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The Foundation of the Right Bank in Wadi-Zarat Dam

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SYNOPSIS The geotechnical engineering characteristics of a calcarious crust formation are evaluated in order to determine the feasibility of its stability under the right bank of Wadi Zarat Dam. The crust is a rock similar, extremely hetrogeneous, material with location of collapsing succeptibility when saturated. The formation is caverned and locally very permeable and can present a risk of lossing the reservoir water, dissolution, settlement, and piping. In this case study, several alternatives to treat the crust formation are presented, discussed, and compared. Rational justifications for the adopted solution are given and the predicted performance during operation of the dam is provided in order to be compared with the observed behaviour.

GENERAL INFORMATION

The WADI ZARAT dam is an earth dam located 80 km South -West of Tripoli City, Capital of Libya. The body of the dam is constructed from alluvium with a loess (loam) core and protected slopes. The general layout of the dam is given in Fig.1, and it has the following characteristics :

Length	2700 m
Crest height from valley bed	32 m
Road width of crest.	10 m
Width at valley bed	175 m
Catchment area	175 Km^2
Reservoir volume :	
Max. storage level(MSL)	8.61x10^6 m^3
Exceptional water level(EWL)	24.75x10^6 m^3
Max.water level (MWL)	28.1x10^6 m^3

The main purposes of the dam is the protection of Wadi El-Hay irrigation project and to supply it with water by means of a pipe leading from the dam to the irrigated parameter.

The geology of the site can be briefed as a Quaternary cover soils underlain by a Triassic bedrock consisting of dolomitees and clays. At the bottom of the Wadi (valley),the clays are covered by Quaternary conglomerate, and at the banks, by dolomites. Above these dolomites there is a calcareous crust formation. A section along the axis of the dam showing the sub-surface profile is given in Fig.2. Geotechnical investigations have shown that the conglomerate could be described as homogenious but cracked and of good mechanical characteristics, where the dolomite formations are less favourable characteristics, cracked, covered, conglomerate, dolomite, and clay are presented in Table I. Details concerning the crust formation are dealt with in the following section.

CHARACTERISTICS OF THE CRUST FORMATIONS

These formations exist directly below both banks of the dam. However, at the right bank the formation is much thicker and of unfavourable characteristics, where at the left bank it has sufficient characteristics as a foundation material. Due to the fact that the crust formation at the right bank can collapse and/or settle at presence of water, several detailed studies have been performed before and during construction to investigate its engineering properties and to predict its behaviour as a foundation material.

TABLE I. Engineering Properties of Conglomerate, Dolomite, and Clay Bed-rock.

	Conglomerate	Dolomite
Unit weight, KN/m^3	24.7 - 26.5	20.3-25.7
Compr.strength,MN/m^2	43.8 - 98.9	11.2-91.8
Deformation modLGN/m^2	24.0 - 38.5	21.5-31

	Clay Layer
Mineral	generally Illite.
Clay,%	30 - 80
Liquid Limit,%	40 - 80
Plasticity Index,%	20 - 48

According to the original design, the crust formation at the right bank, starts next to the spillway at station 1650 with a length of about 1000 m.and a thickness up to 25 m.beneath the base of the dam. It is extremely beterogeneous and anisotripic with respect to lithology and geo-technical characteristics. It has been described by different investigators as a combination of beds of soft vesicular limestone and beds of hard cracked limestone, levels of marl and clay, detrital clays with limestone fragments clayey breccia with dolomite fragments, and calcarious sand. A log of the crust formation as obtained by excavation of a vertical reconnaissance 3 m.diameter shaft is shown in Fig.3.

