Journal of Geoscience and Environment Protection, 2024, 12, 38-54
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

Road Layout Cuts Volume Evaluation by Electrical Resistivity Tomography: Case Study of Gagnoa-Gueyo-Bamenadou Road Project

Kouamelan Serge Kouamelan[1*], Assi Martial Yapo[1,2], Yacouba Ouattara[1], Eric Thompson Brantson[3]

[1]Laboratoire de Géologie, Ressources Minérales et Energétiques (LGRME), UFR des Sciences de la Terre et des Ressources Minières, Université Felix Houphouët-Boigny, Abidjan, Côte d'Ivoire
[2]Laboratoire du Bâtiment et des Travaux Publics (LBTP), Abidjan, Côte d'Ivoire
[3]Department of Petroleum and Natural Gas Engineering, GNPC School of Petroleum Studies, University of Mines and Technology, Tarkwa, Ghana
Email: *kouamelan2006@yahoo.fr

How to cite this paper: Kouamelan, K. S., Yapo, A. M., Ouattara, Y., & Brantson, E. T. (2024). Road Layout Cuts Volume Evaluation by Electrical Resistivity Tomography: Case Study of Gagnoa-Gueyo-Bamenadou Road Project. *Journal of Geoscience and Environment Protection, 12,* 38-54.
https://doi.org/10.4236/gep.2024.1210003

Received: August 25, 2024
Accepted: October 22, 2024
Published: October 25, 2024

Abstract

A study of excavated material on the Gagnoa-Guéyo-Bamenadou road project in southwest Côte d'Ivoire was carried out using electrical resistivity tomography with a dipole-dipole configuration. This study aimed to determine the nature and volume of the studied cuts. Based on the cumulative distances of the longitudinal sections of the road alignment superimposed on the tomographic profiles, a cumulative volume of 104681 m^3 of material was determined. This volume comprises 88557 m^3 of soft cuts and 16,124 m^3 of rocky cuts, which can be reused in specific embankment zones. This work may, therefore be useful in the characterization of cuts in a preliminary design study, in order to anticipate changes during the road's development and asphalting.

Keywords

Electrical Method, Longitudinal Section, Cut, Soft and Rocky Materials, Côte d'Ivoire

1. Introduction

Road infrastructure plays a vital role in the sustainable socio-economic development of nations (Nawir et al., 2023; Akpan & Morimoto, 2022; Lykova, 2021; Gibson & Olivia, 2010). In Côte d'Ivoire, the poor state of the road network was costing the national economy almost 1000 billion FCFA a year, according to a study by the Ministry of Agriculture, Rural Development and Food Production. Since

2011, the state of Côte d'Ivoire's roads has improved considerably, thanks to the government's huge investments in the sector (CICG, 2019). The asphalt road network has expanded significantly, from 6500 km in 2015 to 8100 km in 2024 (https://www.economie-ivoirienne.ci/activites-sectorielles/etat-des-infrastructures-routieres.html). Despite the efforts made, the road network remains a real factor slowing down the development process. In fact, in 2023, 73900 km of the Ivorian road network (82000 km) consisted of earth roads (www.ageroute.ci/gestion-du-reseau/reseau-routier). In addition, the dilapidated condition of some asphalt roads makes it difficult for people and goods to move around. To alleviate these difficulties, the Ivorian government has embarked on a new initiative to maintain and safeguard the country's road heritage, not forgetting the upgrading and asphalting of certain roads, focusing on the implementation of major road projects throughout the country.

The execution of a road project requires preliminary design studies, which include the road alignment study (Solodkiy & Gorev, 2018). In Côte d'Ivoire, several intercity road projects are currently underway, including the Gagnoa-Gueyo-Bamenadou road development and asphalting project. Pre-project studies, including excavation studies, are of paramount importance in assessing project costs and minimizing cost overruns during execution (Robson et al., 2022). The study of the cut areas of the Gagnoa-Guéyo-Bamenadou route is located in a granitic geological context of the Ivorian basement. The aim of this research work is to locate and quantify the granitic and soft rock cuttings of the project by means of a geophysical investigation.

The approach used is that of electrical resistivity tomography, a rapid technique that can be used to delineate the profile of the rocky roof in relation to the unconsolidated layers. This method is one of the most widely used in geotechnical and environmental research (Alam et al., 2024; Whiteley et al., 2023; Ayolabi et al., 2012).

2. Geographical and Geological Context

The Gagnoa-Guéyo-Bamenadou road is located in south-west Côte d'Ivoire (**Figure 1(a)**). It links the departments of Gagnoa, Guéyo and Sassandra. The area's geomorphology is marked by an undulating peneplain with topographical variations ranging from 19 to 364 m (**Figure 1(c)**), with vegetation once dominated by dense forest (PEMED-CI, 2015).

This zone is located in the basement region. It is mainly composed of granitoids, but also includes sedimentary and volcano-sedimentary rocks (**Figure 1(b)**). The granodiorites of Sassandra-Guéyo constitute the two chemically distinct rock poles (tonalitic to granodioritic or calc-alkaline granitic) of a single massif. These granitoids are affected to the west by metamorphism that has produced a banded orthogneissified facies in the granodiorite (Milesi et al., 1989). The massifs have ages (Rb-Sr on total rock) of around 1700 Ma for Sassandra and 2090 Ma for the one at Guéyo (Papon, 1973). They are sometimes in contact with migmatites and Liberian gneisses.

