Assessing the quality of compaction of clay liner using electrical resistvity measurements

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ABSTRACT: The construction of landfill systems usually require the compaction quality control of placed landfill liner material. The conventional geotechnical methods used in such compaction verification are however invasive, laborious and time consuming. This study thus explores the possibility of using electrical resistivity measurements in assessing the quality of compacted clay liner material. A newly constructed cell at the Oti Landfill in Kumasi, Ghana was used for the study. Field electrical resistivity imaging, field geotechnical tests as well as laboratory testing of soil samples were performed. The electrical resistivity imaging was able to show the variation in electrical resistivity in the compacted liner material across the site. Variability in the field dry density and permeability of the compacted liner across the site was also established. Significant relationships were found between electrical resistivity values and the measured geotechnical properties. These relationships were notwithstanding found to be dependent on the moisture content.

Keywords: Clay liner; Electrical resistivity; Dry density; Permeability; Landfill

1. Introduction

The environmentally acceptable final disposal site for generated municipal solid waste (MSW) is the engineered sanitary landfills. This is because it isolates deposited waste from the environment, cheap to construct and has low operational and maintenance cost [1]. The deposited waste can at the same time pose potential problems to public health and the environment through the seepage of leachate into available groundwater resources.

One of the important ways of preventing leachates from these landfills from polluting the underlying groundwater is the use of liners at the base of the landfill. Though, there are geosynthetic materials which can be used alone as landfill liners or in combination with compacted clay to form a composite system providing a more resilient barrier to seepage, it is very expensive, and the technology is not readily available in developing countries like Ghana. Compacted clay liners are therefore mainly used because of the low cost and ease of placement.

To ensure that the placed and compacted clay liners perform its function effectively, the quality of compaction during placement of each lift need to be controlled and verified. This is mostly done by determining the dry density, permeability, and water content of the compacted clay liner and ascertain if it meets the nationally prescribed requirements or specification. Conventionally, the geotechnical methods used in such compaction verification are invasive, laborious and time consuming.

Electrical resistivity method, on the other hand, is non-invasive and can provide large-scale information on the variability of electrical resistivity of the compacted liner. The electrical resistvity results can then be used to infer the required geotechnical parameters. Nonetheless, a good understanding of how these geotechnical parameters affect the electrical resistivity responses is required to make such assessment.

This study therefore explores the possibility of using electrical resistivity measurements in assessing the quality of compacted clay liner in a landfill. A newly constructed cell at the Oti Landfill in Kumasi-Ghana was used for the study. The variability in the resistivity, dry density and permeability of the compacted liner across the site is assessed. The study further establishes the relationships between the geotechnical properties of the compacted clay liner and its apparent electrical resistivity.

2. Material and Methods

2.1. The study area

The Oti Landfill is situated on a 100-acre land at about 10 km from the business centre of Kumasi, the second biggest city in Ghana. It is one of the very few engineered landfills being operated in Ghana. Kumasi is a fast-growing city with a resultant increase in waste generation annually.

The landfill has features typical of a modern and engineered landfill including waste stabilization pond for liquid waste, solid waste receiving area, offices, weighbridge, gas recovery system, etc. The Landfill started operations in 2004 and receives diverse kinds of waste that covers industrial, commercial and domestic, among others. The anticipated life span for each phase of the solid waste receiving area – landfill constructed in phases — is 15 years and has a singular role of providing services to various transfer stations in the metropolis [2,3].

The solid waste receiving area was designed to be constructed in 3 phases. Phase 1 consisting of cells 1-4, Phase 2 consisting of cells 5-7 and Phase 3 consisting of cells 8 and 9 as shown in the Fig. 1.

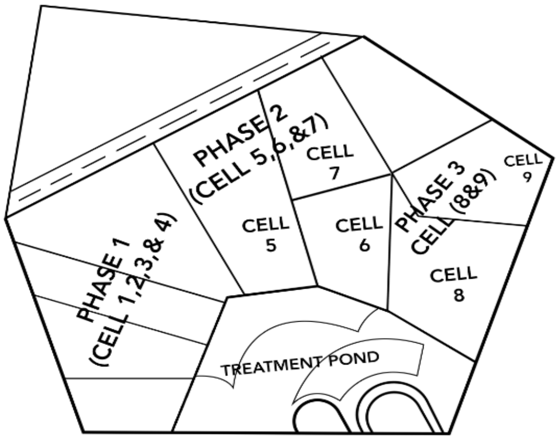

Figure 1. General layout showing construction phases of the Oti land-fill [4].

