In Situ Permeability of a Fractured Rock Formation

La Perméabilité In Situ d'une Formation Rocher Fracassée

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SYNOPSIS Extensive water pressure tests are performed in many borings for determination of permeability of a fractured rock formation at a nuclear power plant site. At zones where high water losses were encountered, the permeabilities are further determined using Lefranc testing procedure. In addition, behavior of structural discontinuities of subsurface formation under pressure are investigated and its implications are deduced. Furthermore, the correlation of subsurface permeability with rock quality designation is obtained and comparisons of water pressure and Lefranc tests permeabilities are provided.

INTRODUCTION

The Turkish Electricity Authority (TEK) is planning to construct of a 600 MWe nuclear power plant at Akkuyu, about 120 km west of the city of Mersin along the Mediterranean coast of Southern Turkey. The subsurface rock formation at ANPP site was composed of medium to thick bedded dolomitic and crystallized limestone. It is determined by geological TV camera studies that intensive geological activity in the past has favored local fractured zones and heavy jointing together with some local karstification. High ground water table and the indispensible deep excavations for the power plant dictated the conduction of continuous testing for the determination of subsurface permeabilities to be used in the design of dewatering scheme. For this purpose, an extensive amount of water pressure and Lefranc tests were implemented as part of the geotechnical investigation program.

SUBSURFACE GEOLOGICAL FEATURES

The subsurface geological investigations showed that the bedrock at ANPP site was entirely composed of light to dark-grey, relatively thinly layered (10 cm to 40 cm) dolomitic limestone formation of *Middle Devonian* geological period. This subsurface formation was later exposed to the Tertiary period orogenetic activites which favoured intensive fracturing, heavy jointing and created a system of complex subsurface discontinuities.

Consequently, the active geological past of the bedrock and the implications of karstification due to this intensive fracturing and weathering, necessisated the preparation of a bedrock verification program which at the same time would give the relevant engineering design parameters. The geotechnical investigations consisted of both the direct measuring techniques as TV Camera logging, deformation modulus testing, water pressure tests, resistivity, SP and γ- ray logging, and the indirect measuring techniques as crosshole survey, seismic refraction, surface resistivity and microgravimetric studies, (*Tezcan and Durgunoğlu, 1978*). The location of the boreholes together with a preliminary plant layout is presented in Fig. 1. Although extreme care was given to drilling of the boreholes, the rock quality designation (RQD) values were generally very low if not zero. The laboratory tests which are performed on intact core samples showed that the rock at the site was classified as EM-DM according to *(Deere and Miller, 1966)*.

It was determined that the poor core quality and low RQD values were due to intensive joints, fractures, and beddings; therefore, the TV camera soundings were utilized to statistically analyze the system of discontinuities, to correlate subsurface and surface geology and to investigate the subsurface for karstification. As a result, it is concluded that due to the impurity of the limestone formations and the relatively thin layered lithologically different rock sequence, large scale karstification is not a characteristic of the ANPP site.

However, all investigations showed that the existing slight karstification which persisted down to a depth of 20m-30m was due to the highly weathered, narrow-spaced (20 joints/m) discontinuities. Such subsurface formations would favour high water permeabilities.

THE METHOD OF TESTING

Single packer water pressure tests (WPT) were continuously applied in the boreholes for an initial test length of 3.0 m. The pressure steps chosen were 300, 600, 1000, 600 and 300 kPa. In cases when the 130 lt/min discharge capacity of the utilized pumps was not enough to attain the pressure of 1000 kPa, the initial test length of 3.0 m was further decreased down to 2.0 and 1.0 m. Tests were repeated twice at each pressure step and for constant durations of five minutes.

