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Full Length Research Paper

An application of grout curtains to the Dalaman - Akköprü Dam

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Grouting is one of the most popular methods used to control water leakage in fill dam constructions. Geological and geotechnical properties of the rock/soil to be grouted are important parameters influencing the design of the grouting. In this study, geotechnical properties of Dalaman-Akköprü Dam's base rock and the grouting procedure have been investigated in view of their suitability to grouting. In the study, detailed investigations of the foundation injection applications were made into the main rock, the reasons and types of application are made. The materials used in grouting and the grouting pressures are investigated at site and the obtained results are presented. The improvement study and application type is evaluated and background information on different applications of grouting is presented.

Key words: Grouting, dam, Akköprü Dam, imperviousness.

INTRODUCTION

In dam constructions, it is obligatory to take certain precautions for granting impermeability and stability of base rock where dam will be installed. The procedure of base rock grouting via excavation into the base rock along dam axis has been the most widespread method among these precautions. Grouting is defined as the procedure of filling fluid with pressure into structural and lithological defects or cavities between ground layer and base rock, generally via boreholes (Kutzner, 1991-1996). Within a certain period of time that fluid material or gel becomes hardened. The main aim of grouting is to form high-strength or less permeable foundation ground (Tosun, 2000). Water leakages have been observed along the discontinuities found in the serpentinized harzburgite ultra-basic rocks round the axis of Dalaman-Akköprü Dam. Because leakage might cause serious engineering problems in the axis of the dam at the long run, building a single lined curtain grouting is considered in order to prevent the leakage problem in the ultra-basic rocks, and to decrease permeability for basic rock, thereby strengthening the fissured basic rock. In the study, basic grouting applications on the basic rock, the reasons and patterns of application have been analyzed in detail. By examining the improvement work and the application, background information on different applications has been aimed at.

GENERAL INFORMATION CONCERNING DALAMAN-AKKÖPRÜ DAM

Dalaman Akköprü Dam and hydroelectric power

Plant is located on Dalaman River, in 24 km east to Köyceğiz District of Muğla Province. Being Energy + Land Irrigation + Flood protection, with the water collected in the dam, average 343 GWh of energy per year will be produced in the power plants. While the probable flood damages local tourist's investments, Dalaman Airport and Dalaman and Ortaca Districts, Dalaman River floods will be prevented by Akköprü Dam construction; and irrigation of Dalaman plain will also be provided (Table 1).

GROUTING AND TYPES OF GROUTING

Grouting is defined as the procedure of filling fluid with

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Table 1. Dam and dam lake features.

Features	
Dam:	
Type	Clay core rockfill
Crest elevation	207.50 m
Crest length	668.70 m
Crest width	12.00 m
Thalweg height	112.50 m
Thalweg elevation	95.00 m
Upstream cofferdam crest elevation	129 .00 m
Downstream cofferdam crest elevation	111.00 m
Total body volume	12.30 hm^3
Dam lake:	
Area of precipitation	5132.60 km^2
The average annual water	1620.40 hm^3
Regulated water	849.76 m^3
Regulation	52%
Minimum water level	173.50 m
Normal water level	200.00 m
Maximum water level	204.00 m (in case of flood)
Volume of minimum water level	195.81 hm^3
Volume of normal water level	384.50 hm^3
Volume of maximum water level	419.20 hm^3
Maximum reservoir area	8.92 km^2

pressure into structural and lithological defects or cavities between ground layer and base rock, generally via boreholes (Kutzner, 1991-1996). Within a certain period of time that fluid material or gel becomes hardened. The main aim of grouting is to form high-strength or less permeable foundation ground (Tosun, 2000). It was first used in 1802 by the French engineer Charles Berigny in water and pozzolanic cement mixture ground grouting. Later, with the development of cement and hydraulic binders, the use of grouting in construction and mining engineering has become widespread (Kutzner, 1996).

Self-hardening puzzolanic cement grouting continued to develop in France and England in the 1800s, and was applied in engineering constructions like channels, pools, ports and bridges (Bruce, 1993). In the beginning of the 1900s, many improvements occurred in the grouting techniques due to the developments in the grouting equipment. In the 1914s, grouting operations were performed to fill the cavities in the foundations of the dams. In parallel, there were attempts to reduce the hydraulic permeability of the soil and increase the bearing capacity of the soil through grouting operations.

