CHALLENGES IN DETERMINING GROUND CONDITIONS FOR THE DESIGN OF WATER RESERVOIR DAMS IN THE AITIK MINE

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KEYWORDS

Geotechnical investigation, Hydrogeological investigations, Veiki Moraine, Geotechnical interpretation

ABSTRACT

Boliden Mineral AB contracted Golder (now WSP) for the investigation for and the design of three new water reservoir dams near the tailings area in the Aitik mine. The dams have crest lengths of approximately 3,7 kilometers and a height ranging from 20 to 25 meters. One of these dams will reach approximately 50 meters in height following tailings deposition. To determine the ground conditions geotechnical investigations were conducted. The investigations included test pit excavations, sondes (Jb-Tot, Jb-2, HfA) including sampling in soil, core drilling in rock, as well as laboratory tests and hydrogeological tests. The investigations were carried out during the years 2017-2020, with a total of over 365 days at the field.

The challenges with this type of investigation are identifying moraine type, its characteristics and establishing a correlation between each investigation method primarily based on sounding. Other challenges included dealing with a type of moraine known as Veiki moraine, local variations in moraine type, layers/lenses of sand and gravel, boulders, and varying strength of the moraine. The works also posed significant challenges with marshy ground, hilly terrain, and harsh weather conditions such as sandstorms, extreme cold, and snow.

The investigations revealed a moraine, sandy-silty moraine to silty-sandy moraine, with a thickness of up to 40 meters. The presence of layers with sand and gravel in the dam's foundation poses a risk of unwanted water transport in the moraine, which could endanger the dams. A significant focus was placed on identifying the layers/lenses, which proved to be a real detective work. Identification of potentially water-bearing layers was mainly based on ram penetration soundings (HfA), supported by correlation analysis with other

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sondes and samplings. This process involved analogously evaluating and interpreting results using crayons on long paper rolls, to the great curiosity and delight of colleagues.

The project's success hinged on close collaboration between Bolidens project organization and contractors, field teams from Ramböll, Sweco, Afry, Drillcon and Golder/WSP, allowing year-round investigations. This synergy, coupled with the experience gained, led to ongoing refinement of the investigation methods and procedures.

1. INTRODUCTION

Boliden, in accordance with the current permit [1], has committed to the construction of a new reservoir, the HS reservoir, for the deposition of high-sulfur enrichment sand, a purification plant, and a new Water Reservoir, see Figure 1. The purpose of the reservoir is to manage the water flow from the HS reservoir, increase the water storage capacity in the system, to reduce the amount of water discharged to the recipient, and to better control when water is to be discharged.

Figure 1. Orientation figure with approximate length measurement for dam V1, V2, and VR [11].

Prior to the construction of the Water Reservoir, a feasibility study [2] was carried out and a permit application [3] was prepared. Golder (now WSP) was commissioned by Boliden Mineral AB in 2017 to carry out the detailed design of the Water Reservoir. The task also involved investigating the appropriate location for the moraine quarries for sourcing material for the construction of the dams.

2. OVERALL GEOTECHNICAL CONDITIONS

The terrain is hilly, with low parts in the middle of the investigation area with marshland and lakes/ponds. In the northwestern and southeastern parts of the area, there are higher lying areas. Northeast of the area is the sand magazine and southwest is a transport road. The ground generally slopes from the transportation route down to the sand magazine [4].

Figure 2. Drone photo over the dam area, to the right of the road you can see the construction of the dam V2 [12].

Most of the investigation area has been covered with fir and pine forest, which is now felled, but also marsh areas and smaller ponds exist, see Figure 2. The vegetation and soil layer varies between about 0,6-1,0 m.

The geology in the area according to the Geological Survey of Sweden's (SGU) soil map [5] is Veikimorän, a special type of moraine back landscape (hilly moraine), Veikimorän is characterized by plateaus with ridge edges and intervening depressions that are often filled with water and/or peat. The shapes of the depressions are often round [6]. Veikimorän was formed [7] as dead ice moraines during the melting of the first ice age phase during the Weichselian deglaciation. The material composition for Veikimorän is characterized by varying proportions of sorted sediment and moraine, which is also typical for dead ice moraines.

