

Using Engineering Survey Techniques for the Tonkolili Railways Project

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Key words: Sierra Leone, rail way, design, stake out, EGM96, UTM

SUMMARY

Tonkolili Railways Project is the biggest development project in Sierra Leone since the end of the civil war 10 years ago. It is the construction of 120 km of new railway from Lunsar to Tonkolili council. Three companies are principal contractors, Dawnus, Basil Reed and WBHO with AML being the principal client. The rail will be used to transport the iron ore from Tonkolili to Pepel port. The survey operations were taken two stages:

- First stage when the surveyors went on field to stake out the center line of the new rail. An autonomous position was used to stake out the coordinates, and a D6 Cat dozer to cut through the vegetation growth.

- Second stage – multiple surveys and stake out operations involved in construction. Establishing GPS control points and office post processing, original survey and stake out. Calculate and stake out alignment (horizontal and vertical), with straight, transitions and curves. Also calculate top of batter cut positions and toe of batter fill positions with slope distances and fill heights. A complete cross section survey every 20m taken at the start of the job and a weekly survey taken at work locations as job progressed. Volumes calculated from these surveys. The main problems have been to establish new control points in the desired map projections and geoid model.

I work for Dawnus, a Welsh civil engineering company, responsible for 50Km of new rail construction and 70Km of rail refurbishment. The engineers are all British and the surveyors are from Romania, who work closely together with Sierra Leone engineers. So there is three quite different cultures that mix together and have to make it work for the project to be a success.

Many villages have to be passed and everyday the surveyors got involved with local people. So again there is a big mix of cultures and sometimes the challenge can be difficult, but most of the time it is worthwhile.

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1. INTRODUCTION

1.1 Scope of Work

African Minerals (AML) are planning to begin mining operations at their Tonkolili mine in North East of Sierra Leone during early 2010. The initial development of the AML railway/operations includes the rehabilitation of an open access Cape gauge (1067mm) rail line and port site at Pepel Port. This is the first open access railway in Sierra Leone. The last train was loaded and ran on this railway in 1985.

Initially, the iron ore will be hauled by road to a stock pile location close to but west of the town of Lunsar which will allow a connection to the previously used Cape gauge (1067mm) railway which ran from Marampa to the Port of Pepel in Sierra Leone. The iron ore will be loaded into open top and bottom dump iron ore wagons for the rest of the journey to the port, a distance of approximately 76 km.

While using this railway, it is also planned to construct and operate a heavy haul standard gauge railway (1436mm) of approximate distance of 210 km from the mine at Tonkolili to the new port at Tagrin in Sierra Leone with the capacity of 40 tonne axle loading with annual haulage rate of plus 50 million tonne per year.

The final goal of these projects would be:

- Bulk Earthworks construction for the proposed railway alignment from Lunsar (0 km) to the mine at Tonkolili (approximately 125 km). This section covers all work in connection with the construction of cuts and fills, the removal to spoil of material unsuitable for use, the construction and compaction of bulk fills with cut material from the road way prism or borrow material from approved borrow pits, the compaction of the bulk earthworks and finishing off cuts and fills, up to the stage where the fills are ready for construction of the layer works.

- Structural Layer works construction for the proposed railway alignment from Lunsar to the mine at Tonkolili. This section covers all work in connection with the construction and compaction of the structural layer works, with approved cut material (suitably processed) from the road prism or borrow material from approved borrow pits, up to the stage where the fills are ready for placing the ballast layer.

- Supply, stake out and Installation of drainage culverts for the proposed railway alignment.

- Construction of stone pitch lined side drains (Immediate works only);

- The setting out of Cut Off Drains and Banks on top of cuttings for Community Projects;

- Supply and Stockpiling of ballast stone.

Due to the size of the project and the specified time frame, the earth work has been divided into three work packages as follows:

- Work Package A: Construction of the earth works from km 0 to the bridge at km 50
- Work Package B: Construction of the earth works from the bridge at km 50 to km 85
- Work Package C: Construction of the earth works from km 85 to the Tonkolili mine, inclusive the tail track and ore load out loop.

Also, Africa Minerals is in the process of refurbishing their Iron Ore port at Pepel, Sierra Leone. Pepel Stockyard is situated near Pepel, Northern Province Sierra Leone, Western Africa. Pepel is at the North Eastern end of Freetown Harbour, on Atlantic seaboard, located near the mouth of the Sierra Leone River, an estuary formed by the Rokel River with Port Loko Creek.

