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ORIGINAL ARTICLE

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Karst engineering studies at the Akköprü Reservoir area, southwest of Turkey

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Abstract Akköprü Dam, which is under construction, is located at Dalaman Basin in the southwest of Turkey. The base rock at the Akköprü dam site and reservoir area is autochthon Aktas limestone and Gökseki flysch formation. Allochthon Cehennem Deresi limestone, a complex series of ferro- (melange) and peridotite–serpentine units, overlay this unit with tectonic contact. These units are covered by young sedimentary series. The outcrops of karstified Aktas limestone are observed at 2 km upstream of the dam site, at the right reservoir abutment. This unit is very permeable and the groundwater level is very deep, 100–116 m below the Dalaman riverbed. After impoundment, 250,000 m^2 of this unit will be submerged. Groundwater which percolates in this unit discharges at the coastal springs. This study analyzed the watertightness of Akköprü reservoir related to the karstified limestone in the left reservoir bank and discussed possible options of remedial works to reduce seepage.

Keywords Dalaman River · Karst engineering geology · Karst hydrogeology · Karst water resources · Turkey

Introduction

Lower Dalaman Project is located at Dalaman basin in the southwest of Turkey in the Aegean region (Fig. 1). The study area covers approximately 170 km^2 along the Dalaman River. Four dams have been proposed in this project and Akköprü Dam, which is under construction at 1 km downstream of the confluence between Dalaman River and its tributary Çayhisar Creek, is one of them.

The permeability features of Akköprü dam site and reservoir area have been determined by detailed geological and geotechnical studies during the feasibility and final design stages.

General geology

The whole Paleozoic and Mesozoic series up to the Upper-Cretaceous period are exposed within the Lower Dalaman Basin. On the upper part the series is exposed in the form of allochthon rocks that overlay the autochthonous flysch, or composite sandstone. The autochthonous units which form the bedrock are represented from the bottom upward by Aktas limestone and Gökseki flysch.

Aktas limestone is registered at 1 km south of Akköprü and on the left bank. This limestone is white and light gray in color, dense but jointed and very karstified (Figs. 2, 3).

Gökseki flysch is formed as the upper layer of the autochthonous series and covers the very large area between Akköprü and Gürleyik, especially at the left bank. The flysch consists of mudstone, marl, sandstone and limestone, which are intercalated. The flysch is gray to grayish-brown in color.

From a watertightness point of view, the conglomerate sediments have an important role because they are deposited over the karstified and very pervious limestone, and locally over the flysch.

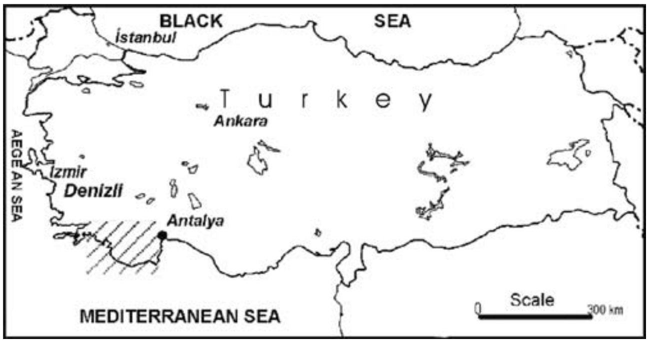

Fig. 1 Location of investigated area

In the study area, all the Paleozoic and Mesozoic aged series are thrusted over the autochthonous units. Regionally these movements continued from Eocene to Lower Miocene (Şekercioğlu and Özgüler 1999).

Karst features

The Paleocene Aktas limestone, at the bottom of the reservoir (el. 115–125 m as1) and along the left reservoir bank, is extremely tectonized and karstified. The limestone is dissected with a dense net of almost parallel and subvertical joints mostly filled with calcite. The thickness of calcite veins varies from 0.5 to 5 cm, rarely up to 10 cm. However, some joints are open, and subvertical karst shafts with apertures from a few centimeters up to a few meters occur along them. These open joints are the key watertightness problem of the Akköprü reservoir. A number of open joints and deep subvertical karst shafts were registered during excavations in the quarry. Many others were discovered by radar investigations.

By applying speleological methods, some shafts were investigated down to 50 m. Measured depth of some is about 90 m. This pattern indicates very deep karstification, probably until elevation of zero or even deeper.

Permeability of limestone is typical for tectonized and karstified rocks. In some boreholes permeability is zero or very low, but mostly it is relatively high and varies between 20 and 50 Lu.