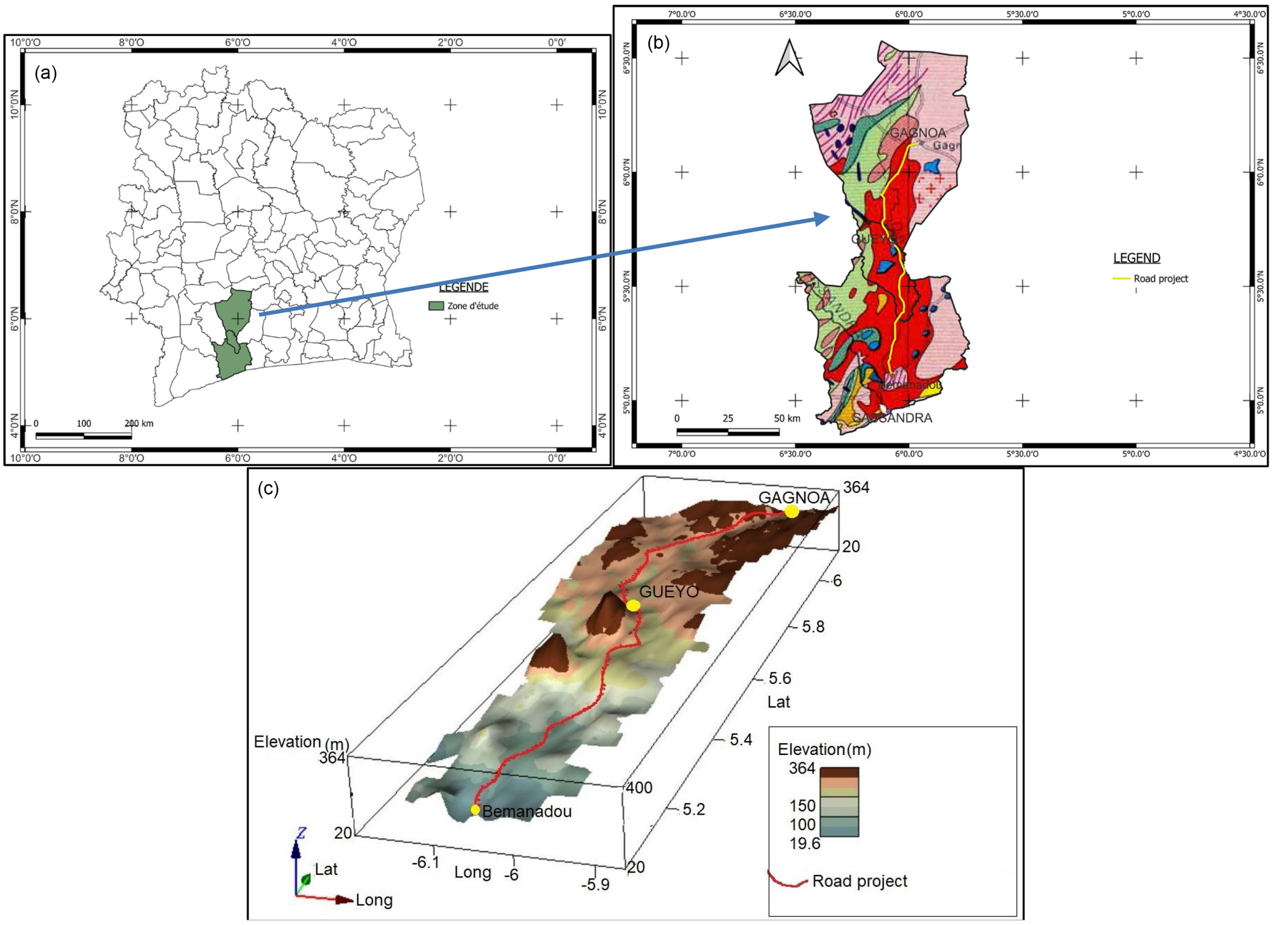


Figure 1. Geological map and location of the study area.

3. Methodology

3.1. Longitudinal Section and Determination of Cut Areas

The longitudinal section of a road alignment shows the variation between the natural terrain elevation (ZTN) and the project's red line (ZPr). Based on the longitudinal section (Figure 2), the cut and fill have been marked out using the elevation of the natural terrain and the elevation of the project's red line (Figure 2).

Excavated areas have a natural terrain elevation (ZTN) higher than that of the project's red line (ZPr): ZTN - ZPr > 0. They represent masses of earth that need to be removed to a specific depth in order to level or lower the ground level. Eleven cut zones (1 to 11), of varying lengths, were identified as part of this study (Table 1). In addition, the elevations of the natural terrain and the project were taken with an application length of 40 m during the project.

3.2. Electrical Resistivity Tomography

For data acquisition, the configuration used for electrical resistivity tomography is the dipole-dipole (Figure 3) with an inter-electrode spacing of 10 m. This configuration comprises current (AB) and potential (MN) dipoles, which are usually placed linearly on the ground (Figure 3). The length of the tomographic profile depends on the length of the studied cuts. The entire length of the cut is studied, so as to obtain a 2D profile superimposed on the longitudinal section of the cut. Electrical resistivity tomography measurements were carried out on eleven (11) cuts from the Gagnoa-Guéyo-Bamenadou road layout.

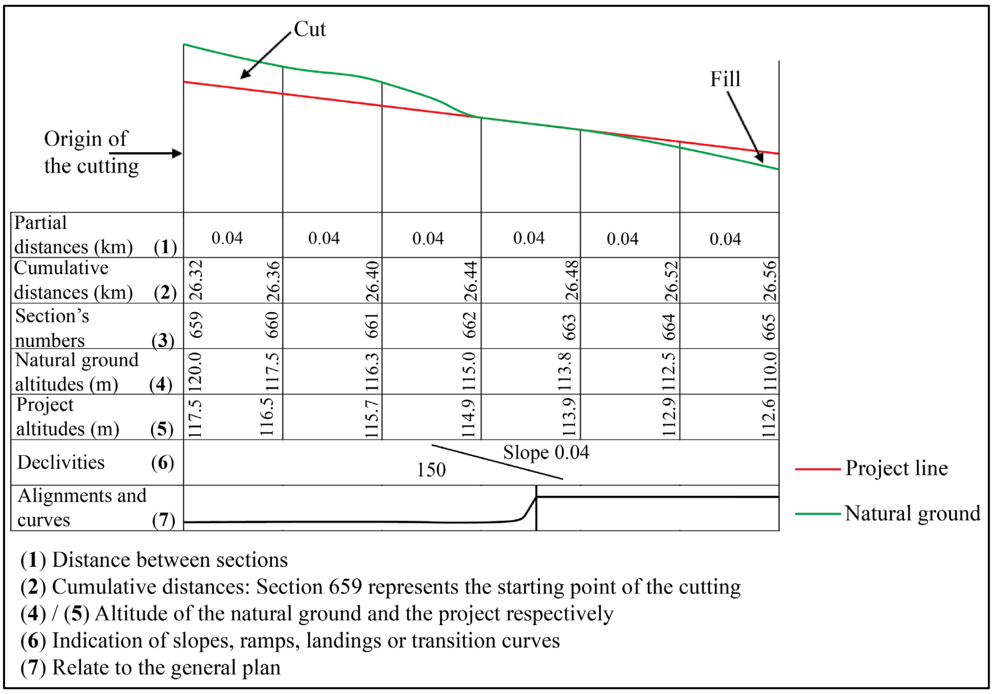


Figure 2. Longitudinal section of a road layout.

Table 1. Characteristics of the studied excavated material.

Cut number	Beginning of section		End of section		Cut length (m)
	X (m)	Y (m)	X (m)	Y (m)	
1	819372.17	653598.2	819267.37	653427.86	200
2	820123.63	647817.57	820087.99	647580.38	240
3	820176.51	643673.11	820215.72	643355.52	320
4	829428.57	617722.31	829578.82	617486.03	280
5	828164.98	604894.02	828106.08	604661.36	240
6	829881.85	600865.51	829903.82	600832.09	40
7	829969.99	595988.84	829772.82	595792.83	280
8	828321.5	594363.37	828244.9	594223.02	160
9	823320.91	572986.35	823205.37	572875.67	160
10	822993.24	569688.17	823009.43	569569.56	120
11	823068.63	569421.17	823118.51	569312.03	120

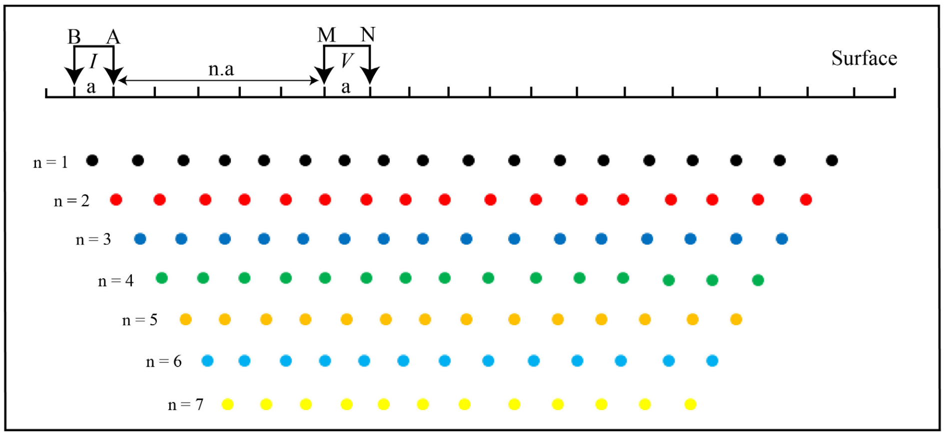


Figure 3. Dipole-dipole array.

3.3. Cut Type and Volume Calculation

The approach consists of determining the bedrock profile, if any, from the tomographic profiles carried out on each cutting. Characteristic tables have been drawn up for each studied cut. These tables make it possible to determine the nature of the investigated cut (NDB) and the thickness of the material (rock or loose material), by calculating the difference between the altitude of the bedrock (ZRX) and that of the project red line (ZPr):

$$NDB = ZRX - ZPr. \quad (1)$$

There are two possible cases:

- NDB > 0, we have a rocky cut;
- NDB < 0, we have a soft cut.

