without the use of machines, while the filtered water infiltrated thru material. At the Żelazny Most TSF, the required compaction index $I_s = 0.92$ is achieved on all beaches.
- By using the method of gravity segregation in the time of flow or e.g. hydrocycloning, the composition of the collected material can be modified.
- The process is stable over time due to the limitation of machines and the use of mainly physical phenomena.

The disadvantages of such a construction system include:

- The need for access to large amounts of water as a carrier medium. KGHM Polska Miedź S.A. Hydrotechnical Unit pumps over 13 million m^3 of water monthly.
- The need to organize the collection of water after the hydraulic fill process.
- Possibility of disturbing the process by changing the slope of beaches caused by e.g. earthworks, changing the grain size parameters of the source, changing the slurry density. All this can lead to the incorporation of layers of material with undesirable parameters, e.g. increased dustiness at a small drop of beaches, formation of cones at the outflow, i.e. an increase in the drop with increased density or a significant change in grain size.
- The need to rebuild the supply and spigot installation along with the construction of supporting structures.

With stable operating parameters, the process does not pose any operational problems, but it is relatively easy to deviate from the expected parameters, e.g. when changing the angle of the beach. For example, after the formation of extending dams on the crowns for the laying of pipelines, the beaches are flattened due to the material being taken from them for the superstructure. The initiation of the spigotting after formation causes the run-off on the beaches with a lower slope, therefore at a slower speed, causing a change in the deposited material. A special case is to prevent falls on beaches, or to create pools of water in which the entire grain size of the delivered material is deposited. When it is necessary to segregate the material, as is the case at the Żelazny Most TSF, this is a particularly undesirable phenomenon, as it leads to the formation of interlayers of the material with much lower geotechnical parameters, which may constitute privileged slip planes.

3.5. Description of the methodology adopted at Southern Quarter TSF

Due to the need to limit the growth rate of the Żelazny Most TSF and at the same time maintain the production volume of KGHM Polska Miedź S.A. there was a need to build a new object. The analyzes have shown that (in terms of all the analyzed variables) the optimal location will be the area adjacent to the existing facility on the southern side, with an area of approximately 600 hectares.

The construction of the initial dams consisted in forming a fragment of the air side of the dam's body from material extracted from the Southern Quarter's canopy, and in subsequent stages, the dam's body is to be supplemented and erected with segregated sandy material from the slurry, while the interior of the canopy is filled with thickened fine-grained slurry. Therefore, the storage of waste in the South Quarter requires processing – segregation and thickening of slurry and its development with the use of two separate hydrotransport networks for fine and coarse material. In combination with this, waste at the Żelazny Most TSF is stored without additional processing, using a single hydrotransport network.

How is it easy to predict the introduced method is more energy-consuming and labor-intensive, so what was the reason for its choice? Well, there are two main factors: technological and safety.

Technologically, the decision to change the technology was dictated by the significantly smaller landfill area compared to the currently operated one. The creation of beaches of a safe length and a body of water with a surface allowing for water clarification and maintaining safe retention allowing for water management requires a significant area of land designated for the facility. The Żelazny Most TSF covers an area of approximately 1,600 hectares, the Southern Quarter of approximately 600 hectares. Thus, the application of an analogous storage methodology would involve a significant reduction in the amount of waste that can be deposited in the Southern Quarter during the year. Therefore, it was required to modify the method of storage to adapt to the surface of the facility.

Safety concerns relate to the method of dam construction and the quality of the embedded waste. In terms of the construction method, the literature distinguishes three main types of hydraulic fill dams, upstream, downstream and center line [10] (Fig. 6).

Żelazny Most TSF is erected using the upstream method, which means that, above a certain height, new dams are erected on the soils washed in the previous period. According to international guidelines, the downstream construction method is now considered a safer method [12, 13]. At the same time, the use of this method is in line with the change in waste segregation and fill technology related to the reduction of the area of the new facility. The designers adopted a modification related to the construction of the Southern Quarter dam

