ROCK MASS PERMEABILITY AT RANTEMBE HYDRO POWER PROJECT SITE

by

A. U. Gunasekera

Synopsis

Assessment of Rock Mass Permeability is of utmost significance for dam projects, specially, if the dam is to be constructed on bedrock, so as to design the foundation treatment required, and to control the water seepage and uplift pressures.

This paper shows how the rock mass permeability was evaluated at Rantembe Hydro Power Project site. It gives an account of the geotechnical investigations done in stages. Briefly discusses the Engineering Geological conditions encountered at the said site and elaborates in detail on the methodology of water pressure testing in boreholes. Further, water pressure tests results are analysed in relation to the project in the light of the Engineering Geological conditions encountered at the dam site. Consequently, the Engineering Geological conditions which influence and / or determine the rock mass permeability of Rantembe site are established.

Also it is shown how Rock Quality Designation (R.Q.D.) can be misleading, if solely used to make judgement about water absorbtion of rock in similar geological conditions, as encountered at Rantembe. The causes for this are established and explained.

1.0 Introduction

Evaluation of rock mass permeability is a significant aspect of any geotechnical investigation programme of a hydropower project. Hence, insitu tests for determining rock permeability are always conducted as a part of the basic investigation programme in dam projects and Rantembe Hydropower project was no exception to this rule.

Rock mass permeability of such projects is significant because water seepage can cause:

- Loss of water through the dam foundation.
- Erosion which in the course of time endanger the stability of various parts of the project or the total project.
- Produce uplift pressures in the foundation of structures, negatively effecting their stability.

Consequently, the rock mass permeability of a hydro power project site can have a direct and a sizeable impact on the cost which would be incurred on sealing measures such as rock grouting to reduce the permeability to the point that its negative impact is tolerable.

Shown below is the method used to assess the permeability of bedrock at Rantembe Hydro Project site for foundation treatment purposes.

Rantembe project site is situated immediately downstream of the confluence of Uma Oya with river Mahaweli, about 35 km South East of Kandy. General Geomorphology of this area is shown in Figure No. 1.

It consists of 41.5 m high concrete gravity dam, a power house with a maximum installed capacity of 53 MW and an ogee type spill way with a capacity of 10235 m^3/sec. The construction cost of the project was about Rupees 3030 Million.

2.0 Geotechnical Investigations

Geotechnical investigations of Rantambe hydropower project were carried out in two stages, namely for the feasibility study and for final designs.

These comprised the following:

i) Detail Engineering Geological mapping of the reservoir area (Scale : 1:10,000) and dam foundation area (scale 1 :10,000)

ii) Exploratory drilling with core recovery.

iii) Exploratory test pits at the dam site.

Eng. (Dr.) A.U. Gunasekera, PhD, MSc (Hon), .FIMM (UK) MIE (Aust.) Ceng,FIE(SL) Presently working as a Senior Lecture (Geotechnical Engineering) at the Open University and a Visiting Lecture at University of Moratuwa

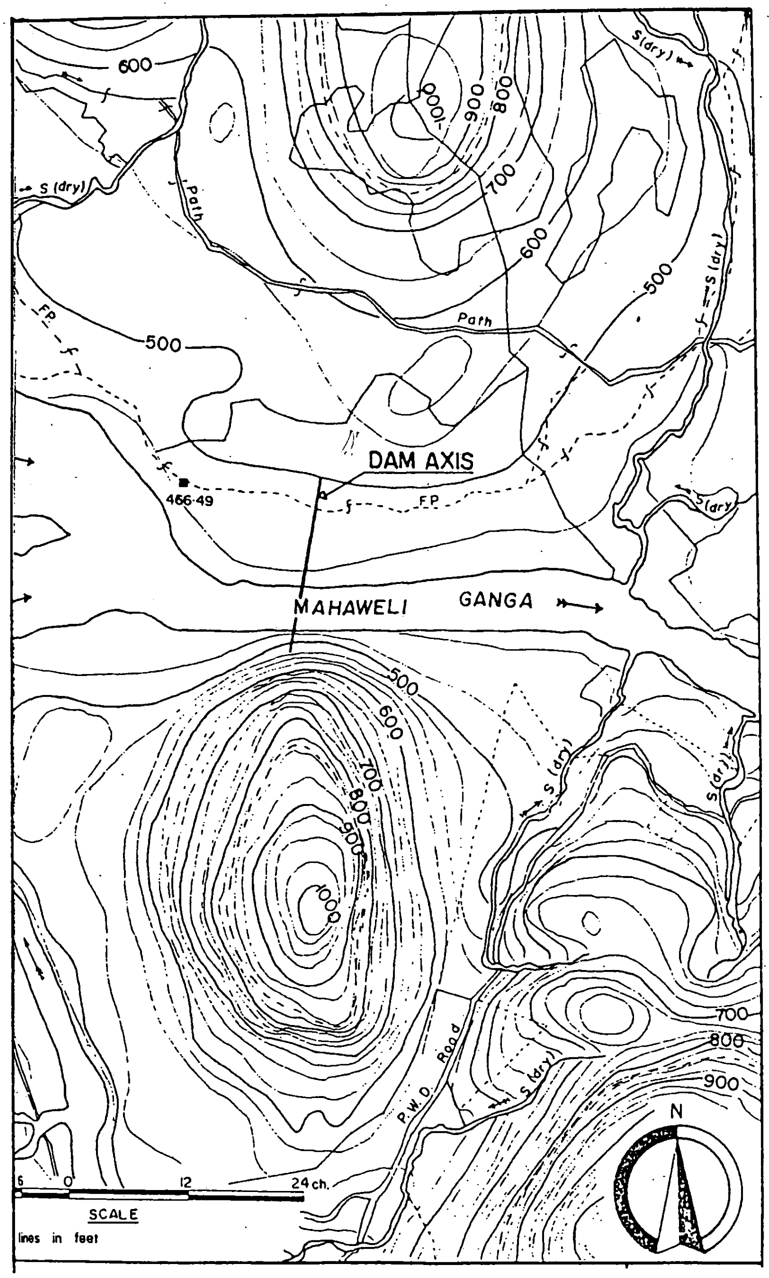


Figure No. 01. Location of Rantembe Dam

iv) Investigations for construction material (quarry sites and borrow areas).

Engineering Geological mapping of the dam site was carried out to a scale 1: 1000 during which, special measurements were made on "joint characteristics", which could be observed on all rock out crops within the site and riverbed. Exploratory drilling at Rantambe project site was carried out during the period from June 1979 to February 1980. It comprised thirteen numbers of boreholes of depths varying from 60m to 80 m, totalling up to a metreage of 886 m. The general layout of the boreholes is shown on Figure No. 2. The diameter of the drill holes was NX. For recovering the core generally a double tube core barrel was used, whereas a triple tube core barrel was utilised for the overburden and the decomposed rock / highly weathered rock.

The following field tests were done in the boreholes and on the recovered core to investigate the quality of the bed rock, specially with respect to the permeability and the bearing capacity of the rock mass within foundations of the proposed structures:

- Record of degree of weathering and rock type
- Record of core recovery
- Calculation of rock quality designation (R.Q.D.)
- Water pressure tests in drill holes.

