A COMBINATION OF JET GROUTING AND MPSP GROUTING IN ISKAR RIVER CASCADE HYDROPOWER PLANT IN BULGARIA

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ABSTRACT

Grouting technologies are ground treatment techniques used for modifying the behaviour of a mass of soil or rock by injecting a mixture. The sleeved port pipes (also called Tube A Manchette) are highly diffused for grouting treatment of coarse soils and fissured rocks. This paper describes a combination of jet grouting and rock grouting with MPSP (multiple packer sleeve pipe) technique that has been used to realize waterproof curtains under fluvial structures for a cascade hydro-power plant. This is composed by five mini hydro-power plants, placed along the Iskar river, in Bulgaria, and composed by a penstock followed by the power house, a spillway, and an earth dam containing the reservoir. The geology of the site is characterized by an upper alluvial deposit lying over the bedrock. In each site, similar treatments were carried out: an impervious curtain along the plant section, obtained by executing jet-grouting columns in the surficial alluvial layers and grouting the underlying fractured rock by means of port pipes. The temporary embankment, built during the works for protecting each site from the possible river floods, has been waterproofed and stabilized by reinforced jet-grouting columns. The grouting processes have been controlled and monitored by a computerized system.

Keywords: rock grouting, MPSP, jet grouting, ground impermeabilization

INTRODUCTION

The Iskar river cascade hydropower plant is situated northern of Sofia, Bulgaria, and it is composed by nine plants. Actually five of them have been built and produce energy. Each plant is composed by a penstock followed by the turbine building, a spillway, and an earth dam that contains the reservoir.
The Iskar rivers runs in a narrow valley characterized by diorite or diabase rocks, with an upper deposit of alluvial soil, composed mainly by gravel and sand.
Each plant requires an impervious curtain under the structures and in correspondence of the earth dam: this has been obtained by means of a jet grouting treatment of the alluvial coarse soil, and a grouting treatment with cement mixtures of the underlying rock using the MPSP technology.
During the construction of the structures, the site has been shielded from the river water by a temporary earth embankment that has been statically improved and waterproofed by jet grouting columns reinforced with steel tubes; this allowed to work without interruption even in case of flood of the Iskar river.

THE DESIGN OF THE PLANTS

The design of each plant included a detailed campaign of geotechnical investigation, and a long term monitoring system for the control of the efficiency of the impervious curtain and of the stability of the earth dam.

Geotechnical investigation

The execution of several corings along the main cross section of each barrage allowed to reconstruct the bedrock surface covered by the surficial alluvial layer.

In each hole, permeability tests have been carried out at different depths: Lefranc test into the alluvial soil strata, Lugeon test in the rock. Usually the corings put in evidence that the upper part of the rock is rather fractured, being these information very often confirmed and better described by the Lugeon test results. The cross section in Fig. 1 concerns the plant of Lakatnik.