To calculate the volume, the cut section obtained is multiplied by the planned road width. The cut section is delimited by the profile of the natural terrain and the project red line. By superimposing the project's red line and the 2D sections of the electrical resistivity tomographs, we were able to determine, where they exist, the rocky sections and calculate the volumes.

The Gagnoa-Guéyo-Baménadou axis is a two-lane road with a pavement width of 2 × 3.5 m (7 m) and shoulders of 2 × 1.5 m (3 m).

Since the total width of the road is 10 m, the volume of cut (V) can be expressed for each profile (P) or abscissa by:

$$V = l \times L_A \times h_i \quad (2)$$

with:

l: road width (m);

L_A: application length (m);

h_i: Cut thickness at the profile (i) (m).

4. Results and Discussion

4.1. Cut 1 (DB 1)

Figure 4 shows a tomographic section of DB 1 located between PK 26320 and PK

26520. The section highlights the vertical and horizontal variations in geoelectric signatures observed along the cut. Indeed, depending on the variation in color scale, three electrical signatures can be identified in this 2D inverse section of DB 1. A conductive layer (blue) with resistivity ranging between 115.6 and 270 Ohm·m. An intermediate resistivity layer (green) with a resistivity between 270 and 490 Ohm·m. Finally, a reddish resistive layer with resistivities extending from 490 to 1344.5 Ohm·m.

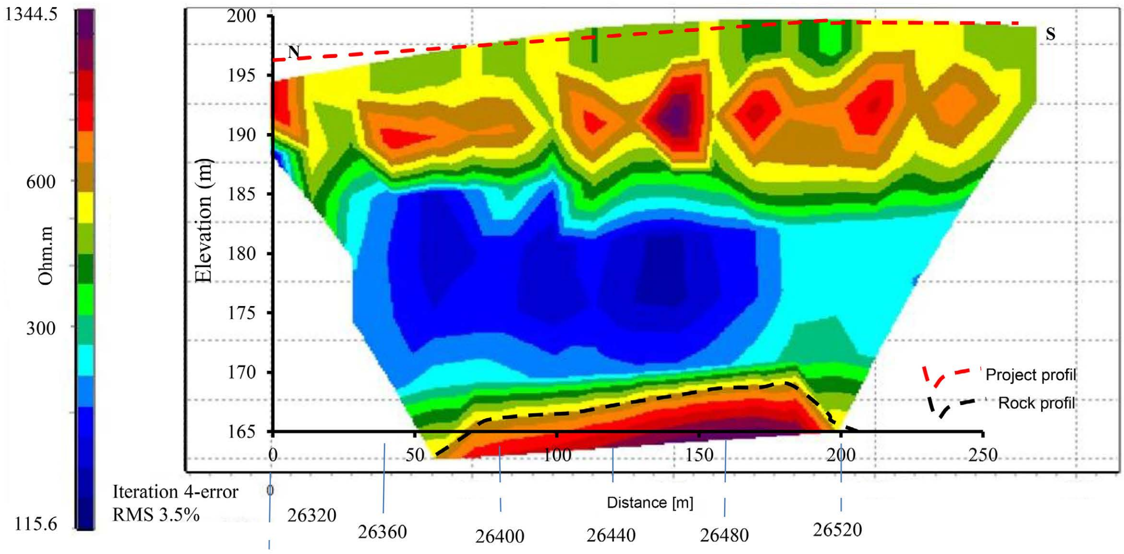


Figure 4. 2D section between PK 26320 and PK 26520.

Moreover, an analysis of the volume measurement shows that this excavated material is not rocky, but rather entirely soft, with an estimated cumulative volume of 5980 m³ (Table 2).

Table 2. DB 1 volume calculation.

Section's numbers	Cumulative distance	Cut thickness (m)	Thickness (m)		Road's width (m)	Cut surface (m^2)		Length (m)	Cut partial volume (m^3)		Cut cumulative volume (m^3)	
		ZTn-ZPr	Rock ground	soft ground		rock ground	soft ground		rock ground	soft ground	rock ground	soft ground
P659	26320	0.52	0	0.52		0	5.2	40	0	208	0	208
P660	26360	2.35	0	2.35		0	23.5	40	0	940	0	1148
P661	26400	3.8	0	3.8	10	0	38	40	0	1520	0	2668
P662	26440	3.77	0	3.77		0	37.7	40	0	1508	0	4176
P663	26480	2.99	0	2.99		0	29.9	40	0	1196	0	5372
P664	26520	1.52	0	1.52		0	15.2	40	0	608	0	5980

4.2. Cut 2 (DB 2)

Located between PK 32560 and PK 32800, the 240 m-long tomographic profile of DB 2 reveals three (03) geoelectric units (Figure 5). A conductive unit marked by blue coloration, with resistivity values ranging from 149.5 to 500 Ohm·m. This formation mainly forms the superficial part of the profile, although in places it lies below the project's red line. Next to this unit is an intermediate resistivity layer (green) with resistivity values oscillating between 500 to 1150 Ohm·m. Beyond this unit, a brightly coloured signature indicates the presence of a resistive layer (red) with resistivities ranging from 1150 to 4540.4 Ohm·m. This formation is mostly found at greater depths and could therefore correspond to the basement.

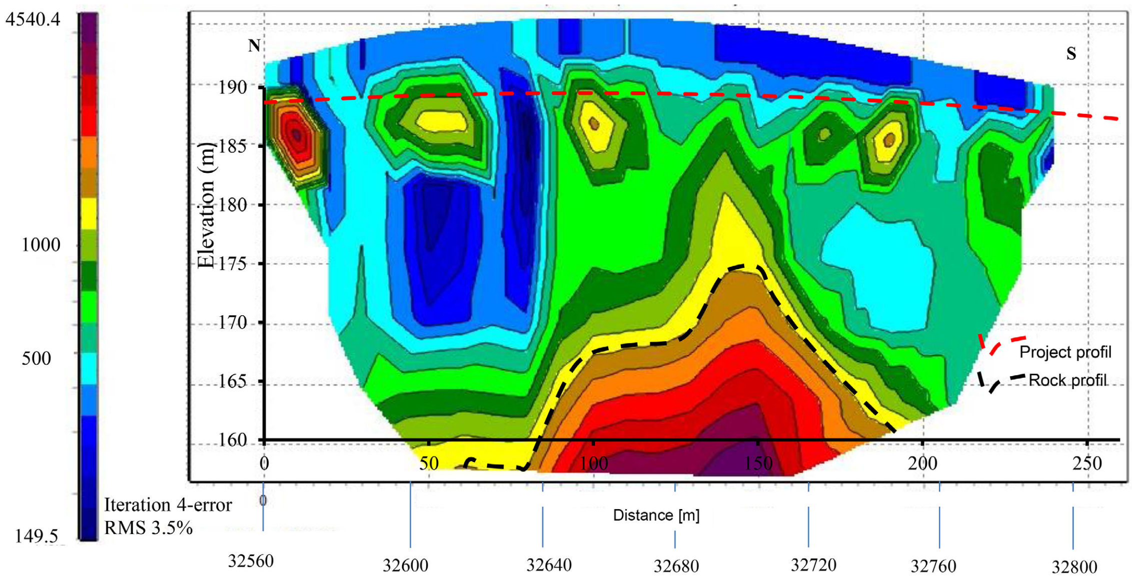


Figure 5. 2D section between PK 32560 and PK 32800.

On Figure 5, the project's red line is above the basement roof profile. The cuts therefore consist of soft rocks. It is therefore not rocky. An analysis of Table 3 shows that the cut zone has a volume of 12124 m³ of soft rock to be removed.

Table 3. DB 2 volume calculation.

