Non-Destructive Testing Techniques for Corrosion Assessment in Reinforced Concrete Structures in Kenya

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Abstract

Deterioration of concrete structures is inevitable due to the fact that it is subjected to deterring environmental factors. Therefore, inspection and maintenance of these structures should be done to ensure their serviceability. Many concrete structures have been constructed in Kenya. A survey of some of the existing multi-storey buildings shows that even some of the old ones are in good condition; examples are the Norfork Hotel, Sarova Stanley Hotel and the railway bridges built in early 1900s. Yet, ageing structures require periodic monitoring to check their serviceability. Currently, inspection of most structures is done solely by simple visual means which is not always adequate. In order to enhance reliable assessment of structures, the present research introduces non-destructive testing (NDT) techniques for corrosion damage diagnosis in Kenyan concrete structures. Visual inspection is followed by half-cell potential measurements, carbonation tests and chloride tests. Laboratory analysis as well as field testing shows that NDT techniques provide safe, fast and reliable tools for the assessment of structural integrity.

Keywords: Reinforced Concrete, Deterioration, Inspection, Non-destructive testing

1.0 General introduction

1.1 General state of concrete in Kenya

Over the years, many types of concrete structures have been built. In many countries, a high per cent of the major infrastructure is made of concrete and these structures show different forms of deterioration. As construction costs are very high, regular maintenance and repair are required to keep these structures in serviceability state.

Many concrete structures that have been built in Kenya are old and have exceeded their design service life. Some of these structures in Nairobi which are still in service are given in Table 1. The table is not exhaustive; we have for example the old railway bridges dating back to early 1900s and are still in service. It is clear that the concrete which was used to produce these high-rise structures was of good quality; this supports the idea that the risk for failure as a result of deterioration associated with the design and construction phase is minimal. Although the high-rise structures seem still to be in good condition, long term deterioration may be possible and therefore, their health needs to be monitored.

The situation for structures in the coastal region is different. Chlorides from sea water are present and therefore chloride-induced corrosion of reinforcement in these structures can be expected. For example New Nyali and New Mtwapa Bridges are both bridges in the coastal region of Kenya. These two bridges were constructed in 1980, and are today marked by different damaged areas. The damages were first detected in 1992 and the damage progressed over the subsequent years. During an evaluation in July 1997 considerable damage on the two bridges was reported and required urgent rehabilitation. For both bridges major repair work as from 2001 was done including replacement of expansion joints, pavement replacement, epoxy resin grouting for concrete cracks and placement of corrosion-resistant coating on the superstructure, piers and abutments (World Highways, 2006). From the repair work the deterioration of these coastal structures could be due to corrosion of steel rebars.

The above mentioned concrete structures were constructed with good quality concrete. However not all concrete structures in Kenya are of good quality. A baseline survey was conducted by researchers in the department of civil and structural engineering, Moi University on the “quality of concrete produced in Kenya”. The visited sites were basically of low-rise construction. From the survey, it was found that, the concrete produced in all the visited construction sites were of poor quality for various reasons, mostly related to the quality of materials used, the batching process and site inspection (Njeru et al, 2010). From the survey, it was clear that the life of most of these structures could be shorter than the expected lifespan of the structure.

Concrete structures need regular inspection and maintenance which is not the current practice in Kenya; moreover, inspection is often limited to visual inspection. Moreover, structures vary in construction methods, structural design, construction materials, concrete mixes and quality control in place for construction process and inspection and so on. Because of these variations, each structure will show different patterns of deterioration in time. In view of these observations, the objective of the present research is to introduce NDT techniques for corrosion assessment, because rebar corrosion due to carbonation and chloride ingress is found to be the dominant cause of deterioration in most concrete structures worldwide (Gaal, 2004).

NDT techniques may be applied to any type of test object without changing or altering that object, in order to determine the absence or presence of conditions or discontinuities that may have an effect on the usefulness or serviceability of that object (Hellier, 2003).

1.2 Application of NDT Techniques

The application of NDT techniques in the domain of concrete structures is widely accepted, all over the world. This is illustrated with some examples.

At present and for the past few years a large amount of existing buildings and bridges in Bulgaria have required reconstruction and renovation. The major task was the determination of the actual technical condition of the load-bearing elements of the structures, in order to know if they could be preserved and utilize them in future. A method for assessing the condition of the Rotunda load-bearing structures in the open square in front of the Sofia Central Railway Station involved the following investigations: ultrasonic testing, depth of carbonation measurement, rebound hammer test and corrosion evaluation. As a result of their application, reliable input data were obtained which allowed to accelerate the design preparation and the accomplishment of the reconstruction (Dimitar, 2003).

A bridge in Dallas County, Missouri (USA) was rehabilitated using carbon fiber reinforced polymer (CFRP) and steel reinforced polymer (SRP) laminates by the Missouri Department of Transportation (MoDOT) and the Center for Infrastructure Engineering Studies (CIES) at the University of Missouri-Rolla. An investigation was carried out in this bridge to provide installation criteria for FRP strengthening of civil structures. This investigation covered measurement of surface preparations, evaluation of bond properties by pullout tests, detection of fiber alignment, and detection of delaminations between concrete substrate and CFRP by NDT techniques, such as impulse-echo, ultrasonic, and microwave (Ekenel et al, 2004).

For all the cases mentioned, NDT techniques have proven to be very handy and to produce reliable results.

1.3 Use of NDT in Kenya

Since the 1920s, nondestructive testing has developed from a laboratory curiosity to an indispensable investigation tool. Visual examination is no longer the principal method for quality determination. Use of NDT is still an area yet to develop, for instance, as of 2006 much of the overall railway system has been neglected and is in need of repair. Inspection of bridges is performed twice a year, by visual examination; other more elaborate methods need to be incorporated. Today, there is no organization in Kenya which applies NDT techniques. One could argue that the transportation sector should be concerned. Indeed, the transportation infrastructure is a major part of the country's infrastructure which consumes billions of the country revenue. For this reason the present research is focused on the possible use of NDT techniques for assessment of the Kenyan concrete structures for maintenance purposes.