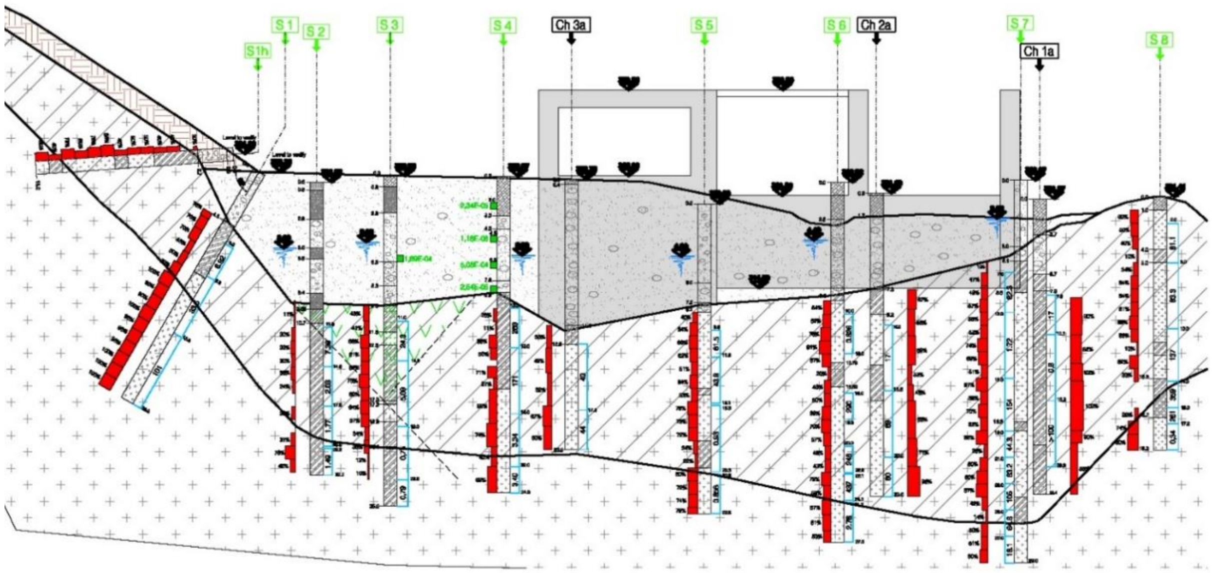

Fig. 1 Geotechnical investigation at the power plant of Lakatnik

Power plant design

Each plant is composed by: the main building that includes the intake channel, the turbine, the outlet channel, the control hall; the weir with the gates; the lateral earth dam (see fig. 2).

Fig. 2 Geotechnical investigation at the power plant of Lakatnik

During the plant construction, an earth embankment was built in order to protect the front, the back and a side site of the area from the river, as shown in the following figure 3. The embankment has been waterproofed by executing, down to the bedrock level, a line of jet grouting columns. This allowed to work for the execution of the concrete structures and the installation of the turbine and the electromechanical devices regardless of the variation of the flow rate of the river: no seasonal interruptions of the activities were necessary.

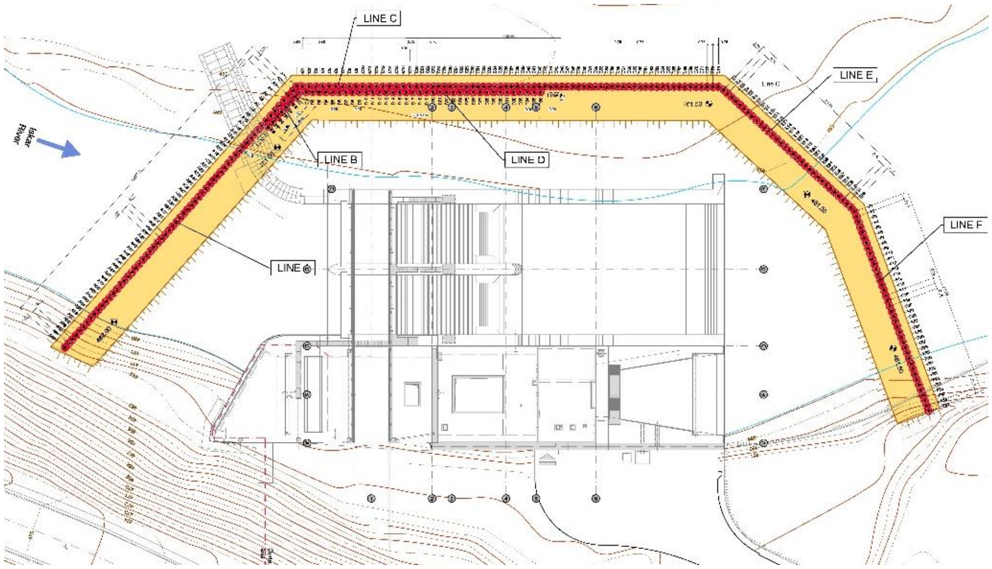

Fig. 3 Temporary embankment as protection of the site during the activities in case of river flood

In some sites the plant lies in correspondence of a narrow section of the valley, so in order to guarantee the necessary flowing section of the river, the embankment was placed beside the external alignment of the abutment wall of the plant. In this case the embankment has been considered as a gravity structure, with two lateral lines of jet grouting columns axially reinforced with a steel pipe anchored into the bedrock (see fig. 4).

