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Geopysical and Geotechnical Investigation of Cham Failed Dam Project, Ne Nigeria

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Abstract

The geophysical and geotechnical techniques were applied in order to determine the immediate and remote causes of a failed dam project in Cham area NE Nigeria. Details of site investigation for the Cham dam are presented. Geologically, the dam-site rests on the geologically disturbed Yolde Formation. The course of the Cham River is structurally controlled by the underlying strike-slip and dip-slip faults. Ground geological investigation revealed the presence of joints, faults and associated slicken-sides and shear zones as well as desiccation cracks within the rock formations. Geophysical investigations confirms that these joints and fault zone extends more than 35 meters below the river beds. It also revealed the presence of shally clay, lateritic dark clay, fissile shale and friable siltstone to depths of more than 35 meters below the river bed.

Laboratory studies of the engineering properties of the rocks disclosed a mean optimum moisture content of 14.6% at a mean maximum dry density of 1.80 mg/m^3, mean plasticity index value of 34.5% and a mean CBR value of 3% suggesting a highly weathered, plastic, friable and structurally weak rocks. These studies helped in explaining both the immediate and remote causes of the failed dam project.

Keywords: Geological investigation, geophysical studies, laboratory studies, cham area, northeast, Nigeria.

Introduction

An adequate assessment of geologic and geotechnical conditions of the proposed site is imperative for a safe dam design and construction (Blyth and De Freitas 1998). Over 50 percent of all dam failures in the United States of America can be linked to geologic and geotechnical problems according to information provided by the Association of State Dam Safety Officials (ASDO). The geologic and geotechnical problems range from foundation defects caused by inadequate investigation to internal erosion through the embankment (Piping). Each dam site may have its own unique set of geologic and geotechnical challenges since the design requirements are different for dams of different size, purpose and hazard potential classification.

Geotechnical geophysics is an important exploration tool for dam site investigation. It is the application of geophysics to geotechnical engineering problems; such investigations normally extend to a total depth of less than several hundred feet but can be extended to thousands of feet in some instances. It is routinely used for many types of dam site and highway engineering investigations including site characterization and estimation of engineering properties of earth materials. A geotechnical geophysical survey is often the most cost-effective and rapid means of obtaining subsurface information especially over large study areas (Sirles 2006). Other advantages of geotechnical geophysics are related to site accessibility, portability, noninvasiveness and operator safety. Geophysical equipment can often be deployed beneath bridges and power lines, in heavily forested areas, at contaminated sites, urban areas, on steeply dipping slopes, in marshy terrain, on pavement or rock and in other areas that might not be easily accessible to drill rigs or cone penetration test (CPT) rigs.

It was this exigency that prompted the use of integrated geophysical and geotechnical methods to assess the geologic and geotechnical conditions of the failed dam in Cham area of NE Nigeria. This is with a view of finding the remote and immediate causes of the failed dam inorder to suggest ways of avoiding such occurrences in the future.

An integrated geotechnical and geophysical survey (using vertical electrical sounding) was done in order to; i) To establish causes of the failure of the structure. ii) Determine the optimal depth to bed rock. iii) To use raw VES data to Prepare apparent resistivity pseudo section. iv) To construct Geoelectric sections from the layered parameters

Study area: The study area fall on Latitude 09^{0}43. 686' N and Longitude 11^0 43.686' N and about 409 m (1349 feet) above mean sea level. It is located about 50 km Northwest of Yola Nigeria. The study area is accessible through Yola-Cham- Gombe Road and Bauchi-Gombe-Yola road to the study Area (figure 1). It is characterized by two climatic seasons; the rainy and the dry seasons. The rainy season fluctuates between April and May and ends around October; the mean monthly rainfall in May, August and October is 120mm, 220mm, and 40mm respectively while the mean annual rainfall is about 960mm. The temperature remains moderately high for a greater part of the season owing to its proximity to the equator. The hottest month is around April with temperature most times above 40^0C, while the coldest month is around December when the temperature reads as low as 10^0C.

It falls within the Sudan Savannah belt of Nigeria and has sparsely spaced vegetation. Most of the area is covered by different species of grasses. The area is generally rugged undulating and dissected by numerous streams and rivers. The area is predominantly hilly prominent among them are the Cham hills, Nyiwar hills (1900m above mean sea level). The low land areas are composed of black cotton soils (product of weathered shale) suspected to be the marine Dukkul Formation. The drainage pattern is generally dendritic network of streams and rivers. The streams are seasonal flowing during the rainy season and dries up during the dry seasons. Prominent among the streams are; the Lafiya, Yolde and Cham Streams all flowing in a Southerly direction. The area is characterized by black cotton soil (weathered shale) which is highly impermeable and gives rise to muddy surface during the rainy season. It develops high shrinkage cracks called desiccated cracks during the dry season.

Regional Geology: The entire Cham and Environs lies within Dadiya syncline, an important geologic structure of the Yola-arm within the Benue Trough. The cretaceous Benue Trough of Nigeria is an intracratonic, intercontinental basin that stretches for about 1000m in length oriented NE-SW and uncomformably resting on the Precambrian Basement. It is divided into the lower, Middle and the upper Benue Trough. Stratigraphically the upper Benue Trough comprises of two sub basins namely the Gombe and Lau sub Basins or the Gongola and Yola arms, represented by thick sequence of cretaceous sediments. The Lau Sub Basin of the upper Benue is stratigraphically underlain by continental and marine Cretaceous Aptian–Early Santonian deposits.

The Bima Sandstone is the oldest sedimentary sequence in the entire Benue Trough and was deposited under continental condition and is intercalated with carbonaceous clays, shale's and mudstones. The Cenomanian Yolde Formation lies conformably on the Bima Sandstone which represents marine incursion into this part of Benue Trough, and was deposited in a transitional/coastal marine environment. The Yolde is overlain by Lower Turonian marine Dukkul Formation. The Dukkul represents marine Formation which overlies the Yolde directly. It is composed of limestone, marlstone, mudstone and shale. The Jessu overlies the Dukkul Formation which consists of shale, siltstone, mudstone and Sandstones. The Cenomanian sequences are (sekuliye, Numanha and Lamja sandstones and Tertiary Basalts.

Site Geology: Yolde Formation: This Formation at the dam site is composed of a sequence of grayish/whitish and brownish shales, mudstone and occasional fine grained laminated sand in some areas within the dam site. These rocks were obscure by weathered shale which forms dark overburden clay (figure 1).

Structures: Structures observed in the dam site could be controlled by deep seated faults of the cretaceous tectonic deformations; this is due to the observed sharp flexures of the overlying sediments, and most importantly the E-W orientation of fractures, which represents the late Aptian tensional faults. Fold rocks were also observed along the proposed spillway, faulting is also conspicuous, as the silty limestone was deformed resulting to a zone of subsidence with visible grabens. These fissures could widen to constitute points of loss of water or collapse of dam structures.

The site is blanketed by highly weathered and desiccated shale to dark clay, which forms the overburden (top soil), to a thickness of about 0.61m, in most areas of the dam. This is in turn underlain by darkish grey to brownish or whitish shale and calcareous silty limestone in some areas. This dark shale thickens about 2m in the north-western part of the dam around the reservoir area.

Deposits of basaltic boulders are seen scattered along the river channel. Outcrops of calcareous silty limestone or marl, is commonly observed at the depth of 1m (3.28ft) mostly around the irrigation outlet, the base of the embankment, within the main river core and around the upper part of the reservoir, toward the upstream, northeast ward at about the same depth (1m). The exposed section along the river channel; includes intercalation of calcareous silty limestone or marl and shale which thickens to about 6m (19.7ft). The dam proposed embankment is flanked to the west by a Tertiary volcanic basaltic hills.

Hydrology and Hydrogeology: The Cretaceous Yolde sedimentary Formation constitutes the main aquifer system in the Cham dam site. Groundwater occurs both under confined and unconfined conditions (figure 2). The aquifers appear to be partially hydraulically interconnected with the Cham stream and the main sources of recharge is the direct rainfall at the upstream part of the basin[3,4,5]. The depth to groundwater level varies from meters at the dam site to more than meters to the NE of the study area (recharge area). The saturated thickness varies from 5 m to 12 meters in the Cham dam site to 15 meters in the recharge area.

The floodplain of Cham stream has an areal extent of about m^2 and in hydrologic continuity with the groundwater systems[6]. It occurs in depressions and in contact with groundwater and consists of organic and lateritic calcic lime enriched black cotton soils (weathered shale). It is underlain by the unconfined alluvial aquifer with a thickness range of 35 meters.

Material and Methods

A careful study of existing geology of the area indicate that the study area is underlain by two rock formations namely the Yolde Formation and the Dukkul Formation.

Geophysical survey was carried out on the site. Vertical Electrical resistivity soundings were undertaken using ABEM SAS 4000 Terrameter by means of the Schlumberger system of electrodes arrangement. The points have a maximum electrodes separation of AB/2 equals 160m. This type of electrode configuration has been used World Wide with satisfactory results. The method of electrical sounding furnishes detail information on the vertical succession of different conducting zones and their individual thickness and true resistivity. For this reason, the method is particularly valuable for nearly horizontal stratified ground. Seven VES stations were conducted along a profile that runs E-W about 1200 metres along the failed structure. This orientation was chosen in conformity with the W-E direction of the failed segment. The length of the traverse VES stations were determined by the length of the embankment about 1200metres and station interval of 200metres was adopted.

The sample for geotechnical test was collected into a plastic bag and transported to the soil laboratory of the soil was air dried and crushed into small pieces. The crushed sample was then sieved through 4.75 mm opening. The sieved soil was wetted with tap water (pH = 7.4) then the moistened soil was sealed in a plastic bag and stored for 3 days to allow moisture equilibration and hydration (BS1377:1990). The soil was later used for other geotechnical tests. The tests were conducted in duplicate for each particular soil condition to ensure the reliability of the test result.

The basic test such as specific gravity, particle size distribution, compaction test and Atterberg limits of the soil were performed according to the British Standard (BS 1377:1990). The data of these index properties were used to classify the soil following the United Soil Classification System (USCS) classification.