At the same time in Germany, a step forward was taken with the development of the chemical-based mixtures by Dutchman H. Joosten in 1926. Through the Joosten-system, highly concentrated sodium silicate and calcium chloride were successfully applied on gravel and coarse and medium-sized sand. Chemicals that auto-reacted as a result of the grouting made the soil less permeable and more competent. After 1930, the Joosten-system was widely used in the railroad tunnels. After the 1980s, in parallel with the development of environmental awareness and the increasing official demands to protect the ground water, the chemical grouting operations were reduced. Concordantly, in many applications high-pressure grouting was substituted for chemical grouting. Cement grouting techniques did not remain in the level of the 1930s and more fine-grained cements were produced. At the same time, the most recent developments have been the use of resins and foam material in grouting operations (Kutzner, 1996). Developments in the grouting technologies have paved the way for the advancements in the underground constructions and dam grouting operations (Raymond, 1996).

Modern grouting operations which started in mining engineering have later been used in construction engineering in the support of construction foundations, filling of rock fissures, stabilization of loose soil, reducing the risk of liquefaction in saturated granular soils, providing impermeable foundations for the dams, forming impermeable curtains in the underground, in the control of groundwater flow under the existing building, in increasing the stability of granular soils and reducing the vibrations of machine foundations (Shroff and Shah, 1993). Grouting is still used in foundation engineering.

One of the recent areas of applications is the

Table 2. The uniaxial compressive strength test results of the collected samples (Üşenmez, 2005).

Sample no.	Uniaxial compressive strength (t/m^2)	Lithological comment
1	1406	-
2	745	Significant discontinuities observed
3	745	Significant discontinuities observed
4	743	Significant discontinuities observed
5	1600	-
6	970	Significant discontinuities observed

prevention of the ground and underground water pollution through waste water leakages in waste depots.

The grouting methods applied for the improvement of the soil are listed under the following headings:

1. Filler grouting: In this operation, grouting mixture is injected into rock fissures and soil cavities without damaging the natural form.
2. Compaction grouting: The grouting mixture remains as a mass without deformation by allowing it move in the soil within control; as a result, the weak area around the grouting log is compacted with pressure using the grouting mixture
3. Fissure grouting: the natural structures of the materials are disrupted by grouting the mixture under pressure into the fissured rock or soil and thereby, the penetration of the mixture into the fissured areas is provided (Shroff and Shah, 1993).
4. High-pressure grouting: Water-cement mixture at atmospheric pressure 300-500 is introduced into the soil and hence mixing with the soil is provided. High-pressure grouting provides the necessary improvements in numerous properties of the soil (Raymond, 1996).
5. Contact grouting: In this operation, by filling the cavities between the engineering structures and the soil, integrity between the structure and the soil is provided.

The mixtures used in the groutings are generally defined as suspension (grained) and solution (nondimensional/ grainless) mixtures. While suspension mixtures include soil, cement-lime, asphalt, emulsion, etc., solution mixtures include a wide range of chemical group. Soil or clay-water mixtures are primarily used in the compaction and the impermeability of grouting. Although the bonds in the clay suspensions are weaker than the bonds in the cement suspensions (Shroff and Shah, 1993), these mixtures improve the geotechnical properties of the soil by forming stowing in the cavities.

Cement mixtures are used to increase both the impermeability and the resistance of the soil. By filling the cavities these mixtures form resistance and prevent soil slumping. Water/cement rations of the cement mixtures may vary around 0.5/1 and 5/1. Mixtures form higher resistance in lower water/cement rations, but the availability of the grouting of the mixture decreases at the same rate.

In Dalaman Akköprü Dam, along the body of the dam, curtain and cover grouting were applied on basic rock on which the clay core would be settled. The materials which form the slurry of the grouting, mixing ratios have been anaylsed and technical codes of practice have been determined.

GEOLOGICAL AND GEOTECHNICAL PROPERTIES OF BASEMENT ROCK OF THE DAM

Geology of the dam area was examined from MTA 1997. Due to the fact that the body of the dam was built on peridodite serpentines, which is the basic rock unit, weathered ultra-basic rock and the terrace unit, which is incompetent against water and load, were scraped; and thereby, a competent surface was attained out of fresh peridodite-serpentines. After grouting, by cleaning this floor with air, a floor surface was formed for the clay which is the core material for body stowing. The uniaxial compression test results and index properties of the base rock are given in Tables 2 to 4.

