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Impact of Geological-Geotechnical Studies on Design

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SUMMARY

- INTRODUCTION
- LESSONS FROM ACCIDENTS
- STUDY METHODOLOGY FOR SOILS AND ROCK MASSES
- WHAT WILL BE EXPECTED IN THE FUTURE?

INTRODUCTION

How would we answer the following questions?

- How are the building underground floors and foundations constructed safely and economically in terms of geological and geotechnical aspects?
- How to choose the most appropriate communication and transport infrastructure route based on the geological conditions?
- How is determined the location of natural materials required for construction of dams and roads? And how do we evaluate their relevant geotechnical characteristics?
- How is a safe tunnel or an underground facility excavation done?
- What are the required geological and geotechnical conditions to store urban, toxic and radioactive waste?
- Which are the observation equipment and ground improvement methods for controlling instability, water percolation, etc.?
- How do we identify, prevent and reduce geological hazards?
- Which are the magnitude and characteristics of seismic events that are expected to affect the structure?

Easily we understand that only with adequate geological-geotechnical studies, comprising site ground investigations, its possible to answer the needs of geotechnical structures design.

INTRODUCTION

Scope of Geotechnical Engineering

The aforementioned Civil Engineering structures are in the scope of Geotecnical Engineering, branch of Civil Engineering concerned with the behaviour of soil and rock materials.

Geotechnical Engineering uses principles of Soil Mechanics and Rock Mechanics to:

- Assess risks induced by site conditions
- Investigate subsurface conditions and materials
- Determine the relevant physical, mechanical and chemical properties of these materials
- Evaluate stability of natural slopes and man-made soil deposits
- Design earthworks and structure foundations
- Monitor site conditions, earthwork and foundation construction.

Closely related and with large areas of overlap with the fields of Geotechnical Engineering is Engineering Geology. However, the field of Geotechnical Engineering is a speciality of Civil Engineering, while the field of Engineering Geology is a speciality of Geology.

INTRODUCTION

Scope of Geotechnical Engineering

Recent progress in Geotechnical Engineering, allowing the construction of bigger and bigger dams, tunnels, buildings, etc., on more and more difficult conditions, generally, with increasing high standards of safety, is the result of two main factors:

- Developments in geology and geotechnics, have made it easier to investigate the structure of the foundation ground
  - to quantify its geotechnical characteristics, between selected confidence limits
  - to predict its behavior with an adequate degree of reliability, thus facilitating the correct design decisions with a convenient safety margin
- Development of a number of treatment construction methods for improving the soil and rock materials in the foundations and in the fills and excavations at the weak zones.

Among the geological-geotechnical studies the most exigent and complete are those related with the design and construction of fill dams and concrete dam foundations, but the art of applying Geology, Soil Mechanics and Rock Mechanics is the same for other geotechnical works.

LESSONS FROM ACCIDENTS

Civil Engineering has conceived important works over the centuries according to experience taking into account the successes but above all the failures.

Geotechnical Engineering has great benefits from the lessons provided by failures and incidents. So, many case histories accounts on accidents have been widely shared.

Among these accounts, the ones involving dam failures have been well studied and understood and are very well documented.

LESSONS FROM ACCIDENTS

Teton Dam failure

Idaho, USA, Zoned Earthfill Dam, 90 m height, 11 deaths (1976)

View of the spring on the right abutment at 10:30

View at 11:30

LESSONS FROM ACCIDENTS

Teton Dam failure

Idaho, USA, Zoned Earthfill Dam, 90 m height, 11 deaths (1976)

View at 11:55

View of the dam breech early afternoon

LESSONS FROM ACCIDENTS

Teton Dam failure

This failure, during the first filling of the reservoir, was a significant event for geotechnical engineers concerned with the design and construction of earth dams, because no earth dam of such height had previously failed.

The dam foundation consisted of rhyolite welded tuff (volcanic rock), intensely jointed in the abutments, with joint aperture widths typically between 0.6 to 7.5 cm, which makes it extremely permeable.

