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GENERAL REPORT SESSION 5: Treatment methods for soluble rocks

RAPPORT GENERAL SESSION 5: Méthodes de traitement des roches solubles

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Engineering problems of construction on or within soluble rocks involve some kind of treatment. It is therefore appropriate that the Symposium on Engineering Problems of Soluble Rocks should have Treatment Methods for Soluble Rocks as the last item on the Agenda. Beside the establishment of the properties and the physical condition of such rocks in any actual dam or structural foundation or investigation of reservoir suitability which were discussed in the previous Sessions, also the methods available to implement engineering problems of projects in such a particular environment should be discussed. The problems arising are of interdisciplinary scope and it is appropriate that several scientific disciplines should be involved.

There are two kinds of problem related to construction in soluble rocks, viz.:

- percolation and seepage of impounded water from reservoirs and through the foundation of dams or hydrotechnical structures,
- bearing capacity, stability and deformation of foundations of heavy structures.

In both kinds of problem the essence of the treatment is filling cavities, joints and fissures with suitable material.

The most appropriate design alternatives of rock treatment depend on many details of the rock structure, of the degree and character of its degradation by tectonics, erosion or solution and of the degree of groundwater circulation. The knowledge of such data, to such a degree of accuracy as can be achieved, is a prerequisite to any feasible solution. A complete fund of data to satisfy complete knowledge of the rock condition can rarely be attained, so treatment should be adapted accordingly as works proceed and new facts are discovered. Thus a satisfactory amount of additional work and cost of treatment should be provided for in the feasibility study as well as in the design, in order to cover contingencies and surprises.

The papers presented to this Session all treat problems related to percolation of impounded water. They are:

Altug S. : Leakage study of the east side of the Oymapinar reservoir, Turkey.

Ataman Y. (1) : The grout curtains of the Oymapinar dam and the right bank problems.

Poupelloz B.: Toulemont M. Stabilisation des terrains karstiques par injection: Le cas du Lutétien gypseux de la région de Paris.

Ertürk A. (1) : Geoelectrical study of the Tigris dam reservoir and its axis.

Jahren N., Rockaway J., Easterly M. (1) : Foundation improvement for prevention of seepage through limestone bedrock at Clarence Canyon dam, Missouri, USA.

Altug describes the complicated conditions established by comprehensive exploration of the left abutment of the Oymapinar dam in the Manavgat river. The karstified Paleozoic limestone ridge on which the dam is founded is covered on the upstream and downstream side by less permeable formations. A source discharges into the Manavgat downstream of the dam foundation at a rate of up to 7 m^3/s. A grout curtain is being implemented across the ridge at the far end of the left wing grout curtain in order to intercept possible connections of the karstic channels with impounded water in the reservoir at greater distance from the dam. The grout consumption in the partly completed curtain is 1,6 t/m of grouted hole. At the lower downstream part, in the vicinity of the faulted contact with the schist, the grout take in some stages was more than 100 t, but no effect on the discharge of the source was established. This illustrates the complexity of conditions in the karst and the unsatisfactory degree of knowledge remaining even after very extensive exploration and study, that can be mastered only by purposeful trial and error grouting.

Ataman presents the grout curtain in the foundation and on the right wing of Oymapinar dam, where the rock is fairly impervious and the grout consumption averages 0,1 t/m of hole.

Jahren et al. describe the successful treatment of the Clarence Canyon Dam foundation on Carboniferous limestone, which displays a considerable degree of solution weathering along joint sets and bedding planes. The original foundation preparation plans had to be considerably modified and amplified as more detailed geological data became available during construction.

Ertürk describes the geophysical investigation of the Dicle (Tigris) reservoir and dam site, which is actually within the scope of Session 4 and should be discussed in connection with that Session.

As some of the announced papers to this Session regretfully were not presented at the Symposium, the full scope of the Session is not covered. Therefore the General Reporter will try to present the missing items very briefly and to illustrate them with some examples.

The state of the art of treating karstic and soluble rock offers a variety of solutions to diminish percolation of accumulated water or to strengthen unsatisfactory foun-

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dations. The reduction of water percolation rate can be achieved by:

- blanketing of ingress areas within the basin bottom and on the abutments,
- grouting of impervious curtains of appropiate extent and depth.

Strengthening or modification of unsatisfactory foundation rock may be attained by

- grouting the overstressed rock volume beneath the foundation,
- softening of too stiff rock zones where uneven settlement may cause overstressing and cracking of parts of the structure.