Section's numbers	Abscisse (m)	Cut thickness (m)	Thickness (m)		Road's width (m)	Cut surface (m²)		Length (m)	Cut partial volume (m³)		Cut cumulative volume (m³)	
		ZTn-ZPr	Rock ground	soft ground		rock ground	soft ground		rock ground	soft ground	rock ground	soft ground
P815	32560	2.87	0	2.87		0	28.7	40	0	1148	0	1148
P816	32600	5.12	0	5.12		0	51.2	40	0	2048	0	3196
P817	32640	5.95	0	5.95		0	59.5	40	0	2380	0	5576
P818	32680	6.02	0	6.02	10	0	60.2	40	0	2408	0	7984
P819	32720	5.09	0	5.09		0	50.9	40	0	2036	0	10020
P820	32760	3.35	0	3.35		0	33.5	40	0	1340	0	11360
P821	32800	1.91	0	1.91		0	19.1	40	0	764	0	12124

4.3. Cut 3 (DB 3)

On the tomographic profile of this site (between PK 36720 and 37040), the electrical signatures can be broken down into three entities according to variations in coloration (Figure 6). Firstly, conductive formations (in blue) with resistivities ranging from 182.9 to 590 Ohm·m. These are mainly located below the project's red line, except for a few at the beginning and end of the profile. The profile then shows the presence of intermediate layers with greenish hues and resistivities vacillating between 590 to 1480 Ohm·m. Finally, there are resistive formations with more pronounced electrical signatures (vivid colorations), with resistivities ranging from 1480 to 64754.4 Ohm·m. This resistant ensemble is superficial between PK 36720 - 36880 and more deeply rooted between PK 36880 and 37040. It is also crossed by the project's red line along the entire length of DB 3.

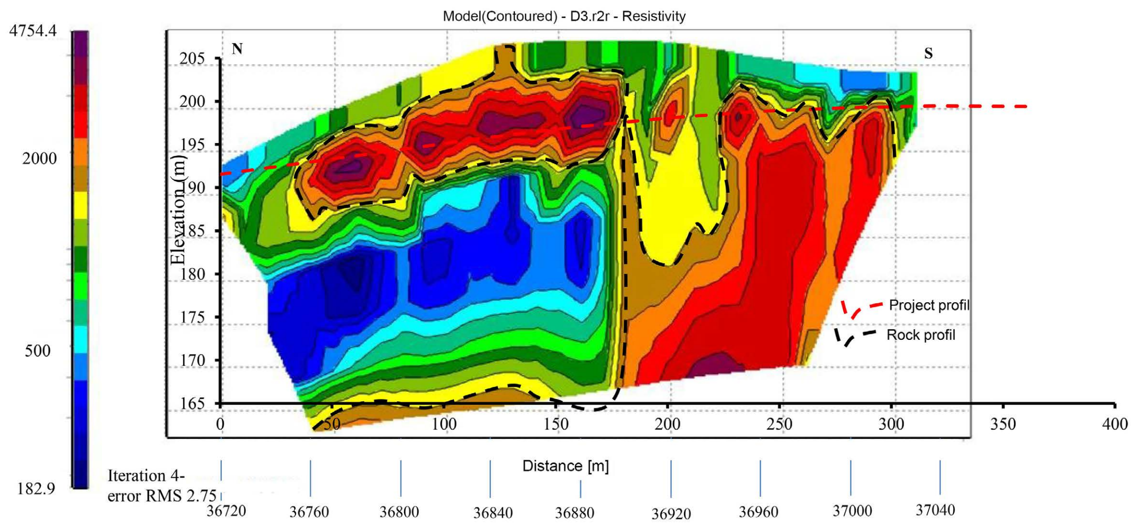


Figure 6. 2D section between PK 36720 et PK 37040.

Moreover, the volume calculation analysis shows that DB 3 is made up partly of soft formations and partly of rock over most of the cut. Volume calculations give a cumulative volume of 11888 m³ of rocky cuts and 12272 m³ of soft cuts (Table 4).

Table 4. DB 3 volume calculation.

Section's numbers	Cumulative distance	Cut thickness (m)	Thickness (m)		Road's width (m)	Cut surface (m²)		Length (m)	Cut partial volume (m³)		Cut cumulative volume (m³)	
		ZTn-ZPr	Rock ground	soft ground		rock ground	soft ground		rock ground	soft ground	rock ground	soft ground
P919	36720	1.88	-	1.88	10	-	18.8	40	0	752	0	752
P920	36760	5.76	1.04	4.72		10.4	47.2	40	416	1888	416	2640
P921	36800	8.57	2.82	5.75		28.2	57.5	40	1128	2300	1544	4940
P922	36840	11.58	11.58	0		115.8	0	40	4632	0	6176	4940
P923	36880	10.83	6.93	3.9		69.3	39	40	2772	1560	8948	6500
P924	36920	9.68	4.43	5.25		44.3	52.5	40	1772	2100	10720	8600
P925	36960	7.08	2.19	4.89		21.9	48.9	40	876	1956	11596	10556
P926	37000	5.02	0.73	4.29		7.3	42.9	40	292	1716	11888	12272

4.4. Cut 4 (DB 4)

The tomographic profile of DB 4 between stations PK 66520 and PK 66800 shows two major units of differing geoelectric nature (Figure 7). A conductive unit whose coloration varies in the order of blue, characterized by resistivity ranges between 29 and 295 Ohm·m. This unit occupies almost the entire site and is located below the project's red line. This is followed by a moderately resistant layer with greenish to yellowish hues of resistivities between 295 and 1998 Ohm·m. This represents the dominant formation of DB 4.

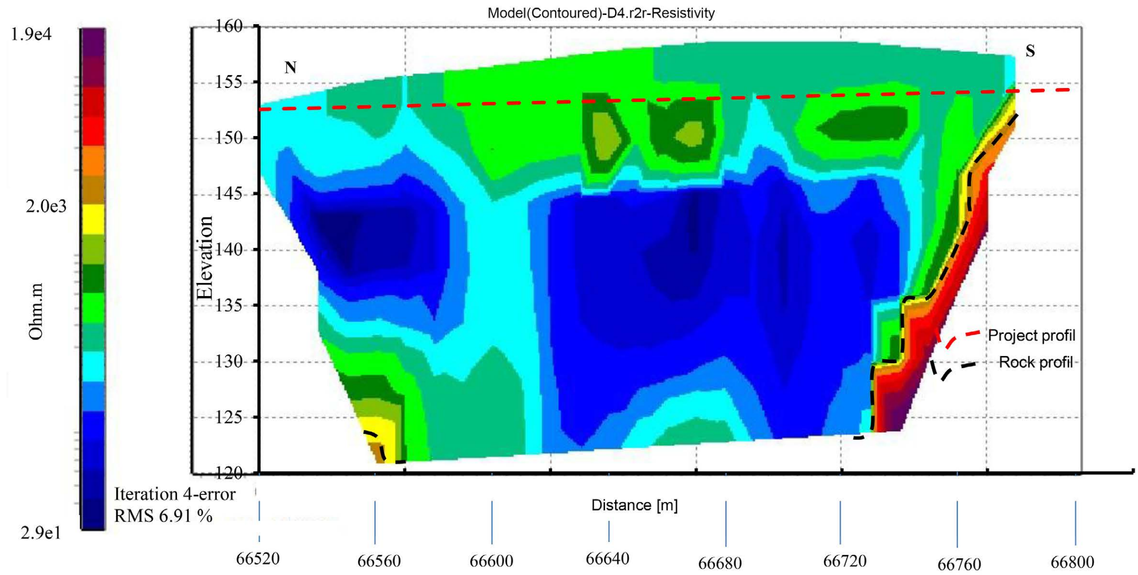


Figure 7. 2D section between PK 66520 and PK 66800.

Moreover, no bedrock was detected within the 30 m depth of investigation, so the studied cut is essentially soft materials.

This is also evidenced by the volume estimation analysis (Table 5). This shows that the cumulative volume of material to be removed is around 11132 m³ of the soft formation.

Table 5. DB 4 volume calculation.