The investigations showed that the bedrock is overlaid by moraine of varying thickness. The moraine, sandy silty moraine to silty sandy moraine, is mainly quite homogeneous but the investigations show the occurrence of sandy/gravelly layers and vertical lenses and parts with more sandy moraine. Depth to bedrock and rock quality varies along the planned dam lines. The bedrock consists mainly of granitic rocks and gneiss with elements of pegmatitic and mafic rocks. Strongly weathered rock has been observed in some boreholes, mainly near the rock surface.

3. CHALLENGES WITH THE INVESTIGATIONS

Generally, the time spent performing the geotechnical investigations has been longer than planned due to boulders, difficulties in sampling loose soil layers at greater depths, and machine breakdowns due to harsh weather.

For the hydrogeological investigations, the irregular soil layer sequence and the proximity to the 450 m deep open pit have created challenging and special hydrogeological conditions. This has meant that conductive soil layers or rock at depth can have unsaturated conditions while water is present in superficial soil layers.

External factors such as peatland, hilly terrain, and harsh weather with sandstorms, severe cold, and snow have also affected where, how, and when certain areas can be investigated.

4. INTERPRETATION OF THE INVESTIGATIONS

Approach, interpretation of the moraine

Direct shear tests have shown that the existing naturally deposited moraine has a friction angle of at least 35 degrees. In the interpretation and evaluation of the moraine, 35 degrees has been used as a reference value for the required strength [4]. When evaluating the friction angle of the moraine, the following equation from the Plattgrundläggningshandboken [8] has been used.

$$\emptyset' = 29 + 2{,}3 * HfA_{(netto)}^{0{,}46}$$

To achieve a friction angle of 35 degrees, at least 12 hammer blows/20 cm subsidence are required after deducting 3 degrees for silt and adding 2 degrees for gravel. The equivalent to achieve a friction angle of 35 degrees for Jb soundings has been correlation-calculated to a sink rate of ≥3 sec/0,2 m when the hammer is on and the feed force is ≥4 kN.

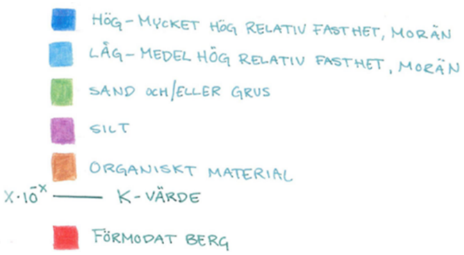

Figure 3. Classification of soil types during interpretation [4].

The interpretation was carried out on printed drawings along each dam with sections every 50 meters and a profile drawing along the centerline of the dams. The soil was classified according to Figure 3. Light blue represents a moraine with a friction angle <35 degrees and dark blue represents a moraine with a friction angle ≥35 degrees.

In Figure 4 below, an example of how the interpretation has been reported is shown. The interpretation of these three soundings differs. For the left sounding, there is screw sampling, HfA, and Jb sounding. In the left sounding, mainly screw sampling and HfA results are used and the interpretation is more simple. In the other two soundings, there is only screw sampling and Jb sounding, but the interpretation is more difficult in the right one because the feed force, sinking rate, and hammer drilling vary.

In the left sounding, there are also hydrogeological falling-head tests performed and in the associated groundwater pipes slug tests are also performed. Hydrogeological tests have mainly been performed where screw sampling has shown a high proportion of sand and/or gravel and that low relative strength has been measured in soundings.

