DETERMINATION OF SOIL MOISTURE CONTENT AND DENSITY USING ELECTRICAL RESISTIVITY VALUES

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DETERMINATION OF SOIL MOISTURE CONTENT AND DENSITY USING ELECTRICAL RESISTIVITY VALUES

by

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LIST OF SYMBOLS

A	Cross section area
A(n)	Sampling point an
a	Electrode spacing
B(n)	Sampling point bn
C	Coefficient factor
C(n)	Sampling point cn
C1	Current electrode 1
C2	Current electrode 2
cm	Centimeter
D_{10}	Maximum size of the smallest 10 percent of the sample
D_{30}	Maximum size of the smallest 30 percent of the sample
D_{60}	Maximum size of the smallest 30 percent of the sample
d	Particle size
e	Void ratio
ex	Exponential
f_s	Sleeve friction
Gs	Specific gravity
g	Gram
Hz	Hertz
hr	Hour
I	Current flow
K_v	Vertical hydraulic conductivity
k	Kilo
L	Length

ln	Natural logarithm
M	Mega
MP	Mackintosh value
MC	Moisture content
m	Meter
ml	Milliliter
mm	Millimeter
N	North
(N)	Standard penetration test value
na	Distance between a current electrode to nearest potential electrode
P	Compressional wave
P1	Potential electrode 1
P2	Potential electrode 2
R	Electrical resistance of object or sample
R^2	Coefficient of determination
R_f	Friction ratio
r	Correlation coefficient
S	Shear wave
Sr	Degree of saturation
s	Second
V	Potential difference across object
V_p	P-wave velocity
Vs	S-wave velocity
w	Water content and moisture content
ρ_a	Apparent resistivity

σ_a	Apparent bulk conductivities
ρ_{Bulk}	Bulk density
q_t	Cone resistance
$^\circ$	Degree
ρ_d	Dry density
ρ_w	Density of water
σ	Electrical conductivity
ρ	Electrical resistivity
∞	Infinity
$<$	Less than
α	Linearly proportional
$>$	More than
μ	Micron
μm	Micrometer
Ω	Ohm
%	Percentage
π	Pi
η	Porosity
θ	Volumetric water content

LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing Materials
BS	British Standard
CC	Coefficient of Curvature
CPT	Cone Penetration Test
CQA	Construction Quality Assurance
CST	Constant Separation Traversing
CWI	Chemical Weathering Index
DC	Direct Current
DCPT	Dynamic Cone Penetration Test
EC	Electrical Conductivity
EDG	Electrical Density Gauge
EDX	Energy Dispersive X-Ray Spectroscopy
EM	Electromagnetic
ER	Electrical Resistivity
ERCP	Electrical Resistivity Cone Probe
ERI	Electrical Resistivity Imaging
ERM	Electrical Resistivity Method
ERT	Electrical Resistivity Tomography
ERV	Electrical Resistivity Value
FVRP	Field Velocity Resistivity Probe
GPR	Ground Penetrating Radar
KED	Kriging with External Drift
LL	Liquid Limit

LME	Linear Mixed Effect Model
MEMS	Micro Electro Mechanical Systems
MI	Intermediate Plasticity
MIP	Mercury Porosimetry
MSW	Municipal Solid Waste
PAW	Plant Available Water
pH	Potential of Hydrogen
PI	Plasticity Index
PL	Plastic Limit
POSD	Pores-Size Distribution
PPT	Pressure Plate Test
PSD	Particle Size Distribution
RCPT	Resistivity Cone Penetrometer
RMSE	Root Mean Square Error
SAS	Signal Averaging System
SCPTù	Seismic Piezocone Test
SM	Silty SAND
SDMTà	Seismic Flat Dilatometer
SMP	Soil Minipenetrometer
SP	Poorly Graded SAND
SPI	Special Property Index
SPSS	Statistical Package for the Social Sciences
SPT	Standard Penetration Test
SR	Seismic Refraction
SRT	Seismic Refraction Tomography

SWC	Shallow Soil Water Content
SWM	Surface Wave Method
SWV	Soil Volume Wetness
TDR	Time Domain Reflectometry
UC	Coefficient of Uniformity
UKM	Universiti Kebangsaan Malaysia
USCS	Unified Soil Classification System
VES	Vertical Electrical Sounding
VLF	Very Low Frequency
XRF	X-Ray Fluorescence
XRD	X-Ray Diffractometry
1-D	One-Dimensional
2-D	Two-Dimensional
3-D	Three-Dimensional

