GEOTECHNICAL PROPERTIES OF DIFFERENT SOILS USING SPECTROSCOPY TECHNIQUE

A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE

OF

MASTER OF TECHNOLOGY

IN

GEOTECHNICAL ENGINEERING

Submitted by

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CANDIDATE'S DECLARATION

I, Shruti Aggarwal, 2K16/GTE/17, 2016-2018 student of M.Tech (Geotechnical engineering), hereby declare that the project Dissertation titled "Geotechnical Properties of Different Soils Using Spectroscopy Technique" which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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CERTIFICATE

I hereby certify that the Project Dissertation titled "Geotechnical Properties of Different Soils Using Spectroscopy Technique" which is submitted by Shruti Aggarwal, 2K16/GTE/17, Civil Engineering Department, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

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(Prof. A. K. Sahu)

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(Shruti Aggarwal)

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ABSTRACT

Different soils with low, medium and high plasticity undergo changes in volume upon wetting and drying which has serious implications on planning, design and construction and overall performance of engineering infrastructure. The traditional method of assessing soil plasticity is time consuming, labour intensive and the continuous sampling of site may also not be feasible. Interpolation of limited number of samples to get the desired results may lead to overlooking of any problematic soil. Remote sensing technique was an excellent alternate option in such a situation.

For the study, 24 samples of soil were collected from various parts of India. Soil engineering parameters – Atterberg Limits – Liquid Limit (LL), Plastic Limit (PL), Shrinkage Limit (SL), Plasticity Index (PI) and Shrinkage Index (SI) were measured in Soil Mechanics Laboratory. Reflectance spectra of each soil were acquired using ASD Fieldspec spectroradiometer to develop a relationship between the geotechnical properties and reflectance spectra. Laboratory analysis revealed variation in their swelling and shrinkage potential. On the basis of Indian Standard Soil Classification System (ISSCS), fine grain classification can be given on the basis of Plasticity Index and Liquid Limit.

Multivariate prediction models like partial least square regression (PLSR) and multiple linear stepwise regressions (MLR) analysis are used to construct empirical prediction model for the estimation of engineering parameters from their reflectance spectra. Correlation coefficients obtained showed that a large portion of variation in the engineering parameters can be accounted for by the spectral parameters. The high value of prediction model ($r = 0.989$, 0.979 and 0.990 for LL, PL and SL respectively) indicates the spectroscopy potential in estimating geotechnical properties of soil from their reflectance spectra. Therefore, remote sensing has potential applicability in the geotechnical investigations of soils.

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LIST OF ABBREVIATIONS

SYMBOL	TITLE
AASHTO	American Society of State Highway and Transportation Officials
ASD	Analytical Spectral Device
ASTM	American Society for Testing Materials
DTA	Differential Thermal Analysis
IS	Indian Standard
LL	Liquid Limit
MLR	Multiple Linear Regression
PI	Plastic Index
PL	Plasticity Limit
PLS	Partial Least Square
PLSR	Partial Least Square Regression
SI	Shrinkage Index
SL	Shrinkage Limit
VIP	Variable Importance Predictor
XRD	X Ray Diffraction
λ_x	Reflectance corresponding to the x wavelength of spectra

CHAPTER 1

INTRODUCTION

1.1. Background

Among the various properties of soils that have serious impact on the planning, designing, performance and the overall maintenance of infrastructure are their ability to expand and shrink with the change in moisture. They are found in many parts of the world but create problem in regions of high seasonal variations (1983). These volume changes cause extensive damages to infrastructures; especially on small buildings, shallow foundations and structures which are lightly loaded like roads, pavements, pipelines etc (e.g., Chen, 1988; Day, 2001; Gourley et al, 1993; Kariuki, 2003; Nelson and Miller, 1992; Wilson, 1987).

Shrinking and swelling characteristics can be attributed to the mineralogical composition of soils (e.g. Chen, 1988; Day, 2001; Gourley et al, 1993; Mitchell, 1993).

In the early stages of site investigation, it is important to know the occurrence of the type of soil in order to obtain the extent of problems that should be expected and hence, to take the necessary precautionary measures.

In several studies (e.g., Gourley et al., 1993), it is said that the conventional techniques should be supported by other methods for the better understanding of soil and also to avoid inaccuracies. Because of this, efforts were done to develop techniques. Successful results have been found by remote sensing methods (e.g. Goetz et.al., 2001; Kariuki, 2003; Van der Meer, 1999a).

Remote sensing methods are used for geotechnical investigations about the construction sites and materials (e.g., Bowles, 1984; Hawkins, 1986; Johnson and Petterson, 1988) and these methods give an added advantage of being quick, cheap and covering large area (Van der Meer, 2004a). Also has spatial extent for continuous sampling (e.g. Goetz et al., 2001; Kariuki, 2003).

1.2. Objectives of Research

The main research objective is to develop an empirical model from reflectance spectra of soils for predicting geotechnical properties of soils.

1.2.1. Specific Objectives

- To develop a relationship between soil reflectance spectra and the laboratory determined geotechnical parameters of soil.
- To identify sensitive bands sensitive to geotechnical parameters used in the identification of soil type.
- To explore application of reflectance spectroscopy in identifying soil type.

1.3. Research Questions

- Potential of reflectance spectroscopy for studying geotechnical parameters of soil.
- Which characteristic can be best described by spectral parameters?
- How is spectroscopy beneficial for site investigation?

1.4. Research Hypothesis

Mineralogical composition of soil determines the extent of difficulty and damage posed by the soil.

Hypothesis 1: Soils have unique spectral signatures can be identified based on the differences in spectral response which are a function of wavelength. Different spectral responses are due to the different mineralogical composition (Clark, 1999).

Hypothesis 2: Model can be developed between laboratory determined geotechnical properties and reflectance spectra. There is a strong correlation between soil reflectance and soil properties (Farshad and Farifteh, 2002). But the issue here is whether the model developed in one place are universally applicable or not. It is unlikely that these models are universally applicable due to differences in parent material, climate, topography and organic matter (Fitzpatrick, 1980; Gray and Murphy, 2002).

Hypothesis 3: Engineering parameters of soil can be determined with reflectance spectroscopy. Spectral features help to distinguish between different types (Van der Meer, 1999).

Hypothesis 4: Site investigation can be done using reflectance spectroscopy in a cost effective manner and covers large area (e.g. Goetz et al., 2001; Van der Meer, 2004a). Also, it complements the conventional methods.

1.5. Methodology and Thesis Structure

For the thesis, preparation of field work, collection of data and post data analysis is done. Before the field work, significant geotechnical properties which are good indicators of soil type are decided. Along with this, literature survey and the study area were also studied.

Soil samples were collected. After that, laboratory results and soil reflectance spectra were processed, integrated, analyzed and interpolation is done. Detailed explanation is given in chapter 4. Below is the brief summary of the work:

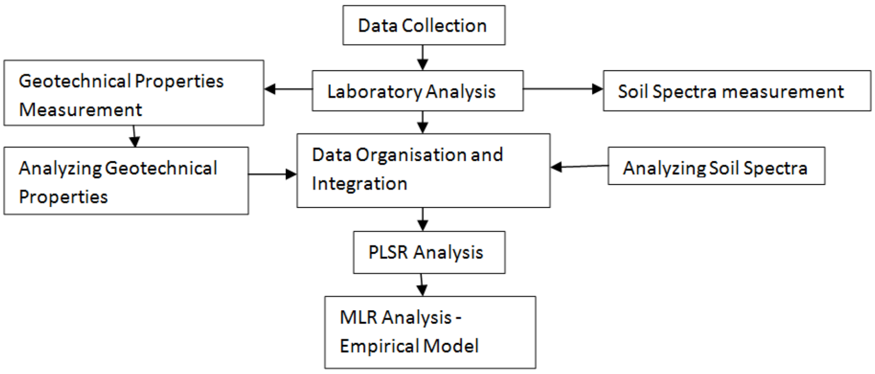

Fig. 1.1 Methodology Structure

This thesis is divided into 5 chapters. Chapter 1 introduces the topic and discusses the objective and methodology. Chapter 2 discusses literature review and the aspects of research topic. Chapter 3 describes materials and methods for this research. Also, it includes details like sample collection, laboratory measurements of geotechnical parameter, spectral measurement and the result analysis. Chapter 5 gives results and discussion and the use of partial least square regression (PLSR) and multiple linear regressions (MLR) to predict the model. The last chapter i.e., chapter 5 gives conclusion and future recommendations.

