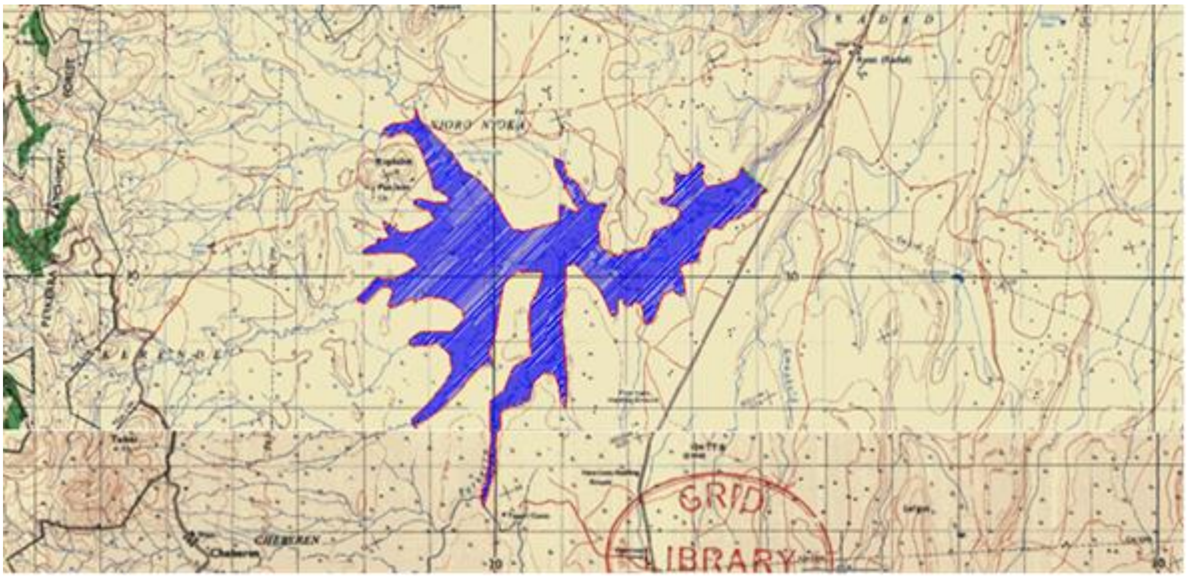
FEASIBILITY STUDY, DETAILED DESIGN AND PREPARATION OF TENDER DOCUMENTS FOR RADAT DAM, BARINGO COUNTY

Contract No. NIB/T/016/2013-14



Feasibility Study Report
Annex III
Geological and Geophysical Investigation Report

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EXECUTIVE SUMMARY

The 'Perkerra Irrigation Scheme Expansion Project Study' proposed to expand the scheme irrigation area to 2020 hectares, which will be eight times its present area. Three sites were studied to establish the geological conditions of the foundation rocks in order to select the most suitable site for detailed geological investigations.

The general objective of the reconnaissance geological survey and preliminary geophysical investigations was to study the geological aspects of the general project area and evaluate the foundation conditions at the proposed dam site. The scope of work entailed desk study of available geological, hydrogeological and soil survey reports of the general project area.

The proposed Radat dam project area is 30km south-west of Marigat Township, in Koibatek District of Baringo County. The project area is in Radat-Marigat plains with low lying volcanic hills

The most comprehensive study of the geology of the general project area is covered by Report No. 83 of the Mines and Geological Department, "Geology of the Eldama Ravine-Kabarnet Area" by J. Walsh (1969).

The geology of the general project area is composed of volcanic rocks of Miocene to Recent age. The geology of project area is composed of volcanic rocks of Miocene to Recent period. The volcanic rocks exposed in the proposed Radat project area have been variously weathered and only slightly fractured.

The structural geology Radat dam project is characterized by intense faulting that especially affected the young volcanic rocks during the formation of the Great Rift Valley during Quaternay times.

The seismicity of the project area can be assessed from existing reports. Due to the highly faulted nature Radat project area it is deemed prudent for seismic survey to be carried out in this area.

In the effort to study the subsurface geological conditions of the dam site, geo-electrical resistivity methods were employed by use of ABEM SAS 300B Terrameter and GEOTRON at Radat dam site. Preliminary field geophysical investigations were carried out from 25th to 30th April 2014 in three proposed dam sites.

The river valley at this is very rocky and with steep cliffs so that only two horizontal electrical resistivity profiles (HERP) were carried out. Six vertical electrical soundings (VES) were selected on the profiles and done.

Geological correlation cross section (Figure 3.3) shows that the foundation rocks at Radat Proposed Dam Site 1 are highly weathered and slightly fractured.

Both field geological reconnaissance survey and preliminary geophysical investigations have indicated that the foundation rocks at the three proposed Radat dam sites are highly weathered and slightly fractured.

During reconnaissance visits it was observed that soils suitable for in an earth fill dam were apparently absent. It was therefore proposed that since the project area is replete with rocks can be used for a rock fill dam, preliminary survey to identify areas with potential rock fill construction materials.

1 GEOLOGICAL STUDIES

1.1 Background Information

The Perkerra Irrigation Scheme Expansion Project Study' proposed to expand the scheme irrigation area to 2020 hectares, which will be eight times its present area. Such expansion will require 25Mm^3 90 day storage dam project. The Terms of Reference require the Consultant to review a pre-feasibility report on the proposed dam project. The Consultant has carried out reconnaissance surveys in the project area to gather relevant information in order to produce a feasibility study report for the proposed dam project.

The proposed Radat Dam project is on Perkerra River. Four (4) dam sites (Radat, Kaplelwo, Koipokaplelach and Kapng'etuny) were initially proposed. However, Radat Dam site at a proposed dam height of 80m has been identified as the best option to meet the potential of the proposed dam project.

The current feasibility study carried out reconnaissance geology and preliminary geophysical investigations on Radat Dam site. Initial soil investigations by trial pits were also done at this site. The proposed Radat Dam project has three sites which have potential to meet the estimated storage of up to 260Mm^3. The three sites were studied to establish the geological conditions of the foundation rocks in order to select the most suitable site for detailed geological investigations.

1.2 Objective of Investigations

The general objective of the reconnaissance geological survey and preliminary geophysical investigations was to study the geological aspects of the general project area and evaluate the foundation conditions at the proposed dam site. The specific objectives were to:

1. Study of the geological conditions of the general project area.
2. Evaluate the structural geological conditions in relation to foundation stability.
3. Evaluate foundation conditions and the nature of overburden at the dam site.
4. Evaluate geological lateral variations within the dam site area.
5. Select possible sites for core drilling to evaluate geological variations with depth.
6. Evaluate the need for foundation treatment and the mode of foundation treatment.
7. Assess availability of construction materials within close proximity to the dam sites.

1.3 Scope of Works

The TOR for the feasibility study requires the Consultant to carry out reconnaissance geological survey and preliminary geophysical investigations within the Radat proposed dam project area. The scope of work entailed desk study of available geological, hydrogeological and soil survey reports of the general project area. This was followed by reconnaissance geological investigations for ground-truthing of the information in reviewed reports.

Preliminary field geophysical investigations were carried out at using geo-electrical resistivity method in order to:

i. Establish the depth to bedrock at the dam site(s);

ii. Study lateral geological variations along the proposed dam axis;

iii. Determine the presence of buried geological features such as fractures, local faults and lithological changes, e.g. buried paleao-river beds that would be highly permeable;

iv. Select the most suitable dam site for further detailed geological and geophysical investigations; and

v. Determine the thickness of overburden at the dam site and the nature of cut-off to be done.

The field work also included initial evaluation of availability of suitable construction materials by excavation of trial pits to collect soil samples from the dam general project area. This was to evaluate the suitability of the soils as embankment construction fill materials. The field investigations were carried out from 24th through 30th April 2014.

1.4 Location of Project Area

The proposed Radat dam project area is 30km south-west of Marigat Township, in Koibatek District of Baringo County. The proposed dam project is a zoned rock fill dam with an impervious core to be constructed across Perkerra River whose upper reaches is the Mau Escarpment Hills. The location of the proposed Radat project area is shown on Figure 5.1.

2 GEOLOGICAL RECONNAISSANCE INVESTIGATIONS

2.1 Review of Previous Geological Works

The most comprehensive study of the geology of the general project area is covered by Report No. 83 of the Mines and Geological Department, "Geology of the Eldama Ravine-Kabarnet Area" by J. Walsh (1969). The project area is in Radat-Marigat plains with low lying volcanic hills. The Perkerra River has deeply incised into the almost relief forming steep gorges. Review of previous geological studies of the general project has been covered in depth in that Report No. 83.

The geology of the general Radat project area is composed of volcanic rocks of Miocene to Pliocene period. Rock exposures of the volcanic rocks and some tuffs with intercalating sediments are found at river valley flanks and the floodplain. Previous geological studies have been done by many geologists who had interest in the formation of Great Rift Valley system.

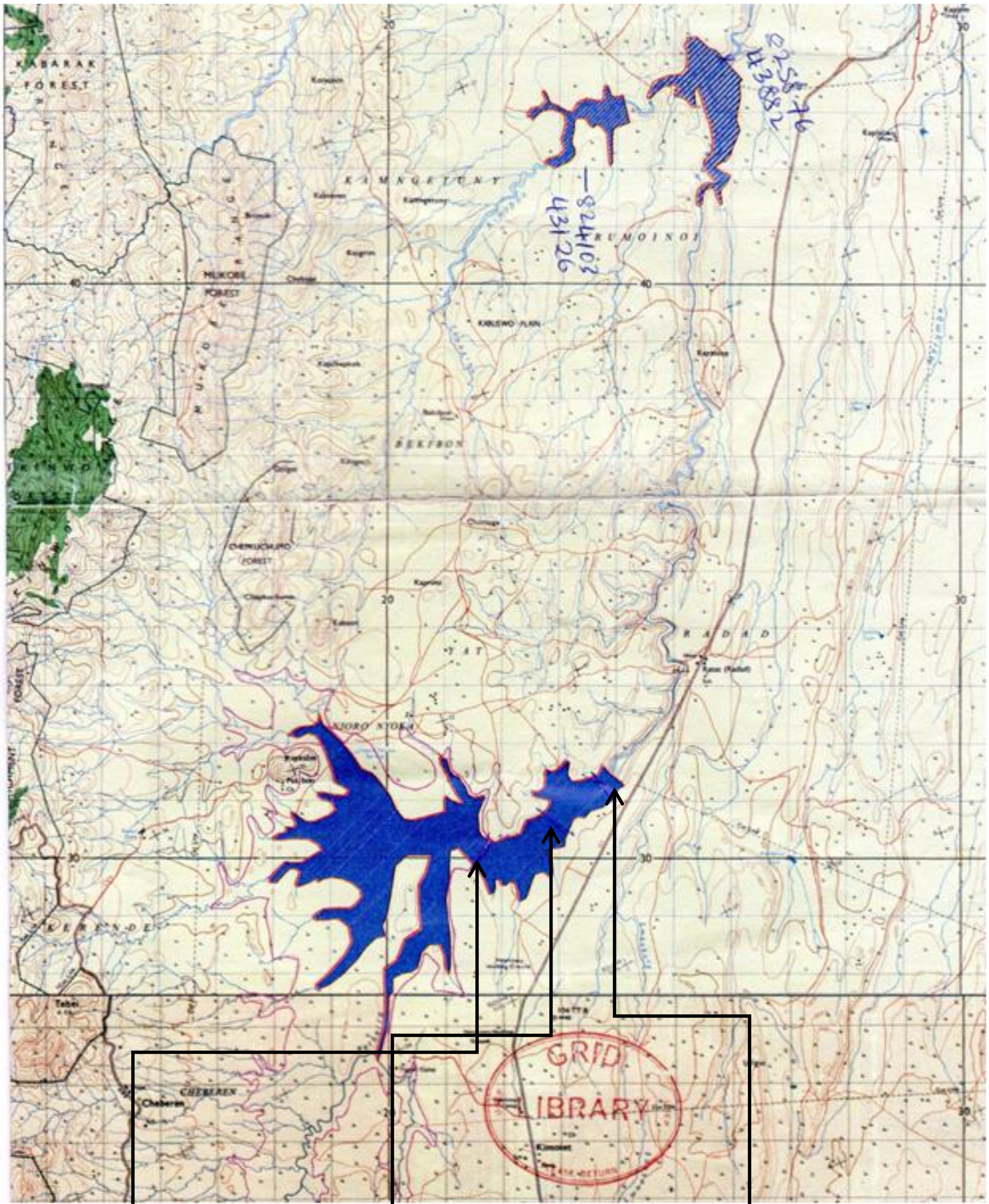

Figure 2:1 Location of Proposed Radat Dam Project Area

Upper Radat Dam site   Middle Radat dam site   Lower Radat dam site (main)

2.2 Review of Previous Geological Works

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2.3 Geology of the General Project Area

The geology of the general project area is composed of volcanic rocks of Miocene to Recent age. The oldest volcanic in the succession are basalts of the Samburu Basalt series (Tvb1). The Samburu basalts are largely hard, fine-grained and non-porphyritic. These basalts area deeply weathered and exist only as fragments solid rock in clayey formation.

The next oldest volcanic rocks in the succession are non-porphyritic phonolites of the Lower non-porphyritic phonolite series (Tvp1). Together with upper porphyritic phonolites they are described as the Uasin Gishu phonolites.

The next oldest rocks in the succession are the Eldama Ravine tuffs and sediments (Tvf2) that rest on the Uasin Gishu phonolites or the Samburu basalts (as was observed both at proposed dam site 2 and dam site 3).The sediment are riverine in origin and wedge out near Radat.

The next oldest rocks in the succession are basalts of the Kwaibus olivine basalts (Tvb3) that overlie the Eldama Ravine tuffs and sediments. These basalts are grey, fairly coarse-grained with macroscopic phenocrasts of feldspar, olivine and pyroxene.

The next oldest rocks in the succession (the youngest unit in the area) are phonolites of the Lower porphyritic Lake Hannington Phonolites unit (Tvp3). These rocks are exposed on the right hand side of Perkerra River valley at Radat area where they are faulted with a down to the east. They directly abut on the phonolites (Uasin Gishu phonolites). The succession of the rocks in the project area is as summarized here below:

1. Lower porphyritic Lake Hannington Phonolites unit (Tvp3).
2. Kwaibus olivine basalts (Tvb3).
3. Eldama Ravine tuffs and sediments (Tvf2).
4. Uasin Gishu phonolites.
5. Samburu Basalt series (Tvb1).

2.4 Detailed Geology of the Project Area

The geology of project area is composed of volcanic rocks of Miocene to Recent period. The volcanic rocks exposed in the proposed Radat project area have been variously weathered and only slightly fractured. The oldest rocks the Samburu basalt have been intensely weathered and can only be observed as solid fragments in weathered clayey formation. The younger volcanic rocks are also variously weathered and slightly fractured with the youngest Kwaibus basalts forming discontinuous scarps on the upper flanks of the steep river valleys (see Plate 2.1).

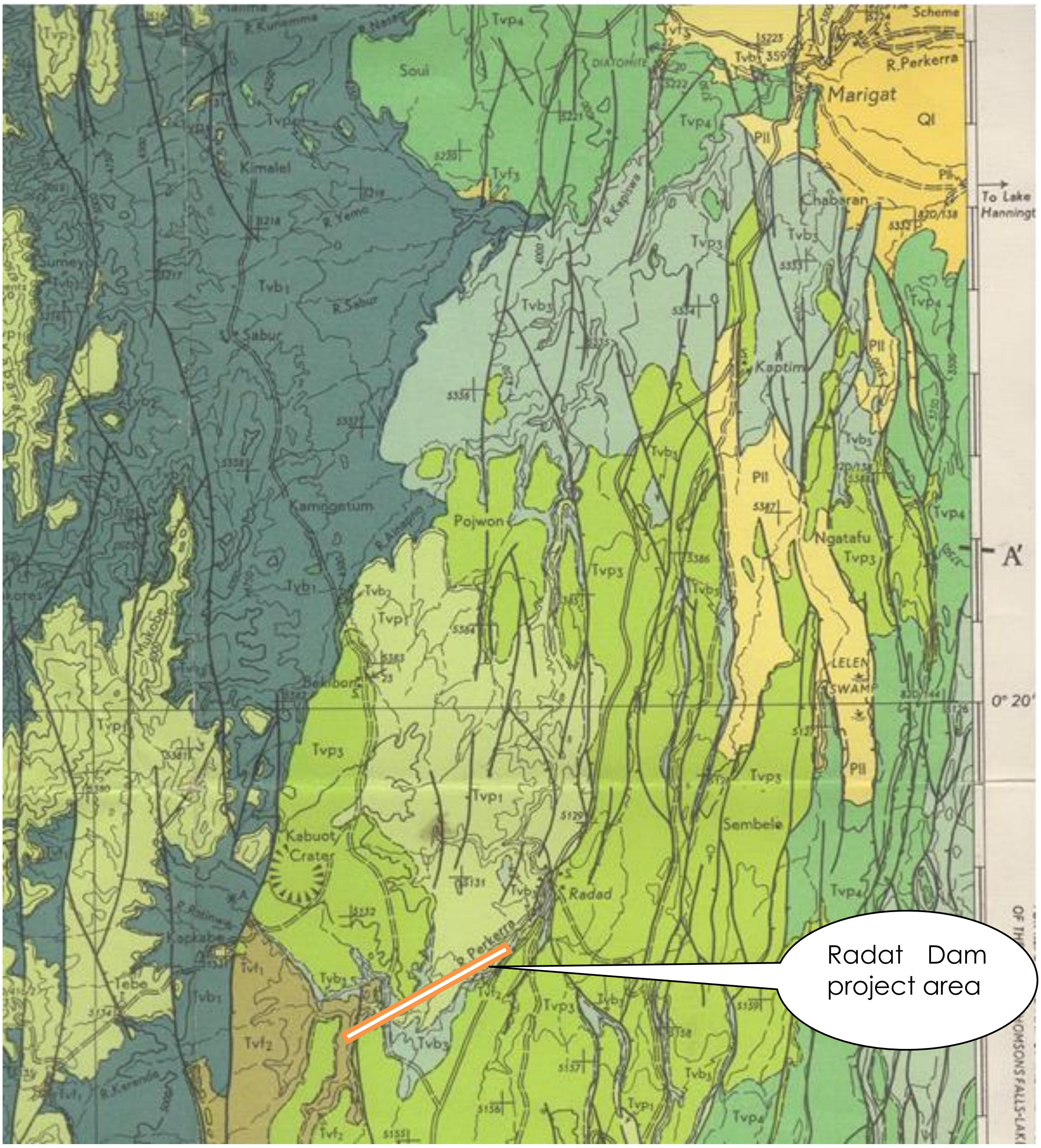

Figure 2:2 **A geological map of the general proposed Radat project area is shown in Figure 2.1.**