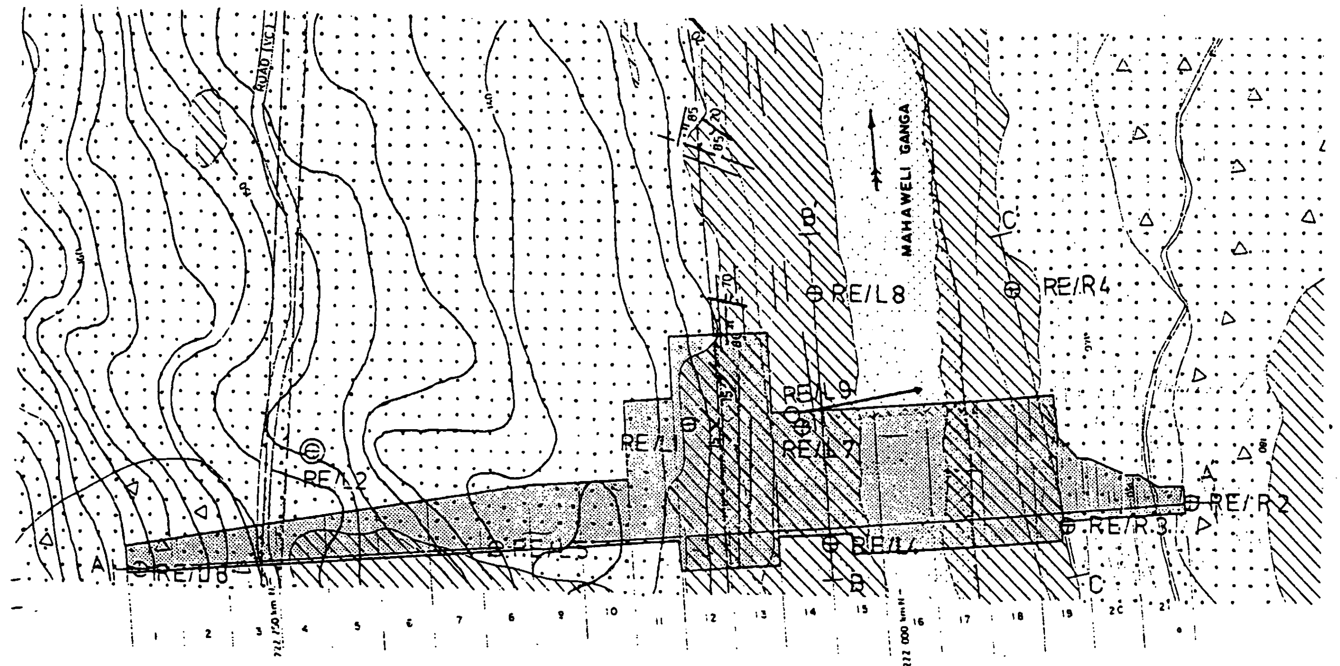


Figure No. 02. Rantembe Dam-General Layout with Bore Hole Locations

Rock type and the degree of weathering were recorded according to the legend and the weathering classification (Bulletin of the International Association of Engineering Geology 1981) given in Figure No. 3A. Core recovery which was determined is a measure of weakness, disintegration, and dissection of the rock mass by joints and fractures etc.

The rock quality designation (R.Q.D.) is a criterion of the quality and soundness of the rock mass. For the determination of R.Q.D. the core recovery percentage of pieces of sound core, over 10 cm long was calculated.

The permeability of the bedrock mass was determined by water pressure tests according to the Lugeon method.

3. Engineering Geological conditions of the dam site

3.1 Geomorphology of the dam site

As shown in Figure No. 1 the right abutment rises steeply up to an isolated hill which summits at an elevation of about 300 m MSL. This hill is East-South Eastwards, separated from the mountain range by a deeply located saddle zone which shows an elevation of about 175 MSL. The left abutment is characterised by a flatly rising flank showing an inclination of about 10^0 up to an elevation of about 175 m from where a steeper slope continues Northward.

3.2 Bed Rock :

Within the limits of the structural foundations (Dam, Spillway and Power House) rock types predominantly encountered are dark coloured (granulitic gneiss with biotite) and light coloured (Quartzo - feldzpathic gneiss and granulites), fine to medium grained gneiss and granulites with scattered garnets, in varying quantities. The gneissic texture is well pronounced in rock occuring in the riverbed area and left bank, but is less developed in the rock on the right bank which is predominantly granulitic. (see Figures No. 3A and 3B).

3.3 Structural Geologic Features :

3.3.1 Foliation

The foliation planes, being the planes of separation between one layer of minerals and the next, reflect the former bedding planes (i.e. the situation prior to the process of metamorphism), where the gneissic texture is well developed. The spacing of foliation planes ranges from a few centimeters in gnessic metasediments to some tens of centimeters and even meters in massive granulitic gneiss.

The development of foliation planes is prominent on the left bank of the river, whereas on the right bank, it is not well pronounced.

The foliation plane dips at an angle from 10^0 to 30^0 and the dip direction is towards North-West (290^0-350^0).

3.3.2 Faults and Joint Patterns

In the structural foundation area, four well-developed joint patterns are observed which are in conformity with the regional tectonism.

According to the observations and measurements made during mapping of dam foundation and foundations of other structures the following joint patterns were distinguished:

Pattern I :	Dip Direction :	North West (290° - 350°)
	Dip Angle :	10° - 30°
Pattern II:	Dip Direction :	South East (125° - 145°)
	Dip Angle :	70° - 85°
Pattern III :	Dip Direction :	South or North (180°-205°)
	Dip Angle 75°-85°	
Pattern IV:	Dip Direction :	North East (50°-75°)
	Dip Angle:	60°-75°

Please see Figure No. 3A and No. 3B. for Engineering Geologic map of foundations, which was prepared after excavation was done.

Joint pattern III is the most developed in the power house and irrigation outlet area, where it is represented by fracture zones of about 15-25 cm wide. Other two patterns are represented mostly by individual joints, as well as occasionally developed fracture zones. Their intensity of fracturing is comparatively lower, compared to joint pattern III.

A few minor faults with minor displacements were observed, on the left bank. A fault zone also was found striking parallel to the joint pattern II, intersecting the foundations of block No. 7 and No. 8. (See Figure No. 3A).

Another fault zone developed through the entire area from power intake to tail water channel was observed parallel to joint pattern III, with minor displacement, which strikes South West. This indicates that it has a link with Mahaweli lineament, the main tectonic feature of the region.

Secondary formations such as chlorite (mostly found in gneiss or granulites, rich with dark minerals), kaolin (encountered in quartzo-feldzpathic gneiss on the left bank) and iron pyrite were observed in fresh rock along the above referred to fracture zones and joints.

In moderately weathered rock weathering has penetrated along the joint planes in locations where the rock is affected by extensive fracturing.

In highly weathered rock, secondary formations referred to above have been transformed to clay.

4.0 Methodology of Testing Permeability In Bed Rock Mass

The permeability of the bedrock was determined by performing water pressure tests in the boreholes and the tests were conducted according to the Lugeon method. Lugeon test was performed with a single air packer or mechanical packer in the descending order along with the drilling process. A test length of the bore hole was strictly 3 m and a complete test comprised 5 pressure steps in ascending and descending succession i.e. 2-5-10-5-2 bars. Each pressure step was maintained for 6 minutes and the obtained water loss was converted to "Lugeons".

The Lugeon value is the water loss of 1 Ltr. per meter length of the borehole (Nx diameter) at a pressure of 10 bars, per minute.

Equipment arrangement for the water pressure test is shown in Figure No. 4

Method of calculation of Lugeon value is given in annex I.