CHAPTER 2

LITERATURE REVIEW

In this chapter, various researches done by different researchers on the more or less same topic have been written.

2.1. Soil

Hawkins (1986): Geotechnical properties of soil are to be properly determined for any civil engineering work to ensure the stability and overall performance of structure.

R. W. Day (2001): This gives the importance of classification of soil type for the stability of the structure.

Gourley et al. (1993): Soils with high plasticity undergo significant volume change due to change in moisture content. They cause considerable damage in construction sector, especially to light weight where downward pressure from structure exceeds the upward pressure from soil. Damage from expansive soil exceeds the damage by other hazards.

Chen et al. (1988): Several factors cause volume change of these soils like mineralogy apart from seasonal variation. Clays have large specific surface area and net negative charge. They absorb a large amount of water and cause volume change when they come in water content. Relations between clay mineralogy and geotechnical properties have been developed.

2.2. Geotechnical Properties

Perloff and Baron (1976): Atterberg limits, named after the Swedish scientist, A. Atterberg, represent the consistency ranges (ease of soil deformation) of cohesive soil as a function of change in water content. These limits indicate the boundary of 4 states of cohesive soil due to change in water content i.e., solid, semi-solid, plastic and semi liquid states. Liquid limit is the water content above which soil behaves as liquid or turn into semi- liquid state. Plastic limit is the water content over which the soil exhibits plastic behaviour. The shrinkage limit (SL) is the water content below which there is no change in volume.

Lamb and Whitman (1979): Water has a significant role on the engineering behaviour of clayey soil as the soils with higher water content are weaker and deform easily as compared to the low water content soil.

2.3. Identification and Classification

Nelson and Miller (1992): Mineralogical identification and indirect measurements (Index properties) are used to group into three categories.

Chen (1988): To determine basic clay properties, X-ray diffraction (XRD), differential thermal analysis (DTA), dye absorption, chemical analysis and electron resolution methods are used but these are costly and not commonly available in soil mechanics laboratory. Indirect methods are Atterberg limits (LL, PL, SL, PI, SI) which are used for soil identification.

Skempton and Northey (1952): Atterberg limits tell the amount of water attracted to the surface of soil particles and show the consistency states of cohesive soils with respect to water content. Physical properties of soil are influenced by water. The study is of great importance to geotechnical engineering. For example – Plasticity Index indicates the range over which the soil remains plastic. The higher the plasticity index, the higher the plasticity and compressibility of the soil, and so they exhibit greater volume change. Atterberg limits are used for soil classification and also indicates its strength. They also give indication of soil sensitivity Construction specifications for the quality of material of construction to be used in fill, embankment etc are also determined using Atterberg limits (e.g. AASHTO, 2002; ASTM, 1989; British Standard Institution, 1981 etc).

Table 2.1: Relationship between Soil Expansion Potential, Atterberg Limits and Types of Clay Mineral (Nelson and Miller, 1992)

CLAY MINERAL	ATTERBERG LIMITS			EXPANSION POTENTIAL
	LL (%)	PL (%)	SL (%)	
Kaolinite	10-20	30-100	25-29	Low
Illite	60-120	35-60	15-17	Moderate
Smectite (Montmorillonite)	100-900	50-100	8.5-15	High

Bell (1983): For a particular mineral, there is no specific PL, LL and PI value due to the crystal lattice structure of clay minerals.

2.4. <u>Role of Remote Sensing</u>

Johnson and Pettersson (1988): Remote sensing plays an important role in geotechnical investigations and survey for the selection of construction site. Satellite Imagery is also used in the geotechnical investigation. Other information like faults, lineaments, landslides, erosion features etc. can be known from aerial photograph and image interpretation. Using technology, identification and mapping of soil is possible.

2.4.1. Spectroscopy

Clark (1999): Spectroscopy is defined as the study of light as a function of wavelength that is emitted, absorbed, reflected or scattered from materials either solid, liquid or gas. It helps to get qualitative and quantitative information about its properties. Spectroscopy is sensitive to certain bands which change with the change in chemical composition of material. Hyper Spectral images can be obtained using hyper spectral imaging devices.

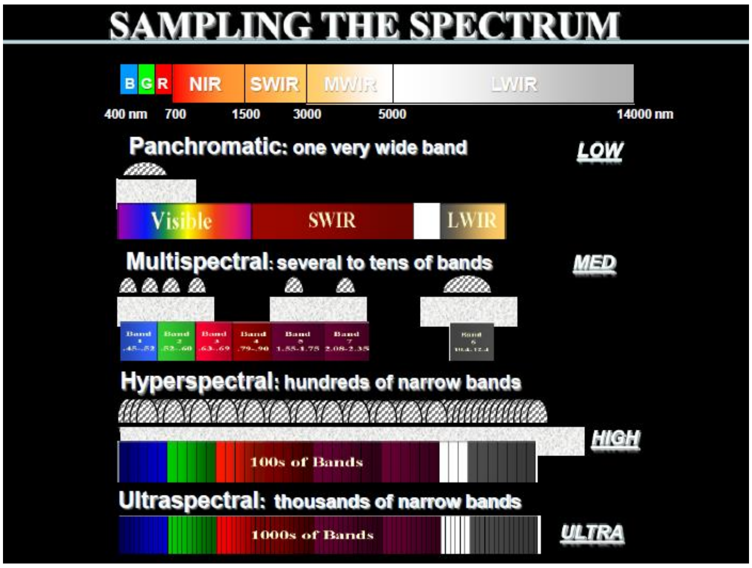

Fig. 2.1: Sampling of Spectrum

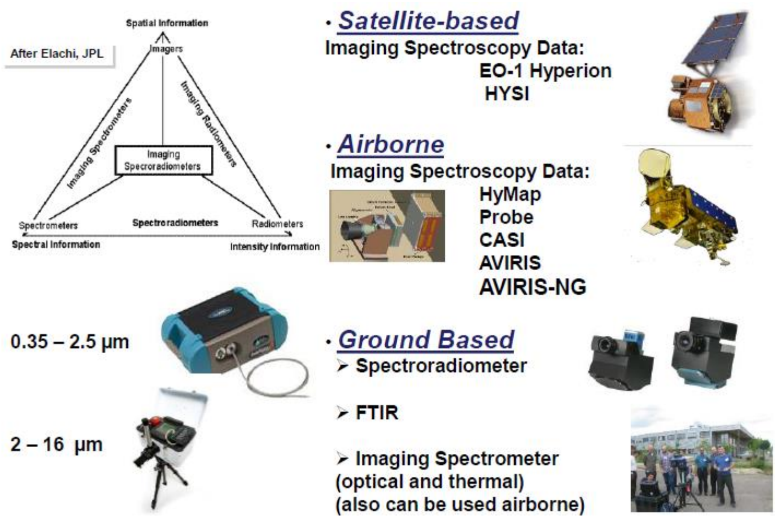

Fig. 2.2: Types of Hyperspectral Sensors

2.4.2. The ASD Field Spec Spectrometer

The ASD (Analytical Spectral Devices, Inc) Field spec spectrometer is field portable spectrometer that covers 350-2500nm of electromagnetic spectrum i.e. visible, near infrared and short wave infrared spectral region. It is used in various disciplines including identification of soil minerals and determination of soil potential.

