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DETAILED GEOPHYSICAL INVESTIGATIONS OF STABLE AND UNSTABLE SECTIONS OF SARKIN PAWA-MANGORO ROAD, NIGER STATE, NIGERIA

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ABSTRACT

Geophysical investigations involving the Schlumberger vertical electrical sounding (VES) and the magnetic method have been carried out along stable and unstable sections of the Sarkin Pawa-Mangoro road in Niger State, Nigeria. This is to investigate the factors responsible for the incessant pavement failure within the area. A profile with a total of 28 VES stations at a separation of 50 metres covering a distance of 1350 metres was established parallel to the road pavement on each side of the road. ABEM SAS 300 terrameter was used for the measurements. The magnetic survey was conducted using the Proton Magnetometer at a station interval of 25 metres along two profiles on each side of the road and running parallel to the road pavement. The profile separation was 7 metres. The two innermost profiles are on the same VES profiles above. The geoelectric sections along the stable segments of the road show generally resistive subsurface, while the magnetic profiles show a homogeneous subsurface devoid of geological features. Beneath the unstable segments, the geoelectric sections show low resistivity clay topsoil, water absorbing substratum, and near-surface water table. The magnetic profiles indicate a prominent low magnetic linear feature which is suspected to be a fault within the basement, or an old stream channel which has been covered with sand. This magnetic feature corresponds to a visible subsidence on the earth's surface. The unstable sections, which correspond to pavement failure, can hence be delineated using geophysical investigations and thus enabling necessary remedial actions to be taken when constructing the road.

KEYWORDS: Vertical Electrical Sounding, Magnetics, Mangoro, Geoelectric Section, Resistivity, Pavement Failure

INTRODUCTION

A road pavement section may be generally defined as structural materials placed above a sub-grade layer (Woods and Adeox, 2002). In asphaltic pavement (common on Nigerian roads), these structural materials include the sub-base, base and the surfacing. Road pavement is supposed to be a continuous stretch of asphalt laid for a smooth ride or drive, but discontinuity in the road network resulting in cracks, potholes, bulges and depressions gives rise to road failure (Aigbedion, 2007). The sub-grade soil beneath a stable highway pavement is expected to possess sufficient strength to support the structure or wheel load imposed on it. Unfortunately, due to the heterogeneous nature of the soil and the subsurface geological structures, the above condition is rarely met and hence the strength of the sub-grade decreases and eventually, the pavement on it fails. In 2006, a total of 3 billion naira was said to have been spent on the rehabilitation of federal government road network along Akwa Ibom/Calabar axis (Aigbedion, 2007) and between 2001 and 2007 the sum of 113 billion naira was spent on federal government roads in Nigeria (Kashim, 2009).

Road failure, therefore, is a problem that every Nigerian should be concerned about with a view to finding a lasting solution. In the light of our present economic situation, we need to devise measures to curtail the large amount of money spent on road repairs and reduce the daily loss of lives and property due to bad roads. Needless to say, therefore, that if these must be achieved, sufficient technological data and investigations on the causes of highway failure must be carried out.

Field observations carried out by Adegoke-Anthony and Agada (1980), Mesida (1981) and Ajayi (1987) have shown that road failures are not primarily due to usage or design construction problems alone, but can equally arise from inadequate knowledge of the characteristics and behaviour of the residual soils on which the roads are built. This present research has investigated and identified those geological factors responsible for the incessant road failure witnessed within the study area using resistivity and magnetic geophysical techniques. Geophysical surveys are efficient and cost-effective in providing geotechnical information since they combine high speed and appreciable accuracy in providing subsurface information over large areas (Momoh et al., 2008).

GEOLOGY OF THE STUDY AREA

The study area (Latitude 09 ˚ 52 ˈ N and Latitude 09 ˚ 58 ˈ N; and Longitude 07 ˚ 12 ˈ E and 07 ˚ 28 ˈ E) lies within the basement complex of the North-Central Nigeria. The rocks within this basement complex are grouped into three categories; these are the older granites, gneiss and magnetite; the older metasediments; and the younger metasediments. According to Ajibade and Wright (1980), the rocks of the basement complex are believed to have evolved in at least four orogenic events namely: the Pan African (600±150My), The Kibaran (1100±200My), The Eburnian (2000±200My) and the Liberian (2800±200My) orogenies.

Site Area Description

Figure 1 shows the location of the study area. Sarkin Pawa is about 87 km from Minna, Niger State Capital. The distance between Mangoro and Sarkin Pawa is about 20 km, within this distance lies the study area. The elevation above sea level ranges from 500 metres to 615 metres.

METHODOLOGY

Geophysical survey involving the vertical electrical sounding and the magnetic method was carried out along both the stable and unstable sections of the road.

The vertical electrical sounding was carried out using the ABEM terrameter SAS 300. Two traverses P_1 and P_2 each of 1350m long, with one on each side of the road, were established parallel to the road pavement. A total of 28 vertical electrical soundings spaced at a station interval of 50m were taken on each traverse. A maximum current electrode spacing (AB) of 200m was used with the aim of probing a depth of at least 1/3 of AB. A current variation in the range of 0.2-1.0A, found suitable in the basement terrain (Badmus et al., 2005), was used in the survey.

The ground magnetic survey involved the measurement of the total magnetic field of the earth in the study area using the proton precession magnetometer. A total of four parallel profiles were established, two on each side of the road. The separation between these profiles on each side of the road is 7 metres. The innermost profiles are the same as P_1 and P_2. A station spacing of 25 metres was adopted to allow high resolution of the near surface sources. A base station was established for the four profiles. Readings were taken before the commencement of measurement and immediately after all the profiles have been occupied to enable diurnal correction. Three point readings were taken at interval of three seconds and an average adopted in each case.

DATA ANALYSIS AND INTERPRETATION

The interpretation of geophysical data involves expressing the information obtained from the surface measurements into geological section/form, from which both qualitative and quantitative deductions can be made.