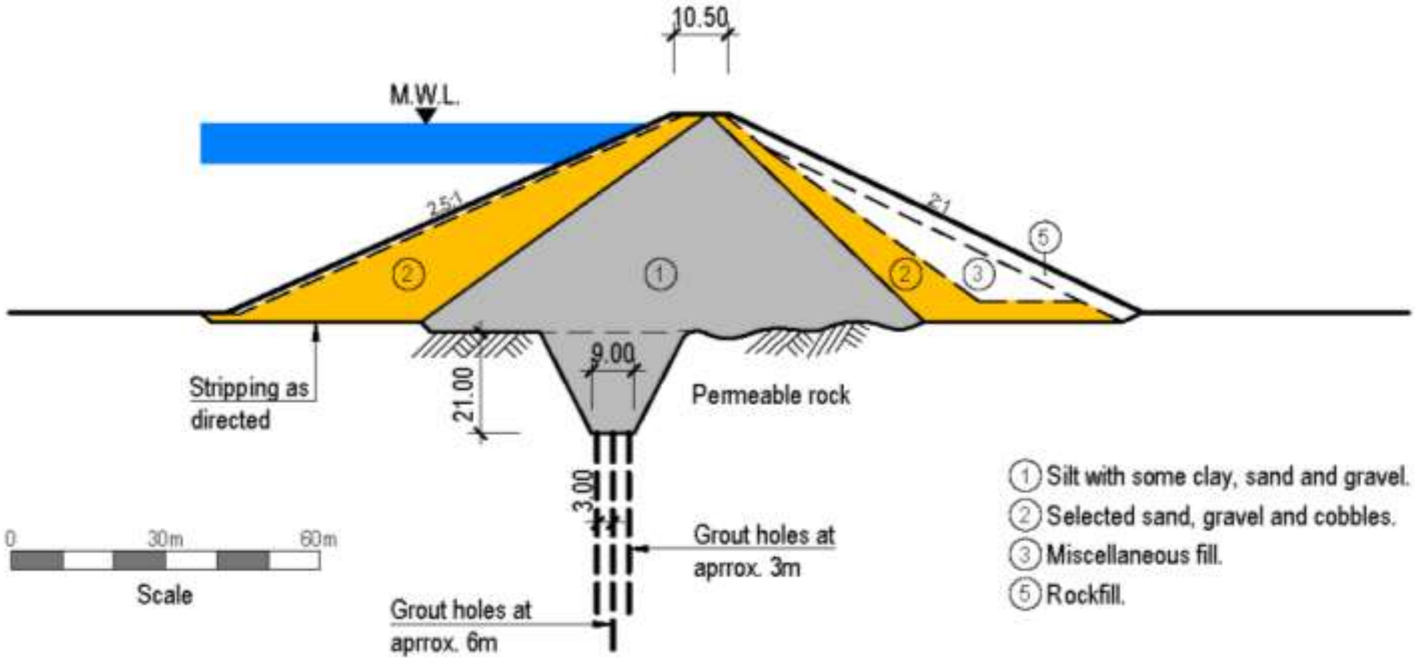
The abundance of wind-blown silt deposits upstream of the site of the dam, led the designers to use substantial quantities of this material in the dam cross-section.

Tests of the silt deposit showed it to have good strength characteristics and low permeability (of the order of $5x10^{-8}$ m/s) but to be erodible and brittle.

LESSONS FROM ACCIDENTS

Teton Dam failure

On the abutments a section with wide core of aeolian silt with coarser soils in the shells was adopted, with key trench with slopes of 0.5H/1V excavated through the upper 21 m of the permeable rock and backfilled with the silt material. In the key trenche the silt backfill was in direct contact with the jointed rock.