5.0 Water Pressure Tests results and their analysis

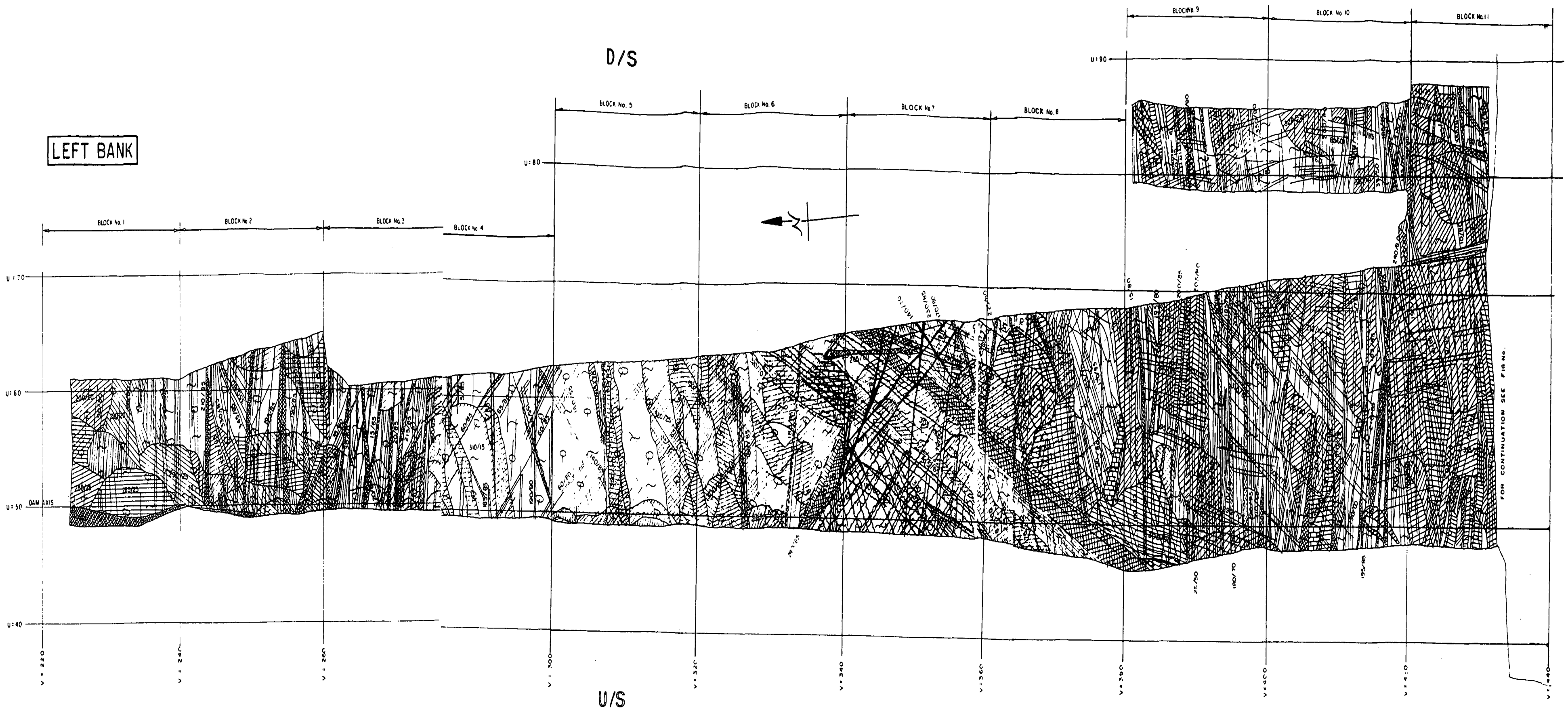
Lugeon type water pressure tests were performed in twelve bore holes (RE/L1, RE/L2, RE/L3, RE/L4, RE/L5, RE/L6, RE/L7, RE/L8, RE/L9, RE/R2, RE/R3 & RE/R4) located on the left bank, river section and right bank. (Shown in Figure No. 2).

The results of these tests, referred to above are plotted with the RQD values on the geotechnical sections AA', BB' and CC' as shown in figures No.5 & 6.

Diagrams showing water absorbtion with depth have been compiled, separately for the left bank, river bed and right bank as shown in Figures No.7,8 and 9.

In near surface zones (in boreholes) performance of pressure tests was impossible due to occurrence of soil (over burden) or due to leakage around the packer.

ENGINEERING GEOLOGIC MAP OF DAM FOUNDATION
(FROM BLOCK NO.1 TO BLOCK NO. 11)



LEGEND

- MODERATELY WEATHERED ROCK.
- FRESH ROCK. AND SLIGHTLY WEATHERED ROCK
- MARBLES: LIGHT COLOURED, MEDIUM TO FINE GRAINED, GRANULITIC IMPURE CALCAREOUS ROCK. GENERALLY CONTAINS A VARIETY OF SILICATE MINERALS IN VARING AMOUNTS SUCH AS OLIVINE, DIOPSIDE AND MICA
- QUARTZ, FELDSPAR GNEISS AND GRANULITE: WHITE OR LIGHT COLOURED, MEDIUM TO FINE GRAINED GNEISSOSE OR SUGAR TEXTURED ROCK WITH SCATTERED GARNETS. MAIN COMPONENTS ARE QUARTZ, FELDSPAR AND BIOTITE.
- GRANULITIC GNEISS: BLACK TO GREENISH OR DARK COLOURED, BASIC INTERMEDIATE OR ACIDIC TYPES ARE INTERBANDED WITH EACH OTHER WITH OR WITHOUT SCATTERED GARNETS. MAIN COMPONENTS ARE PYROXENE, AMPHIBOLE FELDSPAR AND QUARTZ.
- PEGMATITE: MEDIUM TO COARSE GRAINED, MAIN COMPONENTS ARE QUARTZ AND FELDSPAR.
- QUARTZ, FELDSPAR GNEISS WITH GARNETS: WHITE COLOURED, PREDOMINENTLY MEDIUM TO FINE GRAINED, OCCATIONALLY COARSE GRAINED SUGAR TEXTURED ROCK WITH A HIGH CONCENTRATION OF GARNETS.
- BIOTITE SCHIST: DARK COLOURED, FINE GRAINED, PREDOMINENTLY WITH BIOTITE AND SCATTERED GARNETS.
- JOINT WEATHERED AND FILLED WITH CLAY.
- JOINT WEATHERED.
- AOLINITICIZED
- AOLINITICIZED AND SLICKENSIDED
- ED
- IZED KAOLINITICIZED.
- IDED AND CHLORITICIZED
- FRACTURED ZONE
  - a. WITHOUT CLAY FILL
  - b. WITH CLAY FILL
- FRACTURED ZONE - WEATHERED.
- FRACTURED ZONE - MYLONITE - CHLORITICIZED.
- GEOLOGICAL BOUNDARY
  - a. ASSUMED
  - b. OBSERVED
- DIP DIRECTION AND DIP ANGLE.