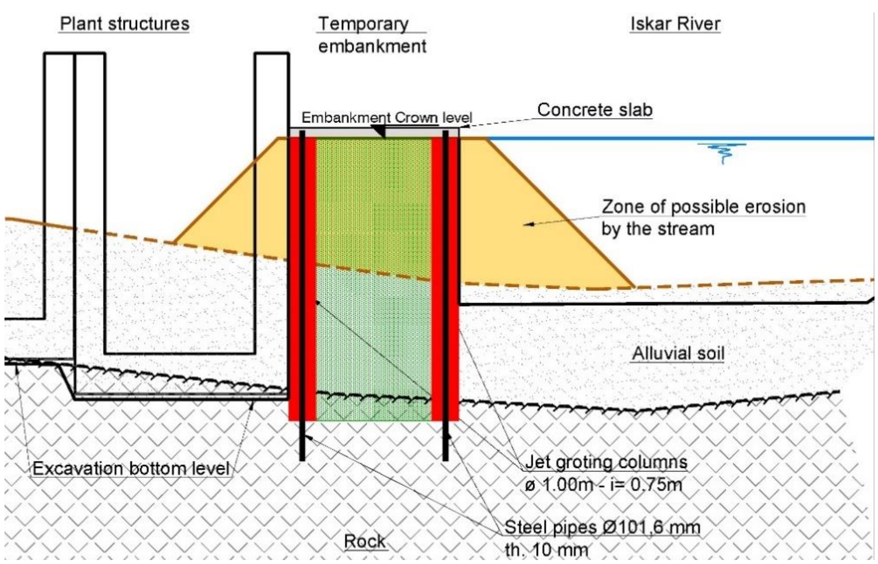

Fig. 4 Temporary embankment reinforced with jet grouting columns and steel pipes

The internal side of the embankment has been excavated up to uncover the jet grouting columns; during the works the grouted wall was protected with a mesh reinforced shot concrete, until the cast of the abutment wall finally covered the vertical surface. The reinforcements were designed taking into account that the water flow might remove the slope of the embankment, and considering the hydraulic effort applied to the remaining treated core with the deeper level reachable during the plant excavation. So the reinforced double jet grouting sheet has a double functions: to assure the equilibrium of the embankment; to protect it from the erosion by the river water.
For each plant a FEM analysis of the steady-state seepage process following the construction of the dam and hence the presence reservoir was carried out by applying a three-dimensional finite element code (Fig. 5).

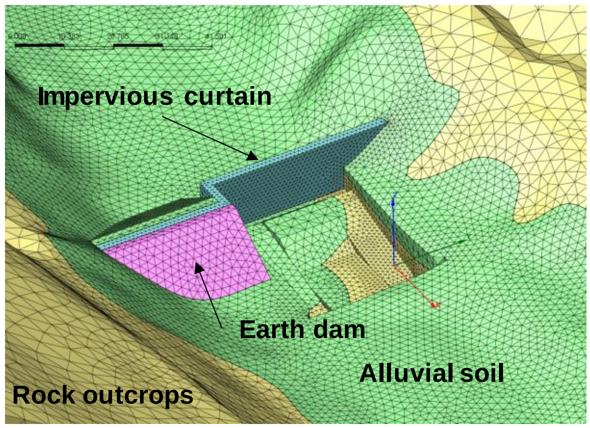

Fig. 5 The 3D model mesh

The setup of the geometry of the three-dimensional model was performed starting from the implementation of the 3-D DTM (Digital Terrain Model) model of the area and assembling the geometry of the dam structure according to the proper design. Then, based on the hydraulic properties of the rocks and the soils affected by the dam construction, which have been derived from the results of the investigations available, and the boundary conditions assigned to the model, the continuity equation governing the water seepage in the soil domain was integrated in order to derive the values of the hydraulic head for each node and the values of the pore water pressure accordingly. The main features of the seepage regime consequent to the construction of the dam were calculated in order to design the impervious curtain under the weir and the dam foundation. A sensitivity analysis was carried out taking into account different values of the size of the impervious curtain to assess the optimal length of the same structure according to a cost-effective solution (fig. 6 and 7).