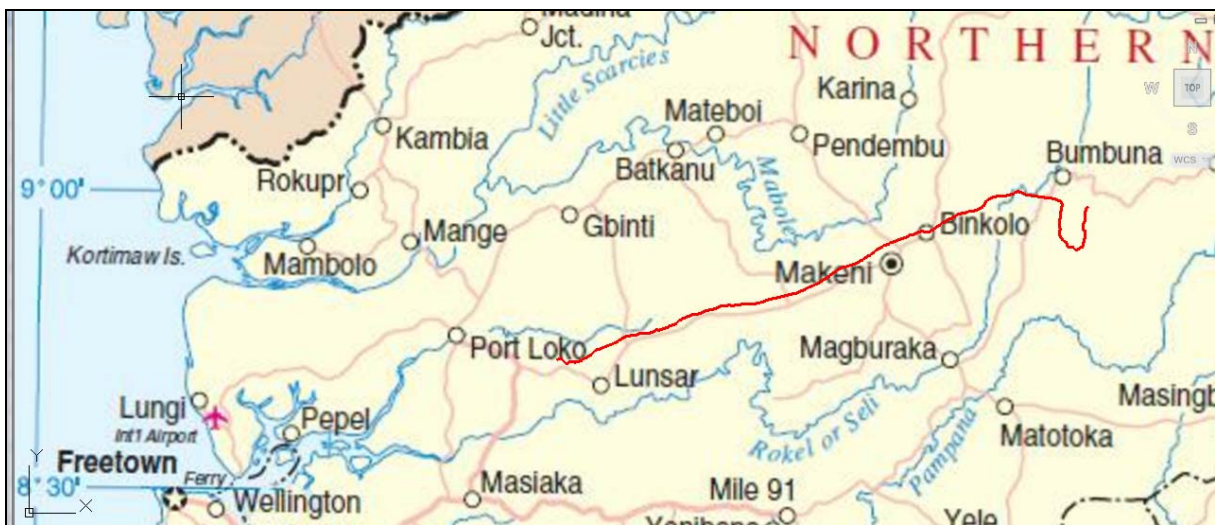


Figure 1 - Project development throughout the country

The scope of works at Pepel, was the construction of all Civil Works pertaining to a new Train dump station, conveying and stockpile system. The operations described in this section will refer to surveying for the setting out all the restricted earthworks and Civil Engineering work.

In this paper we will only refer to the topographic operations conducted for the construction of the railway between km 0 and km 50. The topographic operations performed in order to stake out the constructions and the auxiliary installations necessary for storing and loading iron ore from port Pepel will also be described.

1.2 Geodetic parameters

An original survey was done in 2009 year using Lidar techniques. This was done in order to obtain information about the terrain (Natural Ground Level – NGL) in order to accomplish the execution project.

The projection system used was UTM on the WGS84 ellipsoid. The survey area is

split between UTM zone 28 and UTM zone 29.

The UTM28 and UTM29 parameters are as follows:

Name	UTM Z28
Zone Number	28
Central Meridian	15° 00' 00.00000" W
Hemisphere	Northern

Name	UTM Z29
Zone Number	29
Central Meridian	9° 00' 00.00000" W
Hemisphere	Northern

The WGS84 ellipsoid parameters are as follows:

Name	WGS84
Semi-major axis (a)	6378137.0
Reciprocal Flattening (1/f)	298.257223563

The geoid model approved and used was EGM96. For commercial reasons, no information about the geodetic equipment used will be provided.

2. PHASE ONE – PATH FINDER

Once the contractual obligations were fulfilled, the field work started. In the first phase, the designer provided the coordinates of the railway axis points, 50 meters centres along the alignment.

The first emergency was to stake out the railway axis and to clear the route from vegetation.

The stake out method used was the RTK method, using two geodetic receivers with dual frequency, and RTK capability. No information was provided on geodetic control points and also no topographic work done in the past could be identified. Because of this, to start the vegetation clearing procedures, a control point obtain by autonomous observations was used.

The work started approximately at km 14, where a site organization was placed. A team of surveyors were staking out the route, as the D6 bulldozer was clearing the vegetation.

The team was comprised of: An engineer from Wales, An engineer from Sierra Leone and Two local workers.

As the team was moving away from the first point, more control point were necessary to have radio coverage. The points were obtained through the RTK method, the precision being sufficient for their purpose.

The operations started March 2010 and continued until the end of the year.

3. PHASE TWO – DESIGN AND STAKE OUT

3.1 The design

At the end of September 2010, the designer provided information about the geometry of the railway axis. The axis geometry was provided as follows:

- The horizontal position of the axis was described by: Planimetric coordinates of the curve peaks, The length of the alignments, The radius of the connecting curves and The length of the transition curves.