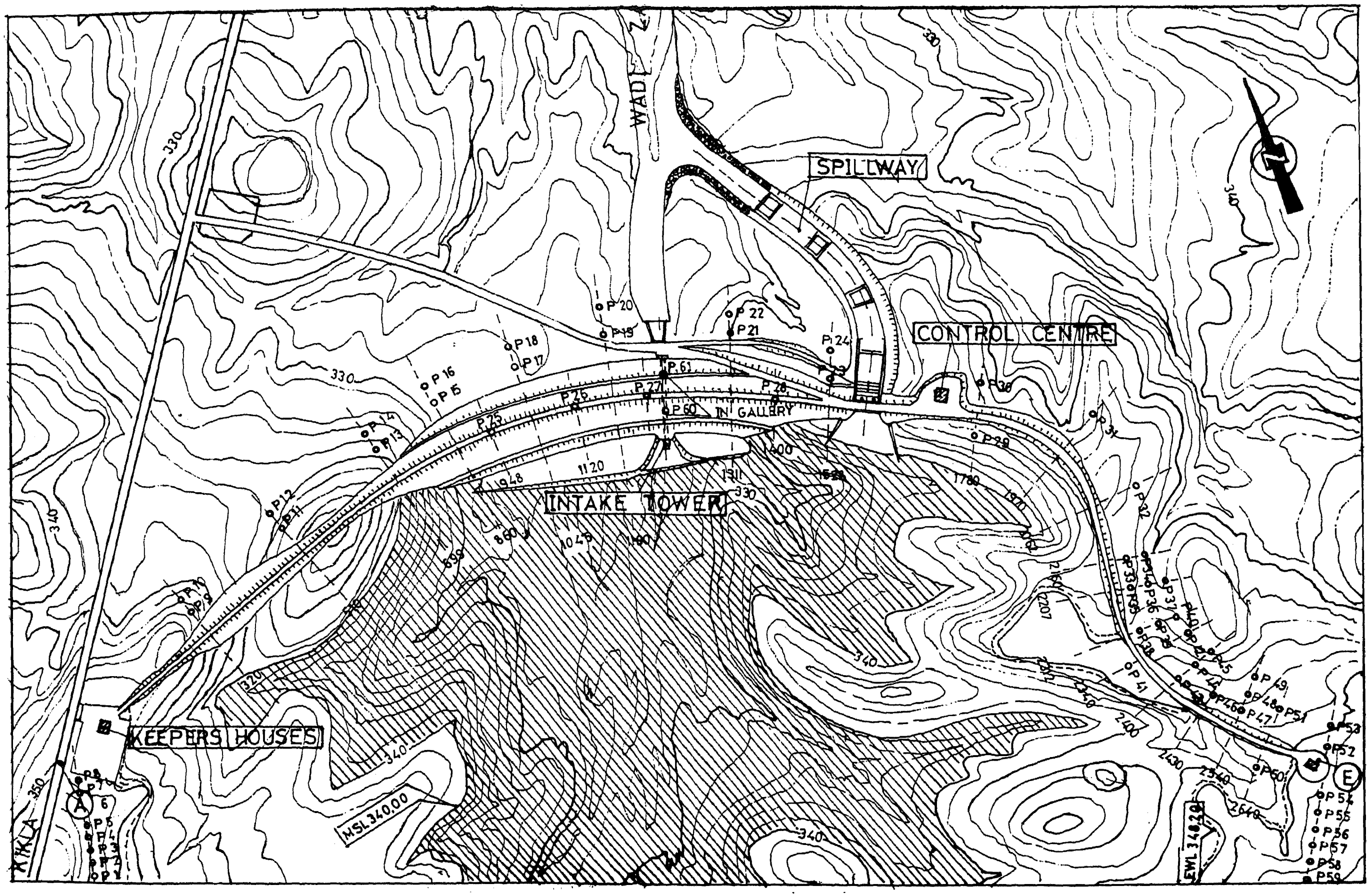

Fig. 1 Layout of Wadi Zarat Dam

This Shaft was lined with concrete blocks and equipped with observation windows, steel ladders and rest platforms in order to allow visual inspections and sampling. It is worth mentioning that undisturbed samples were only obtainable where lenses of silty and clayey soils are existing. A large number of laboratory tests have been performed before and during construction,however, due to the hetroginity of the crust they could be considered as qualitative indications. Some of the tests results are given in Table II. The soil/rock mixed materials that constitute the crust formation exhibited variable field permeability ranging from cracked rocks with fracture permeability to impervious rocks.