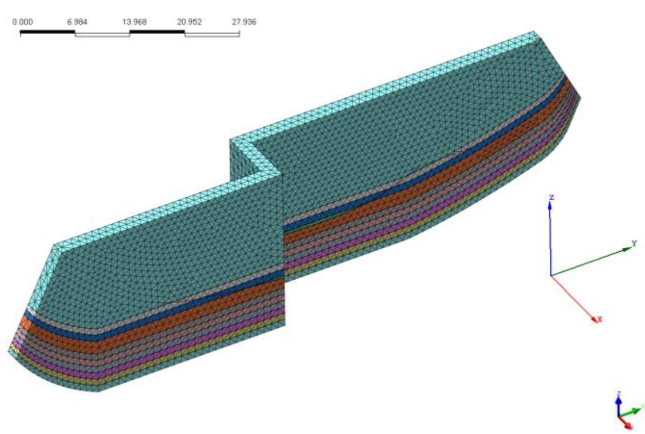

Fig. 6 A detail of the curtain elements (on the left)

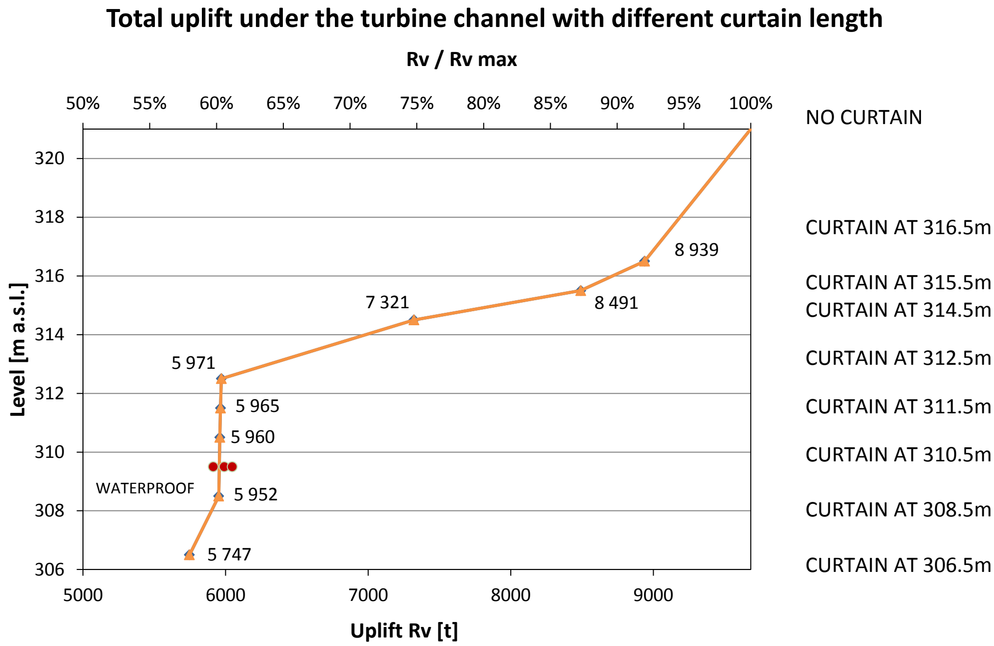

Fig. 7 Sensitivity analysis of the curtain depth

The impervious curtain

For all the plants the deepest excavation level is placed in the area of the power house, where the bedrock is always uncovered. Hence the impervious curtain required to treat the most surficial rock mass, all along the alignment, the coarse surficial deposit on the sides of the section, and the earth dam core.

The investigations showed that the upper part of the bedrock was normally cracked for a thickness variable from 2 m to 5-÷6 m, hanging from the local geological condition of each site, presenting very low RQD values; the permeability values, measured with Lugeon test, vary normally between 3 and 50 UL, and in several cases they can rise up to 600 UL. According to the design model, the target of the treatment for the curtain was to not exceed 3 UL.

The alluvial formations were composed by gravel and sand, in some sites including 15-30% of silty fraction; boulders were detected in the zone of the current bed river and in the food plain side areas, but normally only in surficial position. The permeability, measured with Lefranc test, gave results included between $10^{-4}÷10^{-6}$ m/s: the target after the soil treatment in those strata and in the earth dam core was fixed in $1÷5*10^{-7}$ m/s.

For the execution of the impervious curtain, it was decided to treat the soil with two lines of double fluid jet grouting columns Ø 1,30 m, and to grout the rock with cement mixes. The curtain was carried out after the execution of the earth dam, and, usually (but not always, due to the main works scheduling), after the cast of the weir and power house foundation plate.