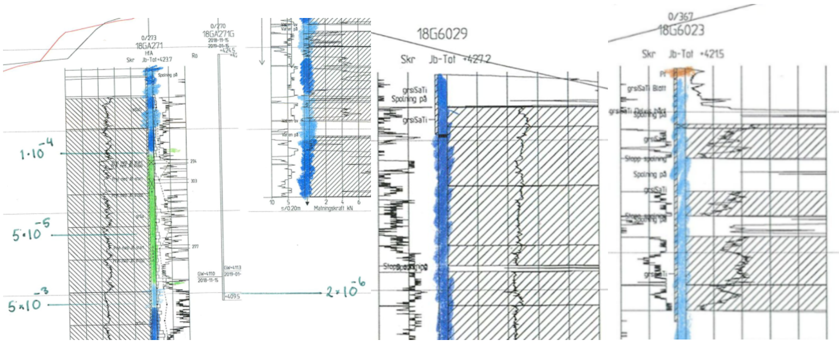

Figure 4. Examples of interpretation of soundings. To the left, interpretation of sounding with sampling, HfA and Jb sounding incl. K-value; middle, interpretation of sampling and Jb sounding; to the right, interpretation of sampling and Jb sounding

The hunt for water-permeable layers

In the interpretation of the soil's permeability, it is based on the above correlation between HfA/Jb but also with a weighting of results from hydro investigations. Our assessment was that if the hammer sounding shows more than 25 blows/20 cm, hydro investigations often show that the soil is low permeable i.e., k < ca 10-6 m/s. At fewer than 25 blows/20 cm, the soil can be either high or low permeable. As a complement to the correlation between soundings and permeability, results and ocular assessments from sampling and site visits, field notes on e.g., water losses, and geohydrological assessments have also been weighed in [9].

For dam V2, discontinuous layers and layers of sand and gravel were identified in the beginning of dam V2, called chainage 0, approximately between km 0/200 – 0/550. Hydrogeological investigations in these layers showed a hydraulic conductivity of about 10-5 m/s [9]. In Figure 5, all investigation points where layers/layers of sand/gravel have been identified are shown.

Generally, the planned chainage 0 is located on top of a ridge and starts at a natural slope in section about 0/150. Along the ridge, high-permeable moraine is found, both on top and along the respective slope. The high-permeable moraine is underlain by moraine with low permeability. The high-permeable moraine decreases in thickness along the chainage and the natural end of the ridge (about section 0/550) [9].

Three different types of sections for the soil profile have been identified, type section A (0/225 – 0/325), B (0/325 – 0/425), and C (0/425 – 0/550), see section marking in Figure 5. Type sections were then used in leakage calculations of the dam's subsoil. In this paper, only type section A (0/225 – 0/325) is described.

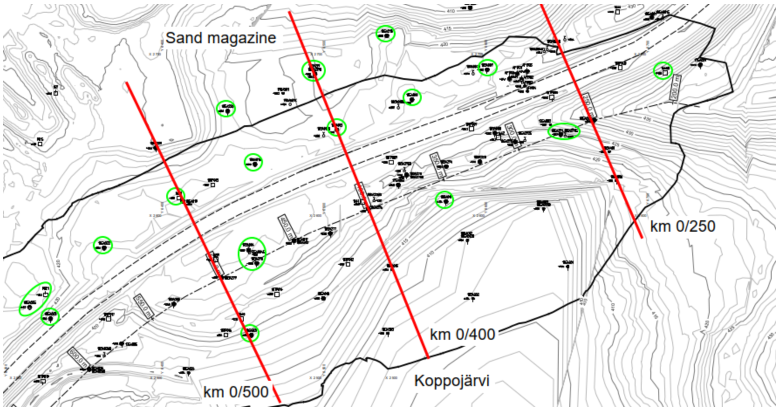

Figure 5. Plan with investigation points over chainage 0, dam V2, and section marks. Green circles around investigation points show where layers of gravel/sand have been identified.

0/225 – 0/325

The soil consists of sandy silty moraine to silty sandy moraine with medium-high relative strength. In places, in two points, inclusions of gravel have been encountered. Towards the depth (>16 m), the investigations show that there are layers in the moraine of coarse sand and gravel. However, the sampling method means that sampling below the groundwater surface at these depths can miss fine material due to washing out. Towards the depth, the relative strength of the moraine increases from medium-high to high to very high.

