Geophysical and Geotechnical Investigation of a Proposed Dam Axis of the River Butulu, Northwestern Nigeria.

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ABSTRACT

An integrated geophysical and geotechnical investigation was conducted at a proposed dam site located approximately 6km southeast of Rijau in Niger State, Nigeria. The aim of the investigation is to determine the depth of overburden, physical and mechanical properties of soils, bedrock and other subsurface engineering/geological conditions which might affect the safety of the proposed dam. The geophysical investigation involved a resistivity profiling using Werner configuration array. A total of 104 profiling measurements were carried out across the main dam axis. The geotechnical investigation involved surface geological mapping, trial pitting and soil/rock coring at the location mentioned above. This was done to provide controls on the geophysical interpretations. The investigation delineated five subsurface layers which include the topsoil, subsoil, weathered layer, partly weathered/fractured basement and the fresh basement. Depths to the bedrock are generally less than 7.0m. The general characteristics of the subsurface materials show that they are competent and suitable to host an earth dam. However, while the configuration of the bedrock relief may aid groundwater flow into the stream channel, the delineated numerous joints which characterize the foundation rocks may act as conduits for anomalous water seepage beneath the proposed dam axis, if not factored in the design of the dam foundation.

(Keywords: resistivity profiling, joints, bedrock fractured basement, earth dam, seepage)

INTRODUCTION

An earth dam has been proposed across River Butulu in Magama Local Government Area of Niger State of Nigeria to harness the potential of the river for agricultural purposes. River Butulu which is to be impounded flows roughly from West to East. The proposed dam axis has a bearing of N16.5^{0} E and is about 1.3-1.5km East; off the Rijau–Kotangora road. The site of the proposed earth dam is located in Jama'are, with longitude $05^{0}17'30''$ E and latitude $11^{0}03'36''$ N (Figure 1). A high evapotranspiration has been the experience of the northern part of Nigeria, for reasons of climatic conditions (Ajayi, 2005). As a result of this, there is a great reduction in the water level throughout the year. As a way of alleviating this ordeal, a small earth dam was proposed for this area. The proposed dam site (figure 1) is located within the basement complex area.

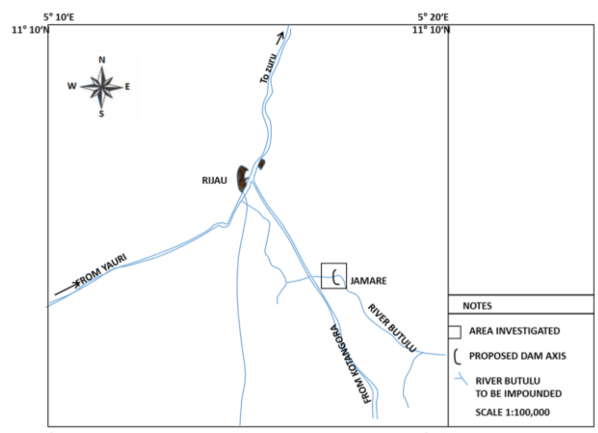

Figure 1: Location Map of the Study Area.

The objectives of the site investigation are:

- To determine the physical and mechanical properties of soils and bedrock
- Map all bedrock structures such as faults, fractures, joints, lineaments and any other lateral inhomogeneity's that might affect the safety of the proposed dam.

The above information is required for the design and construction of the dam axis foundation for the assessment of the ease of excavation and for the delineation of possible seepage zones. Therefore, geophysical techniques are often employed, and a small number of boreholes are then drilled to yield subsurface information that could serve as control on the geophysical interpretation (Ako, 1976; Ojo and Ayangbesan., 1990; Alna et al., 1996). Hence an integrated geophysical (electrical resistivity survey) and geotechnical (borehole drilling/coring) investigation was effected at the site of the proposed earth dam.

