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Geoscientific assessment of Kemanji Dam site using Kemanji and Semon river, Kaiama area, Kwara state, North-Central Nigeria

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ABSTRACT

Proposed Dam site is located in Kemanji. Its axis is approximately 994m in length situated across Kemanji and Semon river. The study aims to investigate the sub-soil profile for a water tight reservoir condition that will be sustainable during the dry season for irrigation of farmland. Geotechnical field work entailed boring trial/test pits in the area along the proposed dam axis. The lithological facies were 3 groups of Brownish silty clayey sand, Brownish mottled silty clay and Light brownish soil/lateritic concretions. The average Maximum Dry Density compacted was 1814.61 kg/m3 and optimum moisture content (OMC) of 41.83%. The natural moisture content varied between 2.81-7.61%, while the bulk density varied between 1200-1922.10 kg/m3. The liquid limit and plastic index ranges from 30-39% and 2.6-8.5% respectively. The specific gravity ranges between 2.75- 2.85. The average Maximum Dry Density compacted is 1814.61 kg/m3 and optimum moisture content of 41.83%. VES revealed thickness from 0.81-4.94 m, weathered/fractured basement layer of 3-10.01 m and fresh/hard basement layer rock which is infinitely thick. The resistivity values revealed a range of 14.0-3522 Ωm. Investigated area of Kemanji is suitable to construct a dam due to Geologic materials of sandy top soil, weathered and fresh basement rocks readily available in the area. For the dam to be water tight, excavation must be done to about 12meters depth for its foundational footing to rest on fresh basement rocks. This will reduce seepage to minimal level, especially during the dry season when the reservoir water will be needed mostly.

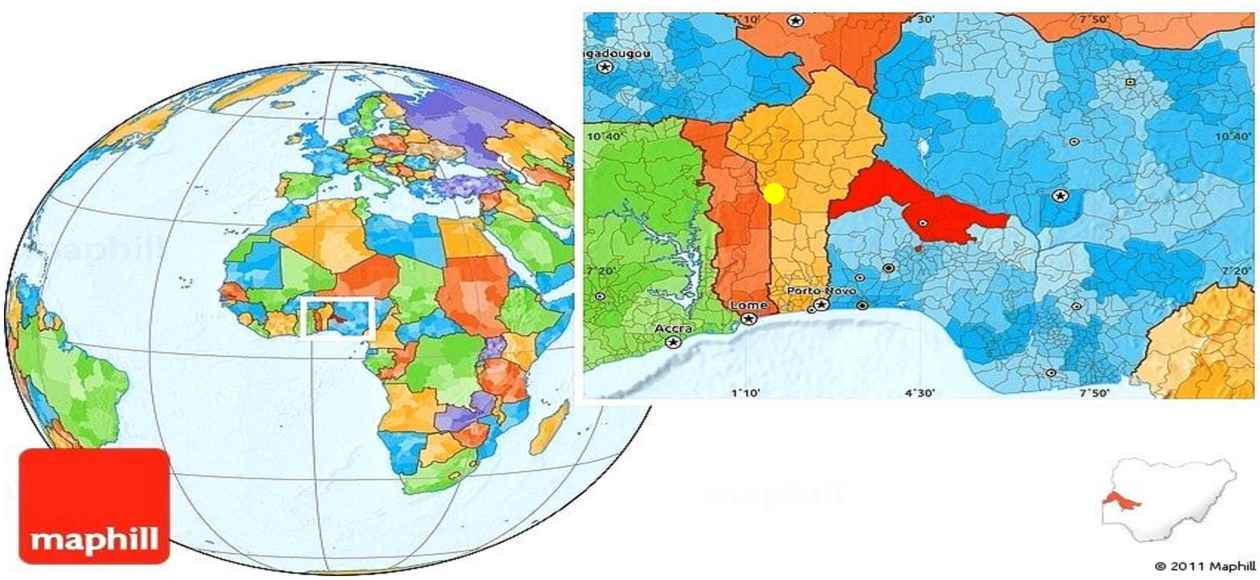
Keywords: Vertical Electrical Sounding, Atterbergs limit, Geotechnical. Lithological beds, Plasticity index and Resistivity

1. INTRODUCTION

With a growing population in Nigeria and indeed in the study area, the need for the production of varieties of crops to sustain the food security of the nation is very important. The essence of the article is to geo-scientifically study the area for its suitability and further Engineering design and construction phases of the proposed structural Dam project. Combing of the study area was done geophysically and geotechnically to describe the lithological facies, salient Engineering Geological parameters, fracture zones and more importantly, the durability of the proposed dam. Adequate assessment of Geologic and geotechnical conditions are critical for most important aspects of dam design and development in accordance with appropriate Engineering principles to ensure safety and best practice. Moreover, good feasibility studies about the site conditions of any proposed construction project is also essential in designing the appropriate foundation. It is based on this background that the geotechnical and geophysical investigation exercise for the proposed Kemanji Irrigation Dam in Kaiama area was done. Mohammed et al., (2018) provided insight into how complementary cut-off wall can be determined and designed in Karkheh dam.

Location

The proposed dam axis geographical location lies between Latitude N9° 41′ 30.6′′, Longitude E3° 54′ 32.7′′ and Latitude N9° 41′ 26.1′′, Longitude E3° 55′ 06.6′′. The proposed dam site is located in Kemanji village about 10 kilometers from Kaiama town (Figure 1), Kwara State. The dam axis is approximately 984 meters long situated across Kemanji and Semon river to be developed for irrigation purposes.



Kemanji study area

Figure 1 World Earth map showing Kwara state in Nigeria and other notable towns with Kemanji study area

Geology of the area

Generally, the study area is underlain by bedrock of the Precambrian Crystalline Basement Complex. The main rock units as revealed by the Geological survey of the area are pegmatite, quartzite, Granite gneiss, undifferentiated Igneous and Metamorphic rock. The surface layers are usually loamy soil underlain by lateritic materials and clay at various depths. The test pit/auger borings revealed predominantly brownish silty sands at the surface and it is underlain by brownish lateritic soil/laterite concretion and grayish silty clayey weathered quartzite at deeper depths. The topography of the area is gentle as observed and can be described as relatively rolling and well drained.

Aim and objectives of the study

The aim of the study is to assess the Geoscientific suitability of the Kemanji area for the design and construction of the proposed dam as a reservoir potential for water storage that can be utilized during the dry and rainy season for irrigation of farmland.