The critical issues of this solution were hence:

- the locally highly fractured rock in the transition zone to the upper alluvial deposit
- the possible weakness of the jet grouting treatment at the bottom of the columns, in correspondence of the contact with the underlying rock
- the contact zone between the ground and the concrete foundations of the weir and the power house, because of the surficial disturb of the rock due to the excavation (made with blasting or with non-explosive agent) and of the discontinuity with the concrete casts that needs to be properly sealed.

In order to obtain a homogeneous treatment in all those critical zones, it was decided to perform the rock grouting by means of the MPSP (multiple packer sleeve pipes) placed into the holes that crossed the jet grouted soil or the concrete foundations.

THE GROUND TREATMENTS

Jet grouting

Jet grouting columns were executed as first, using air and a water/cement ratio W/C =1 for the grout, injected with a pressure of 40 MPa.
At the beginning of the activities, a trial field was executed in order to evaluate the result of treatment (see pictures in fig. 8) of the discovered columns) and to set up the operational parameters (flow rate and pressure of grout and air, uplift velocity, rotational speed) after the treatment energy procedure (Tornaghi et al. 2004).
In order to allow a more regular high pressure injection during the uplift phase, even in presence of boulders, each column execution was preceded by a predrilling, carried out 1 m down into the bedrock, by means of a dedicated drilling unit.
Some preliminary pre-drillings along the columns alignment (for the temporary embankment as well as for the impervious curtain) were initially made, in order to detect the bedrock level and hence to draw an accurate profile of the alluvial deposit base.
The geometry of the treatment involved the execution of inclined columns at the two ends of the curtain, with drillings made with angles up to 43° from the vertical.

Fig. 8 Jet grouting trial columns executed at the start of the works

During the treatment of the temporary embankment, the steel pipe reinforcement was usually inserted in the hole made for the jet grouting.
The effect of the treatment was successfully tested during the excavation for the plant construction. The picture in fig. 9 shows on the left the jet grouting wall that separates the bed river from the area of the site for the power house and the gates building. No significant water income from the waterproofed embankment occurred.

Fig. 9 On the left - Works in progress with the jet grouting wall protection from the river bed
On the right – The road on the crown of the embankment, used for the site traffic

This allowed to complete all the activities for the power plant construction (from the embankment construction to the test on the turbine) in 18 months without any interruption. In case of seasonal interruption (without the waterproofing of the temporary embankment), 6 additional months should have been considered. Until today, during the works for the five plants made, only in one occasion the river has overflown the embankment crown, causing a flood that interrupted the works. The site was evacuated on time, thus limiting the damages. Two months were necessary for restoring the yard.

Rock grouting

The treatment of the rock for the impervious curtain was carried out using the MPSP (Multiple Packer Sleeve Pipe) system. After the hole drilling, a Ø 1"1/2 pvc TAM (40/48) was installed, equipped, every 3÷5 meters, with several Heavy Duty Obturator Bags, made in polypropylene geotextile and mounted on one or two sleeves. The bags were initially folded and fixed to the pipe at the ends by a metallic tie (see fig. 10). The tube was centered by means of plastic collars.

Fig. 10 Folded and injected obturator bags mounted astride a manchette

Once the pipe was in place, the bags were filled with injecting cement grout (ratio W/C=0,6÷1) by a double packer lowered to one of the correspondent sleeves, and finally sealing the annular space between the plastic pipe and the borehole. Under the pressure of the injection, the cement of the grout separated from the water, being the latter ejected per seepage through the geotextile. As a result, the hole was divided into several sectors with predefined length by means of the tough sealings obtained injecting each obturator bag; a curing time of 18÷24 hours were sufficient for the aim (see fig. 11).