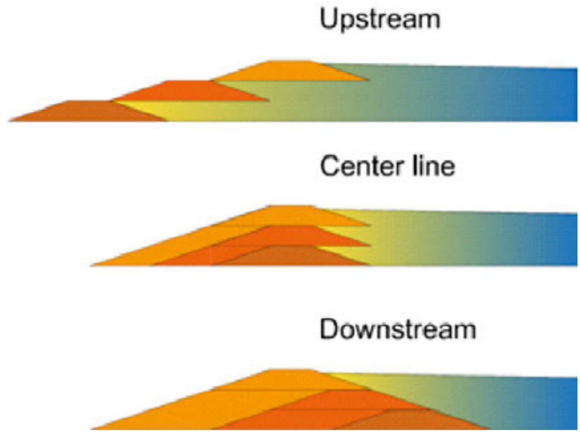

Fig. 6. Hydraulic fill dam raising technology

body. Namely, initial dams were formed from the native soil from the canopy, constituting the basis for leading coarse waste hydrotransport pipelines to be built into the body. With their use, material selected with hydrocyclones will be built in the dam body zone. On the upstream edge of the body, pipelines will be laid leading the waste to be folded into a bowl, i.e. a material not suitable for installation in the body due to too fine graining. With the increase in the ordinates of the body along the upstream slope, fine-grained waste pipelines will be transferred, thanks to which the entire static body of the Southern Quarter dams will be placed on segregated coarse-grained material with controlled parameters (Fig. 7).

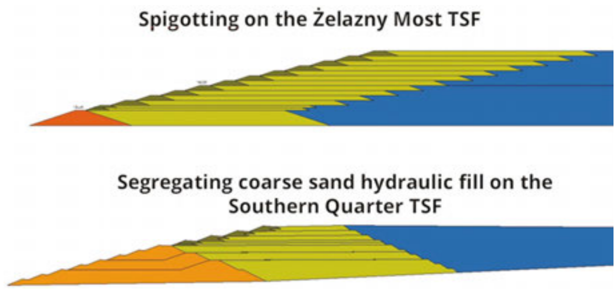

Fig. 7. Raising dam methods on Żelazny Most TSF and Southern Quarter

An important change in the field of hydrotransport is the thickening of slurry destined for storage in the Southern Quarter. Both coarse and fine-grained slurry will be thickened at the station of segregation and thickening tailings to a density of about 1.5 Mg/m^3. Thus, of the current 5 m^3 of water per ton of dry mass waste, only 1 m^3 of water per tonne of rock will end up in the Southern Quarter. This will simplify the water management, however, the hydrotransport and water-transfer processes will change the current parameters, e.g. hydraulic losses, beach slope, material segregation during the flow.

3.6. The scope of work related to the adopted technologies of hydraulic fill

As described above, differences in the technology of building the material into the body result from the density of the spigotted material. The cycle of works related to washing and superstructure to the next stage in the non-compacted waste spigot technology (without processing the waste after the flotation process) includes: several times the washing process and draining water from the body, with the maximum period of spigotting up to three weeks resulting from the amount of infiltrating water, cutting and putting away the pipeline, forming the embankment increased by 2.5 m, re-laying the pipeline. The range of forming by earthmoving machines (bulldozers, excavators, scrapers and rollers) includes an embankment with a trapezoidal cross-section 2.5 m high, with a 10-meter crown and slopes with a slope of 1:3. The length of the embankment corresponds to the length of the dam crowns. In addition, such embankments are formed as piers running 200 m deep into the canopy, serving as the base of the pipeline for the discharge of dusty/fine slurry directly into the basin. The spacing of these piers at the Żelazny Most TSF is 500 m on average. The construction material is taken from the washed beaches of the facility. The length of the movement of the dam forming material is up to 150 m and results from the slope of the beaches, and more precisely from the condition of preventing the fall into the dam crest after completion of the works.

The material deposited on the beaches during the spigotting has appropriate parameters both in terms of grain size, i.e. it contains no more than 30% of dusty parts, and in terms of compaction, i.e. a compaction index above 0.92. Thus, a significant part of the body is erected using the rinse and does not require additional handling with the equipment.