The objectives include

Evaluation of the field lithological distribution of the soil and bedrock facies using test pits

Geotechnical assessment of the area on salient Engineering geologic parameters for dam suitability

The delineation of the resistivity layers, values and thicknesses of the mapped dam axis area

2. METHODOLOGY

A non-evasive method of geophysical survey was used, employing Schlumberger electrode arrangement to estimate the depth of overburden ie topsoil down to the bedrock and to locate probable fractured zones along the proposed dam axis that will be sealed if need be was done. It entailed sending current of about 5-7 milli-amperes into the subsurface. The Engineering Geophysics is crucial for the determination of soil stratification, bedrock location and location of possible fracture zones which are important in the design of the proposed dam construction.

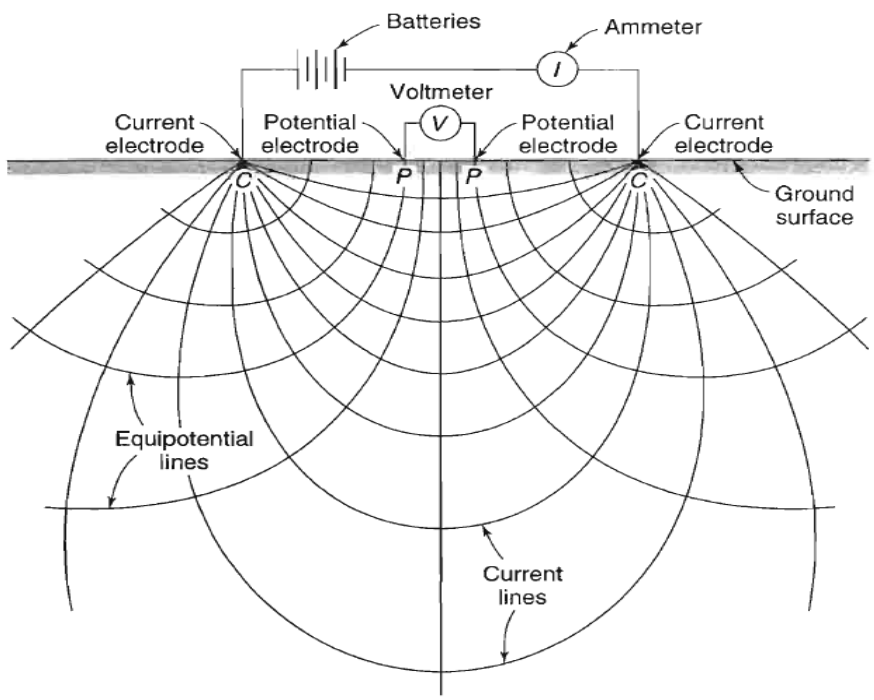


Figure 2 Electric lines of forces during the conducted Vertical Electrical Sounding

Five Vertical Electrical Sounding points (VES 1 to VES 5) were carried out along the proposed dam axis using this Electrical resistivity technique (Figure 2), with measurement used in delineating subsurface layers, resistivity values and possible fracture zones capable of holding the anticipated load of the dam and its fluid content. The soundings were carried out at 1-5m intervals with a spread of 30m along all traverses, as such a total of 30m depth of investigation conducted. 11 Test/Trial and 1 borrow pits were dug to get samples for geotechnical laboratory analyses.

Field work data collection and interpretation

11 trial test pits (TP) and 1 borrow pit were bored into the Kemanji area along the proposed dam axis to facilitate the logging and collection of study samples for geotechnical laboratory analysis.

The essence of this is to have the best representative samples of the dam axis soil profile that can better be described for the strength and stability of the dam with very little or no leakages. Collected samples from the pits were subjected to laboratory studies for different geotechnical properties. 14 samples (Table 1) were collected from the trial pits (Figure 3 and 4) coded as Trial Pit (TP) 1-Trial Pit (TP) 11, while 2 samples were collected from the borrow pit (Table 1).

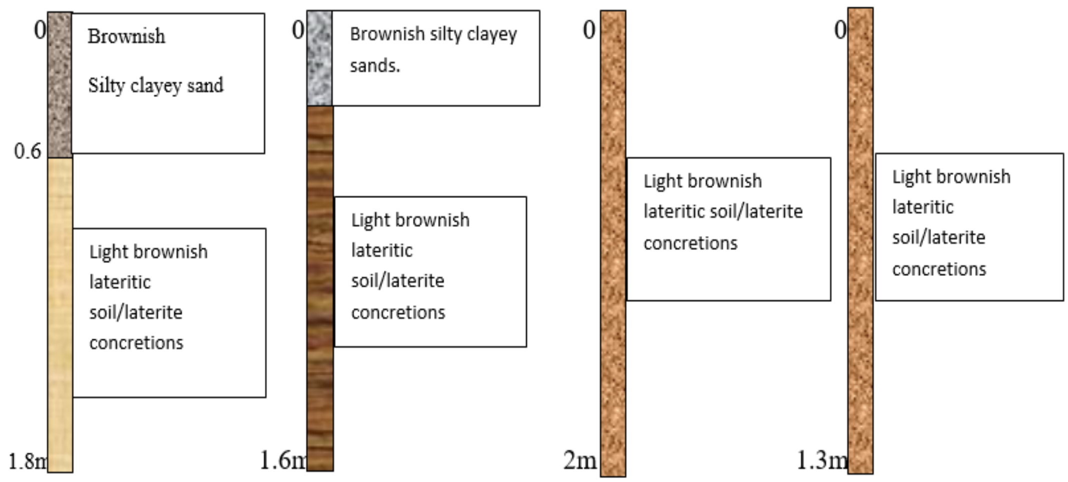


Figure 3 Trial pits 1, 2, 3 and 4 drilled along sampling locations of Kemanji area