At the time of this research (February-March 2017), cells 1-4 had been used up and sealed with an impermeable cap, and cell 5 was still being used. Cells 6 and 7 were newly constructed and had not been in use. The construction of Cells 8 and 9 had not been completed although excavation and construction had begun. Cell 7 was considered for this research for ease of access from the major road within the facility. The cell has a clay liner compacted in four individual lifts of 150mm and covered with granitic chippings. It covers a total land area of 20,000 m^2. 11 gabion baskets or gas vents are installed for gas escape to reduce gas pressure build-up.

2.2. Field data acquisition

The field studies performed on the compacted clay liner of the selected cell 7 included electrical resistvity imaging, soil sampling and insitu geotechnical tests. Laboratory tests were also perfomed on retrieved soil samples to characterize them.

2.2.1. Electrical resistivity imaging

Four survey lines, each measuring 41.5 m and spaced at 25 m intervals, were established for the electrical resistivity measurements. The equipment used for the field resistivity measurements was the AGI super Sting R1/IP Resistivity equipment with 28 electrodes. The granitic chippings along the survey lines were removed to expose the liner for the insertion of the electrodes. The electrodes were spaced at 0.3 m to limit depth of investigation to the thickness of the placed clay liner.

Each spread with the 28 electrodes spanned 8.1 m ‚hence‘roll-along‘ technique was deployed to cover the total length of 41.5 m for each survey line. In conducting the electrical resistivity measurements, dipole-dipole configuration was used due to its high sensitivity to lateral variations in the sub-surface resistivity. Dipole-dipole also has the advantage of low EM coupling [5].

2.2.2. Soil Sampling and in-situ geotechnical tests

After field electrical resistivity measurements, the data was first processed to get a 2-D image showing the variation in resistivity of the subsurface measurements for each survey line. From the 2-D images, three points of an anomalously high or low resistivity on each of the 4 survey lines were selected. Both disturbed and undisturbed samples were then taken at these selected points, stored in polythene bags and transported to the laboratory for further testing. The samples were picked from the surface to a depth of 60 cm following the BS 1377:1990. At these same locations, field tests for permeability using the Guelph permeameter and field density tests following the BS 5930:1990 were performed.

2.3. Laboratory work

The disturbed soil samples taken from the field were characterized following the BS 1377-2:1990. The Particle Size distribution, Atterberg’s limits, Particle density, Linear Shrinkage and Moisture Content of the samples were determined. The compaction characteristics of the various soil samples using the Proctor method were determined following the BS 1377: Part 4: 1990. Other engineering properties such as the void ratio and field natural moisture content were also determined.

The undisturbed samples were used in the laboratory permeability determination. Falling head method was used for all the test samples due to the high proportion of fines in the soil samples and was performed according to BS 1377: Part 5: 1990.

3. Results and Discussions

3.1. Electrical resistivity imaging

The measured apparent resistivity data was processed and analysed using the Earth Imager 2D software. Generally, the resistivity values were found to have a minimal variation up to a depth of 0.6 m which represented the compacted clay liner. There were however some areas with very high and low resistivities which may be consdiered to be as a result of varying geotechnical properties. Few of these anomalous areas (very high, high and low resistvity) on each survey line up to a depth of 0.6m were identified and selected (encircled in black in Fig. 2) for further probing. Samples were then taken at a depth of 0.5m for laboratory testing, and the resistvity values at that depth was also extracted from the 2D image. Some very high resistvity values that were observed at depths below 0.6m in the images were later found to be locations of perforated PVC drainage pipes, a component of the leachate collection system, in the landfill.