TONKOLILI IRON ORE PROJECT 01/10/2010

Alignment: LT HA 000-050

CURVE NAME	POINT	CHAINAGE (m)	NORTHING (m)	EASTING (m)	ELEMENT	LENGTH (m)	DEFLECTION ANGLE
	START	-0+694.907	965997.553	102655.739			
					STRAIGHT	35.736	
	BTC	-0+659.17	966017.117	102685.644			
					SPIRAL	80	
	BCC	-0+579.17	966058.965	102753.796			
1	PI	-0+468.742	966121.37	102845			35°31'39.2" Right
	CC		965645.057	102976.463	R = +470.000	210.803	
	ECC	-0+368.367	966114.581	102955.302			
					SPIRAL	80	
	ETC	-0+288.367	966113.614	103035.27			
					STRAIGHT	2.451	
	BTC	-0+285.916	966113.514	103037.719			

Figure 2 - The horizontal geometric elements of the axis

- The horizontal position of the axis was described by: The length of the alignments, The tilt of the alignments, The elements on the vertical of the curves.

Vertical Alignment: VA 000-050
Vertical Description:
Vertical Style: VA Display

	Station	Elevation
Element: Linear		
	START	-0+694.907
	PVC	-0+568.282
	Tangent Grade:	1:-156.6766
	Tangent Length:	126.625
Element: Circular		
	PVC	-0+568.282
	PVI	-0+420.253
	PVCC	-0+411.976
		24554.246

Figure 3 - The vertical geometric elements of the axis

Of course, these elements couldn't be used to stake out the railway axis. The geometric elements had to be used to obtain the coordinates of points on the axis of the railway.

For this the functions of AutoCAD Civil3D were used.

The order of the operations was the following:

- The coordinates of the curve peaks were reported in the software
- The alignments were drawn
- The elements of the connection curves and transition curves were inserted
- The elements of the vertical profile were inserted
- The chosen interval was 20m

The result of these calculations were the x,y,z coordinates of the points that define the railway axis, at a 20m interval. The coordinates were exported in a .csv format, containing the mileage, respectively the coordinates of the point, at that kilometre.

3.2 Control points

It was obvious that the coordinates of the control points that came from autonomic determinations could not be used for the stakeout of the points. Even if theoretically a network could be developed from these coordinates, their use would make the connection of the three mentioned railway sections impossible. Therefore it was necessary to develop a network of control points to ensure homogeneity of the points for the whole project, starting from Pepel, and finishing at Tonkolili.

The task of developing these networks fell in the beneficiary's hands and it was done in two campaigns:

- In the first campaign the primary control points (primary control network) was developed in a major network, covering all perspectives of the beneficiary projects. The distance between the points was of tens of kilometres, and as starting bases, the coordinates of South African and Spanish permanent stations were used. Unfortunately, excepting the coordinates and a placement scheme of the points, no details about the processing method were provided (figure 4).