Among the uniaxial compressive resistance values (ASTM, 1980), the values are quite low in the partially weathered samples which have significant discontinuities. When compared to the samples which present partially weathered and fissured structure, the uniaxial compressive strength of the core samples of massive structure is about two times higher. Peridodites and serpentines which are found along the shaft of the dam are semi-permeable and their permeability is $k = 10^{-4} - 10^{-5}$ cm/s degree (DSİ, 1999). According to IAEG (Anon, 1979) permeability classification which is presented in Table 5, the permeability of the axis of the dam is at middle level.

In Dalaman-Akköprü Dam, hydraulic pressure tests (HPT) was applied in all levels of the core or coreless control wells drilled on each anod and core drilled anod wells along the grouting curtain. Experiments demonstrated the necessity for the grouting curtain (Table 6).

THE GROUT CURTAIN IN THE AXIS OF THE DAM

Along the axis of Akköprü Dam, probable leakages in the base rock on which the body of the dam would be built

Table 3. Results of the experiments on the collected samples (Üşenmez, 2005).

Sample no.	Saturated weight (g)	Dry weight (g)	Weight in water (g)	Volume (cm^3)	Pore space (cm^3)	Solid volume (cm^3)	Dry unit volume weight (g/cm^3)	Saturated unit volume weight (g/cm^3)
1	740.27	735.75	464.46	275.81	4.52	271.29	2.66760	2.68299
2	703.15	696.07	427.86	275.29	7.08	268.21	2.52850	2.55422
3	715.15	709.29	438.82	276.33	5.86	270.47	2.56682	2.58803
4	708.05	700.71	432.13	275.92	7.34	268.58	2.53954	2.56614
5	744.03	739.40	468.29	275.74	4.63	271.11	2.68151	2.69830
6	731.92	727.05	457.06	274.86	4.87	269.99	2.64516	2.66288
Weighted average				2.60486			2.62559	

Table 4. Various physical parameters of rocks.

Sample no.	Porosity, n (%)	Void ratio, e (%)	Permeability (m/s)	Compasity (%)
1	1.63	1.66	3.12×10^{-4}	98.33
2	2.57	2.63	2.82×10^{-5}	97.36
3	2.12	2.16	9.23×10^{-4}	97.83
4	2.66	2.73	3.46×10^{-5}	97.26
5	1.67	1.70	4.88×10^{-4}	98.29
6	1.77	1.80	6.23×10^{-4}	98.19

Table 5. Degrees of permeability (Anon, 1979).

Class	Permeability	
	k (m/s)	Description
1	$> 10^{-2}$	Very high
2	10^{-2}-10^{-4}	High
3	10^{-4} - 10^{-5}	Middle
4	10^{-5}- 10^{-7}	Low
5	10^{-7}- 10^{-9}	Very low
6	$< 10^{-9}$	Almost impermeable

Table 6. Relations between Lugeon values and the necessity for the grouting (DSI, 1993).

Type of engineering structure and/or foundation property	Lugeon values 1 min^{-1} m^{-1} (in 1 MPa)
Concrete dams - single lined curtain	3-5
Clay core earth fill - more than one single lined curtain	7-15
Abradable material in the foundation	3-4
Cases when leaking water is hazardous to the environment	1-3

may cause water loss. By expanding over time and creating uplift pressure, these leakages might cause the destruction of the dam and floods. These leakages do not present any danger in the base rock if they occur in certain limits. These limits are the same as the limits checked in the control wells. At the influence area, effect of the grout depth and length determined by the DSI (General Directorate of State Hydraulic Works) is accepted (DSI, 1993; DSI, 2003).

In order to lengthen the possible leaking depth in peridodite-serpentines which form the base rock of Dalaman-Akköprü Dam and to decrease uplift pressures