Typical cross-section over abutment sections founded on jointed rhyolite

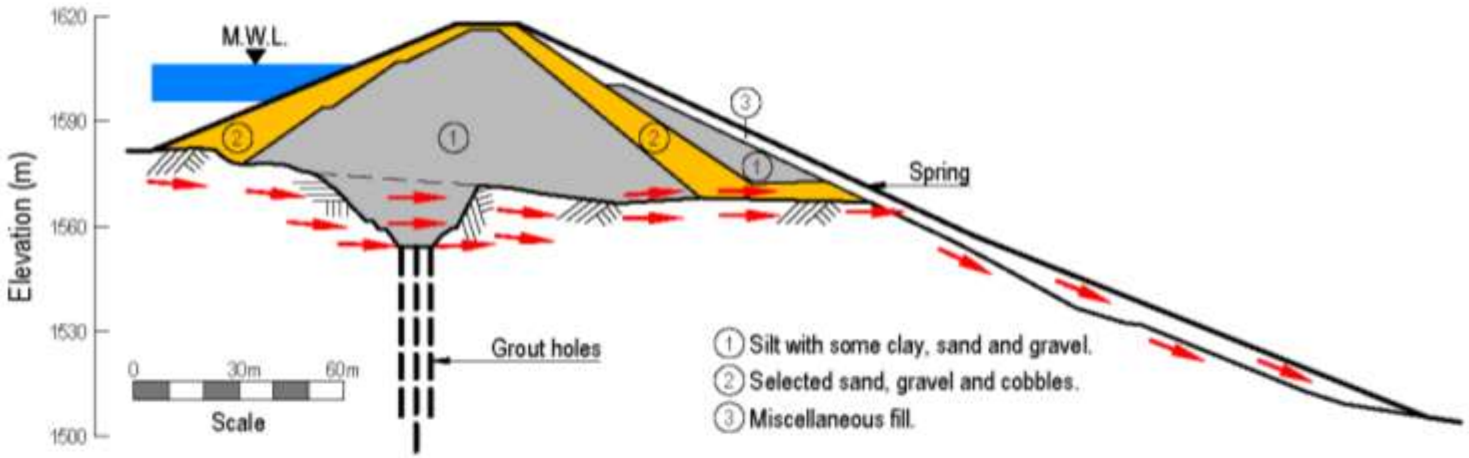
LESSONS FROM ACCIDENTS

Teton Dam failure

The two triggering mechanisms that most likely led to the failure were:

• The flow of water from the highly erodible and unprotected key trench filling through joints in the unsealed rock immediately beneath the grout cap in the right abutment and the consequent development of an erosion tunnel across the base of the key trench fill

• Cracking caused by differential settlement or hydraulic fracturing of the core material filling the key trench, that could also result in channels through the key trench fill which permit rapid internal erosion.



Probable path of water in early stages of leakage

LESSONS FROM ACCIDENTS

Teton Dam failure

The main causes of Teton dam failure were:

- In the design it was not envisaged to seal rock discontinuities with high gradients (no grouting of rock above bottom of trench) and very steep and deep cutoff trench in the abutments were adopted
- Rock mass was mapped and joint patterns were intensively known in the design phase, but significance of information was not understood.

LESSONS FROM ACCIDENTS

Geological factors influencing dam rupture mechanisms

Several case histories of dam failures allow to conclude for:

- Inadequate geological investigation (the simple inclusion of a geologist on a project, will not, by itself, isolate such projects from disasters)
- Lack of engineering knowledge of the geologist
- Investigation of dam site without knowing which type of dam is being considered
- Lack of knowledge and misunderstanding of site geological conditions
- Collection and report of geological data, but lack of understanding in terms of potential dam failure modes.

Why geological data alone is not enough by itself?

- Geological data must be synthesized and the geological features must be sorted by importance
- Data must be understood in terms of the dam’s vulnerabilities (failure modes)
- The significance of the information must be clearly discussed (discussions can require assertiveness)
- Geologists must take responsibility for understanding and portraying geological uncertainty in the design.

STUDY METHODOLOGY FOR SOILS AND ROCK MASSES

Geological exploration philosophy

The geological investigation philosophy shall include:

- Successive approaches and real time updating of plans, sections and 3D model (engineering geology involves high level of detective work)
- Geology is collected, analyzed, synthesized and used for ongoing engineering analysis (it is usually impossible to investigate, understand and evaluate the foundation conditions without detailed geological sections and maps); this is transforming geological data into knowledge
- Understand the structure's vulnerabilities (potential failure modes) is key to focusing data collection and investigation priorities
- We must be aware that data by itself does not solve problems or prevent problems or failures. Many geotechnical problems derive not from lack of information or analysis but from lack of imagination and interpretation.

STUDY METHODOLOGY FOR SOILS AND ROCK MASSES

Design integrated team

The design team should be an integrated team of geologists, engineers and technicians (geology must not be treated as a separate and independent science).

The geologists must be integrated into answering the important engineering questions; collecting geological data without consideration of these questions is not productive or very useful.

Principal design leader shall be an experienced Geotechnical Engineer versed in understanding failure-mode case histories and analytical requirements.

Brainstorming, mentoring and teaching are critical aspects of all work.