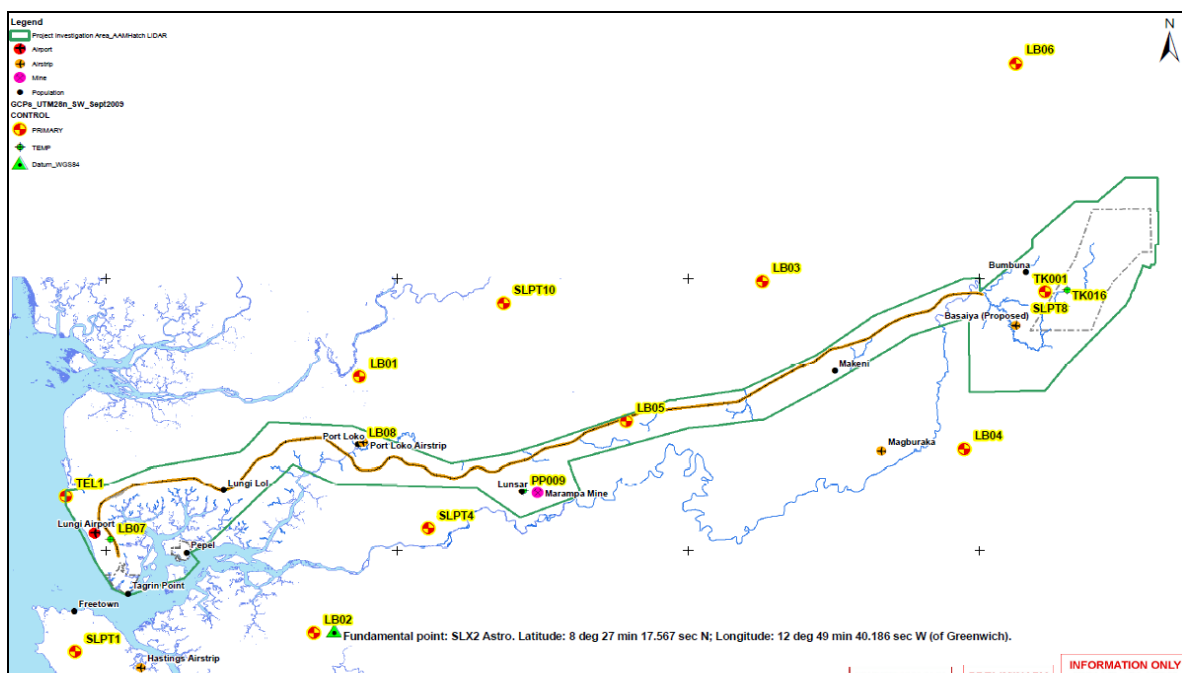


Figure 4. The primary control points scheme

- From the points thus determined, networks have been developed to ensure sufficient covering with control points for all the projects developed by the beneficiary. For the studied project part, 13 new points were determined, at a

distance of approximately 5km.

I have verified the coordinates of these points, in a network developed by the constructor. The differences can be studied in the following table.

	DX	DY	DZ
DTK01	0.014	0.022	-0.040
DTK02	0.013	0.017	-0.019
DTK03	0.010	0.016	-0.002
DTK04	0.007	0.016	-0.007
DTK0	0.003	-0.002	0.020
DTK05	0.010	-0.005	0.037
DTK06	-0.002	-0.007	0.052
G31	-0.002	0.002	0.062
DTK07	0.001	-0.004	0.009
G51	-0.008	-0.007	0.013
DTK08	-0.004	-0.011	0.012
DTK09	0.003	-0.011	0.025
DTK10	0.005	-0.013	0.028

If in the planimetric position no substantial differences can be identified, the height values are quite high. With DTK01 in the west extreme side of the project, it is found that the biggest elevation difference is approximately at the middle of the project. These heights were obtained by corrections of the geoid, applied to the ellipsoidal heights. It has become obvious that it was necessary to carry out precision levelling.

3.3 Precision Leveling

The problem of performing a geometric levelling, was the same as for the control points: the absence of any levelling references. In this situation, in the discussions with the client, there were two proposals:

- The geometric levelling should be done between the GPS control points, using EGM96 geoid;
- The geometric levelling should be done starting from the first point(Km 0), until the last point (Km 50), and back;

Personally, we expressed our scepticism in accomplishing a levelling on a distance of 100 km. Besides the great distance, obstacles made this operation impossible:

- Too much time needed to cover this – in the same time, most of the site operations would not benefit of levelling references;
- Rough relief – at the time of land levelling, the terrain did not benefit of major cut – fill work;
- Railway axis was not completely cleaned – there still were swampy areas that would have made a levelling line crossing impossible.

For economic reasons, the cut fill work started at Km 20 and continuing to Km 30.

GPS control points from the area were DTK06, G31 and DTK07. So we decided performing the following levelling routes:

- DTK06 – G31
- G31 – DTK07.

The levelling was done using a level with an accuracy of 0.2 mm, with a double horizon. Between the control points, new points were placed (bench marks), for which it was intended to determine the planimetric coordinates and the height.

The height, of the GPS control points were used. The results were surprising.

First of all, the differences between the two horizons did not exceed 3 mm. Height errors were of tens of millimeters.

DTK07	1.5620	30.2600	71.5900	9074.0700	-0.6328	72.979	73.027
					[dH]=	1.6495	
					Wh=	0.0485	
					Tolerance	0.0301	

As we can see, on a length of 9074 m, the error was 48 mm. It isn't a big value in the given conditions. But compensating this levelling line, and checking the value obtained in G31, it was found that the height from the levelling it is very close to the GPS height, obtained in GPS network, done by the contractor. Therefore we performed a new calculation, this time using the height values obtained by our processing. The result can be studied below.

DTK07	1.5620	30.2600	71.5900	9074.0700	-0.6328	73.024	73.027
					[dH]=	1.6495	
					Wh=	0.0035	
					Tolerance	0.0301	

The result is surprising, and the control done in G31, showed a difference between the calculated height, and the GPS height, if 2,5 mm.

As already mentioned, on the levelling route, some new control points were made. To determine the coordinates of these points, a network of vectors were made, constrained on DTK06 and DTK07. To make the network, four L1/L2 geodetic receivers were used.