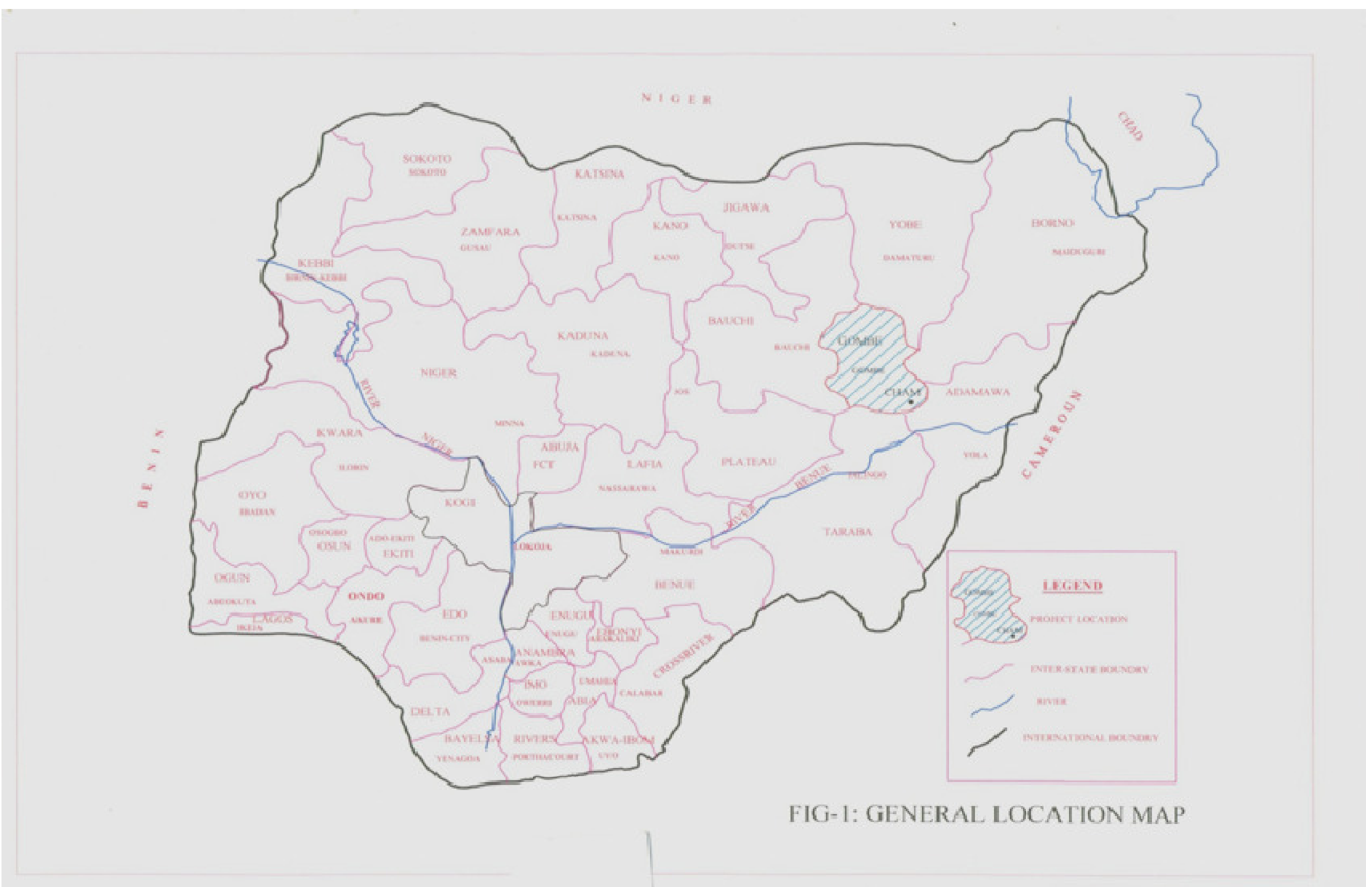


Figure-1
General Location Map

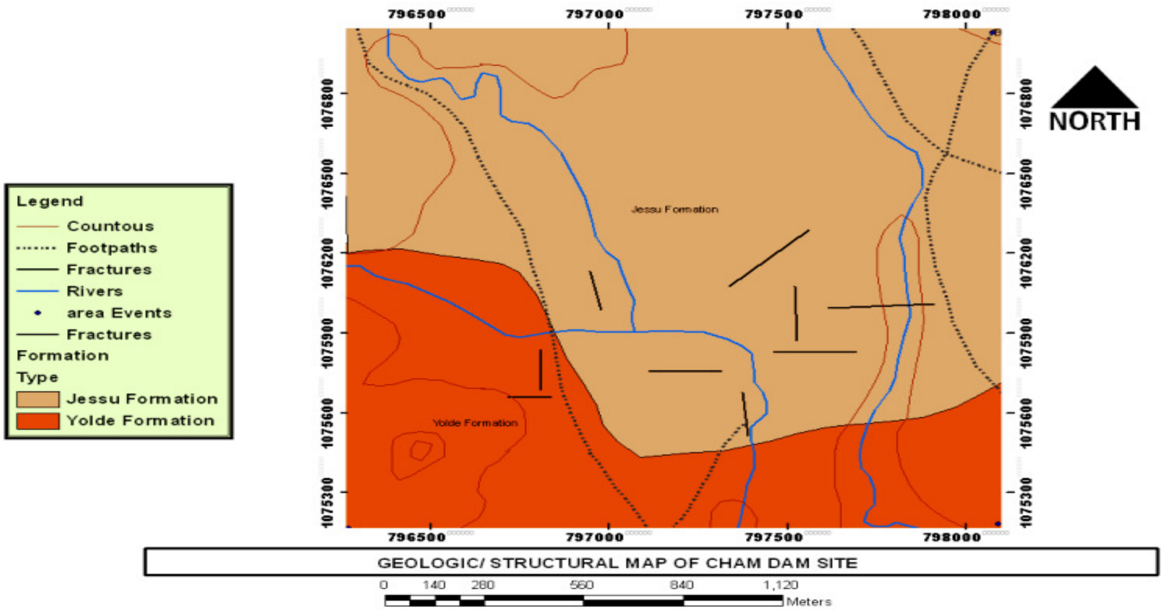


Figure-1
Geologic/Structural Map of Cham Dam Site

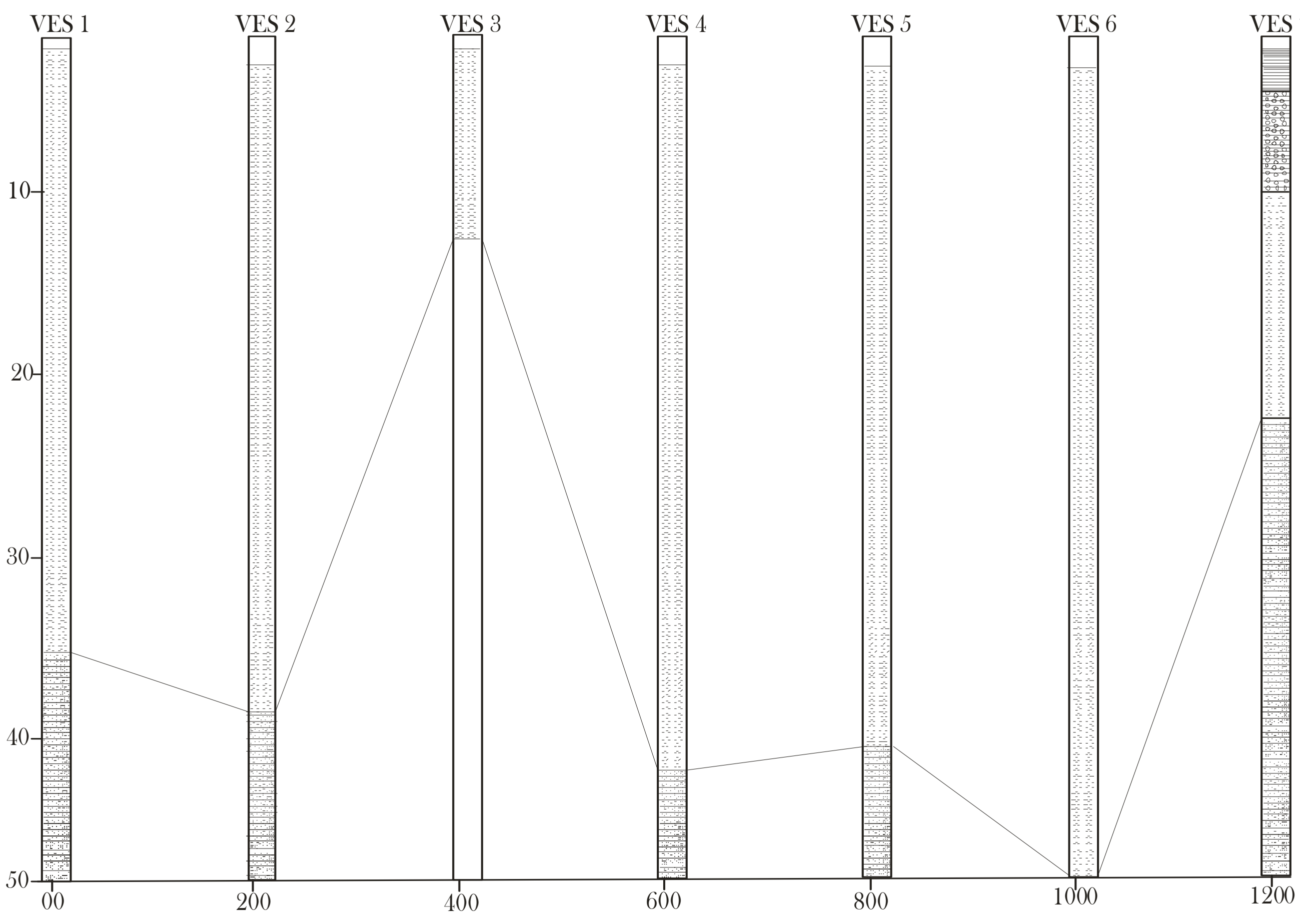


Figure-2
Exposed Lithologic Cross Section along a River Channel within Cham Dam

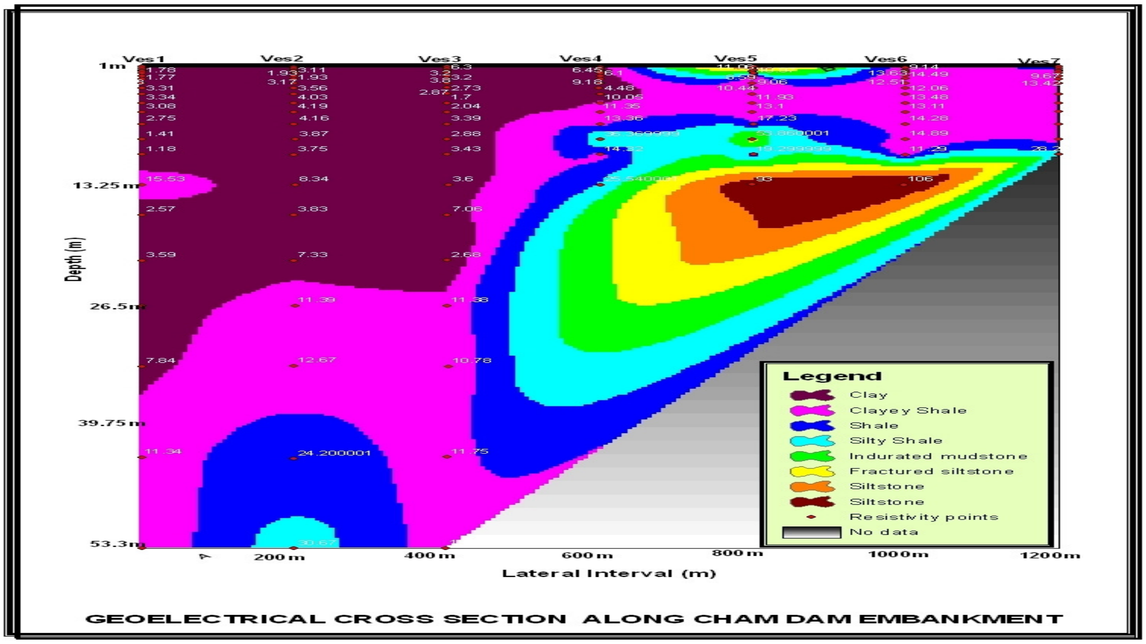


Figure-3
Geoelectrical Crosssection along Cham Dam Embankement

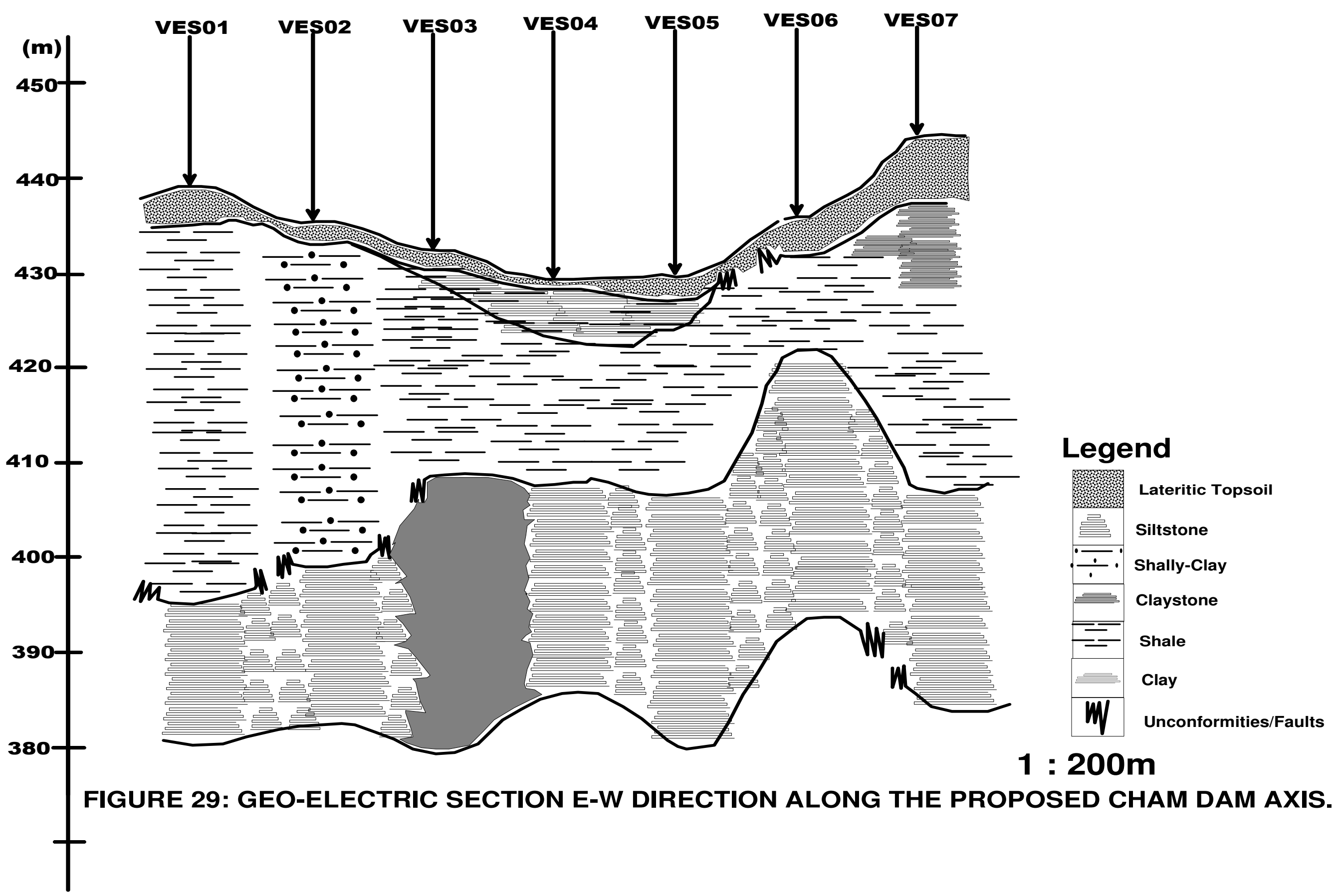


Figure-4
Geoelectrical section of proposed cham dam axis (subsurface layers)