Analysis and Interpretation of Resistivity Data

The apparent resistivity values at each sounding point have been calculated from the resistance values obtained on the field. The apparent resistivity values calculated are presented as sounding curves for all the VES points using IPI2Win software designed for interpreting vertical electrical sounding data (Bobachev, 2001). Nine curve types have been identified within the study area. These are A, H, K, AK, HK, HA, AH, KH, and QH type with the H type as the predominant curve type

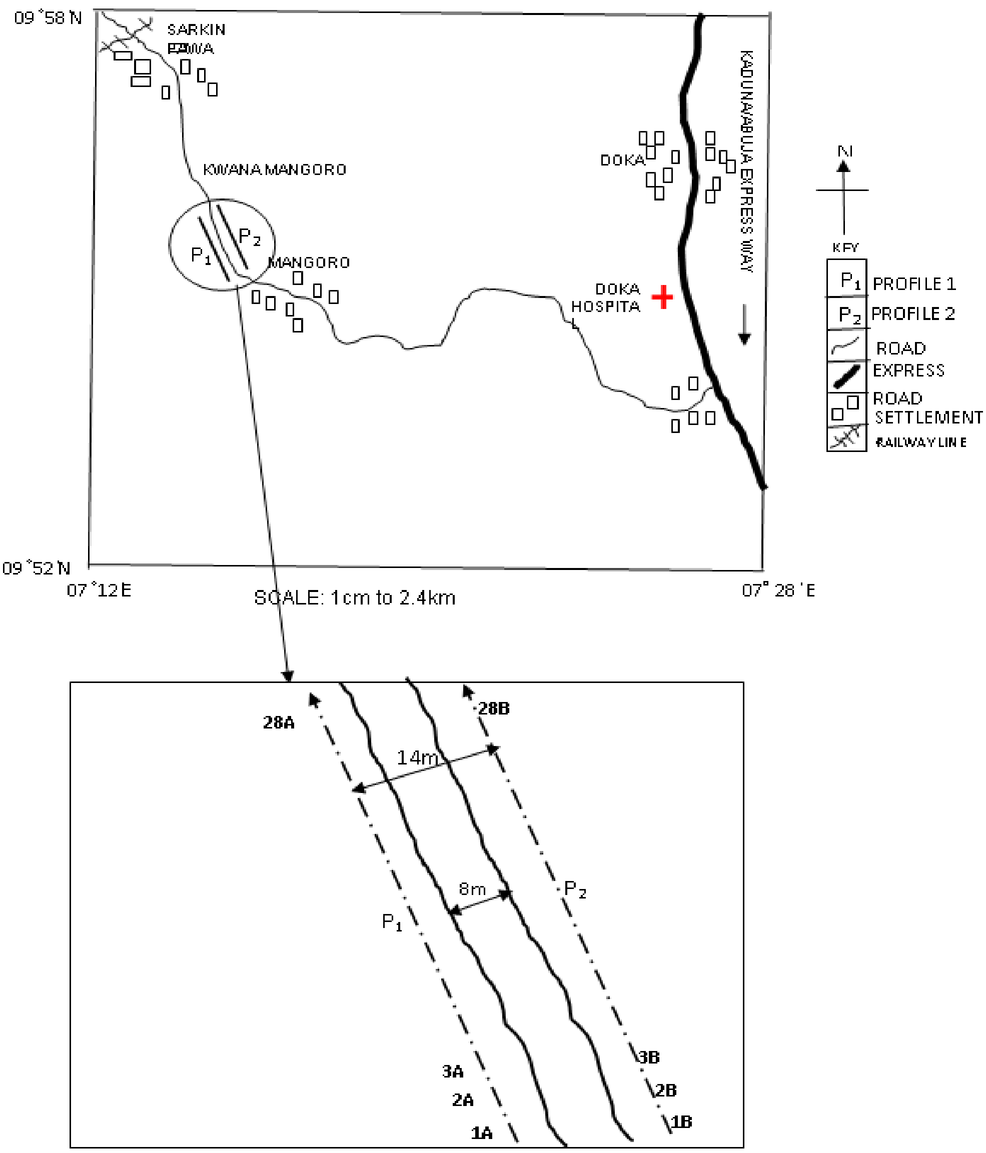


Figure 1: The Location of the Study Area with Arrow Showing the Profiles P_1 and P_2

(Figure 2). Typical curve types obtained from the field are shown in Figure 3 along with their model interpretations using IPI2Win. The 2D geoelectric and geologic sections along the two profiles are shown in Figures 4 and 5. Four geoelectric/geologic subsurface layers comprising the top soil, weathered layer, partially weathered/fractured basement and the fresh basement have been delineated.

The first layer which is the top soil has resistivity values ranging from 20-640Ωm. It has average thickness of about 2.5m. It is evident from the range of resistivity values within the layer that it does not consist of the same material across the entire length of the profile. For example, VES 1 to 5, 10 to 13 and 18 to 22 in the two profiles have resistivity values that range from 120-640Ωm. This is resistivity of lateritic soil, clay/sandy soil or sand. The resistivity values within the remaining VES points of this first layer range between 20-120Ωm. These portions are likely to consist of clay and sandy clay material with high moisture content.

The second layer is the weathered basement with resistivity values that vary between 20-500 Ωm and thickness of between 2.5-20.0m. There is an indication of high degree of saturation within VES 5 to 10, 15 to 18 and 22-26 as their resistivity values are generally below 150 Ωm. This suggests that these sections are predominantly composed of clay or sandy clay materials.

The third layer is the partially weathered/fractured basement with resistivity values of 75-700 Ωm. The presence of fractures within the basement is responsible for the weathering action that has taken place within the layer.

The fourth layer is the fresh basement whose resistivity values are 900 Ωm and above and extends to an infinite depth. It forms the bedrock of the entire study area.

Depth to the fresh basement ranges from 3.5-35.0 metres. Table 1: shows the depth ranges of the overburden, aquiferous layer and the fresh basement.Table 2: shows the resistivity values of the layers delineated from the study area.

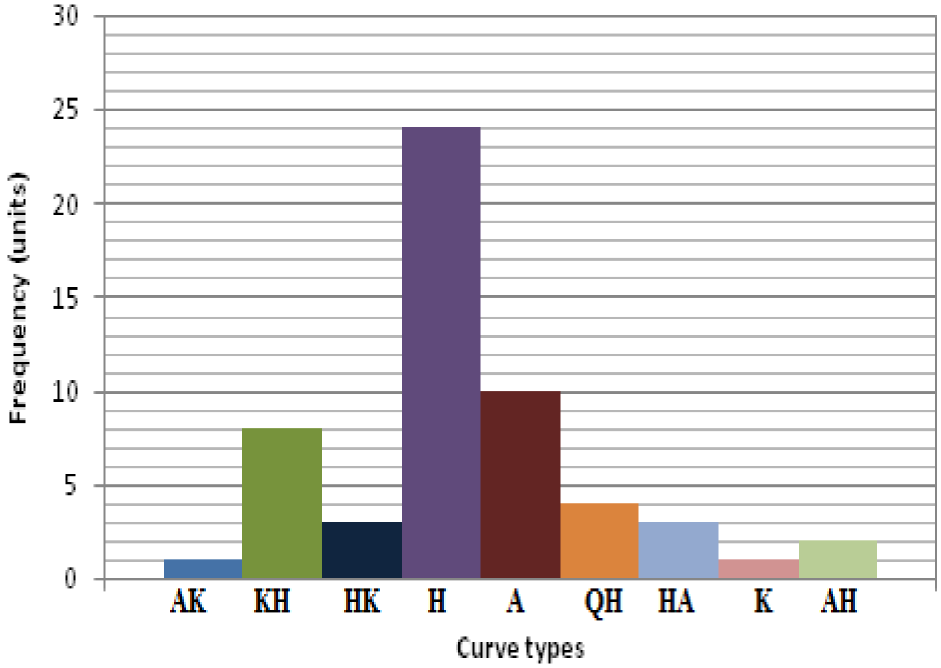
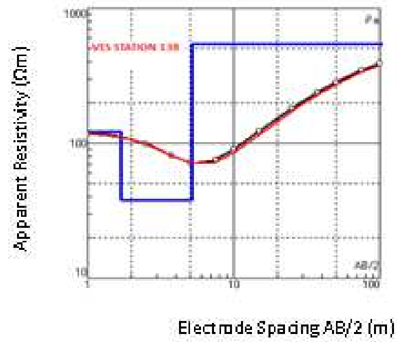
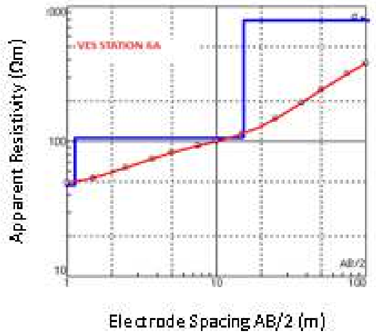