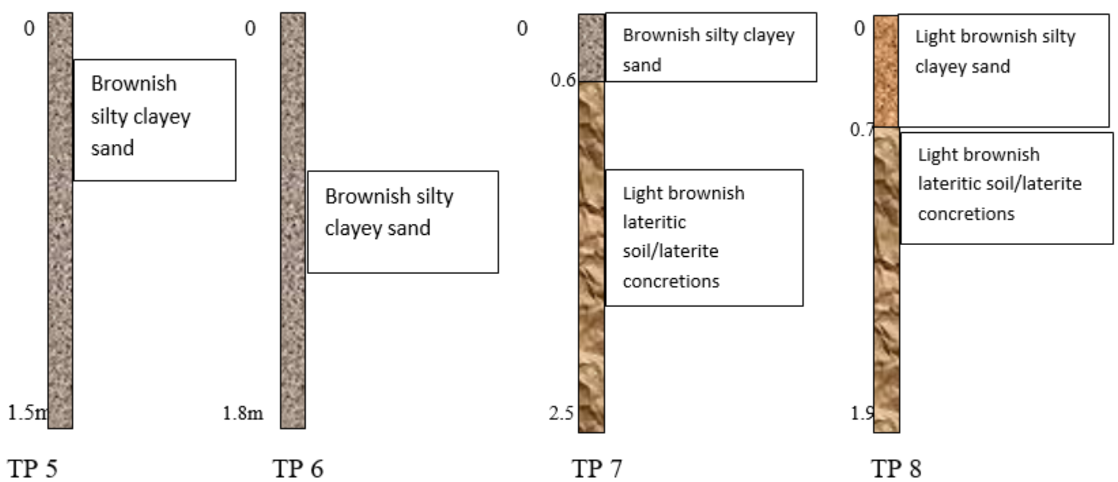


Figure 4 Trial pits 5, 6, 7 and 8 drilled for sample collection during the investigation.

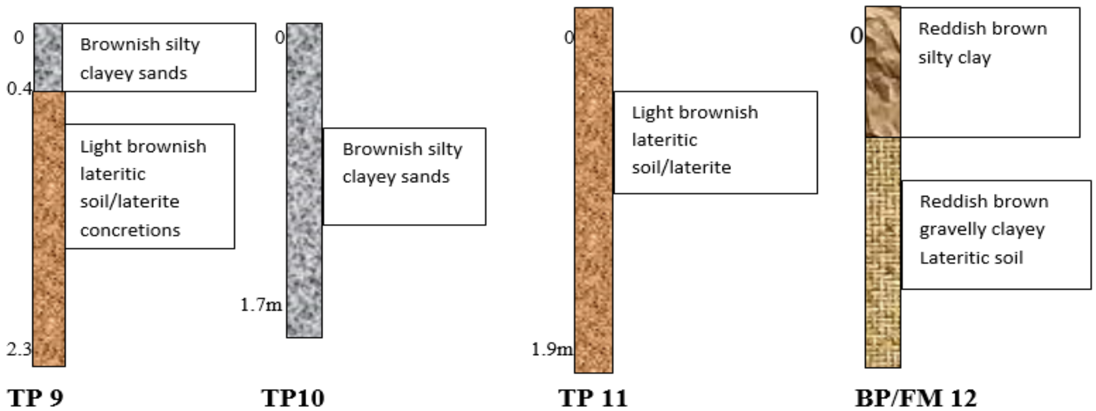


Figure 5 Trial pits 9, 10, 11 and Borrow pit (BP/FM) 12 drilled for sample collection during the investigation.

3. LABORATORY WORK

The geotechnical Engineering analyses of the data derived from the laboratory tests were performed in order to establish the design criteria for the dam foundation and the choice of seepage control technique for Engineering construction work. The following tests were conducted on the collected samples for the purpose of soil classification, strength analysis and design. They include:

Sieve/grain size gradational analysis

Atterberg's consistency limit test

Compaction strength test

All the tests were performed in accordance with BS 1377: 1990 and relevance practice in Nigeria. The summary of the laboratory test result for the material encountered along the dam axis and the construction materials were further interpreted.

Sieve/grain size analysis

The Sieve analysis of the study samples was done and this has revealed a wide gradational difference across the study samples of the 3 identified groups evaluated.

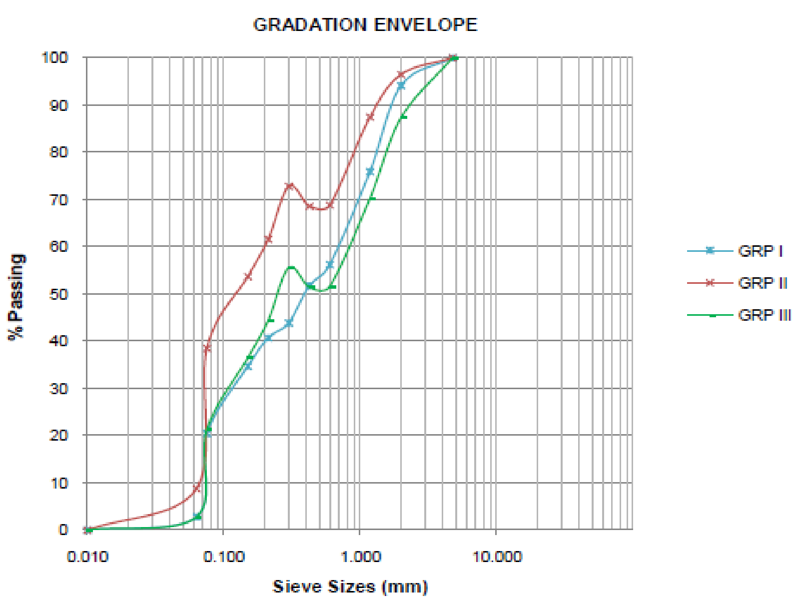


Figure 6 Gradational curves of Groups 1, 2 and 3 samples of the test pits along the dam axis

Studied samples from these pits were categorized into 3 groups and analysed at D10, D30 and D60 for their particle size distribution on the suitability for dam design and construction. At D10, all test pit samples of the 3 groups revealed a common unique value of 0.07 mm in diameter (Figure 6), as such, at D10, soil sample composition from the gradational curve lie together with almost same Engineering property of very low fine material with high proportion of coarse-grained sand in the matrix. The fine and medium grained sand components of the samples from these pits revealed it is moderate for the foundational material of a dam with no envisaged collapse. D30 grain size fraction revealed a little variation among the 3 groups of 0.07-0.15 mm (Figure 6). D60 showed a wide gradational difference across the 3 groups of samples that ranges from 0.21-0.9 mm (Figure 6).

The material in the borrow area identified along Kaiama – Kemanji road is at close proximity to the proposed dam site, as such was subjected to sieve analysis (Figure 7). It is Reddish brown silty clay at the top 0 – 0.6m and reddish brown gravelly clayey lateritic soil material at an average 0.6–2.5m depth intervals. The material is adequate and sufficient for impoundment/embankment purposes and by extension construction process. The gradational curves of the borrow material revealed more fine-grained silt and clay fraction in the second quadrant of 0.1-1.0 mm (Figure 7). BH1S1 and BH1S2 revealed good area where fine to medium grained of clay, silt and laterite can be sourced for the construction process of the proposed dam (Figure 7). This was similarly reported by.