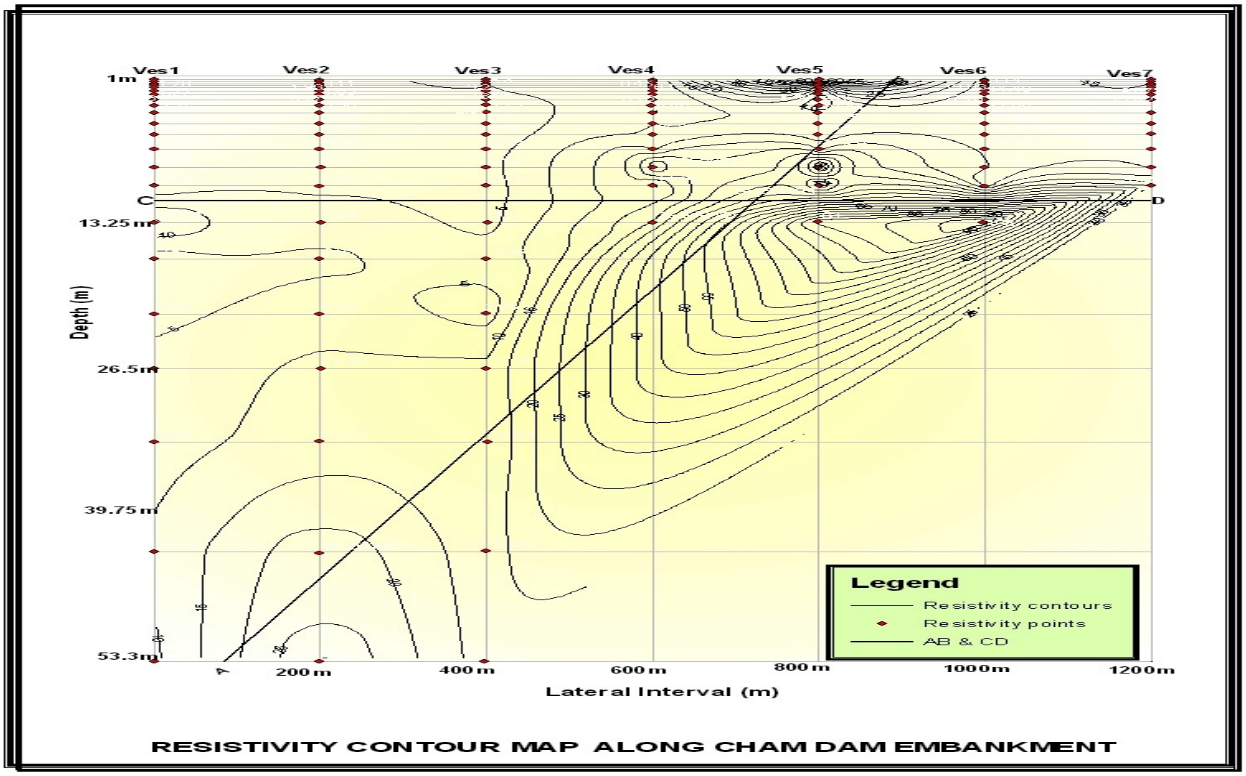


Figure-5
Resistivity Contour Map along Cham Dam Embankement

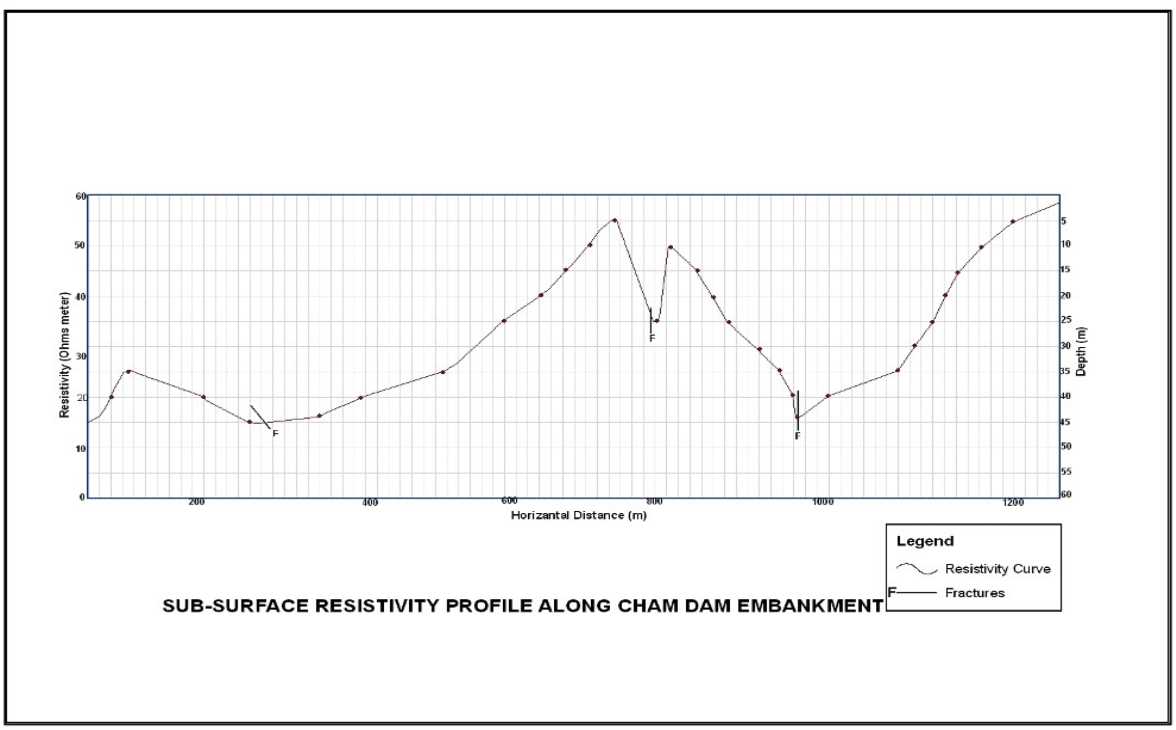


Figure-6
Sub-Surface Resistivity Profile along Embankement

Results and Discussion

The contoured apparent resistivity pseudo section was produced from plots of VES points against electrode spacing. The pseudo section was generated using IP12WIN Computer interpretation software. The curves were interpreted qualitatively through visual inspection and quantitatively using 1XD RESIX and IP12WIN Computer interpretation software's simultaneously. Interpreted results were used to construct geoelectric section from the layered parameter. The field curves show three, four and five to six layers case. Most of the curves indicate multiple increases and decreases of resistivity with depth (types H, HK, KHK and HKH). Below is the curves, Pseudo section, and geoelectrical representation of the various VES.

Figures 3 and 4 are the geoelectrical cross-section along Cham dam axis and embankment whereas figures 5 and 6 are the resistivity contour map along Cham dam embankment and subsurface resistivity proflile along dam embankment respectively. The resistivity contoure map covers a total horizontal distance of about 1200m. The former shows the cross section of rocks along the embankment. The area is underlain by shally clay and top soil to an average depth of 35m, and a siltstone bed extend to an unknown depth around VES 1, this is approximately similar to those of VES 2 and 3, while VES 4, is an array of chronologic lateritic dark clay to friable shale which extend to about 35m (figures 7, 8, 9 and 10). This is immediately underlain by probable silty shale to muddy shale to an unknown depth below. VES 5 (800m) is characterized by abrupt high resistivity which indicates that siltstone out crops from about 50m to about 1.5m to the surface (figure 11). This point is characterized by abrupt fall in resistivity between the depths of 10-25m; this represents a probable displacement (fault).