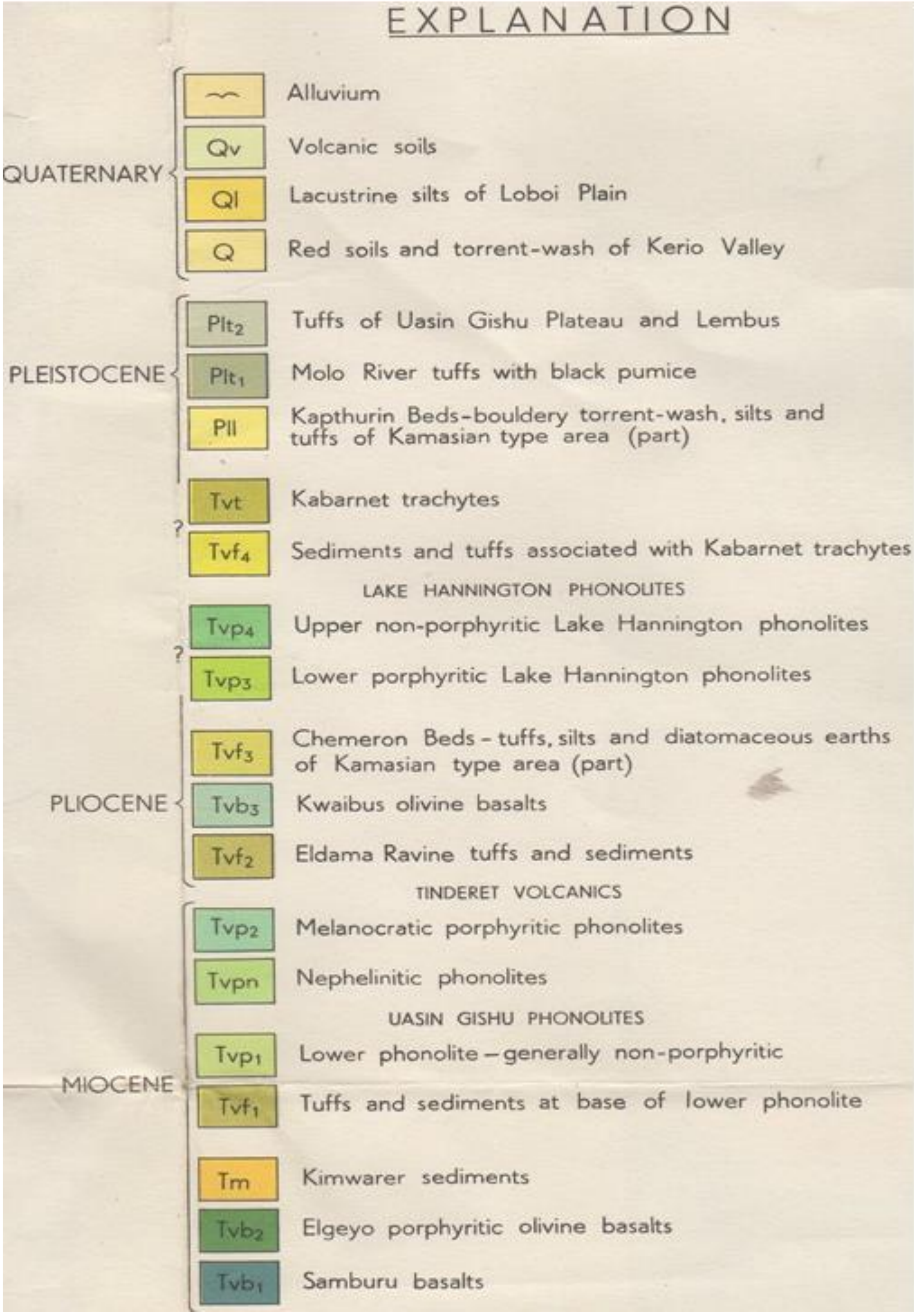

Figure 2:3 **Geological map of the general project area (extract from J. Walsh, 1969)**

The ground surface is strewn with cobbles and boulders with very thin layer of soils derived from the weathering of the parent rocks. Also significant is the presence of volcanic breccia which is the product of faulting activity in the area.

	
Plate 2.1: Steep-sided left bank at Radat dam site 1	Plate 2.2: Young Basalts resting on completely weathered Old basalts (Samburu basalts)

The ground surface is strewn with cobbles and boulders with very thin layer of soils derived from the weathering of the parent rocks. Also significant is the presence of volcanic breccia which is the product of faulting activity in the area.

	
Plate 2.3: Highly weathered Samburu basalts upstream of the bridge site	**Plate 2.4:** Phonolites resting weathered basalts near the Bridge (dam site 3)

The rocks have disjointed lateral extent leading to absence of continuous bedrock as observed in geophysical investigations. Eldama Ravine tuffs and sediments are well exposed in proposed dam site 3 where sediments are intercalated with tuffs (Plate 2.4).

	
Plate 2.5: Intercalated tuffs and sediments Dam site 3 area	Plate 2.6: Intercalated tuffs and Sediments resting on basalts (Dam site 3 area)

A map of detailed reconnaissance geology of the proposed Radat dam project area is shown Figure 2. 4.

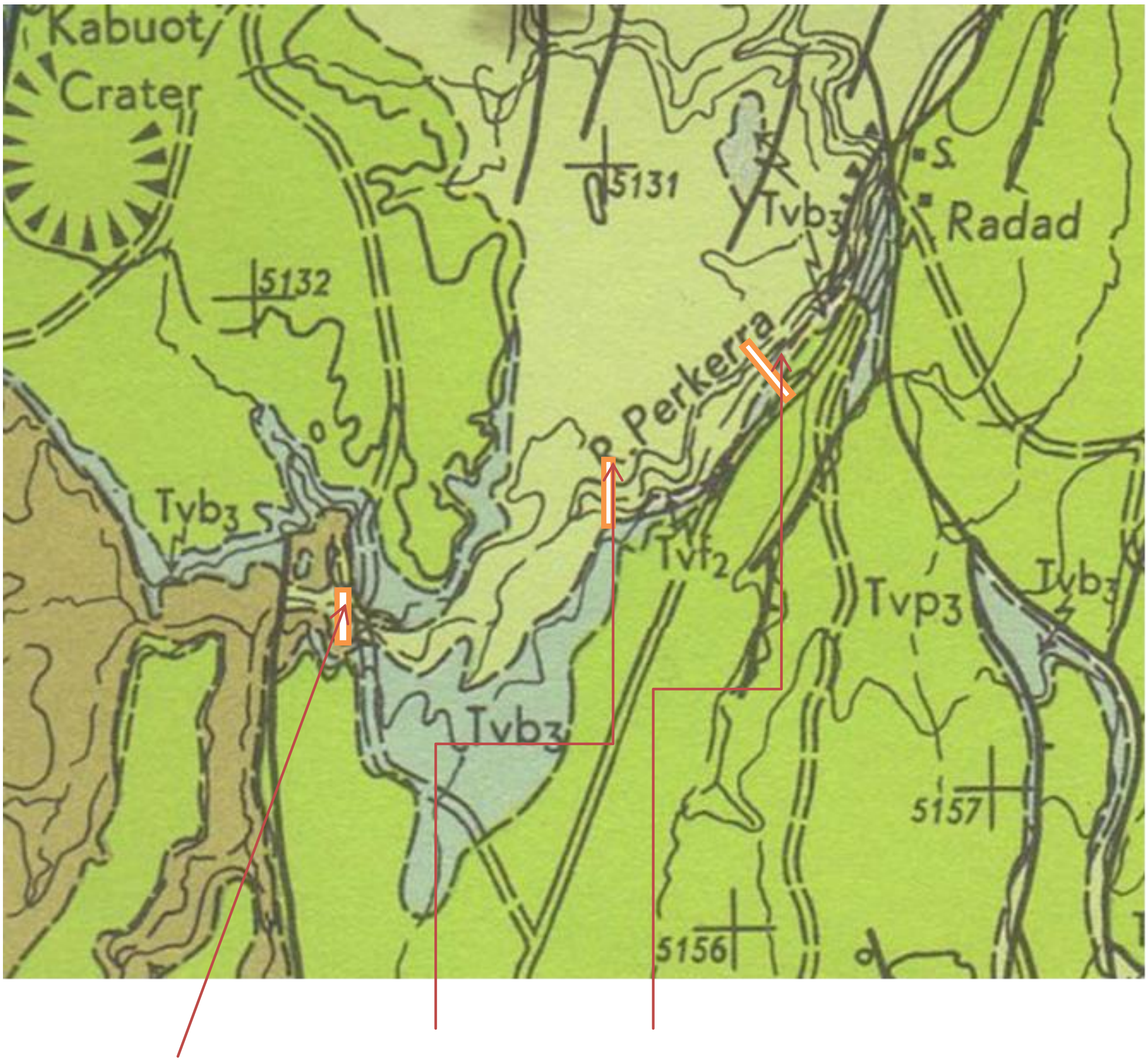

Figure 2:4 Geological map of Proposed Radat Dam Site Area

Proposed Dam Site 3 (Kipting' Bridge) Proposed Dam Site 2 Proposed Dam Site 1

Geological Key

PLIIOCENE AGE

Tvp_3	Lower porphyritic Lake Hannington phonolites
Tvb_3	Kwaibus olivine basalts
Tvf_2	Eldama Ravine tuffs and sediments
Tvp_1	Lower phonolite – generally non-porph

2.5 Structural Geology of the Project Area

The structural geology Radat dam project is characterized by intense faulting that especially affected the young volcanic rocks during the formation of the Great Rift Valley during Quaternay times. Of particular interest during the design process of the proposed Radat dam would nature of faulting and to what extent the foundation rocks have been affected faulting. The general project area has undergone grid-faulting, but around the proposed Radat has only experienced minor faulting that dies out south-westwards. A map of the structural pattern the general project area is shown Figure 2.3.

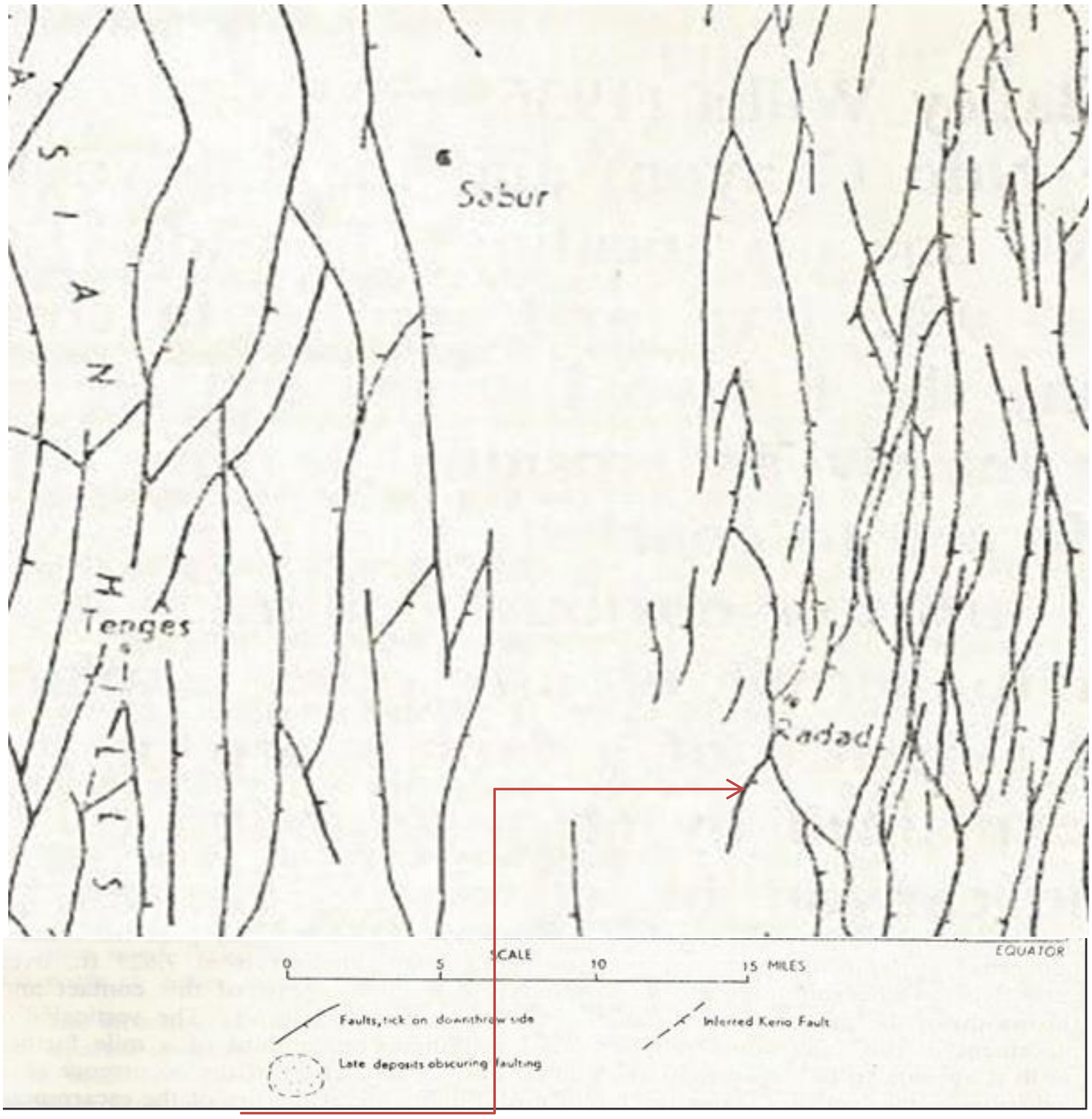

Figure 2:5 **Map of Structural Pattern of Radat Project Area Proposed Radat Project Area**

2.6 Seismic Activity in the General Project Area

The seismicity of the project area can be assessed from existing reports. Due to the highly faulted nature Radat project area it is deemed prudent for seismic survey to be carried out in this area. This will produce useful information which will be necessary for during the design of the proposed dam.

In the seismic zoning map of Kenya (Loupekine, 1971) the project area lies in Zone VIII - IX in the Modified Mercalli Scale of earthquake intensities. The seismic zoning map of Kenya is given in Figure 2.5, while the Modified Mercalli Scale of earthquake intensities is summarized in Table 2.1.

In accordance to available data on earthquake parameters, other areas with similar geological setting have applied the following design parameters:

- Design Basis Earthquake (DBE): amax = 0.20g;

- Maximum Credible Earthquake (MCE): amax = 0.45g.

We believe a design basis earthquake (DBE) loading of amax = 0.25g and maximum credible earthquake (MCE) of amax = 0.45g can be applied in stability analysis during the designing of the Radat dam.

Consideration is also made on other earthquake factors that may have influence on dam stability, namely close proximity to earthquake epicentres and the historical background of earlier earthquakes. The distribution of earthquake epicentres in Kenya is shown Figure 2.6. A map of widely felt earthquakes in Kenya is presented in Figure 2.7: the project area is located about 50 km from the estimated epicentre of the major shocks of the 1928 Subukia earthquake (M=7) with estimated peak ground acceleration of 50cm/sec2 or 0.05g.

Other considerations are the effects of the filling of the dams: in a number of reported cases the filling of dam reservoirs has resulted in induced seismicity. The mechanism behind induced seismicity is generally thought to be:

- The triggering effect of additional stresses from the weight of the water, and
- The reduced friction along faults because of increased pore water pressure.

Historical data have shown that no induced earthquake of magnitudes greater than 5 have occurred for dams lower than 100m height. The filling of Radat dam of 80m is not expected to result in induced earthquake.