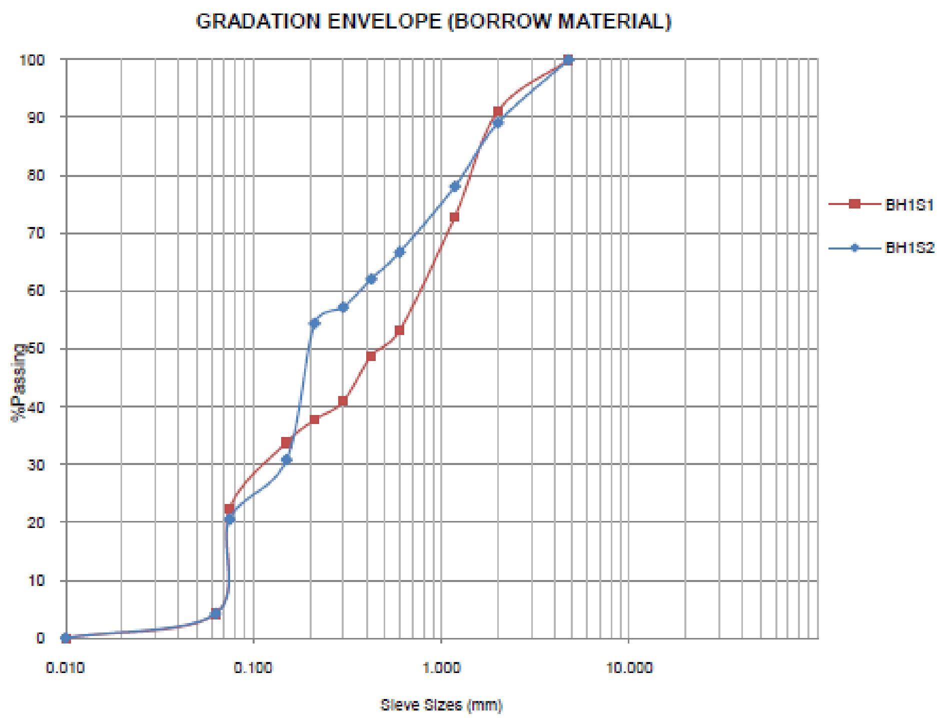


Figure 7 Gradational curves of Samples 1 and 2 of Borrow pit along the dam axis

Atterberg consistent limit

Atterberg's test was carried out on the group 1 of the 3 groups of study samples to reveal the liquid limit, plastic limit and plasticity index that varied at 30%, 27.4% and 2,6% respectively, some of the study pit samples with high clay/silt content in their matrix (Figure 8). As such, the liquid limit, plastic limit and plasticity index were determined for the samples to know if they will need be excavated and replaced with a suitable geologic material that will be crucial for the dam construction load. TP1S1, TP04S1, TP05S1, TP06S1, TP08S1 and TP09S1 all constitute the group 1 samples investigated for Atterberg's consistency limit test 30% liquid limit recorded by these samples in the group (Figure 8) has revealed the moisture content at which the fine-grained soil no longer flows like a liquid, as such desirable for dam construction. 27.4% plastic limit refers to the moisture content level in the samples at which the fine-grained soil can no longer be remoulded without cracking for the proposed dam to give way. Since the Plasticity index is a function of the clay content in the matrix of the samples, defined by variation of liquid limit to that of the plastic limit, then 2.6% plasticity index recorded is enough to give a durable dam in the area and as reported by (Koerner, 1970; Ichikawa, 1999).

Similarly, the Atterberg's test was carried out on the group 2 of the 3 groups of study samples to reveal the liquid limit, (Figure 9) plastic limit and plasticity index that varied at 39%, 30.5% and 8.5% respectively. TP06S2 and TP07S2 samples of this group are equally within the tolerant limit to give a good dam construction. 39% liquid limit recorded by these samples in the group has revealed the moisture content at which the fine-grained soil will not flow like a liquid, as such desirable for dam construction. 30.5% plastic limit refers to the moisture content level in the samples at which the fine-grained soil can no longer be remoulded without cracking for the proposed dam to collapse. Since the Plasticity index is a function of the clay content in the matrix of the samples, defined by variation of liquid limit to the plastic limit, 8.5% plasticity index is enough to give a durable dam in the area (Figure 9).

The group III samples of TP01S2, TP02S1, TP03S1, TP07S1, TP10S1 and TP08S2 displayed a liquid limit of 32.4%, plastic limit of 26.8% and plasticity index of 5.6% (Figure 10). The analysed samples point towards a stable earth dam construction with little or no seepage. Moreso, the quantity of fines that tends towards the clay content is low and as defined in the Plasticity index and is enough for the construction of the proposed dam. Reported 21.7%, 39.2% and 7.9% for Karkheh Dam.