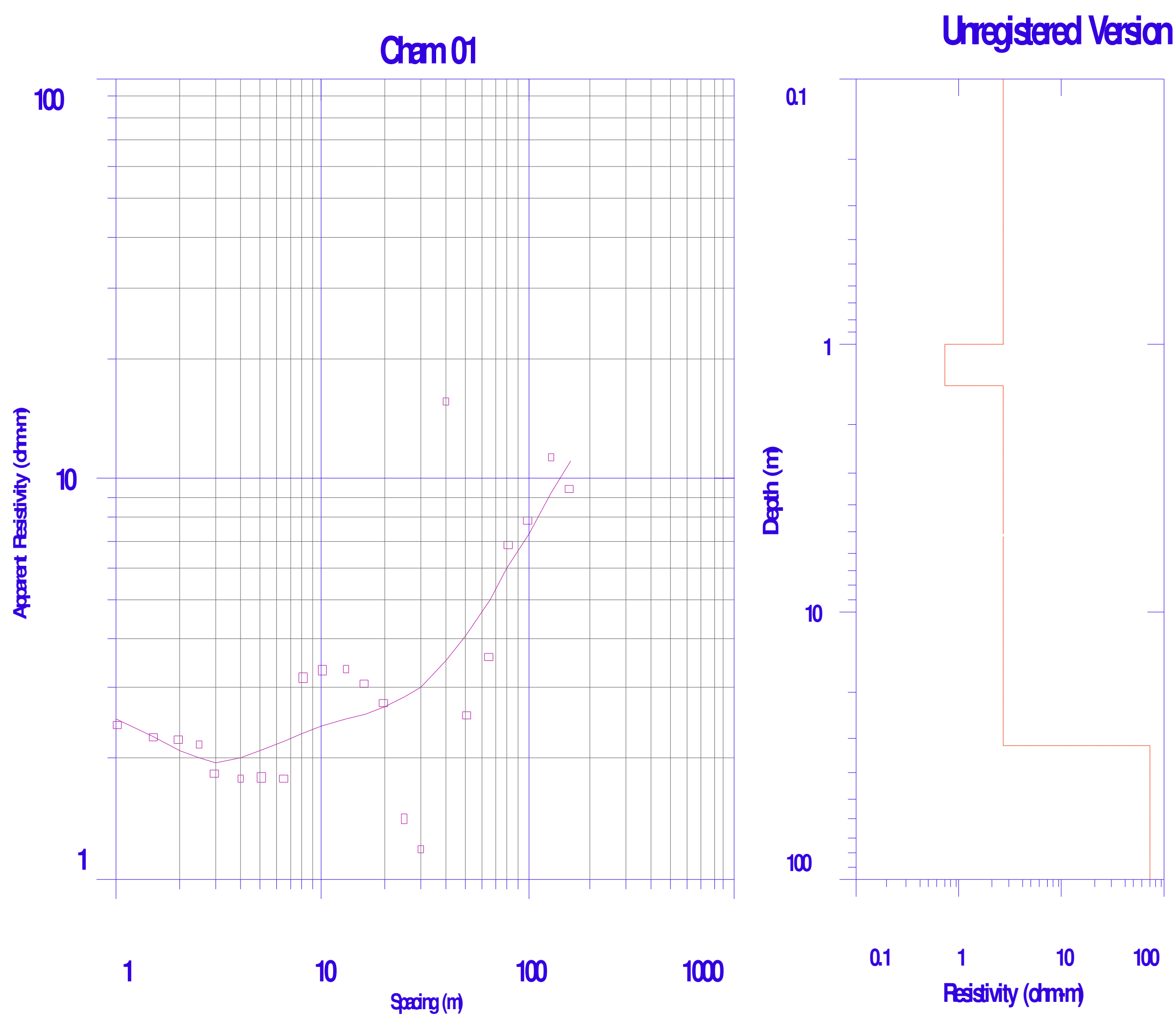


Figure-7
Resistivity Curve of VES 01

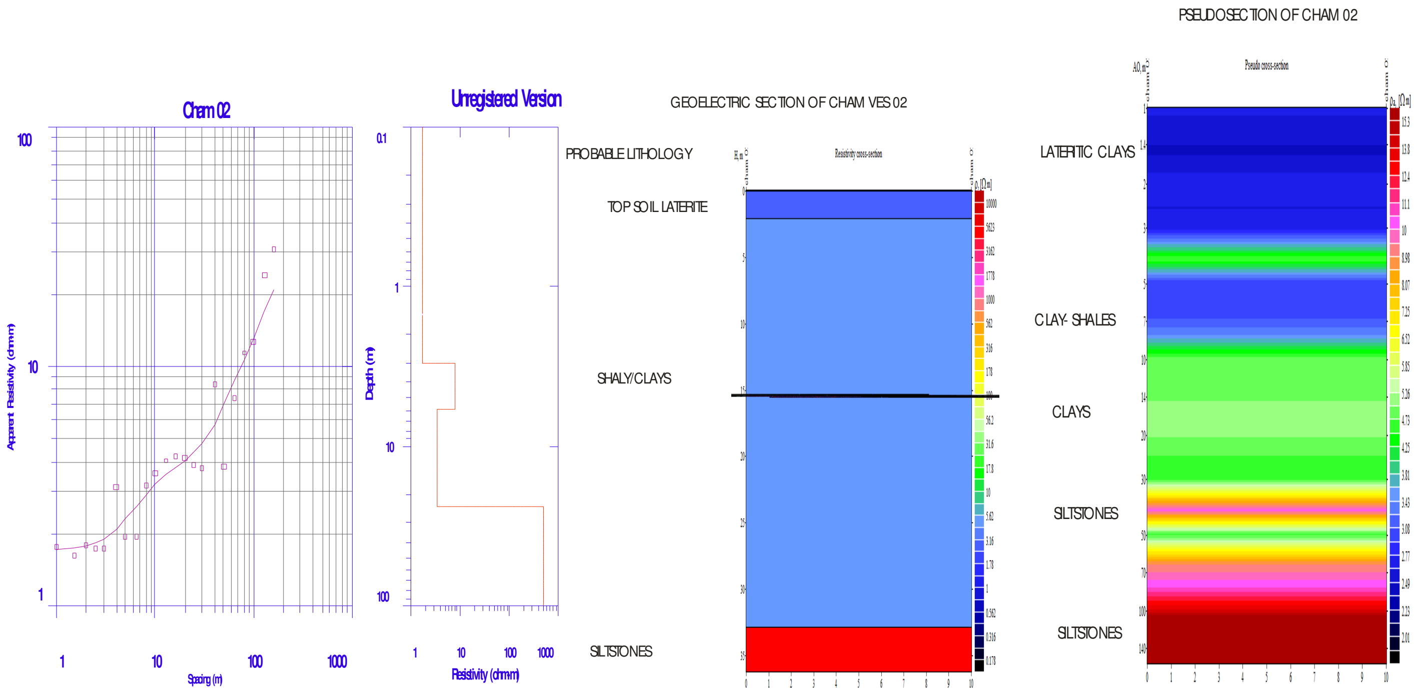


Figure-8
Resistivity Curve, Pseudo section and Geoelectrical Section of VES 02

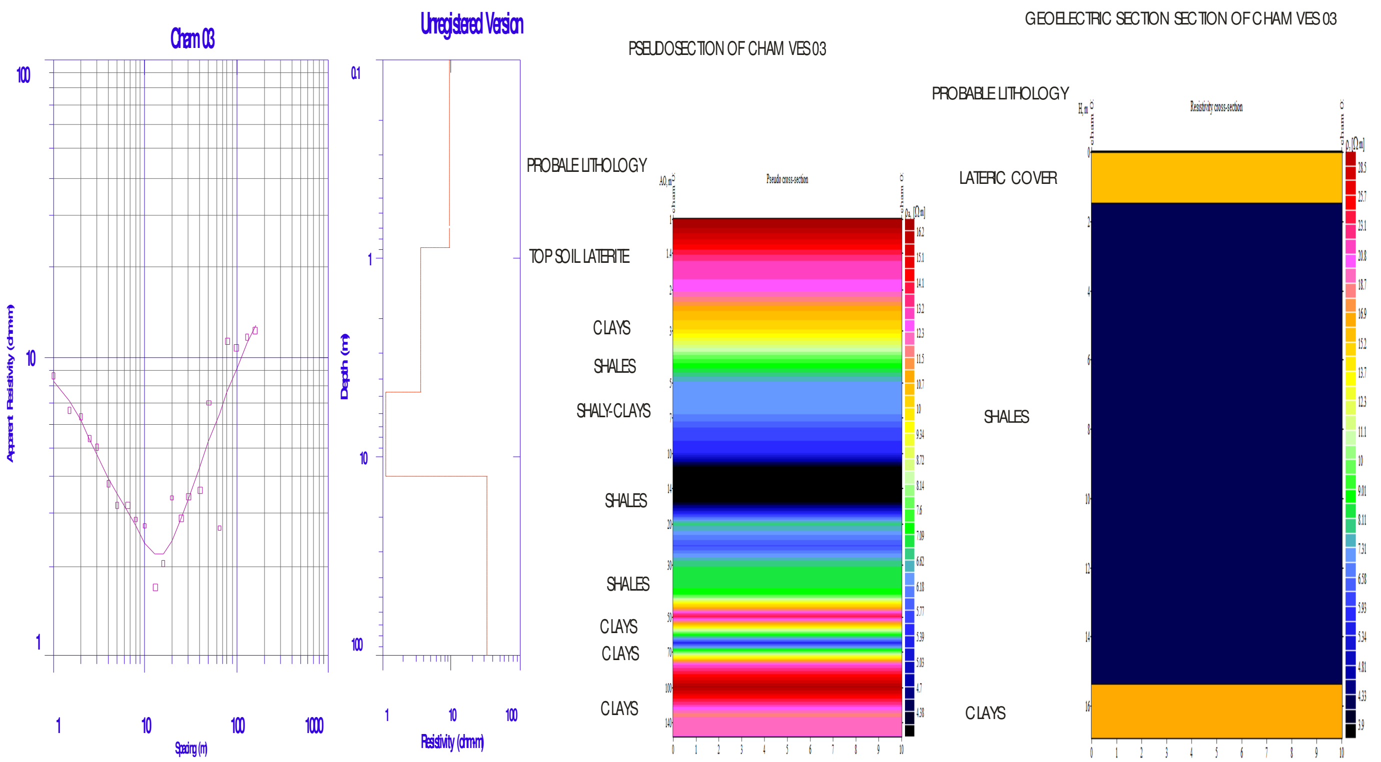


Figure-9
Resistivity Curve, Pseudo section and Geoelectrical Section of VES 03

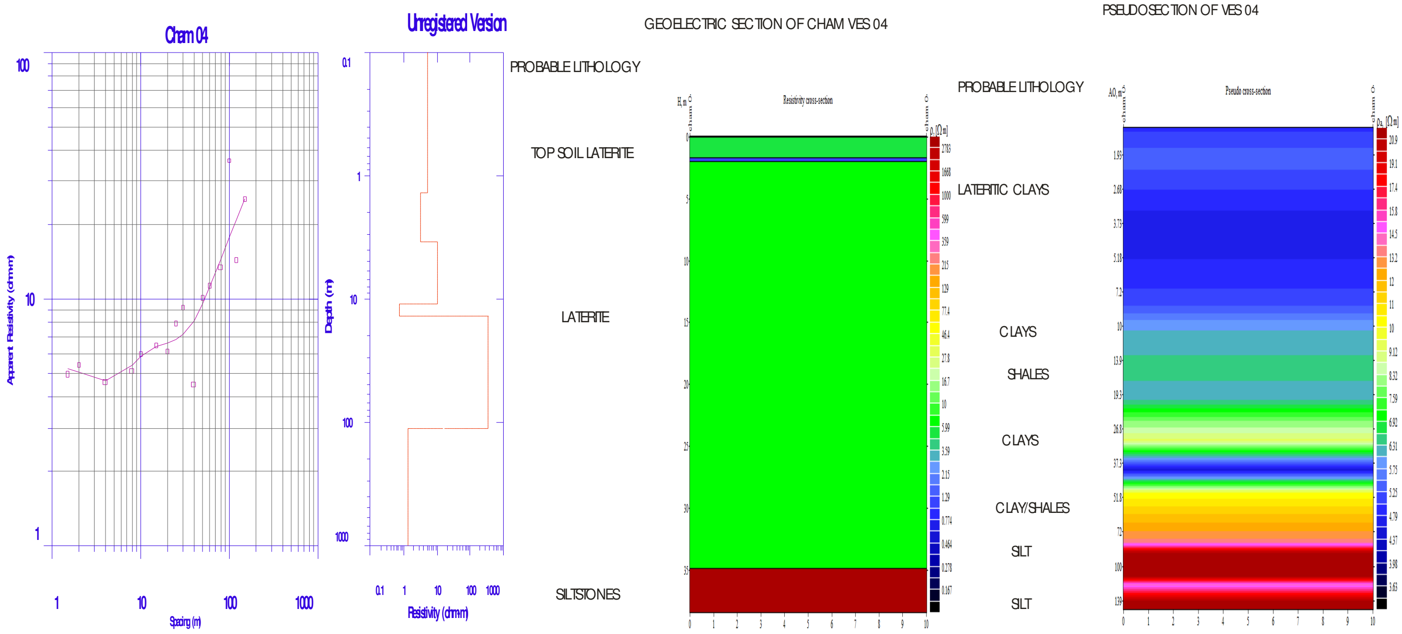


Figure-10
Resistivity Curve, Pseudo section and Geoelectrical section of VES 04

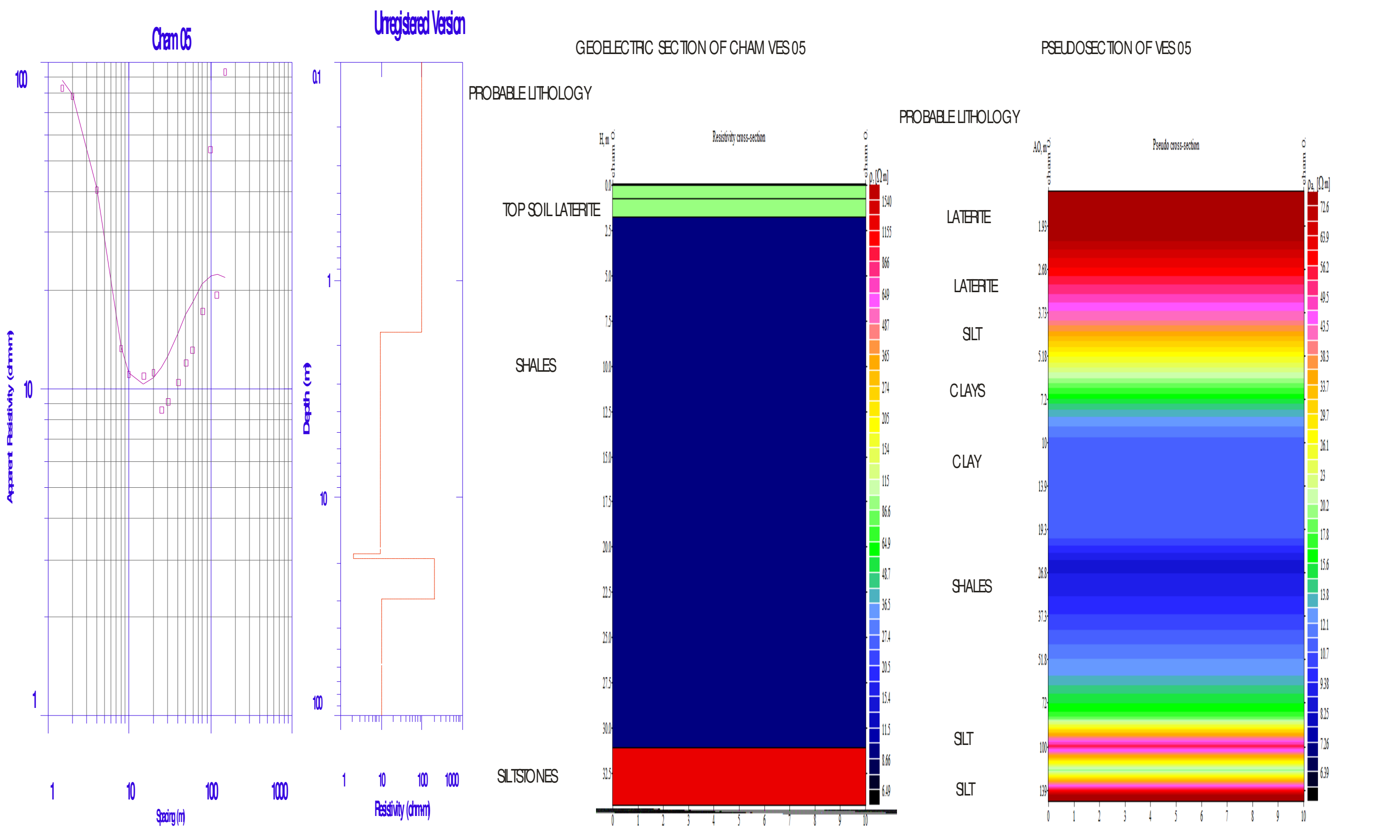


Figure-11
Resistivity Curve, Pseudo section and Geoelectrical Section of VES 05

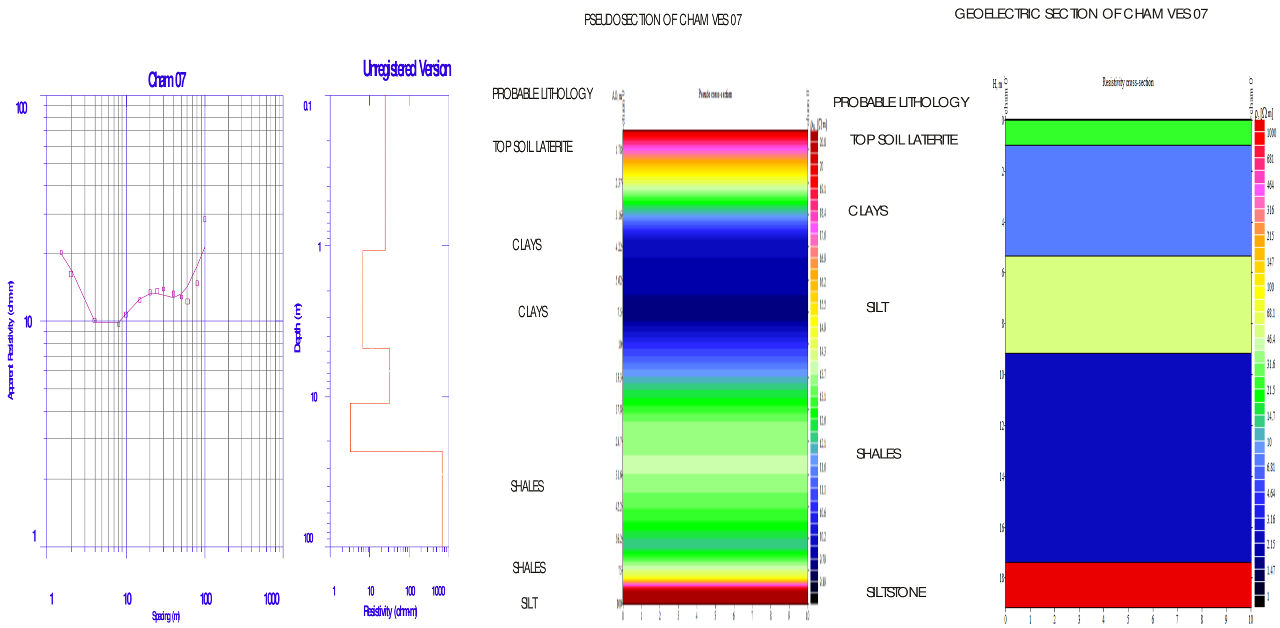


Figure-12
Resistivity Curve, Pseudo section and Geoelectrical Section of VES 06

VES 6 is characterized by shallow beds of siltstone at 1.5m to 45m, this is however cross cut by a minor fault between depths 35-45m (figure 12). The resistivity contour map of the same area from which the profile of the study area was plotted clearly indicates displacement at depth 39.75m along VES 3 and at about 7-10m depth along VES 4 to VES 7 (figure 5). It shows that the western part of the studied area with reference to the starting point is underlain by high resistivity rocks at shallow depth of 1-40m. The shape of this resistivity curves is related to the subsurface geology the entire surveyed area.

This show that moderate resistivity rocks occurs between 0-200m horizontally. This represents low resistivity rocks between the ranges of clay to shally rocks. The resistivity increases steadily between 400m and 1000m horizontally, with its highest peak at approximately 700m horizontal distance, showing the existence of a hard rocks from approximately 7m depth. Between 400m and 1200m, is shallow depth of higher resistivity rocks, these ranges in vertical depth from 1.5m to approximately 40m down the subsurface.

Drilling Program: Although no comprehensive drilling program was carried out at the dam axis. Shallow holes were dogged to 3m depth around the reservoir area and samples were collected to determine the construction integrity of fill materials. However the exposed cross sections within the holes were correlated with exposed outcrops (see plates 1and 2) within the deep river cuts through the earth (i.e. along the cliff), and the following profiles and structures were established from correlations. The correlated sections were compared with the resistivity profiles to corroborate the possible existence of displaced structures as earlier anticipated and establish the true rock units within the subsurface of the investigated area point 800m, 41m at point 1000m and 25m at 1200m. It also indicates probable displacement between 200m and 400m at an approximate horizontal distance of 300m at depth 38m, and between 400 and 600m at an approximate depth of 13m – 43m along a horizontal distance of 500m. The abrupt fall in resistivity is also observable at a horizontal distance of 900m, at depth 25-55m which indicates displacement at those points.