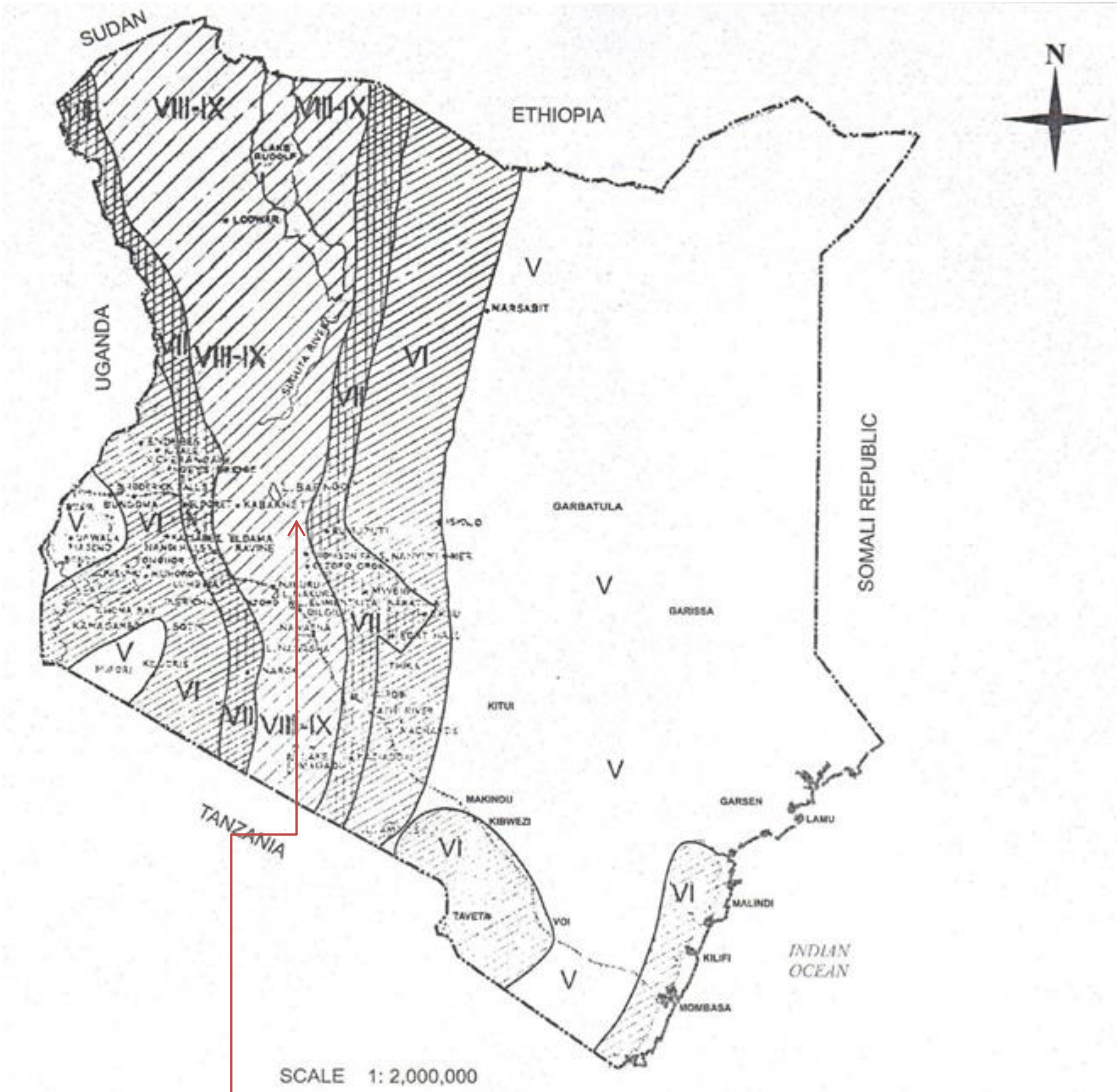

Figure 2:6 **Seismic Zoning Map of Kenya (I. S. Loupekine, 1971**

Proposed Radat Dam Project Area

Intensity Zone	Descriptive Term	Effects	Acceleration (cm/s^2)	Acceleration (g)
I	Imperceptible	Not felt. Registered only by seismographs.	< 1	< 0.001
II	Very slight	Felt in upper storeys solely By persons at rest.	1 – 2	0.001 – 0.002
III	Slight	Felt indoors. Vibrations like those caused by light trucks passing by.	2 – 5	0.002 – 0.005
IV	Moderate	Hanging objects swing. Vibrations like those caused by heavy trucks or a jolt such as that occasioned by a heavy object striking the wall. Parked cars are set in seesaw motion. Windows, doors and crockery rattle.	5 – 10	0.005 – 0.01
V	Fairly Strong	Felt outdoors. Sleeping persons wakened. Small objects not anchored are displaced or overturned. Doors open and close. Shatters and pictures are set in motion. Pendulum clocks stop and start or change their speed.	10 – 20	0.01 – 0.02
VI	Strong	Walking is made difficult. Windows, crockery and glass break. Knick-knacks, books, etc. fall off shelves; pictures fall from wall. Furniture moves or is overturned. Cracks in weak plaster and materials of construction Type D. Small bells ring (church, school).	20 – 50	0.02 – 0.05
VII	Very Strong	Noticed by car drivers and passengers. Furniture breaks. Materials of construction Type D sustain serious damage. In some cases, cracks in materials of construction Type C. Weak chimneys break at roof level. Plaster, loose bricks, stones, tiles, shelves collapse. Waves created on ponds.	50 – 100	0.05 – 0.10
VIII	Destructive	Steering of cars made difficult. Very heavy damage to materials of construction Type D and some damage to materials of Type C. Partial collapse. Some damage to materials of Type B. Stucco breaks away. Chimneys, monuments, towers and raised tanks collapse. Loose panel walls thrown out. Branches torn from trees. Changes in flow or temperature of springs. Changes in water levels of wells. Cracks in moist ground and on steep slopes.	100 – 200	0.10 – 0.20
IX	Highly Destructive	General panic. Materials of construction Type D completely destroyed. Serious damage to materials of Type C, and frequent collapse. Serious damage also sustained by materials of Type B. Frame structures lifted from their foundation, or they collapse. Loadbearing members of reinforced-concrete structures are cracked. Pipes llying below ground burst. Large cracks in the ground. In alluvial areas, water, sand and mud ejected.	200 – 500	0.20 – 0.50
X	Extremely Destructive	Most masonry and wooden structures destroyed. Reinforced steel buildings and bridges seriously damaged; some of them destroyed. Severe damage to dams, dykes and weirs. Large landslides. Water hurled onto the banks of canals, rivers and lakes. Rails bent.	500 – 1000	0.50 – 1.00
XI	Disaster	All structures collapse. Even large, well constructed bridges are destroyed or seriously damaged. Only a few buildings remain standing. Rails greatly bent and thrown out of position. Underground wires and pipes break apart.	1000 - 2000	1.00 – 2.00
XII	Major disaster	Large-scale changes in the structure of the ground. Overground and subterranean streams and rivers change in many ways. Waterfalls are created, lakes are dammed up or burst their banks. Rivers alter their courses.	> 2000	> 2.00

Construction method A: Good workmanship, mortar and design; reinforced especially laterally, and bound together using steel, concrete, etc.; designed to resist lateral forces.
Construction method B: Good workmanship and mortar; reinforced but not designed to resist strong lateral forces.
Construction method C: Ordinary workmanship and mortar; no extreme weaknesses such as failing to tie in at corners, but neither reinforced nor designed to resist horizontal forced.
Construction method D: Weak materials such as adobe; poor mortar, low standards of workmanship; horizontally weak.

Figure 2:7 Modified Mercalli Scale (1956) of Intensities

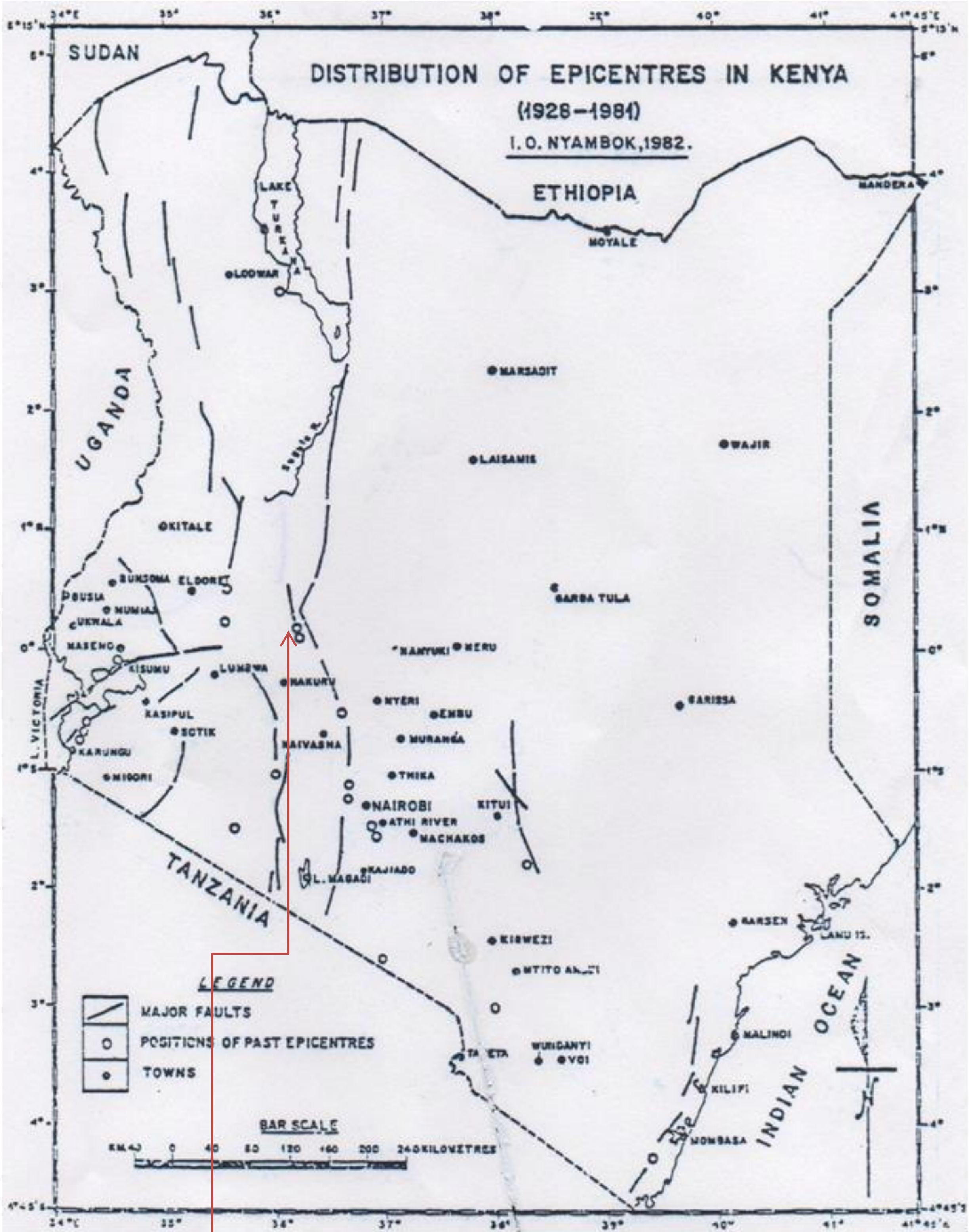

Figure 2:8 **Distribution of Earthquake Epicentres in Kenya (I. S. Nyambok, 1982)**

Project Area o - Epicntre

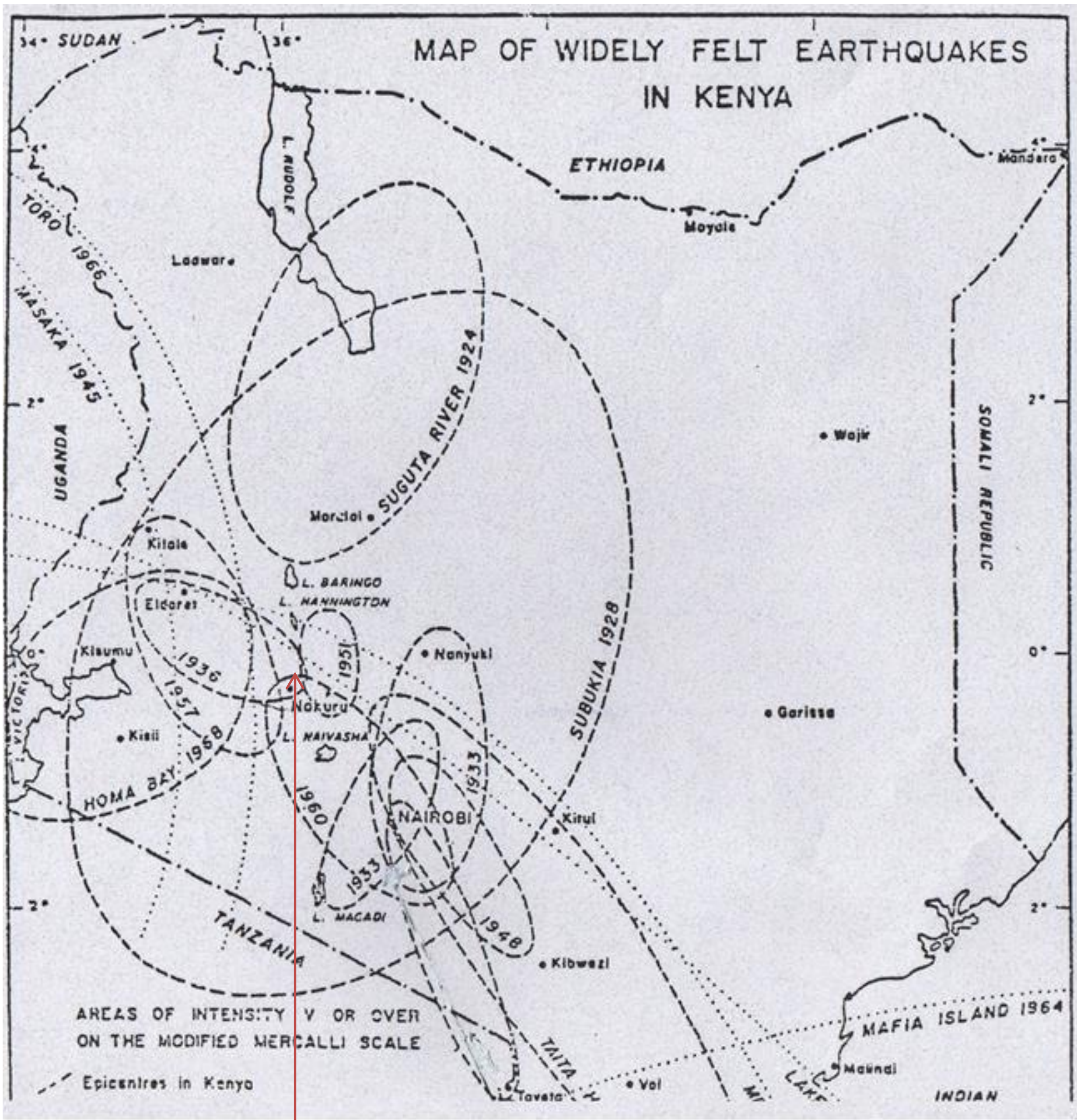

Figure 2:9 Map of Widely Felt Earthquakes in Kenya (I. S. Nyambok, 1982)

Proposed Radat Dam Project Area

3 PRELIMINARY GEOPHYSICAL INVESTIGATIONS

3.1 Overview of Geophysical Methods Applied

In the effort to study the subsurface geological conditions of the dam site, geo-electrical resistivity methods were employed by use of ABEM SAS 300B Terrameter and GEOTRON at Radat dam site. The machines used employ geo-electrical principles and have reliable efficacy. The equipment is of high resolution and therefore quite effective in subsurface exploration.

Two approaches were applied which include: Horizontal Electrical Resistivity Profiling (HERP) and Vertical Electrical Sounding (VES). The profiling and soundings were designed to capture certain areas of in the proposed dam site. The layout of the profile lines was influenced by the geomorphology of the dam site area and construed general strike of the underlying rocks. The profile lines were carried out perpendicular to the drainage pattern in order to investigate the lateral variations of the subsurface features (this being underlain by volcanic rocks, subsurface features vary very frequently and at small distances). The soundings (VES) were carried out at points noted to have deep weathering or weaknesses detected by profiling. The aim of vertical electrical soundings (VES) was to probe the variations of rocks with depth and also to establish the depth to bedrock.

In this method electric current is introduced into the ground using current electrodes (A and B), thus creating an electric field between them and the potential difference in that field is measured using potential electrodes (M and N). According to Ohm's Law, the resistance of rock formations (as the conductor) is obtained by dividing the potential difference (at any point in that field) by the electric current. The property that determines the conducting nature of any material is known as resistivity which obtained by multiplying the measured resistance with a geometric coefficient K. The geometric coefficient is dependent on the configuration of the electrodes. The Wenner configuration was used for profiling technique while the Schlumberger configuration was used for vertical electrical soundings (VES) with the array of electrodes as shown in Figure 3.1.

The resistivity ρa is obtained as follows:

$$\rho_a = K * \Delta V / I$$

where: $K = \pi \dfrac{(AB/2)^2 - (MN/2)^2}{MN}$

ρ_a – Apparent resistivity in Ohm.m
K – Geometric coefficient
π – Pie constant = 3.142
AB – Current electrodes separation
MN – Potential electrodes separation.

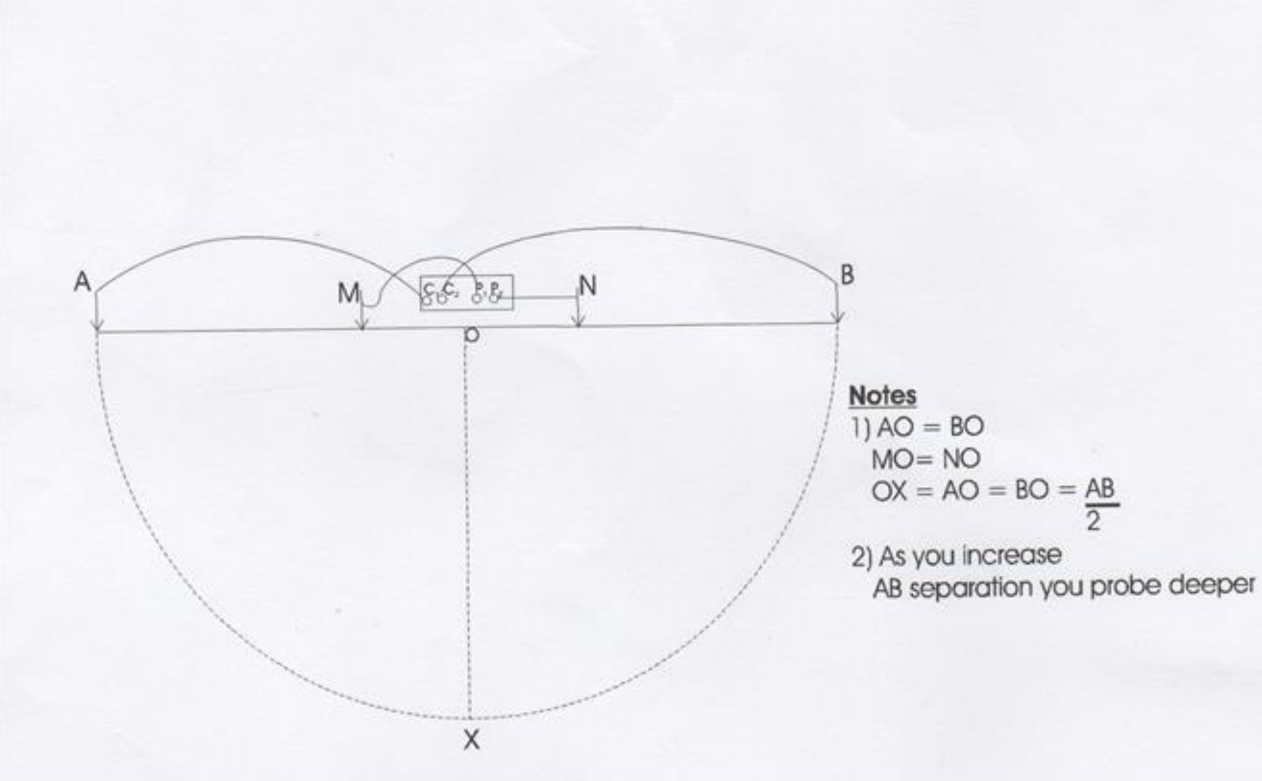

Figure 3:1 Schematic Schlumberger Configurations of Electrodes

3.2 Geophysical Field Investigations

Preliminary field geophysical investigations were carried out from 25th to 30th April 2014 in three proposed dam sites. Proposed Dam Site 1 is about 1km from Radat Trading Center; Proposed Dam Site 2 is about 2km Radat Trading Center; and Proposed Dam Site 3 is about 5km (near the bridge to Kenamoi).

3.3 Results of Geophysical Investigations at Dam Site 1

The layout plan of geophysical profiles (HERPS) and vertical electrical soundings (VES) at Radat Proposed Dam Site 1 shown on Figure 3.11. The coordinates of the vertical electrical sounding (VES) locations are in Table 3.1.