PHYSIOGRAPHY AND GEOLOGY OF THE AREA

Generally, the relief of the area under investigation consists of low-lying ridges, not more than 92m (Figure 2) above sea level in the Northern part of the River Butulu. The terrain tends to be undulating towards the river. This area provides large 'fadamas' close to the banks of the river, for large-scale farming and grazing. The major river in the area is the Butulu River which is being dammed and it is fed by few tributaries, all which are seasoned, including the Butulu River.

The river is about 1.5km away from the main highway, Rijau-Kotangora road. The seasonal nature of the river makes it imperative to dam it in order to enhance the agricultural activities of the area (National Steel Raw Material Exploration Agency-NSRMEA, 1990).

The climate of the area is similar to that of the other upper middle Belt areas of the country, viz. raining season and dry season. During the dry season, usually between October and April, the temperature can be as high as 38^0c in the afternoon and as low as 24^0c in the night, especially during the 'Harmattan' period. However, during the raining season, usually between May and September, the climate can be more friendly, with average temperature of 33^0c. The average annual precipitation is about 1,100mm while the highest relative humidity can be as high as 74-80% during the raining season (Iloje, 1981, Nigeria Steel Development Authority-NSDA, 1975).

Vegetation of the area is more or less a transition between savannah grassland in the North and the woodland area of the Middle Belt in the South. Hence, it consists of grass, shrubs and very few scattered trees. In the raining season, the vegetation provides good areas for local grazing, while in the dry season 'bush burning' for hunting and preparation of shifting cultivation' becomes the order of the day for the farmers in the area. The study area falls within the basement complex of Nigeria which is a large area of South-Western, part of North-Western, Central and

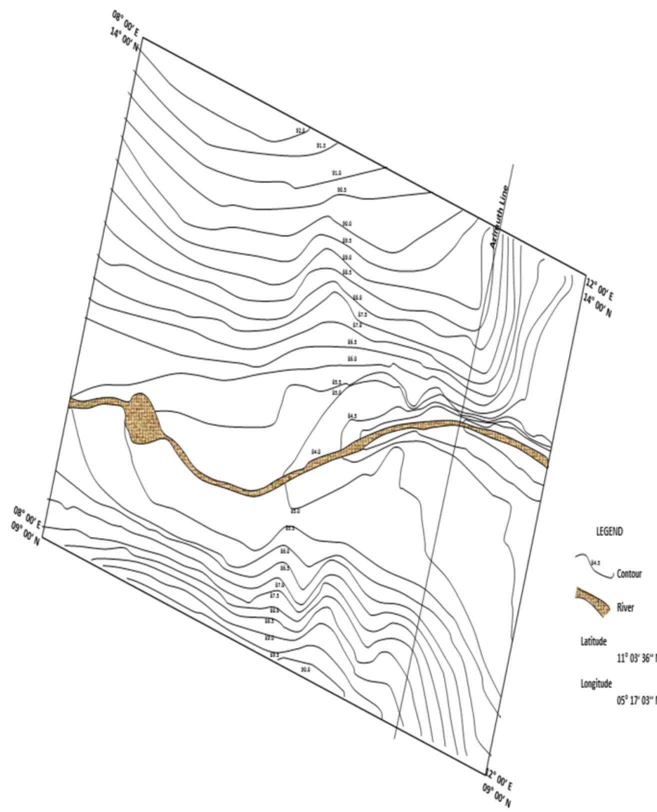

Figure 2: Topographical Map of the Study Area.

Northeastern Nigeria. According to Oyawoye (1965), the basement complex, which is Precambrian in age, consists of three distinct groups of rocks which are; the older metasediments, the gneisses, migmatites and the older granites and the younger metasediments Rognes (1948) described rocks of the West African Precambrian consisting of metasediments, orthogneiss and migmatites as Dahomeyan with the type area as the gneissic shield of Dahomey. The area under investigation (Figure 3), based on geological traversing, pitting/trenching and boring, has been conveniently divided into three zones (i) the North-Eastern part (ii) the Central area and (iii) the Southern part (figure 2). Zone I consists of fine-grained banded biotite gneiss and schist which have been variously reworked, migmatised and weakened and being weathered into soft friable parts in many places.

