

CORRELATION OF CBR WITH INDEX PROPERTIES OF SOIL

A Dissertation Submitted
In Partial Fulfilment of the Requirements
for the degree of

MASTERS OF ENGINEERING
IN
INFRASTRUCTURE ENGINEERING

Submitted by:
VIKARAN MAHAJAN
(ROLL NO. 801223008)

UNDER THE SUPERVISION OF

RAJESH PATHAK
Associate Professor
Department of Civil Engineering
Thapar University, Patiala

TANUJ CHOPRA
Assistant Professor
Department of Civil Engineering
Thapar University, Patiala



DEPARTMENT OF CIVIL ENGINEERING
THAPAR UNIVERSITY,
PATIALA-147004
JULY 2014

DECLARATION

I, Vikaran Mahajan hereby declare that this thesis entitled "**Correlation of CBR with Index Properties of Soil**", is an authentic record of my study carried out as requirement for the award of degree of **Master of Engineering in Infrastructure Engineering** in the Civil Engineering Department, under the supervision of **Mr. Rajesh Pathak, Associate Professor and Mr. Tanuj Chopra, Assistant Professor**, Department of Civil Engineering, Thapar University, Patiala during July 2012 to July 2014. The matter embedded in this report has not been submitted in part or full to any other university for the award of any degree.

Date- 18/07/2014


(VIKARAN MAHAJAN)

Roll No. : 801223008

CERTIFICATE

This is to certify that the above statement made by the student concerned is correct and true to the best of my knowledge and belief.


Mr. RAJESH PATHAK

Associate Professor
Department of Civil Engineering
Thapar University, Patiala


Mr. TANUJ CHOPRA


Assistant Professor
Department of Civil Engineering
Thapar University, Patiala


Dr. NAVEEN KWATRA

Associate Professor & Head
Department of Civil engineering
Thapar University, Patiala

COUNTERSIGNED


Dr. S.K. MOHAPATRA


Dean, Academic affairs
Thapar University, Patiala

ACKNOWLEDGEMENT

With my aesthetic attitude of learning management to the best, I am in a state to submit this dissertation and would like to express my gratitude to all persons and organizations who contributed directly or indirectly to this report with their support, encouragement and advice.

Acknowledgement is due first and foremost to my supervisors, **Mr. Rajesh Pathak, Associate Professor and Mr. Tanuj Chopra, Assistant Professor** Department of Civil Engineering Thapar University who permitted me to carry out research work under their able guidance. I am truly indebted for their advice and guidance. Their abundant knowledge in civil and construction field is a benefit for me.

I wish to express my sincere thanks to Dr. Naveen Kwatra, Associate Professor and Head, CED Thapar university Patiala, who has been a constant source of inspiration for me throughout this thesis work.

This report required hard work, sincerity and devotion which I tried my best to put in this project and in turn gained a lot of knowledge and confidence from this report. Special words of appreciation go to Sh. Muneesh kapila, Sh. Avtar singh, Sh. Amarjeet singh and other laboratory colleagues, who helped in my experimental work.

Above all, my gratitude and thank goes to my parents, sister and friends for their support and motivation during the entire course of my thesis work. I render my gratitude to Almighty who bestowed self confidence, ability and strength in me to complete this work.


VIKARAN MAHAJAN

ABSTRACT

California bearing ratio is most used indirect method to assess the stiffness modulus and shear strength of subgrade in the design of flexible pavement. The type of soil not only affects the CBR value, but the CBR value also varies with different properties possessed by the soil. CBR value of soil depends on many factors like maximum dry density (MDD), optimum moisture content (OMC), liquid limit (LL), unconfined compressive strength, percent fines etc. Determination of CBR is a bit lengthy and time consuming process.

In this study, soil samples were taken from 11 different locations within 50 km radius of Patiala city and various tests were performed on these sample. An attempt has been made to correlate soaked as well as unsoaked CBR value with percent fines, LL, MDD and OMC. ANN model is also developed to established best linear fit between the experimental values and the literature value.

The correlation is established in the form of an equation of CBR as a function of different soil properties by the method of regression analysis. It has been observed that the predicted values are in the domain of experimental values and the results indicated a strong correlation with value of $r^2=0.901$ for unsoaked CBR and $r^2= 0.897$ for soaked CBR.