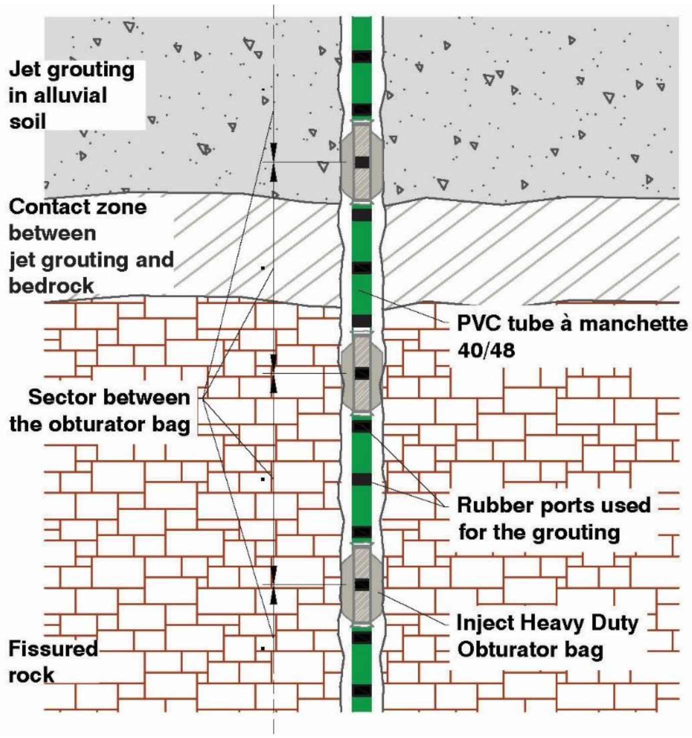

Fig. 11 Scheme of the MPSP system grouting

The grouting of each sector was then made after the usual TAM injection procedure: the double packer was placed astride one of the sleeves of the deeper sector, but in this case no plastic sheath was necessary. In fact, the grout filled initially the annular void space between the pipe and the borehole, and then it flushed into the fissures intercepted by the hole sector.

The injection was then carried out following the prescribed rules for the rock treatment.

The curtain was formed by two alignments of TAMs, spaced 1,50 m and with interaxis of 1,50 m between the boreholes. In a first phase primary pipes were drilled and injected; then the secondary pipes phase followed (fig. 12).

Along the earth dam axes the holes were drilled passing through the jet grouting columns.

The obturator bags were installed every 3÷5 m in the pipe stretch into the rock to be treated. Another bag was mounted about 1 m above the contact between rock and jet grouting, in order to treat this transition zone with a higher care.

In correspondence of the structures founded directly on the bedrock, the holes were drilled using as guides some plastic tubes previously embedded in the cast concrete.

The upper obturator bag was placed about 1 m under the foundation level, in order to obtain a sealed contact between rock and concrete. In this area a third alignment of pipes was executed, inclined towards the reservoir, in order guarantee a better treatment from the side of the hydraulic head.

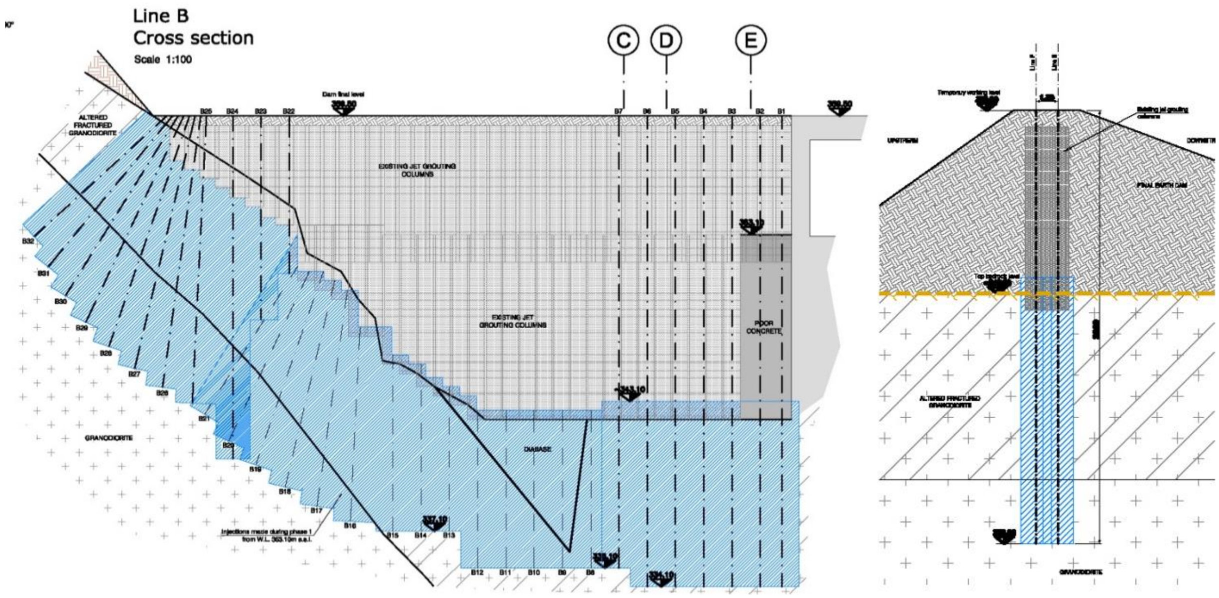

Fig. 12 Cross sections of the treatment for the impervious curtain along the earth dam