The rocks generally strike 335^0-345^0 azimuth, dip eastward at an average of 60^0-65^0 and plunged gently South-East at 15^0. The rocks in this zone are highly jointed. The joints are vertical or near vertical and in few cases are oblique and they generally trends E-W and N-S. These measurements correspond with those obtained by Amadi et al.; 2011 who worked in the adjacent state, Kaduna State; on strain estimation on gneisses in the area (Figure 3). Zone II, the central part, is more or less a transition between Zone I and Zone III. The area consists of quartzite, pegmatitic quartzite, feldsparthic (felsic) granites and feldsparthic gneisses. These rocks are more massive than either of the other zones; hence they have much less geologic features.

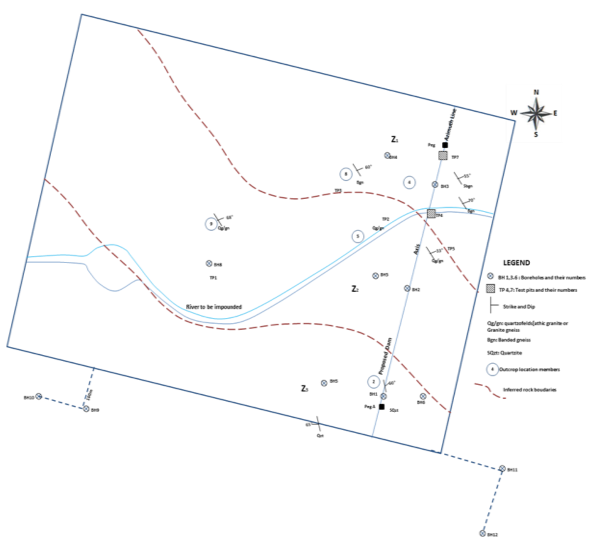

Figure 3: Geological Map of the Study Area showing the Rock Types.

They trend concordantly with those rocks in zone I and dip 65^0-70^0E. The third zone on the other hand, differs from the adjacent zone II, because the quartzite has more geologic features. The rocks are highly micaceous schistose quartzite in some sections and massive in few places. Both the schistose and massive quartzites are cut by fewer joints than that of Zone I. In this Zone, minor structures like kink and chevron folds are easily noticeable in the quartzite. As evidenced from our boreholes and exposures from the river beds, the quartzite is enclosed within the gneisses/migmatite complex. Russ (1957) described similar rocks of metasediments from Niger and Sokoto areas and included arkosic quartzite and other high grade schist in this assemblage.

MATERIALS AND METHODS

The resistivity survey used the profiling measurement techniques. A total of 104 profiling measurements were taken using ABEM (AC) Terrameter along eight (8) profiles at 25m station interval. A Werner electrode configuration was used with four (4) different cable spread such that ‘a’ the distance between each of the four electrodes is 2m, 4m, 10m and 20m, respectively.

The four electrodes were maintained at equal distance to each other as they are moved from point to point for each of the cable spread. Their measurements give an idea of the lateral variation in resistivity value which delineates lithology at different depth of penetration of the input current for each cable spread. Therefore, when the cable spread for ‘a’ is 2m and 4m would be taken to imply probing the topsoil and the immediate underlying dry soil respectively while cable spread ‘a’ is 10m and 20m probes the partially weathered bedrock and the bedrock respectively.

The resistivity profiling data were plotted as profiles (i.e. apparent resistivity values for the different cable spread) were plotted against the point of measurement for all the cable spread and interpreted qualitatively. The interpretation was carried out by way of visual inspection to characterize the curves according to their signatures which images the layering of the subsurface. For the geotechnical investigation, pitting, shell and auger borings, sampling and penetration tests were carried out. Seven (7) test pits were dug and (8) shell and auger borings were sunk in the study area (Figure 4).