Geotechnical Evaluation: The study area covers some parts of Cham in Balanga Local Government Area of Gombe State. It is underlain by rocks of Yolde and Jessu Formations of the Yola arm of the Benue Sedimentary Basin. Geotechnical investigations of soils from the proposed dam sites on the basis of Atterberg limit, particle size and compaction tests were carried out to assess the geopedologic and hydrologic conditions. As would be seen on laboratory test report below post-depositional structures observed during investigation of the dam foundation include: desiccated cracks, joint, faults and potential land slide areas (see plates 3, 4 and 5).

Desiccated cracks: These were observed as polygonal or linear fractures in weathered sediments of darkish grey shale or dark mud within the entire dam site, they occur as partings or openings in the bulk surface of the underlying rocks of the reservoir area. They are potential points of water lost (leakages). Examination of these features revealed a polygonal shape showing that it is structurally controlled (see plate 3).

The above figure is an exposed cross-section of the underlying beds and structures along a river channel within the dam area, it could form an average representation of the studied area along the embankment. From the figure above, it could be deduced that, shally clay overlies siltstone to a depth of 35m at point 00, 39m at point 200m, 13m at point 600m, 45m at faults: These are also planar discontinuities observed along the floor of the reservoir area west ward and along the spillway (table 1). These result from offloading by erosion causing minor fractures to open. This also could be due to stress or increase hydraulic head acting in this area and also due tectonic tensional forces. The faulting of the calcareous siltstone at the river bed is tectonically controlled, because of its N-S orientation. This is connected with the famous N-S tensional tectonic deformation of the Yola-arm of the upper Benue Trough, during the emplacement of the Cameroon Volcanic Line. These are common around the southwestern part of the dam around the reservoir (plate 3).

Plate-1
Lithologic cross-section of rock type along Cham River around investigated area; it shows top lateritic clay overlying a clayey shale layer