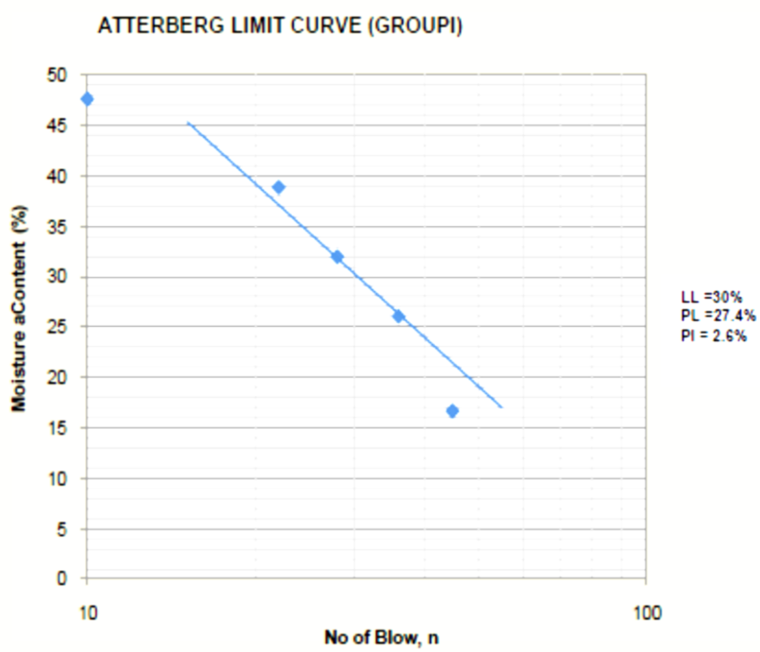


Figure 8 Atterberg's limit curve for Group I samples

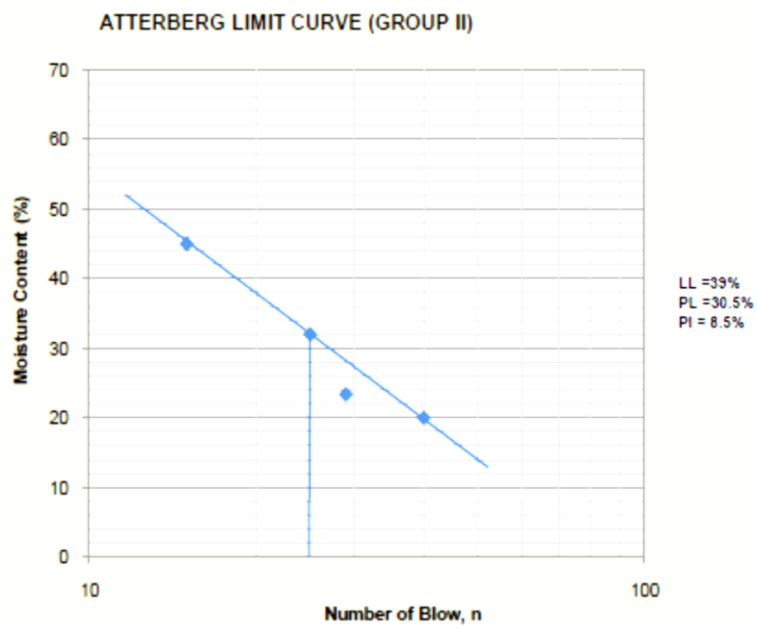


Figure 9 Atterberg's limit curve for Group II samples

Further consistency limit test was conducted on the borrow pit samples (Figure 11). The essence is to evaluate the geotechnical property of the source materials to be used as construction materials. BH1S1 and BH1S2 recorded liquid limit of 30.5% and 30%. Plastic limit of 26.3% and 27.5%. The plasticity index varied at 6.2% to 2.5% all respectively. It is worthy of note that the flow line ie liquid limit line was taken for each analysis at the 25th blow thus depicting the moisture content that corresponds to the flow lines to give the liquid limits of all investigated samples.

Similarly, a flow index was proposed $= \frac{W1 - W2}{\text{Log}\ (N2/N1)}$

Can be evaluated at certain points of the group samples, where W1 and W2 are moisture contents corresponding to N1 and N2 respectively as advanced by.

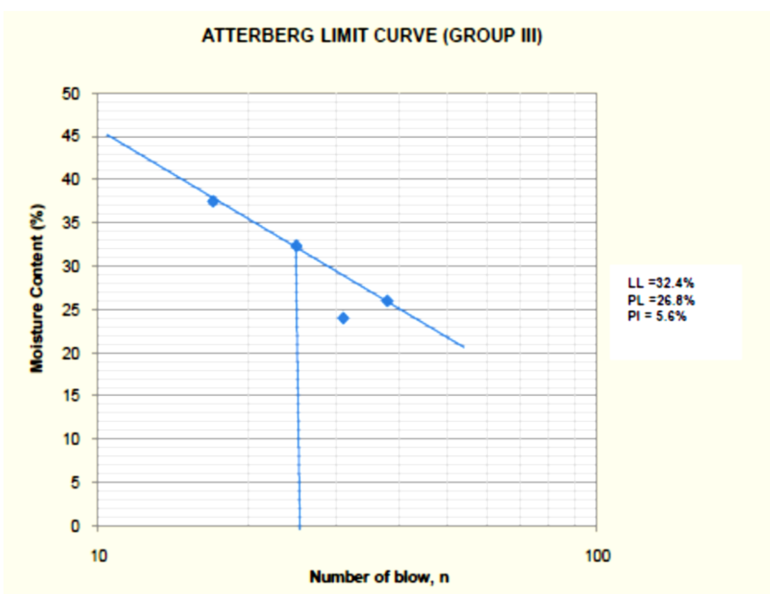
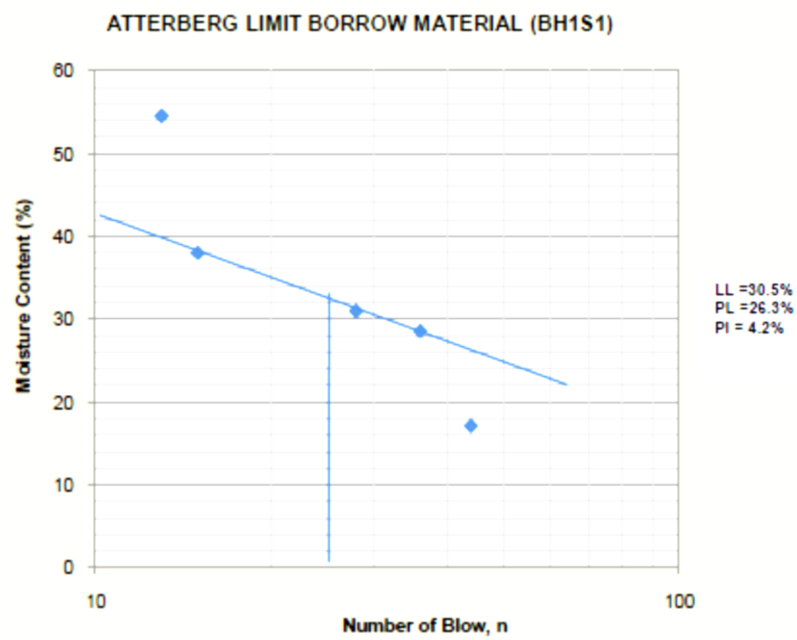