Figure 2: Histogram of Curve Types Obtained from the Study Area



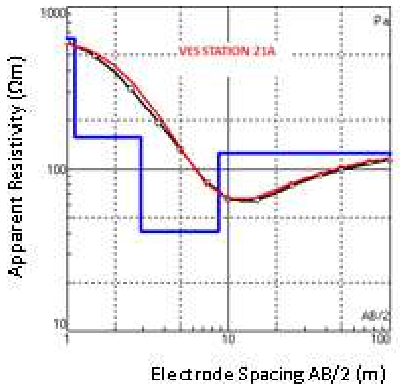
N	ρ	h	d
1	122	1.7	1.7
2	38	3.5	5.2
3	544		

Figure 3a: Curve Type H



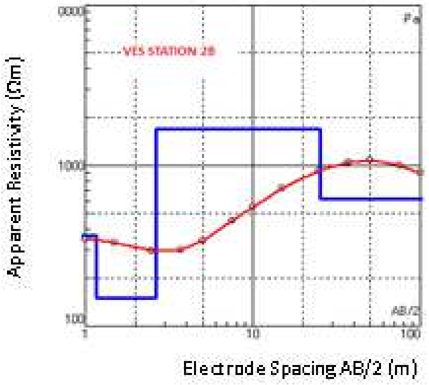
N	ρ	h	d
1	47	1.3	1.3
2	106	14.1	15.4
3	782		

Figure 3b: Curve Type A



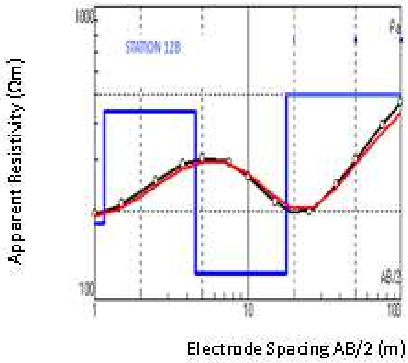
N	ρ	h	d
1	639	1.1	1.1
2	157	1.8	2.9
3	41	5.9	8.8
4	125		

Figure 3c: Curve Type QH



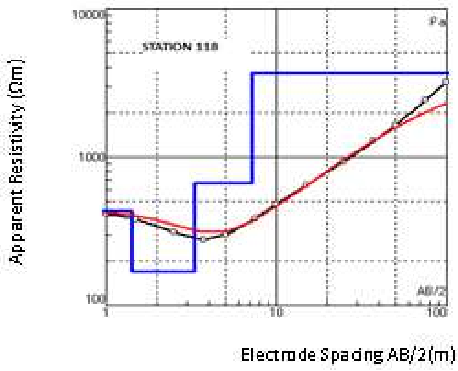
N	ρ	h	d
1	367	1.2	1.2
2	149	1.5	2.7
3	1688	22.6	25.3
4	619		

Figure 3d: Curve Type HK



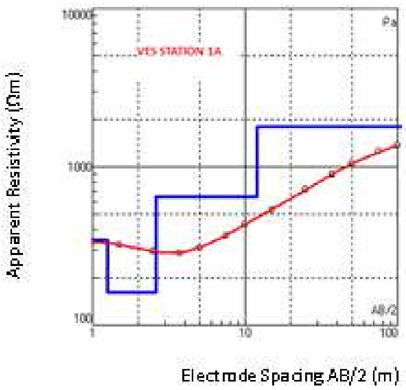
N	ρ	h	d
1	182	1.2	1.2
2	439	3.4	4.6
3	122	13.2	17.8
4	769		

Figure 3e: Curve Type KH



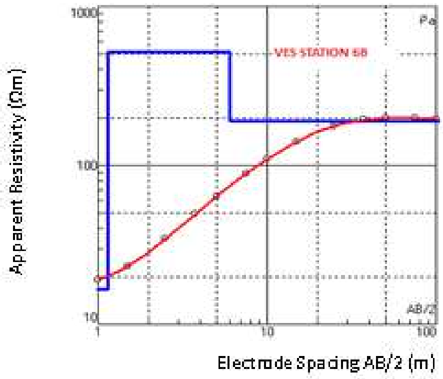
N	ρ	h	d
1	436	1.4	1.4
2	169	1.9	3.3
3	668	3.9	7.2
4	3672		

Figure 3f: Curve Type HA



N	ρ	h	d
1	347	1.3	1.3
2	162	1.4	2.7
3	648	9.3	12
4	1792		

Figure 3g: Curve Type HA



N	ρ	h	d
1	17	1.1	1.1
2	518	4.9	6
3	190		

Figure 3h: Curve Type K

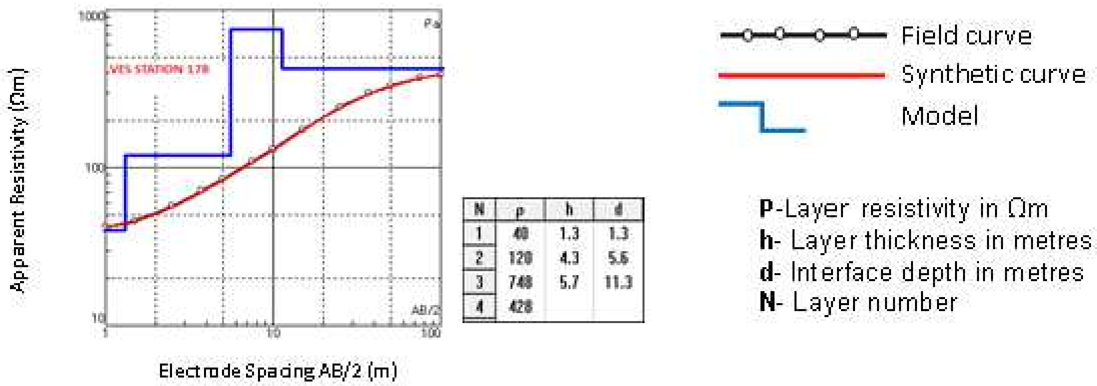


Figure 3i: Curve Type AK

Figure 3: Examples of Sounding Curve Types Obtained From The Study Area and Their Model Interpretation