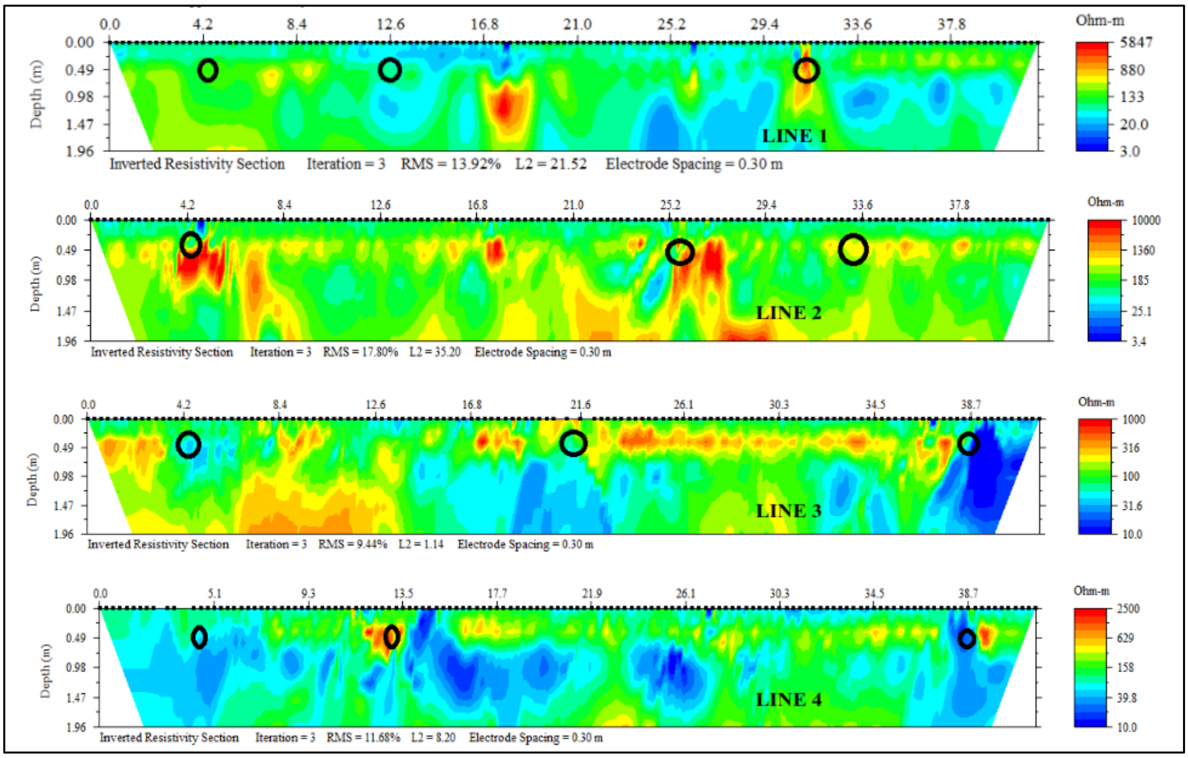

Figure 2. Inverted 2-D resistivity images for survey lines 1,2,3 and 4.

3.2. Characteristics of in-situ liner material

The results from the PSD showed that the liner material had a high proportion of fines i.e clay and silt and ranged from 54 % to 75 %. Clay content varied from 0 % to 2 % (Table 1) with silt accounting for the majority of the fines. The lack of clay sized particles accounts for the general low plasticity of the samples.

Table 1. Index properties of liner material

Sample Point	Field Moisture content (%)	Particle Density (Mg/m^3)	Atterberg Limits			Particle Size Distribution (%)			
			LL (%)	Plasticity Index (%)	Linear Shrinkage (%)	Gravel (%)	Sand (%)	Silt-Sized (%)	Clay-sized (%)
L1P1-4.2	17	2.58	38	14	7	8	37	52	2
L1P2-12.6	19	2.58	33	7	7	10	35	53	2
L1P3-31.7	26	2.54	39	13	6	4	36	59	1
L2P1-4.2	17	2.63	43	9	4	3	40	55	2
L2P2-25.2	19	2.51	37	8	4	5	40	53	1
L2P3-32.8	19	2.59	46	11	3	3	43	53	1
L3P1-4.2	22	2.55	38	10	3	1	24	74	1
L3P2-21.0	22	2.53	40	3	3	5	41	53	0
L3P3-37.8	22	2.56	41	9	4	3	40	56	1
L4P1-4.2	20	2.58	40	10	4	4	33	61	1
L4P2-13.2	24	2.59	40	6	4	1	43	55	0
L4P3-38.4	25	2.59	38	4	4	4	31	65	0