CONTENTS

| S. No. | | Page No. |
|------------------|---|----------|
| | CERTIFICATE | i |
| | ACKNOWLEDGEMENT | ii |
| | ABSTRACT | iii |
| | CONTENTS | iv |
| | LIST OF TABLES | vi |
| | LIST OF FIGURES | vii |
| | | Page No. |
| CHAPTER 1 | INTRODUCTION | |
| 1.1 | General | 1 |
| 1.2 | Statement of the problem | 1 |
| 1.3 | Objective | 2 |
| 1.4 | Soil | 3 |
| 1.5 | Properties of soil | 3 |
| | 1.5.1 Physical properties | 3 |
| 1.6 | Classification of soils | 4 |
| | 16.1 Requirement | 4 |
| | 16.2 Soil classification systems | 5 |
| 1.7 | Outline of thesis | 6 |
| CHAPTER 2 | REVIEW OF LITERATURE | 7 |
| CHAPTER 3 | EXPERIMENTAL PROGRAM AND RESULTS | 15 |
| 3.1 | Index properties of soil | 15 |
| | 3.1.1 Sieve analysis | 15 |
| | 3.1.3 Atterberg limit | 16 |
| 3.2 | Compaction test | 16 |
| 3.3 | Unconfined compression test | 17 |
| 3.4 | California bearing ratio | 17 |
| | 3.4.1 Laboratory test | 17 |

| | | |
|------------------|---|-----------|
| 3.4.2 | Equipments and tool required | 18 |
| 3.4.3 | Preparation of specimen | 19 |
| 3.4.4 | Compaction | 20 |
| 3.5 | Test results | 21 |
| CHAPTER 4 | ANALYSIS OF RESULTS | 40 |
| 4.1 | Multiple linear regression | 40 |
| 4.2 | Artificial neural networks | 40 |
| 4.3 | Experimental results | 41 |
| 4.4 | ANN model to establish best-linear fit | 42 |
| 4.5 | Correlation of CBR with soil parameters by MLR | 45 |
| CHAPTER 6 | CONCLUSIONS AND FUTURE SCOPE | 49 |
| | REFERENCES | 50 |
| | ANNEXURE-1 | 52 |
| | ANNEXURE-02 | 54 |
| | ANNEXURE-03 | 56 |
| | ANNEXURE-04 | 58 |
| | ANNEXURE-05 | 60 |
| | ANNEXURE-06 | 62 |
| | ANNEXURE-07 | 65 |
| | ANNEXURE-08 | 68 |
| | ANNEXURE-09 | 70 |
| | ANNEXURE-10 | 73 |
| | ANNEXURE-11 | 76 |

LIST OF TABLES

| S. No. | Title | Page No. |
|--------|--|----------|
| 3.1 | Loads adopted for different penetrations | 18 |
| 4.1 | Properties of tested soil specimen for sample (1-4) | 41 |
| 4.2 | Properties of tested soil specimen for sample (5-8) | 41 |
| 4.3 | Properties of tested soil specimen for sample (9-11) | 42 |
| 4.4 | Results of trained data (Unsoaked CBR) | 43 |
| 4.5 | Results of trained data (Soaked CBR) | 44 |
| 4.6 | Results of CBR(unsoaked) from experiments and analysis | 46 |
| 4.7 | Results of CBR(soaked) from experiments and analysis | 47 |

LIST OF FIGURES

| S. No. | Title | Page No. |
|--------|---|----------|
| 2.1 | Comparison between laboratory CBR and analysed CBR (unsoaked) | 08 |
| 2.2 | Comparison between laboratory CBR and analysed CBR (soaked) | 08 |
| 2.3 | Comparison of un-soaked CBR actual Vs predicted from ANN, MLR | 10 |
| 2.4 | Comparison of soaked CBR actual Vs predicted from ANN, MLR | 10 |
| 2.5 | Linear correlation graph between predicted and Laboratory CBR | 12 |
| 2.6 | Comparison of laboratory and computed CBR value | 13 |
| 2.7 | Scattered plot of observed Vs predicted CBR for best model by MLR | 14 |
| 2.8 | Scattered plot of observed Vs predicted CBR by ANN | 14 |
| 3.1 | CBR apparatus | 19 |
| 3.2 | Gradation curve for sieve analysis for sample1 | 20 |
| 3.3 | Compaction curve for determination of MDD and OMC for sample 1 | 21 |
| 3.4 | Load Vs penetration for determination of CBR value for sample 1 | 21 |
| 3.5 | Gradation curve for sieve analysis for sample 2 | 22 |
| 3.6 | Compaction curve for determination of MDD and OMC for sample 2 | 22 |
| 3.7 | Load Vs penetration for determination of CBR value for sample 2 | 23 |
| 3.8 | Gradation curve for sieve analysis for sample 3 | 23 |
| 3.9 | Compaction curve for determination of MDD and OMC for sample 3 | 24 |
| 3.10 | Load Vs penetration for determination of CBR value for sample 3 | 24 |