Section's numbers	Cumulative distance	Cut thickness (m)	Thickness (m)		Road's width (m)	Cut surface (m²)		Length (m)	Cut partial volum (m³)		Cut cumulative volum (m³)	
		ZTn-ZPr	Rock ground	soft ground		rock ground	soft ground		rock ground	soft ground	rock ground	soft ground
P1664	65520	0.51	0	0.51	10	0	5.1	40	0	204	0	204
P1665	65560	2.62	0	2.62		0	26.2	40	0	1048	0	1252
P1666	65600	3.41	0	3.41		0	34.1	40	0	1364	0	2616
P1667	65640	4.64	0	4.64		0	46.4	40	0	1856	0	4472
P1668	65680	5.25	0	5.25		0	52.5	40	0	2100	0	6572
P1669	65720	5	0	5		0	50	40	0	2000	0	8572
P1670	65760	3.85	0	3.85		0	38.5	40	0	1540	0	10112
P1671	65800	2.55	0	2.55		0	25.5	40	0	1020	0	11132

4.5. Cut 5 (DB 5)

Analysis of the tomographic profile of this study section between PK 80840 and PK 81080 shows three major geoelectric signatures from surface to depth (Figure 8). Firstly, a conductive unit marked by a blue hue, with resistivities varying from 95 to 410 Ohm·m. This unit mainly occupies the superficial part of this study section and lies mostly above the project's red line. Secondly, an intermediate layer with a greenish signature and resistivities ranging from 410 to 1100 Ohm·m marks the transition from superficial formations to deeper units. Finally, a resistive entity with reddish staining, with resistivity between 1100 and 5991.6 Ohm·m represents the deepest formations. The upper part of this formation is in places above the project's red line, indicating the presence of rocky materials.

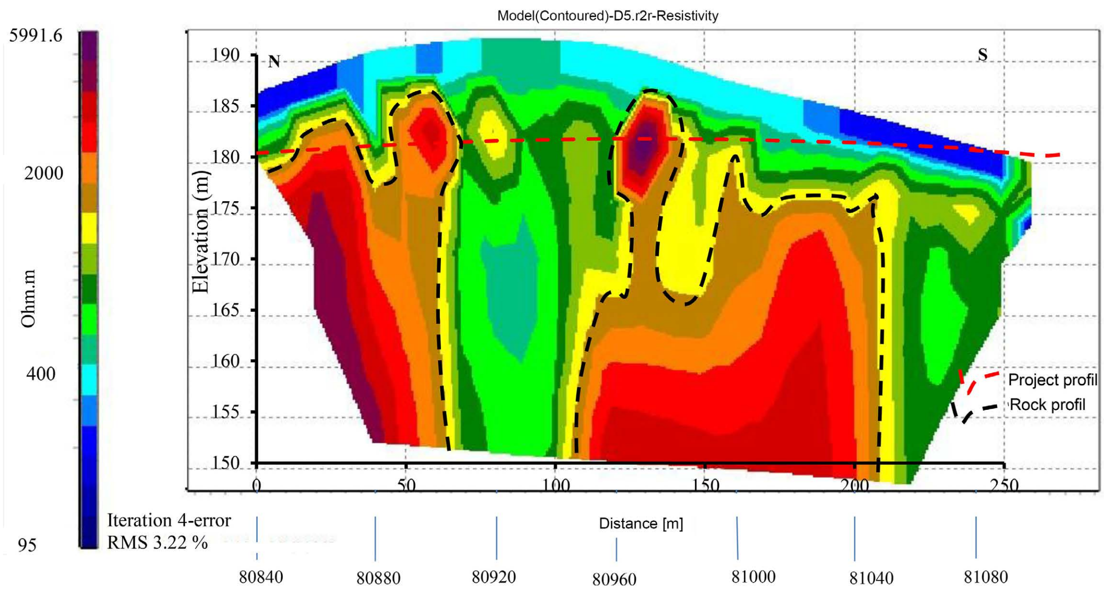


Figure 8. 2D section between PK 80840 and PK 81080.

The bedrock roof levels show that DB 5 is both soft and rocky formations throughout the section, with a cumulative volume of 15156 m³ of soft material and 2966 m³ of rocky material (Table 6).

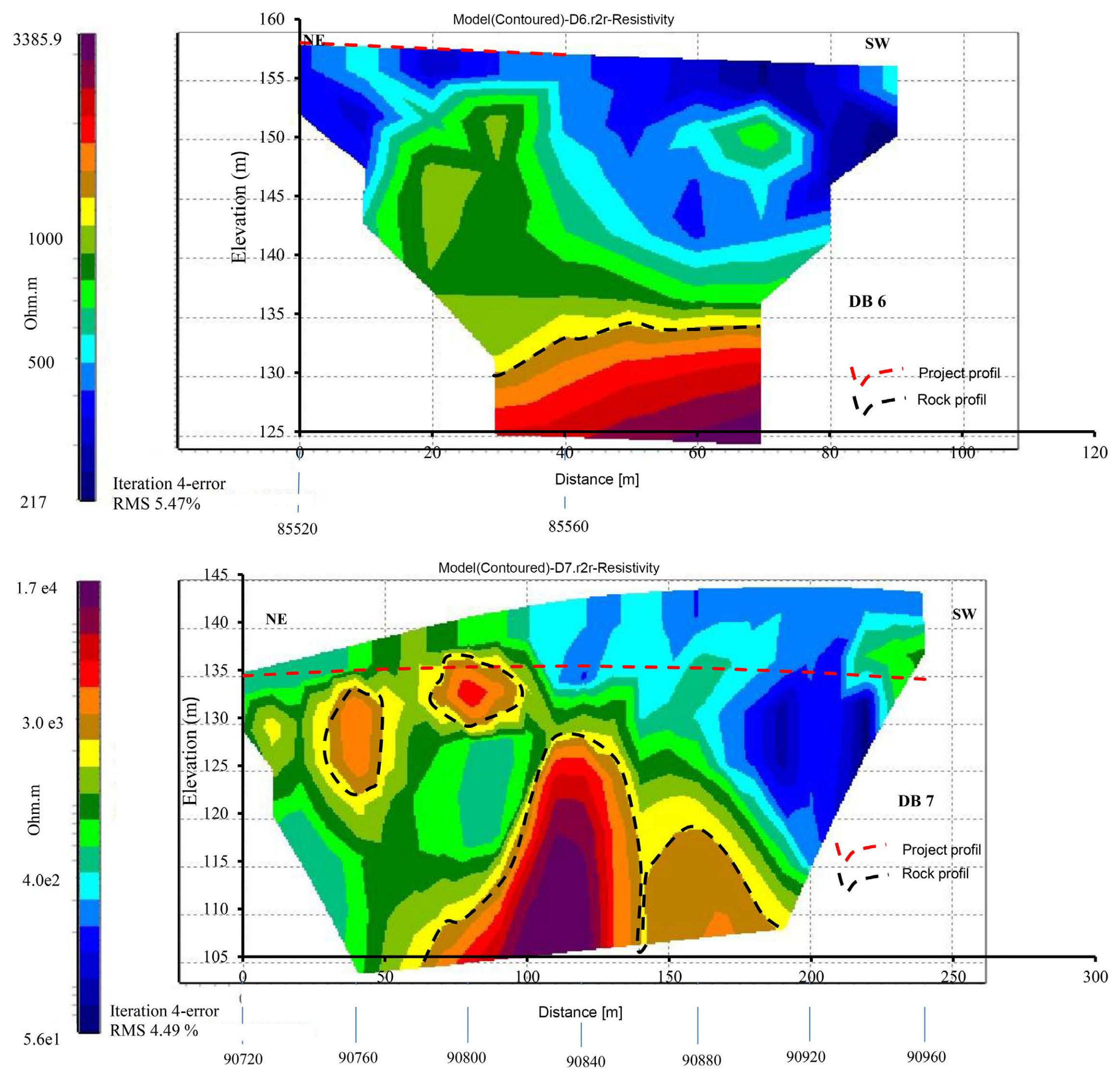
Table 6. DB 5 volume calculation.