The PI for liner material varied from low to medium plasticity with the lowest PI of 3 and highest PI of 14. Linear shrinkage varied from 3 % to 7 % and particle density also varied from 2.51 Mg/m^3 – 2.63 Mg/m^3. From the field results given in Table 2, all the permeability results fell short of the EPA recommended value of 1.0 x 10^{-9} m/s for compacted clay liners. Nine (9) out of the 12 values still had a permeability of the same order of magnitude as the recommended permeability. The field densities obtained at each of the locations are also provided in the Table 2.

Table 2. Results of field tests on clay liner material

Sample Point	Bulk Density (Mg/m3)	Field Moisture Content (%)	Field Dry Density (Mg/m3)	Guelph Permeameter m/s	Apparent resistivity, ohm-m
L1P1-4.2	1.96	17	1.68	1.79E-09	82
L1P2-12.6	1.95	19	1.64	8.97E-09	53
L1P3-31.7	1.96	26	1.56	2.00E-08	89
L2P1-4.2	1.98	17	1.69	1.70E-09	118
L2P2-25.2	1.94	19	1.63	9.66E-09	66
L2P3-32.8	2.82	19	2.37	1.21E-09	241
L3P1-4.2	1.93	22	1.58	3.31E-09	84
L3P2-21.0	1.91	22	1.57	3.51E-09	80
L3P3-37.8	1.92	22	1.57	3.51E-09	68
L4P1-4.2	2.00	20	1.67	8.77E-09	107
L4P2-13.2	1.86	24	1.50	2.77E-08	71
L4P3-38.4	1.88	25	1.50	2.77E-08	71

3.3. Variation of Electrical Resistivity, Dry Density and Permeability of Compacted liner

The variation of the measured properties (electrical resistivity, dry density and permeability) of the compacted clay liner across the site was examined using contour plots as shown in Fig. 3, to give the general variation of these parameters at a depth of 0.5m. The contour plots is to give an indication of any likelihood of correlations between these parameters.

The apparent resistivity values across the site were found to be predominantly of low values but transitioned into higher values close to the middle section shown in the contour plot. The variation in the resistvity values observed in the contour might be an indication in variability of compaction quality with high resistivity representing well compacted areas and vice versa.

Generally, the variation in field dry density across the liner was minimal with low values at the top and bottom section and high values recorded close to the middle section of the contour plot. The contour variation of dry density is analogous to that of the resistivity plot indicating a posible positive relationship between the two parameters.

Field permeability on the other hand, displayed a contrasting image to the apparent resistivity and field dry density. Permeability had low values around the middle section and high values at the top and bottom sections. The overall outlook from the contour plots necessitated further analysis of data using scatter plotters to establish relationships and mathematical models between the measured parameters.