After GPS processing, also the heights of the points resulted, on EGM96 geoid model. Differences obtained by geometric levelling and heights resulted from GPS processing, can be studied below:

BM23320	0.008	BM27620	-0.004
BM23580	0.010	BM27701	-0.013
BM23880	0.000	BM27900	-0.005
BM24120	-0.004	BM28160	-0.010
BM24880	-0.012	BM28580	-0.005

BM25500	-0.006	BM29040	-0.003
BM25700	-0.005	BM29420	0.002
BM25960	-0.005	BM29980	0.004
BM26400	0.007	BM30950	0.001
BM26820	0.007		

The biggest difference is of 13 mm, but still this value is smaller than the tolerance imposed by the beneficiary, respectively 20 mm.

After these studies, the following decisions were made:

- The planimetric coordinates and the heights of the intermediary control points (benchmarks) will be determined by GPS processing, monitoring the results carefully; The height of the projected points, will be made through geometric leveling, using the heights of the determined GPS points;
- The checks done between the benchmarks were stunning. Only by accident there were errors bigger than 20 mm, in which case these points were not used.

By determining the intermediary control points using these methods, meant a signifying advantage for the production, in the situation where, in the second half of february, GPS equipment started to be installed in the working machines. Since work was carried out on several working points, and several kilometers, intermediate control points could provide a sufficient coverage for all the equipment used.

3.4 Stakeing out geometrical elements

The stake out of the geometrical elements was made in two stages:

- In the first stage, the railway axis (CL) was staked out,
- In the second stage, the geometrical elements of the railway were calculated and staked out.

3.4.1 Stake out CL

The railway axis was relatively simple to perform, and there were no major problems. Once the coordinates of the axis were determined (Cap 3.1), the points were loaded in the GPS equipment portable computers. The surveyor teams were formed by engineers, helpers and Sierra Leone citizens.

The railway axis was stake out with points at a distance of 20 meters, and marked with wooden pegs. Every peg was marked with the point number – which coincides with the chainage of the alignment.

After staking out the point, the real values of the planimetric coordinates, and heights were recorded. This approach allowed creating a data file, which was named “Preplot – postplot comparison”.

Chainages	Design			Stake out			dE	dN	dD	dh
	E	N	h	E	N	E				
0	103298.947	966016.596	66.407	103298.949	966016.576	66.307	-0.002	0.020	0.020	0.100
20	103313.361	966002.732	66.480	103313.372	966002.724	66.402	-0.011	0.008	0.014	0.078
40	103327.461	965988.548	66.539	103327.421	965988.563	66.476	0.040	-0.015	0.043	0.063
60	103341.448	965974.252	66.584	103341.441	965974.224	66.511	0.007	0.028	0.029	0.073
80	103355.429	965959.952	66.615	103355.421	965959.924	66.582	0.008	0.028	0.029	0.033
100	103369.411	965945.651	66.632	103369.387	965945.695	66.538	0.024	-0.044	0.050	0.094
120	103383.392	965931.350	66.636	103383.378	965931.351	66.532	0.014	-0.001	0.014	0.104
140	103397.374	965917.049	66.628	103397.322	965917.042	66.565	0.052	0.007	0.052	0.063
160	103411.356	965902.748	66.612	103411.349	965902.760	66.585	0.007	-0.012	0.014	0.027
180	103425.337	965888.447	66.587	103425.338	965888.462	66.574	-0.001	-0.015	0.015	0.013
200	103439.319	965874.146	66.554	103439.289	965874.155	66.576	0.030	-0.009	0.031	-0.022
220	103453.300	965859.846	66.513	103453.287	965859.861	66.550	0.013	-0.015	0.020	-0.037
240	103467.282	965845.545	66.463	103467.299	965845.569	66.563	-0.017	-0.024	0.029	-0.100
260	103481.264	965831.244	66.405	103481.252	965831.216	66.558	0.012	0.028	0.030	-0.153
280	103495.245	965816.943	66.339	103495.222	965816.936	66.432	0.023	0.007	0.024	-0.093
300	103509.227	965802.642	66.269	103509.260	965802.643	66.430	-0.033	-0.001	0.033	-0.161
320	103523.208	965788.341	66.200	103523.216	965788.337	66.397	-0.008	0.004	0.009	-0.197

The information provided by this file was very useful, and allowed:

- Identifying possible stake out errors,
- Identifying fill routes, respectively cut routes, important aspect in staking out and determination of geometrical elements of the railway.

3.4.2 Stakeing out geometrical elements

On the basis of geometrical elements provided by the designer, all of the infrastructure elements sizes could be determined (Figure 5).