Figure 10 Atterberg's limit curve for Group III samples



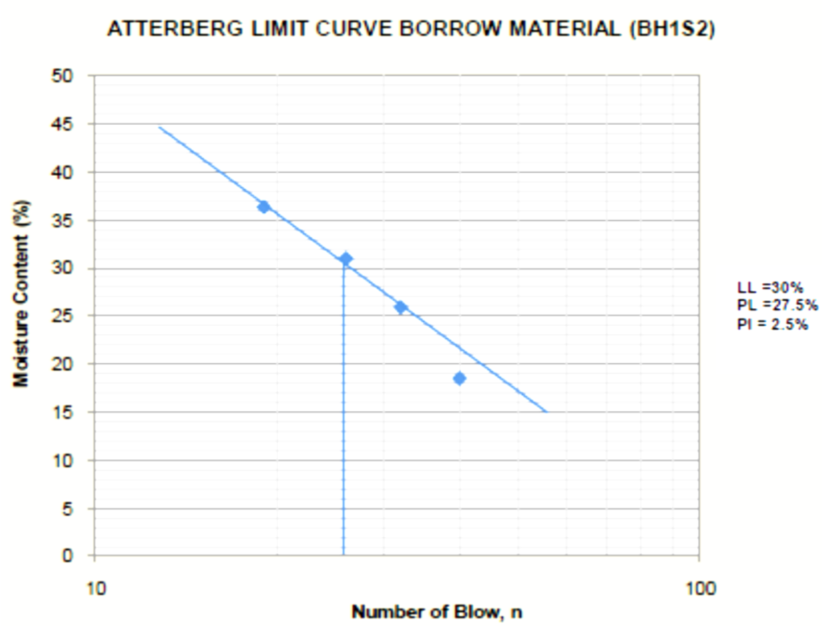


Figure 11 Atterberg's limit curve for Borrow material of BH1S1 and BH1S2

Table 1 Atterberg's limit values recorded for Groups I, II, III, BH1S1 and BH2S2

S/N	Groups	Pits and sample I.D	Plastic limit (%)	Liquid limit (%)	Plasticity index (%)
1	I	TP1S1, TP04S1, TP05S1, TP06S1, TP08S1 and TP09S1	17.1	21.0	9.3
2	II	TP06S2 and TP07S2	39	50.5	8.5
3	III	TP1S2, TP2S1, TP3S1, TP7S1, TP10S1	32.4	26.8	5.6

		and TP8S2.			
Atterberg's limit of borrow pit samples					
4	B	BH1S1	30.5	26.3	4.2
5	B	BH2S2	30	27.5	2.5

Compaction strength test

DCP test was carried out in addition to the moisture content with interpretations pointing towards a good area for the design and further construction of an earth dam. DCP test entailed driving a solid cone of 60° into the ground, using repeated blows of a hammer with a fixed mass of 10 kg falling through a distance of 550 mm having maximum diameter of 20 mm. The hammer struck the anvil which was rigidly fixed to the rods and were of smaller diameters than the cone, as such transmitted the hammer energy to it. As the cone was driven into the ground, the number of blows required to drive each increment (typically 100 mm) was recorded. The point of refusal was recorded and the test terminated at depths where hammer blows were greater than 50 and caused less than 100mm penetration. The blow count was inputted into appropriate excel software to provide a more-or-less continuous profile of penetration-resistance with depth and consequent determination of the bearing capacity usually at 0.5m depth interval.

Table 2 Compaction strength properties of Group I samples.

TP1S1, TP04S1, TP05S1, TP06S1, TP08S1 and TP09S1= GROUP I					
Dry Density (g/cm3)	1810	1920	1740	1620	1344
Moisture Content (%)	12.1	31.7	46.3	55	73.6

The compaction strength analysis of the Group 1 samples has revealed a variability of the dry density of investigated samples that ranges from 1810 g/cm3 to a significant drop of 1344 g/cm3 (Figure 12 and Table 2). Conversely, the corresponding moisture content increased from 32.7-73.6 %. Thus, good compacted strength recorded. Reported similar values for the ground evaluation for Kentucky bridges.

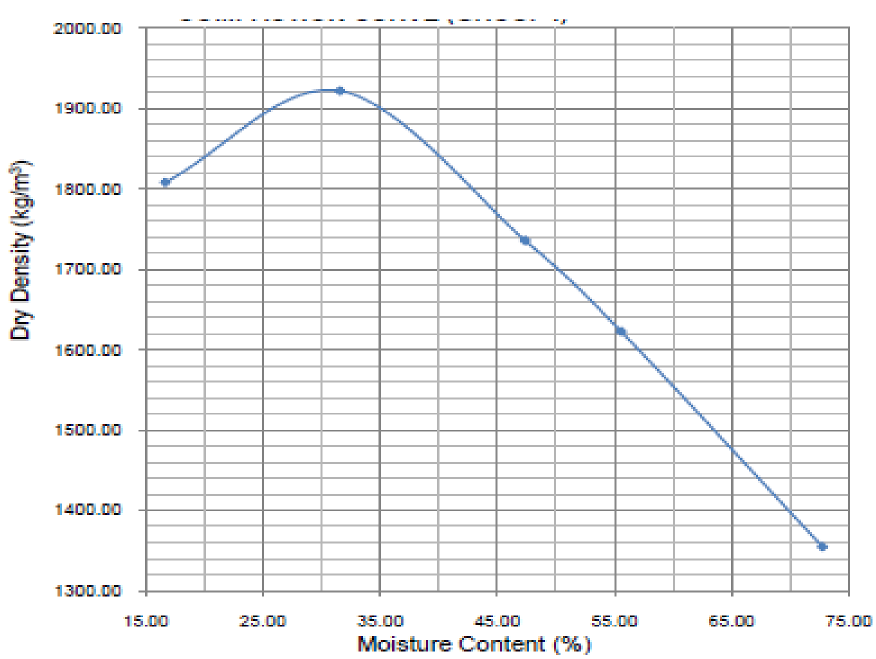


Figure 12 Compaction curve of Group 1 investigated samples in Kemanji dam site.

The compaction strength analysis of the Group II samples has revealed a variability of the dry density that ranges from 1748 g/cm3 to a significant drop of 1593 g/cm3 (Figure 13 and Table 3). With a steady increase in the dry density curve from 1748 to 1897 g/cm3, then a sharp drop was recorded onward to 1593 g/cm3(Figure 13 and Table 3). Conversely, the corresponding moisture content increased from 6.3-27.6% steadily across the area. Evaluated samples in this category include the TP06S2 and TP07S2.

Table 3 Compaction strength properties of Group II samples.