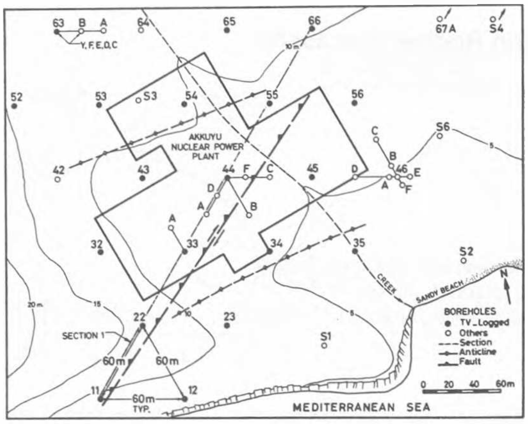

FIGURE 1 SITE PLAN

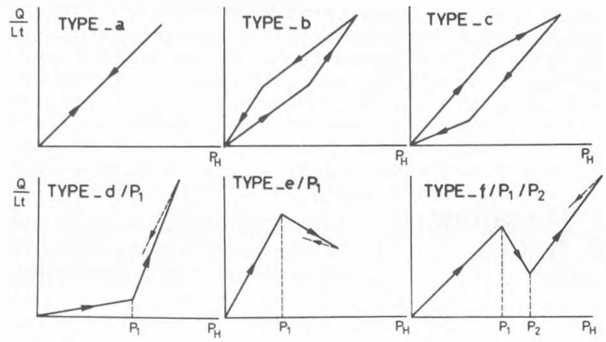

FIGURE 2 RESPONSE OF DISCONTINUITIES

In the evaluation of such tests, Lugeon value, L_V, is used which is defined as the amount of water loss in liters through one meter length of subsurface formation in one minute and at a constant pressure of 1000 kPa *(Lugeon, 1933)*. Thus, one Lugeon value approximately corresponds to a permeability of 10^{-7} m/s.

It is evident that it will be possible to achieve Lugeon values as high as 130 with the utilized method of testing. However, at some highly fractured zones it was not possible to conduct the test due to excessive water loss. Furthermore, it is well established that in engineering evaluations of Lugeon values, the reliability decreases with increasing L_V values, *(Housby, 1977)*. Consequently, at zones where L_V was greater than 10, representative permeability of the subsurface was further obtained by a constant head test known as Lefranc test *(Banzil, 1952)*. As a result, a total of over 500 WPT and over 150 Lefranc tests were performed.

EVALUATIONS

The Lugeon values were determined from a plot of unit discharge, (Q/Lt in lt/min-m) versus the actual pressure applied to the test zone, (P_H in kPa) which requires the calculation of the friction losses in the test rod. These plots of WPT were also used in evaluation of the response of fracture zones under the applied pressure and in determining the nature of discontinuities. The cycling curve in this kind of plot indicates whether the discontinuities are of the opening or closing type upon the application of pressure. Various types of response of the subsurface discontinuities at ANPP site is presented in Fig. 2. Evaluation of each test accordingly is indispensable for selection and design of the dewatering scheme.

The results of the water pressure tests are summarized in Table I for only the highly permeable and geotechnically important upper 25 m of the subsurface. The water pressure tests are sorted according to Lugeon values, the coefficient of permeability at 300 kPa, and the type of behavior of discontinuities during the application of pressure. It is observed that the Lugeon values are greater than 10 along 71.4 percent for the upper 25 m of subsurface. The coefficient of permeability at 300 kPa is greater than 1 x 10^{-6} m/s, along the 65.6 percent and is less than 1 x 10^{-7} m/s along the 6.7 percent of upper 25 m of subsurface. In about one third of the tests, the water losses were linearly proportional with the applied pressures as shown by Type-a in Fig.2. In other cases, it is observed that the opening type of discontinuities as in types b,d and f are in majority. Consequently, it is concluded that the discontinuities are generally opened with the application of high water pressures.

A typical variation of WPT permeability coefficient and Lugeon values with depth is presented in Fig. 3. The Lugeon values and the permeabilities calculated from the discharge of water at 300 kPa pressure are comparatively plotted. It is observed that the Lugeon values and the permeabilities closely follow each other, giving further proof of elastic type of behavior, in such zones, with the increasing water pressure, especially below the depth of 25 m. However, at depths of 5m to 15m below the ground surface, it is seen that the permeabilities at low pressures drop below the Lugeon value which is a clear implication of further opening of discontinuities upon application of pressure.

The permeability values measured from two different testing procedures are correlated in Fig.4.

The coefficient of permeability from water pressure tests and Lefranc tests are indicated by k_w and k_l , respectively. It is important to note that Lefranc tests are performed just after the WPT at highly permeable zones and therefore, its results are affected by the change in subsurface discontinuities upon application and subsequent release of pressure during WPT.

It is observed that for k_w =(1,0-5,0) x 10^{-6}, Lefranc tests showed higher permeability values whileas beyond this range the Lefranc test permeabilities drop below the $k_l = k_w$ line. This implies that, in extensively fractured zones where Lefranc tests were employed, for L_V values 10 to 50, the subsurface discontinuities open with the applied pressure and do not return to their original state upon release of pressure. On the other hand, at zones for $L_V > 50$ relative decrease in Lefranc permeability values is observed.