Table 3:1 Coordinates and Elevation VES Points (HERP 1 & 2 in Dam site 1)

HERP LINE No.	VES No.	X	Y	Elevation (m)
RADAT HERP I	RAD1-1VES 1	0823943	0031073	1368
	RAD1-1VES 2	0823918	0031087	1369
	RAD1-1VES 3	0823884	0031104	1375
	RAD1-1VES 4	0824085	0031055	1408
	RAD1-1VES 5	0824047	0031069	1396
	RAD1-1VES 6	0824008	0031079	1375
RADAT HERP 2	RAD1-2VES 7	0824019	0031174	1373

	RAD1-2VES 8	0824059	0031165	1384
	RAD1-2VES 9	0823938	0031192	1403
	RAD1-2VES 10	0824123	0031129	1415

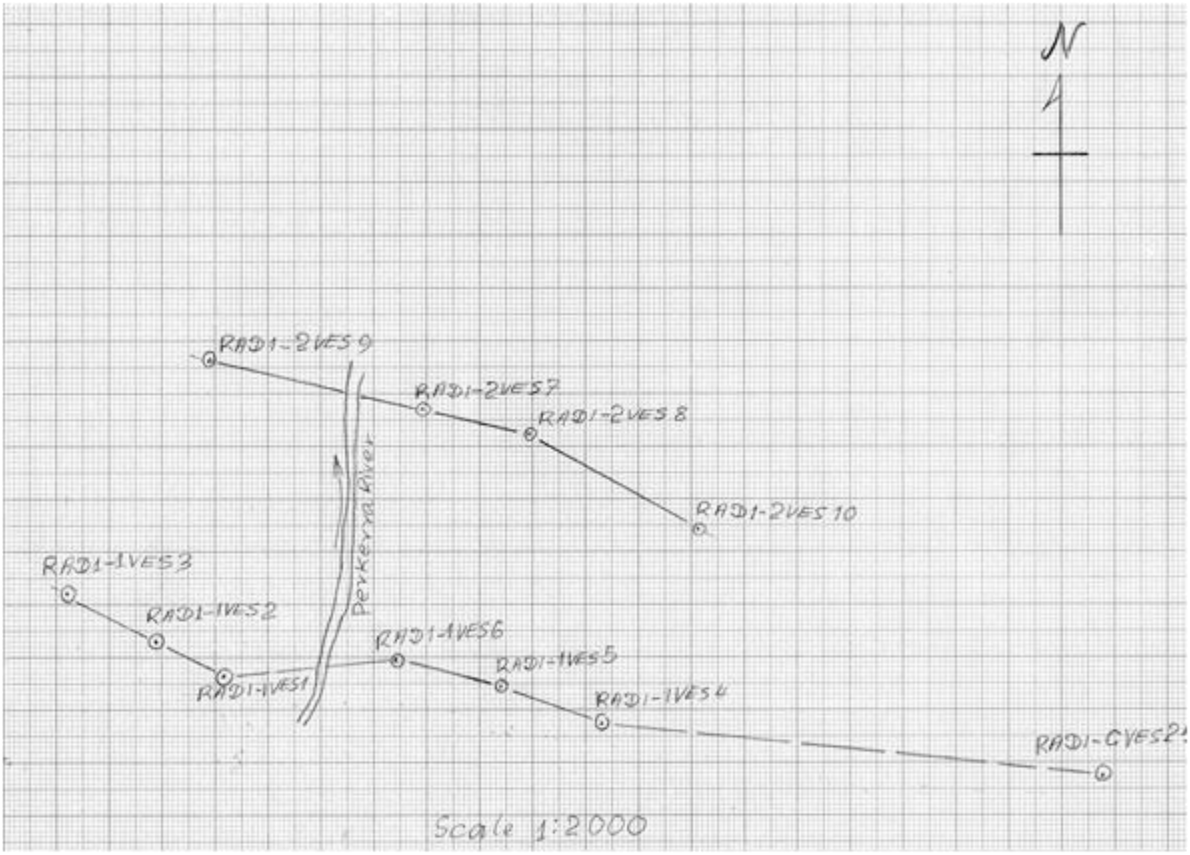

Figure 3:2 Layout Plan of HERP and VES in Radat Proposed Dam Site 1

The river valley at this is very rocky and with steep cliffs so that only two horizontal electrical resistivity profiles (HERP) were carried out. Six vertical electrical soundings (VES) were selected on the profiles and done. Detailed results of interpreted geophysical investigations are given in the Appendices.

3.3.1 Interpretation of Geophysical Investigations Results

Due to the rugged nature of the topography production of results in 2D and 3D tomography presented challenges because of many gaps resulting extrapolations. We have generated a 2D tomography of the foundation using the electrical profiling and vertical electrical data obtained in the field. The field HERD field data were plotted as in Figure 3.12.

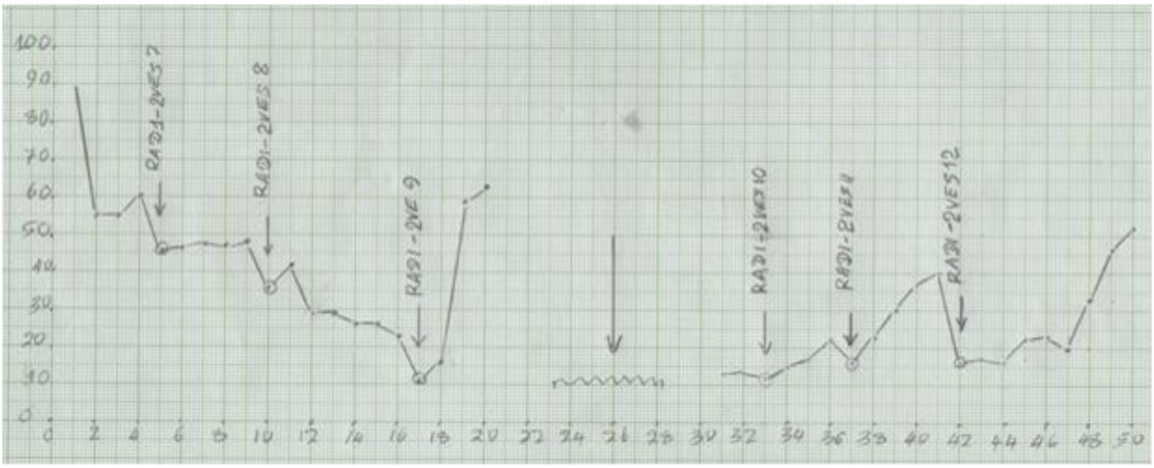

Figure 3:3 HERP Field Data

The interpreted geophysical investigations results for Proposed Dam Site 1 are presented in Tables 3.2 and 3.3.

Table 3:2 Interpreted Geophysical Results for VES on HERP Line 1 (Main Dam Axis)

HERP No.	VES No.	Depth (m)	Thickness (m)	Resistivity (Ohm-m)	Formation Description
RAD-HERP 1	RAD1-1VES 1	0.0 – 1.4	1	24	Top soil composed of fine sands and silts
		1.4 – 6.5	5	30	Wet sandy clay with silts
		6.5 – 7.7	1	28	Wet sandy clay with silts
		7.7 – 24.0	16	9	Wet clay
		24 – 47.0	23	17	Wet clay with fine sands and silts
		> 47		10	Wet clay with silts
	RAD1-1VES 2	0.0 – 1.4	1	152	Top soil composed of weathered rock
		1.4 – 3.9	1.5	15	Wet clay with fine sands and silts
		3.9 – 7.3	3	43	Wet clayey sands with silts
		7.3 – 10.6	3	20	Wet sandy clay with silts
		10.6 – 26.3	16	16	Wet clay with fine sands and silts
		26.3 – 26.7	0.5	15	Wet clay with fine sands and silts
		> 26.7		20	Wet sandy clay with silts
	RAD1-1VES 3	0.0 – 1.3	1	110	Top soil of weathered rock-gravelly sands
		1.3 – 1.9	0.5	9	Thin layer of wet clay
		1.9 – 5.3	3	19	Wet sandy clay with silts

HERP No.	VES No.	Depth (m)	Thickness (m)	Resistivity (Ohm-m)	Formation Description
		5.3 – 15.7	10	13	Wet clay with silts
		15.7 – 16.6	1	30	Wet clayey sands with silts
		> 16.6		40	Wet clayey sands with silts
	RAD1-1VES 4	0.0 – 3.3	3	39	Top soil of wet clayey sands with silts
		3.3 – 7.4	4	2500	Fresh volcanic rock – basalts
		7.4 – 9.5	2	550	Slightly weathered volcanic rock-basalt
		9.5 – 12.0	2.5	750	Slightly fractured volcanic rock-phonolite
		12.0 – 24.0	12	640	Slightly weathered volcanic phonolite
		> 24.0		2000	Fresh volcanic rock - phonolite
	RAD1-1VES 5	0.0 – 1.4	1	33	Top soil of clayey sands with silts
		1.4 – 1.5	0.1	9	Thin layer of clay
		1.5 – 11.2	9	8	Wet clay
		11.2 – 12.9	1	82	Thin layer of wet sands
		12.9 – 28.0	15	13	Wet clay with silts
		28.0 – 30.0	2	10	Wet clay with silts
		> 30		500	Slightly weathered volcanic rock
	RAD1-1VES 6	0.0 – 1.0	1	18	Wet/moist top soil of sandy clay with silts
		1.0 – 2.3	1	8	Wet clay
		2.3 – 4.6	2	6	Wet clay
		4.6 – 9.4	5	8	Wet clay
		9.4 – 21.5	12	5	Wet clay
		> 21.5		10	Wet clay with silts

A deep vertical electrical sounding (VES) was done as control at the top of the right abutment at proposed dam site 1 (RADAT1-CVES 25) in order to evaluate the succession of rock formations from the top: The position of this VES is X: 0824275 (E), Y: 0031075 (N) at elevation 1475m. The data for this VES is included in Table 5.3 for correlation with VES on HERP Line 1.

Table 3:3 Interpreted Geophysical Results for CVES 25 on HERP Line 1 (Main Dam Axis)

HERP No.	VES No.	Depth (m)	Thicknes s (m)	Resistivity (Ohm-m)	Formation Description
RAD-HERP 1	RAD1-CVES	0.0 – 1.2	1	389	Top soil composed of weathered rocks

HERP No.	VES No.	Depth (m)	Thickness (m)	Resistivity (Ohm-m)	Formation Description
	25	1.2 – 4.7	3.5	36	Clayey sands with silts and cobbles
		4.7 – 18.9	14	87	Wet sands with gravel and cobbles
		18.9 – 43.9	25	18	Wet sandy clay with silts
		43.9 – 78.1	34	60	Wet sands with gravel and cobbles
		78.1 – 122	44	12	Wet clay with silts
		> 122		100	Wet highly weathered volcanic rock

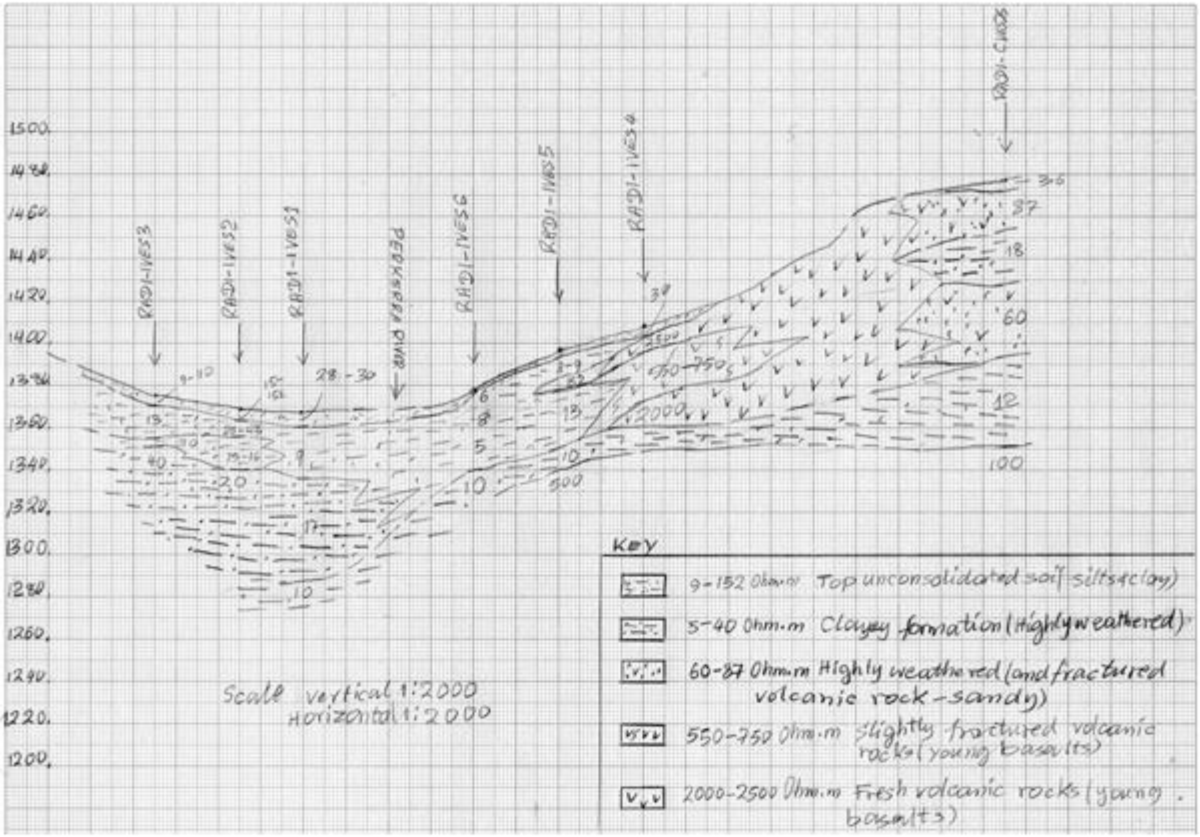

Figure 3:4 Geological correlation cross section along Profile Line 1

Geological correlation cross section was done for only VES on HERP Line 1, however the interpreted geophysical results for VES on HERP Line 2 (50m downstream of the main proposed dam axis) are given in Table 3.4

Table 3:4 Interpreted Geophysical Results for VES on HERP Line 2 (50m downstream main axis)

HERP No.	VES No.	Depth (m)	Thickness (m)	Resistivity (Ohm-m)	Formation Description
RADAT1-HERP2	RAD1-2VES 7	0.0 – 1.6	1.5	218	Top soil composed of sands and gravel
		1.6 – 3.2	1.5	22	Wet clay with fine sands and silts
		3.2 – 6.6	3.5	11	Wet clay with silts
		6.6 – 7.0	0.5	9	Wet clay
		7.0 – 12.4	5.5	8	Wet clay
		12.4 – 23.4	11	7	Wet clay
		> 23.4		10	Wet clay with silts
	RAD1-2VES 8	0.0 – 0.9	1	581	Slightly weathered volcanic - basalts
		0.9 – 1.6	0.5	8	Thin layer of wet clay
		1.6 – 5.2	4	50	Wet sands
		5.2 – 6.1	1	9	Wet clay
		6.1 – 11.0	5	4	Wet clay
		11.0 – 14.0	3	9	Wet clay
		14.0 – 37.5	23.5	1935	Fresh volcanic rocks – phonolites
		> 37.5		200	Slightly weathered volcanic rock
	RAD1-2VES 9	0.0 – 1.7	2	119	Top soil composed of weathered rocks
		1.7 – 7.9	6	20	Wet clay with fine sands and silts
		7.9 – 12.8	5	13	Wet clay with fine sands and silts
		12.8 – 19.2	6	12	Wet clay with silts
		19.2 – 32.0	12	14	Wet clay with fine sands and silts
		32.0 – 63.9	32	11	Wet clay with silts
		> 63.9		20	Wet clay with fine sands and silts
	RAD1-2VES 10	0.0 – 1.1	1	169	Top soil composed of weathered rocks
		1.1 – 1.2	0.1	5	Wet clay
		1.2 – 8.9	8	6	Wet clay
		8.9 – 9.0	0.1	5	Wet clay
		9.0 – 9.1	0.1	4	Wet clay
		9.1 – 115.4	106	3	Wet clay
		115.4		5	Wet clay

3.3.2 Assessment of Proposed Dam Site 2

Geological correlation cross section (Figure 5.18) shows that the foundation rocks at Radat Proposed Dam Site 2 are highly weathered and fractured. However, different rock formations have been differently affected by weathering. The foundation rocks may also have been affected by a minor transverse fault that is notable at Radat area but not well observed at the site. The weathering and faulting actions have resulted in highly fragmented foundation rocks producing volcanic breccia, with clayey fine sands and silts leading in low resistivity values.

The deep control vertical electrical sounding (RADAT1-CVES 25) done at the top of the right abutment gives a more complete picture of the vertical geological variation at this site. A reconnaissance geological map of proposed Radat dam site area is shown on Figure 3.4.

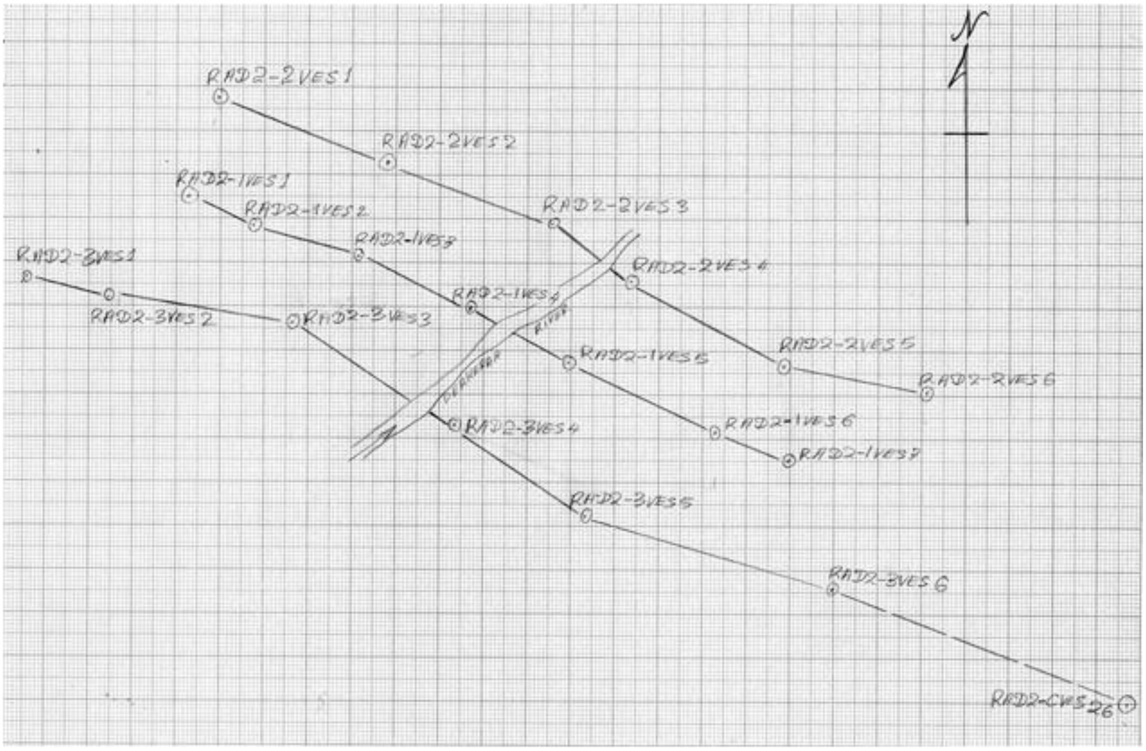

Figure 3:5 Layout plan of HERP and VES in Radat Proposed Dam Site 2

The interpreted geophysical investigations results for Proposed Dam Site 2 are presented in Tables 3.5 – 3.8. Geological correlation cross section along Profile Line 1 (HERP 1 – proposed Dam Axis) is presented in Figure 3.18.

Table 3:5 Interpreted Geophysical Results for Dam SITE 2 (VES on HERP Line 1 Main Dam Axis)

HERP No.	VES No.	Depth (m)	Thickness (m)	Resistivity (Ohm-m)	Formation Description
RADAT2-	RAD2-	0.0 – 1.9	2	1598	Dry top soil with volcanic

HERP No.	VES No.	Depth (m)	Thickness (m)	Resistivity (Ohm-m)	Formation Description
HERP1	1VES 1				boulders
		1.9 – 5.6	4	266	Dry soil with volcanic cobbles
		5.6 – 13.0	7	32	Wet/moist sandy clay with silts
		13.0 – 29.3	16	100	Weathered volcanic rock
		> 29.3		50	Wet sands
	RAD2-1VES 2	0.0 – 1.4	1	435	Top soil of sands and cobbles
		1.4 – 5.4	4	30	Wet/moist sandy clay with silts
		5.4 – 6.5	1	7	Wet clay
		6.5 – 18.7	12	13	Wet clay with silts
		18.7 – 20.7	2	7	Wet clay
		> 20.7		5	Wet clay

Table 3:6 Geophysical Results for Dam SITE 2 (VES on HERP Line 1 Main Dam Axis)-contd.