PENENTUAN KANDUNGAN LEMBAPAN DAN KETUMPATAN TANAH MENGGUNAKAN NILAI KEBERINTANGAN ELEKTRIK

ABSTRAK

Ciri geoteknik merupakan elemen penting dalam kerja-kerja rekabentuk dan pembinaan kejuruteraan awam. Pada masa lalu, ciri geoteknik diperolehi menggunakan teknik penyiasatan tapak konvensional melalui penggerudian dan pengorekan. Kaedah tersebut mempunyai beberapa batasan dari segi kos, masa dan liputan data. Maka kajian ini mewujudkan penentuan ciri geoteknik asas (kandungan lembapan dan ketumpatan) menggunakan korelasi data geofizik terutamanya nilai keberintangan elektrik. Kajian ini dijalankan pada tanah pasir dan pasir berkelodak dengan tahap ketumpatan yang berbeza melalui ujikaji makmal, model fizikal lapangan dan lapangan. Sampel tanah diuji di dalam makmal untuk pencirian geoteknik dan ujian keberintangan kotak tanah masing-masing berpandukan BS 1377 (1990) dan AASHTO (T-288-91). Dua model fizikal lapangan homogen pasir dan pasir berkelodak diuji menggunakan keberintangan elektrik dan pengelasan tanah. Pengesahan keputusan dibuat melalui ujikaji lapangan di Kuala Kangsar (pasir) dan Lenggong (pasir berkelodak). Analisis data dibuat menggunakan kaedah statistik dan perisian keberintangan komersial iaitu Statistical Package for the Social Sciences (SPSS), Microsoft excel dan RES2DINV. Ujikaji makmal mendapati bahawa perkaitan antara nilai keberintangan elektrik tanah dengan kandungan lembapan dan ketumpatan adalah pada korelasi sederhana hingga sangat kuat (r = -0.405 – 0.949). Satu siri nilai keberintangan elektrik tanah telah dihasilkan, justeru membolehkan penentuan cirri asas geoteknik tanah menggunakan persamaan statistik yang dihasilkan. Ciri asas geoteknik lapangan terutamanya kandungan lembapan dan

ketumpatan boleh diperolehi menggunakan persamaan statistik dengan menggunakan faktor pekali (C) yang dihasilkan daripada ujikaji model fizikal lapangan. Didapati nilai keberintangan elektrik tanah adalah berbeza dalam keadaan longgar (L) dan tumpat (D) dengan pekali penentuan, R^2 kandungan lembapan dan ketumpatan diperolehi pada nilai 0.7530 – 0.9706 dan boleh digunakan untuk anggaran melalui penggunaan faktor pekali (C) menggunakan persamaan berikut: $MC_{(L)} = 591.61\rho^{-0.557}$, $MC_{(D)} = 723.64\rho^{-0.723}$ dan $\rho_{bulk(L)} = 5.3011\rho^{-0.193}$, $\rho_{bulk(D)} = 3.3351\rho^{-0.109}$ untuk pasir dan $MC_{(L)} = 186.81\rho^{-0.265}$, $MC_{(D)} = 259.01\rho^{-0.373}$, $\rho_{bulk(L)} = 0.376\ln(\rho) + 4.3043$ dan $\rho_{bulk(D)} = 4.591\rho^{-0.138}$ untuk pasir berkelodak. Pengesahan keputusan di Kuala Kangsar dan Lenggong mendapati bahawa teknik ini boleh diguna pakai dalam menentukan kandungan lembapan dan ketumpatan tanah lapangan yang efisyen kerana pantas, ekonomi, sebaran data yang luas serta bersifat lestari dengan alam sekitar.

DETERMINATION OF SOIL MOISTURE CONTENT AND DENSITY USING ELECTRICAL RESISTIVITY VALUES

ABSTRACT

Geotechnical properties are crucial element in design and construction of civil engineering projects. In the past, geotechnical properties were determined using conventional site investigation technique based on drilling and excavation method. The techniques experienced several limitations due to cost, time and data coverage. Hence, this study established basic geotechnical properties determination (moisture content and density) using correlation of geophysical data, particularly electrical resistivity values. This study was performed on SAND and Silty SAND soil with different degree of denseness via laboratory, miniature model and field testes. The soil samples were tested in laboratory for geotechnical characterization and soil box resistivity test according to BS 1377 (1990) and AASHTO (T-288-91) respectively. Two physical field models of homogeneous SAND and silty SAND were tested using electrical resistivity and geotechnical classification. Results validations were performed via field test at Kuala Kangsar (SAND) and Lenggong (Silty SAND) sites. Data analyses were performed using statistical method and commercialize resistivity software via Statistical Package for the Social Sciences (SPSS) software, Microsoft excel and RES2DINV software. Laboratory tests identified that relationship between soil electrical resistivity value with moisture content and density were moderate to very strong correlation (r = -0.405 – 0.949). A series of soil electrical resistivity value has been produced, thus allow determining moisture content and density of soil using statistical equation developed. Field basic geotechnical properties particularly on soil moisture content and density were able to determine using established statistical equation by applying coefficient factor (C) developed from miniature model test. It was apparent that the soil resistivity value was different under loose (L) and dense (D) conditions with moisture content (MC) and density (ρ_{bulk}) coefficient of determination, R^2 being established at 0.7530 – 0.9706 and applicable for prediction via applying coefficient factor (C) using the equation as follows: $MC_{(L)} = 591.61\rho^{-0.557}$, $MC_{(D)} = 723.64\rho^{-0.723}$ and $\rho_{bulk(L)} = 5.3011\rho^{-0.193}$, $\rho_{bulk(D)} = 3.3351\rho^{-0.109}$ for SAND and $MC_{(L)} = 186.81\rho^{-0.265}$, $MC_{(D)} = 259.01\rho^{-0.373}$, $\rho_{bulk(L)} = 0.376\ln(\rho) + 4.3043$ and $\rho_{bulk(D)} = 4.591\rho^{-0.138}$ for Silty SAND. Result verification at Kuala Kangsar and Lenggong sites found that this technique was applicable in determination of field moisture content and density efficiently due to fast, economic, large data coverage and sustainable to our environment.

CHAPTER 1

INTRODUCTION

1.0 Background of study

Geotechnical data is an important parameter used in design and construction, monitoring, maintenance and rehabilitation purposes during the pre and post construction or forensic investigation. Commonly, several processes were involved in order to obtain geotechnical data related to mapping, sampling and laboratory testing. In exploration stage, the objective and interest was typically related to subsurface profile characterization such as determination of layers, thickness, lithology, water table and SPT (N) value. According to Clayton et al. (1995), the foremost conventional geotechnical site investigation method for subsurface profile exploration is the application of boring (light percussion drilling, power augering and washboring), drilling (rotary drilling and coring), probing (Mackintosh probe, dynamic probing) and examination in-situ (trial pit, large bored shafts, tunnel and drifts). However, the effectiveness of the conventional method was dependent on several factors such as site topography and accessibility, total area of sites covered, time consumption and cost.