TABLE I RESULTS OF WATER PRESSURE TESTS, FOR THE UPPER 25 m

BORING NO.	NUMBER OF TESTS	TEST LENGTH, m	LUGEON VALUE, Lv			PERMEABILITY, $x10^{-7}$ m/s			RESPONSE TYPE						
			<1	1-10	>10	<1	1-10	>10	a	b	c	d	e	f	v(1)
11	7	21	0	15	6	0	15	6	15	-	-	6	-	-	-
22	3	9	0	6	3	3	6	0	3	-	-	6	-	-	-
23	9	20	2	6	12	4	6	10	4	4	2	2	2	2	4
32	8	19	5	2	12	6	6	7	11	2	-	6	-	-	-
33	5	14	3	7	4	3	9	2	3	3	8	-	-	-	-
33A	9	18	0	2	16	0	2	16	6	-	2	8	-	-	2
34	5	15	0	0	15	0	0	15	6	-	-	-	-	-	9
35	10	18	3	2	13	3	2	13	5	6	-	1	-	1	5
42	6	18	0	3	15	0	0	18	-	3	-	-	-	-	15
43	4	11	3	3	5	3	3	5	-	5	-	-	-	-	6
44	6	18	0	3	15	0	3	15	6	-	3	-	-	-	9
44A	5	10	0	2	8	0	4	6	2	-	-	2	-	-	6
44B	5	10	0	2	8	0	4	6	8	2	-	-	-	-	-
44D	8	16	0	4	12	0	4	12	4	-	2	-	-	-	10
44E	11	22	0	4	18	2	8	12	8	8	2	-	-	-	4
46	2	6	0	0	6	0	0	6	-	-	-	-	-	-	6
46C	10	20	0	4	16	0	10	10	10	6	-	-	-	-	4
46F	10	20	0	2	18	0	2	18	6	2	4	-	-	-	8
53	6	11	1	6	4	1	6	4	4	2	2	-	-	3	-
54	9	20	0	0	20	0	0	20	7	7	3	3	-	-	-
55	6	18	0	3	15	0	3	15	-	-	-	3	-	3	12
56	4	11	0	3	8	0	3	8	2	6	-	-	-	3	-
63	5	10	0	4	6	0	4	6	-	6	-	4	-	-	-
64	3	9	0	3	6	0	3	6	-	3	-	-	-	-	6
65	9	17	0	0	17	0	0	17	3	4	-	1	-	-	9
67A	10	20	0	12	8	2	8	10	16	-	-	-	-	-	4
TOTAL	175	401	17	98	286	27	111	263	129	69	28	42	2	12	119
PERCENTAGE (%)	-	-	4.2	24.2	71.4	6.7	27.7	65.6	32.2	17.2	7.0	10.5	0.5	3.0	29.6

(1) Type cannot be determined due to excess water loss

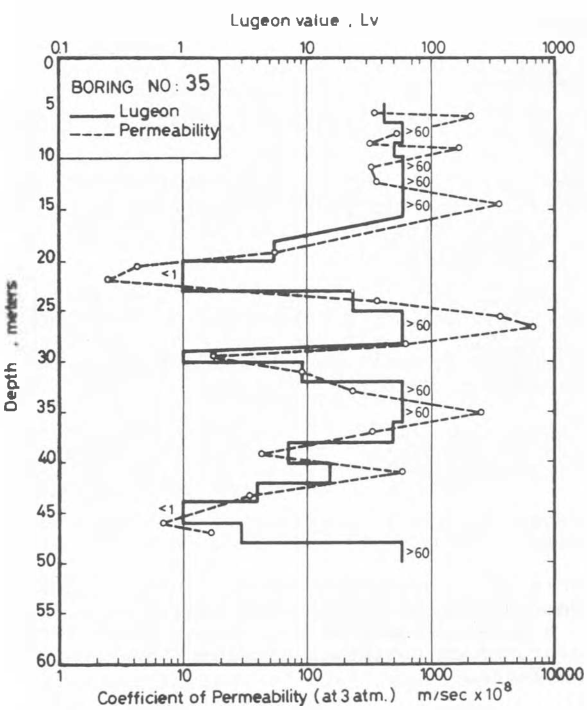

FIGURE 3 WATER PRESSURE TEST RESULTS, S35

CORRELATION OF PERMEABILITY WITH SUBSURFACE GEOLOGICAL FEATURES

It is important to determine an indepth correlation of the subsurface permeabilities and geological features. The degree of jointing and karstification observed by TV soundings is correlated with the results of the permeability testing, *Durgunoğlu, et. al. (1979)*. It is seen that, in zones of high degree of jointing and karstification encountered by the TV logging, especially between 10 to 20 meters, the Lugeon values are very high. Furthermore, the correlation between the coefficient of permeability, k_w and RQD is presented in Fig. 5. It is seen that there is a substantial decrease in k_w values for increase in RQD values. However range of values for a given RQD is guite large as expected depending upon the nature of discontinuities. High values of k_w reflect generally open discontinuities whereas, on the other hand low values indicate filled-in discontinuities. It is further stated that range of k_w decrease with increase in RQD.