NOTES

1. KAOLINITE IS MAINLY FOUND IN JOINT FILLING OF QUARTZ – FELDSPAR GNEISS & GRANULITES. CHLORITE IS FOUND IN JOINT FILLING OF GRANULITIC GNEISS.
2. IN ALL FRACTURE ZONES WHERE CLAY FILLINGS WERE ENCOUNTERED THE CLAY MATERIAL WAS REMOVED FROM THE FOUNDATION AND CLEANED UP TO HIGHLY WEATHERED ROCK PRIOR TO THE PLACEMENT OF FILL CONCRETE.
3. DEGREE OF WEATHERING

DECOMPOSED ROCK: ROCK IS DECOMPOSED AND STRENGTH COMPLETELY LOST WHEN CHANGED TO SOIL ORIGINAL FABRIC IS PRESERVED. CORE STONES SCARCE

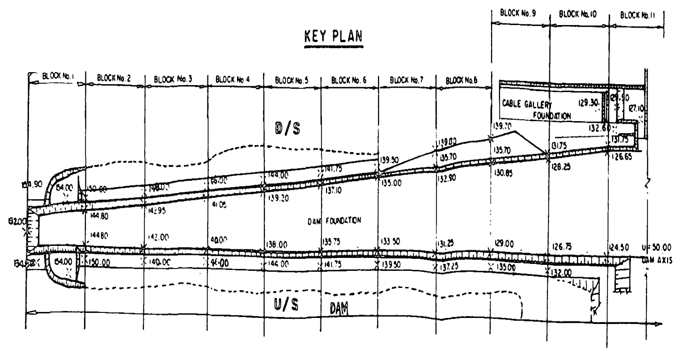
HIGHLY WEATHERED: ROCK IS DISCOLOURED. DISCONTINUTIES MAY BE OPEN AND HAVE DISCOLOURED SURFACES AND THE ORIGINAL FABRIC NEAR DISCONTINUTIES MAY BE ALTERED. ALTERATION STARTS DEVELOPING ALONG THE JOINTS.

MODERATELY WEATHERED: ROCK IS PARTLY DISCOLOURED. DISCONTINUTIES MAY BE OPEN AND SURFACES DISCOLURED WITH ALTERATION DEVELOPED ALONG THE JOINTS.

SLIGHTLY WEATHERED: ROCK MAY BE DISCOLOURED, PARTICULARLY ADJACENT TO DISCONTINUTIES WHICH MAY BE OPEN AND WILL HAVE SLIGHTLY DISCOLOURED SURFACES. ROCK IS NOTICEABLY NOT WEAKER THAN FRESH ROCK.

FRESH ROCK: ROCK IS UNEFFECTED BY ANY WEATHERING.

KEY PLAN



NOTE: THE LEVELS SHOWN IN THE KEY PLAN ARE DESIGNED LEVELS.

FIGURE NO - 3A

ENGINEERING GEOLOGIC MAP OF POWER HOUSE, BOTTOM AND IRRIGATION OUTLET, SPILLWAY AND DAM FOUNDATIONS

(FROM BLOCK No.11 TO BLOCK No.21)

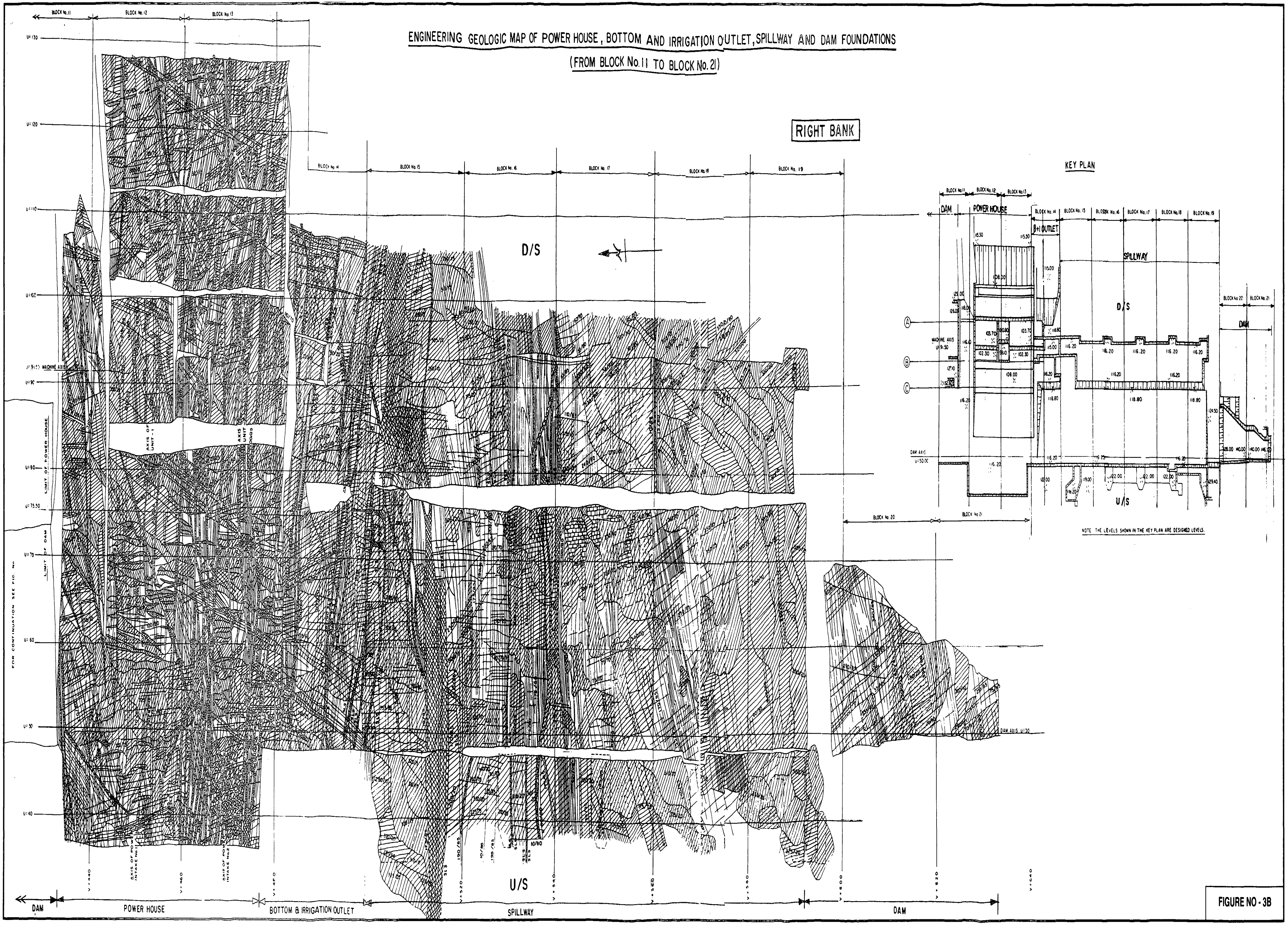
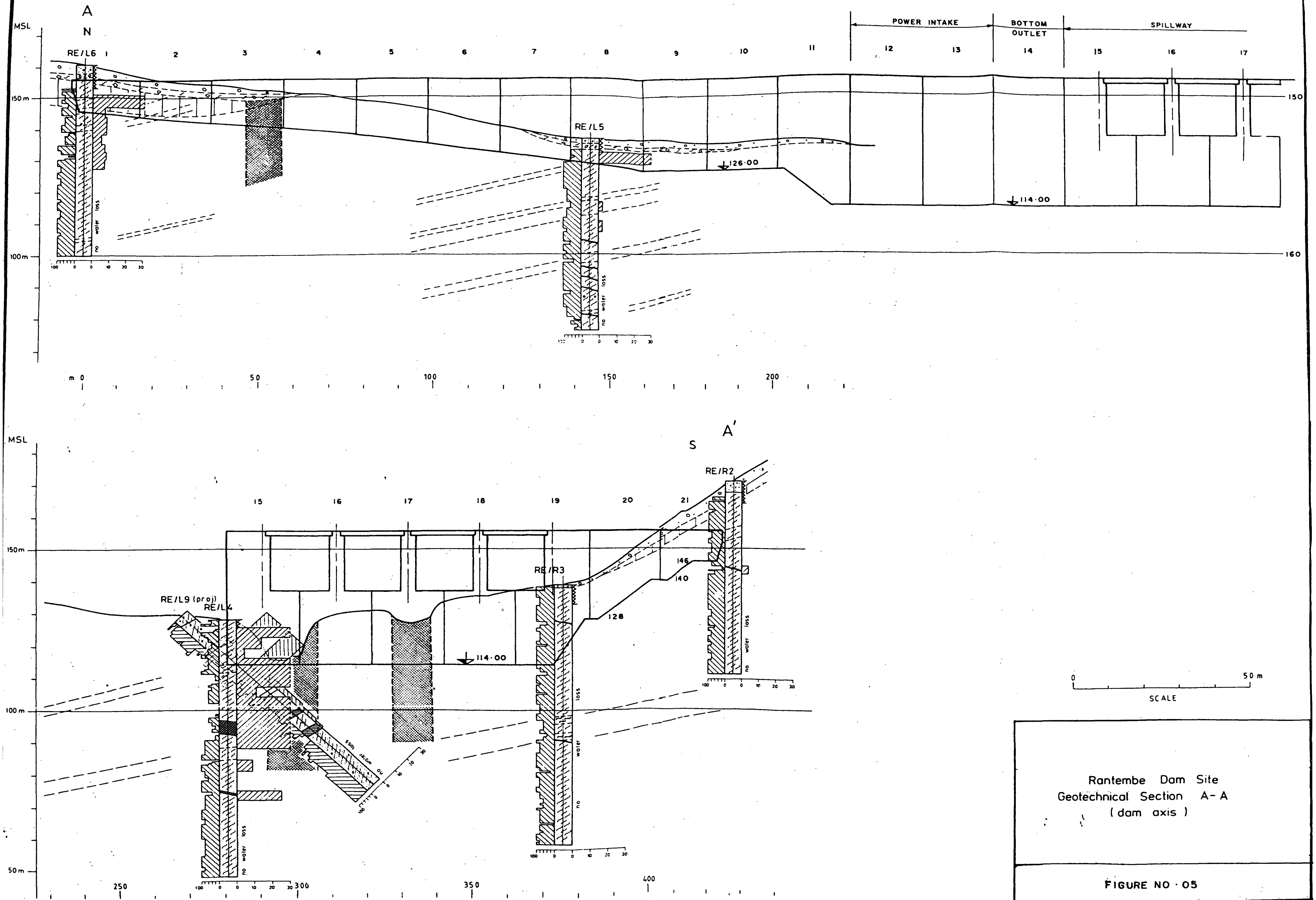