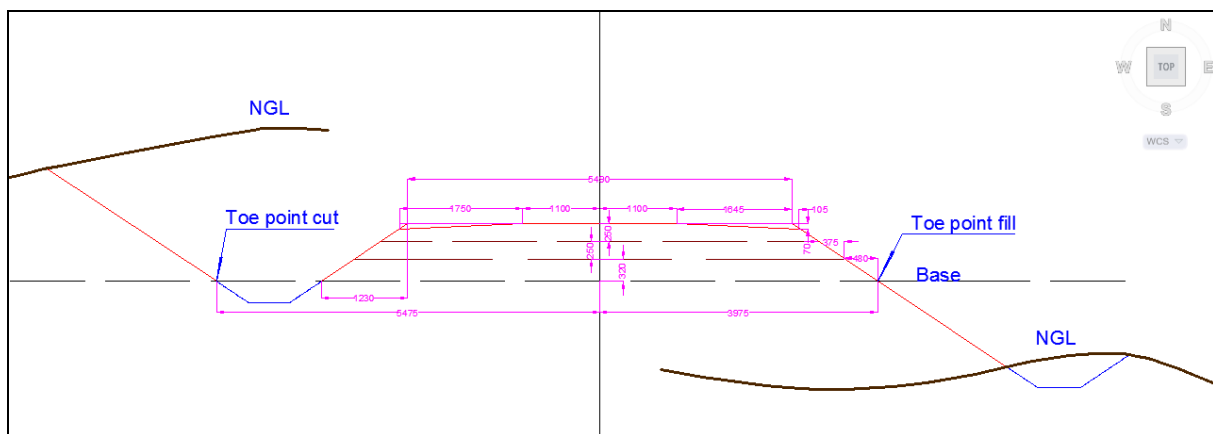


Figure 5. The dimintions of the geometry elements of the infrastructure

Further, depending on the GPS equipment capabilities, the two toe points were established:

- Infrastructure basis for fill – distance from axis of 3975 mm,
- Embankment basis for cut – distance from axis of 5475 mm.

From the file specified in Chapter 3.4.1, the points that were in fill, respectively the points that were in cut could be determined exactly.

Lists were made for all the determined points, with the left – right distance values from the railway axis. Next, the coordinates of all left – right toe points were determined. The coordinates were determined using AutoCad's Civil3D special functions – respectively offset – points functions.

The coordinates thus obtained were loaded in portable computers and began staking them out. The information obtained was different from cut (or fill) and the distance until the respective toe point. With a pocket calculator, these values were checked depending on the embankment projected slope (1:1.5) and establishing the position of the start point of the cut, respectively of the fill. These points were after materialized with special beacons according to known procedures.

It is worth mentioning that these dimensions were calculated both for the base geometry for the railway as well as for the layers that form the embankment. The determination of the x, y and z coordinates for all the points determined this way made it possible to create digital models for each project phase. The digital models were loaded in the GPS equipment – which led to an ease in stake out, as well as in the special equipment mounted on working vehicles.

3.5 Topographic operations done for staking out the installations and constructions from Port Pepel

As shown at the beginning of the project, AML started extensive work for redeveloping the loading installations of the iron ore in wagons. The constructions and installations mainly consisted of:

- A station for unloading iron ore from wagons;
- A station for loading iron ore into ships;
- A complex network of conveyor belts to ensure the transportation of the iron ore.