The fine grained portion of the crust materials has a liquid limit of 20 to 50%, a plasticity index of 6 to 26% and a compression index ranging from 0.02 to 0.3. Soaking of the crust material in water leads to different reactions from remaining unchanged to softening to diminishing in volume. A qualitative method,Gibbs and Bara (1962), which is only applicable to fine-grained soils, as a liquid limit test is utilized, showed that the susceptibility to collapse is low,Fig.4. Double consolidation tests,(Jennings and Knight (1957), to evaluate the effect of wetting of samples subjected to variable vertical stresses with water, showed that the collapse is about 5 to 7% of the initial height of the tested specimens. However, the tested fine grained material from only a small fraction of the whole mass of the crust formation exists as a soil binder or in thin silty and clay seems. Therefore, there is still a suspect of collapsibility in the presence of water in some localities of high permeability and present due to their chemical composition in addition to loss of the storage water a risk of disolution, cavities, piping and settlement which jeopardize the safety of the dam.

TOPOGRAPHY,LEVELS, AND GRADIENTS

Shown in Fig.1, the topography of the site and the extension of right bank. Levels of the dam foundation, crest, and stratification of different layers are given in Fig.2. Important levels are listed in Table III.

The probability of saturation of the crust area is governed by the water level in the reservoir and the duration of its existance. At the storage level of 340 m, it is highly probable that the crust foundation below the dam will get saturated; Coming to the effect of saturation, the situation could be described as uncertain. Due to the lack of information about the effect of saturation i.e. sufficient field and laboratory testing to cover the extreme heteroginity is of the crust formation, the situation , unpredict-