FIGURE NO - 3B



Rantembe Dam Site
Geotechnical Section A-A
(dam axis)

FIGURE NO · 05

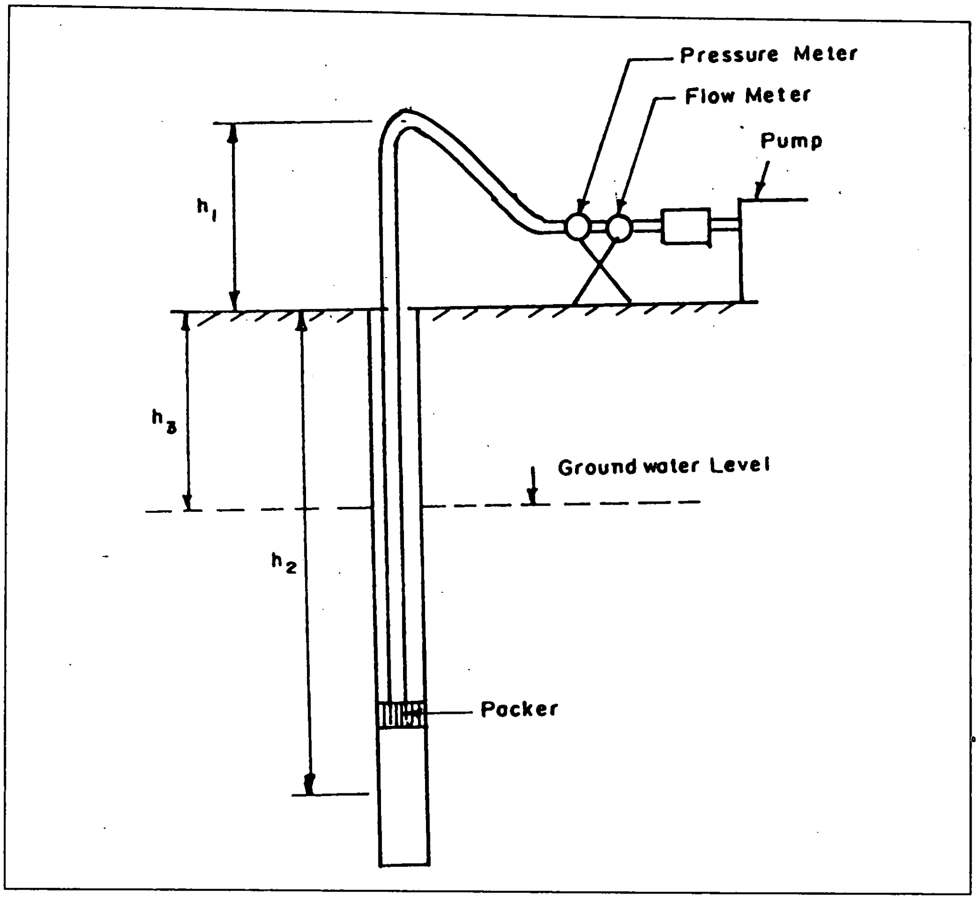


Figure N0. 04. Equipment Set Up for the Permeablity Test

Bore hole No.	Depth Intervals where no pressure tests could be performed
RE/L1	0.00-1.76 M
RE/L2	0.00-4.94 M
RE/L3	0.00-8.76 M
RE/L4	0.00-2.38 M
RE/L5	0.00-4.43 M
RE/L6	0.00-7.74 M
RE/L7	0.00-0.80 M
RE/L8	0.00-1.63 M
RE/L9	0.00-4.63 M

As indicated by the drill logs the above are the zones of either overburden or highly weathered rock and these were found to be very highly permeable.

For classification of rock according to permeability the criteria given below have been used, which are in conformity with the normal engineering practice. (Karl Evert Friedrich 1985)

0.0 to 4.9 Lugeon - technically impermeable

5.0 to 9.9 Lugeon - permeable

10.0 to 19.9 Lugeon - highly permeable

20.0 to 49.9 Lugeon - very highly permeable

over 50.0 Lugeon - extremely permeable.

a) Permeability of the rock mass on left bank.

Figure No. 7. (diagram which shows the water absorption of the rock on left bank) based on results of ninety nine water pressure tests, indicate the variation of water absorption with depth of the rock mass. It indicates that for depths of sixty to sixty eight metres more than 95% of test results have Lugeon values of < 5 reaching.

Beyond that depth up to 80 M the test results indicate no water absorption.

At 25 m, one test gives a Lugeon value of 15 (highly permeable rock) and three others (at depths around 6m, 15m and 37 m) indicate water absorptions over 50 Lugeons (extremely permeable rock).

The above permeability test results (Figure No. 7) give grounds to conclude that generally the rock mass on left bank is technically impervious with Lugeon values less than 5.