Sampling interval of spectra is 1nm (ASD, 1999)

Contact mode or distance can be used for measurement. Little or no sample preparation is required and it takes few seconds per sample to take the measurements.

2.4.2.1. Purpose of Spectro – radiometer

It is a ground based Remote Sensing device which helps to understand basics of target and EM interaction. It is a study based on point or single pixel. It acts as a reference for upscale to satellite/ airborne imaging sensors with required bands. It acts as a reference for spectral ground truth of Satellite Remote Sensing.

2.4.2.2. Components of Spectro- radiometer

1. A Light source

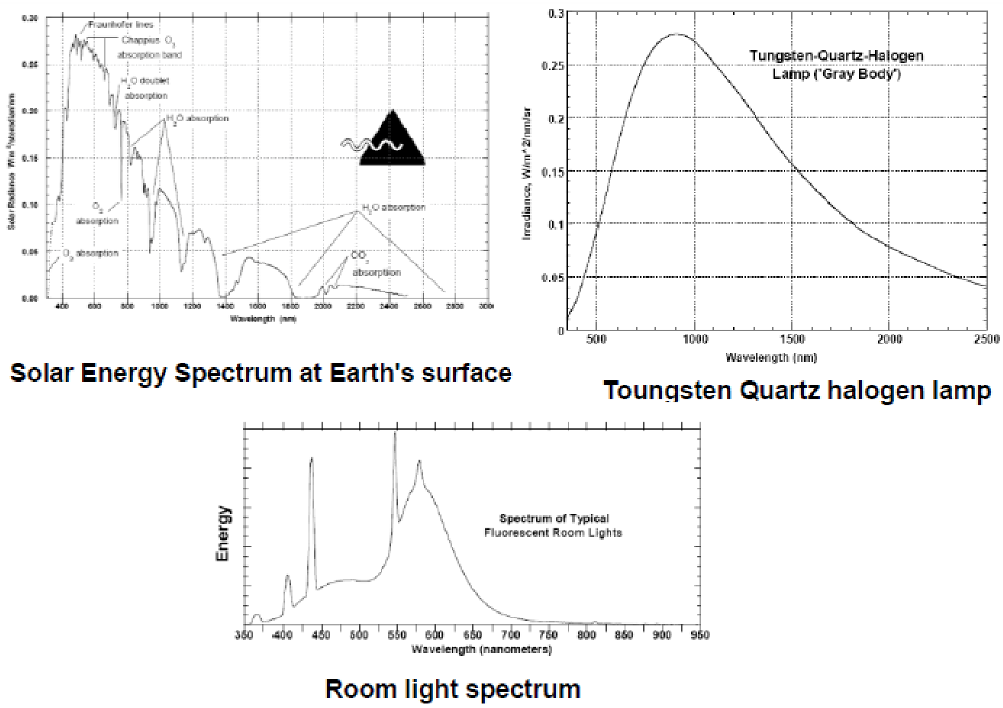

Fig. 2.3: Types of Light Source

2. A dispersive unit (monochromator)

Portable spectro – radiometers are used outside the laboratory. They are exposed to much higher levels of ambient light which may stray into the sample being measured.

3. A detector

Spectral Sampling – interval between the sample points in the spectrum.

Spectral Resolution – full - width – half – maximum (FWHM) of the instrument response to a monochromatic source.

Field of View – the smaller field of view reduces errors associated with the instrument self – shadowing while the larger field of view has the advantage of taking fewer measurements.

4. Fibres

ASD spectroradiometers are designed with a permanent mount fibreoptic cable which feeds directly into the spectroradiometer. This gives the advantage of no signal loss.

5. Absorbance/ reflectance standard

A material with 95-99% reflectance across the entire spectrum is called a white *reference panel* or white *reference standard*. Spectralon from Labsphere is the white reference standard that is very suitable for the VNIR and SWIR spectral ranges of ASD instruments.

Spectralon is made of polytetraflouroethylene (PTFE) and cintered halon. It has the characteristic of being nearly 100% reflective within the wavelength range of 350 nm to 2500 nm. A Spectralon white reference scatters light uniformly in all directions within that wavelength range

2.4.2.3. Properties

- It can record a complete 350 - 2500 nm spectrum in 0.1 seconds.
- It has fast speed in combination with extremely low Noise-equivalent- Radiance (NeDL) which makes it the optimal spectroradiometer.

2.4.3. Reflectance Properties of Soils

Physical and chemical properties influence the spectral reflectance characteristics of soil (Van der Meer, 2001). Absorption bands are due to the electronic and vibrational processes (Clark, 1999).

Water bearing clay mineral groups, Smectite are sensitive to 1400nm due to OH stretching and near 1900nm due to the H-O-H bending and OH stretching. Clay minerals, Al, Mg or Fe ions are sensitive to 2200-2300nm (Clark, 1999).

Table 2.2: Major Clay Mineral Related Absorption Feature Positions, Molecules Causing the Absorption and the Types of Clay Minerals (after Hauff, 2000 cited in Kariuki, 2004)

MAJOR FEATURE POSITION	MOLECULE	CLAY MINERAL
1400nm	OH and H_2O	Kaolinite/ Smectite/ Illite
1900nm	H_2O	Smectite/ Illite
2170nm	Al-OH	Kaolinite
2200nm	Al-OH	Kaolinite/ Smectite/ Illite
2290nm	Fe-OH	Smectite
2300nm	Mg-OH	Smectite
2340nm	Fe-OH/ Mg-OH	Illite
2384nm	Fe-OH	Kaolinite

2.5. <u>Modeling Approaches</u>

For modeling, univariate or multivariate model can be used depending upon the data type available.

2.5.1. Partial Least Square Regression (PLSR)

Herman Wold (2001), the inventor of this model defined PLSR as the regression by means of projection to latent variables. It came first in 1970's and now it is very popular in various disciplines including spectroscopy. This is more significant where the number of variables is large and even includes noisy data like in spectrometers (Martens and Naes, 1989).

PLS deals with the prediction of a set of dependent variables from a set of independent variables and combines features from principal components and multiple regressions (Herve, 2003). It builds a linear model Y=XB+E; where Y = n cases by m variable response matrix; X = n cases by variable predictor matrix; B = q by m regression coefficient matrix; E = noise term for model, has same dimensions as Y (Wold et al., 2001). Aim is to predict Y from X. PLS finds components from X relevant to Y.

Performance of the model can be evaluated using prediction error i.e. the difference between the predicted and measured response values at the calibration and prediction stages (Martens and Naes, 1989). It is basically for prediction rather than establishing relationship between variables (Scholte, 2005).

2.5.2 Multiple Linear Regression (MLR)

Multiple regression analysis is used to predict the values of a dependent variable, Y given a set of p explanatory variables (x1, x2, ……. xp). In this, there are p explanatory variables, and the relationship between the explanatory variable and the dependent variable is shown by the following equation: $y_i = ß_0 + ß_1 x_{1i} + ß_2 x_{2i} + \dots + ß_p x_{pi} + e_i$;

Where $ß_0$ = constant term

$ß_1$ to $ß_p$ = coefficients relating the p explanatory variables to the interest variables.

Multiple linear regression is the extension of simple linear regression, where there are p explanatory variables. 'Linear' is used because it is our assumption that y is directly related to linear combination of explanatory variables.