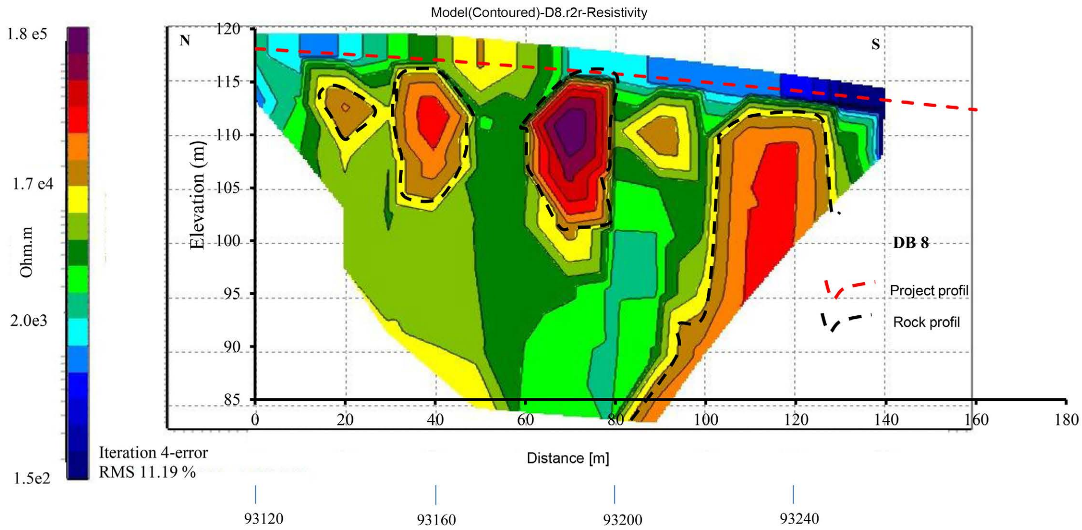
Section's numbers	Cumulative distance	Cut thickness (m) ZTn-ZPr	Thickness (m) Rock ground	Thickness (m) soft ground	Road's width (m)	Cut surface (m²) rock ground	Cut surface (m²) soft ground	Length (m)	Cut partial volume (m³) rock ground	Cut partial volume (m³) soft ground	Cut cumulative volume (m³) rock ground	Cut cumulative volume (m³) soft ground
P2022	80850	6.47	0	6.47		0	64.7	40	0	2588	0	2588
P2023	80880	10.09	4.89	5.2		48.9	52	40	2445	2080	2445	4668
P2024	80900	10.78	0	10.78		0	107.8	40	0	4312	2445	8980
P2025	80955	9.88	-	9.88	10	0	98.8	40	0	3952	2445	12932
P2026	80960	6.12	5.21	0.91		52.1	9.1	40	521	364	2966	13296
P2027	80990	3.71	0	3.71		0	37.1	40	0	1484	2966	14780
P2028	81040	0.94	-	0.94		-	9.4	40	0	376	2966	15156

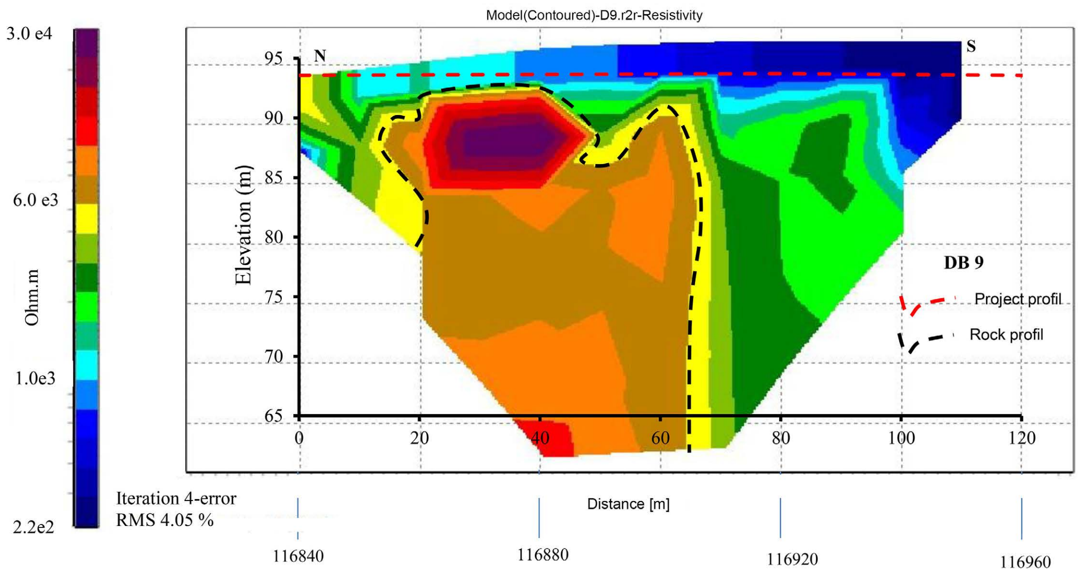
4.6. Cut 6 to Cut 11

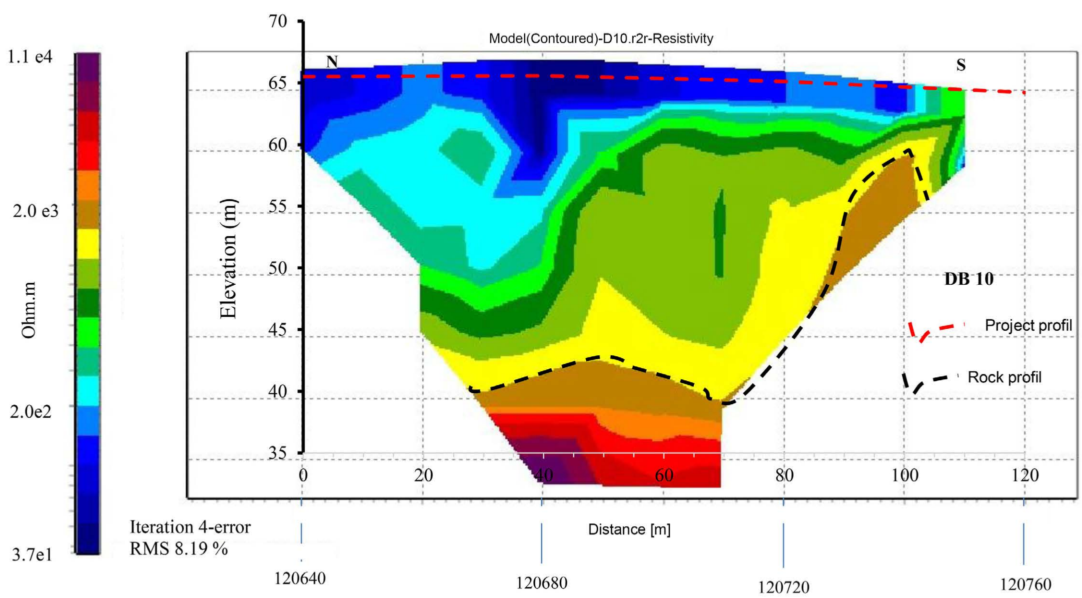
The same approach was applied to all other cut sections (DB 6 to DB 11). Analysis of the tomographic profiles of these different cuts also revealed these three geoelectric signatures. Conductive units with lowest resistivity values ranging from 37 to 217 Ohm·m (shades in the order of blue) (Figure 9). In most cases, these units occupy the profiles' superficial parts, intersecting by the project's red line. Alongside them are intermediate resistivity units (300 - 1000 Ohm·m) with greenish hues (Figure 9). Finally, there are resistive units with high resistivity values (>1000 Ohm·m) and reddish signatures. In most cases, these are rooted and lie below the project's red line, except at DB 7.