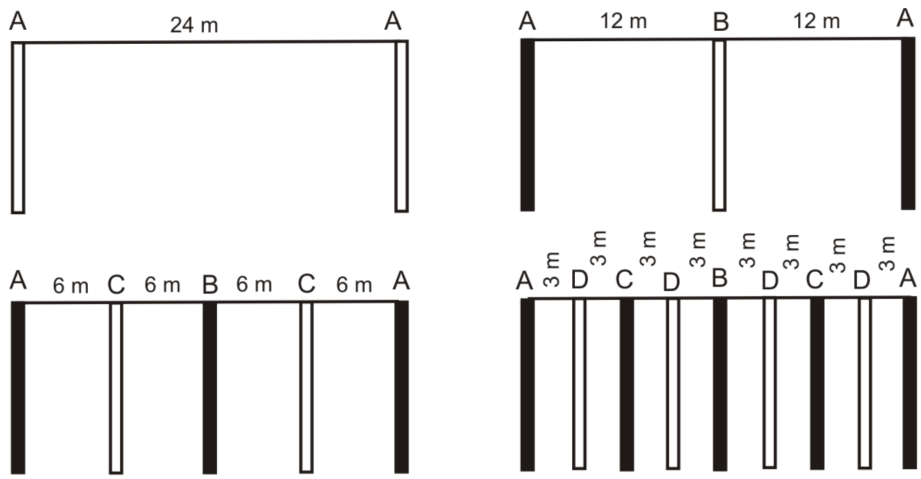

Figure 1. Schematic diagram of grouting bores; A: Primary wells; B: Secondary wells; C: Tertiary wells, and D: Quarternary wells.

which can occur in the body of the dam, a single lined curtain grouting was performed. In addition, in order to reinforce the irregularly jointed structure, to increase the bearing capacity and extend the length of leakage, consolidation grouting was performed in parallel to the curtain in the sections where the clay core settled. In the axis of the dam, there are two grouting galleries; one in the right shore at an elevation of 140 and 97.60 m long and the other in the left shore at an elevation of 137.50 and 190 m long. These galleries were built in order to increase the penetration depth of the grouting curtains in the slopes, to collect and discharge the water that can leak from the slopes and to be able to treat the troubles that can occur during dam operation (Ünal, 2001). From the foundation of the dam to the galleries vertical grouting curtains were performed up to 70 m of depth. In the sections corresponding to the galleries, inclined to the upstream, curtain grouting was performed so that it vertically passed 3 m of the base of the gallery. From the inside of the gallery vertical curtain grouting was performed up to 60 m of depth and access grouting wells were built to cut the wells drilled from the surface.

BASE ROCK GROUTING APPLICATION

Curtain groutings were planned to be formed along a 777 m line with 3 m intervals by core drilling the ano heads in the form of 24 m anos along the axis of the dam. The grouting application order was performed according to “contracting ano method”. According to this, in each ano, by grouting the drilled ano head and ano end wells a passage to the middle wells were provided; then, the grouting was completed when the tertiary and the last quaternary wells were drilled and grouted (Figure 1). The groutings started after the drilling operation had been finished and the wells had been cleaned with high pressure clean water. For the drilling operation, the entire completion of the groutings waited. Moreover, although no such requirement had been encountered, it was paid attention that the grouting operation of the wells, which were close to the well point where the drilling would start, had to be completed at least 24 h before the grouting started In the sections which corresponded to the grouting galleries, on the galleries, from the surface inclined to upstream, and beginning from the bottom of the gallery in depth of 3 m curtain groutings were performed; and from the inside of the galleries contact groutings were performed that cut 5 m of these wells. Also within the gallery, curtain grouting wells were drilled in vertically 60 m of depth (Figures 2a and b)

Moreover, through the drainage wells drilled with an inclination from the inside of the gallery towards the downstream, leaking water from the curtains or around will be collected and discharged. As the body of the dam might be damaged with the uplift pressure of the leaking water from the curtain, drainage wells serve as the safety valve Consolidation (cover) groutings both from the upstream and downstream were applied in the curtain groutings between the galleries. They were drilled 3 m both in width and longitudinally as staggered and their lengths were arranged as 25, 15 and 10 m according to their distance to the grouting curtain (Figure 3). In accordance with the narrowing ano method, the curtain groutings were not applied till the completion of the groutings of 3 anos of cover grouting which are close to each other. Before starting all grouting operations, temporary capping concrete was poured – to be broken later – and by reducing the contact of the slurry with the surface to the minimum slurry wastes were prevented, and by forming a clean and ordered work environment, a fast work environment was attained.