CHAPTER 3

MATERIALS AND METHODS

3.1. Description of the Study Area

Soil samples were collected from different locations across India extending from $8^0$4’ N to $37^0$6’ N latitude and $68^0$7’ E to $97^0$25’ E longitude, which is shown in Figure – 3-1. Samples are taken from Uttarakhand (Rudrapur; Rurki), Telangana (Warangal; Nizamabad), Madhya Pradesh (Gwalior, Indore; Katni; Jabalpur), Uttar Pradesh (Lumb, Baghpat; Kirthal, Baghpat; Mukandpur, Baghpat; Soop, Baghpat; Kurdi, Baghpat; Chhaprauli, Baghpat), Maharashtra (Baramati; Ardhapur; Juhu, Mumbai), Haryana (Farrukhnagar) and Jharkhand. Total number of samples are 24.

India has tropical type of climate with mean temperature of 40^0C to 45^0C in summer; 10^0C to 15^0C in winters in north and 20^0C to 25^0C in south. June to September are the rainy months.

Fig. 3.1: Map showing Indian states (source: Google images)

3.2. Data Collection

During the sample collection, the samples were all in dry condition. Little grass over the site was removed by spade and disturbed soil samples were obtained from top 0-30 cm of the surface because that part represents the mass properties of the ground (British Standard Institution, 1981). Hand digging equipment, spade and shovel were used to dig twenty four soil samples. Construction sites, places of man – made deposits, location on bare rocks, inaccessible valleys were rejected for sampling site. Description of soil sample is given below.

1-2 Kg of sample were collected from each location, labeled and stored as per AASHTO, 2002 standards. All soils were air dried before storing in polythene bags.

Fig. 3.2: Air Dried Soil Samples in Polythene Bags

3.3. <u>Laboratory Analysis</u>

Engineering tests (Atterberg limits) were conducted in Geomechanics Laboratory, Delhi Technological University. Atterberg limits test was conducted on each of the twenty four soil samples.

After the engineering test, reflectance spectra of soil were acquired at Indian Agricultural Research Institute, Pusa, New Delhi in Remote Sensing Laboratory using ASD Fieldspec (350nm to 2500nm) spectrometers.

Fig. 3.3: Laboratory Readings using ASD

3.3.1. Atterberg Limits (LL, PL, SL, PI, SI) tests

Expansive and shrinking properties are indicated by Atterberg limits.

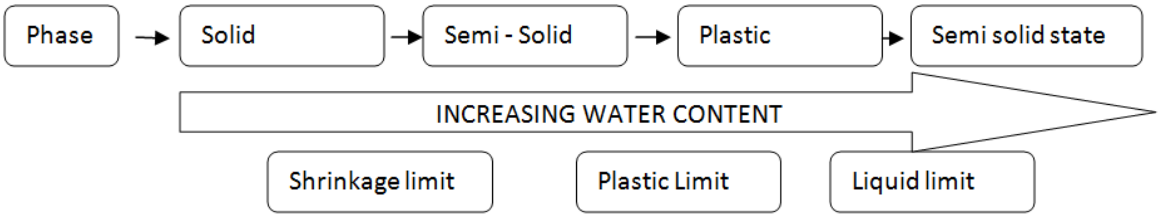

Fig. 3.4: Four Atterberg Limits

Consistency limits were determined in accordance with IS: 2720.

- IS: 2720 (Part -5) - 1985- “Determination of liquid and plastic limit and plasticity index of soils”.
- IS: 2720 (Part -6) - 1972- “Determination of shrinkage limit and shrinkage index of soils”.

Soil samples were oven dried for 24 hours and then passed through 425 microns sieve. The soil sample passing through 425 microns sieve was used for the test.

Liquid limit was measured using Casagrande’s apparatus. The test was performed as per IS: 2720 (Part-5)-1985. 120gm of sieved sample is mixed with distilled water and put in cup of Casagrande’s device. Sharp clean groove is made using the tool and number of blows is recorded. Sample is taken for determining moisture content. Liquid limit was determined using flow curve on semi-logarithmic graph where number of blows is on logarithmic scale and arithmetic scale shows water content. The value corresponding to 25 blows is LL of soil.

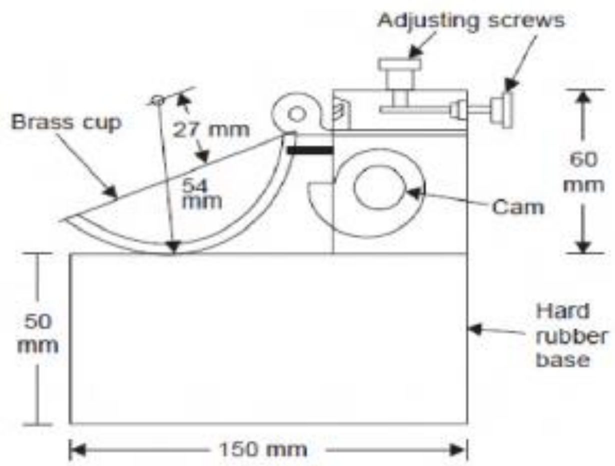

Fig. 3.5: Liquid Limit Device (Source: Google images)

Plastic limit was determined using IS: 2720 (Part-5) - 1985. 20gm of sieved sample is mixed with distilled water to make it plastic so that it is easily moulded with fingers. Then it is rolled into a thread of uniform diameter till crumbles at 3mm diameter. Then the moisture content of the sample is determined which is the plastic limit.
Plasticity Index is the difference of LL and PL.

PI = LL – PL

Shrinkage limit is determined as per IS: 2720 (Part-6) – 1972. 30gm of soil sample is mixed with distilled water and filled in shrinkage dish in 3 layers. Then it is oven dried for 12 to 16 hours at 105^0C to 110^0C. Volume is determined using mercury.
Shrinkage Limit (SL) = SL = W- $((V-V_0)/W_0)$*100; where
W = moisture content of soil
V = volume of dish
V_0 = volume of dry soil pat
W_0 = weight of oven dry pat

Fig. 3.6: Determination of Shrinkage Limit

Shrinkage index is the difference of plastic limit and shrinkage limit.
SI = PL-SL
Some results are attached in Appendix B and summary of all 24 samples for which the reflectance spectra is also available is given in Appendix A.

3.4. <u>Spectral Measurements</u>

Soil spectra were acquired using ASD Fieldspec3 spectrometer with spectral range 350-2500nm of electromagnetic spectrum.

3.4.1. Soil Reflectance Spectra

Spectral reflectance of soils were taken using Fieldspec3 spectroradiometer (ASD Inc., USA) in the Hyperspectral remote sensing laboratory of Division of Agricultural Physics, ICAR – Indian Agricultural Research Institute, New Delhi. The laboratory is designed to act as dark room and calibrated source of light (using two tungsten halogen lamps) provision and contact probes are available for collecting spectral reflectance of soil samples.

Air dried soil sample is taken in their natural state. After the instrument has been switched on, it is allowed to get warm for some time and then the spectra was acquired using ASD Field spec spectrometer in contact mode. This took around hours which was much less than the traditional method which took weeks time.