Surface blanketing may prove to be a treacherous approach to 'catch the bull by the horns' and stop percolation where water may enter the foundation. It is a solution applicable to rock surfaces, where existing openings, joints or fissures can be detected, cleaned out of gouge and plugged with non-erodible concrete, gunite or shotcrete. It has proved to be effective in the case of the left abutment of the Keban dam, as shown in the paper by Bozovic et al. presented at this Symposium and on many other projects. It has not been successful in those cases where the impervious blanket of compacted clay and filters was placed on the bottom of karstic fields covered with alluvial clay. New percolation of water through open fissures in the rock below the blanket erodes new holes in the contact with the alluvial deposit and eventually opens holes through the blanket. The process develops progressively and finally completely destroys the blanket. The collapse of some parts of the upstream blanket of the Tarbela Dam on the Indus River in Pakistan, which was constructed on the deep alluvial deposit consisting of coarse gravel, is one example. Similar failures on blankets of natural alluvial clay occurred in Spain (Camarassa), in Greece (Perdikas reservoir). In Yugoslavia an attempt was made to plug existing holes on the natural clay bottom of a karstic reservoir by excavating down to the rock surface, placing concrete on the existing fissures and filling with compacted clay to the surface. But along the rim of the reservoir new holes opened constantly at other spots causing large losses of impounded water. Not until a deep grout curtain was implemented along the perimeter of the reservoir were the percolation losses reduced to a tolerable amount.

Grouting fissured rock is a routine operation so long as saturation can be achieved and the consumption of grout remains within tolerable limits. In karstified rock the problem is more complicated because very pervious sections of the grout holes may take enormous amounts of grout without any success. In such conditions routine grouting techniques must be substituted by applying masterfuly the art of grouting.

The problem is even more complicated when water flows through large fissures and cavities. In such cases the following remedies can be applied, in the sequence of the order of difficulty encountered:

- intermittent stopping of grouting, with use of fast setting or thixotropic thick grout or mortar, or some other special grout mix,
- filling of open cavities by gravel of uniform gradation and successive grouting with stabilised cement grout,
- use of hot bitumen injected in sections with flowing water, a procedure advertised in the literature but with scarce evidence of successful application,
- plugging of flow channels in cavities by concrete walls built in place.

The application of these measures may be illustrated with some examples.

Special grouts

At Dokan Dam, a 130 m high concrete arch structure, which was completed in 1958, the left abutment consists of a narrow ridge of horizontally bedded dolomitic limestone, karstified and very pervious on some bedding planes and joints. Large grout takes ensued, but where water was flowing through the rock defects it was impossible to achieve saturation of the grouted sections. In such cases a grout consisting of a mix of dry bentonite powder with diesel oil was injected first, then followed by cement grout. When the bentonite / oil mix came into contact with the ground water the bentonite started swelling to a multiple of its initial volume and thus helped in closing the water flow until the subsequently injected cement suspension had set.

The construction site of a concrete gravity dam on a large karstic river in Jugoslavia is sketched on Fig. 1. The valley