STUDY METHODOLOGY FOR SOILS AND ROCK MASSES

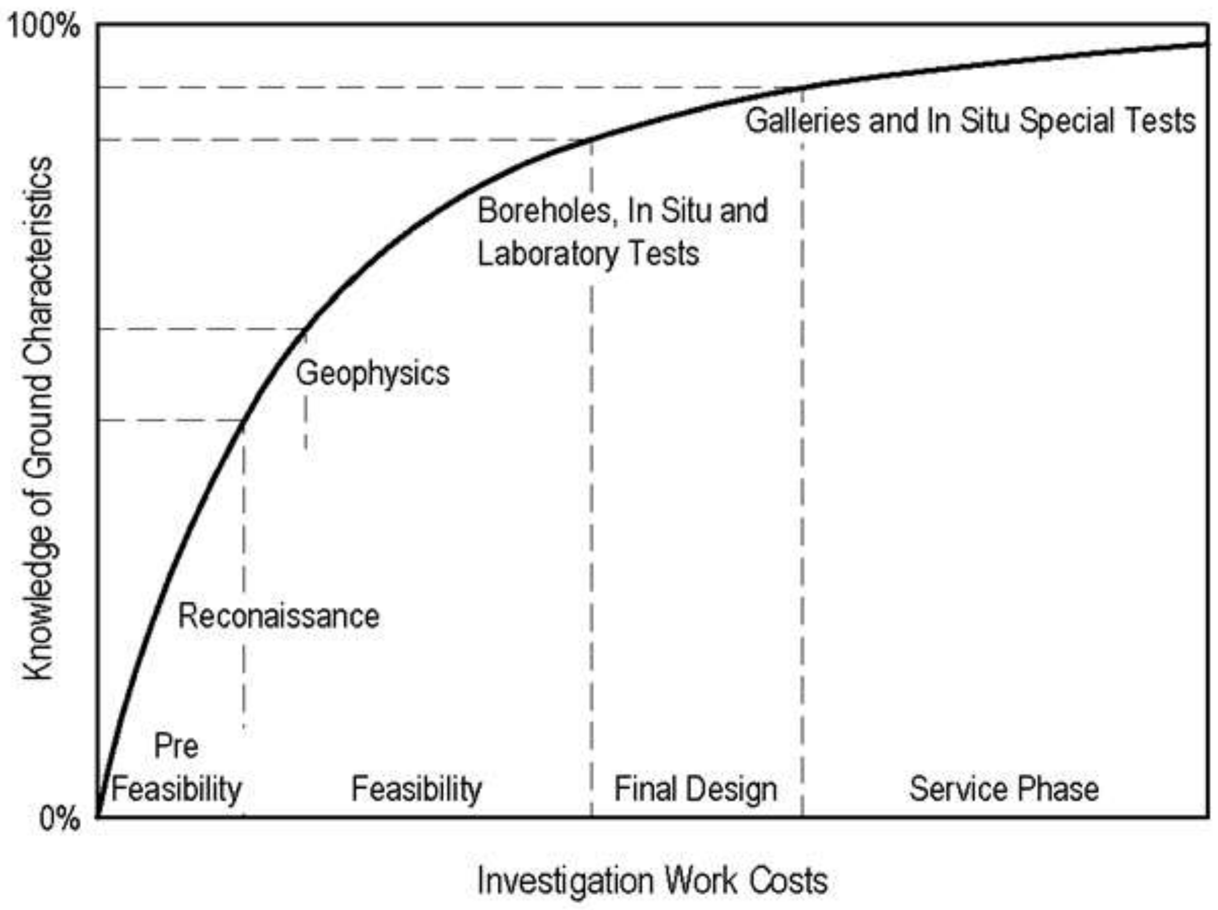
Geological-geotechnical study phases of dams

For dams a sequence of prefeasibility, feasibility, final design and construction, followed by operation phase (inspection, monitoring and preventive and remedial engineering) has been widely adopted.

The study of soils and rock masses shall be conducted by phases, involving the progressive use of more sophisticated and more expensive methods in accordance with the development and the necessities and requirements of the project.

In all design phases there is constant interaction between design and reconnaissance also demanding additional investigations and determining further investigation program.

The goal is to have a deeper knowledge of the geotechnical characteristics using progressively costly investigation techniques.