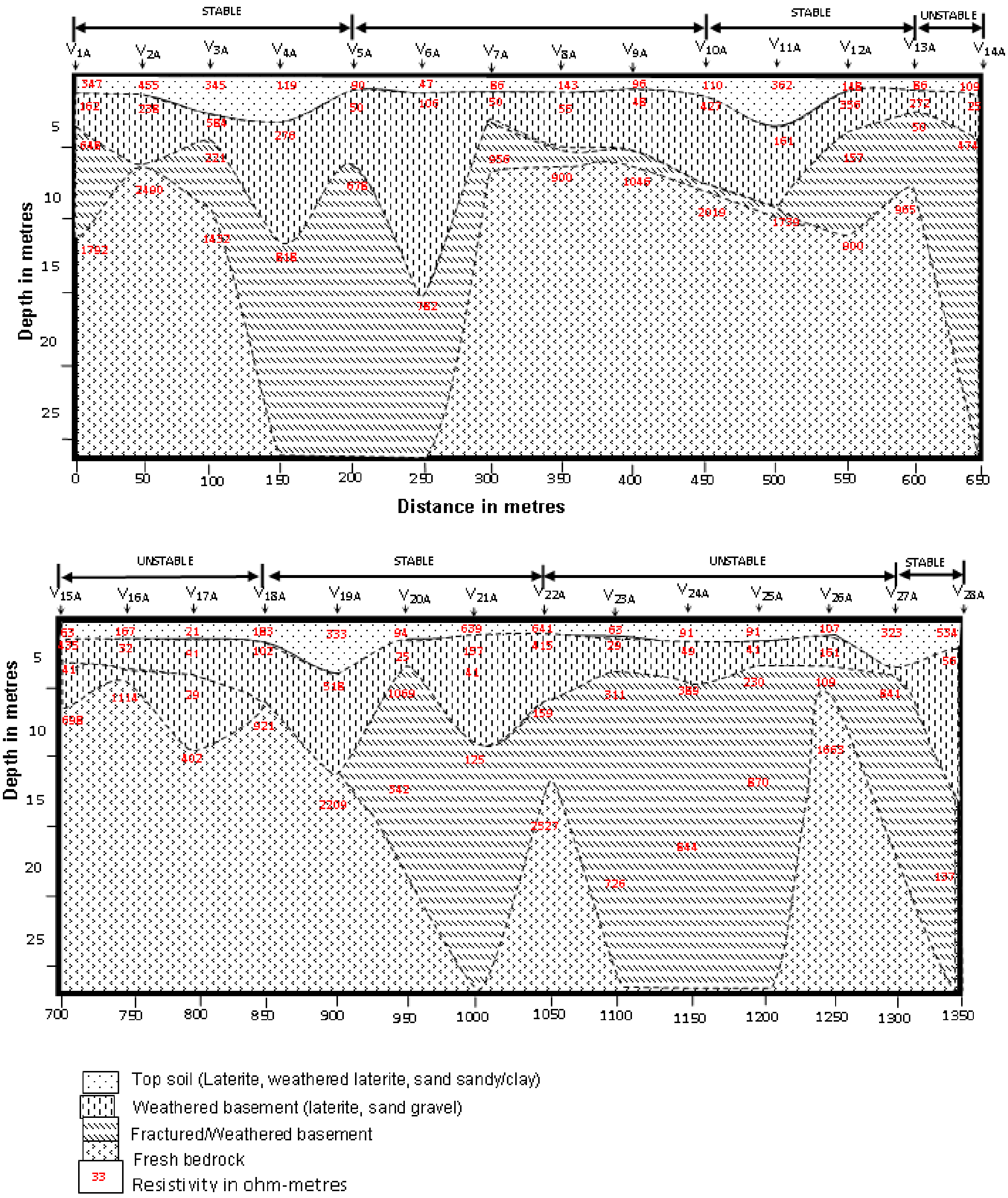


Figure 4: Geoelectric and Geologic Sections Along Profile P_1

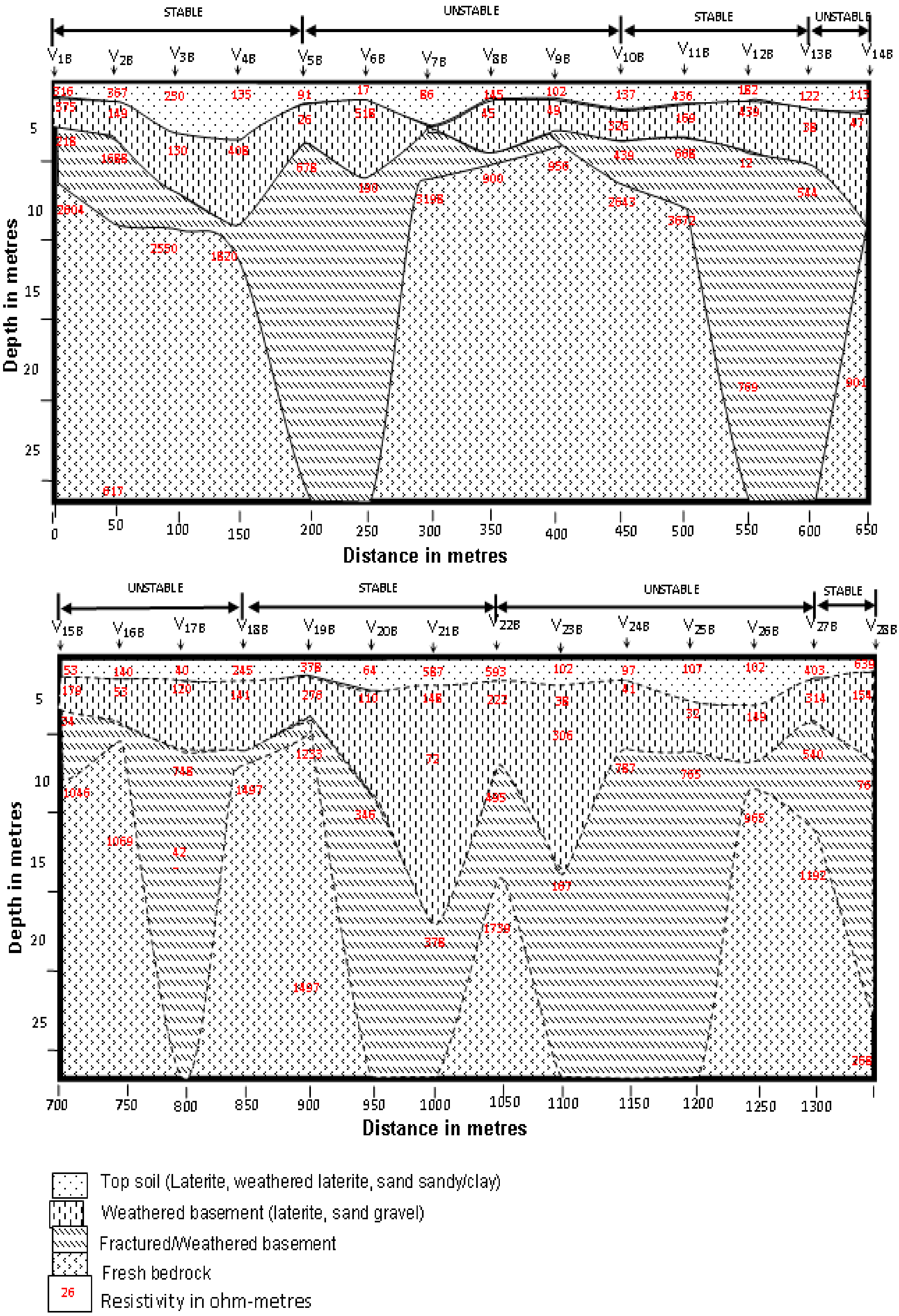


Figure 5: Geoelectric and Geologic Sections Along Profile P_2

Table 1: Thickness of the Overburden, Depth to the Aquiferous Layer and Depth to the Basement

	Stable Section	Unstable Section
Thickness of the overburden (m)	2.5 – 17.0	3.5–15.0
Depth to the aquiferous layer (m)	3.5 – 5.5	1.5 – 2.5
Depth to the fresh basement (m)	3.5 – 35.0	5.0 – 35.0

Table 2: Resistivity Values of Different Layers Obtained From the Study Area

Layers	Resistivity Values (Ωm)	Description
Surface Layer	20-120 120-640	Top soil, consists of saturated clay materials Top soil, consists of sand and laterite materials
Second Layer	24-170 180-450	Weathered Basement, highly saturated with clay Weathered Basement, partially saturated, good as aquiferous layer
Third Layer	75-500	Fractured Basement, considered as the aquiferous zone, as it indicates water accumulation
Fourth layer	>900	Fresh Bedrock, consists of gravel materials

REDUCTION AND INTERPRETATION OF THE MAGNETIC DATA

The total magnetic field data were corrected for diurnal variations after which the residual field was separated from the regional field. This was carried out using the mathematical software MATLAB R2006a which fits a first degree polynomial to the total field data using the least squares method (Matlab, 2006). The results are presented as profiles (Figures 6-9).

The magnetic profiles along the road pavement show a smooth magnetic profile and indicate magnetically, quiet homogeneous overburden of reasonable thickness devoid of any significant subsurface structural feature as most of the variations are less than ±100 nT. However, between the surface distances 950 to 1100 metres, the residual magnetic field for all the profiles indicates a prominent magnetic low of about -200 nT. The causative body is generally of significant wide extent since it reflects on all the four profiles. This may be a fault zone within the basement (Kearey *et al.*, 2002), or unknown ancient tunnel or possibly an old stream channel (Burger and Burger, 1992) which has been covered by sand over time. This may obviously be the cause of the subsidence visibly noticed on the earth's surface at that segment.