Plate-2
Lithologic cross-section of rock type along Cham River around investigated area, it shows alternate layers of lateritic clayey shale and silt overlying massive clay or mudstone

Plate-3
Shows Desiccated cracks within the reservoir area

Plate-4
Shows joints within the reservoir area

Plate-5
Shows fault plain along the proposed spillway area

Table-1
Location and Orientation of Fractures

S. No.	Deformation type	Orientation	Altitude/approximate length	Location
1	Fault	East-West	430m	N9^{0}43.467\` E11$^0$42.727\`
2	Fracture (Burried)	East-West	430m	N9^{0}43.406\` E11$^0$42.636\`
3	Fracture	North-South	433m	N9^{0}43.415\` E11$^0$42.639\`
4	Fracture	East-West	429m	N9^{0}43.410\` E11$^0$42.642\`
4	Fracture	North-South	432m	N9^{0}43.3617\` E11$^0$42.573\`
6	Fracture (Gully)	East-West	430m	N9^{0}43.345\` E11$^0$42.565\`
7	Fault	East-West	434m	N9^{0}43.194\` E11$^0$42.312\`

From the above geo-electrical section of proposed cham dam axis, it is observed that the top lateritic soil is averagely 4m thick around VES 01 and approximately 8m at VES 07. This is immediately underlain by shale to shally clay at the depth of 4m from the topsoil and thickens averagely 40m along VES 01 – 03. At VES 03 – 05 is a patched bed of calcareous siltstone or marl, immediately underlying the topsoil at 11m depths to the center of the dam axis. The siltstone bed thins out at the east and western part of the dam axis.

At VES 07 is a thick layer of claystone (mudstone) it occurs at 9m depth and thickens 8m, and is immediately underlain by shally clay. At VES 06 is a thick layer of siltstone which occurs at 15m depth, and thickens averagely 30m. At VES 01 the siltstone layer outcrops at 45m depth, while in VES 02 it outcrops at depth 33m, and at VES 03 – 05 it outcrops at depth 22m.

Major Displacements: The major displacements are observed at depth 48m in VES 01, 45m at VES 02 and between VES 02 and 03 at 25m depth, others occurs between VES 06 and 07 at depth 53m down the subsurface. Table 2 is a summary of events on the geoelectrical section of proposed Cham dam axis.

Borrowed Pits: Pit1: The proposed borrow pit was located at N9^{0}43.9\`, E11$^0$42.9\` and dug to a depth of about 2m. The top soil at 0-1ft is mainly weathered shale to clay, darkish grey in color. At 2fts, it changes in facies to milky or whitish color. This is underlain by a thin layer of ferruginised calcareous siltstone (3inch). At 1meter is a thick layer of silty mudstone or clay which was collected for analysis as embankment or dump materials.