The solutions to these challenges require multidisciplinary research across the social and physical sciences and engineering (Fragaszy et al., 2011). Some of the alternative method from multidisciplinary field has increasingly adopted in geotechnical characterization due to its ability to enhance the efficiency of cost, time, data coverage and sustainability. Hence this study adopted 2-D resistivity method as an alternative tool for moisture content and density of soil geotechnical characterization. Resistivity method can effectively use in detection of cohesive and non-cohesive soils, saturated and unsaturated zone (Kowalczyk et al., 2014). Resistivity method also has good experienced in sol properties correlation such as moisture content, density and void ratio (Kalinski and Kelly, 1994).

Soil box resistivity (laboratory) and physical field model study of local soil was conducted to established systematically and provide a new soil correlation between geophysical and geotechnical parameter in order to determine basic geotechnical soil properties with particularly reference to soil moisture content and density with different degree of denseness. The result also tested on field measurement for validation.

1.1 Problem statements

Conventional site exploration using drilling technique and laboratory test for soil to perform good and reliable data suffer from several limitations due to cost, time, data coverage and sustainability. Classically, soil properties determination was determine based on geotechnical method which largely based on laboratory tests. Soil sampling using drilling method requires large number of drilling point for detail results, thus increased time, cost and consider non-sustainable to environment due to its destructive exploration technique. Nowadays, site exploration also being performed using alternative method via geophysical tools. Unfortunately, most of geophysical results presented its outcome in qualitative point of view thus unable to be used as a design and construction input. In the past, geophysical method was applied in site exploration for detection and mapping tools yet incapable to assist an engineers in term of design and construction input parameter quantitatively.

Conventional result of geophysical tools were presented by anomaly image with qualitative engineering point of view thus unable to extend its contribution from the perspective of meaningful geomaterials parameter used in design and construction. Hence, correlation between geotechnical and geophysical is needed to overcome the problems. This study performs moisture content and density correlated with resistivity data using resistivity method. The resistivity method performs with two stages (laboratory and physical field model) using soil box and ABEM SAS 4000 resistivity meter respectively. The result correlated with soil moisture content and density values to produce a reliable relation. The relation was validated on field site using 2-D resistivity test. The soil resistivity value related with moisture content and density are tabulated for future reference.

1.2 Research objectives

The research was conducted to fulfill the following objective of:

i) To characterize geotechnical properties of local soil using geotechnical test,

ii) To determine soil electrical resistivity value (ERV) and its relationship to moisture content and density under soil box resistivity (laboratory), physical field model and field test,

iii) To produce soil (moisture content and density) correlation against ERV,

iv) To validate correlation of soil box resistivity and physical field model at real site condition.

1.3 Scope of study

The study was performed using two types of soil namely SAND and Silty SAND through soil box resistivity, physical field model and field test. Soil sampling was performed using standard core cutter test. Soil test was focused on determination of basic physical properties of soil (grain size, moisture content, density, void ratio and porosity) using sieve test (dry and wet), Atterberg limit test, specific gravity test, moisture content and density test according to BS 1377 (1990). Data analysis was performed using statistical (Microsoft EXCEL and Statistical Package for the Social Sciences) and RES2DINV software. Variations of electrical resistivity values was focused from the perspective of basic physical properties of soil. Soil parameter was mainly focused on development of soil moisture content and density correlation relative to electrical resistivity value.

1.4 Significance and novelty of the study

The efficiency of soil characterization using electrical resistivity test (ER) can be increased by integration of the value with geotechnical method. The ER result offer several option in data coverage output from one dimensional (1-D), two dimensional (2-D) and three dimensional (3-D) perspectives.

ER test on soil mainly performed on site followed by laboratory test and integrate with moisture content and density of soil following proper and systematic study to produce correlation of ERV to soil properties. This study was performed by establishment of soil electrical resistivity value database under loose and dense condition. Coefficient factor, C was developed based on physical field model test under each condition. Finally, soil properties of moisture content and density were determined based on adoption of field electrical resistivity value and correlation with coefficient factor established using equation developed in laboratory (soil box resistivity). Natural condition of soil moisture content and density determination were performed using field test for validation. Soil properties with particular reference to moisture content and density were able to be determine quantitatively using electrical resistivity value thus contributing meaningful parameter input to the design and construction for engineering and environmental purposes. Furthermore, this research contribute to the knowledge extension due to the quantification of basic geotechnical properties with particular reference to soil moisture content and density under different denseness degree based on conventional qualitative resistivity anomaly outcome.

1.5 Layout of thesis

This thesis consists of five chapters which;

Chapter 1 describes the study background related to general field of research interest, present and missing knowledge of research and aim of present research. Problem statement, research objectives, significant and study novelty was presented in this chapter. Final section of this chapter is thesis layout which generally describes the whole thesis chapter and content.

Chapter 2 was divided into three sections namely introduction, previous works and chapter summary. The main content of this chapter presents previous researcher works particularly on soil using geotechnical, geophysical including integration of geophysical and geotechnical methods. Final section of this chapter concludes all stated previous researcher works and defines possibility of future research improvement.