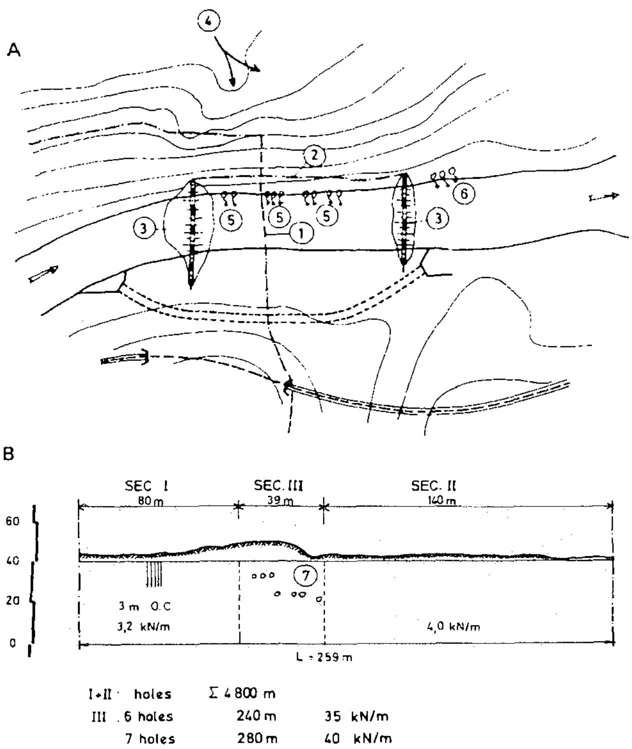

Fig. 1: Foundation of dam in riverbed; (A) plan of foundation, (1) dam axis and main grout curtain, (2) axis of auxiliary grout curtain, (3) upstream and downstream cofferdam, (4) direction of groundwater flow in left abutment, (5) sources along left river bank, (6) same, downstream of foundation excavation; (B) longitudinal section through auxiliary grout curtain, (7) connections form grouting holes to sources.

is situated in Cretaceous limestone, tectonically faulted and jointed and karstified to a high degree, especially on the left bank. In order to excavate the foundations the river was diverted through a tunnel in the left bank, and two rockfill cofferdams with concrete diaphram were constructed. Since quite a few sources on the left bank discharged up to 7 m^3/s in the rainy season, it was necessary to grout an impervious curtain along the left river bank in order to keep the excavation for the dam and powerhouse foundation dry. The curtain closes the river bank from the upstream to the downstream cofferdam. It was executed in three sections as shown on Fig. 1., from the upstream cofferdam to the section with sources, Section I, from the downstream cofferdam to the sources, Section II, and Section III containing the sources. Grouting of the first two sections was a routine operation, satisfactory saturation was obtained with stabilised cement grout without difficulty, with grout consumption of 0,32 t/m in Sec. I and 0,40 t/m in Sec. II. It was not possible to achieve satisfactory saturation of stages with running water in Sec. III, because all grout was washed out at the sources connected to the grouted stage. After studying several alternative grouts it was decided that stabilised cement-sand mortar with the addition of 170 kg/m^3 of cuttings of synthetic sponge was the only one feasible. The sponge cuttings were about 5 x 5 x 15 cm, very compressible and absorbed about 44 % of their volume after expanding. This grout was pumped into the hole by means of a screw type pump capable of achieving 2 MPa pressure. In seven holes of Sec. III connected with the sources 970 t of mortar were injected, which amounts to 4 t/m of hole. The remaining six holes were grouted with normal mixes and 0,35 t/m were consumed. The use of this special grout immediately stopped the discharge from the sources, the ground water flow was eventually diverted to the sources downstream of the foundation excavation shown on Fig. 1.

Treatment of cavities

Karstic cavities in the foundation region pose difficult problems which must be solved in order to prevent adverse consequences for foundation safety and effectiveness. In spite of a comprehensive site exploration, large cavities may be discovered only during the construction, when excavation and dense drilling for grouting is being carried out. Such a case was reported to this Symposium in Session 3 by Bozović et al., another case may be shown here.

For the construction of a 75 m high rock and earthfill dam in the Dinaric Karst in Yugoslavia very complex exploration was carried out, comprising geological mapping, detailed geophysical investigation and extensive exploration drilling. In spite of the evidently very intense karstification generally only rock of modest to high permeability was established. It was decided to implement a grout curtain as shown on Fig. 2 in order to prevent high percolation of impounded water and erosion of joints and fissures filled with gouge material in some intensely fractured fault zones below the dam foundation and through the abutments.

As grouting started, the first hole which was being drilled on the right wing curtain met a 20 m deep void in which the rods were lost. Additional exploration was carried out and speleologists found the entrance to a large cavity on the abutment as shown on the figure. It was also established that with a small upstream shift of the grout curtain axis the cavity could be avoided, and grouting of the right wing curtain was completed without further complications.

A new surprise awaited on the left wing curtain, which was grouted from a gallery in order to avoid idle drilling. A grout stage in a hole towards the far end of the curtain took more than 3 000 t of cement without any success. Speleologists again found the way to a large cavity through a crevice in the wall of the grouting gallery as shown on the sketch. In the cavity large amounts of grout were deposited, and it was possible to put a concrete plug in a crevice in order to stop further penetration of grout