Pit 2: This proposed pit is located at N9^{0}43.6\`, E11^{0}42.9, it is approximately 150m south of pit 1. The outcrop is exactly as that in pit 1.

Results of Geotechnical Assessment: The result of the geotechnical parameters (Viz: Optimum moisture content, maximum dry density, plastic and index limits, and liquid limit) of sampled soil from the trial pit could be seem attached to the scope of this study in form of table and graphs.

Liquid Limit: The liquid limit of the sampled soil is 60% which is relatively high in relation to the specified 35% by Clayton and Juckes[7], (see table 6) this in turn implies high plasticity (figure 13).

Table-2
Geo-Electrical Section of Cham Dam Axis

Ves	Horizontal Distance (1:200m)	1st layer Top soil	2nd layer Shale/ Shally Clay	Interbeding layers of Mudstone	3rd layer Siltstone 1	Interbeding layers of Siltstone 2	Displacement With Depth	Horizontal Position of Displacement
01	0	0 - 4	4 – 40m	-	40 – 55m		48m	140m
02	0-200	0 - 2	2 – 33m	-	36 – 53m	36 – 53m	37m	340m
03	200-400	0 - 2	2 – 24m	-	24 – 53m		32m	500m
04	400-600	0 - 1	10 –21m	-	21 – 43m	-		
05	600-800	0 - 3	4 – 19m	-	19 – 46m	-	3m	1120m
06	800-1000	0 - 4	4 – 10m	-	10 – 29m	-	47m	1200ms
07	100-1200	0 - 07	17 –32m	7 – 17m	32 – 57m	-		

Table-3
Results of liquid limit and plastic limit tests

Test No.		1	2	3	4	5	6
Type of test		**LL**	**LL**	**LL**	**LL**	**PL**	**PL**
No.of blows/ container no.		**16/11**	**26/4**	**38/6**	**50/5**	**/16**	**/15**
Mass of wet soil + container	g	22.4	25.2	24.9	27.5	19.8	20.3
Mass of dry soil + container	g	17.0	19.2	19.0	20.8	17.6	17.8
Mass of container	g	8.5	8.6	8.6	8.5	8.5	8.6
Mass of moist soil	g	5.4	6.0	5.9	6.7	2.2	2.5
Mass of dry soil	g	8.5	10.6	10.4	12.3	9.1	9.2
Moisture content	g	63.5	56.6	56.7	54.5	24.2	27.2

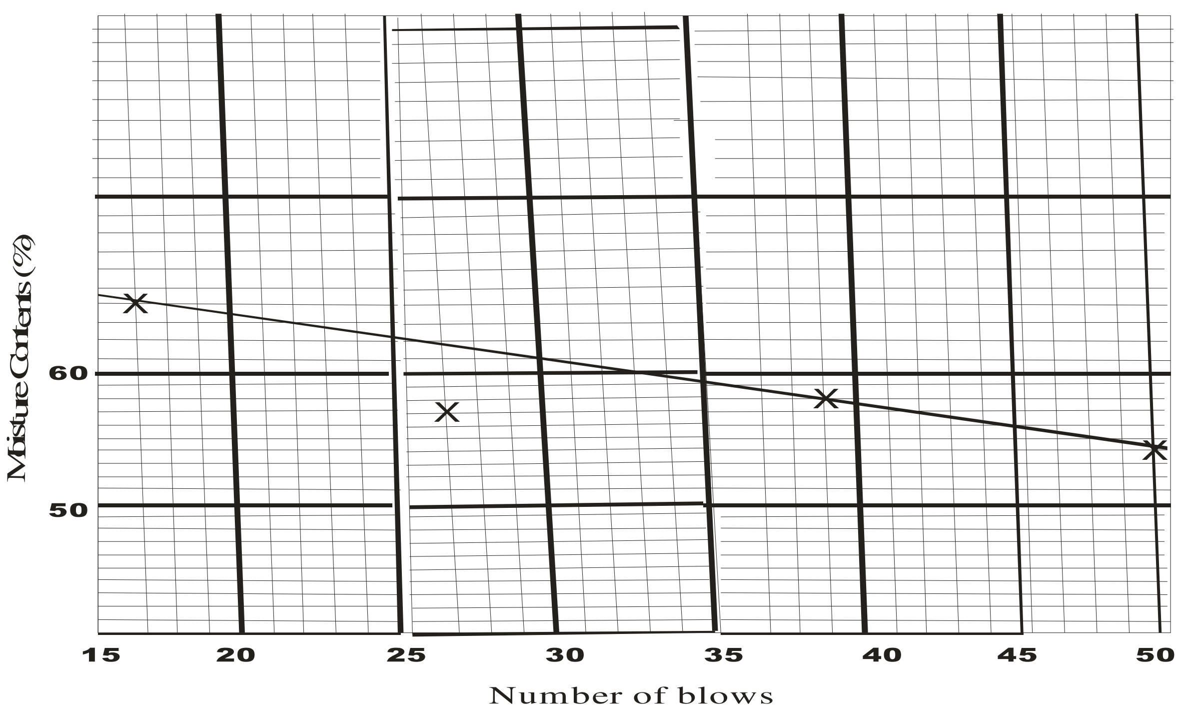
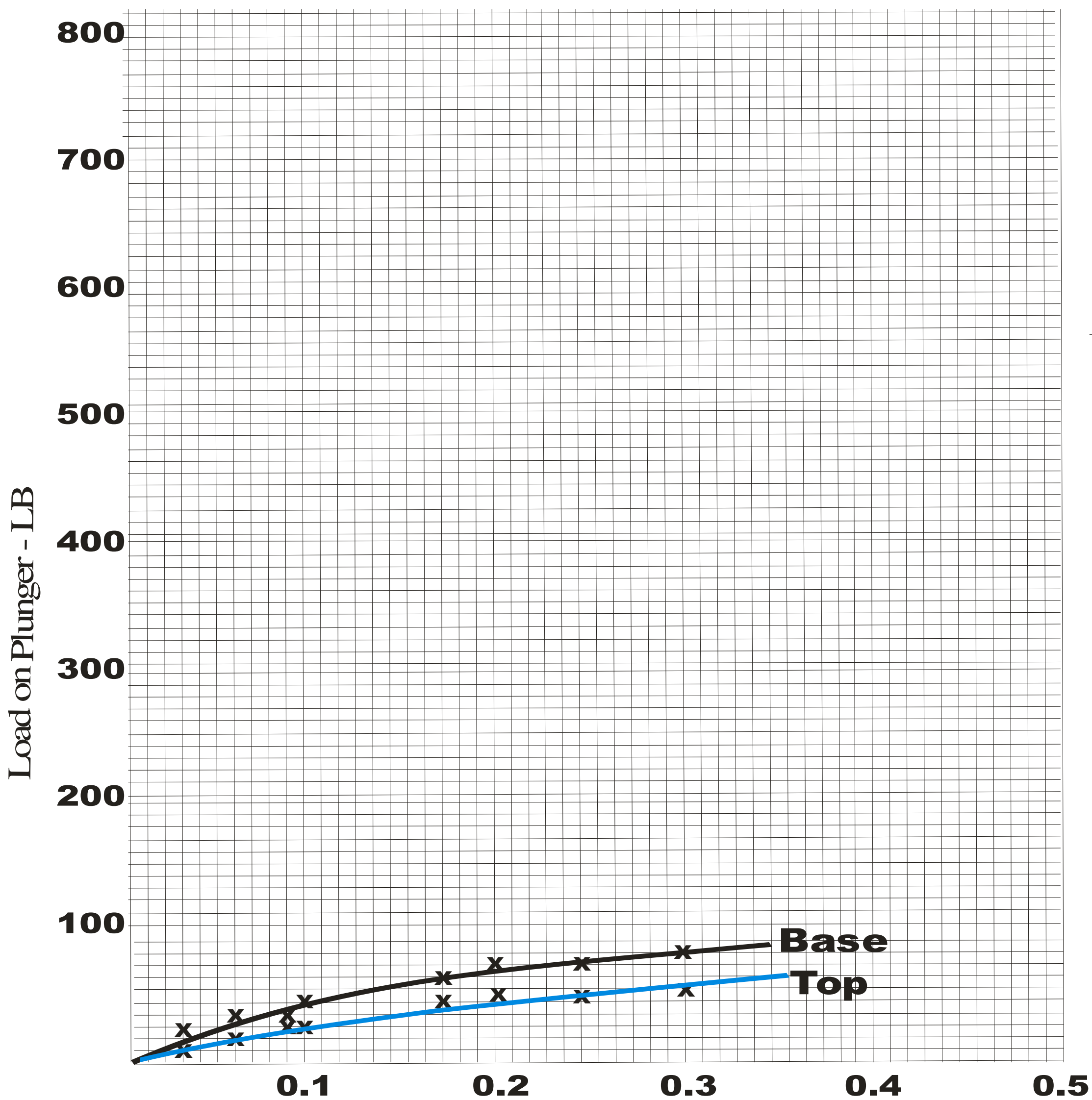


Figure-13
Plot of Liquid Limit Test of Cham Dam Site

Table-4
Results of California Bearing Ratio test

Pen in	Base		Top		Pen in	Base		Top		Pen in	Base		Top	
	Divs.	Load	Divs.	Load		Divs.	Load	Divs.	Load		Divs.	Load	Divs.	Load
.01					.11					.225				
.02	7	18	4	10	.12					.25	24	63	14	37
.03					.13					.275				
.04					.14					.30	27	71	16	42
.05	11	21	6	16	.15	18	47	10	26	.325				
.06					.16									
.07	12	29	7	18	.17									
.08					.18									
.09					.19									
.010	15	39	8	21	.20	21	55	13	34					