STUDY METHODOLOGY FOR SOILS AND ROCK MASSES

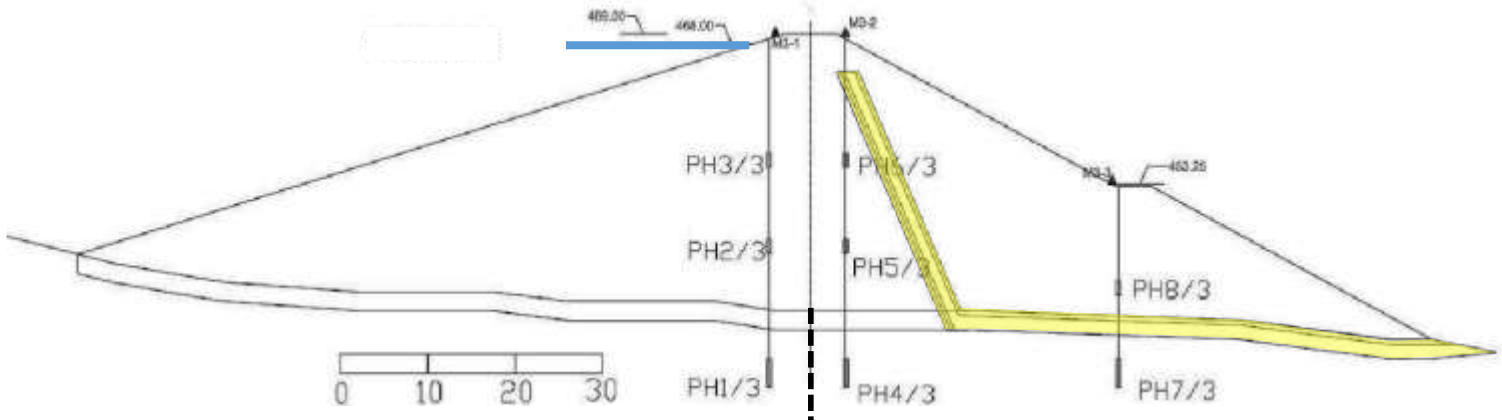
Valtorno-Mourão Dam Remedial Engineering

An example of remedial engineering is the foundation rock mass of Valtorno-Mourão Dam, where, at the first filling, values of percolated flow rates were much higher than estimated, which indicated a reduction in safety conditions.

The dam is a zoned earth dam, with 32 m height above the foundation level.

The rock foundation is constituted by schists and granites, with great lithological complexity and intense and open fractures, numerous faults and tectonized bands of variable thickness.

For the control of percolation through the foundation, a grouting curtain was made from a thin layer of plain concrete plinth.



Dam transversal section

STUDY METHODOLOGY FOR SOILS AND ROCK MASSES

Valtorno-Mourão Dam Remedial Engineering

In the first filling phase, with a hydraulic level of 73% of the full storage level, a foundation percolated flow rate greater than 20 l/s was observed. This result pointed to a flow rate of about 30 l/s for FSL, about 10 times the estimated flow rate of 2.6 l/s.

In addition to safety concerns, the dam would lose its full storage capacity within a year.

There were also symptoms of poor foundation behavior indicated by elevated piezometric levels downstream of the core.

The decision was to carry out a detailed investigation with boreholes and permeability tests which showed that the most convenient solution was to reinforce the foundation's watertightness curtain grouting, drilling from the dam's crest.

In order to allow the analysis of the results of the injection treatment in real time, a geotechnical zoning of the foundation mass was made or adjusted during the works, in order to decide the most appropriate grouting procedures.