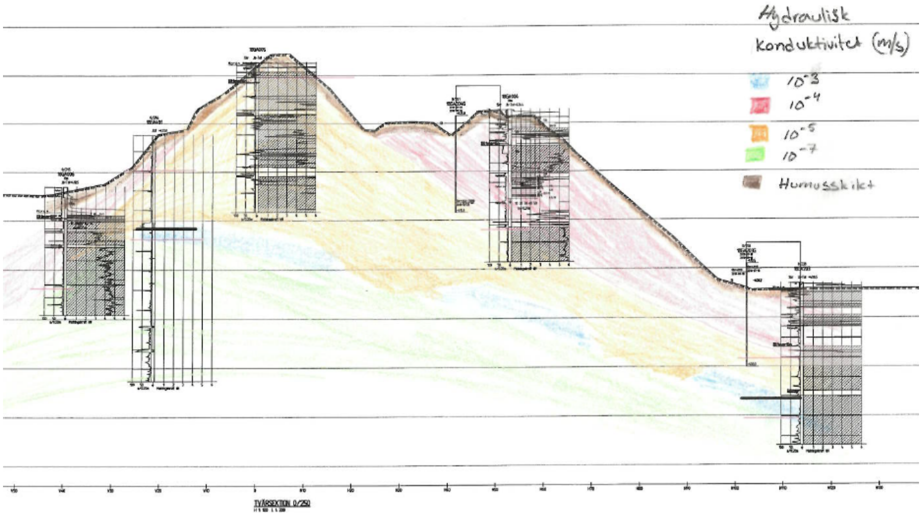

Figure 6. Interpreted soil profile for sections 0/225 – 0/325 (section taken in 0/250).

High-permeable layers occur down to about 10 m depth in the section. In the transition from the high-permeable to the low-permeable materials, there is an approximately 1 m thick non-continuous layer with very high permeability and with a slope towards the Sand magazine. The non-continuous layer goes from level about +414 at Koppojärvi to about +400 on the Sand magazine side, see Figure 6. The extent of the layer decreases with the length measurement. At section about 0/300, the layer is only found on the side towards Koppojärvi pond.

5. INTERPRETATION IN THE CONSTRUCTION PHASE

The results of the investigations and the interpretation, along with other technical results, culminated in, among other things, foundation conditions for the dams. Request documents and work documents were prepared and the contractor began excavation. Dam V2, which was the first of the three dams, served as a pioneer and based on the experiences from investigations and execution, the investigations on the next dam could be optimized.

The dams were to be founded on "dense" moraine, which meant that sand and gravel could not occur in the excavation bottom. During the foundation of the chainage 0 and on other parts of dam V2, the sand and gravel layers identified in the investigation points were encountered. New layers and lenses were also encountered which had not been discovered in the investigations. These layers and lenses could be very local while others were more elongated in both longitudinal and depth directions.

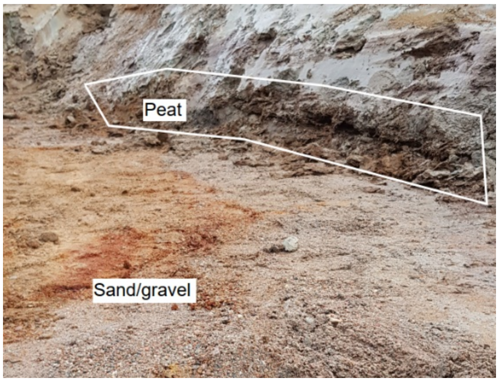

Figure 7. Photo of the occurrence of sand, gravel, and peat in beginning 0 dam V2 [13].

Something that was also encountered in connection with the foundation of dam V2 and in a couple of test pits along the other dams, was 0,1-0,3 m thick peat layers under naturally deposited moraine. The random encounter of sand, gravel, and peat is characteristic of dead ice moraine and Veiki moraine [7].

In connection with the excavation work for the foundation of dam V2, a measure matrix was set up to handle these occurrences more efficiently. The measures depended on the size of the area (larger or smaller diameter than 5 m) and whether it was a single occurrence or not. By single occurrence is meant 1 times/75 m in length and 1 times/20 in width [10]. In Figure 7, the occurrence of sand, gravel, and peat in the dam's subsoil is visible. The different soil materials differ markedly in color, which simplifies the identification of these layers, lenses, and layers during the excavation work for the foundation of the dams.

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