2.0 Methodology

The following techniques are applied in the research project:

2.1 Half-cell potential test

A half-cell potential measurement involves measuring the potential of an embedded reinforcing bar relative to a reference half-cell placed on the concrete surface (NDT Guidebook, Malhotra, 2004). The half-cell is a copper/copper sulphate cell. The concrete functions as an electrolyte and the risk of corrosion of the reinforcement in the immediate region of the test location can be related empirically to the measured potential difference. The potential measurements were performed according to Proceq 2009 Manual for Canin instrument. Half-cell potential values were plotted using the Canin Provista Software.

2.2 Carbonation test

Carbonation extend was measured physically by spraying a freshly exposed surface of the concrete with a 1% phenolphthalein solution (NDT Guidebook). The calcium hydroxide changes to pink on uncarbonated portion and remains uncoloured on the carbonated portion. The test determines the depth of carbonation in concrete.

2.3 Chloride test

The chloride content of concrete is used as an indicator of corrosion. A rotary percussion drill was used to collect a pulverized sample of concrete and a special acid extracts the chlorides. The amount of acid soluble chloride was determined directly by a chloride sensitive electrode connected to an electrometer. The test was performed according to the NDT James Instrument for Chloride, 2005.

3.0 Results, Analysis and Discussion

3.1 Introduction

Before carrying out the field tests it was deemed important to cast blocks to test the effect of the different field conditions on the measured potential. The block sizes were 0.5 m by 0.3 m by 0.4 m as shown in Figure 1. In the blocks shown, the cover depth, bar diameter and curing conditions of the blocks were varied as indicated in Table 2 for measurements to be carried out in different conditions. A total of 10 blocks were cast.

The blocks were tested at 14 and 28 days. Half-cell potential measurements were performed with the rod electrode and data analyzed using the Canin Provista software.

3.2 Block results

The obtained potential maps for the blocks at 14 and 28 days of testing are given in the Appendix. A summary of the measured potentials is presented in Table 3.

From the obtained measured potential values, the following observations were made:

1. More negative values were obtained with cover of 100 than that of 150 mm with a difference of 50 mV.
2. Similar values were obtained when the size of reinforcement was varied
3. More negative values were obtained when corroded bars were used by a magnitude of 50 mV
4. With the varied W/C ratio, the values obtained were the same
5. When the blocks were cured under water and under salty conditions the measured values indicated corrosion in the blocks. But when cured using polythene and when left in the open air, the measured values were in the same range as those of the other blocks.

Discussion

The measured potential values were in agreement with the given values given in Proceq manual as tabulated in Table 4.

It is observed that half-cell potential values for the cast blocks vary; this is due to a number of reasons:

1. Moisture: Moisture has a large effect on the measured potential leading to more negative values.
2. Concrete Cover Thickness: The potential that can be measured at the surface becomes more positive with increasing concrete cover. Variations in the concrete cover can cause deviations in the measurements. Very low concrete cover can lead to more negative potentials which would seem to indicate high levels of corrosion.
3. An increase in chloride ion concentration causes significant steel corrosion. This chloride-induced corrosion is associated with a significant shift of the corrosion potential towards more negative values and an increase in the severity of the steel corrosion.
4. Concrete quality has little effect on the measured potentials.

3.3 Field tests

Field test were conducted on two sites; the twin tanks sited along Maji road in Main campus and the proposed school of health sited opposite the administration block of main campus. The test results are discussed in the next sections.

3.3.1 Twin tanks

The tanks are presented in Figure 2.

The half-cell potential measurements were performed with the wheel electrode since the surface was large enough. The data was analyzed using Canin Provista software and the potential maps are presented in the appendix. After the half-cell measurements in the field, chloride was analyzed in the laboratory and the obtained values are summarized in Table 5. In the potentials maps, the locations of the drilled location for chloride contents analysis are indicated.

3.3.2 Proposed school of health

The proposed school of health is presented in Figure 3.

The slabs measures 6 m by 10 m. Three slabs and 8 columns were selected for testing. For the slabs wheel electrode was used whereas the rod electrode for the columns was used for potential measurement. The measurement results are potential maps and chloride profiles of the structures; they are presented in the appendix. A summary of the chloride content at different depth and test location is given in Table 6.

4.0 State of corrosion in the tested structures

For result interpretation, reference is made to the values given in ASTM C876. It should be noted that these are rough estimates:

ECSE ≥ -200 mV: probability of active corrosion is less than 10 percent

ECSE ≤ -350 mV: probability of active corrosion is greater than 90 percent

Half-cell potential measurements for the twin tanks were on average -100 indicating that the tanks are in a passive corrosion state. Nevertheless, chloride samples were collected to verify the presence of chloride in the concrete. From the analyzed chloride samples at the given depths, the chloride content was on average 0.016 expressed as a percentage by weight of concrete for all the drilled depths. This clearly indicates that there is no chloride external source in the environment; chloride contamination could have been the result of the use of additives in the concrete mix, such as retarders. The experimental results also show no carbonation activity.

The potential values for the proposed school of health were in the range 100 to -500 mV. Active steel corrosion is expected with potential values of -350 mV and below. For this reason, the slabs appeared to be in an active state of corrosion but the chloride content analysis and the carbonation check confirmed that the concrete was still passivated. The high values of the measured potential may be due to high moisture content in the concrete. The chloride content was below the threshold values for steel corrosion to be initiated; the average value was 0.015 similar to that of the tanks. Also the carbonation check indicated that there was no carbonation in the concrete. From the results, it is clear that chloride could have been present from the construction phase and not from an external source.

In the tested structures, neither carbonation nor chloride-induced corrosion was detected but from the background information, carbonation is expected in the inland regions of Kenya whereas chloride ingress is expected in the coastal region due to presence of sea water. To verify carbonation, a structure in Eldoret, Kapsoya Secondary School was tested for carbonation. From the available sources, the structure was built in 1987 but due to financial constraints the construction was stopped. The was a two-storey building and is presented in Figure 4.

From visual inspection, corrosion of the rebars was evident from the spalled concrete and leaching as seen in Figure 5. A hole was drilled through the beam shown to verify carbonation; the concrete cover was 18 mm and the cover was fully carbonated.

This building is just but one of the structures undergoing corrosion; there could be more. The experimental result is an indication of the presence of carbonation in the inland regions of Kenya.