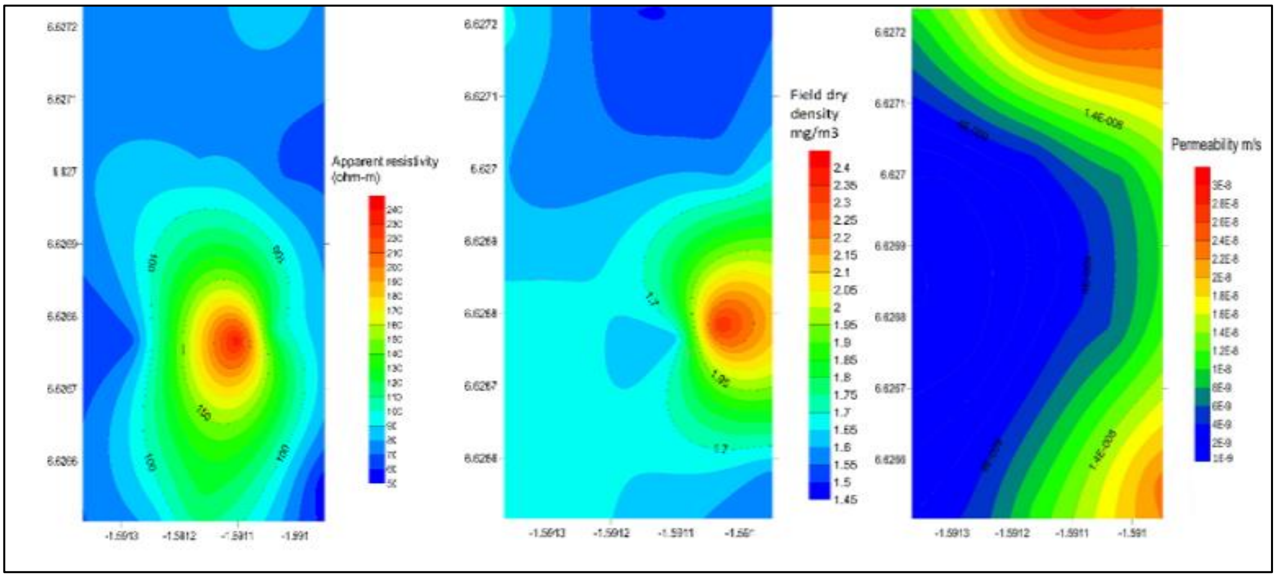

Figure 3. Contour plot of resistivity, field dry density and permeability across the site

3.4. Relationships between resistivity and geotechnical properties

The relationships between electrical resistvity and dry density as well as that of resistvity and permeability was explored using scatter plots of all available data. As shown in Fig. 4 & Fig. 5, the relationship between the parameters was poor yielding an R^2 of 0.3086 for the relationship between apparent resistivity and permeability and as low as 0.142 for that of apparent resistivity and dry density. The poor correlation may be as a result of not taking into consideration the effect of moisture content since they were not uniform. Moisture content is known to affect the electrical resistivity measurements and some geotechnical properties. The relationship between the parameters were therefore further explored by considering the effect of moisture.

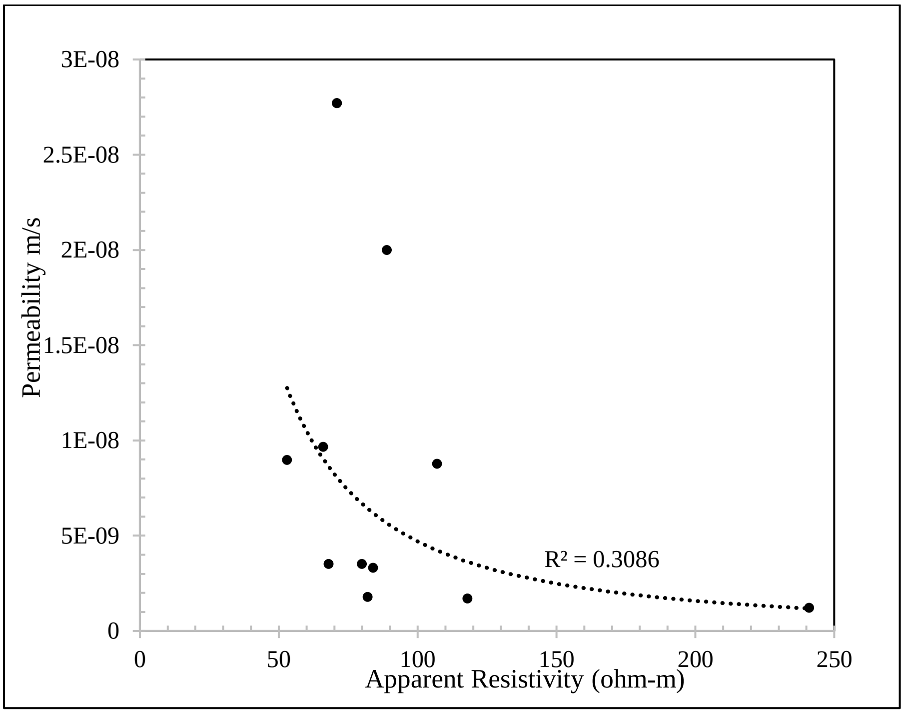

Figure 4. Relationship between apparent resistivity and permeability.