The planned scope of work as part of the spigot cycle in the technology adopted for the Southern Quarter includes: cyclical spigotting and drainage of the washed material, while the washings are short-lived – up to two days, due to the cones formed at the outlets, which quickly "support" them, preventing further flooding, unplanting washed cones with equipment, densification to the required parameters. After reaching the elevation between the outlets that prevents further spigotting, putting back the pipelines, forming dams and piers for the pipelines, reassembling the washing pipelines. Therefore, in combination with the above described method used on the Żelazny Most TSF, an additional scope of work is the unplanting and construction of the material in the dam body. This constitutes a large scope of works, up to 4 million m^3 per year. Also, the scope of forming embankments for pipelines (in a cross-section similar to that for Żelazny Most) is greater, because the spacing of the piers is 100 m, not 500 m as on the Żelazny Most, and an additional pier separating the body and the canopy, therefore twice the embankment of the Żelazny Most TSF (Fig. 8).

Intensive search for methods is currently being carried out to reduce such a large scope of earthworks that require the involvement of machines. Two aspects seem to be promising as a result of these attempts. The first one concerns the compaction index of the material separated with the use of a hydrocyclone spigotted onto the body area. The tested densities of washed cones met the design requirement of the $I_S \geq 0.92$ density index. This allows

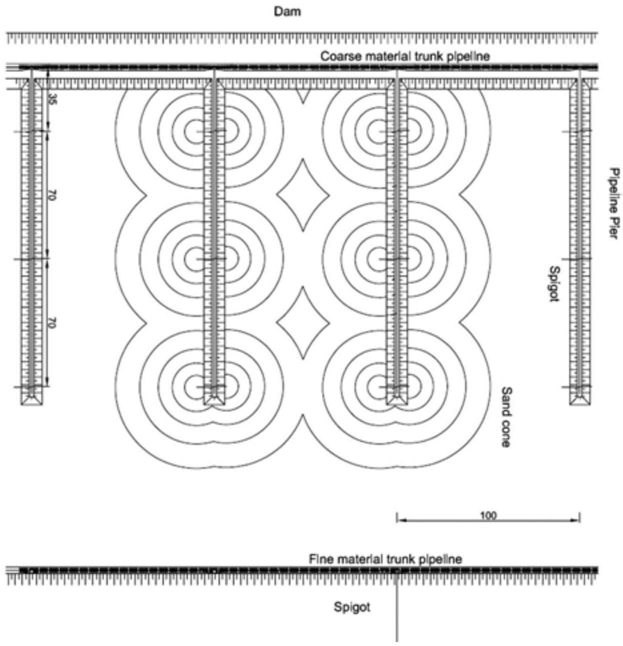

Fig. 8. Sketch of the hydraulic fill method for Southern Quarter TSF

to reduce the scope of work related to the unplanting of washed cones, provided that the task of conducting the wash-up in such a way as to fill the body area as evenly as possible, without limiting the wash-off from fixed points by supporting them with a cone.

3.7. Work on optimizing the spigotting

Floating pipelines are commonly used, for example, for dredged materials from under the water surface. Usually in the form of pipes with a displacement element mounted at a specific spacing, less often as a double wall pipeline. The idea was born to use floating pipes on beaches, i.e. in fact pipes floating on the surface of beaches. The pipes are forced to the surface with a stream of a mixture of waste and water before the water flows out into the basin or into the beach. To check whether the waste deposited on the beaches will lift the pipeline left on it, or whether it will rise along with the increase in waste on the beaches, the Żelazny Most TSF test was performed. The HDPE PE 100 SDR 17 DN 110 pipeline, 50 m long, was used. Both ends are blinded. The prepared pipeline was laid on the beach and secured on both sides against flowing into the basin. The level of the beach is marked on the stakes (Fig. 9).

The slurry was directed to the position prepared in such a way that the sedimenting material would increase the level of the beaches by several dozen centimeters. The pipeline floated to the surface as the level of waste on the beach increased (Fig. 10).

(a) (b)

Fig. 9. Stand for the test floating pipes a) marking the level of the beach; b) pipeline

Fig. 10. Stand for the test floating pipes after spigotting

The tests were carried out twice, placing the tested pipeline transversely and longitudinally to the flow direction of washed waste. No negative impact on the pipeline lift was observed. It should be expected that at a certain limit of water content, for a given grain size, the pipeline will stop being lifted due to too fast filtration of water into the beaches and in some cases it will be covered with washed material. Further tests will be carried out in this regard to determine the potential use of this in the spigotting of coarse-grained slurry with a density of 1.5 Mg/m^3 intended for storage in the Southern Quarter.