According to the borehole logs, there is no evidence of major karst features. This observation does not appear compatible with the frequency and size of karst shafts and channels and solutionized discontinuities seen on the bottom and limestone rim. Boreholes, which are mostly vertical, may not contact major karst voids because of the mostly vertical and subvertical orientation of the cavities and enlarged cracks. Due to this, the boreholes are not connected with karstic voids and Lugeon tests present permeability of the surrounding limestone mass only.

According to Lugeon tests, approximate permeability ranges between 1.7×10^{-3} and 1.7×10^{-4} cm/s. But in reality, permeability of limestone is much higher due to the number of open karst channels.

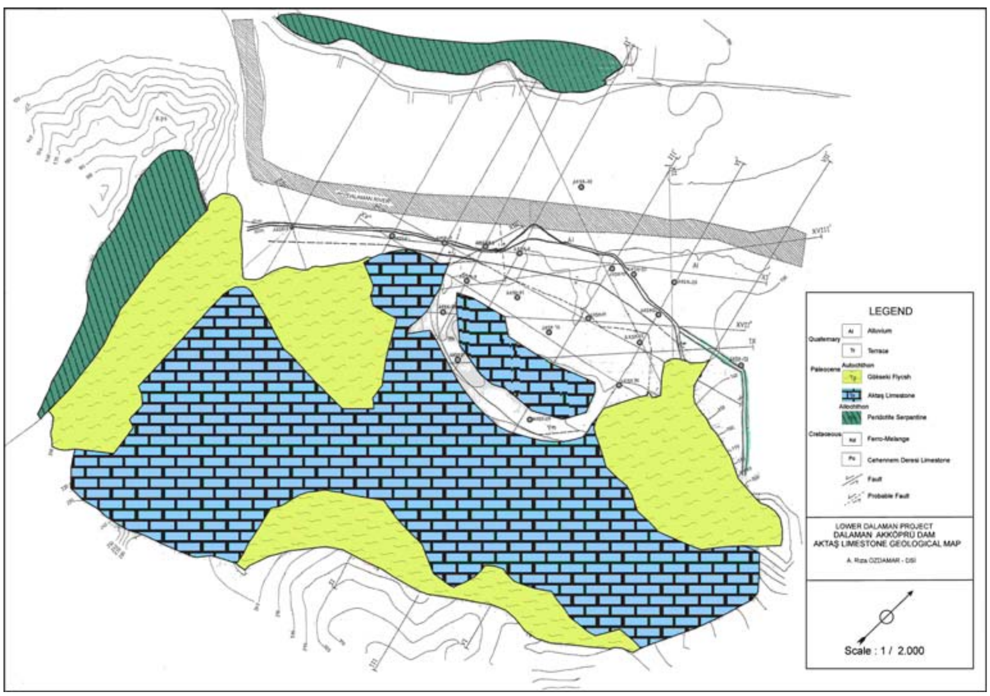

Fig. 2 Geology map of the Aktas limestone area

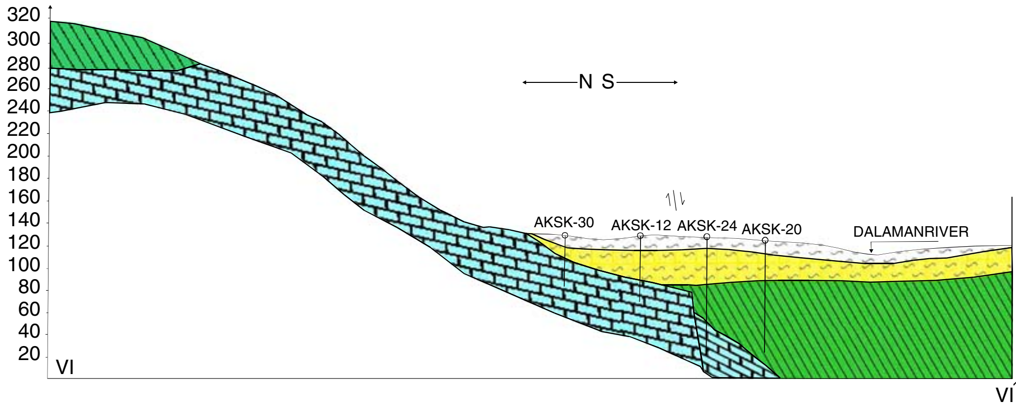

Fig. 3 Cross-section perpendicular to the reservoir bank

Groundwater regime

The water table in the limestone section of the reservoir never rises up to the surface. The water table is about 100–116 m beneath the reservoir bottom. All shafts have a permanent role of swallow holes (ponors). In this section estavelles do not exist.