All the pits and auger borings were sampled at every 0.5m interval approximately. Both disturbed and undisturbed soil samples so obtained were taken to the laboratory for a comprehensive range of identification, mechanical and strength determination tests. Hand operated auger was used for the boring operation.

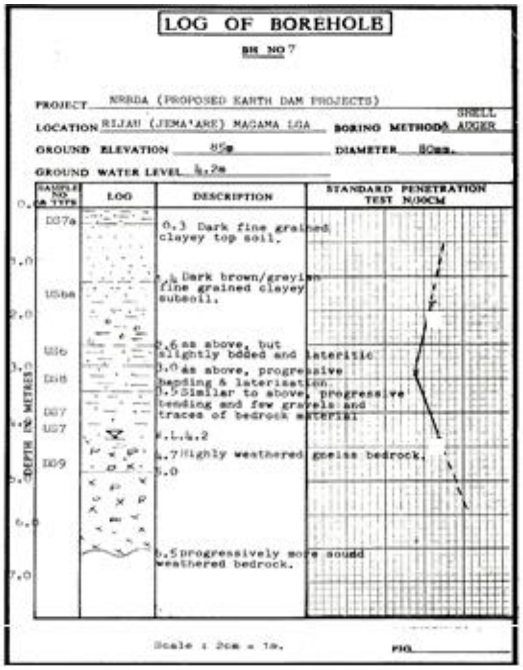

Figure 4: Borehole Log Sample.

RESULTS AND DISCUSSIONS

The results obtained from this investigation can be broadly grouped into field and laboratory results. The field results include those obtained from geological and geophysical operations carried out in the field. Their field results were backed up by simple laboratory tests to identify the soil types including their mechanical properties using the dam axis. The apparent resistivity values when "a" is 4m and 10m, respectively, were developed into isoresistivity maps (Figures 5a and 5b).

The two maps roughly indicate an N-S trend of higher than 50ohm-m resistivity values around the dam axis. The consistence in the trend of resistivity values in the range of 50-150ohm-m on both maps could be inferred to indicate moderately resistive to resistive rock underlying the dam axis at different depth of penetration. There is consistence increase in resistivity values particularly when "a" is 10m and 20m, respectively, and this was taken to indicate contact zone between two rock types of different resistivity values at the subsurface. This was observed at the W-E part. On the basis of the resistivity values, the following lithological sequence was inferred; the moderately resistive and in some cases highly resistive first layer (topsoil) of varying composition, moisture contents and varying degree of induration with thickness range of 0.30-1.35m, a conductive/resistive sandy clay/clayey sand and probably gravelly sand and a moderately resistive to highly resistive weathered bedrock grading into fresh bedrock.

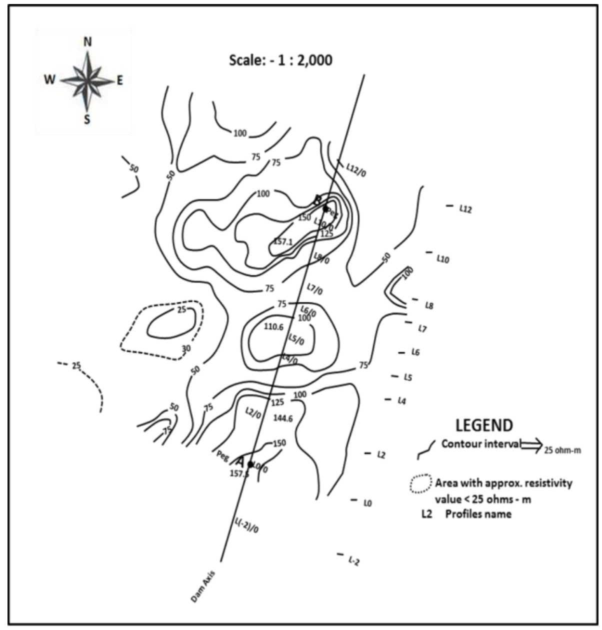

Figure 5a: Isoresistivity Map for "a" equals 4m.