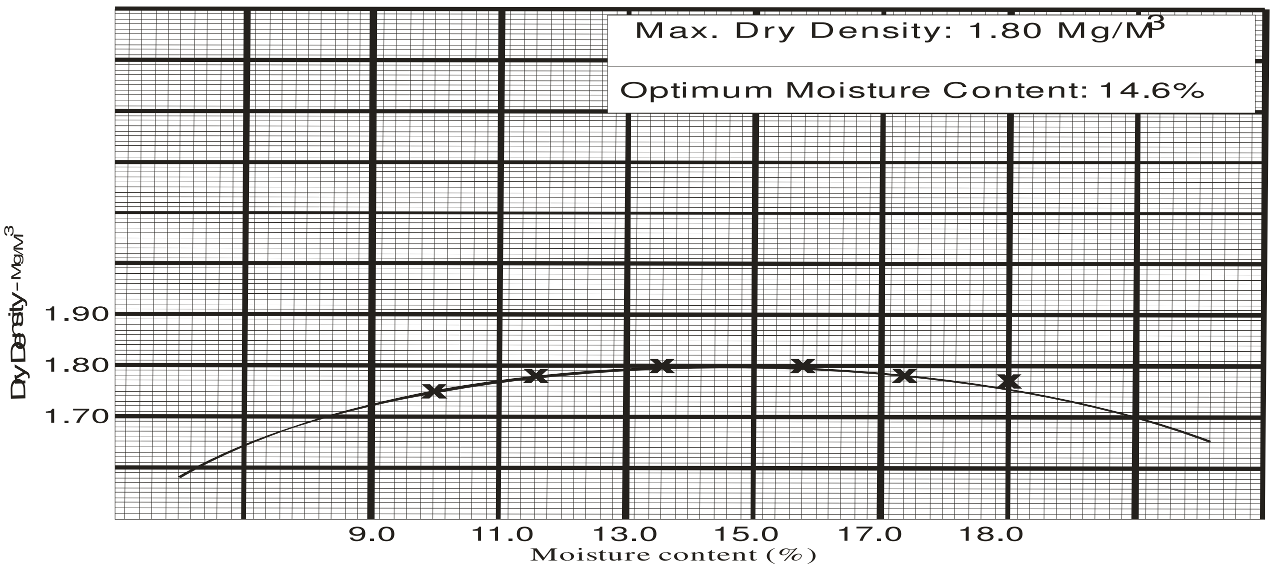


	Top	Base	
0.10	2	3	
0.20	2	3	
C.B.R		3%	

Figure-14
Plot of C.B.R. Test of Cham Dam Site

Table-5
Moisture Content Determination

Container No.	94	67	7	17	41	53	75	85	1	61	38	40
Wt. of wet soil & container……gr	47.9	52.2	60.9	71.0	60.7	61.7	52.6	64.6	52.0	55.1	59.5	54.5
Wt. of dry soil & container….gr	45.0	49.1	56..4	65.3	55.4	56.2	47.8	57..8	46.6	49.4	52.7	48.7
Wt. of container……………gr	15.8	16.0	16.3	15.6	15.7	15.7	15.3	15.9	15.8	15.7	15.5	15.8
Wt. of dry soil………………gr	29.2	33.1	40.1	49.7	39.7	40.5	32..5	41.9	30.8	33.7	37.2	32.4
Wt. of moisture………………gr	2.9	3.1	4.5	5.7	5.3	5.5	4.8	6.8	5.4	5.7	6.8	5.8
Moisture cont. (100Wm/wd)…%	9.9	9.4	11.2	11.5	13.4	13.4	14.3	16.2	17.5	16.9	18.3	17.6
Aver. Moist. Content m……. %	9.7	11.4	13.4	15.5	17.2	15.0						
Dry density (yd=100y/100+m)	1.75	1.79	1.8	1.80	1.79	1.78						
c.b.r (mean of top and bottom)..%												



9.0

Figure-15
Plot of Compaction Curve of Cham Dam Site

California Bearing Ratio: From the result of the CBR test indicates that they are generally below the standard value of 10% for sub-grade materials (table 4 and figure 14) . From the average results of both CBR and Atterberg limit tests, the soils are cohesive. It thus indicates that the soils are susceptible to cracking and fracturing.

Maximum Dry Density (MDD): The standard value for maximum dry density, ranges from 0.76-1.11 and the MDD of sampled soil is 1.80 (table 5). This is slightly above the specified range[8] which means that the soil is highly compactable, and could attain the dense strength as a required embankment material (figure 15).

Plasticity Index: With reference to the table below, the Plasticity index, of the sampled soil is relatively high with a value of 34.3%; compared to the specification on tables 6 and 7, this indicates that the soil is actually cohesive, and non-friable, therefore very suitable for embankment materials. Based on the grading from the sieve analysis result, the soil could be classified under A6-A7 class of soil, signifying a clayey soil material[9]. This is because any value above 20% passing indicates clayey losses zone.

Sieve Analysis: Table 8 which shows the result of sieve analyses conducted on samples collected from the proposed borrowed pits indicate high percentage of fines confirms relatively high plasticity obtained for the study area (figure 16). The results confirms cohesive non-friable soils.

Table-6
Standard Range of Plastic Limits of Soils (Clayton and Juckes, 1978)

Plastic Limit of Soils (%)	**Plasticity**
Below 35%	Low Plasticity
Between 35 – 50%	Intermediate Plasticity
Above 50%	High Plasticity

Table-7
Plasticity Indices and Corresponding States of Plasticity (Burmister, 1997)

S. No.	**Plasticity Index %**	**State of Plastic**
1.	0	Non Plastic
2.	1-5	Slight
3.	5-10	Low
4.	10-20	Medium
5.	20-40	High
6.	>40	Very High

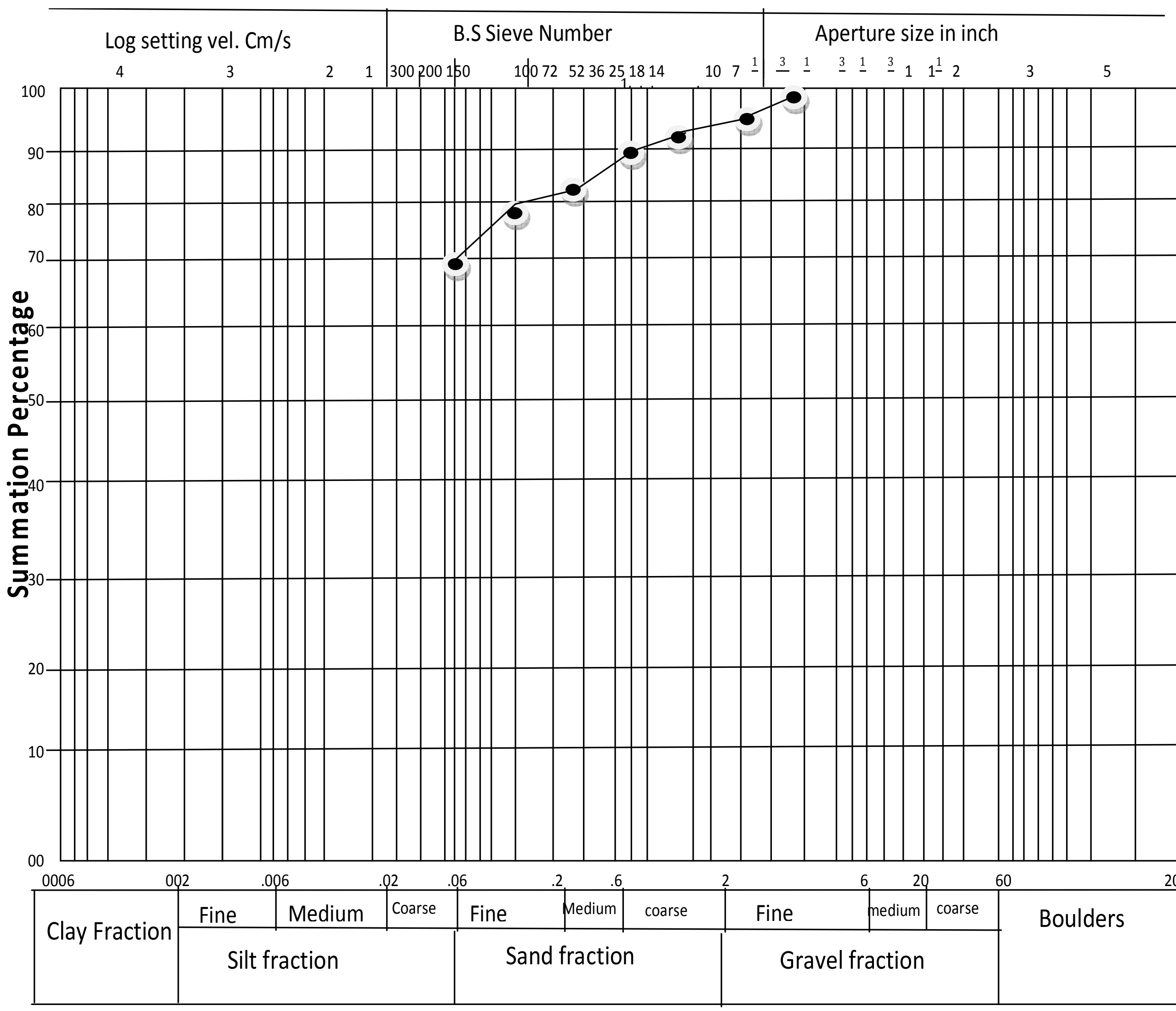


Figure-16
Plot of sieve analyses curve of Cham dam site

Table-8
Sieve Analysis Results

Weight of Sample Before Sieving: 326				
Sieve size	**Weight retained**	**% Retained**	**% Passing**	**Specific limit**
3/4" 20mm	-			
½" 14mm	-			
3/8"10mm	-			
3/16" 5mm	11	1.1	98.9	
Refilled sample passing				
No. 72.36mm	22	2.2	96.7	
No.141.18mm	35	3.5	93.2	
No.25600mm	37	3.7	89.5	
No.36 425um	25	2.5	87.0	
No.52 300um	18	1.8	85.2	
No.722 10um				
No.100 150mm	71	7.1	78.1	
No.200 750mm	86	8.6	69.5	
Passing 750um	695	69.5	-	
Total	Weight B/4	Washing	1000kg	

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