SUBSURFACE ENGINEERINGEVALUATION OF THE STUDY AREA

Table 2 shows the resistivity values of different layers and their description as delineated from the study area. Determined depth to the bedrock varies from 3.5 to 35.0m within the area. Overburden thickness is generally less than 6.0m. The stable sections, which serve as a control in this research, are underlain by high resistive subsurface. From figure 4 and 5, the top soil and the sub-grade are lateritic, significantly thick (up to 4.0m in some places) and thick enough to support imposed wheel load. The weathered basement is less clayey with resistivity values of 180-450 Ωm. The groundwater table is far below the road pavement as observed from Table 1. The magnetic profiles show a relatively homogeneous substratum devoid of any significant geological feature.

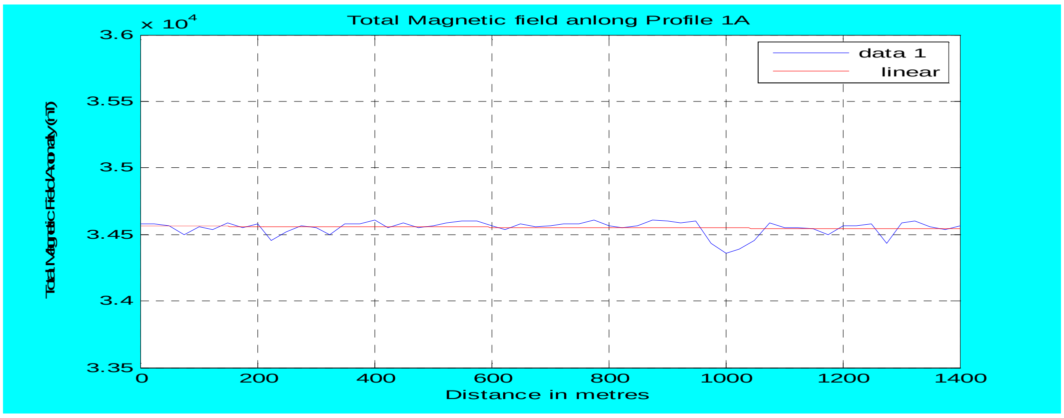
The unstable sections of the road are underlain by lithological units which may be weathered clay, sandy clay and clayey sand. The top soil and the sub-grade are generally clayey with low resistivity values between 20-120 Ωm. This indicates the accumulation of water within the weathered basement, and possibly suggests that the layer which is clayey is not permeable and hence does not drain water quickly. There is also an indication that the water table is near the pavement. Table 2 shows the resistivity values and description of the layers delineated from the study area. All these allow groundwater to percolate into the sub-grade from where it weakens the pavement. The linear feature, observed on the magnetic profiles between surface distances 950 t0 1100 metres, is suspected to be a fault or fractured zone within the basement, or an old buried stream channel which has been covered by sand. This magnetic feature actually corresponds to a visible subsidence on the earth's surface.