5.0 Conclusion and Recommendations

From the analyzed results, the following conclusions were drawn:

1. Based on the obtained field data on corrosion, it is shown that there is no corrosion in the assessed concrete structures. However this conclusion cannot be assumed for all the Kenyan concrete structure in service, variations may exist.
2. The use of NDT techniques for assessment of corrosion in concrete is shown; the research demonstrates the feasibility of using the techniques in assessing the integrity of concrete structures in service. They offer handy tools in the inspection of concrete structures.

From the conclusions, the following recommendations were made:

1. As part of the conclusion, the assessed structures were corrosion free. However more structures exposed to similar environmental conditions should be assessed in order to validate the preliminary conclusion of this research that concrete damage due to chloride induced corrosion and carbonation is not a problem in this Kenyan region.
2. The Kenyan coastal region is definitely an area most likely to be affected by chloride induced corrosion.

For this fact, assessment of coastal structures is recommended.

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Table 1: Existing concrete structures and their age

Structure name	Year	Age (yrs)
Nyayo House	1982	29
Co-operative Bank Head quarters	1981	30
National Bank House	1976	35
Old NSSF Building	1973	38
Uchumi House	1973	38
International House	1971	40
Hilton Hotel	1969	42
Ministry of Works Building	1968	43
Office of the President	1967	44
Harambee House	1962	49
City Hall Clock Tower	1957	54
Norfork Hotel	1904	107
Sarova Stanley Hotel	1902	109

Table 2: Block specifications

Constant parameter	No. of Blocks	Block code name	Variable parameter
Diameter of reinforcement (Y8)	1	B1	Depth of reinforcement 100 & 150mm
Depth of reinforcement (120mm)	1	B2	Diameter of reinforcement Y8 & Y12
Depth and Diameter of reinforcement(cover of 100mm & Y8 bars)	2	B3corr	Bar condition; clean bar
		B3uncorr	Bar condition; Corroded bar
“	2	B40.5	W/C ratio 0.5
		B40.7	W/C ratio 0.7
“ But cured under different moisture content (cover of 100 mm and Y8 bars)	4	B5sat	Cured in clean water
		B5poly	Covered with polythene
		B5salt	Cured under salty water
		B5dry	Not cured at all

Table 3: A summary of the measured potential values for the blocks

Block Name	Description	Measured potentials		
		Parameter	Potential values (mV)	
			14-day	28-day
B1	Concrete cover depth varied	100 mm cover	-250 to -300	-200 to -300
		150 mm cover	-100 to -200	-150 to -300
B2	Bar size varied	Y8 bar	-100 to -200	-50 to -150
		Y12 bar	-100 to -200	-50 to -150
B3	Bar condition varied	Corroded bar	-150 to -250	-50 to -150
		Clean bar	-100 to -200	0 to -150
B4	Water cement ratio varied	0.5 W/C ratio	-200 to -300	-100 to -250
		0.7 W/C ratio	-200 to -300	-150 to -300
B5	Curing conditions varied	Cured under water	-400 to -500	-350 to -500
		Not cured	-150 to -300	-100 to -300
		Cured with salty water	-350 to -500	-350 to -500
		Cured using polythene	-200 to -300	-100 to -200

Table 4: Expected potential values as given in Proceq manual

Concrete state	Value in mV
Water saturated concrete without O2	-1000 to -900
Moist, chloride contaminated concrete	-600 to -400
Moist, chloride free concrete	-200 to +100
Moist, carbonated concrete	-400 to +100
Dry, carbonated concrete	0 to +200
Dry, non-carbonated concrete	0 to +200

Table 5: A summary of the chloride contents for the tanks

		Chloride content as % per weight of concrete	
Test location	Sample depth (mm)	Tank A	Tank B
I	10	0.014	0.016
	30	0.015	0.014
	65	0.017	0.016
II	10	0.016	0.014
	30	0.014	0.014
	65	0.016	0.015
III	10	0.016	0.017
	30	0.016	0.016
	65	0.017	0.017

Table 6: A summary of the chloride contents for the proposed school of health

	Chloride content as % per unit weight of concrete		
Sample depth (mm)	Slab A	Slab B	Slab C
10	0.010	0.015	0.017
40	0.011	0.016	0.015
70	0.015	0.015	0.015

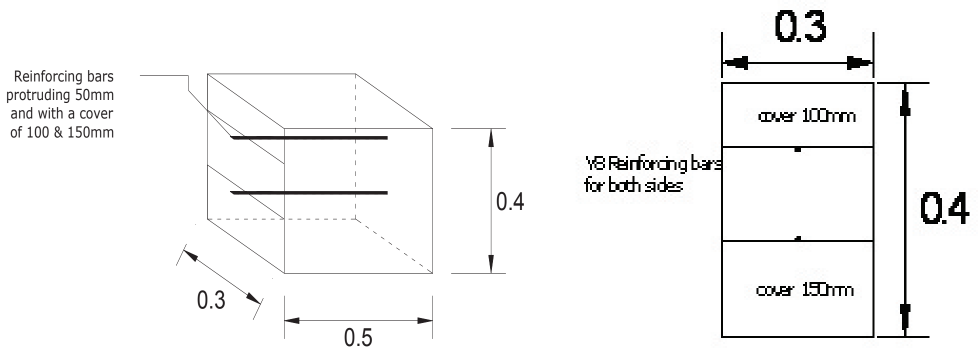


Figure 1: Block B1 specimen and the cross-section

Figure 2: Twin water tanks

Figure 3: Proposed school f health

Figure 4: Stalled construction at Kapsoya Secondary (Eldoret)