Using water circulation rotary machines, curtain and cover grouting wells were opened at 76 mm diameter

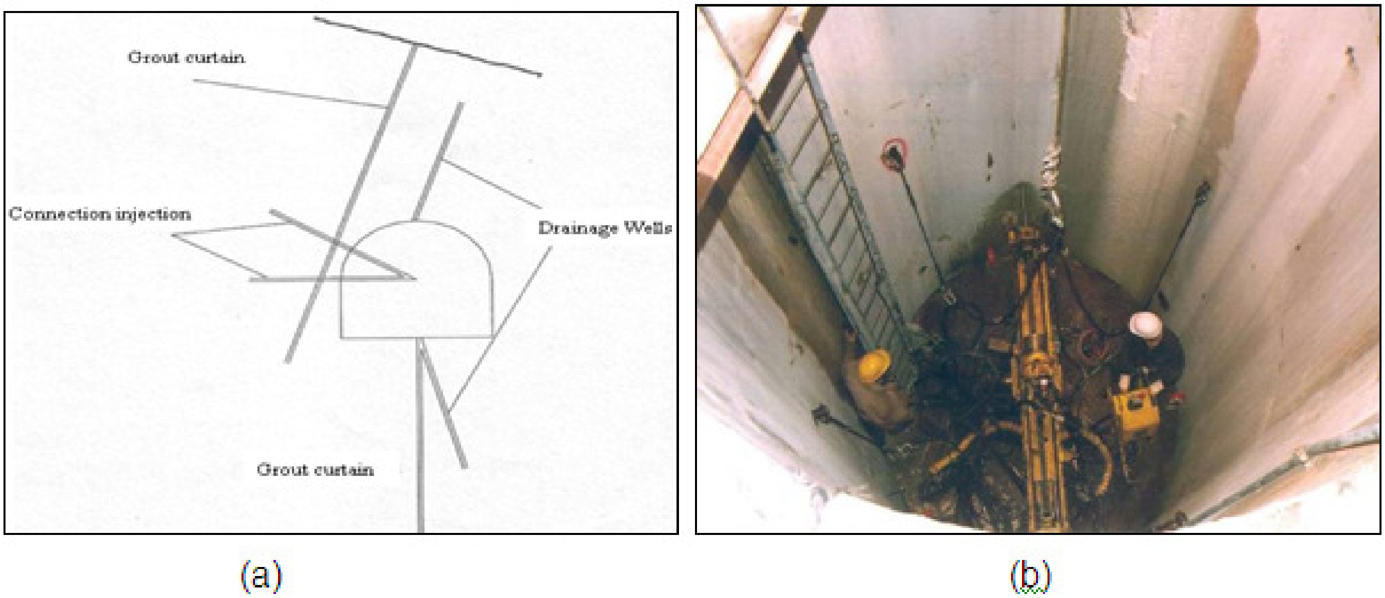

Figure 2. Grouting (a) and drainage wells (b) within the gallery.