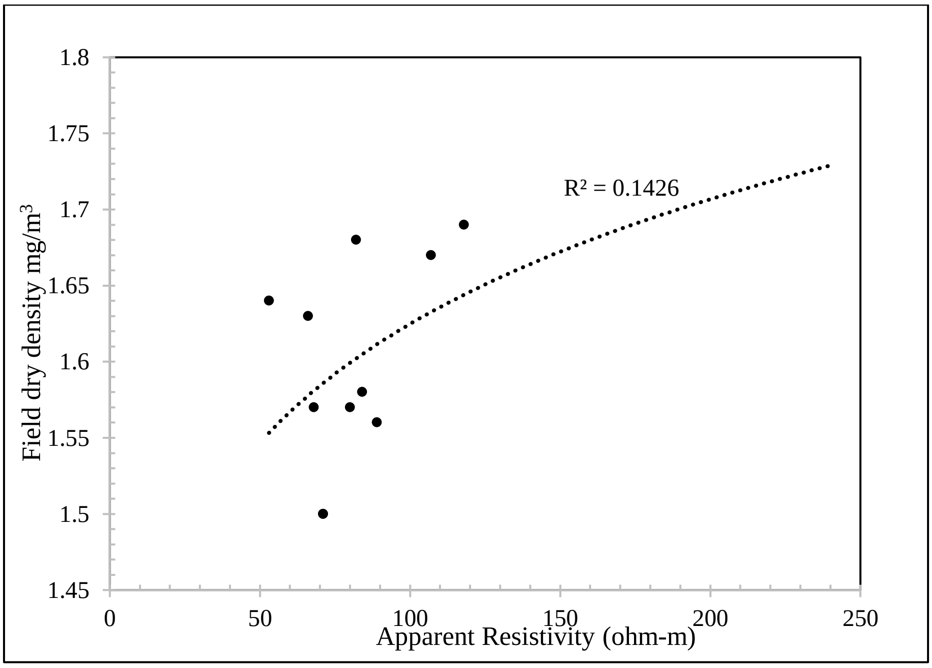

Figure 5. Relationship between apparent resistivity and field dry density

The available data was grouped into different moisture content ranges: 17%-19%, 20%-22% and 24%-26% based on the OMCs (16%-19%) obtained from the compaction tests on the samples. The moisture content group range of 17%-19% is termed as " at OMC", 20%-22% termed as " near OMC", and 24%-26% termed " further above the OMC".

When the effect of water content was considered by grouping the data to different ranges of field moisture contents (FMC), better correlations were obtained. It was observed generally that the samples with higher field moisture contents had lower dry densities and higher permeabilities. A power-law relationship was found to exist between the resistivity and the geotechnical properties. While resistivity had a positive relationship with dry density, it had an inverse relationship with permeability. The power-law relationships all had high correlation coefficients (Fig. 6 and Fig. 7), indicating that the model could explain much of the variation. It must be however noted that the data was very limited (2 points, for example, for the data futher above OMC) and therefore more data is requireed to appropriately establish the relationship. Notwithstanding the limited data, clear relationships are observed suggesting that the field moisture content significantly affect the obtained dry density values and the measured apparent resistivity. It will, therefore, be necessary to normalize the moisture contents to obtain an appreciable relationship between these properties.