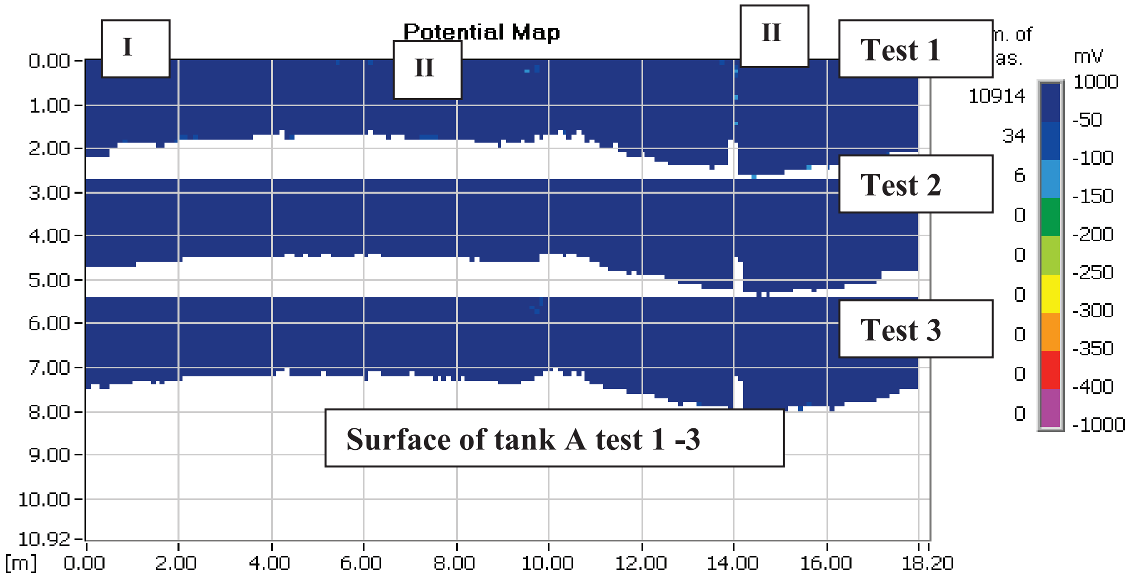
Figure 5: Rebar corrosion of stalled building at Kapsoya Secondary (Eldoret)