HERP No.	**VES No.**	**Depth (m)**	**Thickness (m)**	**Resistivity (Ohm-m)**	**Formation Description**
RADAT2-HERP1	RAD2-1VES 3	0.0 – 1.1	1	20	Top soil of moist clay and silts
		1.1 – 4.0	3	5	Wet clay
		4.0 – 4.1	0.1	9	Wet clay
		4.1 – 10.0	6	19	Wet clay with silt
		> 10.0		3	Wet clay
	RAD2-1VES 4	0.0 – 1.0	1	67	Top soil composed of sands and sits
		1.0 – 1.1	0.1	8	Wet clay soil
		1.1 – 11.1	10	7	Wet clay
		11.1 – 56.0	46	4	Wet clay
		56.0 – 66.8	11	6	Wet clay
		> 66.8		5	Wet clay
	RAD2-1VES 5	0.0 – 2.0	2	181	Top soil composed of sands and gravel
		2.0 – 3.3	1	74	Wet sandy soil
		3.3 – 4.7	1	86	Wet sandy soil
		4.7 – 10.7	6	41	Moist/wet sandy clay with silts
		10.7 – 59.2	48.5	7	Wet clay
		59.2 – 74.6	15	8	Wet clay
		> 74.6		20	Wet clay with silt
	RAD2-1VES 6	0.0 – 1.6	1.5	35	Top soil composed of fine sands
		1.6 – 5.9	4	96	Wet sandy formation

HERP No.	VES No.	Depth (m)	Thickness (m)	Resistivity (Ohm-m)	Formation Description
		5.9 – 7.8	2	83	Wet sandy formation
		7.8 – 12.1	4	7	Wet clay
		12.1 – 26.9	15	11	Wet clay with silts
		> 26.9		30	Wet sandy clay with silts
	RAD2-1VES 7	0.0 – 1.2	1	27	Top soil composed of sandy clay
		1.2 – 8.0	7	31	Wet/moist sandy clay with silts
		8.0 – 25.9	18	15	Wet clay with silts
		> 25.9		40	Wet clayey fine sands silts
	RAD2-CVES26	0.0 – 3.1	3	206	Top soil composed of sands and gravel
		3.1 – 5.3	2	175	Weathered formation- sands and gravel
		5.3 – 13.7	8	157	Weathered formation- sands and gravel
		13.7 – 25.1	12	47	Moist/wet clayey sands with silts
		25.1 – 35.2	10	23	Wet clay with silt
		35.2 – 74.8	40	18	Wet clay with silts
		> 74.8		10	Wet clay

Table 3:7 Interpreted Geophysical Results for Dam SITE 2 HERP Line 2 (50m Downstream Axis)

HERP No.	VES No.	Depth (m)	Thickness (m)	Resistivity (Ohm-m)	Formation Description
RADAT2-HERP 2	RAD2-2VES 1	0.0 – 2.1	2	1063	Dry top soil with volcanic boulders
		2.1 – 2.2	0.1	216	Dry soil with volcanic cobbles
		2.2 – 23.4	21	126	Weathered volcanic rock
		23.4 – 56.8	33	52	Wet sands
		> 56.8		5000	Compact fresh volcanic rocks
	RAD2-2VES 2	0.0 – 1.2	1	59	Top soil composed of sands and sits
		1.2 – 2.6	1	11	Wet/moist clay with silt
		2.6 – 6.0	3	33	Moist sandy clay with silts
		6.0 – 40.9	35	8	Wet clay
		> 40.9		100	Weathered volcanic rock - basalts
	RAD2-2VES 3	0.0 – 1.2	1	36	Top soil composed of fine sands and sits

HERP No.	VES No.	Depth (m)	Thickness (m)	Resistivity (Ohm-m)	Formation Description
		1.2 – 4.3	3	9	Moist clay with silt
		4.3 – 8.4	4	19	Wet clay with silt
		8.4 – 16.1	8	9	Wet clay
		16.1 – 56.7	41	3	Wet clay
		56.7 – 56.8	0.1	4	Moist clay
		> 56.8		10	Wet clay with silt
	RAD2-2VES 4	0.0 – 2.5	2.5	42	Top soil composed of fine sands
		2.5 – 5.2	3	50	Wet/moist sands
		5.2 – 6.3	1	9	Wet clay with silt
		6.3 – 43.3	37	7	Wet clay
		> 43.3		10	Wet clay with silt
	RAD2-2VES 5	0.0 – 1.2	1	344	Top soil of sands and cobbles
		1.2 – 2.3	1	36	Moist/wet sandy clay with silts
		2.3 – 3.0	1	24	Wet clay with silts
		3.0 – 5.5	2.5	184	Slightly weathered volcanic rock
		5.5 – 7.7	2	79	Wet/moist sands
		7.7 – 19.3	12	42	Wet clayey fine sands silts
		19.3 – 21.8	2.5	43	Wet clayey fine sands silts
		21.8 – 31.4	10	128	Weathered volcanic rock - basalts
		> 31.4		200	Slightly weathered volcanic rock
	RAD2-2VES 6	0.0 – 0.7	0.7	185	Dry soil with volcanic cobbles
		0.7 – 3.1	2	153	Weathered volcanic rock
		3.1 – 15.5	12	9	Wet clay
		15.5 – 19.4	4	157	Slightly weathered volcanic rock
		> 19.4		500	Slightly weathered volcanic rock

Table 3:8 Geophysical Results for Dam SITE 2 HERP Line 3 (50m Upstream of Main Axis)

HERP No.	VES No.	Depth (m)	Thicknes s (m)	Resistivity (Ohm-m)	Formation Description
RADAT2-HERP 3	RAD2-3VES 1	0.0 – 1.7	2	1168	Dry top soil with volcanic boulders
		1.7 – 2.2	0.5	212	Dry soil with volcanic cobbles
		2.2 – 4.2	2	540	Slightly weathered volcanic rock

HERP No.	VES No.	Depth (m)	Thickness (m)	Resistivity (Ohm-m)	Formation Description
		4.2 – 13.1	9	68	Weathered formation composed of sand
		13.1 – 17.9	5	30	Moist/wet sandy clay with silts
		17.9 – 28.5	10.5	62	Wet sands
		28.5 – 56.4	28	50	Wet sands
		> 56.4		200	Slightly weathered volcanic rock
	RAD2-3VES 2	0.0 – 1.5	1.5	1841	Dry top soil with volcanic boulders
		1.5 – 2.8	1	966	Dry top soil with volcanic boulders
		2.8 – 11.4	9	165	Slightly weathered volcanic rock
		11.4 – 14.1	3	52	Wet sands
		14.1 – 26.9	3	25	Wet clay with silts
		> 26.9		10	Wet clay with silts
	RAD2-3VES 3	0.0 – 1.2	1	162	Top soil composed of sands and silts
		1.2 – 7.7	6.5	14	Wet clay with silt
		7.7 – 14.6	7	37	Moist/wet sandy clay with silts
		14.6 – 26.6	12	26	Wet clay with silts
		26.6 – 34.0	7	165	Slightly weathered volcanic rock
		> 34.0		1000	Fresh volcanic rock – phonolite
	RAD2-3VES 4	0.0 – 2.8	3	45	Top soil composed of fine sands and sits
		2.8 – 3.5	1	133	Weathered volcanic rock
		3.5 – 4.1	0.5	9	Moist clay with silt
		4.1 – 17.4	13	3	Wet clay
		17.4 – 30.8	13	7	Wet clay
		30.8 – 379	348	3	Thick layer of wet clay
		> 379		6	Wet clay
	RAD2-3VES 5	0.0 – 2.1	2	42	Top soil composed of fine sands and sits
		2.1 – 2.7	0.5	16	Wet clay with silt
		2.7 – 8.5	6	37	Moist/wet sandy clay with silts
		8.5 – 9.4	1	18	Wet clay with silt
		9.4 – 22.7	12	8	Wet clay
		> 22.7		20	Wet clay with silts
	RAD2-3VES 6	0.0 – 1.4	1	280	Top soil of sands and cobbles
		1.4 – 2.4	1	5	Wet clay

HERP No.	VES No.	Depth (m)	Thickness (m)	Resistivity (Ohm-m)	Formation Description
		2.4 – 8.3	6	6	Wet clay
		8.3 – 16.0	8	4	Wet clay
		16.0 – 22.5	6.5	8	Wet clay
		> 22.5		30	Wet sandy clay with silts

The deep control vertical electrical sounding (RADAT2-CVES 26) done at the top of the right abutment gives a more complete picture of the vertical geological variation at this site. A geological correlation cross section of proposed dam site 2 area is shown on Figure 3.6.

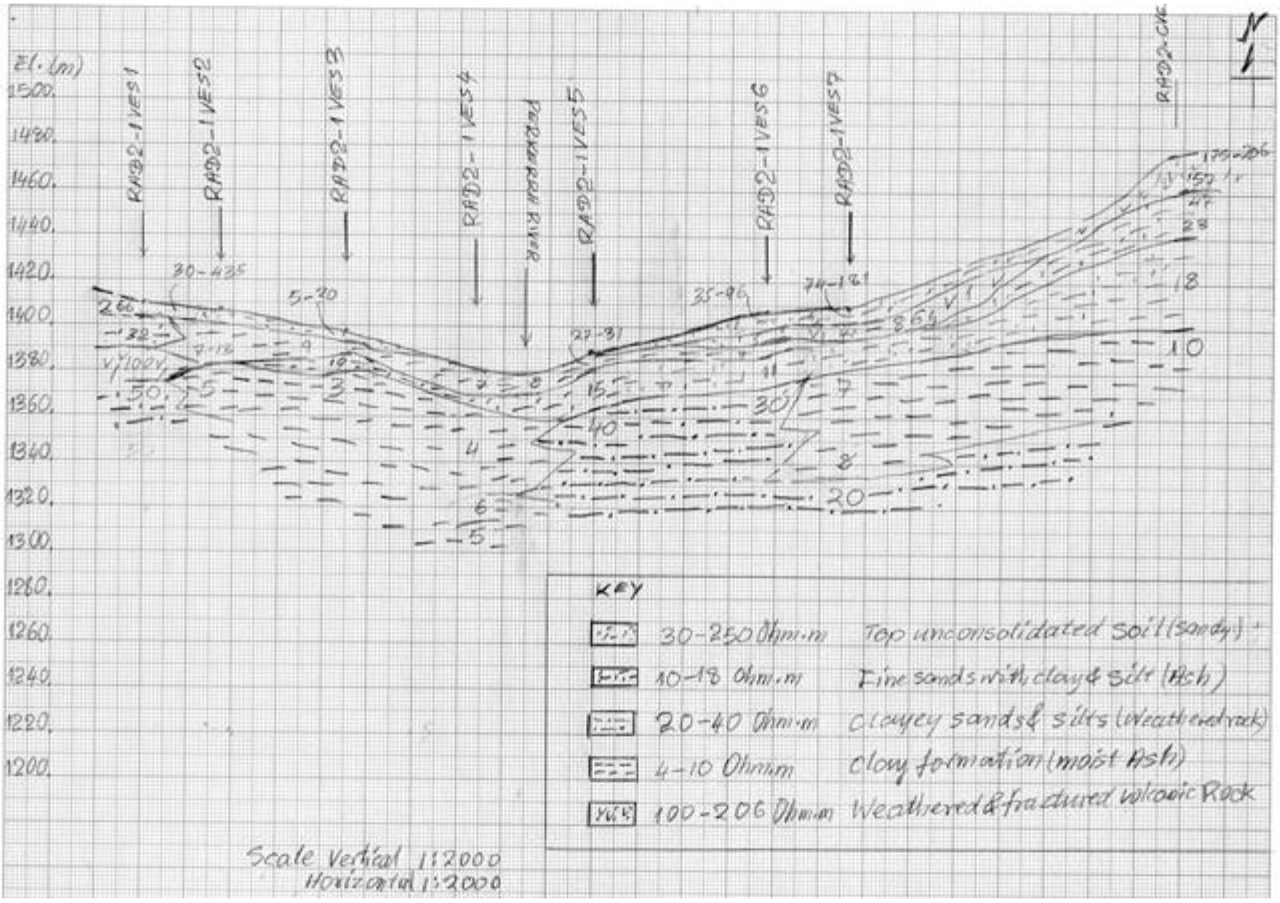

Figure 3:6 Geological Correlation map of Proposed Dam Site 2 Area

3.3.3 Assessment of Proposed Dam Site 3

Geological correlation cross section (Figure 3.20) shows that the foundation rocks at Radat Proposed Dam Site 3 are highly weathered and fractured. However, different rock formations have been differently affected by weathering. The foundation rocks may also have been affected by a minor fault that is notable at Radat area but not well observed at the site. The weathering and faulting actions have resulted in highly fragmented foundation rocks producing volcanic breccia, with clayey fine sands and silts leading in low resistivity values.

The deep control vertical electrical sounding (RADAT1-CVES 26) done at the top of the right abutment gives a more complete picture of the vertical geological variation at this site.

Reconnaissance geological and preliminary geophysical investigations were also carried out at Proposed Radat Dam Site 3 upstream of the Bridge (Kipting') on the road to Kenomoi, about 5km from Radat Trading Center. The layout plan of HERP and VES in Radat Proposed Dam Site 3 is shown in Figure 5.19 (field HERP Data is Shown Figure 5.20), while the same layout in 3D is given in Figure 5.21. The geological Correlation cross-section of Proposed Dam Site 3 Area is given on Figure 3.22. The coordinates and elevation of the VES in Radat Proposed Dam Site 3 are given in Table 3.9.