By analyzing variations in bedrock and the project's red line, different types of cuts were observed throughout the project (Table 7). Soft cuts are the most widespread along the profiles, with a cumulative volume ranging from 88 to 19897 m^3. These volume studies show that DB 7 contains the most soft material to be excavated, while the site with the least soft material to be removed is DB 6.




Model(Contoured)-D8.r2r-Resistivity
1.8 e5
1.7 e4
2.0e3
1.5e2
Ohm.m
N
S
Elevation (m)
120
115
110
105
100
95
90
85
0
20
40
60
80
100
120
140
160
180
DB 8
Project profil
Rock profil
Iteration 4-error
RMS 11.19 %
Distance [m]
93120
93160
93200
93240


Model(Contoured)-D9.r2r-Resistivity
3.0 e4
6.0 e3
1.0e3
2.2e2
Ohm.m
N
S
Elevation (m)
95
90
85
80
75
70
65
0
20
40
60
80
100
120
DB 9
Project profil
Rock profil
Iteration 4-error
RMS 4.05 %
Distance [m]
116840
116880
116920
116960


Model(Contoured)-D10.r2r-Resistivity
1.1 e4
2.0 e3
2.0e2
3.7e1
Ohm.m
N
S
Elevation (m)
70
65
60
55
50
45
40
35
0
20
40
60
80
100
120
DB 10
Project profil
Rock profil
Iteration 4-error
RMS 8.19 %
Distance [m]
120640
120680
120720
120760

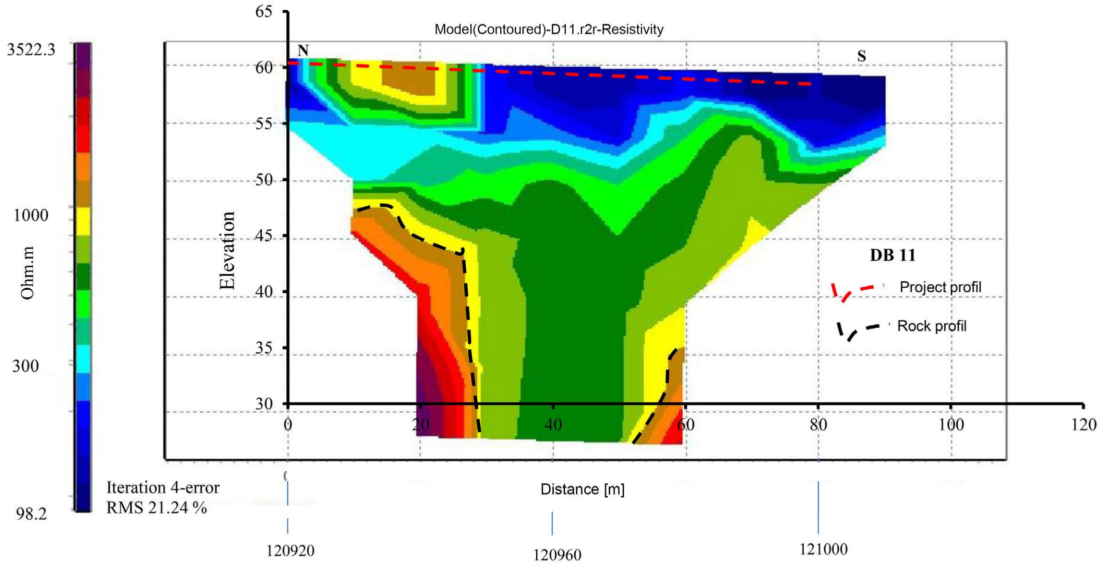


Figure 9. DB 6 to DB 11 2D sections.

Table 7. Volume calculation from DB 6 to DB 11.

Cut	Cumulative distance (m)	Cut thickness (m)	Thickness (m)		Road's width (m)	Cut surface (m²)		Length (m)	Cut partial volume (m³)		Cut cumulative volume (m³)	
		ZTn-ZPr	Rock ground	soft ground		rock ground	soft ground		rock ground	soft ground	rock ground	soft ground
DB6	85520	0.01	0	0.01		0	0.1	40	0	4	0	4
	85560	0.21	0	0.21		0	2.1	40	0	84	0	88
DB7	90720	3.24	0	3.24		0	32.4	40	0	1296	0	1296
	90760	5.88	0	5.88		0	58.8	40	0	2352	0	3648
	90800	7.82	1.08	6.74		10.8	67.4	25	270	1685	270	5333
	90840	8.86	0	8.86		0	88.6	40	0	3544	0	8877
	90880	9.67	0	9.67		0	96.7	40	0	3868	0	12745
	90920	9.82	0	9.82		0	98.2	40	0	3928	0	16673
	90960	8.06	0	8.06		0	80.6	40	0	3224	270	19897
DB8	93120	1.26	0	1.26		0	12.6	40	0	504	0	504
	93160	2.24	0	2.24	10	0	22.4	40	0	896	0	1400
	93190	3	0	3		0	30	40	0	1200	0	2600
	93195	1.88	1.88	0		100	0	20	1000	0	1000	2600
	93200	2	0	2		0	20	40	0	800	1000	3400
	93240	1.39	0	1.39		0	13.9	40	0	556	1000	3956
	93280	0.73	0	0.73		0	7.3	40	0	292	1000	4248
DB9	116840	2.73	0	2.73		0	27.3	40	0	1092	0	1092
	116880	3.28	0	3.28		0	32.8	40	0	1312	0	2404
	116920	3.23	0	3.23		0	32.3	40	0	1292	0	2384
	116960	2.17	0	2.17		0	21.7	40	0	868	0	1272
	117000	1.01	0	1.01		0	10.1	40	0	404	0	1676

Continued

DB10	120640	1.06	0	1.06	0	10.6	40	0	424	0	424
	120680	1.95	0	1.95	0	19.5	40	0	780	0	1204
	120720	1.39	0	1.39	0	13.9	40	0	556	0	1760
	120760	0.23	0	0.23	0	2.3	40	0	92	0	1852
DB11	120920	0.19	0	0.19	0	1.9	40	0	76	0	76
	120960	0.44	0	0.44	0	4.4	40	0	176	0	252
	121000	0.77	0	0.77	0	7.7	40	0	308	0	560
	121040	0.7	0	0.7	0	7	40	0	280	0	840
									Total	**1270**	**31893**

As for rocky cuts, they were mainly found at DB 7 and DB 8, with a cumulative volume of 270 m^3 and 1000 m^3, respectively (**Table 7**).

4.7. Discussion

The electrical tomography profiles carried out on each cut to determine the profile of the bedrock roof, if any, have shown in this study that the subsoil of this road project comprises three main horizons of differing geoelctric nature. By correlating these entities with the geology of the region in particular, and that of Côte d'Ivoire in general, the low-resistivity units correspond to the lateritic cuirass that forms a superficial overlay on the surface. Because of their ferromagnesium content, these formations, which result from weathering processes, are conductive and therefore of low resistivity. Medium resistivity units are associated with alterites and the fractured fringe of the bedrock. Lastly, the resistive units beneath the surface coverings and alterites correspond to the granitic basement.

This lithological layout has been described in numerous studies carried out in Côte d'Ivoire. Indeed, research by Sombo et al. (2017) in several localities in the Ivorian basement domain has shown that in the crystalline basement zone, a lithological alteration profile includes lateritic cuirass, clayey-sandy alterites and a fractured fringe of the basement.

Also, in all the tomographic profiles, the granitic basement appears in the first 30 meters of depth on the Gagnoa-Gueyo-Baménadou axis. This corroborates the results of the simplified geological map of Côte d'Ivoire, which shows a predominantly granitoid geology (**Figure 1(b)**). Thus, this work shows that electrical resistivity is a key parameter for lithostratigraphic differentiation of subsoil formations in geotechnical work, as attested by the work of Akingboye et al. (2020), Maślakowski et al. (2014) and Fadele et al. (2013).