Fig. 3.7: Laboratory Readings using ASD

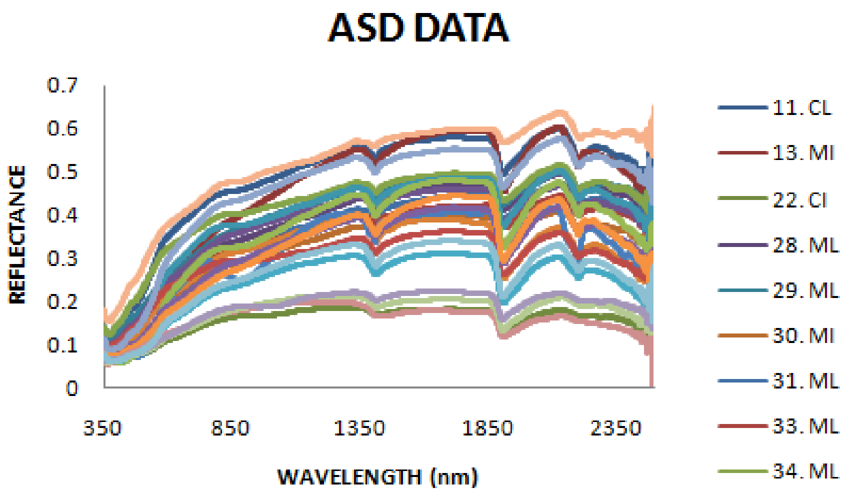

Fig. 3.8: Laboratory Measured Soil Spectra using ASD Field Spec Spectroradiometer.

3.5. Laboratory Results Analysis

3.5.1. Engineering Parameters

Table 3.1 Laboratory Results Summary of Geotechnical Tests for the 24 Samples of Soil (0-30cm depth) for which Reflectance Spectra is also available

S.No.	Soil ID	Location	LL(%)	PL(%)	SL(%)	PI=LL-PL	SI=PL-SL	Soil Type
1.	11	Rurki, Uttarakhand	22.96	11.66	11.44	11.30	0.22	CL
2.	13	Telangana	43.12	26.65	20.08	16.47	6.57	MI
3.	22	Indore, MP	40.40	8.38	2.05	32.02	6.33	CI
4.	28	Lumb, Baghpat, UP	23.60	21.00	17.49	2.60	3.51	ML
5.	29	Kirthal, Baghpat, UP	32.54	22.02	13.59	10.52	8.43	ML
6.	30	Mukandpur, Baghpat, UP	48.74	45.57	42.50	3.17	3.07	MI
7.	31	Rathora, Baghpat, UP	25.98	21.03	19.34	4.95	1.69	ML
8.	33	Soop, Baghpat, UP	23.77	21.86	4.32	1.91	17.54	ML
9.	34	Kurdi, Baghpat, UP	21.76	18.41	4.54	3.35	13.87	ML
10.	35	Chhaprauli, Baghpat, UP	27.88	23.89	18.37	3.99	5.52	ML
11.	42	Juhu, Mumbai, Maharashtra	24.87	21.48	21.34	3.39	0.14	ML
12.	43	Katni, MP	33.54	24.48	18.87	9.06	5.61	ML
13.	44	Jabalpur, MP	32.23	14.96	11.05	17.27	3.91	CL
14.	45	Haryana	20.98	17.15	11.94	3.83	5.21	ML
15.	50	Jharkhand	28.98	20.3	2.91	8.68	17.39	ML
16.	53	Farrukhnagar, Haryana	22.23	18.75	4.48	3.48	14.27	ML
17.	60	Warangal, Telangana	38.98	25.81	10.05	13.17	15.76	MI

18.	61	Nizamabad, Telangana	35.67	18.69	18.06	16.98	0.63	MI
19.	64	Gwalior, MP	29.45	18.69	5.44	10.76	13.25	ML
20.	67	Ardhapur, Maharashtra	68.28	29.41	11.64	38.87	17.77	CH
21.	71	Baramati, Maharashtra	65.45	44.01	38.24	21.44	5.77	MH
22.	72	Indore, MP	40.40	31.62	28.67	8.78	2.95	MI
23.	73	Warangal, Telangana	31.21	23.94	9.64	7.27	14.3	ML
24.	75	Rudrapur, Uttarakhand	34.23	24.83	14.21	9.4	10.62	ML

Examples of Atterberg Limits Test Results

<u>LIQUID LIMIT</u>

Sample 1 (29)

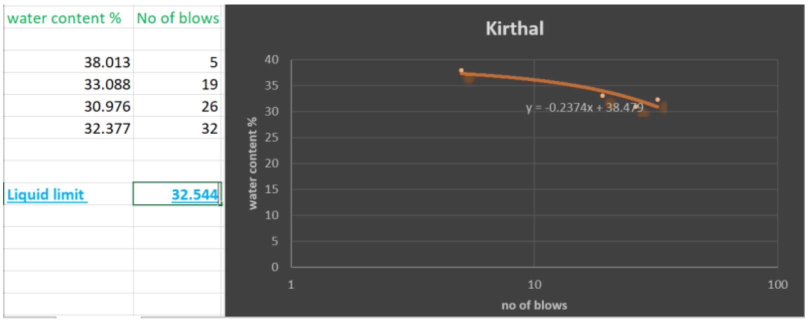

Fig. 3.9 Liquid Limit Graph for Kirthal

Sample 2 (64)

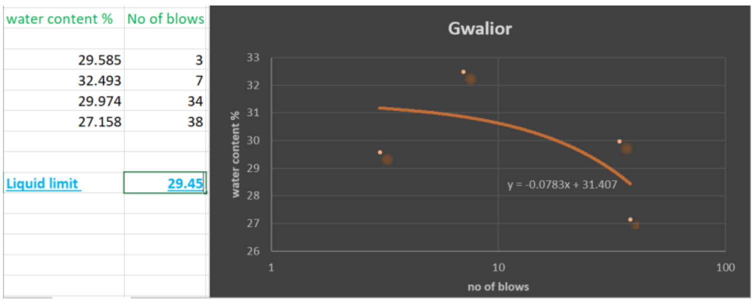

Fig. 3.10 Liquid Limit Graph for Gwalior

Sample 3 (67)

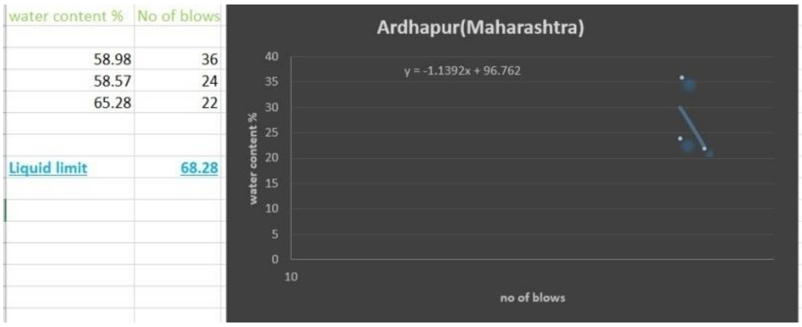

Fig. 3.11 Liquid Limit Graph for Ardhapur

PLASTIC LIMIT

Table 3.2 Readings of Plastic Limit Tests

SAMPLE NO.	**SOIL ID**	**e_w (g)**	**i_w (g)**	**f_w (g)**	**PL (%)**
1.	29	0.35	4.34	3.62	22.02
2.	64	0.59	3.13	2.73	29.45
3.	67	0.54	3.62	2.92	29.41

Where,

e_w = Empty container weight

i_w = Initial weight

f_w = Final weight

PL = Plastic Limit

SHRINKAGE LIMIT (SL = W- ((V-V_0)/W_0)*100)

Table 3.3 Readings of Shrinkage Limit Tests

SAMPLE NO	**SOIL ID**	**e_w (g)**	**i_w (g)**	**f_w (g)**	**W (%)**	**V (cc)**	**V_0 (cc)**	**W_0 (g)**	**SL (%)**
1.	11	13.38	68.79	56.83	27.53	35.62	28.63	43.45	11.44
2.	29	13.38	65.53	53.19	31	35.62	28.69	39.81	13.59
3.	43	13.38	66.28	50.26	43.44	35.62	26.56	36.88	18.87

Where,

e_w = Empty container weight

i_w = Initial weight

f_w = Final weight (f_w)

W = Water content (W)

V = Volume of disk (V)

V_0 = Volume of dry soil pat

W_0 = Weight of dry soil pat

SL = Shrinkage Limit

Liquid limit and plasticity indices are plotted on Casagrande's Plasticity Chart for the soil classification with respect to A- Line as shown in Fig. 3.12. A – Line shows empirical division between soils that is; those falling above it are clayey while below it is silty.