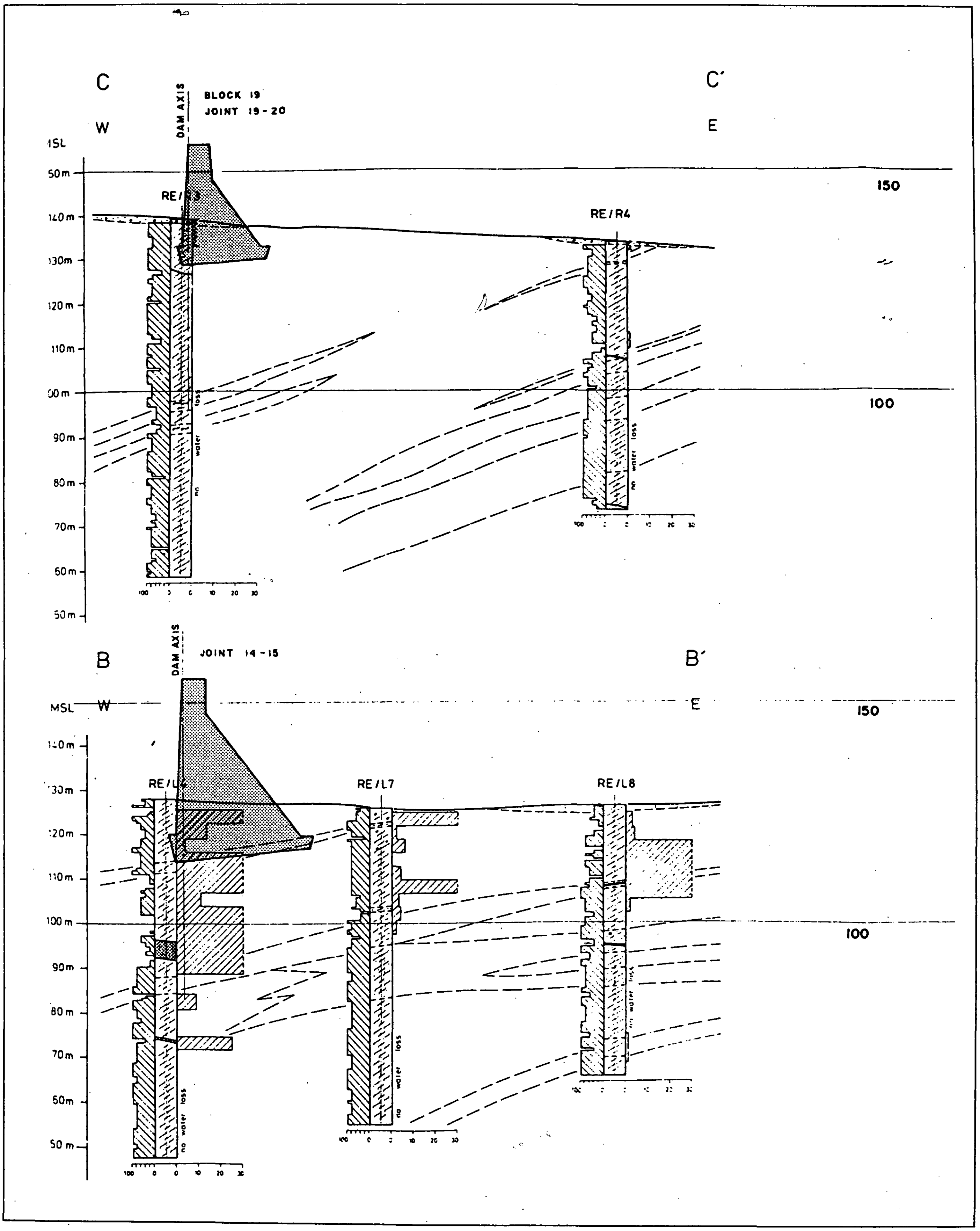


Figure No. 6. Rantembe Dam Site- Geotechnical Sections BB'and CC'