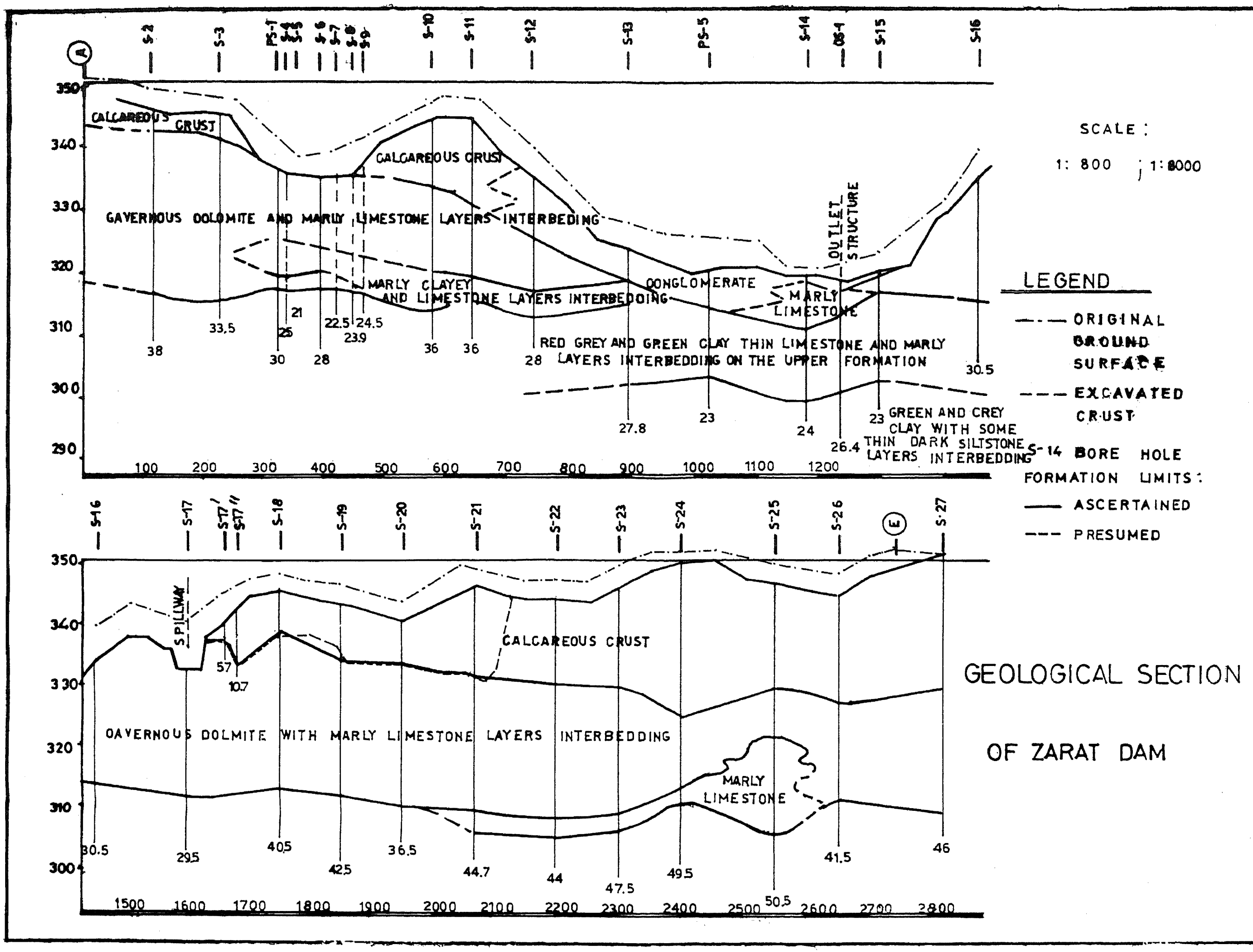

Fig.2. Longitudinal Geological Section along the axis of the Dam.

able. Concluding the following two, almost contradicting, opinions, have been discussed :

1-The reservoir water level will be delivered to the crust material under the dam and that the crust will be saturated up to the reservoir level in any case .Consequently,serious measures must be adopted with respect to water tightness function (to reduce the crusts permeability) and improvement function (to minimize the risk of the crust's settlement or subsidence due to saturation).

2-The saturation of the right bank at Wadi-Zarat is some what uncertain as much as, the crust material may not get saturated even if the reservoir level reaches 344 for short periods only. Also, if it does get saturated and collapses the length of seepage path between reservoir level 344 in the crust up to ground level 343 downstream extends for about 100 m beyond the downstream slope of the dam. The resulting gradients are mild enough and would not create any serious threat to the dam. The height of the dam in the right bank is small and isolated from the main dam. The settlement due to collapse of crust would not be sudden if piezometers are available for pore water pressure measurements, sufficient lead time will be availabel to adopt remedial measures at he site before the cavities in the crust lead to piping.

PROPOSALS OF TREATMENT

What was called "poor geotechnical properties" of the crust led the designer, consultant and contractor to foresee a treatment device the function of which is to fullfill and consider the following points :

-Watertightness function, and how to make the crusts impermeable;

-Volume change control function, or improvement of the crust for the effect of wetting;

-If a grouting device is to be adopted, the groutability of the crust material and how to make crust layer groutable and sametime improved is a critical question. As it will be seen later, the crust seem to be groutable in the sense of absorbing a considerable amount of grounting material but still highly permeable.

TABLE II. Physical and Geotechnical Characteristics (Shaft at Station 2070)

Depth m	Nat.Water Content %	Unit Weight KN/m^3	Sp. Gr. -	Liquid Limit %	Plasticity Index %	Grad. <5mm %	Grading <0.075mm %	Void Ratio -	Compression Index -	Friction Angle Degree
2.5	2.5	1.92	2.70	50	21	41	-	0.41	-	-
4.5	-	-	2.70	40	18	42	15	-	-	-
6.0	-	-	-	38	24	29	-	-	-	-
7.0	-	-	2.68	51	26	50	15	-	-	-
8.5	-	-	2.68	48	24	36	10	-	-	-
8.5*	10.2-12.4	17.7-18.1	2.68	38	24	-	-	0.50-0.54	0.02-0.05	-
9.5 *	6.7-7.1	18.7-19.1	2.69	38	24	-	-	0.41-0.44	-	37
10.0 *	8.5	17.1	2.68	30	13	28	-	0.58	0.07	-
11.0 *	11.1	16.5-17.2	2.71	37	24	45	17	0.59 0.66	0.06-0.15	-
12.0	-	-	2.79	30	14	38	10	-	-	-
13.0	2.6	20.3	2.79	24	9	45	13	0.37	-	-
15.5	-	-	2.79	20	6	13	3	-	-	-

Note: *Undisturbed samples taken from fine brownish silty clayey lenses for consolidation and direct shear tests.

