Internal Erosion and Duration of Grouting Works. Case History of a Small Embankment Dam

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Abstract

Peltokoski hydropower plant in River Mustionjoki, Southern part of Finland, was reconstructed in 1950-1951 and the head of the power station was increased. A low head hydropower plant comprises right embankment dam, a spillway, a power station, a buttress dam and left embankment dam. The embankment dams are homogenous moraine dams and they are mainly founded on moraine. A wooden sheet piling is installed inside the highest part of the embankment dams. The dam belongs to Consequence Class 2 and the dam breach will not cause any loss of life. Also the damages to third person's property are small.

After the reconstruction of the hydropower plant a spring appeared at the backside of the left embankment dam. Other spring was formed in 1980's. The seepage flow was passing through the fracture zone in the bedrock under the embankment dam. After the embankment dam, the water was flowing in the fine sand layer between the bottom moraine and the hard clay layer in the surface. The thickness of the clay layer is approx. 2 meters. The leakage flow increased gradually to 35 l/s and a large sink hole of 3 meter deep was formed approx. 60 meters from the embankment dam in 1987. At the same time part of the dam crest settled approx. 30 cm. The fracture zone in the bedrock was grouted with polyurethane and with cement containing bentonite and filler. An inverted filter was constructed at the place of the burst. The grouting of the fracture zone decreased the leakage flow from 35 l/s to 1.2 l/s.

The leakage has increased during the years. The erosion pipe near the outflow is collapsing forming a sink holes. A process of the backward erosion piping could be verified.

The case history of a small dam and its repairs are presented. The failure mechanism, the mitigation measures and the consequences are discussed in the paper. Also the durability of the grouting works is discussed.

Introduction

The watercourse of River Karjaanjoki is situated in the Southern Finland, approx. 80 km west from the capital of Helsinki. The catchment area of the river system is 2'110 km^2, which consist of 12.1 % lake area. The mean discharge (MQ) is approx. 18 m^3/s.

River Mustionjoki is the outlet from the main lake Lohjanjärvi (82 km^2) to the Gulf of Finland. The length of the river is approx. 27 km and the head difference is 31.5 m. The river is in cascade and has four small hydropower plants. Peltokoski is the second hydropower plant from Lake Lohjanjärvi.

First hydropower unit at Peltokoski was commissioned in 1909. The unit used the head of 3.3 m and had a capacity of 224 kW. Peltokoski hydropower plant has been upgraded in 1950-1951 and the head of the power station was increased to 10.5 m. The hydropower plant comprises right embankment dam, a spillway, a power station, a buttress dam and left embankment dam. The embankment dams are mainly founded on moraine. A sheet piling is constructed in the middle of the dam.

Fortum (Imatran Voima Oy) bought the hydropower plants at River Mustionjoki in 1985.

The dam belongs to the Consequence Class 2 according to Finnish Dam Safety Act (renewed 1.10.2009). The hydropower plant is a run-of-river power plant. The dam breach will not cause any loss of life. Also the damages to third person's property are small.

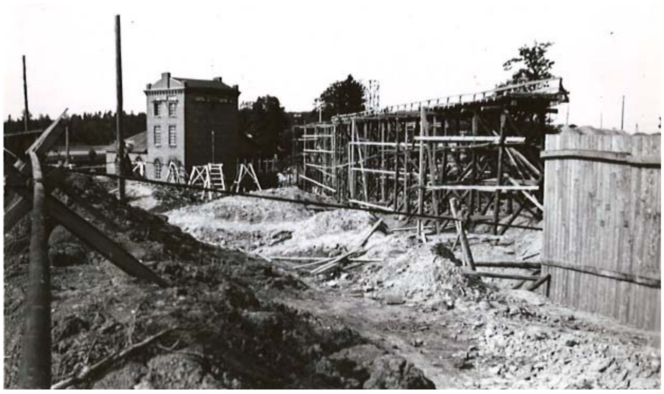

Figure 1: The construction of the left buttress and embankment dam. The wooden sheet piling of the embankment is on the right hand side, August 1950.