Chapter 3 consists of materials and methods applied throughout this research. This chapter explains all materials, testing and data analysis adopted based on geotechnical and geophysical methods. Soil material using SAND and Silty SAND were explained under geotechnical classification tests as referred to BS 1377 (1990). Soil box resistivity (laboratory), physical field model and field test were explained particularly on its experimental procedure and limitations. Laboratory test for basic geotechnical and soil box resistivity test was conducted at Geotechnics Laboratory in Universiti Sains Malaysia (Engineering Campus). Physical field models was constructed and tested at Universiti Sains Malaysia (Engineering Campus) while field test was performed at Kuala Kangsar and Lenggong sites. Common resistivity array with particular reference to Wenner, Schlumberger, Dipole-dipole and Pole-dipole was used for physical field models and field test. Data analysis from geotechnical and geophysical tests was explained through the application of commercialize spreadsheet and software (Microsoft EXCEL, Statistical Package for the Social Sciences (SPSS) and RES2DINV).

Results and discussions was presented in Chapter 4 and divided into three subsections; soil box resistivity, physical field model and field. Soil box resistivity results analyzed using statistical analysis (SPSS and EXCEL) were discussed particularly on relationship between electrical resistivity value with soil moisture content and density, under different degree of denseness. Physical field models results were analyzed using RES2DINV and geotechnical soil classification results were discussed based on relationship between electrical resistivity value with soil moisture content and density, under different degree of denseness. Coefficient factor, C of physical field models were developed using statistical analysis thus contributing to the soil properties determination. Correlation factors developed were presented for all types of array performed (Wenner, Schlumberger, Dipole-dipole and Pole-dipole). Soil properties (moisture content and density) were determine based on the application of coefficient factor, C and correlation equation produced from soil box resistivity results (laboratory) under different degree of denseness. Finally, field results were discussed under natural condition with same process of physical field model for validation purpose.

Finally, Chapter 5 presenting a conclusion of the study including correlation of electrical resistivity value with moisture content and density, under loose and dense condition. Recommendations for future research are also discussed in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

Generally, this literature review presents and comment any related previous research works which associated with geotechnics, geophysics, and integration of geotechnics and geophysics which is related to soil. This chapter was divided into three sections namely introduction, previous works and chapter summary. The first sections of this chapter describe an overall content regarding this chapter. Second section of this chapter explains any previous works related to soil material and divided into three subsections according to method applied; geotechnical, geophysical, and integration methods. Final section of this chapter summarized all previous works stated on section two of this chapter thus contribute to research gaps and study novelty.

2.1 Previous works

This section presents related previous works on soil material based on geotechnical, geophysical and integrated methods. The previous works presented according to the method of studies.

2.1.1 Geotechnical method

Comparison of soil pore-size distribution performed by different methods has been studied by Wang et al. (2017) using mercury porosimetry (MIP) and pressure plate test (PPT). Soil sample was obtained from 1.8 – 2.5 m depth at the Intitute of Buffalo, Academy of Agriculture in community of Naning, Guangxi Province, China. It was found that average size of pores and pores-size distribution (POSD) obtained based on both methods shown some similarity results thus proved that those methods was applicable in determination of POSD in soil mechanics.

Determination of soil moisture content using infrared oven has been studied by So et al. (2016). The capability of soil moisture content using infrared heating has been evaluated with different soil specimen in Hong Kong. Based on two sets of results obtained, there are no differences between infrared and conventional oven method. Majority of soils tested may complete its drying process within 3.5 hours thus efficient in term of time, cost and sustainable for project progress due to its low energy consumption.

Ren et al. (2015) has studied about determination of optimum soil moisture content and maximum dry density based on soil confine compression modulus developed. The experiment was performed using clay, sand and loess soil obtained from Beilu river on the Qinghai-Tibet Plateau and Lanzhou, China. Optimum soil moisture content and maximum dry density were obtained from compression modulus peak value on the curve of force-compression modulus. It was found that the developed method obtained accurate optimum moisture content and maximum dry density for different soil types.

Soil moisture measurement studies have been reviewed by Lekshmi et al. (2014). Soil moisture content was performed via thermo gravimetric (oven drying), calcium carbide, neutron scattering, soil resistivity, dielectric technique, micro electro mechanical systems (MEMS) and nano-sensors. It was found that soil moisture content may be obtained from 28 seconds to 2 – 3 hours of measurement relative to the method used. The soil moisture content determinations were applicable to laboratory and field measurement. However, the methods may be complicated and expensive. Moreover, practicality and reliability of these methods to obtained soil moisture content with different characteristics is still being debated by researchers. It was found that the limitation of the techniques related to various soil conditions such as mineralogy, salinity, temperature, organic matter, matrix structure, etc) has not well being established.

Yalcin (2011) has studied on landslides in geotechnical perspectives. Soil samples were obtained from Trabzon province at the Eastern Black Sea region in Turkey. Geotechnical properties investigated were grain size distribution, plastic index, shear strength, unit weight, specific gravity, Atterberg limit, porosity, void ratio, moisture content and shear strength. It was found that liquid limit average values were between 49 % – 69 % while average plasticity index was varied from 9% – 19% within the landslide materials. As a result, high rain intensity may exceed soil boundary saturation thus critical for triggering the landslide. Laboratory test also revealed that soil tested composed of fine soils related to silts of high plasticity and silty or clayey fine sands of low plasticity. Previous landslides have revealed that 80 % of landslides occurred due to a very high and completely weathered material derived from volcanic and sedimentary bedrock. This study shows that the shear strength parameters decreased with increasing of moisture content, and landslides frequency increased in relation with particle size distribution of clay.

Strength and index properties determination of fine-grained soils using soil minipenetrometer (SMP) has been conducted by Stone and Kyambadde (2007). Clayey soil samples performed in this study was obtained from Bembridge, London, Reading and Wealden United Kingdom. Soil parameters obtained were undrained shear strength, plastic limit, liquid limit and moisture content. This method has improve conventional method due to its simple, quick, easily adjusted, portable and reliable.