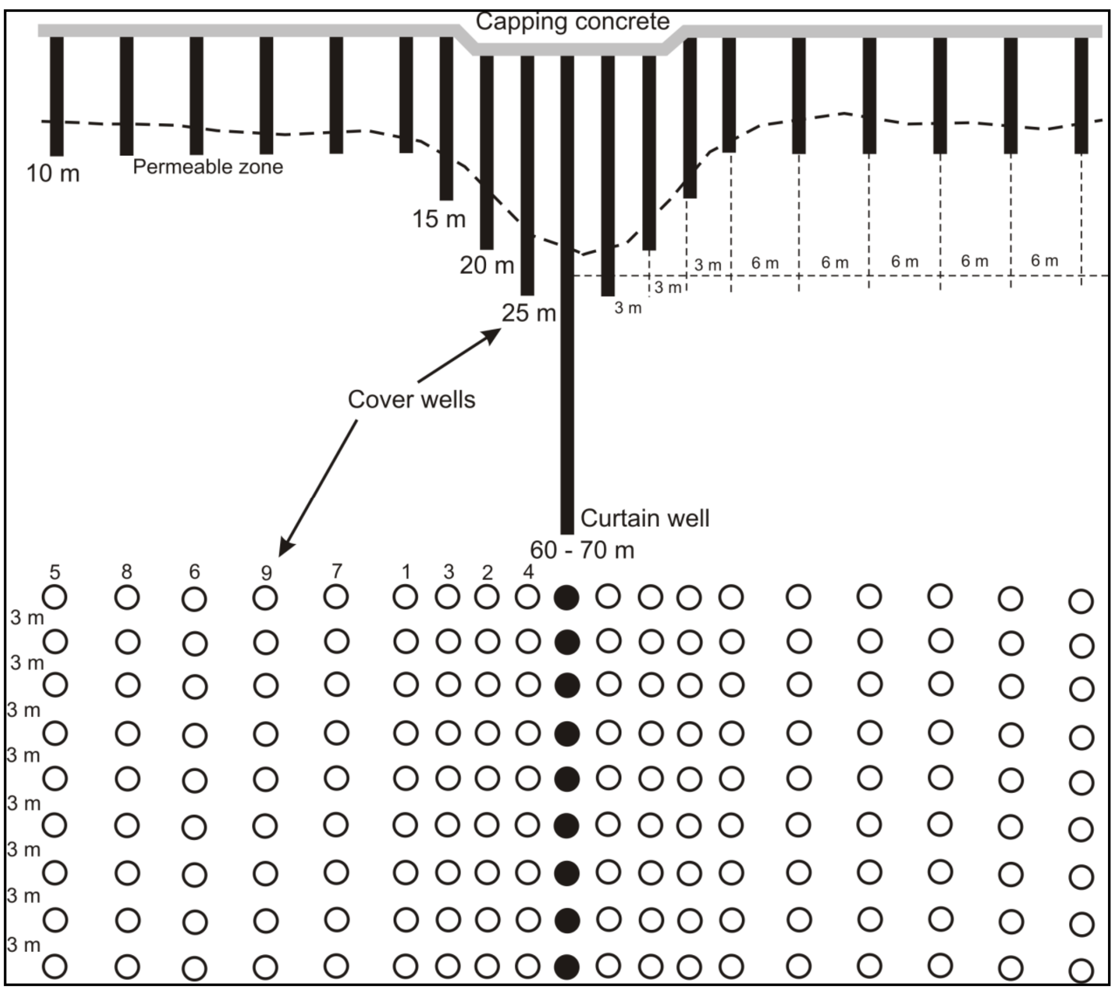

Figure 3. Cross section and grouting plan of an Ano.

Table 7. Slurry mixture rates used in Akköprü Dam.

Mixture (rate lawn / water)	Water (kg)	Cement (kg)	Bentonite %	Bentonite (kg)	Sand %	Sand (kg)	Volume (L)
1/3	150	50	5	2.5	-	-	168.0
2/3	150	100	4	4.0	-	-	186.0
1/1	150	150	3	4.5	-	-	203.0
7/5	150	210	2	4.2	-	-	222.5
7/5	150	210	2	4.2	2.5	52.5	237.5
7/5	150	210	2	4.2	50	105.0	252.5

without degrading the soil; by completely cleaning the internal wall of the well with pressure water, groutings were completed from the bottom to the top in rising step form. In curtain and cover grouting wells, the lengths of the steps were determined as 5 m; the interval of the last 0 to 5 m was completed in two steps of 2.5 m lest it might be damaged during the bottom excavation.

RATES USED IN THE SLURRY OF THE GROUT

In accordance with the slurry rates of the formations, it was passed from the thin mixture in density to the thick mixture. The reason to start the groutings with thin mixture was to provide the penetration of the slurry of the grout into the fissures and the void in the small space or by flowing through the fissures with narrow opening to reach bigger voids, if there are. When started with the thick mixtures, the slurry may leave gaps behind by forming bridges in the channels which are not proper to its viscosity and this contradicts with the purpose of the work.

In each well, grouting operation started with 1/3 cement/water percentage weight, and the density of the slurry was increased in ratios of 2/3, 1/1, 7/5 and finally 7/5, respectively, till 50% sand mixture was attained. The density of the slurry mixture was increased in each mixture after 0.5 m^3 of intake. By subjecting the slurry mixtures to viscosity, stability and specific weight tests, their sedimentation rates and other characteristics were investigated in detail.

In order to increase the stability, bentonite, which had been hydrated in ratio of 1/10 percentage weight at least 24 h before, was used in the mixtures. Due to the fact that the permeability of the basic rock unit peridodite-serpentine is low, a cement, “Blain” value – or specific surface – of which was bigger than 4000 cm^2/g, was used. Slurry mixture rates and volumes of these slurries in litres are shown in Table 7 in detail. As the peridodite-serpentine, which is the basic rock unit in Akköprü Dam, is semi-permeable material, there was no need to use sandy mixtures and results were attained by reaching refusal.