From the results of field geological investigations, the soil profile of the area with varying thicknesses was adequately established; that is, the top soil, sub-soil and the weathered bedrock (Figure 6). The top soil varies in thickness from 0.00m in BH_2 and1.33m in BH6. It is generally made up of fine – grained sand or sometimes slightly sandy grey clayey soil, products of worm and wash unit (Burke and Durotoye, 1971). The layer is thickest in the 'Fadama' or low – lying areas and thinnest in the higher areas. The subsoil ranges between 1.33m in BH_3 and 6.5m in BH_7. In the Fadama areas, it consists of soft to slightly hard grey clayed soil. Figure 6 shows typical type sections of these soils as found in BHs 2, 7 and 8. In few cases, for example in BH_7, the soils still retain some characteristics of their parent rocks with increase in depth (Ojulari 1978). In this case some laminations or banding of relics of banded gneiss can be seen. However, at rear – surface, the sub – soil tends to be more lateritic, getting more gravelly and harder with increase in depth.

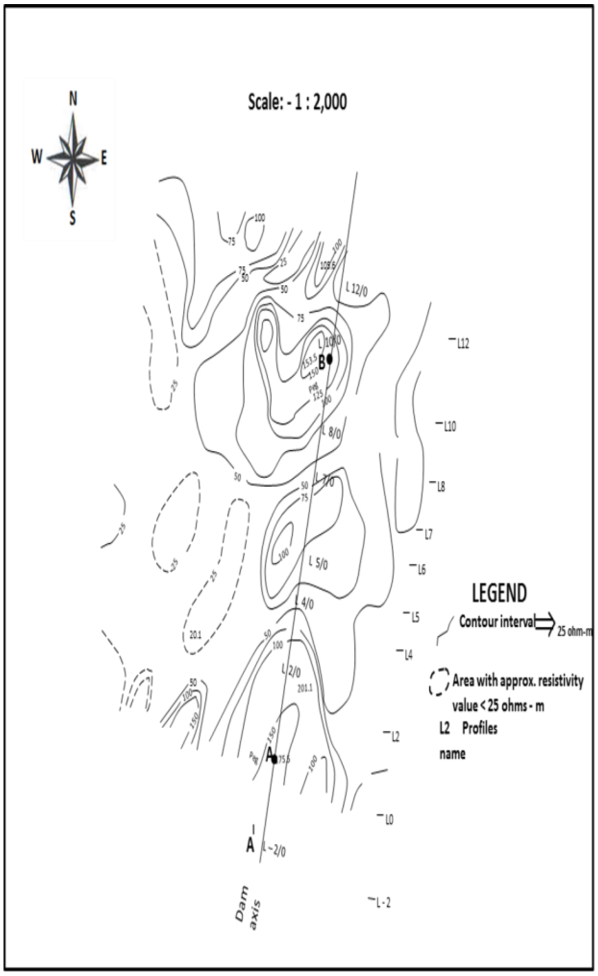

Figure 5b: Isoresistivity Map for “a” equals 10m.