Determination of sand relative density from cone penetration test (CPT) using fuzzy sets has been studied by Juang et al. (1996). The study was performed based on empirical correlations for relative density determination from CPT data for low, medium and high compressibility sands. Argument exists from common available correlation for relative density determination using CPT data. In the past, compressibility parameter has not well being defined and current knowledge on sand compressibility effect to CPT data was limited and qualitative. New approach that integrates correlation available for relative density determination using CPT data was developed based on compressibility measured by friction ratio and expressed as a fuzzy number. It was found the technique able to determine relative density reliably based on CPT data.

BS 1377 (1990) has developed standard method for determination of soil moisture content and density. The oven-drying method is the definitive procedure used in standard laboratory practice for soil moisture content. Soil moisture content was obtained using ratio between soils in wet mass to soil in dry mass. Three methods are specified for soil laboratory density determination. The first applies to soils that can be formed into a regular geometric shape, the volume of which can be calculated from linear measurements. Second method applies volume of the specimen determined by weighing it submerged in water and third method applies volume measured by displacement of water. For in-situ soil density measurement, five standard methods has been developed which four of five standards methods use the direct measurements of mass and volume (Sand replacement, water replacement and core cutter: the choice of which depends upon the type of material), and another one method using gamma rays (Nuclear).

2.1.2 Geophysical method

Lekea at al. (2016) has studied about application of an electrical density gauge for measuring in-situ density and moisture content. Soil densification based on compaction may determine desirable soil properties. Sandy soil tested was obtained from Cape Town. Previous practice of compaction control quality was based on sand cone and nuclear density gauge to measure field dry density and moisture content experienced limitation due to time consuming and health issue. Hence, safer method has been proposed using electrical density gauge (EDG). The EDG results, shows good repeatability according to comparison value tested. Moisture content values from EDG were consistent with conventional oven drying method. In contrast, dry density values of EDG were differed from the conventional sand cone method. The study has concluded that EDG can be used for moisture content determination while density properties need to be revised to increase its accuracy.

Seismic refraction tomography and electrical resistivity tomography integration for engineering soil characterization has been studied by Al-Heety and Shanshal (2015). Study objective is to map the subsurface profile for physical properties characterization of geomaterials (soil and rock) at Mosul University, Iraq. Spread line of seismic refraction and resistivity performed were twelve and ten respectively. Seismic data acquisition was based on twelve geophone of 10 Hz frequency while Wenner array with 3 m of equal electrode spacing (total spread line = 280 m) was used for resistivity data acquisition setting. Data processing of seismic refraction and resistivity was performed using SeisImager/2D and RES2DINV software respectively. Seismic results show three layers case with superficial deposits (340 – 700 m/s), river deposits (840 – 1700 m/s) and marl layers (1900 – 2800 m/s). Resistivity results identified two main zones due to weathered layer; 80 – 320 Ωm from 1– 25 m and clays (1 – 80 Ωm). The study shows that integration of geophysical method is applicable for subsurface characterization thus contributing for engineering design and construction purposes.

Soil water content estimation based on geophysical sensing has been studied by Cafarelli et al. (2015). The study was performed using linear mixed effect model (LME) and kriging with external drift (KED) method. The study objective is to estimate shallow soil water content (SWC) using comparison of LME and KED methods based on geophysical sensing. Study area was performed at south-eastern of Italy using two frequency of ground penetrating radar (600 and 1600 MHz). It was found that LME and KED shows almost similar behaviour. A soil property was able to be estimate using both methods using geophysical data non-destructively.

Assessing complex soil using electrical resistivity has been studied by Kowalczyk et al. (2014). Suitable evaluation of soil variations and hydrogeological characteristics is vital in recognizing composition of soil. This study was performed to detect and characterize peat soil under clay layer at Zwierzyniec, Poland. Electrical resistivity measurement was performed with resistivity cone penetrometer (RCPT) and electrical resistivity tomography (ERT) using ABEM system with Schlumberger protocol (1 – 3 m of electrode spacing). Electrical resistivity data was processed using RES2DINV for result and interpretation. It was found that thin peat (45 Ωm) layer was detected at 4 m depth. RCPT results has verified peat layer at 4 m depth based on results of cone resistance (q_t = 2.5 MPa), friction ratio (R_f = 4.4 %), sleeve friction (f_s = 0.075 MPa) and apparent resistivity (ρ_a = 38 Ωm). ERT has successfully differentiate peat layer beneath clays despite poor peat geometry layer which influenced by sands within the peat occurrences. As a conclusion, RCPT result was recommended for supporting ERT interpretation.

The application of electrical resistivity to monitor soil volume wetness (SWV) of heterogeneous soil was studied by Brillante et al. (2014). This study was performed using Electrical Resistivity Tomography (ERT) at the hillslope of Corton Hill, Burgundy (France). Electrical resistivity and SWV relationships were evaluated with 160 ERT and calibrated using field Time domain reflectometry (TDR) surveys. Statistical prediction function for SVW was proposed based on coefficient of determination, R^2 with value of 0.67 – 0.82. Hence, prediction function proposed may applicable for similar soil types in predicting of soil moisture by ERT. Developing prediction functions using electrical resistivity may contribute to the ease of soil moisture content determination efficiently to cost, time and large data coverage.