Furthermore, it is supposed in the following proposals to fulfill both the watertightness and volume change control functions with only one operation.

TABLE III. Summary of Important Levels.

Dam crest (main dam)	350.00 m
Dam crest (right bank)	350.50 m
Maximum storage level (MSL)	340.00 m
Exceptional water level (EWL) 1000 years	348.20 m
Maximum water level (MWL) 5000 years	349.40 m
Intake levels	325.00,331.00,337.00 m
Spillway sill, control sill	340.00,344.00 m
Crust levels in the right bank:	
Upper surface	340.00 to more than 350.50 m
Lower surface	325.00 to 342.00 m

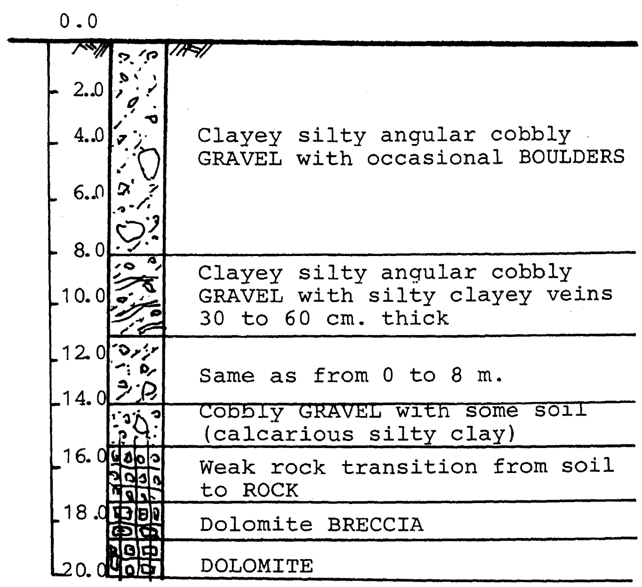

Fig. 3. Profile of the Crust Formation of the Excavated Shaft (Station 2070)

Grout Curtain, Proposals "a"

Grouting with three lines of drilling 0.75 m apart and 2 m spacing along the side lines and 1 m spacing along the central line. Grout mixes are pure cement along the side lines and bentonite cement along the central line. Lines of drillings are increased to four in areas where embankment is higher than 6 m. Results of water tests indicated no reduction in the permeability at the surface between 0.0 and 5.0 m but substantial improvement between 5.0 and 10.0 m depth as follows:

Depth (m)	Permeability in before grouting	Permeability in after grouting
0-5	10.6 L.U.	9.5 - 12 L.U.
5-10	19.4 L.U.	4.8 - 5.8 L.U.

Where the L.U. (Leogon Unit) is the amount of water in litres pumped at a pressure of 10 bars per minute per meter (l/min/m). According