A – Line is given by –

PI = 0.73 (LL - 20); PI = Plasticity Index and LL = Liquid Limit of soil (Perloff and Baron, 1976).

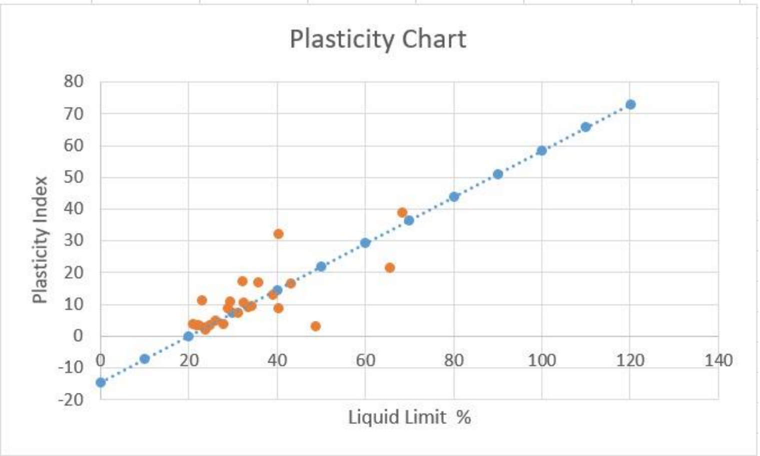

Fig. 3.12: Casagrande's Plasticity Chart

By Casagrande's Plasticity Chart,

1. If LL < 35%, then low plasticity
2. If 35% < LL < 50%, then intermediate plasticity

3. If 50% < LL < 70%, then high plasticity
4. If 70% < LL < 90%, then very high plasticity
5. If LL > 90%, then extremely high plasticity
6. If LL = 0 to 20%, then Non plastic, i.e. its plastic limit is impossible to determine.

CHAPTER 4

RESULTS AND DISCUSSION OF SPECTROSCOPY AND LABORATORY DATA

4.1. Prediction of Geotechnical Parameters

Empirical prediction models have been constructed with the help of multivariate calibration method, partial least square regression (PLSR) and Multiple Linear stepwise Regression (MLR) in a forward direction (Martens and Naes, 1989; Wold et al, 2001) for the quantitative estimation of geotechnical properties from their respective spectra.

4.2. Reflectance Spectra of Soil

Pre – processing of soil spectra was done by using splice correction and then converted to text file.

Difference in the soil spectra can be seen in case of different soil as shown in fig. 4.1.

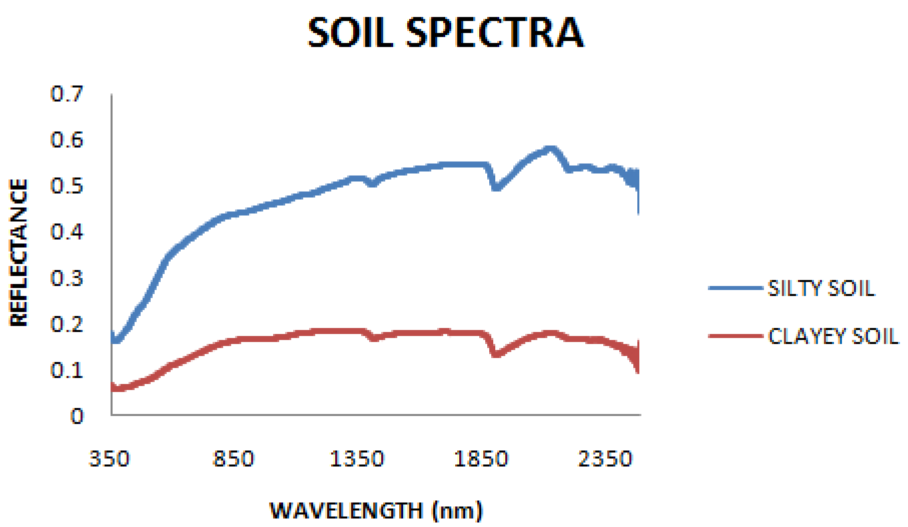

Fig. 4.1: Difference in Spectra for Different Soil.

4.3. PLSR Models to Predict Geotechnical Properties from Soil Reflectance Spectra

Data driven approach given by Scholte (2005) and Kooistra (2004) is used to predict desired response variables using all the wavelengths. This method is also given by Wold et al. (2004).

4.3.1. Data Driven PLSR to Predict Geotechnical Properties from Spectral Data

In this, all the wavelengths of the ASD field spec acquired soil spectra are used. The Variable Importance Predictor (VIP) are selected from PLSR and using these VIPs, MLR is applied to obtain the equation.

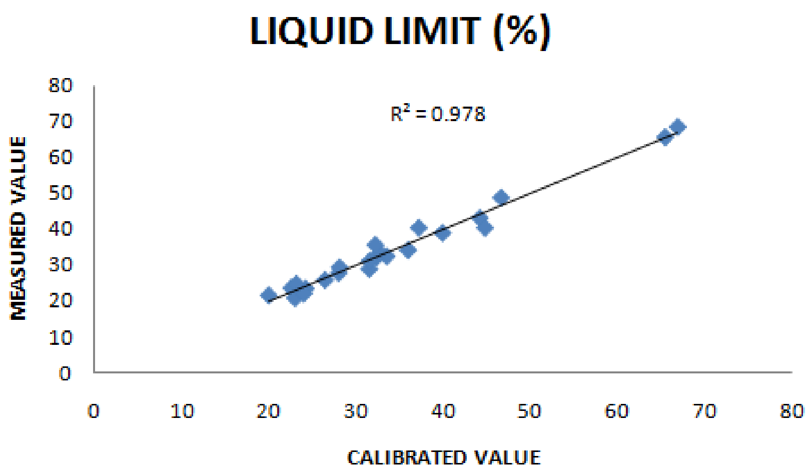

Fig. 4.2: Calibration Curve for Liquid Limit of Soil

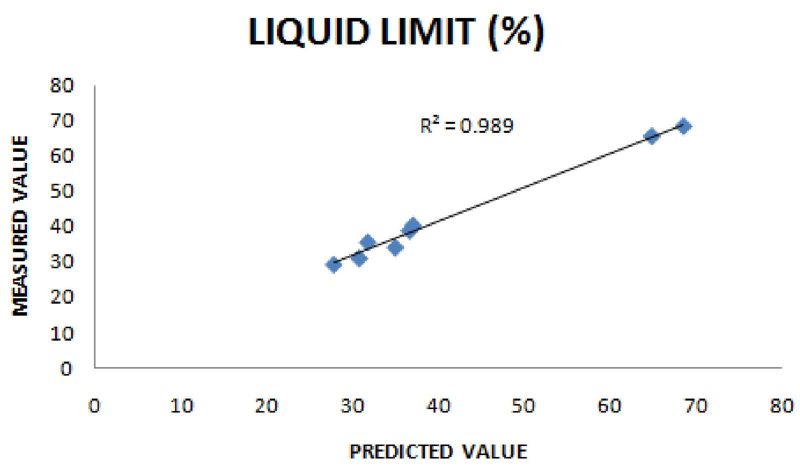

Fig. 4.3: Predicted versus Measured Liquid Limit

Table 4.1: % Error in the Measured and the Predicted Value (LL)