Geophysical survey assessment to estimate riverbed hydraulic conductivity was studied by Wojnar et al. (2013). The study was performed to obtain an effectiveness of geophysical method in investigating riverbed vertical hydraulic conductivity (K_v) at four study sites in Great Miami River. Study site consist of varied riverbed sediment from cobbles to clays. Riverbed estimation was performed using conventional seepage meter, slug tests and heat, and water flow modelling between river and aquifer. The K_v results estimated from the tests were compared to stratigraphic profile using resistivity, seismic and electromagnetic for assessing its efficiency in predicting K_v value. It was found that the K_v values from seepage meters (upper 0.3 m of riverbed) and slug tests (0.45 – 11.2 m depth) were 0.11 – 5.3

m/d and 0.0284 – 9.46 m/d respectively. Moreover, groundwater flow and heat transport modelling provide excellent K_v value (0.015 – 14.9 m/d) estimation in large areas and long duration. Comparison of K_v from conventional method with stratigraphic profiling of resistivity surveys was performed at three study site, despite total of four site studied. It was found that site four shows some inconsistency results because of the existing of clogging between coarse sediment and fine sediment. The study has demonstrated that geophysical method was not suitable to being applied solely in assessing reliable properties of riverbeds, K_v value. Integration of geophysical and hydrogeological techniques was recommended to correlate the resistivity data with hydraulic conductivity.

Kinzli et al. (2012) has studied for laboratory and field calibration comparison of a soil-moisture capacitance probe for various soils. The study was performed using Decagon EC-20 soil moisture sensor together with the development of unique laboratory calibration method. Six types of soil (sand, sandy loam, loam, silt loam, clay and clay loam) from Middle Rio Grande Valley, United States of America has been developed for field and laboratory calibration equations. Field volumetric water content average absolute error for field calibration and laboratory calibration were identified with value of 0.430 and 0.012 respectively. Average absolute error for factory calibrated equation of EC-20 was evaluated as 0.049. As conclusion, the EC-20 is effective (cost), reliable (accurate) and laboratory calibration method also was recommended to be conducted for high accuracy results. EC-20 soil moisture sensor field calibration was recommended to be eliminated due to its time consuming, small moisture content data coverage, destructive to site tested and large error derived from organic residues, voids and density of roots.

Soil electrical resistivity method for chemical properties determination was studied by Murad (2012) for construction and agriculture purpose. Soil sample was taken from different area and tested at laboratory using Fluke 8846A precision digital multimeter. Results for resistivity was varied at 0.05 MΩm – 0.95 MΩm m due to the variation of soil physical (Gravel = 5 – 25 %, sand = 31 – 60 %, silt and clay = 15 – 64 %) and chemical (pH = 3.55 – 5.92) properties. Electrical resistivity was applicable for fast soil properties assessment, low cost and non-destructive.

In-situ soil density evaluation using laboratory resistivity method was studied by Lundberg et al. (2012) to evaluate the prospect of multi-frequency resistivity test for in-situ condition. Resistivity electrode probing was used to measure sand volumetric properties in a controlled laboratory test container. Testing results founds that soil density change was obviously define between 50 Hz and 100 kHz, which shown the different of sand void ratio; 0.75 and 0.6 is close to 250 Ω. It was found that resistivity test at multiple frequencies was successfully measured the soil density change of saturated sand. Recommended in-situ test for measurement frequency spectrum is 0.1 Hz – 100 kHz. Electrical resistivity measurements has good prospect for in-situ soil properties measurements with low cost.

Soil moisture content and unit weight of clayey soil determination using resistivity imaging has been studied by Kibria et al. (2012) to shows relationship and correlation between electrical resistivity and geotechnical properties of clayey soil. Soil samples were obtained from borehole at Midlothian, Ellis Country (Texas). Sieve, Atterberg limit tests were performed for soil classification based on unified soil classification system (USCS). A laboratory soil resistivity test was performed using Super sting IP instruments based on AASHTO T288-9. Results show that soil resistivity decreased significantly with moisture content of 20 % of all soil samples tested. Average reduction of soil resistivity was 13.8 Ωm for the 10 – 20 % moisture content increased. Soil resistivity result shows constant value after 40 % of moisture content. At 50 % of soil moisture content, resistivity value was varied from 2.1 – 2.4 Ωm. Dry state of soil resistivity measurement also conducted to observe the influence of clay minerals despite of the moisture absence. However, dry stated results founds that the resistivity reading was unable to be obtained due to failure of the current flow in soil medium, thus indicate that soil act as a dielectric materials due to the moisture absence. Statistical equation for resistivity against moisture content founds that the best-fitted curves was based on power function (regression type) resulting coefficient of determination, R^2 value of 0.8146-0.9562 ($y = 306.65x^{-1.331}$; $y = 119.26x^{-1.094}$; $y = 328.03x^{-1.351}$ and $y = 247.03x^{-1.224}$). Soil resistivity value was decreased with the increment of soil unit weight. Significant decrease of soil resistivity occurred at 1.91 Ωm between moist unit weight of 13.92 – 15.72 kN/m^3 at 18 % of moisture content. Further increase of moist unit weight in 18 % moisture content shows decreased in soil resistivity value at 0.51 Ωm. Statistical equation for resistivity against moist unit weight founds that the best-fitted curves was based on polynomial regression type resulting coefficient of determination, R^2 value of 0.9539 – 0.999 ($y = -0.4719x + 10.755$; $y = 0.4756x^2 - 16.31x + 145.36$; $y = 0.1957x^2 - 7.0823x + 67.47$ and $y = 0.7107x^2 - 24.541x + 217.98$). The study has demonstrated that electrical resistivity imaging (ERI) was applicable to determine soil moisture content based on correlation of resistivity value and geotechnical properties.