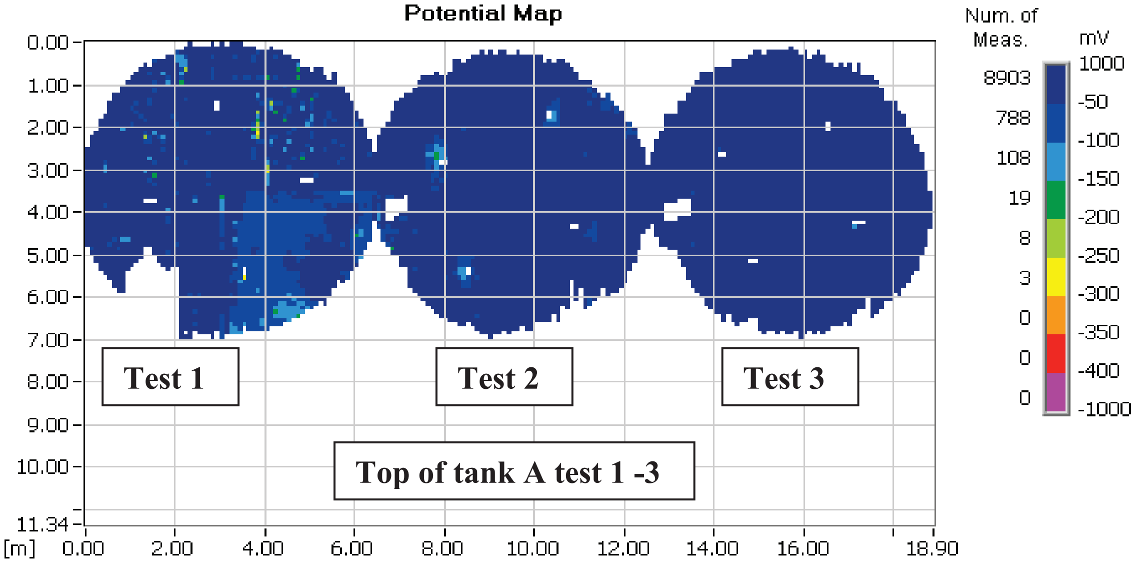
Appendix

Half-cell potential maps for field test

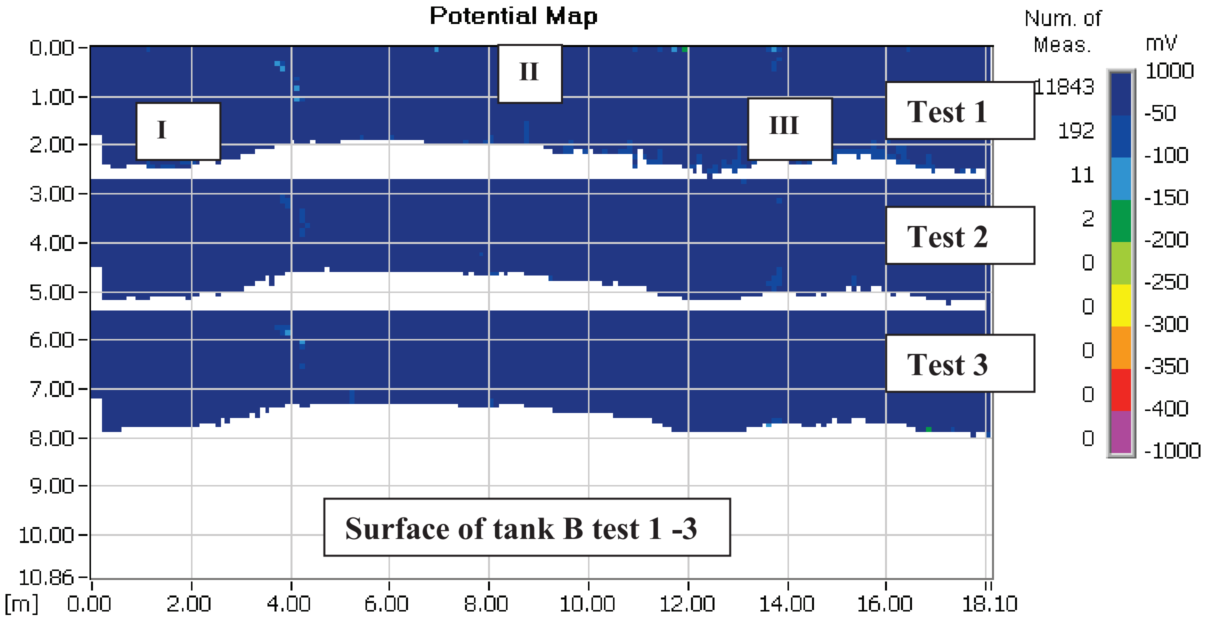
1. Twin water tanks

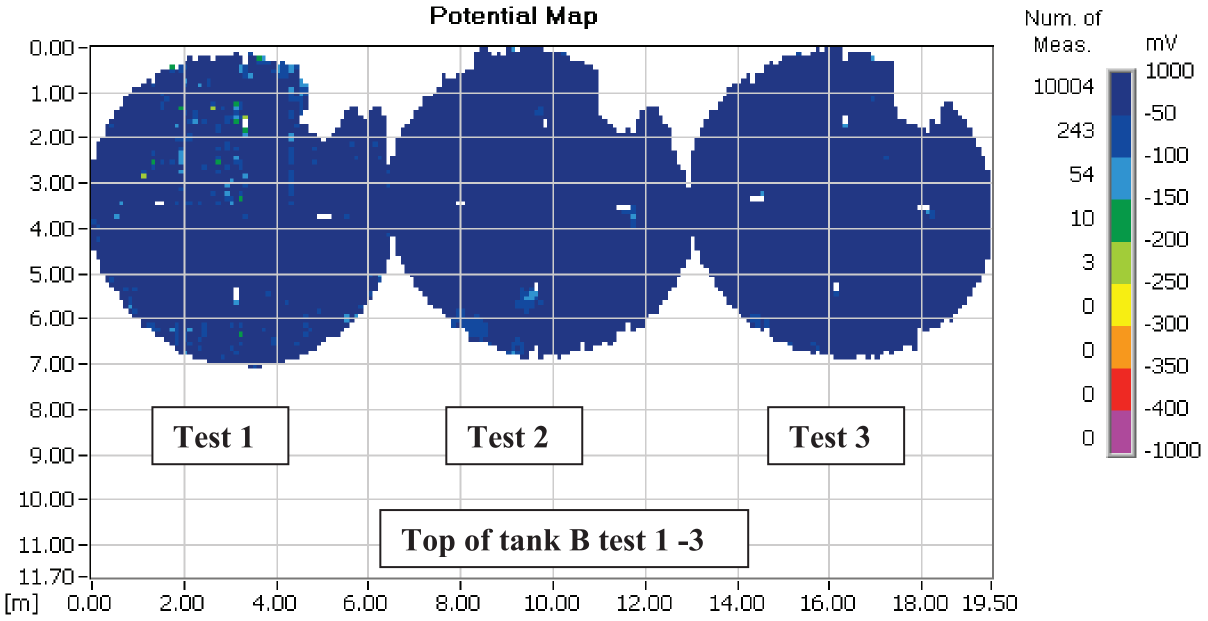
Tank A





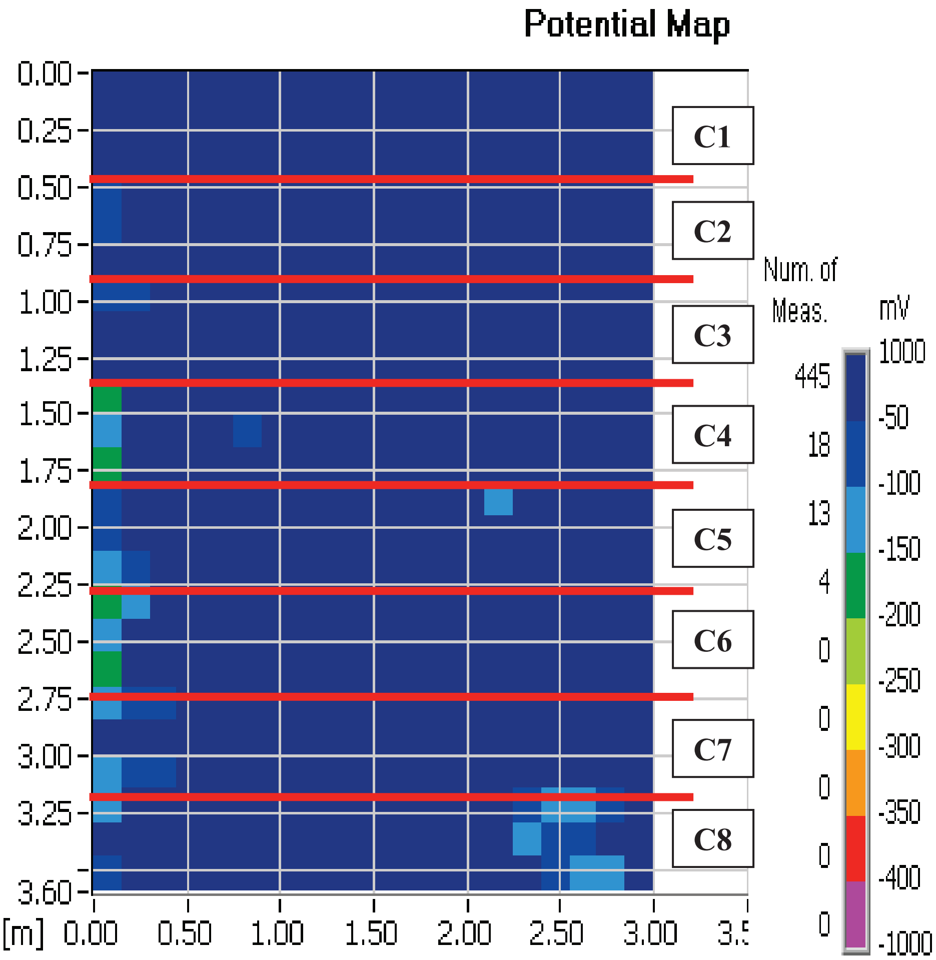
Tank B


Potential Map
Num. of Meas.
mV
I
II
III
Test 1
Test 2
Test 3
Surface of tank B test 1 -3
11843
192
11
2
0
0
0
0
0
1000
-50
-100
-150
-200
-250
-300
-350
-400
-1000
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
10.86
[m]
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.10