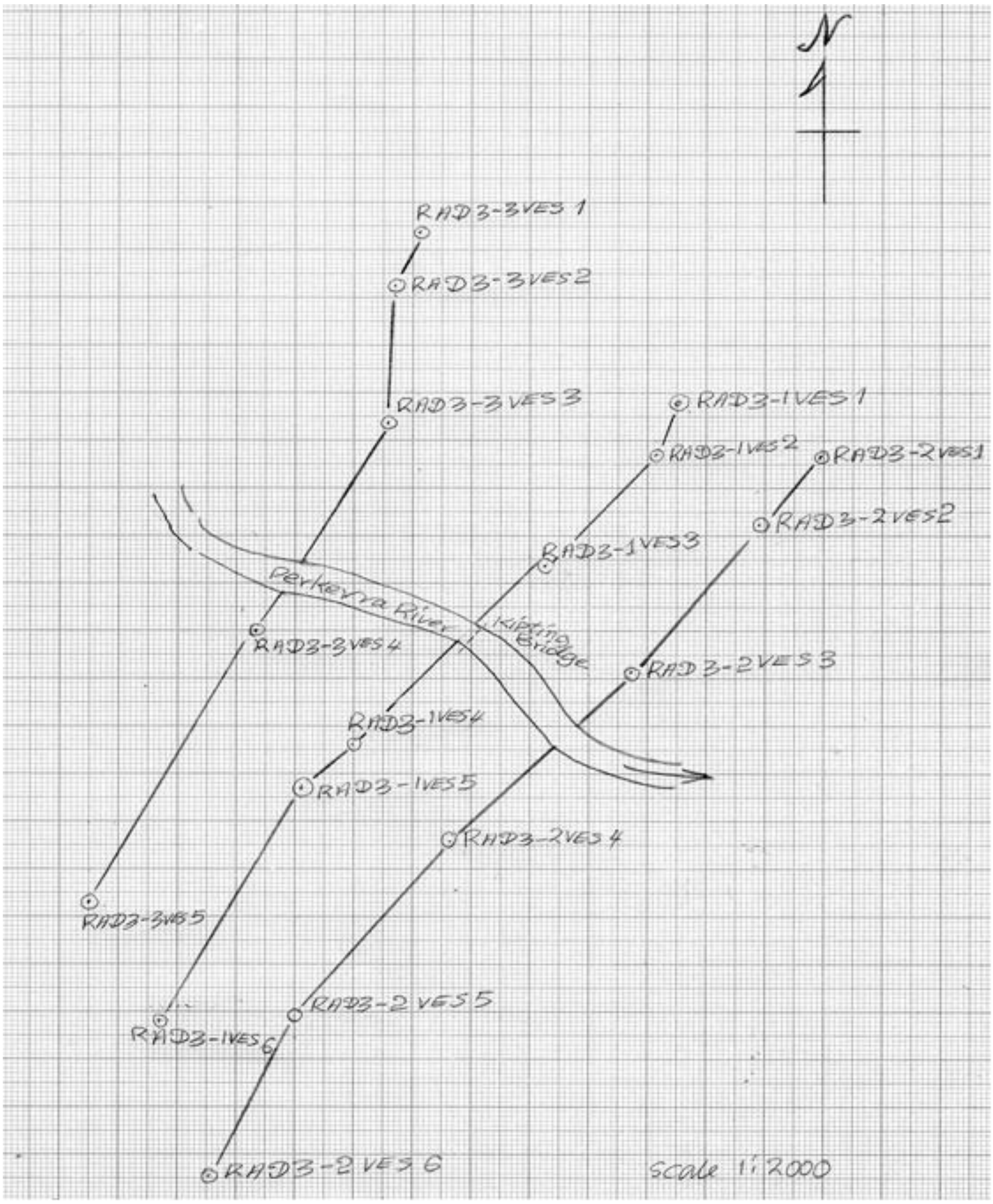

Figure 3:7 Layout plan of HERP and VES in Radat Proposed Dam Site 2

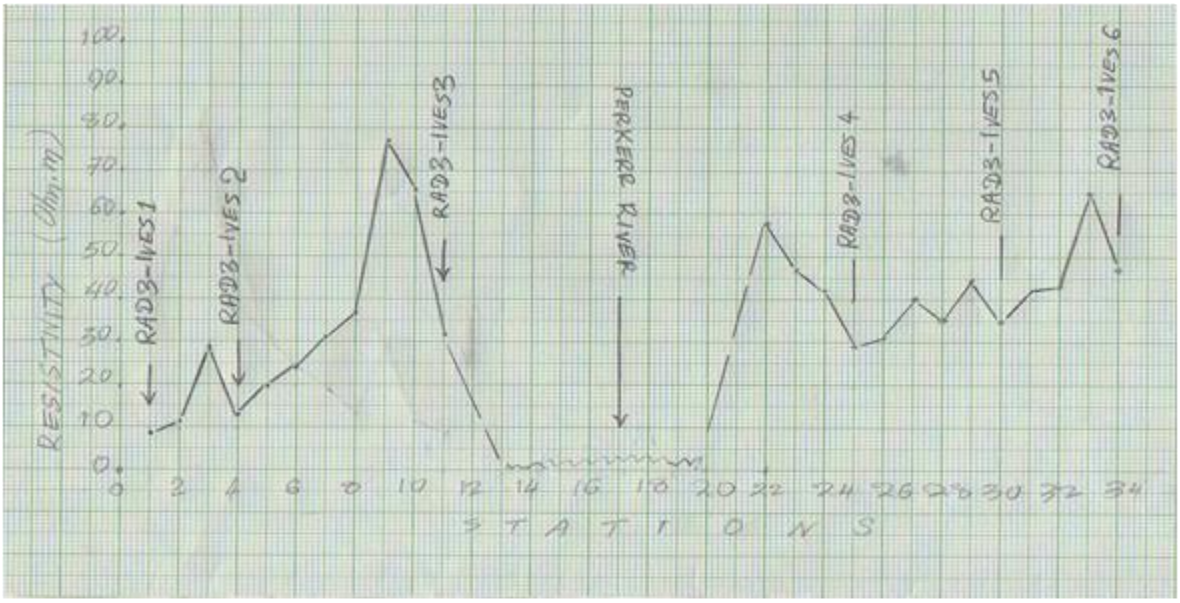

Figure 3:8 HERP Field Data

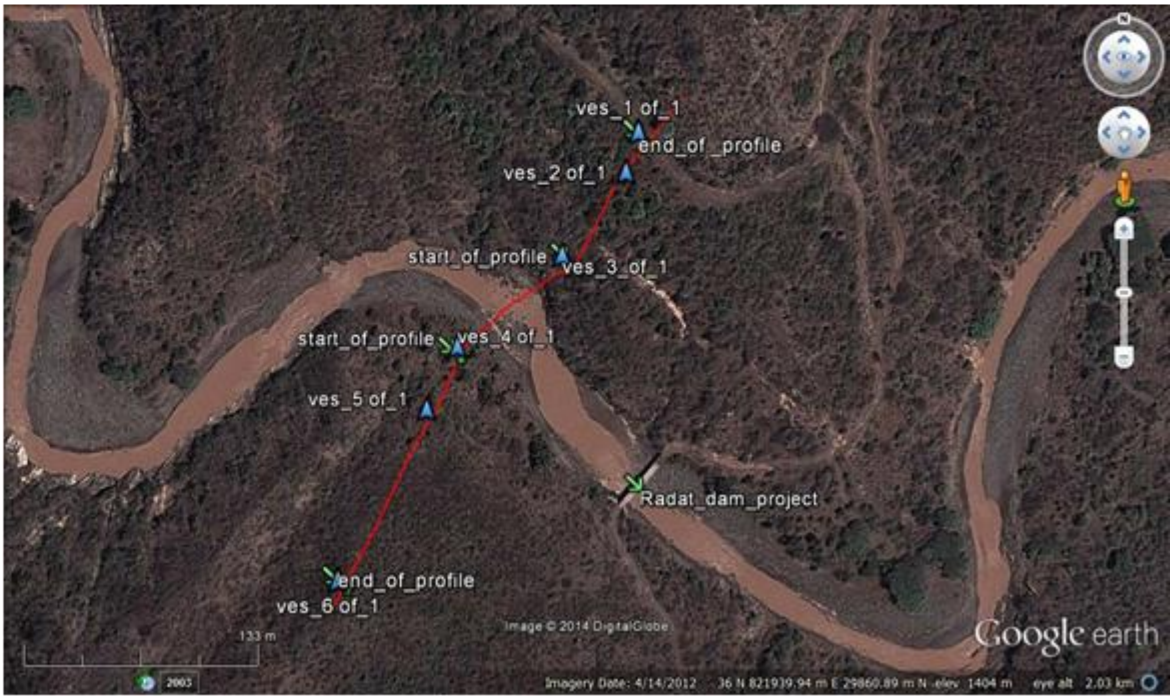

Figure 3:9 : Layout of HERP and VES in Dam Site 3 Kipting Bridge Area (in 3D)

Due to the rugged nature of the topography production of results in 2D tomography presented challenges because of many gaps resulting in extrapolations. We have generated a 2D tomography of the foundation using the electrical profiling and vertical electrical data obtained in the field. The generated 2D tomography is presented in Figure 3.9.

Table 3:9 Coordinates and Elevation of VES Points (HERP 1 - 3 in Dam site 3)

HERP LINE No.	VES No.	X	Y	Elevation (m)
RADAD3 HERP I	RAD3-1VES 1	0821970	0029976	1450
	RAD3-1VES 2	0821963	0029954	1436
	RAD3-1VES 3	0821925	0029907	1400
	RAD3-1VES 4	0821860	0029852	1386
	RAD3-1VES 5	0821842	0029814	1401
	RAD3-1VES 6	0821794	0029716	1446
RADAD3 HERP 2	RAD3-2VES 1	0822019	0029953	1443
	RAD3-2VES 2	0821998	0029924	1437
	RAD3-2VES 3	0821954	0029862	1412
	RAD3-2VES 4	0821893	0029811	1391
	RAD3-2VES 5	0821840	0029709	1440
	RAD3-2VES 6	0821811	0029651	1453
RADAD3 HERP 3	RAD3-3VES 1	0821882	0030047	1464
	RAD3-3VES 2	0821874	0030025	1456
	RAD3-3VES 3	0821872	0029968	1434
	RAD3-3VES 4	0821827	0029880	1386
	RAD3-3VES 5	0821770	0029767	1426

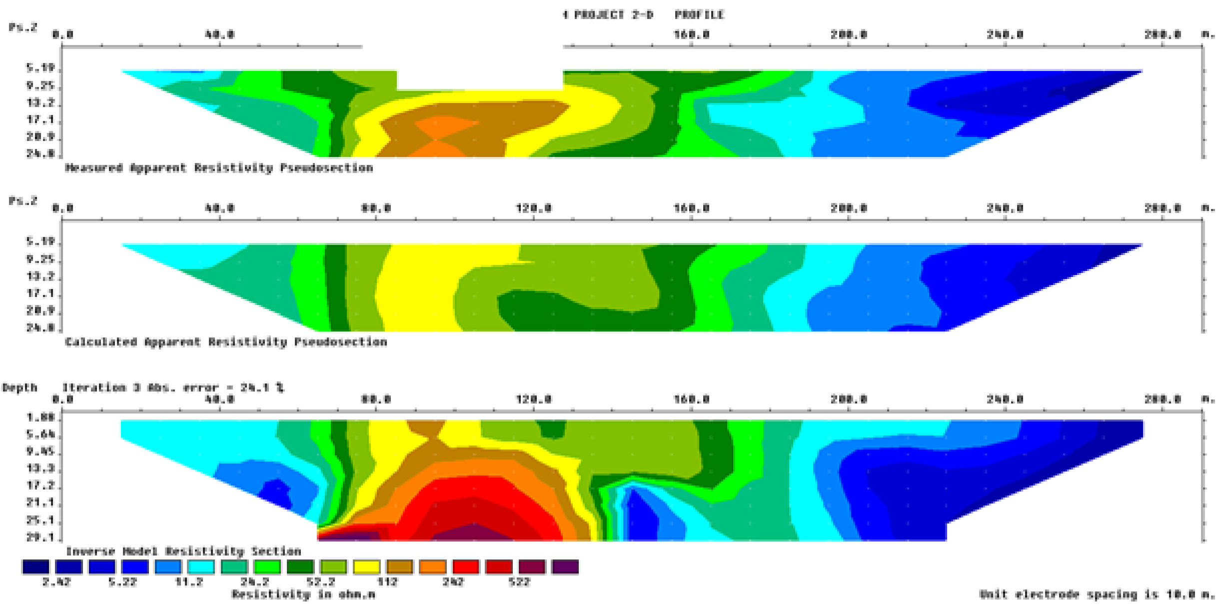

Figure 3:10 Generated 2D Geophysical Model of Selected Radad Dam Site (Kipting Bridge Area)

Notes:

1. 1) The foundation at the middle (center) this profile is underlain by clayey fine sandy formation (resistivity values 11.2 – 52.2 ohm.m). This is

the riverbed area. At depth the formation turns highly clay due to highly weathered older basalts of Saburu Type.

2. On the Left Hand Side a block relatively high resistivity values (52.2 – 522 ohm.m) was detected: this is of localized extent and it is due the young basalt exposed in this area overlying phonolites.
3. Further up on the left bank (resistivity values 5.2 – 112 ohm.m) is weathered phonolites resting/abutting on tuffs and sediments of Eldama Ravine Series (these were observed in the field (see Plate 2.4a above).
4. On the right hand side (Right Bank from riverbed area) the foundation is composed of weathered phonolites overlain by a thin layer of young basalts (Kwaibus type). The phonolites are underlain/abutting on tuffs and sediments (Eldama Ravine Type). The resistivity values progressively from 52.2 ohm.m to 2.42 ohm.m (from clayey sands to highly clay formation)

The evaluations compare very well with the geological correlation cross-section obtained from resistivity sounding (VES) data in Figure 3.13 below. The interpreted geophysical investigations results for Proposed Dam Site 3 are presented in Tables 3.10 – 3.12.

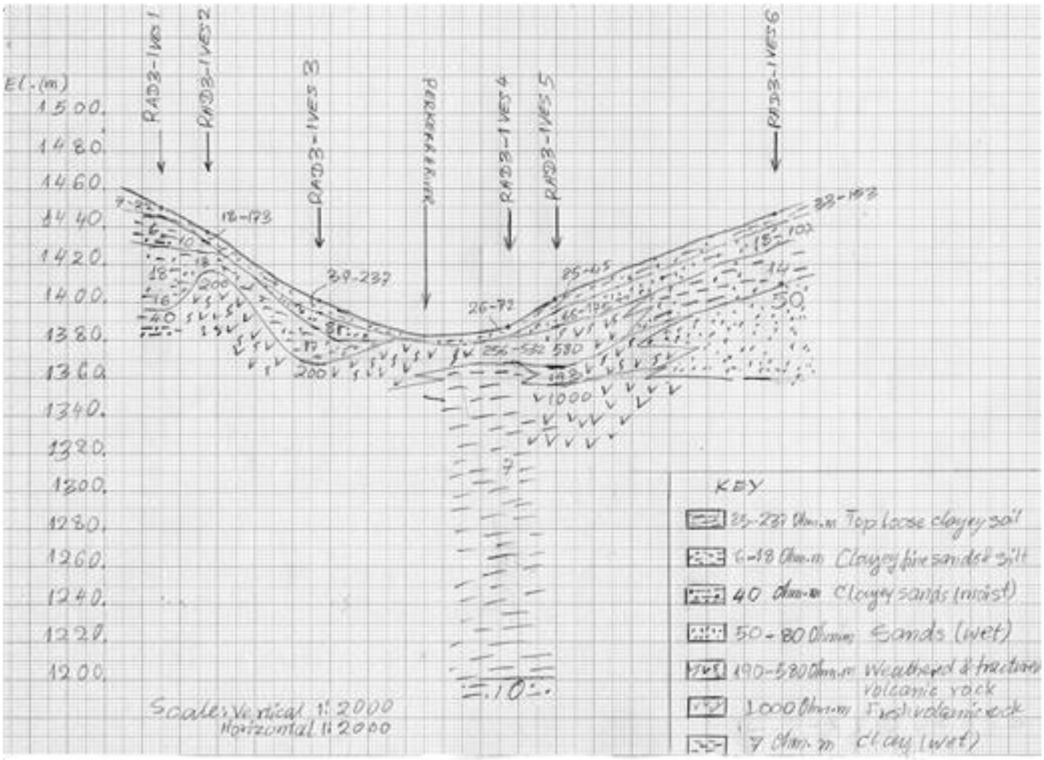

Figure 3:11 Geological correlation cross section along Profile Line 1 (Radad Site 3)

Table 3:10 Interpreted Geophysical Results for Dam SITE 3 HERP Line 1 (Proposed

HERP No.	VES No.	Depth (m)	Thickness (m)	Resistivity (Ohm-m)	Formation Description
RADAT3-HERP 1	RAD3-1VES 1	1.0 – 1.5	1.5	1841	Top very slightly fractured volcanic rock

HERP No.	VES No.	Depth (m)	Thickness (m)	Resistivity (Ohm-m)	Formation Description
		1.5 – 2.8	1	966	Slightly Afractured rocks
		2.8 – 11.4	9	165	Weathered volcanic rock – moist
		11.4 – 14.1	3	52	Weathered wet volcanic sandy formation
		14.1 – 26.9	3	25	Wet clay with fine sands and silts
		> 26.9		10	Wet clay with silt
	RAD3-1VES 2	0.0 – 1.2	1	162	Weathered volcanic rock – moist
		1.2 – 7.7	6.5	14	Wet clay with silt
		7.7 – 14.6	7	37	Wet clay with fine sands
		14.6 – 26.6	12	26	Wet clay with fine sands and silts
		26.6 – 34.0	7	165	Slightly weathered wet volcanic rock
		> 34.0		1000	Fresh volcanic rocks - phonolites
	RAD3-1VES 3	0.0 – 2.8	3	45	Top soil composed of clayey fine sands
		2.8 – 3.5	1	133	Slightly weathered volcanic rock
		3.5 – 4.1	0.5	9	Thin layer of wet clay
		4.1 – 17.4	13	3	Wet clay
		17.4 – 30.8	13	7	Wet clay
		30.8 – 379	348	3	Thick layer of wet clay
		> 379		6	Wet clay
	RAD3-1VES 4	0.0 – 2.1	2	42	Top soil composed of clayey fine sands
		2.1 – 2.7	0.5	16	Wet clay with silt
		2.7 – 8.5	6	37	Wet clayey fine sands and silts
		8.5 – 9.4	1	18	Wet clay with fine silts
		9.4 – 22.7	12	8	Wet clay
		> 22.7		20	Wet clay with fine sands and silts
	RAD3-1VES 5	0.0 – 1.4	1	280	Slightly weathered volcanic rock
		1.4 – 2.4	1	5	Wet/moist clay
		2.4 – 8.3	6	6	Wet/moist clay
		8.3 – 16.0	8	4	Wet clay
		16.0 – 22.5	6.5	8	Wet clay

HERP No.	VES No.	Depth (m)	Thickness (m)	Resistivity (Ohm-m)	Formation Description
		> 22.5		30	Wet clayey fine sands and silts
	RAD3-1VES 6	0.0 – 1.2	1	45	Top soil composed of clayey fine sands
		1.2 – 2.2	1	25	Wet clay with silt
		2.2 – 2.7	0.5	43	Wet clayey fine sands and silts
		2.7 – 6.8	4	172	Slightly weathered volcanic rock
		6.8 – 14.8	8	66	Wet sandy formation
		14.8 – 35.5	21	580	Very lightly fractured volcanic rock
		35.5 – 44.1	9	193	Slightly weathered volcanic rock
		> 44.1		1000	

Table 3:11 Geophysical Results for Dam SITE 3 HERP Line 2 (50m Downstream of Dam Axis)

HERP No.	VES No.	Depth (m)	Thickness (m)	Resistivity (Ohm-m)	Formation Description
RADAT3-HERP 2	RAD3-2VES 1	0.0 – 2.0	2	45	Top soil composed clayey fine sands
		2.0 – 2.1	0.1	3	Wet clay
		2.1 – 6.3	4	5	Wet clay
		6.3 – 87.5	81	3	Wet clay
		> 87.5		10	Moist clay with silts
	RAD3-2VES 2	0.0 – 1.0	1	20	Top soil composed clay
		1.0 – 7.2	6	7	Moist/wet clay
		7.2 – 11.9	4	9	Wet clay
		11.9 – 12.0	0.1	7	Wet clay
		12.0 – 19.9	8	6	Wet clay
		19.9 – 50.0	30	7	Wet clay
		> 50.0		3	Wet clay
	RAD3-2VES 3	0.0 – 1.1	1	271	Loose top soil composed of boulders
		1.1 – 3.6	2.5	27	Moist clay soil
		3.6 – 14.1	10.5	95	Moist sand formation
		14.1 – 251	137	8	Wet clay
		> 251		15	Wet clay with silts and fine sands
	RAD32-	0.0 – 2.0	2	98	Loose top soil – sandy

	2VES 4	2.0 – 2.5	0.5	47	Moist clayey fine sands and silts
		2.5 – 6.3	4	83	Wet/moist sands
		6.3 – 17.4	11	43	Moist clayey fine sands and silts
		17.4 – 51.0	34	66	Wet sands
		51.0 – 55.0	4	45	Wet clayey fine sands and silts
		> 55.0		1000	Fresh volcanic rocks (phonolites)
	RAD3-2VES 5	0.0 – 1.4	1	119	Top loose and dry soil
		1.4 – 3.2	2	9	Moist clayey soil
		3.2 – 7.2	4	41	Wet/moist clayey fine sands and silts
		7.2 – 25.2	18	28	Wet sandy clay with silts
		25.2 – 26.0	1	20	Wet sandy clay with silts
		26.0 – 78.3	52	8	Thick layer of wet clay
		> 78.3		40	Wet clayey fine sands and silts
	RAD3-2VES 6	0.0 – 1.4	1	38	Top moist clayey soil
		1.4 – 2.4	1	13	Moist clayey soil
		2.4 – 20.6	18	28	Wet sandy clay with silts
		20.6 – 22.2	2	20	Wet sandy clay with silts
		22.2 – 43.8	22	15	Wet clay with silts
		> 43.8		40	Wet clayey fine sands and silts

Table 3:12 Geophysical Results for Dam SITE 3 HERP Line 3 (50m Upstream of Dam Axis)

HERP No.	VES No.	Depth (m)	Thickness (m)	Resistivity (Ohm-m)	Formation Description
RADAT3-HERP 3	RAD3-3VES 1	0.0 – 1.8	2	76	Moist loose top soil (clayey fine sands)
		1.8 – 6.2	4	53	Wet sands and silts
		6.2 – 22.5	16	9	Wet Clay formation (deep weathering)
		22.5 – 51.1	29	9	Wet Clay formation (deep weathering)
		> 51.1		30	Wet sandy clays and silts
	RAD3-3VES 2	0.0 – 1.5	1.5	45	Moist loose top soil (sands clay)
		1.5 – 2.3	1	13	Wet sandy clays with silts
		2.3 – 14.6	12	3	Wet Clay from (deep

HERP No.	VES No.	Depth (m)	Thickness (m)	Resistivity (Ohm-m)	Formation Description
					weathering)
		14.6 – 20.3	6	8	Wet Clay formation (deep weathering)
		> 20.3		50	Wet sands and silts
	RAD3-3VES 3	0.0 – 1.5	1.5	174	Top unconsolidated soil will boulders
		1.5 – 5.7	4	18	Wet sandy clays with silts
		5.7 – 14.6	9	59	Wet sands
		14.6 – 31.1	17	19	Wet sandy clays with silts
		> 31.1		40	Wet clayey sands and silts
	RAD3-3VES 4	0.0 – 1.1	1	61	Top loose clayey soils
		1.1 – 2.8	2	9	Wet Clay formation (deep weathering)
		2.8 – 8.7	6	18	Wet sandy clays with silts
		8.7 – 10.7	2	14	Wet sandy clays with silts
		10.7 – 25.0	14	68	Wet sands- aquiferous
		> 25.0		800	Slightly fractured volcanic rocks
	RAD3-3VES 5	0.0 – 1.3	1	118	Loose top soil with weathered boulders
		1.3 – 8.9	7.5	45	Wet clayey sands and silts
		8.9 – 10.0	2	61	Wet sands- aquiferous
		10.0 – 19.2	9	25	Wet Clayey fine sands and silts
		19.2 – 44.7	25.5	15	Wet sandy clays with silts
		> 44.7		40	Wet clayey sands and silts

Figure 3:12 Geophysical investigations in progress at Dam site 3

3.3.4 Assessment of Proposed Dam Site 3

Geological correlation cross section (Figure 3.20) shows that the foundation rocks at Radat Proposed Dam Site 3 are highly weathered and fractured. However, different rock formations have been differently affected by weathering. The foundation rocks may also have been affected by a minor transverse fault that is notable at Radat area but not well observed at the site. The weathering and faulting actions have resulted in highly fragmented foundation rocks producing volcanic breccia, with clayey fine sands and silts leading in low resistivity values. Of particular interest is thick layer of clay observable at the riverbed area at this site.