Internal erosion incident in 1987

At Peltokoski there has been two springs, one from the beginning of the reconstruction and the other from 1980's. These springs were situated approx. 60 meters from the left embankment dam (Figure 2).

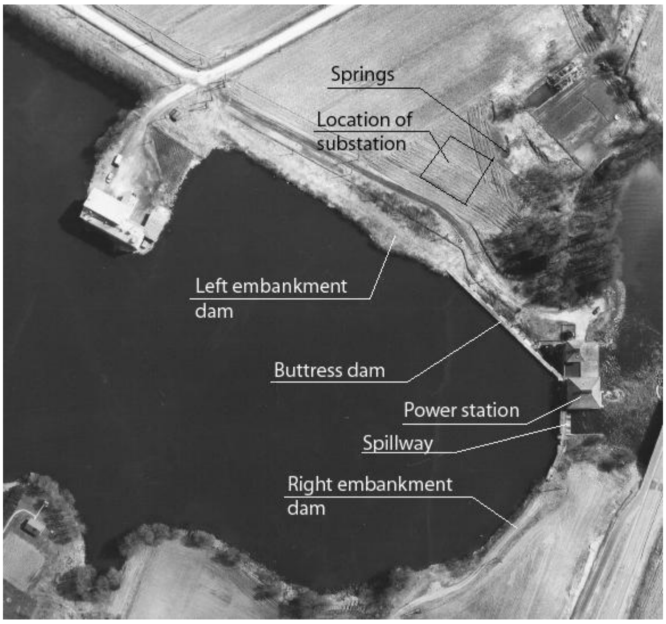

Figure 2: Aerial photograph from 1980's.

The site investigations for finding the leakage paths were started in year 1984. The weight sounding were done in 12 places and soil samples were taken in five spots. Six stand pipes were installed for the monitoring of the pore pressures.

The site investigations behind the embankment dam were carried to the hard soil bottom. The bottom is dense moraine (glacial till) containing sand, gravel and stones. The top elevation is almost horizontal and is at the elevation +16.5...+18.0 m asl. The soil layer above moraine is almost uniformly graded silt/fine sand (d_{50} = 0.03-0.05 mm). The layer is loose in some places. The upper layer is dry stratified clay/silt layer.

Highest groundwater pressures were measured approx. 15 meters from the end of the buttress dam. The area of high pressures is formed perpendicular to embankment dam towards to the spring. The groundwater pressures in the silt/fine sand layer were approx. 60 cm above the ground elevations.

The georadar investigations were carried in winter 1987. The findings were that the bedrock is situated at the deeper elevation at the higher groundwater pressures and the fissured bedrock has a water carrying layer.

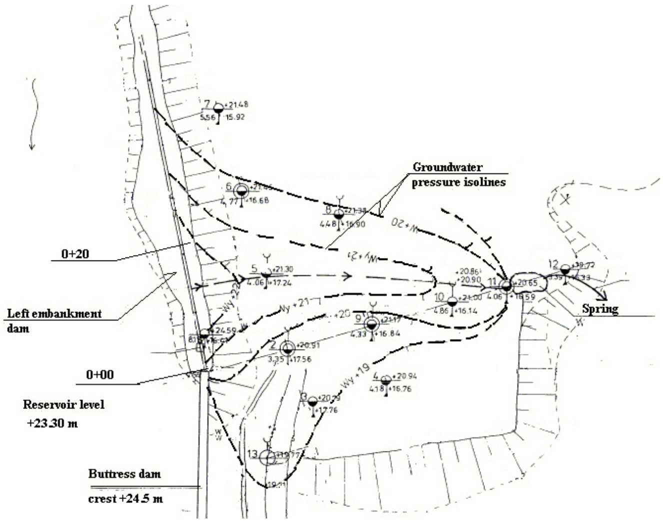

Figure 3: The results of the groundwater pressure measurements (IPT, 1984).