CONCLUSIONS

The following conclusions were obtained when the insitu permeability tests were evaluated together with the subsurface geology of the site:

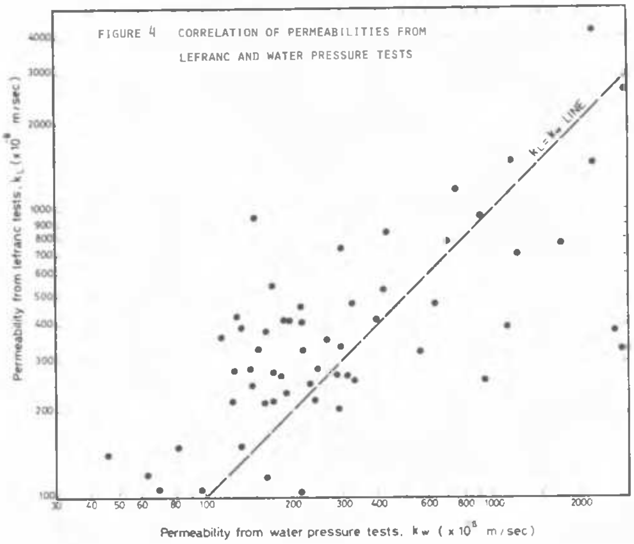

FIGURE 4 CORRELATION OF PERMEABILITIES FROM LEFRANC AND WATER PRESSURE TESTS

1. In relatively less fractured zones where Lugeon values were less than 10, the water losses were linearly varrying with the pressure applied, indicating an elastic type of response. Consequently, at such zones, the permeabilities achieved from WPT were dependable.

2. In highly fractured zones where Lugeon values were greater than 10, the water losses increased extensively over 300 kPa pressure which indicates the opening of discontinuities under high pressure. At such zones, it is determined that discontinuities behaved inelastically by the observation of relatively small decrease in water losses upon the release of pressure. Consequently, at such zones the permeabilities should not be estimated by the use of Lugeon values but rather the water losses below pressures of 300 kPa should be utilized.

3. Further, in highly fractured zones where $10<L_V<100$, a good correlation of permeabilities from WPT and Lefranc testing procedures is obtained. At such zones, slightly higher permeabilities achieved in Lefranc tests, further indicated the inelastic response of the discontinuities in WPT.

4. The use of Lefranc tests was inevitable at very permeable zones where WPT could not be performed.

5. Representative values of insitu permeability in fractured rock formation could only be determined by a careful evaluation of the test data considering the extent, nature and behavior of the discontinuities.

ACKNOWLEDGEMENTS

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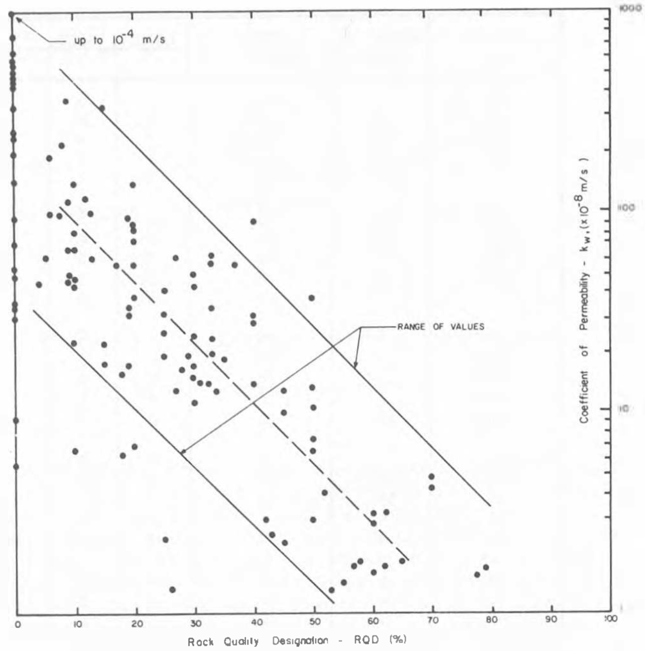

FIGURE 5 CORRELATION OF WPT PERMEABILITIES WITH RQD VALUE

Authorithy. Different insitu testings are conducted by various govermental organizations, as Institute for Electrical Survey(EIEI), State Hydraulic Works (DSI), and Mining Survey and Research Institute (MTA).

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