TP06S2 and TP07S2= GROUP II					
Dry Density (g/cm3)	1748	1860	1897	1840	1593
Moisture Content (%)	6.3	17.1	23.8	27.1	27.6

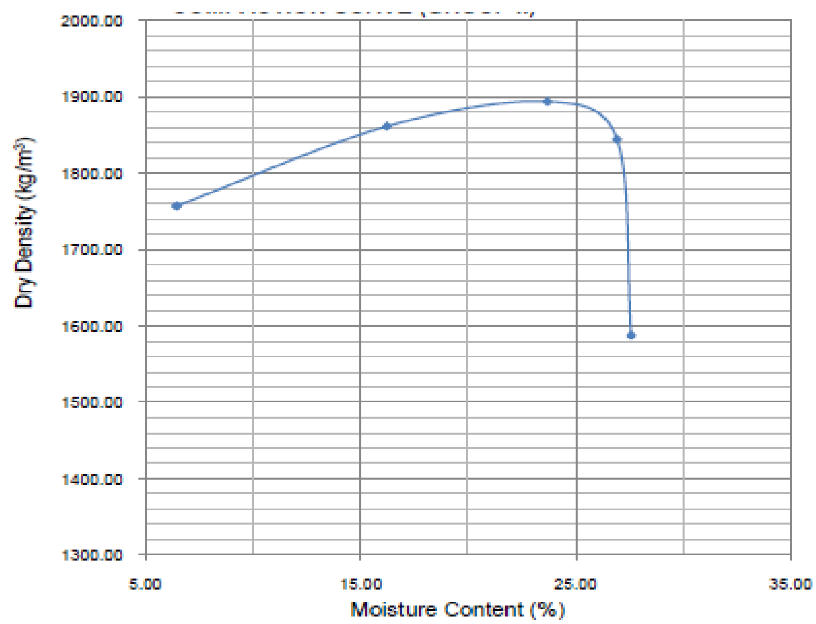


Figure 13 Compaction curve of Group II investigated samples in Kemanji dam site.

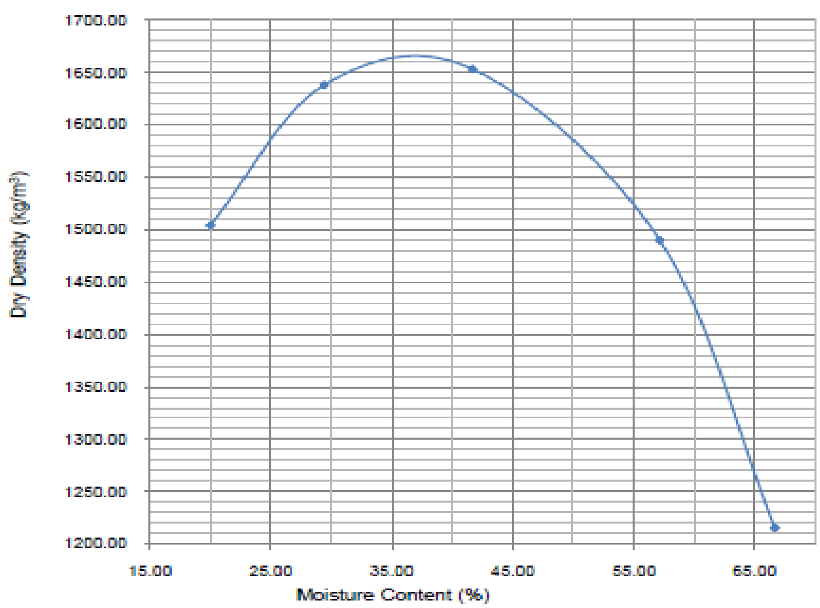


Figure 14 Compaction curve of Group III investigated samples in Kemanji dam site.

Table 4 Compaction strength properties of Group III samples.

TP1S2, TP2S1, TP3S1, TP7S1, TP10S1 and TP8S2 = GROUP III					
Dry Density (g/cm3)	1500	1640	1650	1490	1215
Moisture Content (%)	19.7	26.2	42	56.8	62.5

The compaction strength analysis of the Group III samples has revealed a constant variability of the dry density that ranges from 1500 g/cm3 to a steady rise up to 1650 g/cm3 before a significant drop to 1215 g/cm3 (Figure 14 and Table 4). With a steady increase in the dry density from 1500 to 1650 g/cm3, then the sharp drop recorded onward to 1490 g/cm3 and 1215 g/cm3 can be traced to good compaction of the grains (Figure 14 and Table 4). Conversely, the corresponding moisture content steadily increased from 19.7-62.5%. Evaluated samples in this category include the TP1S2, TP2S1, TP3S1, TP7S1, TP10S1 and TP8S2.

Geophysical analysis

The resistivity data of the Kemanji area has revealed 3-4 main layers of sandy topsoil, clayey sandy laterite, weathered basement layer and/or fresh basement layer. The topsoil and laterite soil layers were further described geotechnically (Figure 3, 4 and 5) to check the suitability as construction material for the dam load. VES 1 has shown a 1.1 meters thick regolith with a resistivity value of 252 Ωm. This component is silty sandy top soil with no incipient fracture that can constitute water seepage in the medium. The 2 other layers consist of 31 and 17009 Ωm respectively. VES 2 (Table 5) is having 4 layers with similar property like VES 1. It consists of 1.5, 3.41, 7.09 meters respectively and infinitely thick layers with resistivity values that ranges from 23, 15, 63 and 69907 Ωm respectively (Table 5). VES 3 data revealed a 3 layer of Sandy topsoil, weathered basement and fresh basement rocks.

The data was collected due to deeper penetration of the current beyond the depth recorded by geotechnical evidence and signifying a condition of thick weathered basement rock of 330Ωm. The dam profile can be excavated to this depth to get a better condition to control seepages. VES 4 has shown a 3-layer model of the earth with an H-type of curve. The resistivity value of 1793Ωm for the first layer which is 4.94 meters thick on the 10.01 meters thick weathered basement rock has shown that its averagely good for the construction of a dam. VES 5 consist of clayey sandy top soil first layer with a resistivity value of 33Ωm and a thickness of 2 meters on the 3 meters thick second layer. The pseudo-section generated for the investigated area (Figure 15) equally revealed that Kemanji area is having large and fresh crystalline rocks at about 12-14 meters that that can serve as good foundational footing for the dam and prevent leakages of reservoir water.

Placing the footing on these fresh granitic rocks will ensure a durable and water tight condition of the reservoir water. Proper excavation of all soil and weathered profiles of the area to a minimum of 12m is desirable for the Kemanji dam to have a strong foundational footing. Reported a shallower depth for the regolith and weathered basement rock of Karkheh Dam. 7-9 meters of excavation will need be done to get to fresh basement rocks of the area. The proposed depth value of fresh basement rocks of the area falls within designed value in a preliminary assessment done in that area using the soil bearing capacity.