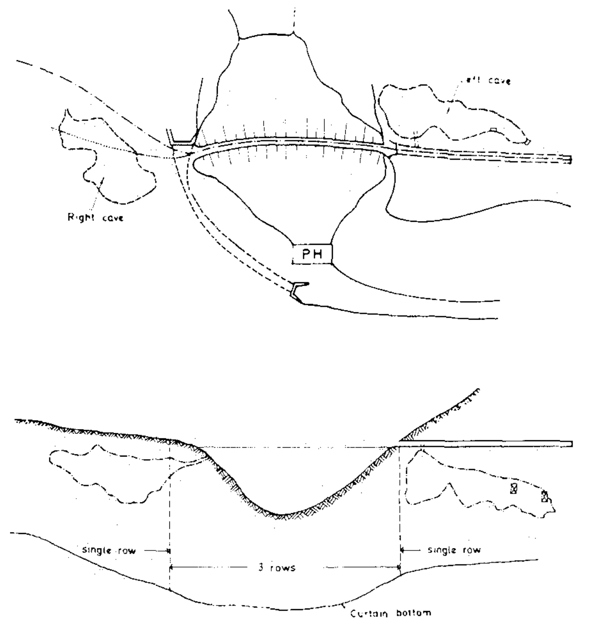

Fig. 2: Plan and section through the grout curtain of a rockfill dam on karstified limestone and situation of cavities discovered in the foundation

into the cave. Grouting of the stage was then successfully completed by pumping thick cement mortar, stabilised with addition of bentonite, by means of a screw type pump with rotating piston.

Comprehensive treatment

On large projects in karstic regions combinations of several treatment methods must be contrived in order to achieve the desired final result. An example from another karstic hydroelectric project will illustrate the problems and the methods of treatment adopted.

A karstic depression of 50 km^2 area in the mountain range along the Adriatic coast was being flooded every year by water discharging from a series of stable and temporary springs along its eastern rim during the rainy season. It was subsequently drained by a series of ponor on its south-western and western rim. The plain was partly cultivated and partly used as pasture land during the dry period.

The bottom of the depression is covered by a 15-20 m thick bed of clay and sandy clay resting on beds of Neogene marl on its north-western part, and on pervious karstified Cretaceous and partly Eocene limestone beds on the rest of the area. The main ponors on the south-western and western rim developed within the limestone on the surface of the clay bed.

Very comprehensive exploration and investigation was carried out in order to prove the feasibility of raising the level of stored water in the depression by some 16 m. Extensive geological, tectonic exploration, core drilling. observation of groundwater levels and hydrological studies of the water balance were carried out for many years. The general features and conditions for water storage are given on Fig. 3. In the natural conditions water stored temporarily in the depression was being drained toward the next lower river valley on the western rim. The water entered the mountain range through ponors on the western rim of the depression and flowed through systems of cavities and karstic channels corroded along joints, bedding planes and fissures, especially along tectonicaly fractured zones, to the lower river valley were it emerges in a few permament springs of variable discharge capacity during the year.

Based on these findings the following measures were devised in order to make feasible permanent impoundment of water with about 16 m head:

- construction of a rock fill dam with central clay core in order to isolate from the reservoir the south-western rim of the depression, were the largest ponors are situated and many sinkholes cut the alluvial clay of the valley bottom,
- grout curtains below the dam and along sink hole zones on the western perimeter, to a depth below the lowest registered ground water level,
- concrete walls in the plane of the grout curtain where it cuts some of the passages from the ponors.

After impounding water in the completed reservoir, seepage losses were measured and the hydrological balance studied in order to establish places were further work would be useful. Some additional grouting proved to be necessary along the western perimeter.

A total amount of 6,8 km of grout curtains with 167 km of grouted holes were executed, and a total of 54 000 t of material was consumed. The average grout absorption