CONCLUSIONS

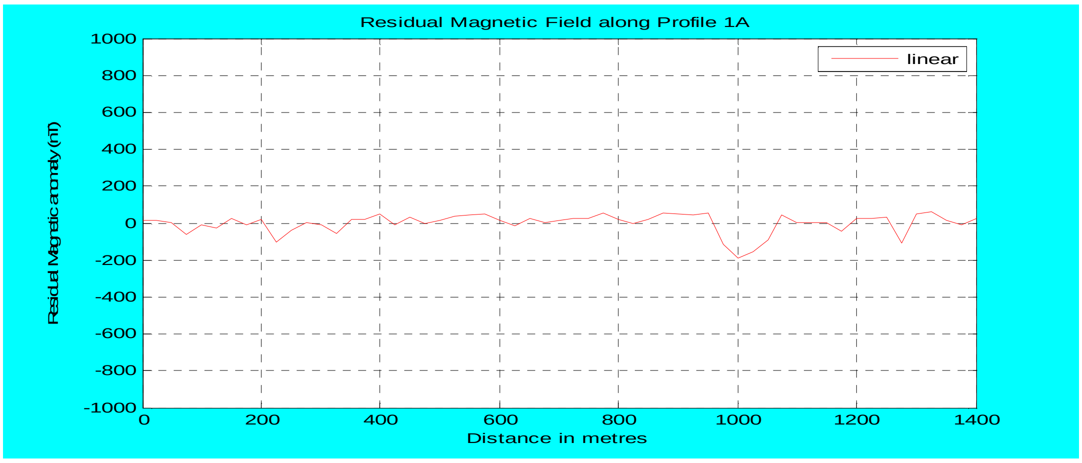
From the findings in this research, it is evident that the clayey nature of the topsoil and the sub-grade has contributed significantly to the failure of the unstable sections of the road. Clay, though highly porous, is not very permeable owing to the poor connectivity of its pores and thus retains water without releasing it; this makes the clay to swell up and collapse at the exertion of pressure and this subsequently leads to the pavement failure.

Near surface linear features such as faults, fractured zones and the existence of buried stream channels/tunnels in the subsoil beneath a road pavement also enhance water seepage and accumulation and eventually lead to pavement subsidence.

Another possible cause of road failure is the closeness of the aquiferous layer to the road pavement. This implies that the road pavement may be resting directly on the water table. This will allow quick access of groundwater to the sub-grade thereby weakening the pavement and subsequently results into road failure.



(a)



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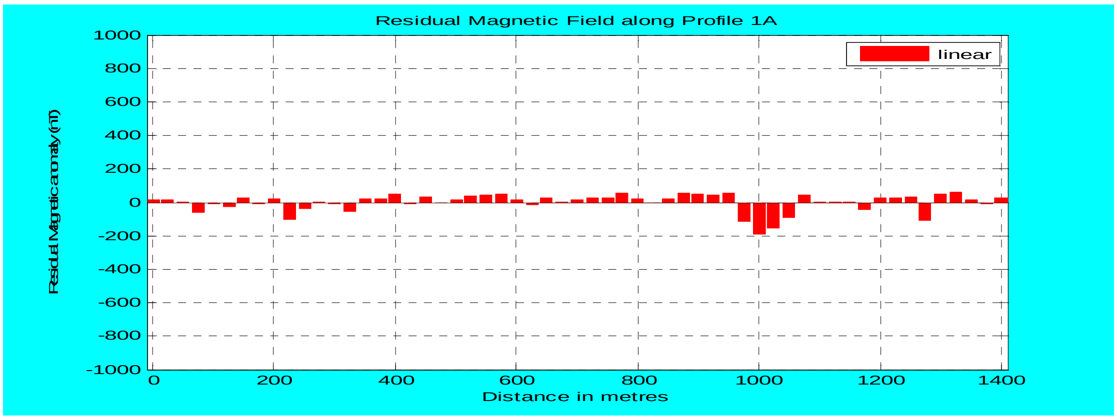
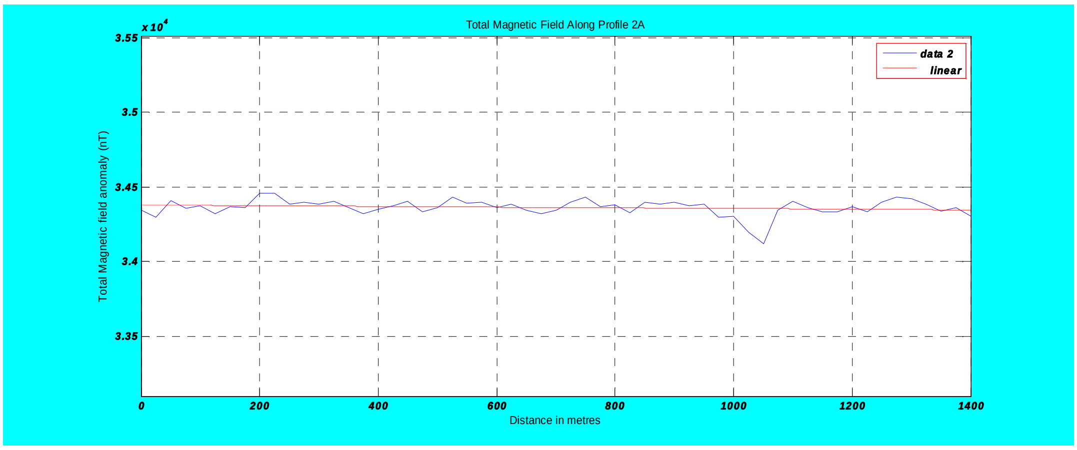


(c)

Figure 6: (a). Total Magnetic Anomaly along Profile 1A, (b) Residual Magnetic Anomaly along Profile 1A and (c) Residual Magnetic Anomaly in Bar Form along Profile 1A



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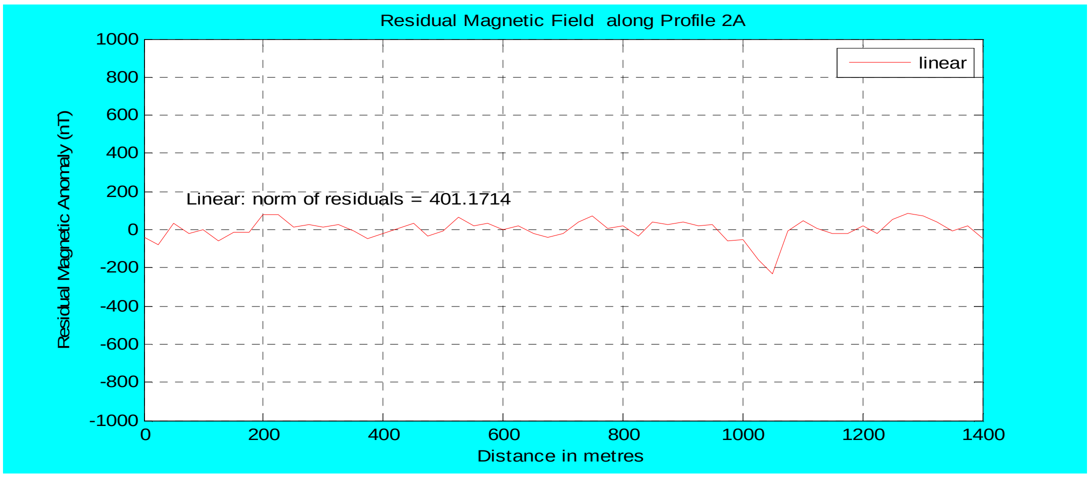