GROUTING PRESSURES

In Akköprü Dam construction, grouting refusal pressures used in all cover wells were formulated with Pt = 0.23 × H formulation (DSI, 1993).

In all curtain wells, formulations were carried out with P=0,33H formulation. Here, Pt is the total effective pressure level; H is the vertical distance (m) between the well top and mid-point level. In converting the effective pressure into the pressure to be read in manometer, correlation of following equation was used (DSİ, 1993; Şekercioğlu, 2007);

$$P_m = P_T + W * \frac{L}{10} * \cos \alpha$$

In this equation, W = specific gravity of grouting slurry; L = vertical distance between the mid-level and manometer, and α = the angle between the well and the vertical. Manometer refusal pressures used in the levels are given in Table 8.

REFUSAL CONDITION

Refusal is the circumstance when the mixture injected into the well at one level completely comes back while the grouting continues. Refusal condition applied in Akköprü Dam, for all the curtain and cover wells while grouting continued in the related level, when the desired pressure was attained and the level did not any more absorb the slurry, by passing to 1/3 thin mixture, this mixture was injected into the well for 20 min. In that period, for the curtain wells in the first 20 m 0.3 L/m/m and for the consolidation wells of 0.6 L/m/m or where less slurry absorption occurs, the refusal condition was considered to be provided.

USED MATERIALS

Cement: As there is no sulphate threat in the underground water, normal PKC/A 32.5 (Portland Cement, TS 197-1) was used. By using cement with specific surface

Table 8. Grouting refusal pressures applied in Akköprü Dam.

Level (m)	Pressure (kN/m^2)	
	Curtain grouting	Cover grouting
0-2.5	10	5
2.5-5	20	10
5-10	20	20
10-15	30	30
15-20	40	40
20-25	50	50
25-30	60	
30-35	70	
35-40	80	
40-45	90	
45-50	100	
50-55	110	
55-60	120	
60-65	130	
65-70	140	

Table 9. Extract of the foundation grouting.

Type of the well	Number of the well	Length (m)	Cement (kg)	Bentonite (kg)	Solid content per 1 m (kg/m)
Cover	1580	24372	344592	14604	14.7
Curtain	365	20889	271249	10846	13.5
Control	31	1952	12101	550	6.5

bigger than 4000 cm^2/g, better penetration of the cement into thin fissures was provided (Batı Söke Çimento TAŞ, 2002).

Bentonite: Pure bentonite with a liquid limit higher than 400% was used. Its properties are given in Table 9 (TS 977, Karakaya Bentonit, 2002).

Sand: Sifted and washed sand which does not include thin materials like clay and sodium sulphate and organic matter was used.

Water: Clean underground water which does not contain harmful substance like oil, acid, alkali was used.

Chemical thinners: As the permeability of the peridodite-serpentines is low, it was anticipated that in case there is water absorption but no slurry absorption, additives like sodium sulphate at the rate of 0.5 to 1% weight of cement or commercial brand, L-10 Melment at the rate of 1 to 2% would be used. However, no such circumstance had been encountered in the application.

Hardening accelerator: Though there was no such need, if required, $NaSiO_3$ in the slurries and $CaC1_2$ in the sandy mixtures were planned to be used.

CONTROL OF THE WORK

In the grouted anos, by drilling core or coreless inclined control wells in a way to cut the levels which relatively absorb high cement, hydraulic pressure tests were applied right after groutings were performed. Thus, the impermeability of the related anos was evaluated according to Lugeon values and it was observed that they were below the limit determined by DSI. In Table 8, total lengths of the curtain, cover and control wells and amounts of the additives are presented.

DISCUSSIONS AND CONCLUSION

Along the body of Dalaman-Akköprü Dam, curtain and cover groutings were performed on the base rock on which the clay core would be settled.

Concerning the materials used in the grouting and constituted the slurry of the grouting, field survey and the control of the work Akköprü Dam was chosen as an applied research and the work performed was observed and investigated on site. It was observed that the values and the validity of the application had been below the limits recommended by DSI. It was concluded that the rates of mixture and codes of application recommended by DSI are appropriate to the geological structure within the scope of the study. When the dam starts to keep water, depending on these data, water leakage in the base rock along the axis of the dam is not expected. With the research, it was intended to be example for the works concerning soil improvement, grouting and impermeability.

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