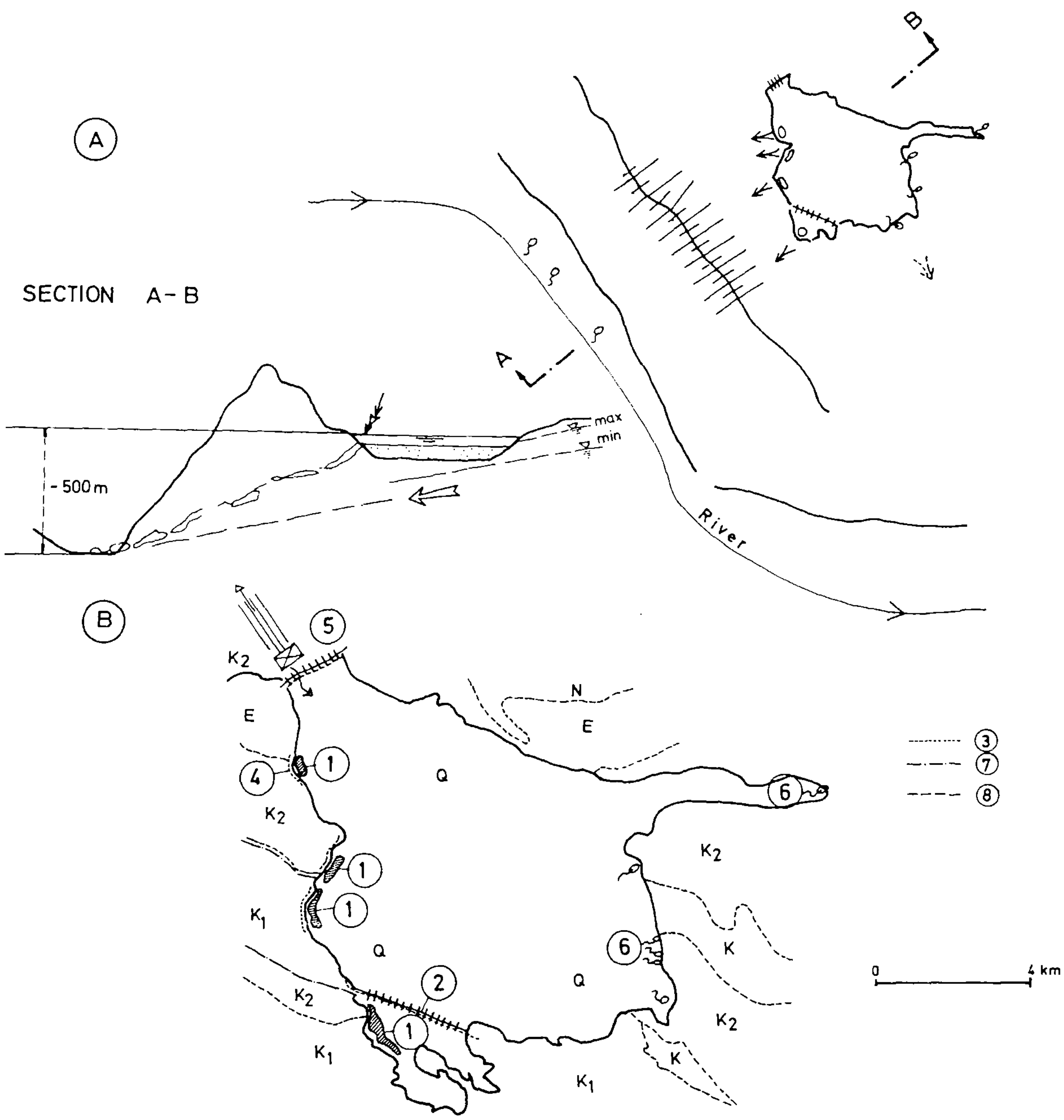

Fig. 3: (A) Sketch of the situation and section of a karstic depression in the Dinaric Mountain Range; (B) Detailed plan of the depression, (1) zone of largest ponors and sink holes on the perimeter and bottom of the plain, (2) dam for isolation of pervious zone, (3) grout curtains, (4) concrete plugs in large channels, (5) auxiliary dam and reversible pumping power station, (6) zone of temporary and steady sources, (7) main faults, (8) boundaries of formations.

was about 0,3 t/m, with a maximum average of 1 t/m around some ponor zones and a minimum of 0,16 t/m below the dam on the southern perimeter.

In this case a variety of treatment methods was applied:
- separation of part of the perimeter from the reservoir by means of a dam,
- deep grouted curtains below the dam and in the back of zones with ponors and sink holes,
- placing concrete plugs in some accessible cavities.

This complex treatment of the karstified rock below and on the perimeter of the reservoir has reduced the discharges from the reservoir from more than 12 m^3/s in its natural condition with about 1 m head to less than 5 m^3/s at full reservoir with 16 m head. Further work for reduction of percolation losses would not be economically feasible.

The purpose of this General Report has been to illustrate the variety of problems which may arise in the treatment of soluble rocks for foundation purposes, especially in karstified limestone. The problems being very complex, a multidisciplinary approach is imperative, with close cooperation of geologists, engineering geologists, geophysicists and civil engineering specialists. This cooperation should be kept operating from the start of feasibility studies, during the design stages and to the end of construction, in order to ensure the best possible solutions of all problems and safe structures at the lowest possible total cost.

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