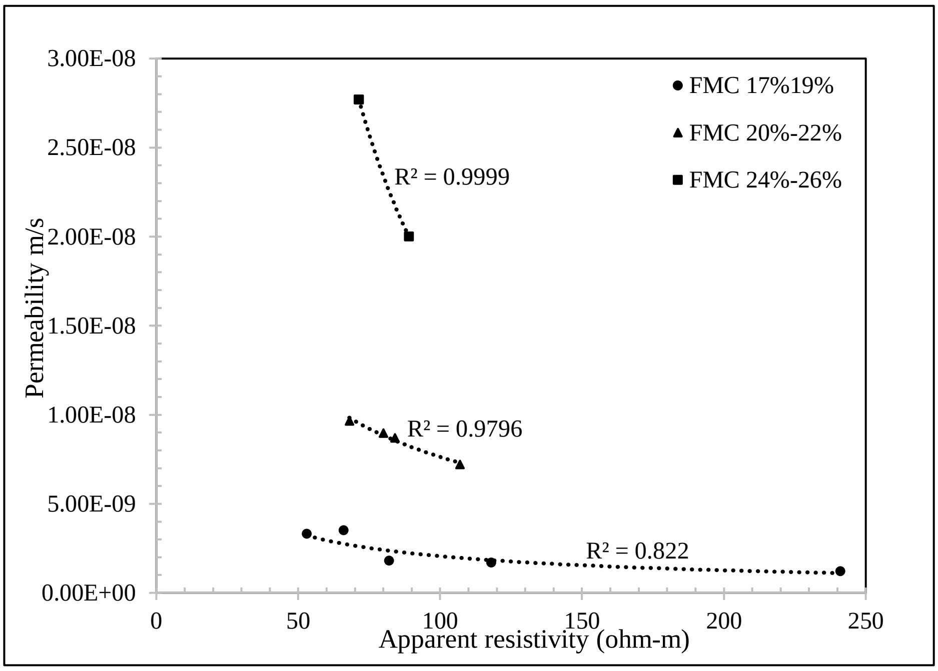

Figure 6. Field permeability vs apparent resistivity

The observed relationships gives an indication of the possibility of using electrical resistvity measurements in verifying the quality of compaction and estimating the permeability of compacted clay liners. The results however indicates that such relationships will have to be developed taking into consideration the moisture content. Another consideration will be to relate the moisture content in terms of degree of saturation and develop a relationship for it.

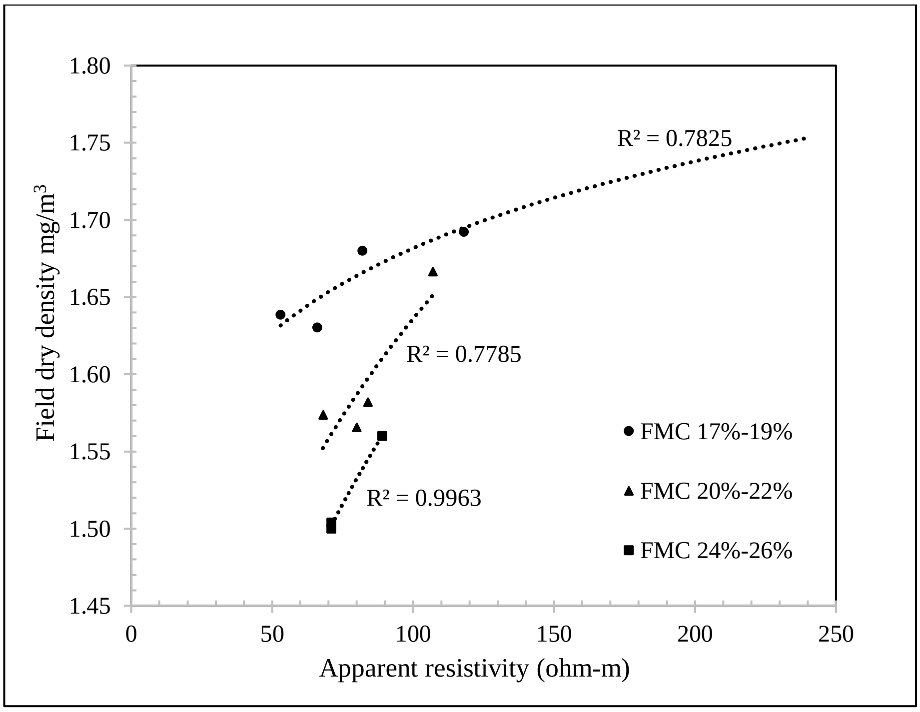

Figure 7. Field dry density vs apparent resistivity

4. Conclusions

This study explores the possibility of using electrical restivity measurement as a quality control tool in compaction of landfill clay liners. Contour plots of the resivitity data, and corresponding dry density and permeability data at depths of 0.5m gave an indication of possible relations between the electrical resistvity and the geotechnical properties studied.

The use of scatter plots also showed resistivity having a positive power law relationship with dry density and an inverse relationship with permeability. Significant relationships were also found between electrical resistivity values and the measured geotechnical properties. These relationships were however found to be dependent on the moisture content. More study will have to be conducted to establish reliable relations which can be used to estimate the dry density and permeability of compacted landfill clay liners from electrical resistvity measurements.

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