In the same vein, the use of 2D and 3D electrical tomography enabled Ayolabi et al. (2012) to solve geotechnical problems in the Gbagada province of Lagos, Nigeria. They were able to highlight different subsoil units based on variations in resistivity. Low resistivity sets are associated with wet formations, while high resistivity values are associated with dry formations. Similar results were found by

Akingboye et al. (2020) and Fadele et al. (2013). In fact, the results of these authors showed that healthy bedrock had the highest resistivity, while medium and low resistivities were associated with the fractured part of the bedrock and superficial formations respectively.

In addition, the surface area and volume of soft or rocky cuts were calculated based on the rock top altitudes of each profile. The method used to calculate the volume of material takes into account the length of application of each profile (40 m in our case) and the width of the planned road (10 m in our case), as well as the thickness of soft or rocky cuts. The latter is determined every 40 m to ensure better superposition between the tomographic profile (10 m step) and the longitudinal section of the road (40 m step). This large discrepancy may result in the loss of some information about the bedrock profile. A tighter measurement interval for the longitudinal profile of the road may enable a better assessment of the cumulative volume. A study of the cuts using electrical tomography has enabled us to distinguish between rocky and soft nature of each cut along the road. The computer programs most often used, such as those presented by Bere (1989) for calculating earthworks on rural roads, do not distinguish between soft and rocky volumes. The use of electrical resistivity tomography coupled with the longitudinal section of the alignment, as demonstrated in this study, can therefore help to better establish a preliminary design, and finally to make the right provisions for the alignment of road sections.

5. Conclusion

Electrical resistivity tomography was used to study the cuts on the Gagnoa-Gueyo-Bamenadou road. Interpretation of the tomographic profiles revealed three geological layers corresponding successively to a conductive surface cover, then more or less conductive units of varying thickness, and finally a very heterogeneous, highly resistive bedrock. Subsequently, the nature and volume of the material in each cut were revealed. In total, a cumulative volume of 88557 m^3 of soft cuts and 16124 m^3 of rock cuts are included in the project cost plan. The majority of the road is therefore made up of soft cuts.

Electrical resistivity tomography, combined with the longitudinal section of the road, can therefore be an effective means of characterizing cuts in a preliminary design study, so that the right provisions can be made for road layout.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Akingboye, A. S., Osazuwa, I. B., & Mohammed, M. Z. (2020). Electrical Resistivity Tomography for Geo-Engineering Investigation of Subsurface Defects: A Case Study of Etioro-Akoko Highway, Ondo State, Southwestern Nigeria. *Studia Quaternaria, 37,* 101-107. https://doi.org/10.24425/sq.2020.133754

Akpan, U., & Morimoto, R. (2022). An Application of Multi-Attribute Utility Theory (MAUT) to the Prioritization of Rural Roads to Improve Rural Accessibility in Nigeria. *Socio-Economic Planning Sciences, 82,* Article 101256. https://doi.org/10.1016/j.seps.2022.101256

Alam, M. J. B., Ahmed, A., & Alam, M. Z. (2024). Application of Electrical Resistivity Tomography in Geotechnical and Geoenvironmental Engineering Aspect. *Geotechnics, 4,* 399-414. https://doi.org/10.3390/geotechnics4020022

Ayolabi, E. A., Enoh, I. J. E., & Folorunso, A. F. (2012). Engineering Site Characterisation Using 2-D and 3-D Electrical Resistivity Tomography. *Earth Science Research, 2,* 133-142. https://doi.org/10.5539/esr.v2n1p133

Bere, A. (1989). *Contribution aux calculs de terrassement en voirie rurale, mise en œuvre de programmes de calculs.* Mémoire de fin d'études, Ecole inter-états d'ingénieurs de l'équipement rural Ouagadougou, Burkina-Faso, 37 p. http://documentation.2ie-edu.org/cdi2ie/opac_css/doc_num.php?explnum_id=1576

CICG (2019). *Pistes rurales, routes et ponts en Côte d'Ivoire: La si longue attente… jusqu'à l'arrivée du Président Alassane Ouattara*. https://www.gouv.ci/impact-developpement/accueil/edito_detail/pistes-rurales-routes-et-ponts-en-cote-d-ivoire-la-si-longue-attente-jusqu-a-l-arrivee-du-president-alassane-ouattara417/8

Fadele, S. I., Jatau, B. S., & Goki, N. G. (2013). Subsurface Structural Characterization of Filatan Area A, Zaria–Kano Road, Using the 2D Electrical Resistivity Tomography. *Journal of Earth Sciences and Geotechnical Engineering, 3,* 73-83.

Gibson, J., & Olivia, S. (2010). The Effect of Infrastructure Access and Quality on Non-Farm Enterprises in Rural Indonesia. *World Development, 38,* 717-726. https://doi.org/10.1016/j.worlddev.2009.11.010

Lykova, O. (2021). The Road Infrastructure Development Impact on the Economy of the Region. *E3S Web of Conferences, 281,* Article 08012. https://doi.org/10.1051/e3sconf/202128108012

Maślakowski, M., Kowalczyk, S., Mieszkowski, R., & Józefiak, K. (2014). Using Electrical Resistivity Tomography (ERT) as a Tool in Geotechnical Investigation of the Substrate of a Highway. *Studia Quaternaria, 31,* 83-89. https://doi.org/10.2478/squa-2014-0008

Milesi, J. P., Feybesse, J. L., Ledru, P., Dommanget, A., Ouedraogo, M. F., Marcoux, E., Prost A. E., Vinchon, C., Sylvain, J. P., Johan, V., Tegyey, M., Calvez, J. Y. & Lagny, P. (1989). Les Minéralisations Aurifères de L'Afrique de L'Ouest: Leurs Relations Avec L'évolution Lithostructurale Au Protérozoïque Inférieur. *Chronique de la Recherche Minière, 497*, 3-98. https://www.scirp.org/reference/referencespapers?referenceid=2972809

Nawir, D., Bakri, M. D., & Syarif, I. A. (2023). Central Government Role in Road Infrastructure Development and Economic Growth in the Form of Future Study: The Case of Indonesia. *City, Territory and Architecture, 10,* Article No. 12. https://doi.org/10.1186/s40410-022-00188-9

Papon, A. (1973). *Géologie et minéralisations du Sud-ouest de la Côte d'Ivoire.* Mémoire BRGM, France, 284 p.

PEMED-CI (2015). *Etudes monographiques et économiques des districts de Côte d'Ivoire: District du Gôh-Djiboua*. https://fr.scribd.com/document/639913973/PEMEDCI-GOH-DJIBOUA-2

Robson, E., Agosti, A., Utili, S., & Milledge, D. (2022). A Methodology for Road Cutting Design Guidelines Based on Field Observations. *Engineering Geology, 307,* Article 106771. https://doi.org/10.1016/j.enggeo.2022.106771

Solodkiy, A., & Gorev, A. (2018). Determination of Basic Factors for the Successful Implementation of the Safe and High-Quality Roads Project. *Transportation Research Procedia, 36,* 741-746. https://doi.org/10.1016/j.trpro.2018.12.097

Sombo, A. P., Kouakou, K. E. G., Kouassi, F. W., Koudou, A., & Bie, G. R. (2017). Profil d'altération et potentiel aquifère en zone de socle cristallin au Sud de la Côte d'Ivoire. *International Journal of Innovation and Applied Studies, 19,* 919-928.

Whiteley, J., Inauen, C., Wilkinson, P., Meldrum, P., Swift, R., Kuras, O. et al. (2023). Assessing the Risk of Slope Failure to Highway Infrastructure Using Automated Time-Lapse Electrical Resistivity Tomography Monitoring. *Transportation Geotechnics, 43,* Article 101129. https://doi.org/10.1016/j.trgeo.2023.101129