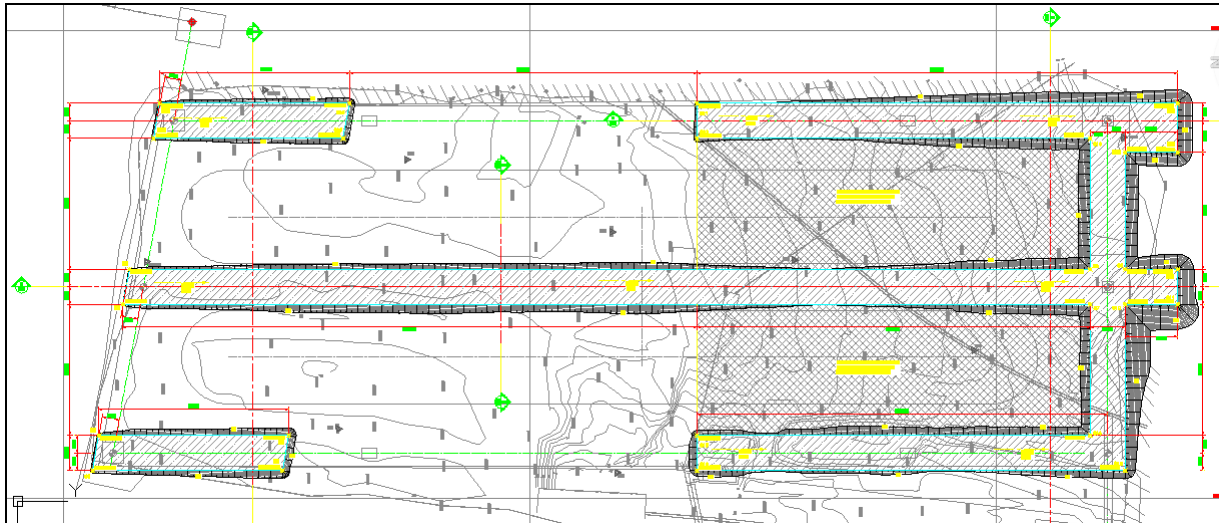


Figure 6. The installation project from Port Pepel

The main problems that occurred in staking out these constructions were:

- Lack of initial control points – the survey has been done more than two years ago. From the initial control points only one was left;
- Two types of survey done – initially the survey was done by GPS, by applying cartographic corrections, and after additions were made with the total station, without cartographic corrections;
- The need of connecting the unloading stations - loading at two fix points imposed by the project;
- High precision stake out imposed.

In order to stake out the constructions and the installations, a high precision network had to be made. For this purpose, new points were placed around the objectives that had to be staked out, in order to assure a good visibility between all the points. As starting point of the observations, the only point left from the initial surveying was used, and for orientation a detail point from the field which could be identified was used.

The idea behind this way of working was to use this point just for a “dummy” orientation that could be corrected in the final network.

Observations were made with a precision total station. Observations were made at night, after the site activities have finished, with applying atmospheric corrections, but without cartographic corrections. All the possible angles and distances were measured. For processing, special software was used to ensure processing by the least squares method.

Coordonate initiale si corectii de coordonate				
Nrp	X0	Y0	dX[cm]	dY[cm]
PEPEL3	948666.259	713614.117	-0.352	0.219
PEPEL4	948948.632	713617.423	0.208	-0.142
PEPEL10	948824.298	713686.111	-0.180	0.028
BM7	948795.322	713777.805	-0.112	0.067
PEPEL7	948609.946	713781.519	-0.162	0.440
PEPEL1	949084.594	713819.534	-0.166	-0.023
BM21	949085.095	713822.054	0.000	0.000
999	948795.356	713777.810	0.000	0.000
Coordonate compensate si erorile medii ale coordonatelor				
Nrp	X	Y	mX[cm]	mY[cm]
PEPEL3	948666.255	713614.119	0.119	0.086
PEPEL4	948948.634	713617.422	0.080	0.070
PEPEL10	948824.296	713686.111	0.059	0.048
BM7	948795.321	713777.805	0.054	0.048
PEPEL7	948609.945	713781.523	0.175	0.091
PEPEL1	949084.593	713819.534	0.092	0.074

Figure 7. The coordinates and the corrections of the new points determined in Port PepeL.

As can be seen, the biggest errors were noticed at the most distant points of the network (PepeL7 and PepeL3), but all errors were below 5mm, below the tolerance imposed at the stake out.

3.6 Other topographic operations

The operations specified in the previous chapters, were not the only topographical operations done. With a huge volume of construction, every day new problems occurred that required the intervention of the surveyors: Relocation of control points, Relocation of beacons, Stake out and height checking, Weekly production survey, Calculation of volumes etc.

Very spectacular 3D models of some locations were created, so calculation of volumes was could be carried out. Special surveys for the creation of 3D models were done at the two stone quarries – Rofayne and Mackeri.

Creating these models allowed developing different exploit methods and precise monitoring of the exploited rock quantities.

4. CONCLUSIONS AND SUGGESTIONS

This paper's goal was to highlight the steps completed in the stake out of a large scale investment project.

As already mentioned, the construction of these 50 kilometers of railway interposed between the existence of an old railway and the construction of the new section (another by a construction firm). The main challenge in accomplishing this work was the precision of the connection between the sections. The described work led to the following results:

- At km 0, the connection precision with the existent section was of 10 mm,
- At km 50, the connection precision with the next section (on common control points) was of 5 mm.

This was done without any compensation measurements. Worth mentioning is the fact that the connection precision with the other section was over 200 mm, that imposed compensation operations. The main problem identified throughout the project was the lack of an adequate cartographic projection. Sierra Leone is crossed by two UTM zones, Zone 28 and zone 29. All the work was done on zone 29, which led to quite big cartographic deformations.