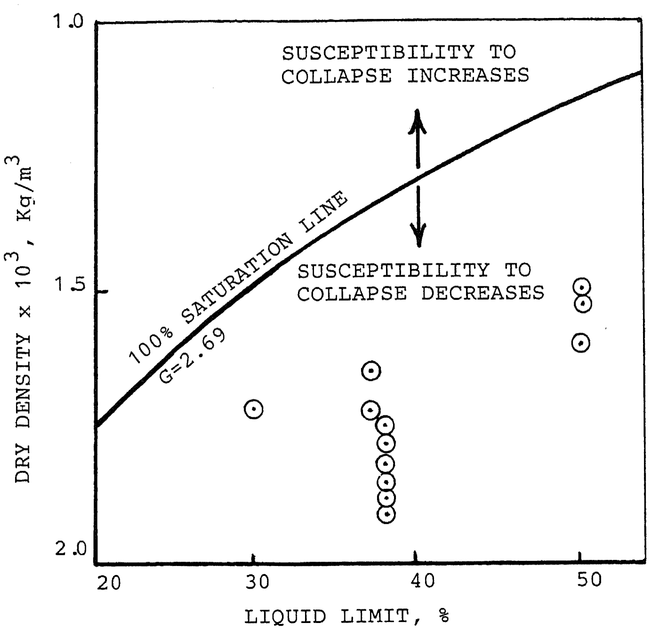

Fig. 4.Liquid Limit, Dry Density Relationship

to original design, a permeability of less than 3 L.U. should be achieved after treatment. It was evident that the crust is ungroutable by cement and bentonite in the sense that these soils accept grout only in their bigger openings like cracks, seams and the like but not in the micropores of the material. Water tests show that even near the holes which have registered high absorptions, the permeability after injection has remained unchanged.

Grout Curtain, Proposal "b".

Based on the above results in proposal "a", it was thought that improvements w.r.t. permeability could probably be made by carrying a series of tests as regards to the length of the grouting stages, the pressures, and the grout mixes. New tests with three lines of drilling-tests in proposal "a" have been limited to two lines of drilling, shorter grouting stage 3 m instead of 5 m in proposal a-, and slightly higher pressures. Variations also of cement/ bentonite and cement/water ratios were considered. Even with these modification, no improvements in the crust's permeability have been noticed.

Grout Curtain Proposal "c".

Carrying out a first phase of injection bentonite cement grout mix to fill up the cracks and cavities followed by a second phase of injecting bentonite and silicate gel. Permeabilities of 16 to 20 L.U. have been measured in water tests after silicate grouting.

Slurry Wall.

The idea of constructing a watertight barrier in the crust was also considered. A slurry wall of bentonite cement 0.80 m wide cutting through the crust and anchored in the dolomite then the barrier is extended into the dolomite by a grout curtain. The slurry wall, inspite of the fact that it would create as watertight barrier it was considered as vulnerable. In the sense that this kind of technology is not available in this Country, and in addition, it might lead to differential settlement under the dam and if moisture in the wall is absorbed by the Crust material cracks will occur in the wall. The designer report was very explicit in this subject.

Removal of the Crust.

The option of excavating the crust and lowering the dam to the dolomite seemed as the only possible solution. The core of the right bank will be taken down to the dolomite and prolonged by a grouting curtain down to the water tight clay and bed rock. In a modification to this, the whole dam (core, slopes and filters) is taken down to the dolomite after excavating the crust with the necessary width.

THE ADOPTED SOLUTION

The adopted solution was to remove the crust and deepen the dam in a 550 m length from station 1650 just to the right of the spillway to station 2150. This implied excavating about 17000 m^3 of the crust material and increasing the height of the dam by 7 to 15 m. Typical section is shown in Fig. 5.

From station 2150 to 2700 (550 m) the crust was not removed but cement grout used just to fill any cavities or cracks that may exist. For this part of the dam (2150-2700), the crust material may not get saturated unless the reservoir levels, above 344, are experienced for long durations. Moreover, the gradient resulting from the reservoir level 344 and the ground level downstream the dam would be mild enough to create any serious threat to the dam. The dolomite formation below the crust was grouted as originally designed, and the grout curtain is extended into the clay bedrock. The adopted solution necessitated a variation order including the works to be omitted from the original project and extra works to be executed.

TREATMENT METHOD DECISION

A Techno-economic comparison is carried between the alternatives presented. However, these alternatives are not equally reliable to have the economic side as a governing factor. The grout curtain with its three proposals was excluded as uneffective with respect to the watertightness function. Similarly the slurry wall was also excluded due to probability of cracking in the wall caused by differential setlement of the parts of the dam a due to water absorption from the slurry by adjacent crust materials. Consequently, the grout curtain and the slurry wall "alternatives" are out of comparison with the crust removal alternatives as not satisfying the basic requirement of design. Any economic comparison between the alternatives in this case would be of interest but not thegoverning factor.