3.4 Discussion

Both field geological reconnaissance survey and preliminary geophysical investigations have indicated that the foundation rocks at the three proposed Radat dam sites are highly weathered and slightly fractured. The geological correlation cross sections at the three proposed dam sites are generally similar:

- The foundation at the riverbed is composed of clayey fine sands and silts with a thickness of over 80m (in all the three dam sites);
- The foundation on the abutments is composed highly weathered volcanic rocks (basalts of Samburu Basalt Series) which are mainly clayey sands gravel;
- At dam site 1 the right hand side abutment (the upper section) the foundation is composed of fresh volcanic rocks (basalts of Kwaibus series) – these basalts are observable on the detailed reconnaissance map (Figure 3.4);
- At dam site 2 the upper section composed of fresh volcanic rocks is absent; the foundation is composed of highly weathered rocks with fragments underlying parent rocks;
- The foundation on left hand side abutment is similar in all the three dam sites and is composed of highly weathered basalts of Samburu basalt series; and
- The foundation at dam site 3 the river bed area is underlain by a very clay layer of 100m.

A general observation is that the at depth the foundation is composed of clays with silts and clayey fine sands which are deemed to be products of weathering of the oldest rock in this area – the Samburu basalts (these well exposed at dam site 3).

4 PRELIMINARY CONSTRUCTION MATERIALS INVESTIGATIONS

4.1 Overview of Constructions Materials Survey

During reconnaissance visits it was observed that soils suitable for in an earth fill dam were apparently absent. It was therefore proposed that since the project area is replete with rocks can be used for a rock fill dam, preliminary survey to identify areas with potential rock fill construction materials.

During the current preliminary survey observations were made at areas with potential as source areas for impervious core identified.

4.2 Soil Sampling by Trial Pits

Preliminary soil sampling by trial pits was done at areas with potential as source areas for impervious core materials. It was noted that in most localities the soils were shallow grey and brownish clayey silts and fine sands with gravel and cobbles derived from the weathering the underlying volcanic rocks.

Seven trial pits (TP) were dug and samples collected: One (1) at Radat Dam Site 1, Four (3) at Radat Dam Site 2 and Three (3) at Radat Dam Site 3. The coordinates of points the where the samples were collected are given in Table 5.13. Test was also made on a rock sample collected from the riverbed area.

4.3 Results of Laboratory Soil Testing

The soils have been taken for laboratory but the full results have not been received.

Table 4:1 Coordinates of Trial Points

Dam Site	TP No.	Coordinates		Remarks
		X	Y	
RADAT SITE 1	TP2- Rad 1 (LB)	0823922 (E)	0031111 (N)	On Figure 3.
RADAT SITE 2	TP1-Rad 2 (LB)	0822994 (E)	0030664 (N)	On Figure
	TP2- Rad 2	0823440 (E)	0030083 (N)	On Figure
	TP3- Rad 2	0823782 (E)	0031178 (N)	On Figure
RADAT SITE 3	TP1- Rad 3	0821969 (E)	0029972 (N)	On Figure 3.7
	TP2- Rad 3	0822020 (E)	0029700 (N)	Plate 4.1
	TP3- Rad 3	0822120 (E)	0029512 (N)	On Figure 3.7

One particular soil sample seems to have promising characteristics was collected from TP near the Bridge (Kipting). This area is recommended detailed soil investigation by auger method. A spot of this area is shown in the figures below

Figure 4:1 **A Layer of Red Clay Soil in Tuffs and Sediments (Soil sample collected here)**

Figure 4:2 **A Layer of Red Clay Soil – same above sowing overlying Basalts**

Kwaibus Basalts (Tvb_3) Red Clay Soil at the top of Tuffs and Sediments (Tvf_2)

4.4 Results of Laboratory Soil Testing

The samples were submitted for laboratory analyses to the "Soil Mechanics Laboratory, of Civil & Construction Engineering of University of Nairobi". The results of laboratory testing are summarized in Table 4.2.

Table 4:2 Summary of Laboratory Soil Testing Results

Sample	Atterberg Limits				Compaction 2.5kg		Triaxial		Permeability	Sieve Analysis
	LL %	PL %	PI %	SL %	MDD g/cm^3	OMC %	C Kg/cm^2	ø deg.	K cm/sec	
TP2- Rad 1 (LB)	34	I8	16	5.7	1576	19.6	0.04	26^0	7.939×10^{-5}	See graph
TP1-Rad 2 (LB)					1414	25.1	0.08	26^0	1.020×10^{-4}	See graph
TP1-Rad 2 (RB)							0.08	25^0	5.021×10^{-4}	See graph
TP2- Rad 2 (0.9m)	53	28	25	10	1559	18.5	0.13	23^0	1.250×10^{-3}	See graph
TP3- Rad 2					1685	16.1	0.12	23^0	4.486×10^{-5}	See graph
TP1- Rad 3					1498	23.3	0.07	27^0	3.836×10^{-4}	See graph
TP2- Rad 3					1712	13.6	0.10	24^0	7.931×10^{-4}	See graph
TP3- Rad 3					1256	34.4	0.08	27^0	2.707×10^{-4}	See graph

Notes: Results of the following tests are attached in the soil Laboratory test results Appendix.

a. *Results for Sieve Analysis – the grading curve graphs are given separately.*
b. *Pin Hole Test indicated that all the samples are NON DISPERSIVE.*
c. *Consolidation and UCS presented separately*

4.5 Interpretation of Soil Testing Results

4.5.1 Particle Size Grading (sieve analysis)

The sieve analyses for eight (8) samples and one rock sample indicate percentage passing Sieve No. 200 (grain size for fine sand) is more than 60% for nearly all the soil samples and that the percentage retained is less than 50%. This means that all the samples are fine grained and further classification can be done using Atterberg Limits (results on Atterberg Limits were received for two samples only). These will be analysed using Plasticity Chart in order to get a further representative classification of the soils in the project area. Otherwise the soils in the project area are clayey fine sands with some gravel. The fact that the soils are non-dispersive is an indication that the silt content is low. The grading curves are presented in Figure 4.3 to 4.10

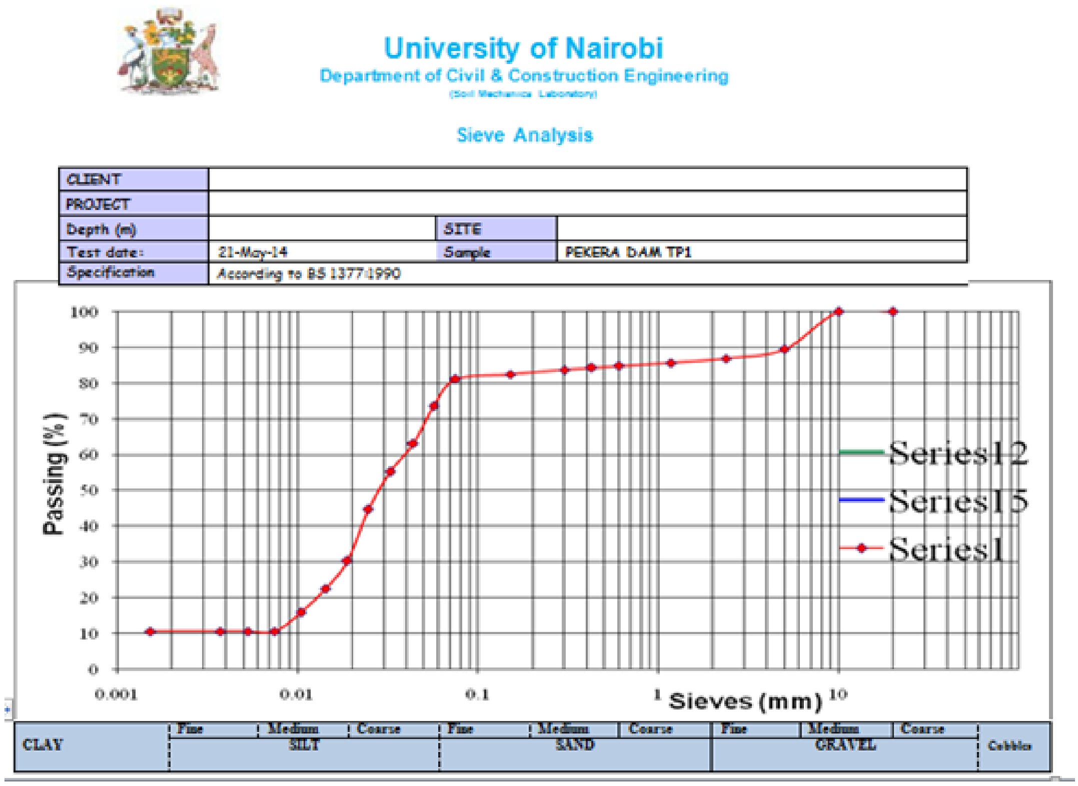

Figure 4:3 Grading curve for Pekera Dam TP1

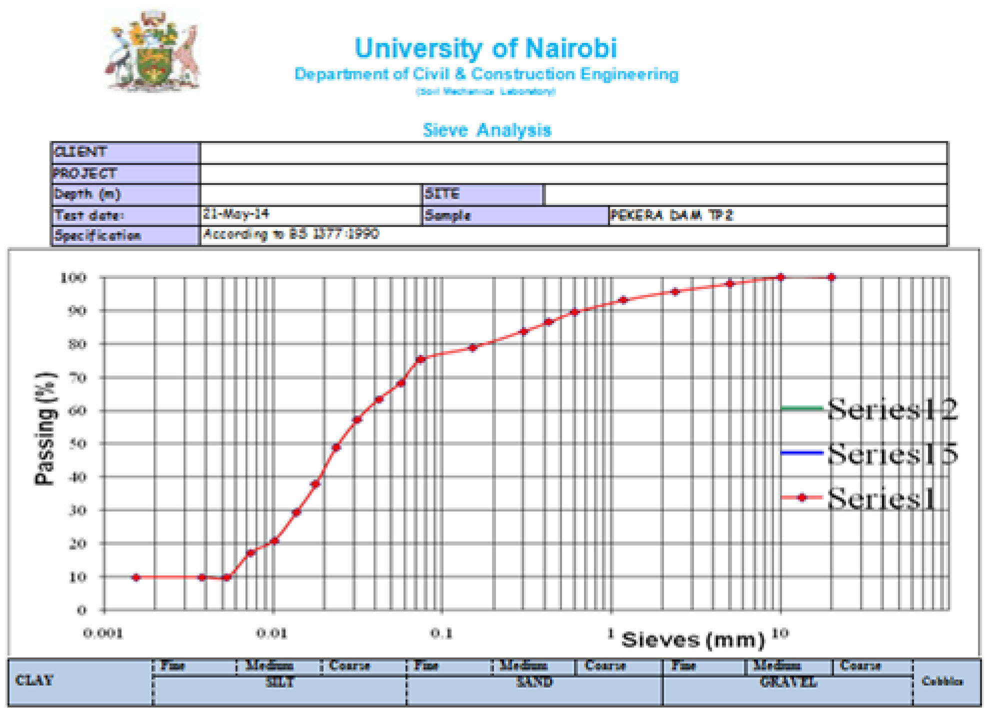

Figure 4:4 Grading curve for Perkerra Dam TP2

University of Nairobi
Department of Civil & Construction Engineering
(Soil Mechanics Laboratory)

Sieve Analysis

CLIENT			
PROJECT			
Depth (m)		SITE	
Test date:	21-May-14	Sample	PEKERA DAM TP3
Specification	According to BS 1377:1990		

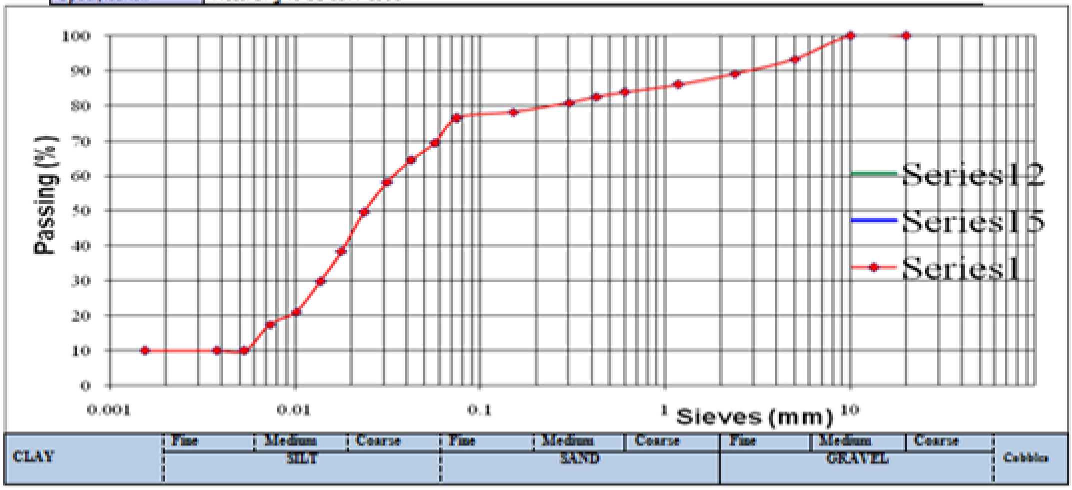

Figure 4:5 Grading curve for Perkera Dam TP3

University of Nairobi
Department of Civil & Construction Engineering
(Soil Mechanics Laboratory)

Sieve Analysis

CLIENT			
PROJECT			
Depth (m)		SITE	
Test date:	21-May-14	Sample	REDDAD KIPLIN SITE TP1 Ra3
Specification	According to BS 1377:1990		

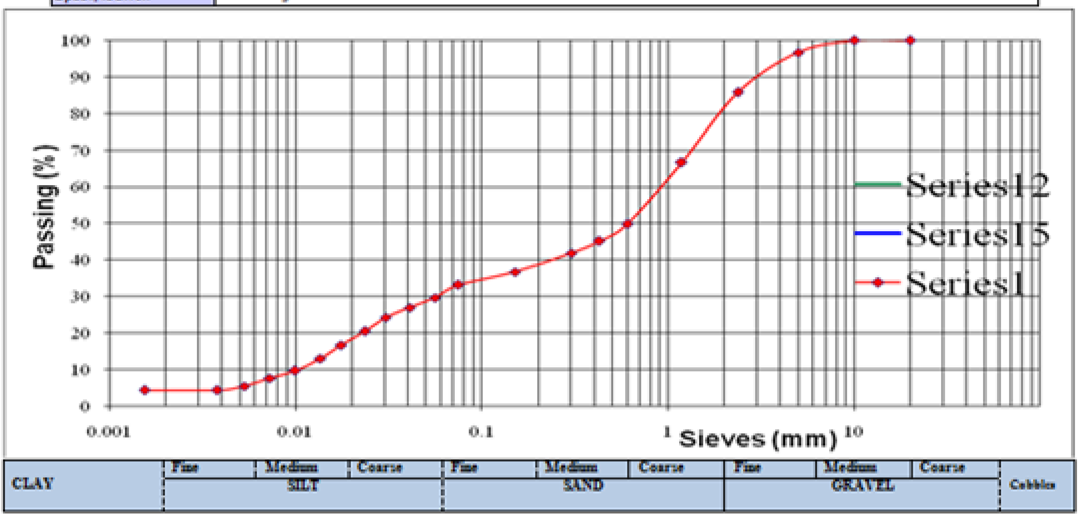

Figure 4:6 Grading curve for REDAD KIPLIN SITE TP1 Rad 3

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(Soil Mechanics Laboratory)

Sieve Analysis

CLIENT			
PROJECT			
Depth (m)		SITE	
Test date:	21-May-14	Sample	ROCK SAMPLE TAKEN AT RIVER BED
Specification	According to BS 1377:1990		

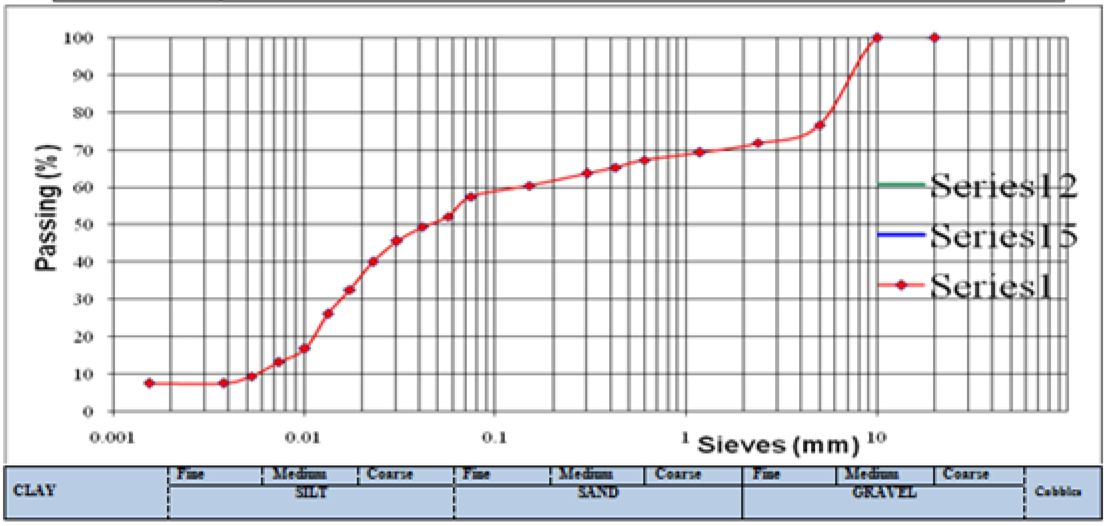

Figure 4:7 Grading curve for Rock sample taken at River bed

University of Nairobi

Department of Civil & Construction Engineering

(Soil Mechanics Laboratory)

Sieve Analysis

CLIENT			
PROJECT			
Depth (m)		SITE	
Test date:	21-May-14	Sample	TP 1 Ra2 (1B) About 100m from Riverbed
Specification	According to BS 1377:1990		