In late winter 1987 the spring collapsed approx. 60 meters from the left embankment dam. A large sink hole of 3 meter deep and a settlement of 29 cm at the dam crest were formed (Figure 4). The collapsed bank was repaired by constructing inverse filter with stones on the surface. Two Thompson overflow weir were constructed behind the inverse filter. Total leakage was 35 l/s. The water was clear without any sediment suspension.

The diver study was carried out in November 1987. A cellar building was left in the upstream dam toe during the construction (Figure 5). The building has a porch of 1.5 * 2 m^2 and two cellars each of 2 * 3.2 m^2. The building was situated approx. 20 meters from the buttress dam. The roof of the building was in the depth of 4 meters. The cellar has had a wooden floor, which has decayed. Hard clay was found under the structures and any water flow could not be observed. It was concluded that the building has not any influence to the leakage.

Figure 4: A large sink hole was formed due to the internal erosion in 1987.

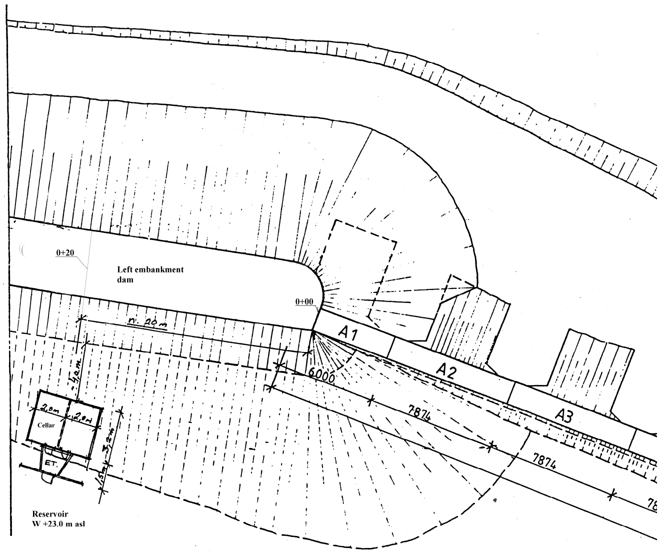

Figure 5: A cellar building is situated at the toe of the left embankment dam (1987).

Grouting works in 1988

The reparation of the leakage was carried out in August - September 1988.

The leakage area at the chainage 0+13 - 0+45 were detected with a georadar. The actual depth of the leakage could not be confirmed with the georadar. Two meters deep fractured rock zone was detected at the depth of 12 meters during the drilling. The connection between the fractured zone and the leakage outlet could be verified with a tracer. The travelling time of the tracer from the fracture rock to the inverse filter was 17 minutes.

The grouting works of the fractured rock were done with polyurethane (1'330 kg), cement (25'600 kg) with bentonite (8'000 kg) and with filler (52'800 kg). Total amount of the grouting mass was 101 m^3.

The leakage flow due to the grouting works decreased from 35 l/s to 1.2 l/s.

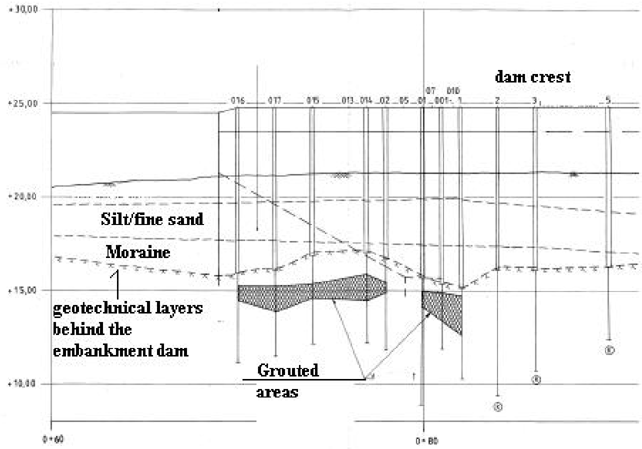

Figure 6: The grouting works in 1988.