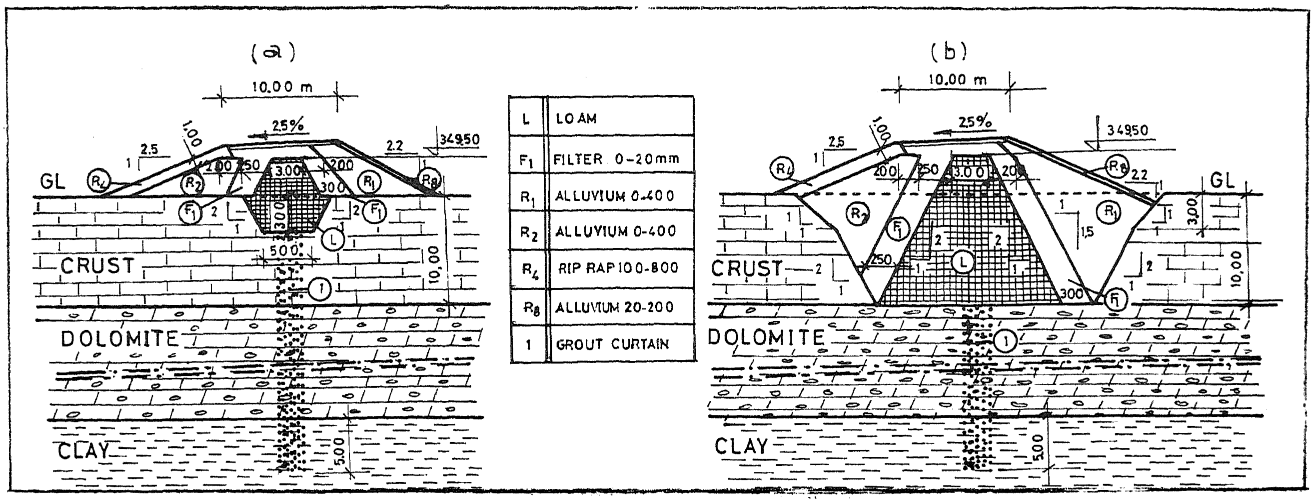

Fig. 5. Cross Section of the Right Bank at Station 1915, before (a) and after Removing of Crust (b)

PERFORMANCE AFTER CONSTRUCTION

According to the Design and Specifications and in order to observe the behaviour of the dam and appurtenant structures during operation stage, several control devices were installed. The basic established observation systems at the right bank were surveying and piezometric networks. The data obtained from these systems will indicate conditions that can affect the stability of the dam. In addition these data can be studied for comparison with the expected behaviour.

Vertical movements (settlement) of the dam crest at the right bank is provided by bench marks installed on the crest at intervals of 50 meters. Maximum value of 1.3 cm. at bench mark No. 39 was recorded on October, 1983 (16 months after construction). This value corresponds to the maximum height of the dam (20.5 m.) in the excavated area of the right bank. No settlement was observed for the rest of the right bank.

During the operation period of the dam the water level in the reservoir reached to a maximum of 326.53 m. on November , 1982 and 328.98m on October, 1983 with a storage of less than 900,000 cu. m.

Piezometric network of the whole dam consisted of 61 piezometer as shown in the layout, Fig.1. 23 piezometers were executed to determine possible leakage under the right bank with a concentration on the unexcavated crust formation. The readings of these piezometers, upstream and downstream, indicate the water table elevation of the area which is about 317 m. and they were not affected yet by the water in the reservoir.

From the above discussion it is evident that th critical stage, when the crust formation under the right bank gets saturated, has not been reached during the past operation stage of the dam, and the measured settlement was mainly due to consolidation of the dam body. Therefore, the predicted behaviour of the treated crust ca only be checked at that stage.

ACKNOWLEDGMENT

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REFERENCES

Gibbs, H.J., and J.P. Bara (1962), "Predicting Surface Subsidence from Basic Soil Tests," ASTM. STP 322, pp. 231 - 247.

Jennings, J.E. , and K. Knight (1957), "The Additional Settlement of Foundations Due to a Collapse of Structure of Sandy Subsoils on Wetting," 4th. International Conference on Soil Mechanics and Foundation Engineering, Vol. 1, pp. 316 - 319.