In spite of the relatively high precipitation in the limestone area, the water levels in wells at quarry and in piezometers also are very deep and fluctuate only a few meters, mostly between 14 and 18 m asl. Recharging of the limestone aquifer occurs mostly from the Dalaman River as percolation through the conglomerate and as direct infiltration at the limited surface of Aktas limestone. In the first few hundred meters the piezometric line is very steep and the gradient is enormously steep. After percolated water reaches the saturated zone (15–20 m above elevation zero), it continues to flow very slowly toward the erosion base level, i.e., toward the discharging zone near the seacoast.

Alternatives of possible remedial works

Feasible concepts (alternatives) for prevention and remediation of leakage from the Akköprü reservoir are:

- Underground sealing treatments
- Surface geotechnical treatments
- Combinations of the above two concepts

Underground sealing

To prevent leakage from Akköprü Reservoir one possibility is construction of a grout curtain in the karstified limestone along the left reservoir bank. To design a grout curtain (Fig. 4d) in the case of Aktas limestone mass the following parameters are important.

At both ends, the grout curtain can be tied into the impervious rock mass. Depth for the curtain is not exactly known. The lower limit of the grout curtain has to be below the base of karstification, obviously below the elevation zero. To define this parameter, additional investigations are necessary. The upper perimeter of the curtain is defined by floodwater elevation, i.e., 204 m. The grout curtain depth has to be at least 230 m, probably locally deeper.

The upper part of the curtain can be installed from surface. However, deeper sections will need closely spaced grouting galleries. In developed karst, as in the Aktas limestone, the spacing between grouting galleries is a maximum of 30 m.

Surface treatment

It is obvious that surface treatment alone is not sufficient to prevent leakage. Any surface treatment needs an additional shallow grout curtain to prevent hydraulic contact of the reservoir water with karstified limestone through the conglomerate. A few different watertight structures are possible.

Grouting blanket

Grouting blanket or ‘‘grouting carpet’’ is a term for consolidation grouting. It means systematic grouting of the surface rock mass to a depth of 10–20 m.

Before grouting, all open shafts have to be filled with limestone blocks and the upper 20–30 m plugged with self-compacted concrete (SCC).

All grouting holes have to be inclined in a direction perpendicular to the main joint system (Fig. 4c).

In conglomerate, vertical grouting holes have to be used. Around the perimeter of the grouting blanket, the grouting holes are drilled through the conglomerate down to the flysch.