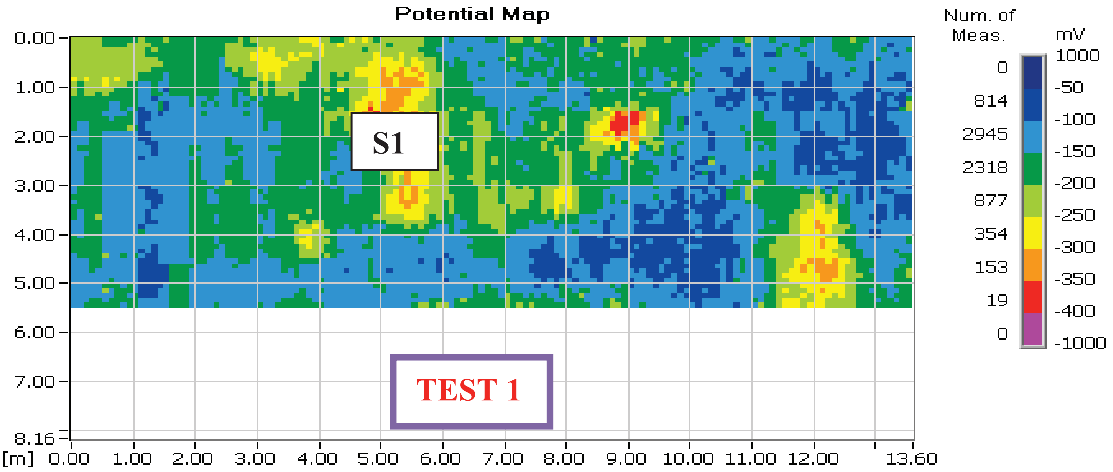

Potential Map
Num. of Meas.
mV
Test 1
Test 2
Test 3
Top of tank B test 1 -3
10004
243
54
10
3
0
0
0
0
1000
-50
-100
-150
-200
-250
-300
-350
-400
-1000
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
11.00
11.70
[m]
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
19.50

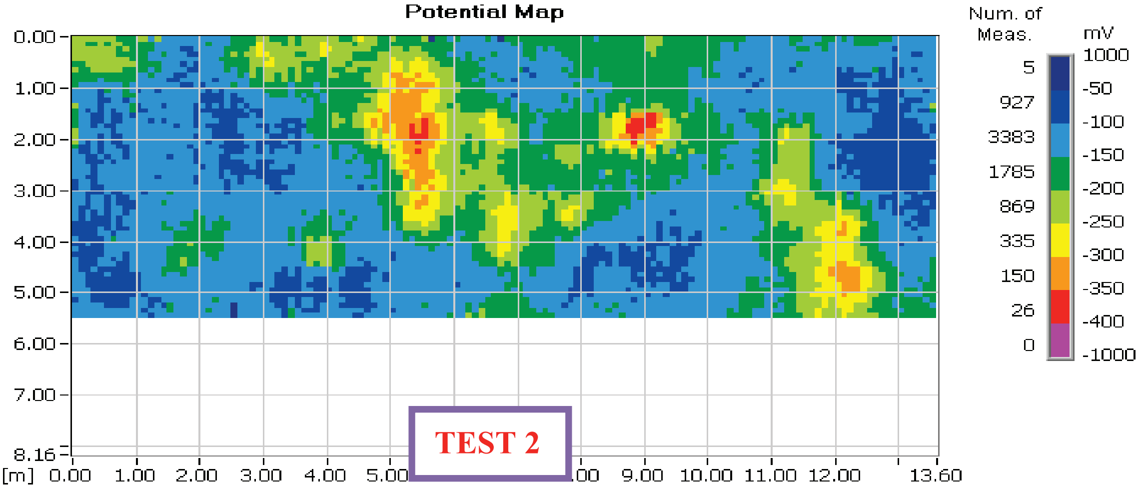
2. Proposed school of health

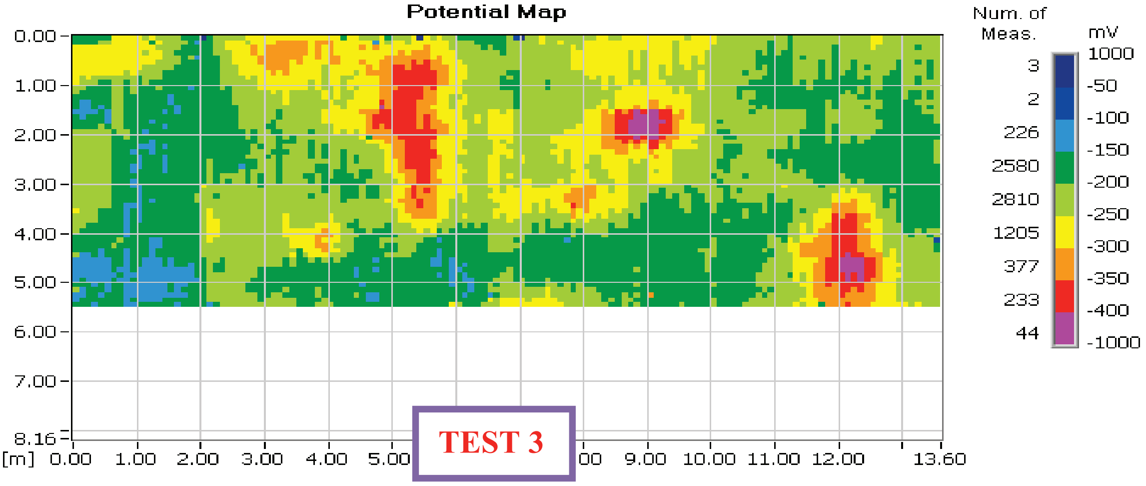
The figure below is a potential map for the eight tested columns C1 to C8