Final controls on the impervious curtain

After the completion of the jet grouting and rock grouting treatments, on each site a final investigation campaign was carried out, with execution of inclined corings along the impervious curtain and Lugeon and Lefranc tests at different depths in the holes, respectively in the rock and in the jet grouted soil.

The tests always showed the fulfilling of the prescribed permeability coefficient, as plotted in the following charts in fig. 13: the diagram on the left shows the permeability values before and after the jet grouting treatment in the soil, whereas on the right the permeability in Lugeon units before and after the rock grouting.

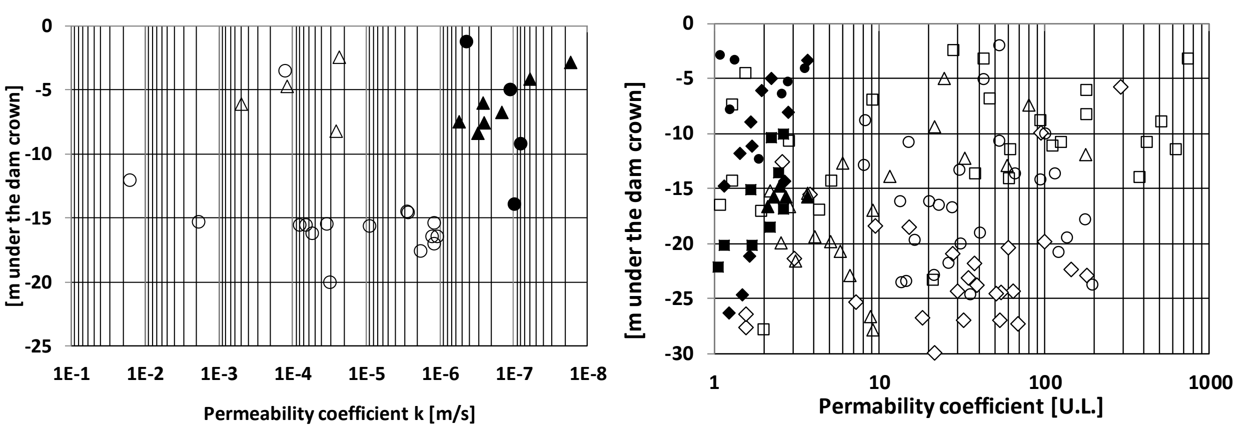

Fig. 13 Final controls on the impervious curtain: Lefranc test in soil (on left), Lugeon test in rock (on right) Permeability values after the treatment are plotted with full symbols

SUMMARY AND CONCLUSIONS

The cascade HPP of Iskar River, in Bulgaria, is composed by nine plants. For each of them, the design required the execution of a temporary embankment for protecting the power house excavation site from the river flow, and of an impervious curtain, along the earth dam and the structures section, against the water seepage in the ground, composed by rock basement underlying alluvial coarse soil. Until today, five plants are completed and regularly operating.
Jet grouting columns reinforced with steel pipes were executed along the provisional embankment in order to make it waterproofed and to work as gravity structure able to withstand the hydraulic effort of the water even in case of floods. This solution allowed to avoid any seasonal interruption during the works in the riverbed, gaining between 4 and 6 month in the execution schedule of each plant.
The impervious curtains have been executed by combining the use of jet grouting for the treatment of the coarse soil layers, and the MPSP system for the grouting of the underlying bedrock. The adoption of the MPSP allowed to save time during the treatment of crushed rock and to obtain a highly homogenous watertight treatment, particularly sealing some critical zones such as: the contact between the rock and the jet grouted soil; the upper part of the rock mass, weakened from the excavations (usually made by blasting); the contact between the rock and the concrete foundation structures of the power house and the weir. Final permeability controls on site into the curtains confirmed the good outcome of the treatments.

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