Sample No.	Predicted PL	Measured PL	Difference	% error
1	36.6539	38.98	2.33	5.98
2	31.7749	35.67	3.90	10.93
3	27.8249	29.45	1.63	5.53
4	68.5789	68.28	0.30	0.44
5	64.8742	65.45	0.58	0.89
6	37.0638	40.40	3.34	8.27
7	30.7994	31.21	0.41	1.31
8	35.0083	34.23	0.79	2.31

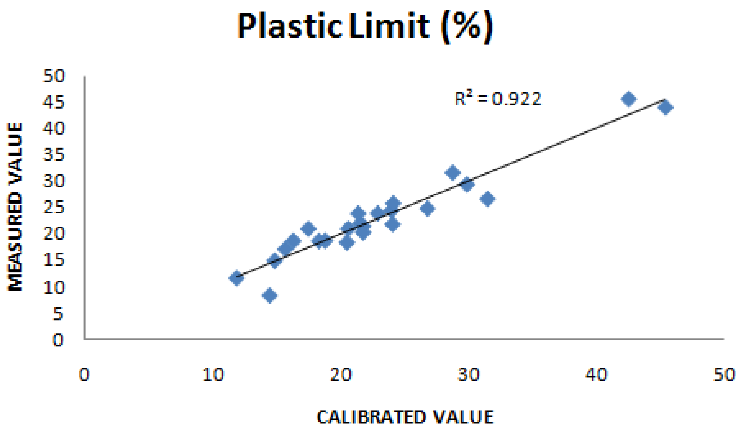

Fig. 4.4: Calibration Curve for Plastic Limit of Soil

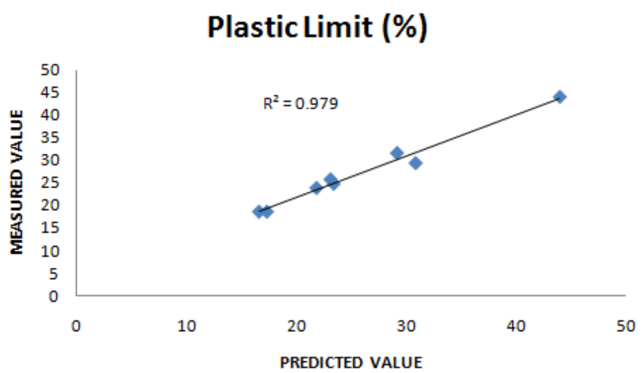

Fig. 4.5: Predicted versus Measured Plastic Limit

Table 4.2: % Error in the measured and the predicted value (PL)

Sample No.	Predicted	Measured	Difference	% error
1	23.0873	25.81	2.72	10.54
2	16.5719	18.69	2.12	11.34
3	17.2876	18.69	1.40	7.49
4	30.8290	29.41	1.42	4.83
5	43.9602	44.01	0.05	0.11
6	29.1370	31.62	2.48	7.84
7	21.8150	23.94	2.13	8.90
8	23.3747	24.83	1.45	5.84

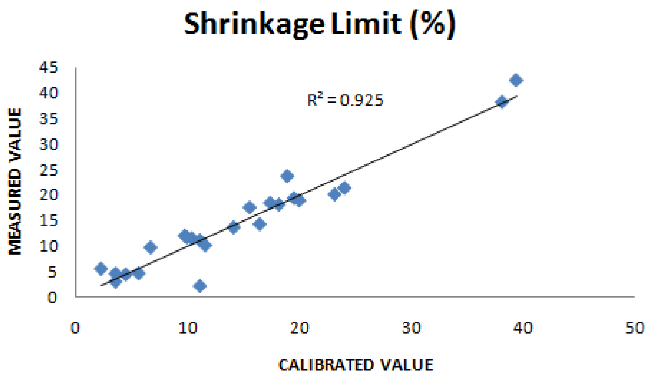

Fig. 4.6: Calibration Curve for Shrinkage Limit of Soil

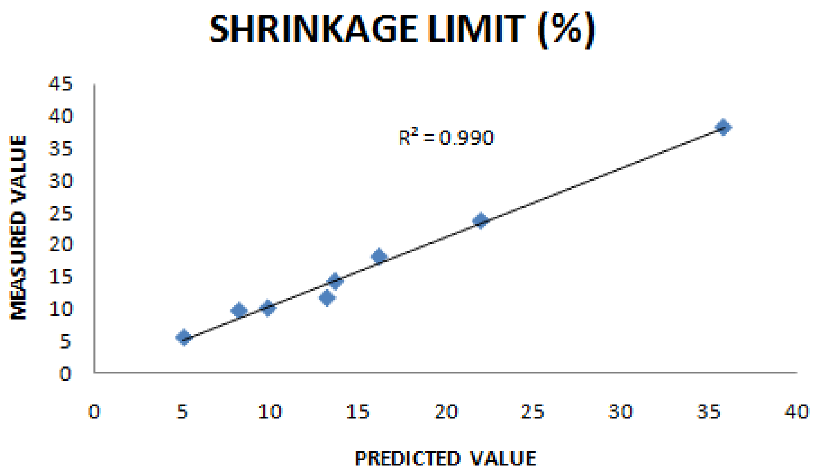

Fig 4.7: Predicted versus Measured Shrinkage Limit

Table 4.3: % Error in the Measured and the Predicted Value (SL)

Sample No.	Predicted Value	Measured Value	Difference	% error
1	9.8073	10.05	0.24	2.41
2	16.1735	18.06	1.89	10.47
3	5.0214	5.44	0.42	7.72
4	13.1870	11.64	1.55	13.32
5	35.8533	38.24	2.39	6.25
6	21.9960	23.67	1.67	7.06
7	8.1682	9.64	1.47	15.24
8	13.6553	14.21	0.55	3.87

4.4. Multiple Linear Stepwise Regressions (MLR)

4.4.1. Data Driven MLR to Establish Empirical Relation between Geotechnical Properties and Spectral Data

VIPs obtained from PLSR are used to develop the equation stated below:

Equation for determining Liquid Limit

$$LL = 11.53966 + 2702.342*\lambda_{547} - 7936.68*\lambda_{562} + 5384.942*\lambda_{567} + 1208.531*\lambda_{1900} - 506.184*\lambda_{1920} - 715.631*\lambda_{1920.1} - 7095.75*\lambda_{2180} + 1428.187*\lambda_{2180.1} + 7465.512*\lambda_{2190} + 6305.714*\lambda_{2190.1} - 12829.7*\lambda_{2200} + 4768.428*\lambda_{2200.1} \quad (1)$$

Equation for determining Plastic Limit

$$PL = 27.00105 + 1499.535*\lambda_{352} - 3170.39*\lambda_{357} - 3163.22*\lambda_{362} + 5071.238*\lambda_{377} + 1593.332*\lambda_{537} - 15116.6*\lambda_{547} + 21513.22*\lambda_{557} - 8231.07*\lambda_{567} + 1497.537*\lambda_{1900} + 1385.715*\lambda_{1920} - 4036.79*\lambda_{1920.1} - 4523.32*\lambda_{2180} + 9669.215*\lambda_{2190} - 2829.53*\lambda_{2200} - 3170.1*\lambda_{2210} - 1954.54*\lambda_{2320} + 4823.979*\lambda_{2380} - 1031.05*\lambda_{2400} \quad (2)$$

Equation for determining Shrinkage Limit

$$SL = 28.70985 - 1527.84*\lambda_{547} + 6116.75*\lambda_{562} - 4846.28*\lambda_{567} + 268.4012*\lambda_{1900} + 33.26479*\lambda_{1920} - 147.036*\lambda_{1920.1} - 10760.7*\lambda_{2180} + 10103.4*\lambda_{2180.1} + 7310.793*\lambda_{2190} + 2436.12*\lambda_{2190.1} - 16053*\lambda_{2200} + 6920.448*\lambda_{2200.1} \quad (3)$$

Where, λ_x represents the reflectance corresponding to the x wavelength of spectra.