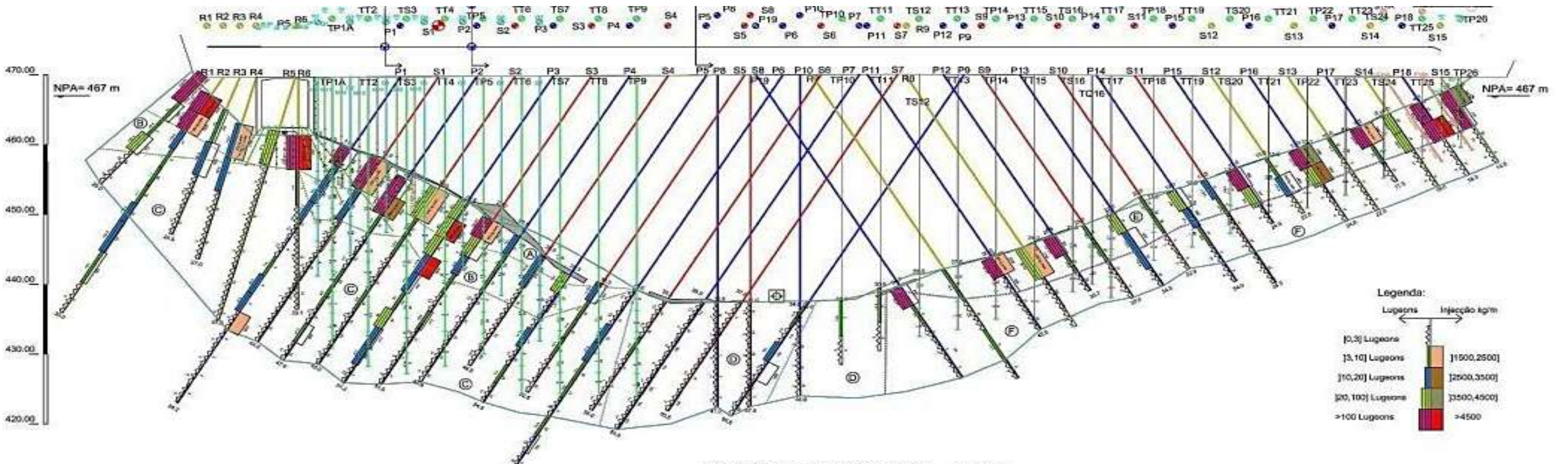
STUDY METHODOLOGY FOR SOILS AND ROCK MASSES

Valtorno-Mourão Dam Remedial Engineering

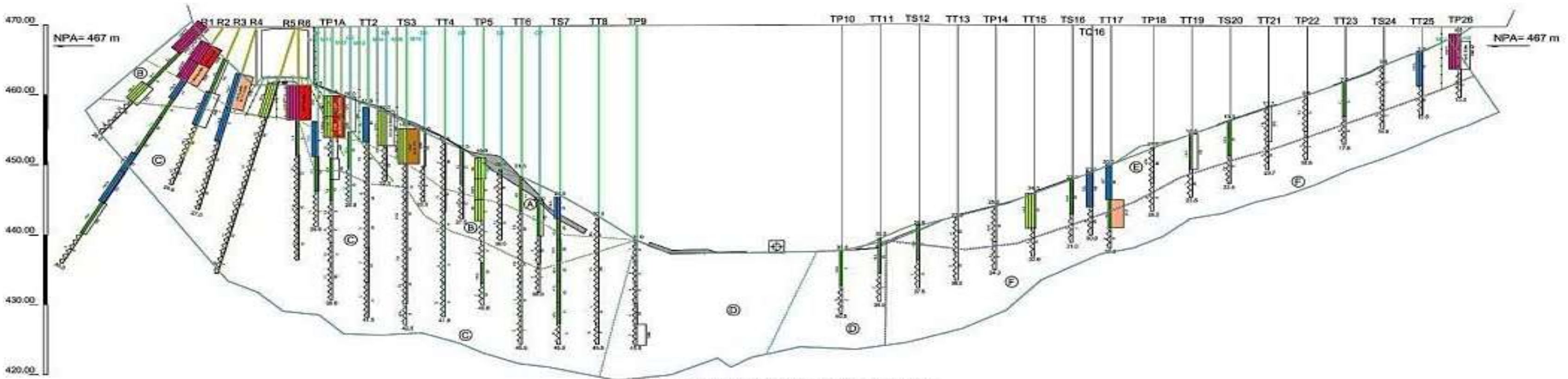
Reinforcement of the curtain grouting was made in two stages, first with primary and secondary inclined holes and second with tertiary and quaternary vertical holes.

The treatment of the foundation made it possible to restore the safety conditions and functionality of the dam.

After treatment, the percolated flow rates through the foundation remained at the expected values.