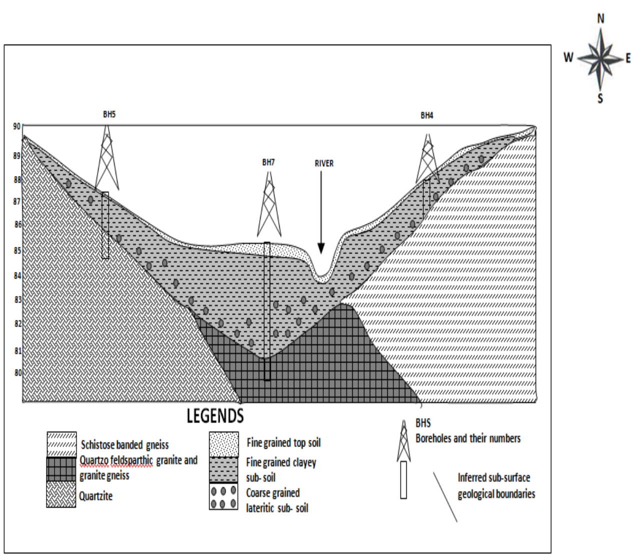

Figure 6: Geological Section across the Dam Axis.

The bottom part of the soil profile is weathered parent rock which consists of fine – grained banded or laminated weak gneissic materials, hence the overburden varies between 1.50m and 6.7m. Schematic model of the sub – surface oil and geology is presented in Figures 7a and 7b.

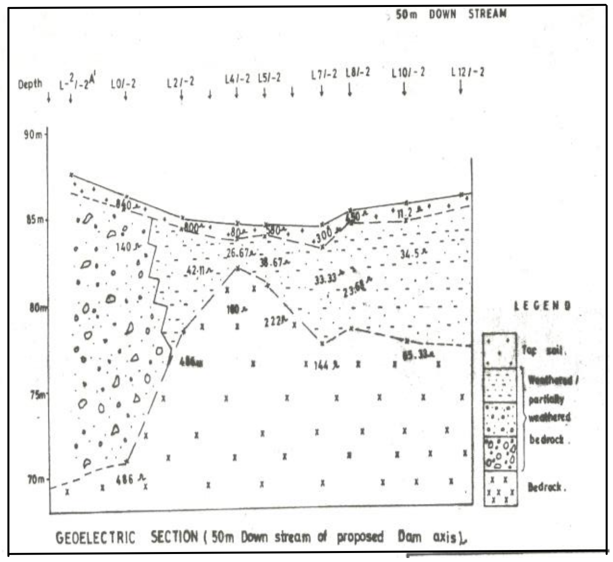

Figure 7a: Geoelectric Section across the Dam Axis (50m Up-stream).

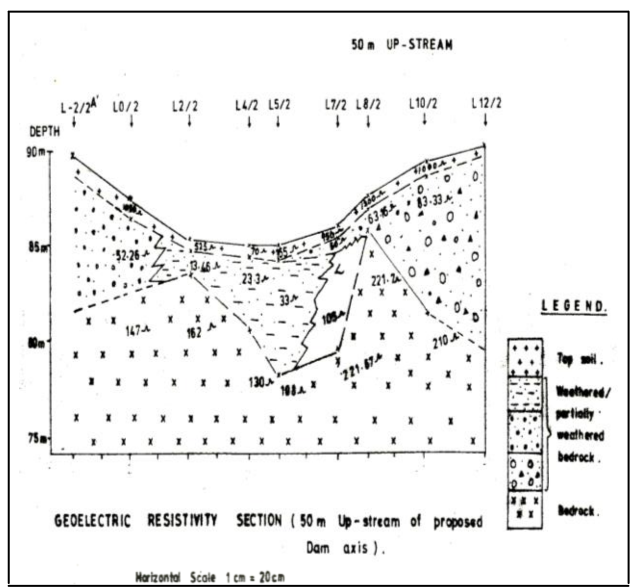

Figure 7b: Geoelectric Section across Dam Axis (50m Down-stream).

The results of the identification/characterization laboratory tests are shown in Table 1. The tests carried out using British Standard (BS) Akroyd (1957), include grain size distribution, liquid limits (LL), plastic limits (PL) and linear shrinkage (LS). The results are as vary as the soil types along the dam axis, but in many areas the lateritic characteristics are still maintained. With these results the LL ranges between 20% and 49.8%, the PL ranges between 16.4% and 31.3%.