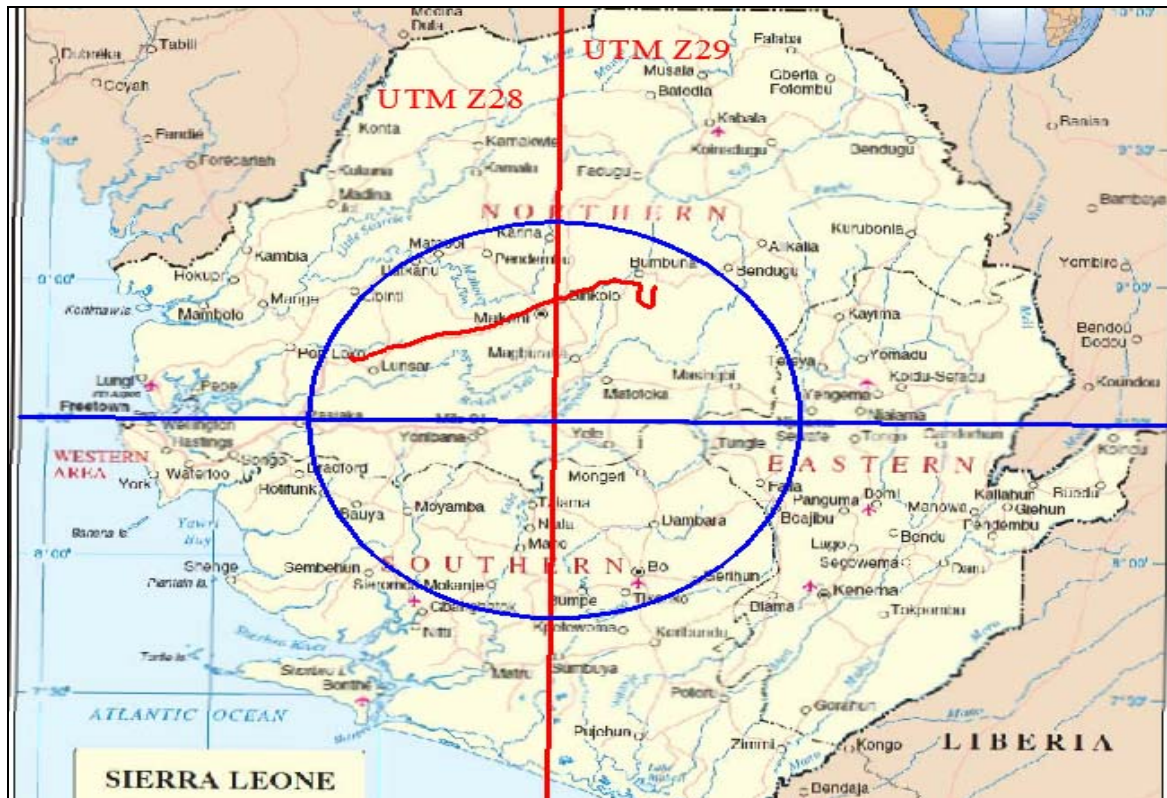


Figure 8. UTM projection and the proposal of stereographic projection for Sierra Leone

For infrastructure projects, the UTM projection isn't quite adequate. Taking into account the shape of the country, a plane projection, stereographic, with the center of projection in the middle of the country - $12^{\circ}W$ and $8^{\circ}30'N$, this option should be considered. The null deformations circle should have an approximate 80-90 km diameter. Such a projection would ensure the homogeneity of all topographical surveys throughout the country, for all the future projects.

However, the coordinates of all involved points are known in geographical coordinates, so their transformation to a new projection should not be a problem.

Even in ideal circumstances – the existence of control points for planimetric positioning and height, the existence of an adequate projection system, accomplishing this kind of project would have been a challenge. The lack of previous surveys (cartographic projection, geodetical points, levelling references, etc.), a relatively low experience for this kind of projects in countries like Sierra Leone, made accomplishing this project, a challenge for all employees, both from the Contractor as well as the Beneficiary.

The teams that helped accomplishing this project were composed of engineers from Wales, surveyors from Romania, and engineers from Sierra Leone.

The problems occurred daily, but perseverance, contributed to a great team. The experience of Wales engineers, with the technical knowledge of Romanian surveyors, and the help received from local engineers and the interference with the local culture, have led to great enthusiasm in the execution of the project.

Even with the mentioned obstacles, Dawnus firm's team of engineers demonstrated knowledge and sufficient skills for accomplishing a project of this size.

Recognition of technical skills came from the employer too – AML, by entrusting the second phase of the project, namely building a new railway of about 90 km.

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