TRABALHOS DE IMPERMEABILIZAÇÃO – 1ª FASE



TRABALHOS DE IMPERMEABILIZAÇÃO – 2ª FASE

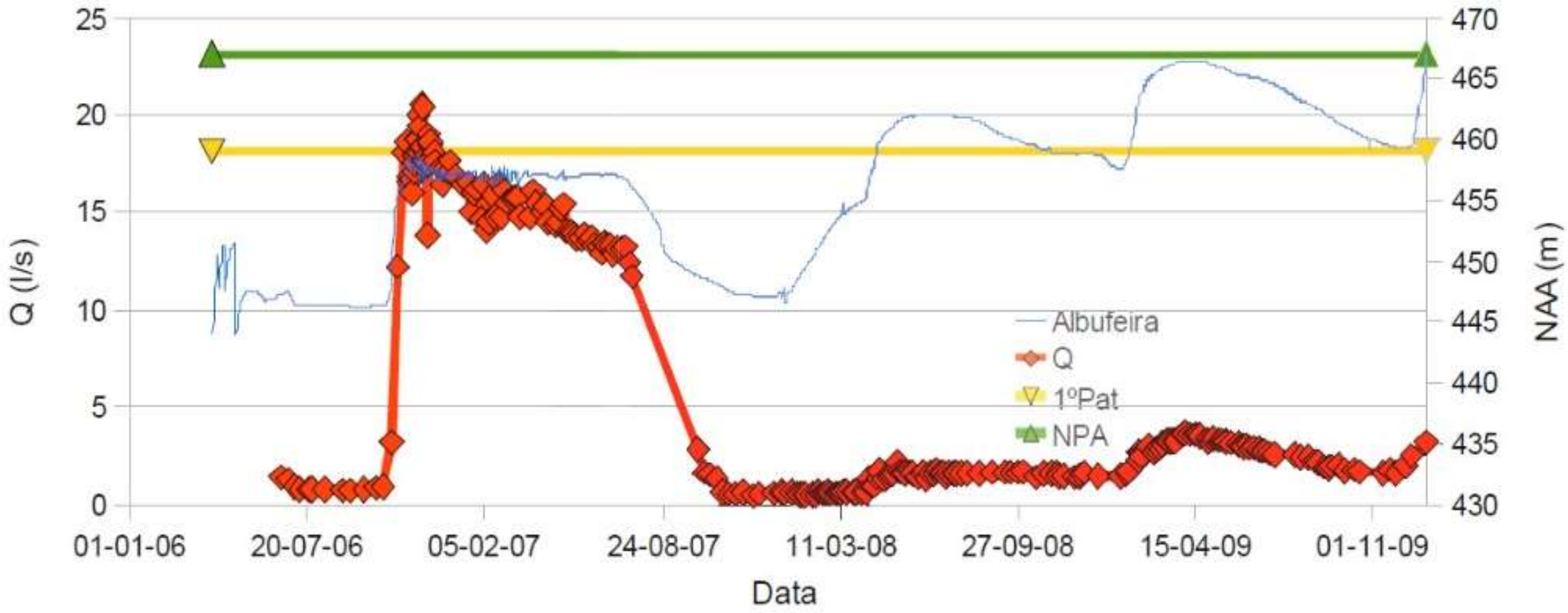
STUDY METHODOLOGY FOR SOILS AND ROCK MASSES

Valtorno-Mourão Dam Remedial Engineering

Execution of the grouting curtain from the dam crest

STUDY METHODOLOGY FOR SOILS AND ROCK MASSES

Valtorno-Mourão Dam Remedial Engineering



STUDY METHODOLOGY FOR SOILS AND ROCK MASSES

Valtorno-Mourão Dam Remedial Engineering

View of the reservoir before and after the execution of the grout curtain

WHAT WILL BE EXPECTED IN THE FUTURE?

In the future Geotechnical Engineering will be able to answer the challenge to larger and more economic structures and will accept more difficult foundation sites with lower risk levels imposed by the society.

This is the result of:

- Permanent advances achieved in Geology and Geotechnics, which allow us to determine the internal constitution of the ground and quantifying its properties in order to predict the behavior and adapt the design to achieve the optimal solutions
- Development of construction techniques, which will allow the improvement of its weak and critical zones.

But human resources are the most important issue and attention should be paid by the Academy to the discussion on the education, training, research and experience of geologists, engineering geologists and geotechnical engineers, thus improving teaching, communication and understanding in the borderline of geology and engineering.

Thank you for your Attention

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