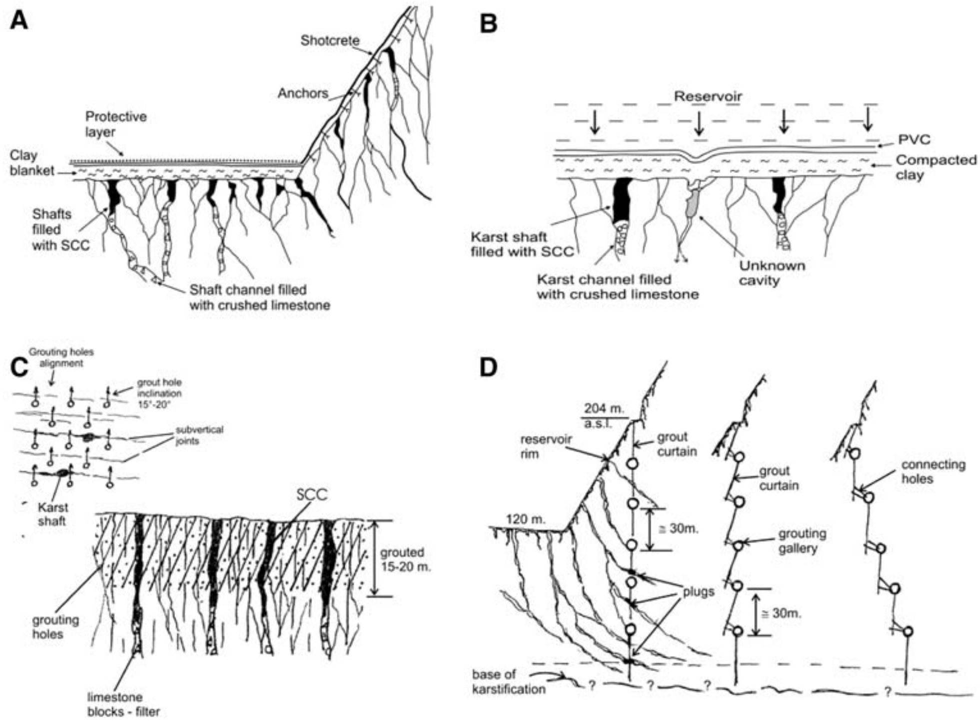

Fig. 4 Alternatives of possible remedial works

Compacted clay/PVC blanket

Using compacted clay or a PVC cover at the bottom and a shotcrete blanket at the reservoir bank is another possibility (Fig. 4a). Before installing the clay blanket, all open shafts would have to be plugged by filling with limestone blocks and SCC in the upper 20–30 m.

The clay blanket has to be situated directly over the limestone, properly compacted and covered with PVC membrane. PVC foil is very elastic, absolutely watertight and easily adaptable under the influence of high water pressure (Fig. 4b). A bearing capacity of pressure above 10 bars will be achieved by laying a PVC liner below a properly compacted clay blanket.

For the reservoir banks, a double layer of reinforced shotcrete as an anti-seepage measure is suggested. To prevent microcracks, steel reinforcement meshes and/or different fiber types (still, plastic or glass) should be used. All open shafts would have to be plugged before shotcreting.

Heavy reinforced concrete slab

Placing reinforced concrete over the reservoir bottom and reservoir bank is another possibility. The previous plugging of all registered shafts is an important prerequisite, as it is in all cases of surface treatment. Shallow cavities beneath the surface will be overbridged and resistant against high reservoir pressure.

Most probably contact grouting between concrete and foundation rock will be required, particularly in the section in which the foundation rock of reinforced concrete slabs is conglomerate.

Shallow grout curtain

Every above-mentioned surface treatment requires an additional grout curtain to block possible water filtration from the reservoir through the conglomerate to the karstified limestone. To prevent this leakage, a grout curtain along the perimeter of the horizontal blanket down to the impervious geological unit should be required. The flysch sediments are an impervious geological unit and the grout curtain should be tight into this formation.

To construct an impervious curtain into the conglomerate, two important questions must be considered: groutability of conglomerate (grouting concept and technology) and the lateral and bottom connection with impervious rocks.

This conglomerate is erodable rock mass and has to be exposed to high pressure (10 bars). Any weak point in the grout curtain can provoke filtration under pressure, turbulent flow and intensive erosion.

However, results of Lugeon tests in flysch indicate watertightness of the upper section of flysch is questionable. In some sections the lower boundary of curtain must penetrate deeper into the flysch. The groutability of flysch should be carefully investigated.

Discussion of possible alternatives

There are arguments for and against each of the presented alternatives.

A grout curtain along the reservoir rim needs long grouting galleries at vertical distances of 30 m. Long access galleries and/or vertical shafts are needed for grout curtain execution. This structure would require plugging of open karst channels and local construction of cutoff walls.

An important advantage of this alternative is the possibility for regrouting (if necessary) after the reservoir is in operation. For any additional regrouting treatment, emptying of the reservoir would not be necessary.

In any of the surface treatments, plugging of open karst features (shafts and caverns) should be completed prior to the final treatment.

Advantages of surface treatment are easier construction of surface blankets and full control of work quality. But all three surface alternatives have two disadvantages. A grout curtain in conglomerate is a possible weak point during the reservoir operation and after reservoir impounding. Additionally, due to the minimal water elevation of 173.5 m, remedial treatment below this level is extremely complicated or practically impossible.

A good, watertight grout curtain in conglomerate to achieve positive cutoff is a key prerequisite for successful surface treatment.

All presented alternatives are technically feasible, but each includes some risks. The final decision has to be based on economical parameters and acceptable risk.

Conclusions

Feasible concepts (alternatives) for prevention and remediation to reduce or eliminate leakage from Akköprü reservoir are: underground sealing treatment, surface geotechnical treatment and combination of these two concepts.

Common underground approaches and remedial structures are: grouting curtains; plugging of karst channels and construction of cutoff walls.

The common geotechnical methods at the surface could be: construction of a clay blanket; using plastic foils and other kinds of geosynthetics; construction of grouting blankets (consolidation of surface rock mass); dental plugging of large karst openings at the surface; a reinforced shotcrete blanket and heavy concrete slab. All surface solutions must include a grout curtain in conglomerate.

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