Lifting the pipeline on the surface of the sedimenting material along with the increase in the level of waste on the beaches allows for the initiation of attempts to use this solution for the washing of beaches at a certain distance from the crown and, perhaps, to reduce the need to build piers as a basis for laying the pipeline running across the beach into the Żelazny Most TSF. In this case, a double-walled pipe should be used, ensuring its uniform displacement along the length during its operation.

4. Summary

The body of the dam of the largest Tailings Storage Facility in Europe (Żelazny Most TSF) has been erected since 1977 using the hydraulic fill method. Over a billion tons of material were washed on the beaches and into the canopy. Having an appropriate source of material and water as a carrier in hydrotransport, it is possible to build large amounts of earth mass with relatively little involvement of machines and people. The washed material is characterized by good compaction parameters and does not require additional compaction. The grain size composition can be regulated to some extent, e.g. by the slope of the washed beach area. The reduction of the area of the new facility in relation to the currently operated one forced a change in the technology of spigotting. At the same time, this change has a positive impact on safety aspects and is in line with the international recommendations of the best available techniques for the operation of this type of facilities. The use of the experience in managing the spigots allows to significantly reduce the scope of earthworks in relation to the classic methods of erecting dams using earthmoving equipment. For large projects, such restrictions translate into significant savings. It is also important to reduce the environmental impact. Thanks to many years of experience related to the persuasion of KGHM Polska Miedź S.A. The Department of Hydrotechnics has introduced many activities related to the improvement of depositing efficiency and is still looking for new opportunities, an example of which is conducting tests with the use of floating pipelines.

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Wznoszenie zapór metodą namywu, omówienie metodyki namywu obiektu unieszkodliwiania odpadów wydobywczych Żelazny Most

Słowa kluczowe: napławianie, Żelazny Most, odpady poflotacyjne

Streszczenie:

Obiekt Unieszkodliwiania Odpadów Wydobywczych (OUOW) Żelazny Most to największa w Europie tego typu konstrukcja i jedna z największych na świecie [9]. To nadpoziomowy zbiornik z zaporami na całym obwodzie wzniesionymi głównie metodą namywu materiału dostarczanego metodą hydrotransportu. Obecnie zapory mają wysokość 80 m w najwyższym punkcie i są ciągle nadbudowywane. Czyni to zaporę jedną z najwyższych w kraju [10], a mając na uwadze jej długość wynoszącą w podstawie nieco ponad 16 km z pewnością najdłuższą. Należy tu podkreślić iż zbiornik w przeważającej części wypełniony jest osadem poflotacyjnym, a jedynie wierzchnią warstwę o głębokości do około 3 m stanowi woda, jednak osad, z racji drobnego uziarnienia również kumuluje znaczne ilości wody pozostając w dużej mierze w konsystencji płynnej.

Korpus zapory zbudowany z namytego materiału głównie o granulacji piasków drobnych nie jest uszczelniany. Krzywa depresji swobodnego zwierciadła wody obniżana jest poprzez drenaż pierścieniowy w postaci ściany filtracyjnej położonej w odwodnej części korpusu, a dalej klasycznie przez drenaż podstawowy zapory. Czasza uszczelniona jest warstwą zgromadzonych w niej drobnoziarnistych odpadów, które również skutecznie ograniczają filtrację wody do drenaży korpusu.

Zbiornik powstałjako miejsce deponowania odpadu powstałego w procesie flotacji rud miedzi, który z racji budowy złoża stanowi nawet do 97% całości urobionego materiału. Odpad ten stanowi skała kruszona i mielona w procesie wzbogacania rud miedzionośnych. Ma postać zawiesiny w zasolonej wodzie technologicznej w przeciętnej proporcji 1 Mg odpadu stałego na 5 m^3 wody. Taka zawiesina jest tłoczona pompami wirowymi w sieć rurociągów prowadzących na korony OUOW Żelazny Most. Na koronach szlam wylewany na plaże spływa w kierunku środka akwenu pozostawiając najgrubsze ziarna w postaci sedymentu powodującego przyrost rzędnej plaż, a wraz z drobnymi frakcjami trafia do akwenu w środkowej części obiektu. Tu woda klaruje się w sposób grawitacyjny, a następnie ujmowana wieżami odprowadzana jest ponownie do produkcji zamykając pętlę obiegu wody technologicznej lub jako nadmiarowa odprowadza jest poza układ wody technologicznej.