Chik and Islam (2012) studied soil particle size using electrical resistivity for site investigations to obtain consistent measurements of soil types using electrical properties in Earth. Different soil samples were tested using resistivity and sieve test. Soil resistivity was performed at construction site in Universiti Kebangsaan Malaysia

(UKM) using portable digital multimeter with test voltage and measuring resistance range of 500 V and 0-200 MΩm. Sieve test with different soil type was performed according to ASTM D-422 at geotechnical laboratory in UKM. Results shows that resistivity value for tested soils was 0.41 MΩm (sample A), 0.67 MΩm (sample B) and 0.89 MΩm (sample C) which due to variations of particle size distribution. It was found that higher coarse grain particle (gravel and sand) obtained high resistivity value (sample C) while higher fine particle (clay and silt) obtained low resistivity value (sample A). Electrical resistivity technique was able to identify different types of soil particle thus offer good prospect in geotechnical site investigation due to low cost, fast, large data and sustainable.

An estimation of soft soil void ratio has studied by Kim et al. (2011) using electrical resistivity cone probe (ERCP) and to demonstrate the applicability of ERCP device in obtaining seashore soft soils resistivity. Measurement of resistivity was conducted on consolidation test, penetration tests and field sites at Incheon and Busan (Korea). ERCP has obtained nearly similar void ratio results from consolidation tests. ERCP void ratio results also agrees well with void ratio of sand-clay soil tested in calibration chamber. Field estimated void ratio is inversely proportional to standard penetration test (N) and cone penetration test. ERCP was applicable for seashore soft soil void ratio estimation. Moreover, thin layers of sand and silt seams in clay layer was able to be detected using ERCP.

Geotechnical investigation of Madhupur clays using 2-D electrical resistivity imaging (ERI) at Jahangirnagar University Campus, Dhaka, (Bangladesh) has been conducted by Kabir et al. (2011) using ERI and basic geotechnical tests. ERI was conducted using IGIS DDR3 DC resistivity meter with field configuration of 50 – 200 mV, Wenner (array) and 25 numbers of electrodes with 1 m constant spacing.

ERI was processed using RES2DINV commercialized software based on smoothness constrained least-squares analysis. Soil samples located inline of the ERI was obtained using boreholes and tested for geotechnical laboratory classification tests (unit weight, water content, grain size, plastic limit, liquid limit and Atterberg limit). ERI was applicable to distinguish Madhupur clay composition by showing resistivity value of 5 – 20 Ωm (silty clay) and 15 – 45 Ωm (sandy clay). The fluctuations of resistivity values is due to lithology complexity and moisture content variations which being verified using borehole data. Soil properties such as moisture content produce significant correlation with resistivity value.

The application of seismic compressional and shear waves velocity for shallow sediments porosity has been studied by Uyanık (2011), to establish relationship of soil porosity and seismic velocity for water saturated sediments analytically. Soil sampling and seismic refraction survey was conducted at selected areas in Turkey consists of water saturated clayey-silty, sandy and gravelly soils. The analytical shows that zero porosity value when Poisson's ratio is 0.5 due to saturation of water. Porosity increases if reduction of water saturation and Poisson's ratio value are lower than 0.5 while porosity decreased when shear modulus increases. However in loose soil, porosity decreased logarithmically when shear modulus is small. During high shear modulus, porosity decrease linearly in dense soil.

A research on compacted soil tomography analysis based on electrical conductivity was conducted by Chik and Islam (2011). Soil resistivity, moisture content and angle of repose were determined via electrical conductivity using precision digital multimeter with microcontroller and MATLAB for data acquisition and processing. Soil sampling and laboratory test were conducted at Universiti Kebangsaan Malaysia, Bangi (Selangor) producing correlation graph of water content, soil resistivity and soil dry density which able to estimate compaction properties of soil indirectly. The application of electrical conductivity to estimate soil compaction was applicable to assist conventional soil compaction determination in roads, damn, embankment and many engineering works due to its good accuracy, fast and low cost.

Geotechnical site classification at Islamabad, Pakistan was studied using geophysical tool (Ali and Gul, 2011). The study was performed based on field test and lab test using super sting resistivity meter and Nilsson 400 soil resistance meter respectively. Soil parameters investigated were related to moisture content, void ratio, friction angle and cohesion. Field and lab resistivity tests (undisturbed soil) was analysed using Earth Imager Software and established soil box formula. Field resistivity results revealed that study area composed of silty sand, clay and silt soil with low plasticity. Lab resistivity results indicate that resistivity increase with bulk and dry density and decreasing soil moisture content. Resistivity of soil also increases with void ratio reduction due to high or dense soil. Friction angle of soil also influence soil resistivity by showing increasing of resistivity value with the increasing soil friction angle. Soil cohesion increment shows the increment of resistivity value due to the presence of moisture or conductive soil. Laboratory soil classification was performed to validate the lab resistivity result interpreted. Finally, field resistivity results at one particular point were compared with lab resistivity results that found to be almost similar. The study revealed that field resistivity may contribute to the ease of subsurface soil properties determination in large data coverage while correlation of laboratory with soil properties shows some understanding of resistivity variations due to soil behaviour, thus useful in site classification.

Near surface soil parameter assessment using seismic refraction method was performed by Almaliki et al. (2011) at King Abdulaziz City for Science and Technology, Riyadh (Saudi Arabia) based on eight spread line to determine compressional (P) and shear (S) waves velocity for construction purposes. Geotechnical properties namely stress ratio, Possion's ratio, material index, concentration index, N-value and bearing capacity of foundation was computed based on seismic velocity identified from the study. For validation purposes, seismic results shows some good agreement with the existing site investigation report as compared to its layers, thickness, lithlogical description and N-value. The study shows that the integration of the geophysical studies was applicable in assisting site characterization.