Development of the internal erosion

A substation was constructed above the leakage path without any consultations in 1994. The substation is constructed on the shallow foundation. The crushed stone layer of 250 mm is under the concrete foundation. The area under the substation is pressurised approx. to the ground level. The sinkholes are refilled appearing. There has been tendency that the sinkholes are slightly moving towards the embankment dam (**Figure 7**).

Figure 7: The sink holes at the substation on March 21, 2007.

The leakage has increased after the grouting works. Now after 22 years the leakage has approx. same value (35-40 l/s) than before the incident. The water is clear and any suspension is not observed.

The leakage was studied with the georadar in 2008. A loose sections in the embankment dam were found and they were repaired with grouting during Spring 2008.

VTT (Technical Research Center of Finland) has carried out electrical profiling studies during summer 2009. The studies indicate that there are two weak spots: one at the foundation approx. at Pl 15+00 - 25+00 and the other at the dam body at approx. Pl 30+00. The grouting of the bedrock started in late Autumn 2009, but the grouting works have to be stopped due to the hard winter conditions.

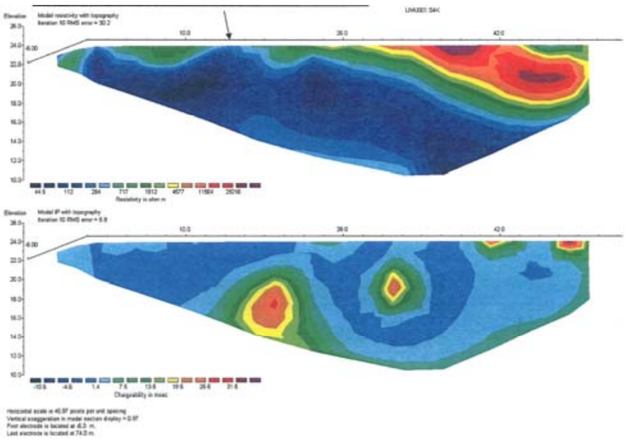

Figure 8: Preliminary results of electrical profiling. The upper figure is the resistivity, which corresponds the density of the soils, and the lower figure is chargeability, which corresponds the leakage (VTT, 2009).

Discussion

The water is leaking through the weak fractured bedrock under the embankment dam and then the water has a flow path to the silt/fine sand layer between the moraine in the bottom and the clay on the surface. Also some water flowing up loosening the embankment dam.

The leakage pipe behind the embankment dam has been formed in 1987, when the leakage was 35 l/s. The grout curtain was created at the line of the embankment dam. The leakage were not stopped totally by grouting and the remaining flow was 1.2 l/s. The re-opening of the leakage path has occurred. There are several explanations:

- small remaining leakage has started the erosion in the weak fractured rock at the contact zone with the grouted material or elsewhere and/or
- the grouted material (cement, bentonite, filler) has started to erode.

First explanation is more likely. The erosion of the grouted material can not be totally excluded. There are not many references of the grouting durability and stability in the fractured zones. The information on the cases studies shall be collected.

The leakage pipe is collapsing time to time and also some settlement of the area could be observed. The inverted filter at the end of the leakage pipe is controlling of the erosion, but the settlements and the sinkholes at the substation indicate that the water contains suspension. The clay and moraine have some cohesion, which resists and decreases the erosion rate in the pipe. The state of the internal erosion is not considered stable and the embankment dam will be repaired.

The backward erosion is observed and the sinkholes are approaching the substation structures. At the moment, this internal erosion through the foundation and the silt/fine sand layer is not a dam safety problem, but it is a problem for the electrical distribution. If a new sinkhole will cause closing down of the electrical distribution, the costs of the bad publicity are many times higher than the structural damages.

The investigations continue and the alternatives for repairing the leakage are studied. Also the preparedness activities are done e.g. control inspections, the masses are reserved at the site.

References

[1] IPT (1984). *Peltokoski dam. Leakage study*. In Finnish.

[2] VTT (2009). *Peltokoski dam leakage study with electrical profiling and IP (induced polarization)- measurements.* Research report. Confidential. In Finnish.