Though Bayewu et al. (2012) obtained higher limits for LL, 38% - 75%, our results are similar to Bello, et al (1210) with LL 15.5 – 48.6% and PL 14.7 – 25.6%. Ola (1980) working on similar soil type in Sokoto, near the present project area, obtained a high clay fraction of 58% which agrees with the values of clay fractions of between 40% and 65% for most of our samples.

The mechanical/strength test results of bulk density, dry density, specific gravity and moisture contents. From the tables the values of both the density and moisture content show a general trend of increase with depth. In the same vein, the samples from the overburden were subjected to laboratory strength tests with the possibility of using the removed overburden in the construction of the dam embranchments. These tests include triaxial compression, consolidation and permeability (Table1). The cohesion of the samples tested varies from $41KN/m^2$ to $95KN/m^2$ and the permeability varies from 1.5×10^{-6} to 6.2×10^{-5}.

Akinrinmade et al (2012) carried out a similar investigation of the River Ero, Ajaba in the South Western Nigeria and also came up with values of cohesion (c) between 45KN/m and $95KN/m^2$. High values of K could be due to microfabric of the soil, especially by the presence of sesquioxides in the soil, Ogunsanwo (1978). From the rock mass characterization, these rocks are weathered, jointed and laminated, but appreciate considerably with depth in view of the evidence from the borings. These materials at appreciable depths of 1.7m and 4.5m in the Northern and Southern flanks respectively can adequately support the proposed dam. The slightly weathered upper part could be excavated and used for the embranchment and as filter materials.

Table 1: Summary of Laboratory Soil Test.

Sample Source		**Index Properties**				**Specific Gravity**	**Moisture Content**		**Triaxial Compression**		**Coeficient of Consolidation**	**Perme-ability**	**Soil Type**
Sample Number	**Depth m**	**LL %**	**PL %**	**PI %**	**LS %**	**K(m/min)**	**Normal %**	**Optimum %**	**C(KN/m^2)**	**O(O_2)**	**CVm^2/min**	**K(m/min)**	
US 1	1.7-2.1	42.4	16.4	26	5.6	1.86	19.4	14.4	91	6.4	1.96×10^{-7}	-	sandy clay
DS 1	1.0-1.2	33.5	19.1	14.4	7.7	-	-	-	-		-	-	sandy clay
US 2	1.3-1.5	39.9	26.5	13.4	4.1	1.81	24.7	14.0	70	9.5	1.27×10^{-5}	1.5×10^{-6}	Silty clay
DS 2	2.6-2.8	44	19.0	25.0	3.7	1.75	18.4	-	-	-	-	-	Silty clay
US 3	1.2-1.6	31.0	25.9	5.1	6.5	1.68	17.9	15.6	78	11.2	-	8.7×10^{-6}	sandy clay
DS 3	1.4-1.6	34.0	18.0	16.0	4.8	1.84	19.6	-	-	-	-	-	silty clay
US 4	1.4-1.7	48.0	35.9	12.1	5.4	1.93	15.3	14.8	74	12.3	-	1.9×10^{-5}	sand clay

CONCLUSION

A dam axis chosen based on field investigation is shown in Figures 5a, 5b and 6. From geophysical evidence backed up by well–spaced borings along the dam axis the depth of the overburden to be removed was established, though this is little in the middle but substantial at the flanks of the dam axis. The materials so removed could be used for the construction of the embranchments and the filter materials.

The results of various laboratory tests, including strength characteristics and permeability values give credence to this conclusion. The dam can be founded on the banded gneiss and schistose quartzite. Those rocks have the capacity to support the proposed earth dam. However, these foundation rocks are well – jointed and many of these joints are open. So there is a need for further work to be done, viz. core drilling and in – situ permeability tests in these rocks. In addition, in depth orientation of these joints might be necessary.

The outcome of this proposed additional investigation might help to reveal to what extent a well selected grouting curtain of lean concrete would be done to reduce the envisaged seepage to the barest minimum.

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