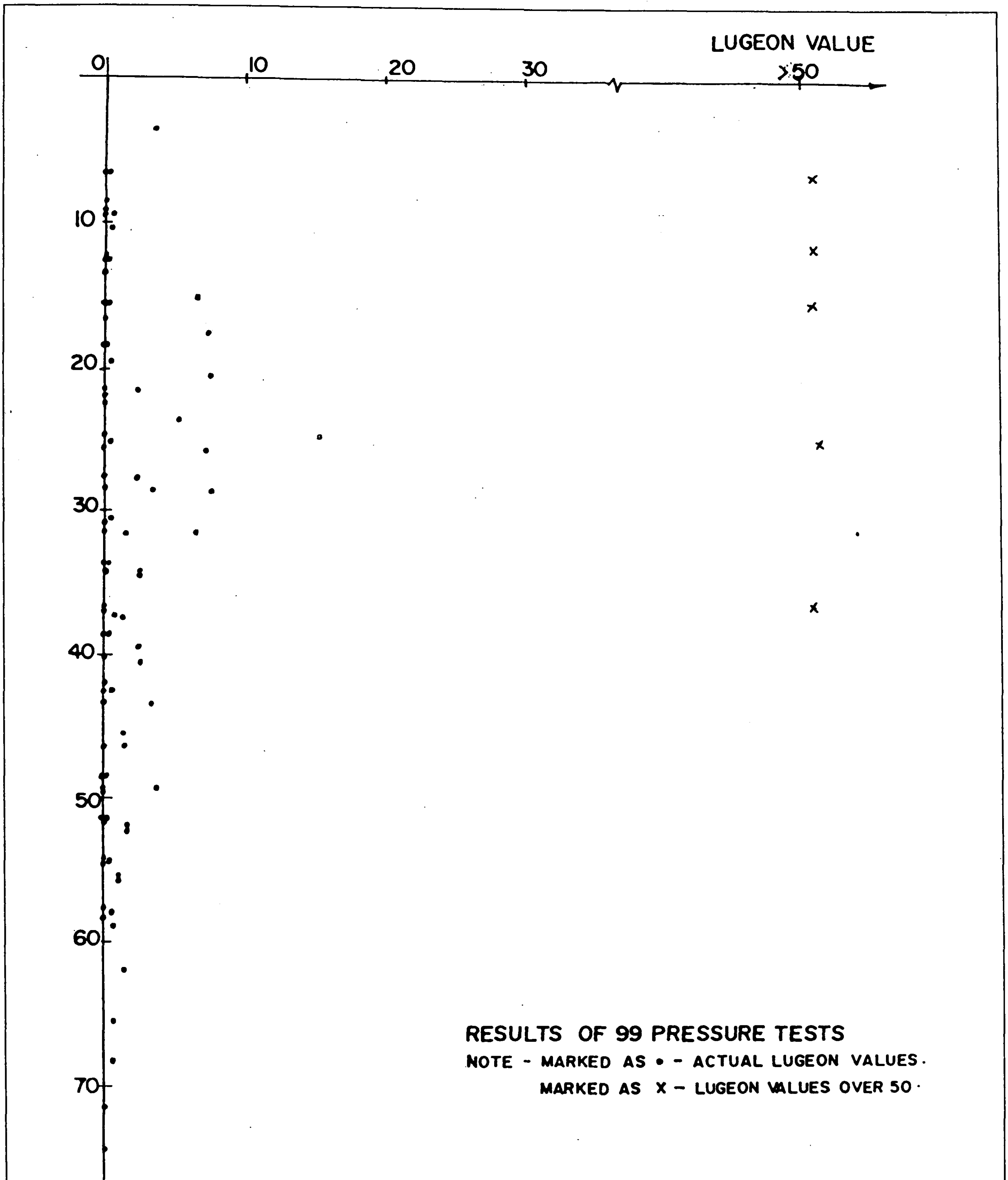


Figure No. 7. Results of 99 Pressure test

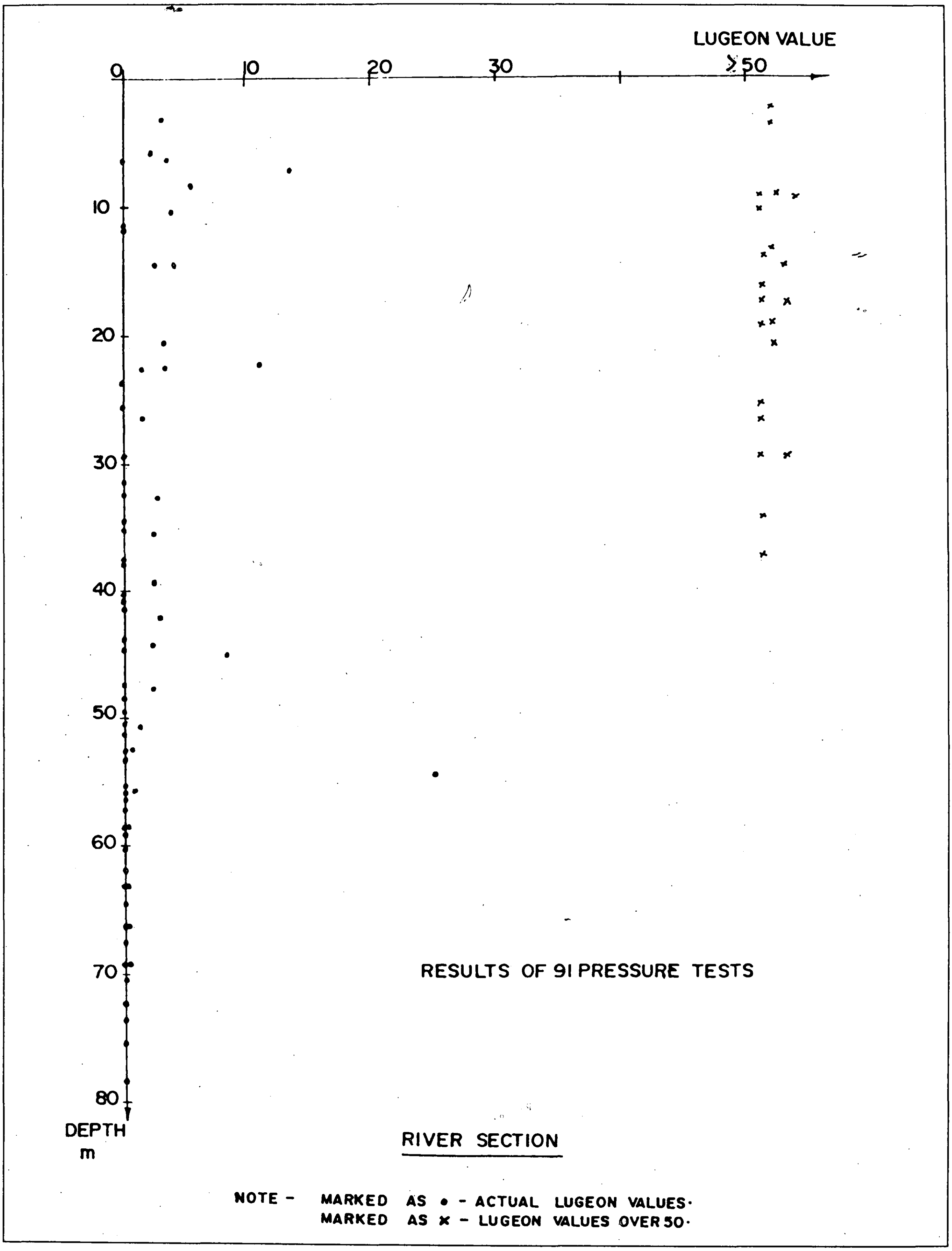


Figure No. 8. Results of 91 Pressure Tests

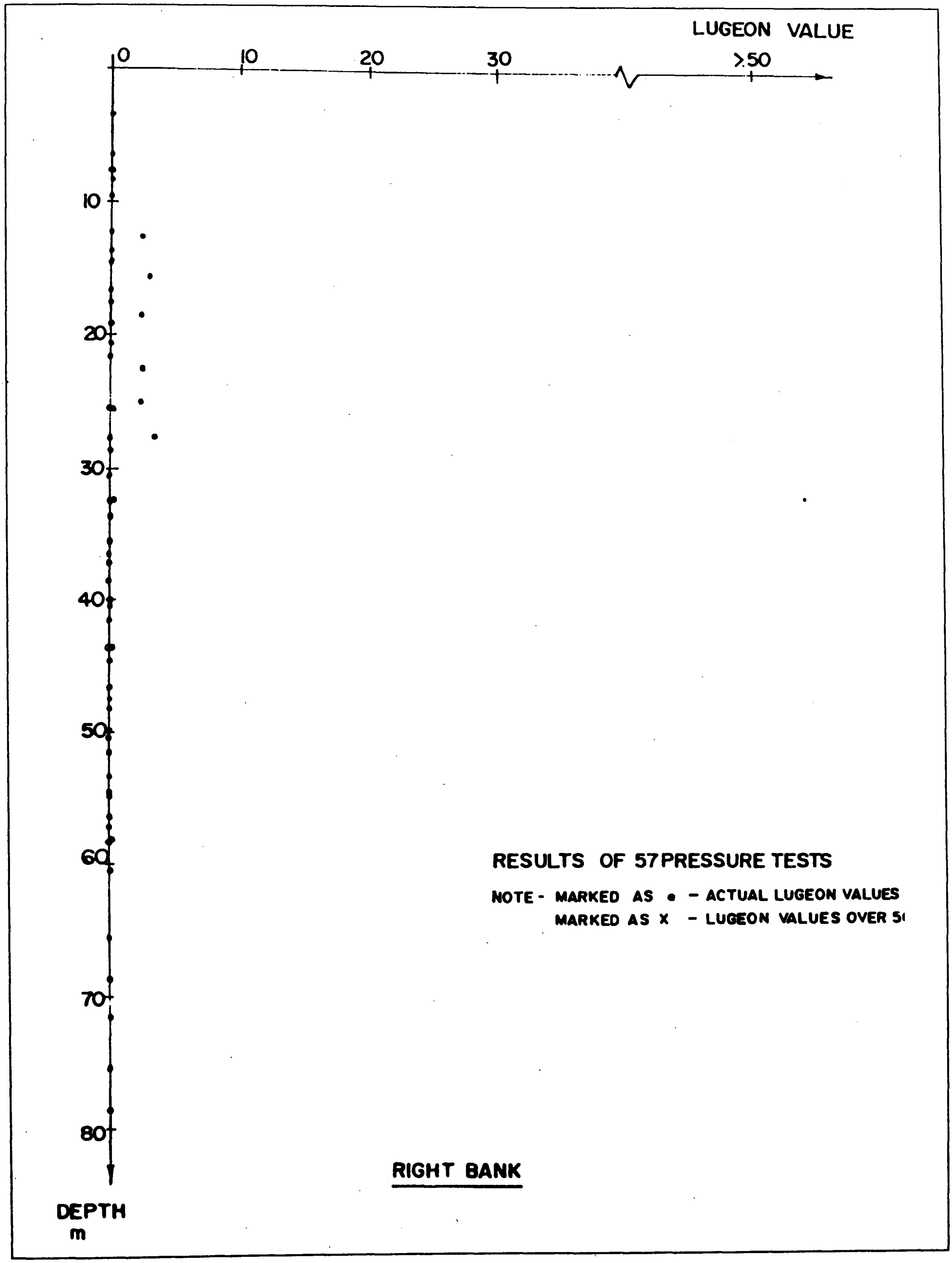


Figure No. 9. Results of 57 Pressure tests

However, few test results, of Lugeon values of 15 and even over 50 indicate that individual narrow zones with open fractures or joints occur separately above depth of 37 m.

b) Permeability of rock mass at the river section.