Instrument performance comparison of soil moisture determination was studied by Francesca et al. (2010) at Siena (Italy) using ECH20 probes (capacitance based), EC-5 (capacitance based) and CS616 (time domain reflectometer sensor). After field calibration, it was found that the entire tests provide acceptable results. All soil types with similar calibration can be performed using capacitor sensor, independent with depth by root mean square error (RMSE) from 2.5 and 3.6 %. However, it was found that time domain reflectometry sensor shows a depth dependent with less of RMSE value (1.6 %). Reliable, robust and portable field soil moisture content determination was important in environmental, hydrological and agricultural applications.

Compacted loess characterization at northwest and northern central of China has been studied by Zha et al. (2010) using electrical resistivity method to investigate the prospect of resistivity test in monitoring and assessing compacted loess quality. Soil resistivity relationship with water content, pore fluid chemical composition, saturation degree and temperature was studied at compacted loess sample. It was found that soil resistivity value reduced with the increment of moisture content, temperature, porosity and degree of saturation. Lower soil resistivity value was due to the greater pore fluid conductivity.

Field velocity resistivity sensor for void ratio and stiffness estimation has been studied by Yoon and Lee (2010). Various soil properties were performed using elastic and electromagnetic waves to determine void ratio and elastic moduli using compressional (P) and shear (S) waves, and resistivity value via field velocity resistivity probe (FVRP). Piezometric disk elements and bender elements was fixed at FVRP frame tip to measured compressional and shear waves. The electrical resistivity probe also fixed at FVRP frame tip to determine electrical resistivity values. FVRP experiments were performed using clay-sand soil in calibration chamber and via silty sand to silty clay soils in field. Laboratory elastic waves and electrical resistivity were determined at 1 cm interval, while the field test was performed at 6 – 20 m depth at 10 cm interval, located at Korean peninsula Southern coastal area. Data from measurement was converted to constraint and shear moduli according to elastic waves. Elastic wave velocities and electrical resistivity were able to evaluate void ratios which similar to the volumetric void ratio. This study has demonstrated that FVRP was able to estimate the void ratio and elastic moduli of soil.

Soil weathering estimation using electrical resistivity at Hwaseong, Korea was studied by Son et al. (2010). Laboratory soil electrical resistivity with different chemical weathering index (CWI) was tested, thus able to produce its correlations. It was found that soil electrical resistivity was varied with different weathering degree, particularly due to water content variations. It was found that, CWI was expressed using electrical resistivity linear equation with volumetric content constant as CWI, (%) = $\alpha\rho + \beta$. The study shows that electrical resistivity was applicable in weathering soil estimation particularly due to water content variations.

Soil moisture and vegetation water abstraction using electrical resistivity tomography in Mediterranean southern (France) has been studied by Nijland et al. (2010). Resistivity data acquisition was performed using 28 electrodes with 1 m electrode spacing with Schlumberger array, while data processing was done using EarthImager2D. Resistivity tomography founds that water was extracted by vegetation at weathered rock layers up to 3 – 6 m depth. For validation purposes, soil pits excavated revealed that soil moisture content for top weathered layer was varied between 5 – 15 % whereas soil moisture may reach up to 25 % in certain high organic content. As a result, it was revealed that the storage of water in weathered rock was crucial for vegetation survival during dry and hot season. The study demonstrates that soil moisture content was able to be evaluated using resistivity tomography thus assisting in agriculture strategic planning.

A case study of soil water content monitoring and deficit for shaley soil using electrical resistivity tomography (ERT) in Cevennes (France) was performed by Brunet et al. (2010) using Syscal Junior Switch 48 with Wenner Schlumberger array. Soil water content was interpreted through ERT based on its low resistivity value (< 100 Ωm). Comparison of ERT moisture content was performed via local tests using Time Domain Reflectometry (TDR) and founds to be satisfied. However, the electrical resistivity interpretation was subjective to soil uncertainties such as variation of porosity, temperature, pore water and moisture content. Several advantage of ERT were non invasive, demonstrate spatial trend and offer an information of soil moisture content with depth.

Soil properties estimation using field resistivity probes at Apaj, Hungary was studied by Ristolainen et al. (2009). This study objectives were testing different soil properties tools and to observe their ability to estimate physical and chemical properties of soil. Multiple regressions were used to estimate soil properties. The experiment result founds that electrical conductivity (EC) of soil was applicable to estimate physical and chemical soil properties, while bulk permittivity and water content of soil might estimate the texture of soil only. The coefficient of determination, R^2 analyzed between estimated and measured values were 0.87 – 0.97 (EC and pH), 0.54 – 0.64 (humus and water content) and 0.60 – 0.88 (texture). This study revealed that the modern technical tools able to ease the soil properties determination due to fast and reliable evaluation.

A study by Ekwue and Bartholomew (2009) on electrical conductivity of soils influenced by density, water and peat content was conducted in Trinidad. Portable Field Scout soil water content and electrical conductivity probe were used on eleven soils from the tropic region on field and in the laboratory to measure the soil's apparent bulk conductivities (σ_a). Laboratory compacted soils show increasing electrical conductivity with the increased of bulk density, water and peat contents. Clay soil also show greater σ_a values at any bulk density, water and peat contents values than the other clay loam and sandy loam soils. Reasonable correlation was made between measured and laboratory values of apparent resistivity and conductivity of saturated water extracted from the soils. The study proves that interactions between soil types with water content, and peat and water contents largely influence by σ_a.

Another study on assessing soil moisture on field by Schwartz et al. (2008) was done using electrical resistivity imaging (ERI) and time domain reflectometry