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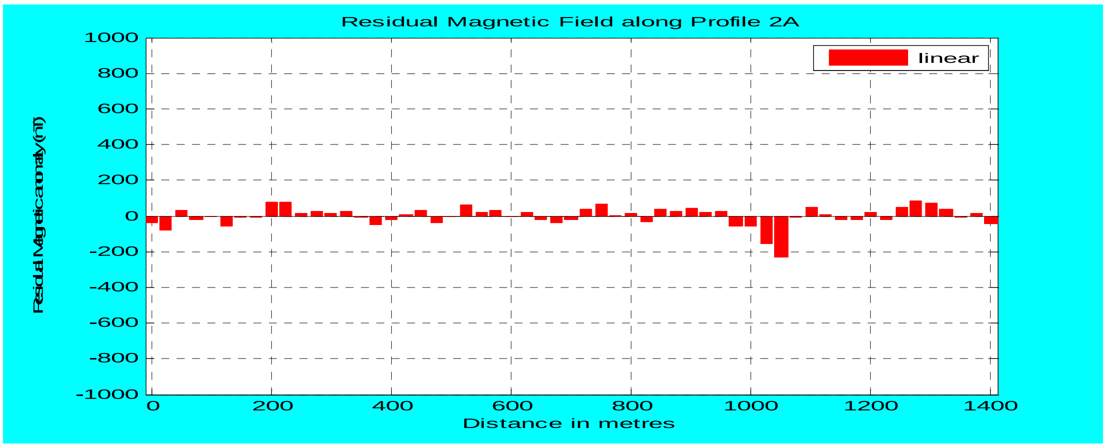
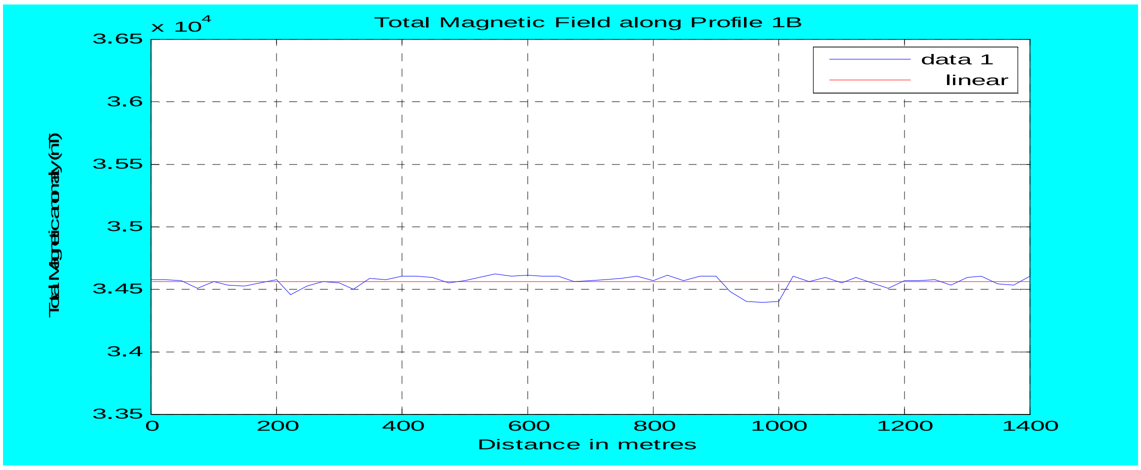


(c)

Figure 7: (a). Total Magnetic Anomaly along Profile 2A, (b) Residual Magnetic Anomaly along Profile 2A and (c) Residual Magnetic Anomaly in Bar Form along Profile 2A



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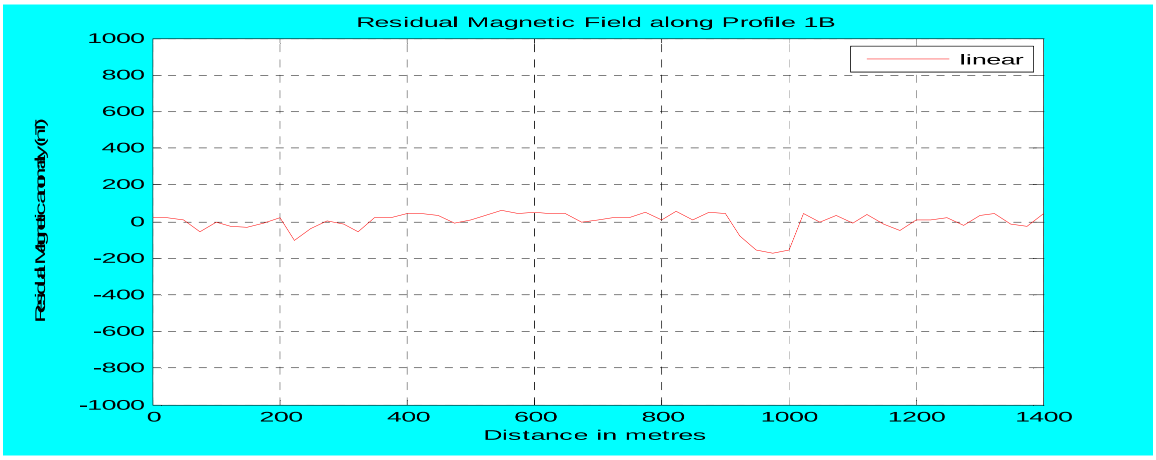