These relations show that a large amount variation can be captured by spectral characteristics of soil spectra.

4.5. Discussion

The results obtained from spectral analysis indicate the spectroscopy potential in complementing the traditional testing methods of geotechnical properties. The spectral interpretation helps to get qualitative information. The empirical relations have been established using PLSR and MLR technique and reliable estimate of geotechnical properties can be obtained using the model. Performance and the prediction accuracy are assessed by correlation coefficients.

It was observed by Kariuki (2004) that sensitive bands are 1900nm due to H_2O molecule; 2180nm, 2190nmm 2200nm due to AlOH mineral; 2320nm and 2400nm due to FeOH/ MgOH mineral. Similar observation was made by the current study.

CHAPTER 5

Conclusions and Recommendations for Future Work

5.1. Conclusions

The traditional testing methodology for the determination of geotechnical properties of the soil as per codal provisions is laborious, time consuming, expensive. Moreover, the continuous sampling of site may not be feasible always. So there is a need to investigate quick, cheaper and reliable methods. In the present study, it is concluded that remote sensing methods, especially reflectance spectroscopy is an excellent option to support traditional testing methods (e.g. Chabrillant and Goetz, 1997-2000; Kariuki, 2003; Van der Meer, 1999a). This will give a more reliable results and efficient geotechnical investigation of soil.

Soil samples can be differentiated on the basis of spectral characteristics (Chapter 5). Soil samples have been classified on the basis of plasticity using the Casagrande's plasticity chart, which is based on Atterberg limit results.

PLSR and MLR proved excellent tools to predict the relationship between the unknowns and also unveiling the spectroscopy potential in the geotechnical exploration,

Prediction ability is found to be good for LL, PL as well as SL.

This method can give quick and accurate result. Apart from this, it is cheaper and gives the advantage of continuous sampling.

5.2. Recommendations

- Clay mineralogy can be studied that influence the properties of soil using this technique.
- Other tests can be done to analyse and develop models for other properties of soil.
- ASD data can be extrapolated to ASTER image and even to satellite image study.

REFERENCES

1. ASTM, (1989). Annual Book of ASTM Standards: Section 4 Construction: Soil and Rock, Building Stones; Geotextiles, Philadelphia, American Society for Testing and Materials (ASTM), pp. 996.
2. Bell, F.G. (1983). Engineering Properties of Soils and Rocks, London, ButterWorths.
3. Bowles, J.E. (1984). Physical and Geotechnical Properties of Soils, Mc Graw Hill, Inc.
4. British Standard Institution, B. (1981). Code of Practice for Site Investigations BS 5930: 1981, London, British Standard Institution.
5. Chen, F.H. (1988). Foundation on Expansive Soils, Elsevier Science Publishers.
6. Clark, R.N. (1999). Spectroscopy of Rocks and Minerals, and Principles of Spectroscopy, in Rencz, A., ed., Chapter 1 in: Manual of Remote Sensing: New York, John Wiley and Sons, Inc.
7. David, H.C. (1999). Analytical Spectral Devices, Inc. (ASD).
8. Day, R.W. (2001). Soil Testing Manual: Procedures, Classification Data, and Sampling Practices, Mcgraw–Hill.
9. Farshad, A. and Farifteh, J. (2002). Remote Sensing and Modeling of Topsoil Properties, a Clue for Assessing Land Degradation, Thailand.
10. Fitzpatrick, E.A. (1980). SOILS; their Formation, Classification and Distribution, Longman Inc.
11. Goetz, A.F.H., Chabrillant, s., and Lu, Z. (2001). Field Reflectance Spectrometry for Detection of Swelling Clays at Construction Sites, Field Analytical Chemistry and Technology, Vol. 5 No. 3, pp. 143-155.
12. Gourley, C., Newill, D., and Schreiner, H.D. (1993). Expansive soils: TRL's Research Strategy, First International Symposium on Engineering Characteristics of Arid Soils, City University, London, Overseas Centre, Transport Research Laboartory, Crowthorne, Berkshire, UK.
13. Gray, J., and Murphy, B. (2002). Parent Material and Soil Distribution, Australian Association of Natural Resource Management, Vol. 5, pp. 3-12.
14. Hawkins, A.B. (1986). Site Investigation Practice: Assessing BS 5930, Geological Society Special Publication, Vol. 2: London, The Geological Society of London, pp. 423.

15. IS: 2720 (Part 5) (1985). Methods of Test for Soils: Determination of Liquid and Plastic limit, Bureau of Indian Standards, New Delhi, India.
16. IS: 2720 (Part 6) (1972). Methods of Test for Soils: Determination of Shrinkage limit, Bureau of Indian Standards, New Delhi, India.
17. Johnson, A.I., and Pettersson, C.B. (1988). Geotechnical Applications of Remote Sensing and Remote Data Transmission, Cocoa Beach, FI., 31 Jan.-1Feb. 1986: Philadelphia, American Society for Testing and Materials (ASTM), pp. 277.
18. Kariuki, P.C. (2003). Spectroscopy and Swelling Soils - An Integrated Approach, PhD Thesis: Enschede, The Netherlands, ITC.
19. Lambe, T.W., and Whitman, R.V. (1979). Soil Mechanics, SI Version: New York, John Wiley & Sons.
20. Martens, H., and Naes, T. (1989). Multivariate Calibration, John Wiley & Sons, INC.
21. Mitchell, J.K. (1993). Fundamentals of Soil behaviour, John Wiley & Sons, Inc.
22. Nelson, J.D., and Miller, D.J. (1992). Expansive Soils Problems and Practice in Foundation and Pavement Engineering, John Wiley & Sons, Inc.
23. Van der Meer, F.D. (1999a). Can we Map Swelling Clay with Remote Sensing?, International Journal of Applied Earth Observation & Geoinformation (JAG), Vol. 1, pp. 27-35.
24. Van der Meer, F.D. (2004a). Analysis of Spectral Absorption Features in Hyperspectral Imagery, International Journal of Applied Earth Observation & Geoinformation, Vol. 5, pp. 55-68.
25. Wilson, M.J. (1987). Handbook of Determinative Methods in Clay Mineralogy, Glasgow etc.; New York, Blackie; Chapman and Hall. pp. 308.

BIBLIOGRAPHY

1. Ben-Dor, E. and Banin, A. (1994). Visible and Near- Infrared (0.4-1.1μm) analysis of Arid and Semiarid Soils; Remote Sensing of Environment, Vol. 48, pp. 261 - 274.
2. Head, K.H. (1994). Manual of soil Laboratory Testing: Volume 2 Permeability, Shear Strength and Compressibility tests, John Wiley & Sons Inc.
3. Kariuki, P.C., Woldai, T. and Van der Meer, F.D. (2004). Effectiveness of spectroscopy in identification of swelling indicator clay minerals. International Journal of Remote Sensing, Vol. 25(2), pp. 455 - 469.
4. Perloff, W.H. and Baron, W., (1976). Soil mechanics Principles and Applications, John Wiley & Sons.
5. Shi, B., Jiang, H., Liu, Z. and Fang, H.Y. (2002). Engineering geological characteristics of expansive soils in China. Engineering Geology, Vol. 67, pp. 63 - 71.
6. Verhoef, P.N.W. (1992). The Methylene Blue Adsorption Test Applied to Geo-materials. Delft, Delft University of Technology.
7. Viscarra, R.A.R., Walvoort, D.J.J., McBratney, A.B., Janik, L.J. and Skjemstad, J.O., (2006). Visible, near infrared, mid infrared or combined diffuse reflectance spectroscopy for simultaneous assessment of various soil properties. Geoderma, Vol. 131, pp. 59 - 75.