As shown in Figure No. 8, diagram of water absorption of the rock mass in the river section based on the results of ninety one tests clearly indicate an extremely permeable rock with Lugeon values over 50 to a depth about 35 m.

The rock mass between the depths 35 m and 55 m has a permeability less than 5 Lugeons except for two narrow fracture zones at depths around 45m and 53 m with high permeability (10 L and 25 L) indicate that the rock within mentioned depths can be considered as technically impervious, except in the said fracture zones.

All the test results below the depth of about 53 m indicate no absorption.

c) Permeability of rock mass on the right bank.

As shown in Figure No. 9 the water pressure tests conducted on the right bank indicate that the water absorption up to a depth of 80 M of the rock mass is predominantly near zero or less than 3 Lugeons, indicating that the rock is impervious.

6.0 Geological factors determining and influencing the rock mass permeabil ity within the Rantambe project site.

The main geological factors determing and influencing the rock mass permeability within Rantambe project site are the fractures / joints, weathering, erosion and the process of chloritisation (formation of the secondary mineral chlorite, during tectonic processes, in the joints sealing them) of joints which have taken place during tectonic processes, causing the formation of dominant joint patterns.

The joint patterns II, III and IV which are of tectonic origin and associated with the Mahaweli Lineament (main tectonic feature of this region) are the main facilitators of water seepage through the rock mass.

These joint patterns are represented by closely spaced fracture zones and fault zones as seen in Figure No. 3A and 3B. All such joints are developed to depths well over 80 M as established during investigations, and have steep dip angles varying from 60° to 90°.

Joint pattern I represent the foliation joints being planes of separation between rock strata of varying mineralogical compositions. These have low dip angles varying from 10^0 to 30^0 and are affected by the weathering process. They are open in near surface zones, and mainly confined to weathered rock.

Another set of very widely spaced joints is observed in near surface zones occuring parallel to the ground surface or valley slopes, formed as a result of rock mass relaxation in the process of stress release. The latter takes place due to erosion of the weathered product from the bed rock surface. They are open and mainly confined to the near surface zones, not more than a few tens of metres deep.

Out of all types of joints mentioned above the joint patterns of tectonic origin basically determines the permeability conditions of the rock mass. Areas where tectonic disturbance has been maximum i.e. the river section, show the highest intensity of fracturing with deeper weathering and therefore zones of high permeability reaching depths of about 55 m. Though the R.Q.D. values relevant to this area have been very low.

Left bank area of Rantembe site has been very much less influenced by tectonic activities compared with the river bed and therefore have caused only a few individual zones with high permeability above the depth of 35m.

The tectonic activity has had no influence on the right bank area and therefore the rock mass there was found to be practically watertight.

In all locations where high permeability was observed, the R.Q.D. values determined on the rock cores indicated extremely low values. But even in tectonically disturbed areas below the zones of high permeability, very low R.Q.D. values have been observed but without any water absorbtion of the rock mass. This remains true at many other locations as shown on the geotechnical sections in Figures No. 5 and No. 6.

This phenomenon was observed only below the weathering depth where fresh rock occurs.

On the drill cores also it has been observed that all such joints / planes are completely chloriticised. Chlorite is a secondary material i.e. a mineral formed during tectonic activity in fault zones or joint planes etc., towards the end of the process of tectonism with low temperatures and pressures. At great depths (where weathering has not reached) all rock joints of tectonic origin (at these depths no other joints occur) are filled with chlorite i.e. healed due to chloritisation rendering the rock in situ impermeable.

However during the drilling investigations, the extracted core samples were found to be in pieces, separated along joints, due to the impact of the drilling machine on one hand and on the other hand chlorite as a fill material is extremely weak or with extremely low bonding strength (tensile strength or shear strength).

In the weathered rock zones chlorite being a mineral with very low resistance to weathering has completely weathered and the joints were open making the rock permeable.

In such areas the rate of permeability is determined by joint spacing and joint opening.

7.Conclusions

- On the left bank of the river Mahaweli at Rantambe project site the rock mass was found to be technically impervious, having a Lugeon value below 5, up to depths of 60 to 68 meters. However in four locations at depths 6 m, 15 m, 25 m, and 37 m narrow individual zones were found with high and extremely permeable rock. (see Figure No. 7) from 68 metre depth to the final investigated depth of 80 m, the rock mass indicated no water absorbtion.
- In the river section the rock to a depth of 35 m was found to be extremely permeable with Lugeon values over 50. From 35 m depth to 55 m the rock mass has a permeability less than 5 Lugeons. Below the depth of 55 m the rock mass was watertight. (see Figure No. 8).
- On the right bank as shown in Figure No. 9 the rock mass was found to be impermeable.
- The main geological factors which determined the permeability are jointing (joints of tectonic origin), weathering, stress release or relaxation of the rock mass and chloriticization of joints.
- All tectonic joints in fresh rock were found chloriticized and watertight even in tectonically disturbed zones associated with Mahaweli Lineament beyond depths of weathering.
- In the tectonically disturbed areas where weathering has penetrated along the joints, chlorite was weathered, joints were open and the rock mass was permeable.
- Intensity of jointing clearly determined the degree of permeability, area-wise at this site, whereas the degree of weathering with depth, determined the degree of permeability with depth.
- As a rule where high permeability was observed, very low R.Q.D. values and weathering were always recorded on drill cores. But where low R.Q.D values were recorded below the weathering depth, no water absorbtion was recorded as a rule due to the fact that the joints were chloriticized and tight, in situ.
- Therefore in geological conditions similar to Rantembe project site to make judgements regarding water permeability of rock masses, R.Q.D. criterion, can not be used in isolation of the other geological conditions.

8. Acknowledgement

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Also the author is very grateful for permission granted by the CECB to publish this paper.

9. References

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Annex I

Method of calculation of the Lugeon value is given below.

P - effective pressure of the investigated section in bars.

P_1 - pressure indicated by the manometer.

P_2 - Hydrostatic pressure of the water column.

P_3 - Pressure loss due to friction of the tubes. With increasing water flow (Q), the pressure loss due to friction in the tubes between the pump and the investigated section rises. The standard size of tubes used for the Lugeon test is of 1 inch, internal diameter and the pressure loss due to friction is determined by using a standard Nomogram.

$$P = P_1 + (P_2 - P_3)$$

Case I : without groundwater.

$$P_2 = \frac{h_1 + h_2}{10} \text{ bars}$$

Case II : With ground water $P_2 = \dfrac{h_1 + h_3}{10}$

Where h_1 - water column above the ground surface

h_2 - water column between the ground surface and the centre of test section.

h_3 - distance between the ground water level and the ground surface.

All measurements of the water columns are in meters and have to be divided by 10, to get the pressure in bars.

Calculation of the Lugeon value was done as follows :

$$\text{Lugeon} = \quad = \frac{q.10}{P} \text{ bars}$$

Where p - effective pressure of the test section

q - Water consumption in the test section per meter length, per minute.