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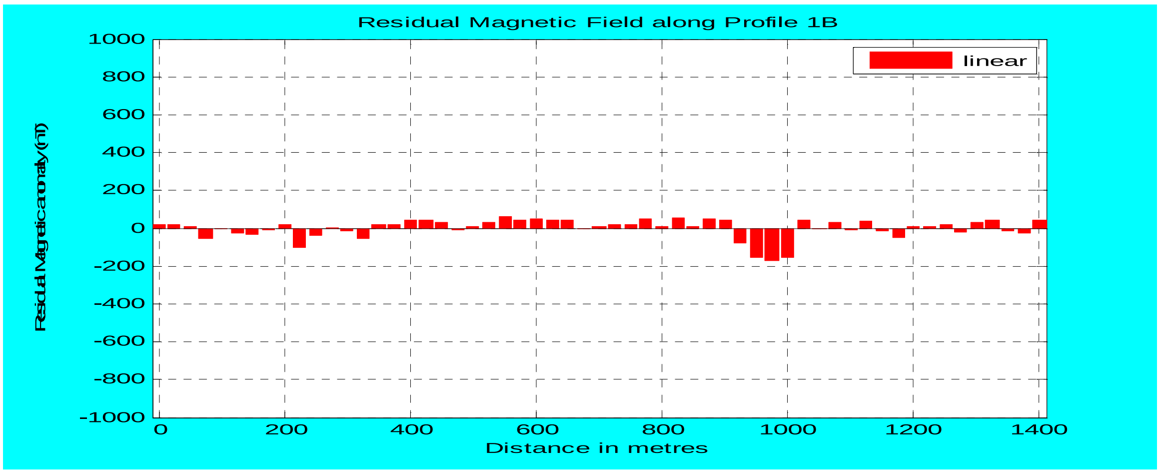
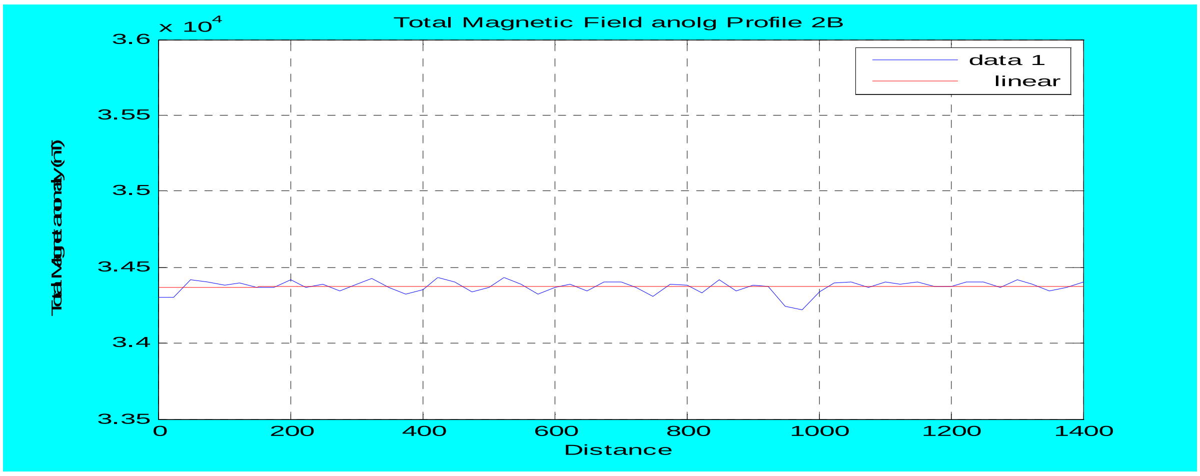


(c)

Figure 8: (a). Total Magnetic Anomaly along Profile 1B, (b) Residual Magnetic Anomaly along Profile 1B and (c) Residual Magnetic Anomaly in Bar Form along Profile 1B



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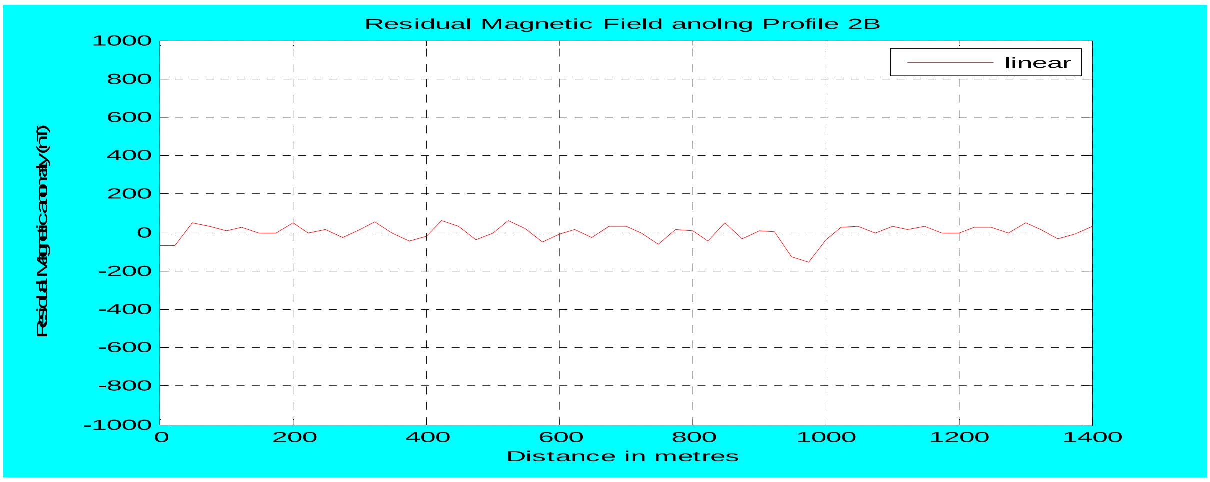

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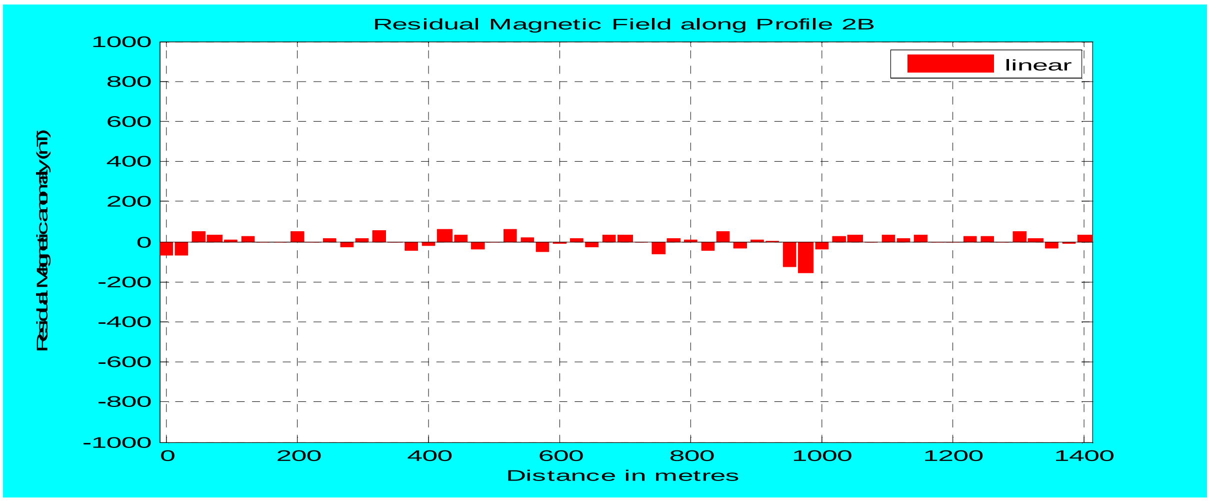

(c)

Figure 9: (a). Total Magnetic Anomaly along Profile 2B, (b) Residual Magnetic Anomaly along Profile 2B and (c) Residual Magnetic Anomaly in Bar Form along Profile 2B

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