Table 5 VES data showing the thickness and resistivity values around Kemanji dam site axis.

VES Location	Material Description	Depth range (m)	Thickness (m)	Resistivity Value μ (Ωm)
VES 1 N90 41′ 30.2′′ E30 54′ 35.90′′	Sandy top soil Weathered basement Hard basement	0 – 1 1 – 3 3 - ∞	1.1 8.9 ∞	252.00 31.00 17009.00
VES 2 N90 41′ 29.30′′ E30 54′ 39.30′′	Sandy top soil Laterite Weathered basement. Hard basement	0 – 1.5 1.5 – 4.91 4.91 – 12 12-∞	1.5 3.41 7.09 ∞	23.00 15.00 63.00 69907
VES 3 N90 41′ 29.30′′ E30 54′42.50′′	Sandy (top soil) Weathered basement. Hard basement	0 – 1.05 1.05 – 5.89 5.89 - ∞	1.05 4.84 ∞	397.00 330.00 2386.00

VES 4 N90 41′ 28.90′′ E30 54′ 45.80′′	Sandy (top soil) Weathered basement. Hard basement	0 – 1.1 1.1 – 8 8 - ∞	1.1 6.9 ∞	1793.00 375.00 9552.00
VES 5 N90 41′ 28.40′′ E30 54′ 48.90′′	Sandy (top soil) Laterite Weathered basement. Hard basement	0 – 1 1 – 5.1 5.1 – 15 15-∞	1 4.1 9.9 ∞	1890.00 533.00 632.00 98300

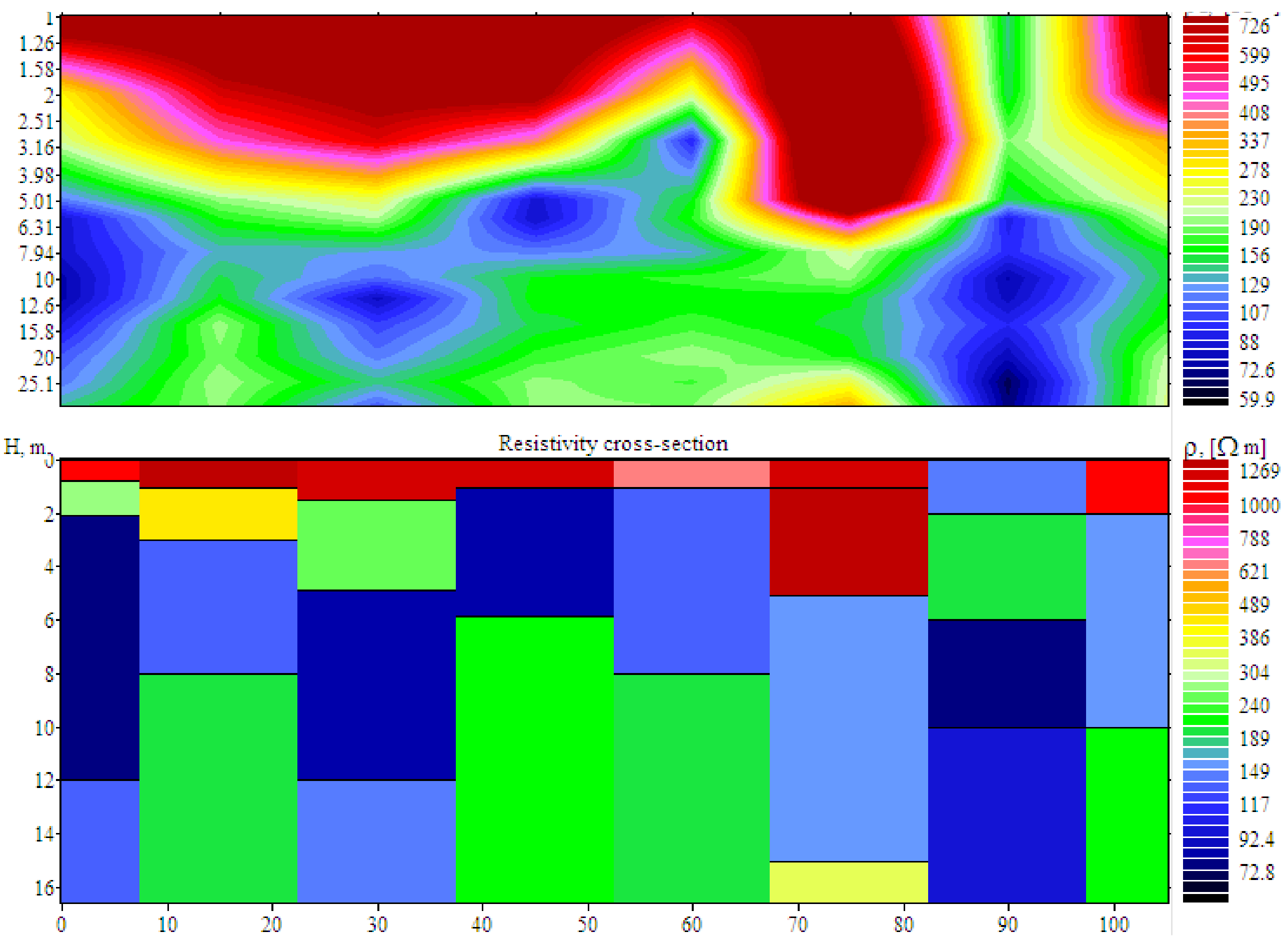


Figure 15 Pseudo and cross sections of the Kemanji dam axis profile across the VES points

4. CONCLUSION

From all available geotechnical and geophysical interpretations, the proposed Kemanji dam site will be water tight, seepage is expected to be very minimal within the tolerant level, especially during the dry season when the reservoir water will be needed mostly. Sealing of few fracture zones at weathered zones of layers 2 and 3 with cement slurry will guarantee better water tight condition of the reservoir. Collapse not envisaged and more importantly, Engineering design and construction phases will be feasible to add value to the socio-economic, agricultural and health values of the people in the environment with attendant food security of the communities, state and nation at large.

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Ethical approval

Not applicable.

Conflicts of interests

The authors declare that there are no conflicts of interests.

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Informed consent

Not applicable.

Data and materials availability

All data associated with this study are present in the paper.

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