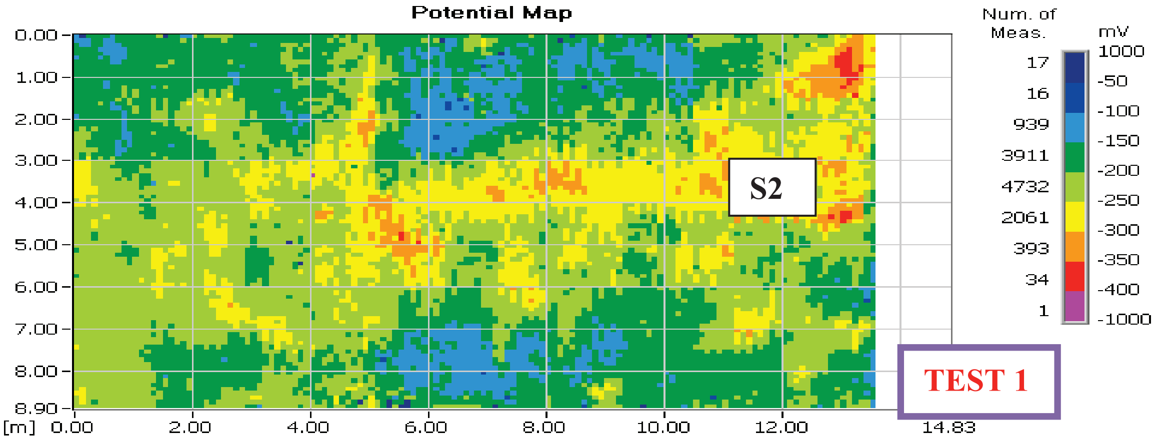
Slab 1

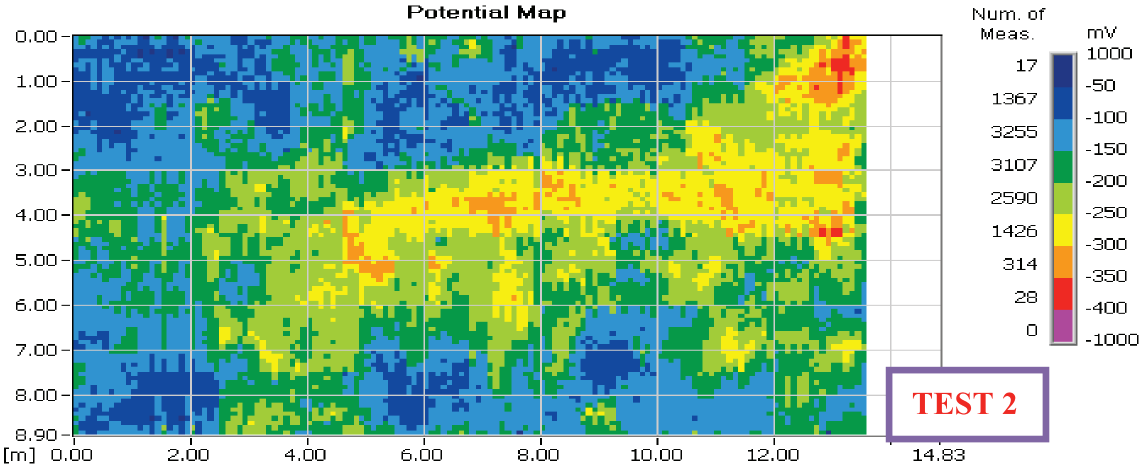

Potential Map
S1
TEST 1
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.16
[m] 0.00 1.00 2.00 3.00 4.00 5.00 6.00 7.00 8.00 9.00 10.00 11.00 12.00 13.60
Num. of Meas.
mV
1000
0
-50
814
-100
2945
-150
2318
-200
877
-250
354
-300
153
-350
19
-400
0
-1000

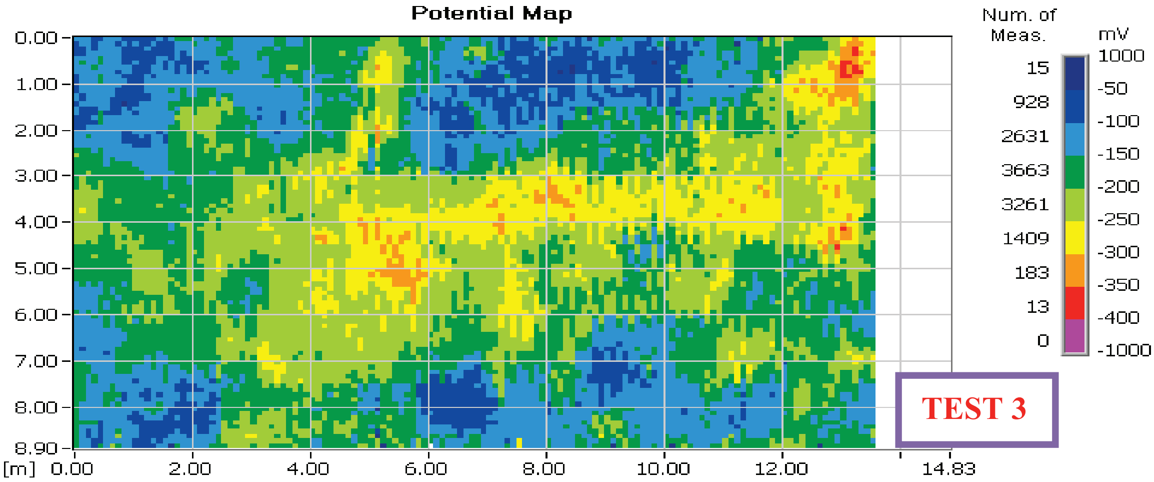

Potential Map
TEST 2
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.16
[m] 0.00 1.00 2.00 3.00 4.00 5.00 00 9.00 10.00 11.00 12.00 13.60
Num. of Meas.
mV
1000
5
-50
927
-100
3383
-150
1785
-200
869
-250
335
-300
150
-350
26
-400
0
-1000


Potential Map
TEST 3
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.16
[m] 0.00 1.00 2.00 3.00 4.00 5.00 00 9.00 10.00 11.00 12.00 13.60
Num. of Meas.
mV
1000
3
-50
2
-100
226
-150
2580
-200
2810
-250
1205
-300
377
-350
233
-400
44
-1000