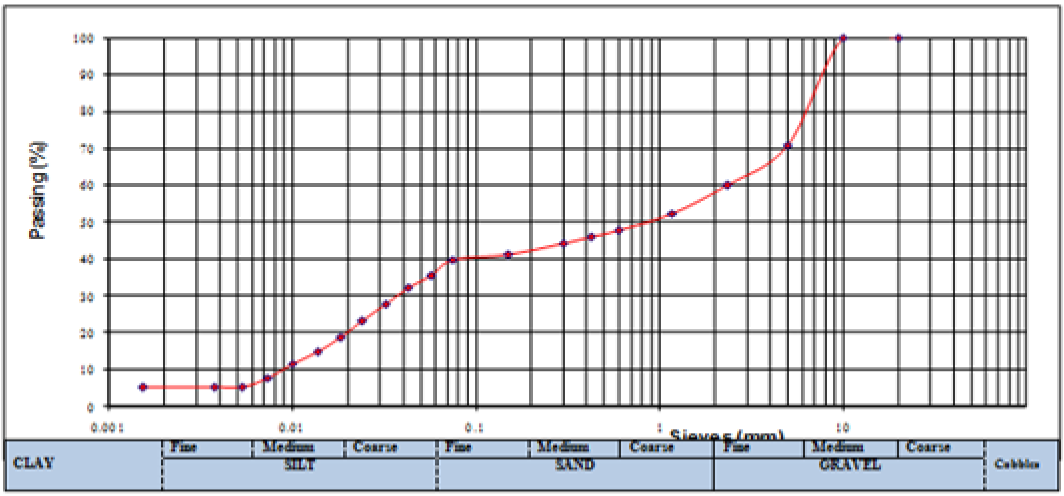

Figure 4:8 Grading curve for TP1 Re2 about 100, from Riverbed

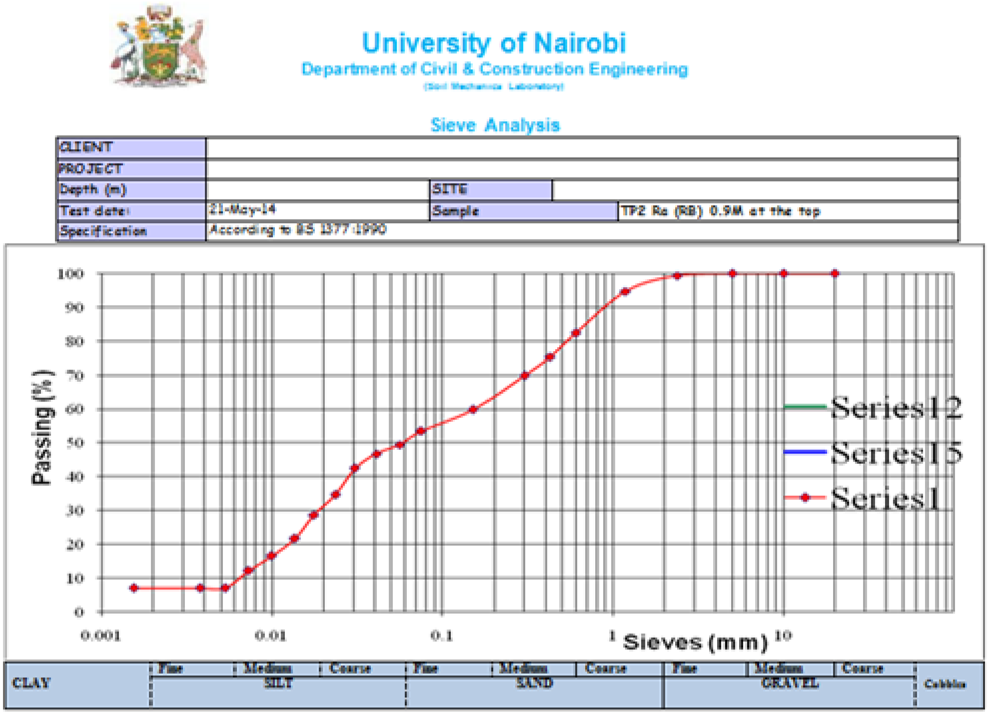

Figure 4:9 Grading curve for TP2Ra (RB) 0.9M at the top

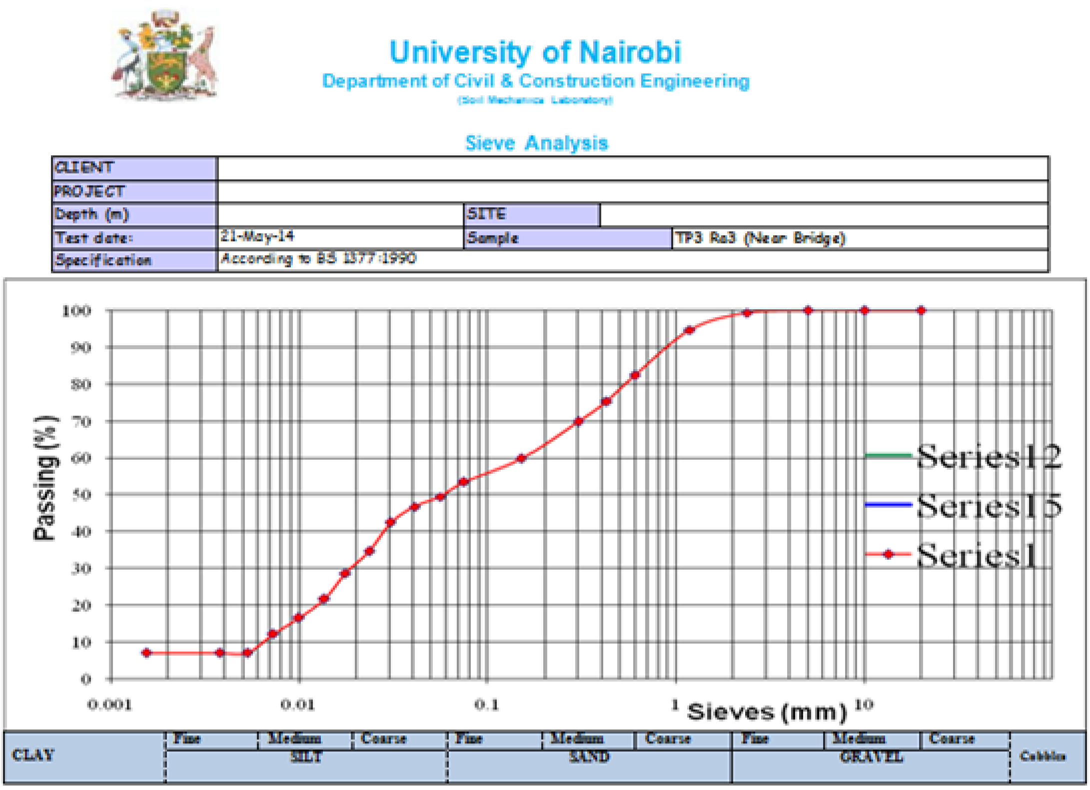

Figure 4:10 Grading curve for TP3 Rad 3 near bridge

Comments:

1) Curve for sample TP1-Rad2 (LB) is CLAYEY fine SAND with some gravel.
2) Curve for sample TP1- Rad 2 (LB) is fine SAND with gravel.
3) Curve for sample TP1- Rad 2 (LB)-taken from100m from riverbed is silty sand with gravel.
4) Curve for sample TP2- Rad 2 is fine SAND with gravel.
5) Curve for sample TP2- Rad 2 (0.9m) from upper zone (0.9m depth) is fine silty SAND with very little gravel.
6) Curve for sample TP1- Rad 3 – in Kipting area is fine SAND with gravel and some silt.
7) Curve for sample TP2- Rad 3 is SAND with some silt and some little gravel.
8) Curve for sample TP3- Rad 3 (Kipting near the Bridge) is fine SAND with some silt little gravel.
9) Curve for rock sample taken from the riverbed is sand with gravel.

All samples indicate they are fine SANDS with gravel and a few with silt. The FINES will be classified using Plasticity Charts.

4.5.2 Atterberg Limits

In using Atterberg Limits to classify the fine grained soils a Plasticity Chart was drawn and Plasticity Indices are plotted against the Liquid Limits for all the samples analyzed. Clays plot above the A-line while Silts plot below it.

The soils samples analyzed for Radat Dam Site plot above A-line, indicating that the soils are Clays with some fine sand and some silt. This is a good finding because silts are incompressible and also tend to cause piping. The Plasticity Chart for samples analyzed is presented on Figure 4.11.

The suitability of the soils as fill material is also confirmed by the relatively high Plasticity Index for the individual (seven greyish browm) soil samples. By definition Plasticity Index of a soil is 'the range of moisture content over which soil is plastic or malleable'. In the given soil samples the Plasticity Index lies between 18 % and 35 % with an average of 25%. This consideration excludes results for sample of rock collected from the riverbed area.

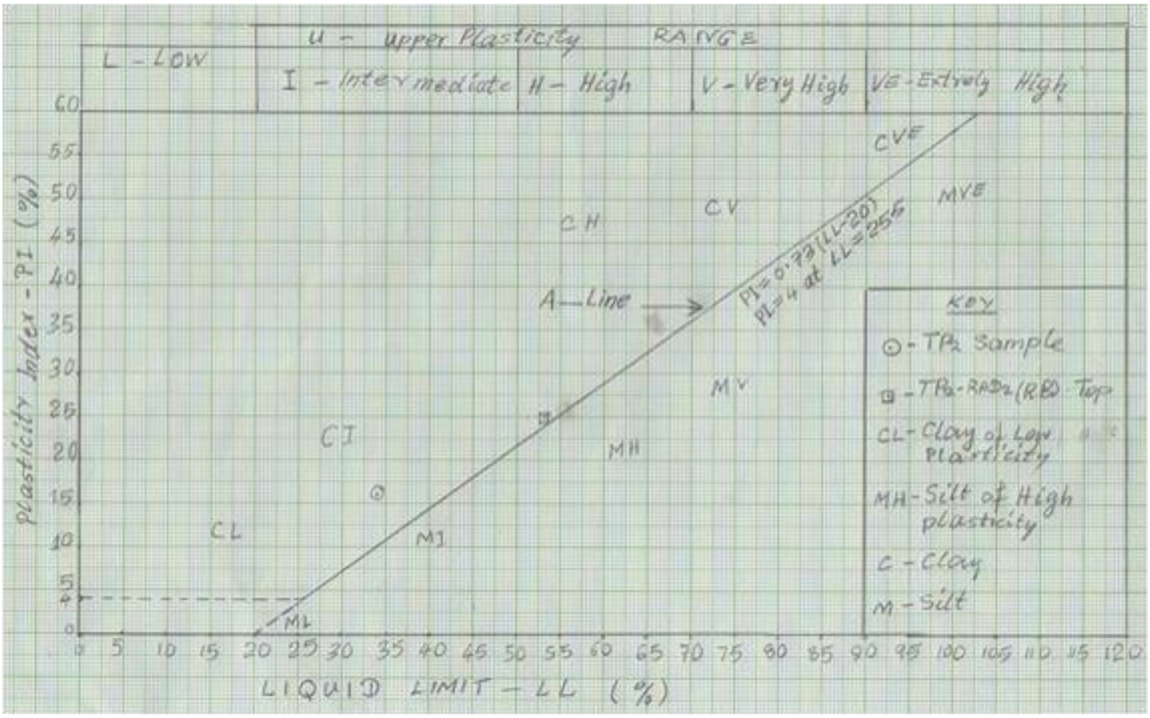

Figure 4:11 Plasticity Chart for Samples analyzed

Note: All samples plot above "A" – Line, the FINES are Clay

The soils are clearly fine SAND with some FINES. A further refined classification may be used, combining the use of ***A-line*** and ***U-line***. This is used when LL = 45% and PI = 25%. The samples collected have average LL = 43.5% and PI = 20.5%. The equation for ***A-line*** is PI = 0.73(LL-20), while for ***the U-line*** it is PI = 0.9(LL-8). The final further classification is shown on Figure 4.3.

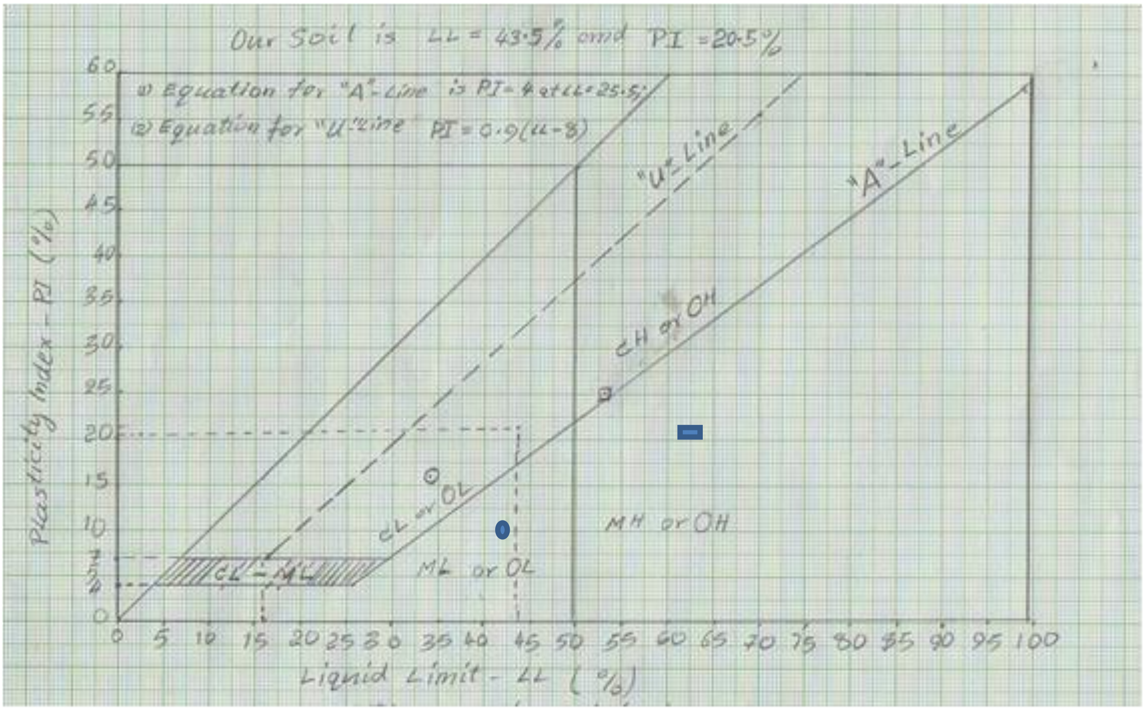

Figure 4:12 Plasticity Chart for the Samples Analyzed

TP2 — TP2-Rad 2 Sample (RB) at the top

From these evaluations the soils are clayey fine SANDS (SCI to SCH) of intermediate to high plasticity with some gravel.

4.5.3 Other Soil Characteristics

Compaction Tests (Proctor Test)

Compaction tests indicate that Maximum Dry Density (MDD) ranges between 1256g/cm³ and 1712g/cm³ (with an average of 1529 g/cm³) and Optimum Moisture Content (OMC) ranges between 13.6% and 34.4% (with an average of 21.5%). This means that the soils are compactible but the rather low OMC means low requirement of water due to the sandy nature of the soil.

Shear Box Tests

Shear Box test results indicate that the Cohesion Coefficient C varies between 0.04 and 0.13kg/cm2 with an average of 0.09kg/cm2. This is due to the presence of fine sand but the Cohesion Coefficient C is acceptable. The angle shearing, ø has range of 23° to 27° with an average of 25° which acceptable although ideally it should be in the range 18° – 24°.

Permeability K

The soils have a high permeability Coefficient K ranging between 6.213 x 10-5 and 1.250 x 10-3 cm/sec. In equivalent terms this is in the range of 51.8 – 833.3 lugeon values. This is rather very high permeability that will require foundation treatment by grouting.

4.5.4 Filter Materials (Sand)

No investigations were conducted for evaluation of filter materials. However, there is sand along the riverbed which needs to be tested and evaluated for suitability for use as filter material. The dam site is replete with rocks and boulders of volcanic origin that will require to be tested for suitability as rock-fill dam construction and also for construction aggregate. Any filter sand must satisfy the following criteria:

- **D15filter/D15base ≥ 5, and**
- **D15filter/D85base ≤ 5;**
- where: D15filter = sieve opening size that allows 15% of the filter material to pass;
    - D15base = sieve opening size that allows 15% of the base material to pass; and
    - D85base = sieve opening size that allows 85% of the base material to pass.

These are the criteria to be checked for sand samples, especially sand in relation to the embankment fill material which will be used as the base material (these requirement criteria may be varied for a rock-fill dam).

4.5.5 Proposed Type of Dam

On evaluation of the geological setting of the project area (the structural geology and the tectonics), we note that the area is underlain by rocks highly weathered volcanic rocks (basalts and phonolites that have affected by faulting in the general). The seismicity is taken into account in deciding a design basis earthquake (DBE) loading of amax = 0.30g and maximum credible earthquake (MCE) of amax = 0.45g in stability analysis during the designing of Radat dam. Further seismic profiling proposed during detailed geological investigations will shed more light on the conditions the foundation.

Construction materials in form red clay soil for an impervious core is apparently available within the dam site, but shell material will be readily available for both rock-fill and Rip Rap. Red clay soils will be further assessed at Radat Dam Site 3 area which also the preferred dam site for this project.

We therefore proposed ***a zoned rock-fill dam with an impervious core***. The only materials to be evaluated in detail to estimate the quantity is the red clay soils. The aggregate and sand for construction of the diversion channel (and other concrete works) can be sourced within the dam site area.

5 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The results of both reconnaissance geological survey and preliminary geophysical investigations have confirmed findings of desk study that the geology of the proposed Radat dam project area is composed of volcanic rocks of Miocene to Pliocene age.

Tuffs intercalated with sediments of the same age are also present in this area but with limited.

The rocks the project area are highly weathered and only slightly fractured. The deeper foundation rocks composed of basalts of Samburu type are more weathered than the upper horizons. The general project area has been affected by grid faulting but the nearest observed fault zone is around Radat Trading Center but it disappears as one approaches dam site 1 (the lower dam site). It significant to note within the proposed Radat dam project area rocks on the right hand side of Perkerra River are part of downthrown block of younger rocks that abut on older rocks on the left hand side of Perkerra River: This may mean that the older faulting may have been obscured the younger lava flows.

The foundation rocks in the three dam sites have undergone almost similar pattern and intensity of weathering however, dam site 1 (the lower dam site) has apparently more stable foundation compared to the other two. The project area is characterized abundance rocks that can readily be used for rock-fill dam. The recent deposits in are composed of a thin layer greyish brown soil with cobbles and stones derived from the parent volcanic rocks.

Finally it is concluded that proposed dam site 1 (the lower dam site) is suitable for a rock fill dam. However, further detailed geological investigations including core drilling and rock testing for strength will be necessary. The structural condition of the foundation rocks will also be necessary using seismic profiling.

Around proposed dam site 3 (about 5km from dam site 1) a layer of red clay was observed with the tuffs and sediments that underlie Kwaibus olivine basalts in that area. The thickness and areal extent of this horizon may be of interest as source for impervious core material.

5.2 Recommendations

The observations and inferences made from the preliminary investigations have led us to recommend the following:

1. Detailed geological including core and testing of the rock strength at the proposed Radat dam site 1. Three sites for core drilling are proposed as follows:
    - Borehole No. 1 at river bed (RADAT1-1VES 6) – right bank (Coordinates X: 0824008 (E); Y: 0031079 (N); El. 1375m above mean sea level);
    - Borehole No. 2 at RADAT1-1VES 4 – right bank (Coordinates X: 08224085 (E), Y: 0031055 (N); El. 1408m above mean sea level); and Borehole No. 3 at RADAT1-1VES 3 – left bank (Coordinates X: 0823884 (E); Y: 0031104 (N); El.1375m above mean sea level).
2. Geophysical investigations by seismic profiling to establish the structural conditions of the foundation to check presence of older faults, and
3. Fully fledged materials survey that should include identification of suitable quarries for the rock fill and laboratory testing of the rocks. The extent of the clay soils observed during this survey will need to be tested using auger method.

6 APPENDIX I: DETAILS OF INTERPRETED VES GRAPHS.

7 APPENDIX II: RETAILED LABORATORY SOIL TESTING RESULTS

8 APPENDIX II: TOR FOR DETAILED GEOTECHNICAL INVESTIGATIONS (SUBMITED SEPERATELY)