W związku z potrzebą ograniczenia tempa przyrostu obiektu OUOW Żelazny Most i jednocześnie utrzymania wielkości produkcji KGHM Polska Miedź S.A. zaistniała potrzeba budowy nowego zbiornika. Analizy wykazały, że optymalną lokalizacją będzie przyległy do istniejącego obiektu od strony południowej teren o powierzchni około 600 hektarów. Z racji lokalizacji obiekt nazwany został Kwaterą Południową.

OUOW Żelazny Most wznoszony jest metodą do środka, co znaczy, że powyżej pewnej wysokości nowe zapory wznoszone są na gruntach namytych w poprzednim okresie. Zgodnie z wytycznymi międzynarodowymi obecnie za bardziej bezpieczną metodą uznawana jest metoda budowy na zewnątrz [13]. Jednocześnie wykorzystanie tej metody wpisuje się z zmianę technologii segregacji i namywu odpadów związaną ze zmniejszeniem powierzchni nowego obiektu. Ważną zmianą dotyczącą hydrotransportu jest zagęszczenie odpadów przeznaczonych do składowania w Kwaterze Południowej. Odpad zostanie zagęszczony na stacji segregacji i zagęszczania odpadów do gęstości około 1,5 Mg/m^3. Zatem z obecnych 5 m^3 wody na tonę namytego opadu na Kwaterę Południową trafi zaledwie 1 m^3 na każdą złożoną tonę skały. Materiałodłożony na plażach OUOW Żelazny Most w czasie namywu ma odpowiednie parametry zarówno pod kątem granulometrycznym, tj. zawiera nie więcej niż 30% części pylastych, jak i pod kątem zagęszczenia. Zatem znakomita część korpusu jest wznoszona z wykorzystaniem namywu i nie wymaga dodatkowych zabiegów z użyciem sprzętu.

Projektowany zakres prac w ramach cyklu namywu w technologii przyjętej dla Kwatery Południowej obejmuje: cykliczne namywy i odsączania namytego materiału, przy czym namywy są krótkotrwałe – do dwóch dni, z uwagi na tworzące się przy wylewach stożki, które szybko „podpierają” wylew uniemożliwiając dalszy namyw, rozplantowanie namytych stożków sprzętem, dogęszczenie do wymaganych parametrów, po osiągnięciu rzędnej miedzy wylotami uniemożliwiającej dalsze namywy, odłożenie rurociągów namywających, formowania zapór i pirsów pod rurociągi, ponowny montaż rurociągów namywających. Zatem w zestawieniu z opisaną powyżej metodą stosowaną na Żelaznym Moście dodatkowym zakresem prac jest rozplantowanie i zabudowa materiału w korpusie zapory. Stanowi to duży zakres prac dochodzący do 4 mln m^3 w skali roku.

Rurociągi pływające są powszechnie stosowane np. przy refulowaniu materiałów spod lustra wody. Zazwyczaj zbudowane są z rur z elementem wypornościowym zamontowanych w określonym rozstawie, rzadziej jako rurociąg z podwójną ścianką. Zrodził się pomysł zastosowania rur pływających na plażach, czyli de facto rur unoszonych na powierzchni plaż. Rury zostają wyparte na powierzchnię strumieniem mieszaniny odpadów z wodą zanim woda odpłynie do akwenu lub w głąb plaży. Aby sprawdzić czy odkładany na plażach odpad uniesie pozostawiony na niej rurociąg, na plażach OUOW Żelazny Most wykonano test. Rurociąg unosił się na powierzchni wraz ze wzrostem poziomu odpadów na plaży, jednak należy się spodziewać, że przy pewnym granicznym udziale wody, dla danego uziarnienia, rurociąg przestanie być unoszony z powodu zbyt szybkiej filtracji wody w głąb plaż i w niektórych przypadkach zostanie zasypany namywanym materiałem. Dalsze próby będą prowadzone pod tym kątem, aby określić potencjalne wykorzystanie tego przy namywie odpadów gruboziarnistych o gęstości 1,5 Mg/m^3 przeznaczonych do składowania na Kwaterze Południowej.

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