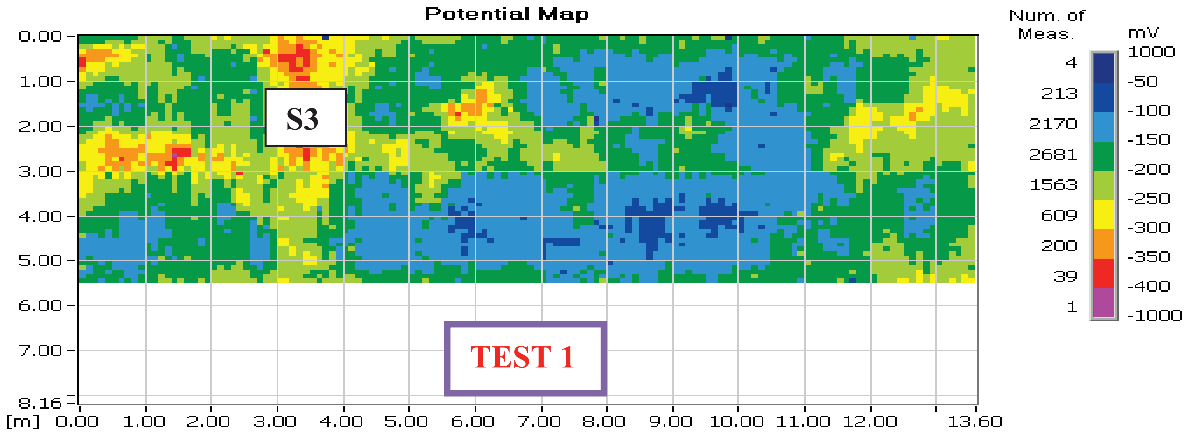
Slab 2

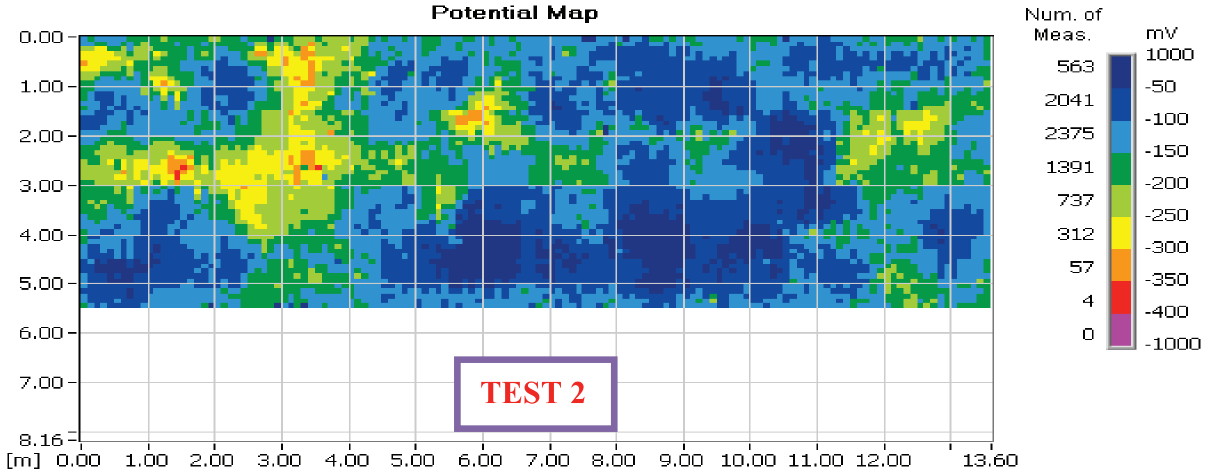

Potential Map
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
8.90
[m] 0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.83
S2
Num. of Meas.
17
16
939
3911
4732
2061
393
34
1
mV
1000
-50
-100
-150
-200
-250
-300
-350
-400
-1000
TEST 1

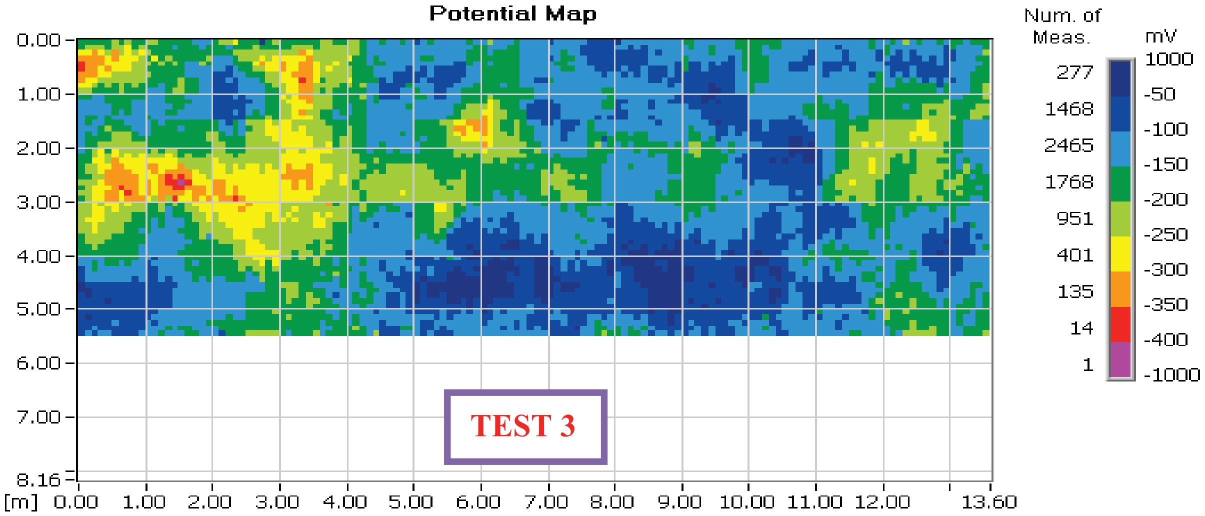

Potential Map
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
8.90
[m] 0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.83
Num. of Meas.
17
1367
3255
3107
2590
1426
314
28
0
mV
1000
-50
-100
-150
-200
-250
-300
-350
-400
-1000
TEST 2


Potential Map
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
8.90
[m] 0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.83
Num. of Meas.
15
928
2631
3663
3261
1409
183
13
0
mV
1000
-50
-100
-150
-200
-250
-300
-350
-400
-1000
TEST 3

Slab 3


Potential Map
S3
TEST 1
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.16
[m] 0.00 1.00 2.00 3.00 4.00 5.00 6.00 7.00 8.00 9.00 10.00 11.00 12.00 13.60
Num. of Meas.
4
213
2170
2681
1563
609
200
39
1
mV
1000
-50
-100
-150
-200
-250
-300
-350
-400
-1000


Potential Map
TEST 2
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.16
[m] 0.00 1.00 2.00 3.00 4.00 5.00 6.00 7.00 8.00 9.00 10.00 11.00 12.00 13.60
Num. of Meas.
563
2041
2375
1391
737
312
57
4
0
mV
1000
-50
-100
-150
-200
-250
-300
-350
-400
-1000


Potential Map
TEST 3
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.16
[m] 0.00 1.00 2.00 3.00 4.00 5.00 6.00 7.00 8.00 9.00 10.00 11.00 12.00 13.60
Num. of Meas.
277
1468
2465
1768
951
401
135
14
1
mV
1000
-50
-100
-150
-200
-250
-300
-350
-400
-1000