| | | |
|------|---|----|
| 3.11 | Gradation curve for sieve analysis for sample 4 | 25 |
| 3.12 | Compaction curve for determination of MDD and OMC for sample 4 | 25 |
| 3.13 | Load Vs penetration for determination of CBR value for sample 4 | 26 |
| 3.14 | Gradation curve for sieve analysis for sample 5 | 26 |
| 3.15 | Compaction curve for determination of MDD and OMC for sample 5 | 27 |
| 3.16 | Load Vs penetration for determination of CBR value for sample 5 | 27 |
| 3.17 | Gradation curve for sieve analysis for sample 6 | 28 |
| 3.18 | Compaction curve for determination of MDD and OMC for sample 6 | 28 |
| 3.19 | Graph showing Compressive Stress Vs Strain 6 | 29 |
| 3.20 | Load Vs penetration for determination of CBR value for sample 6 | 29 |
| 3.21 | Gradation curve for sieve analysis for sample 7 | 30 |
| 3.22 | Compaction curve for determination of MDD and OMC for sample 7 | 30 |
| 3.23 | Graph showing Compressive Stress Vs Strain 7 | 31 |
| 3.24 | Load Vs penetration for determination of CBR value for sample 7 | 31 |
| 3.25 | Gradation curve for sieve analysis for sample 8 | 32 |
| 3.26 | Compaction curve for determination of MDD and OMC for sample 8 | 32 |
| 3.27 | Load Vs penetration for determination of CBR value for sample 8 | 33 |
| 3.28 | Gradation curve for sieve analysis for sample 9 | 33 |
| 3.29 | Compaction curve for determination of MDD and OMC for sample 9 | 34 |
| 3.30 | Graph showing Compressive Stress Vs Strain 9 | 34 |
| 3.31 | Load Vs penetration for determination of CBR value for sample 9 | 35 |

| | | |
|------|---|----|
| 3.32 | Gradation curve for sieve analysis for sample 10 | 35 |
| 3.33 | Compaction curve for determination of MDD and OMC for sample 10 | 36 |
| 3.34 | Graph showing Compressive Stress Vs Strain 10 | 36 |
| 3.35 | Load Vs penetration for determination of CBR value for sample 10 | 37 |
| 3.36 | Gradation curve for sieve analysis for sample 11 | 37 |
| 3.37 | Compaction curve for determination of MDD and OMC for sample 11 | 38 |
| 3.38 | Graph showing Compressive Stress Vs Strain 11 | 38 |
| 3.39 | Load Vs penetration for determination of CBR value for sample 11 | 39 |
| 4.1 | Best-linear fit for experimental and literature values (unsoaked CBR) | 43 |
| 4.2 | Best-linear fit for experimental and literature values (soaked CBR) | 44 |
| 4.3 | Comparison of actual and predicted CBR value (unsoaked) | 46 |
| 4.4 | Comparison of actual and predicted CBR value (soaked) | 48 |

1.1 General

Presently India's infrastructure is growing rapidly. Large number of new urban and lightly trafficked roads are being constructed or planned. The CBR or California bearing ratio is the well known, common and trustful test currently used in road construction. The test is being used for many years and is familiar to organisations involved in the interpretation of results, consequent road design and construction.

California bearing ratio mainly comes under the use of civil engineers particularly for those working in pavement construction to determine stiffness modulus and shear strength of sub-grade. It shows comparison of strength of subgrade material to the strength of standard crushed rock referred in %age values. This method was basically developed at California Division of Highways in 1930s to give an assessment of the relative stability of fine crushed rock base material.

The CBR values are used by the engineers to design the thickness of pavement layer to be laid on the top of the sub-grade. The lower CBR value sub-grade will have more thickness of pavement as compared to the sub-grade that has higher CBR value. In this method the soil sample is compacted in a standard mould and then a plunger is allowed to penetrate in to the soil at a specified penetration rate. Load Vs penetration curve is plotted from the result of penetration and then compared with the bearing resistance of standard crushed rock.

1.2 Statement of the Problem

Soil is diverse in formation and character therefore accurate prediction of its engineering behaviour is of research interest in civil engineering area. The engineering behaviour of soils varies from place to place and also with time. Many attempts are made to predict CBR value from the index properties of soil. Hence determining of factors that influence the soil strength and studying their

relationship with California Bearing Ratio value on representative sample may be considered as good insight of soil behaviour.

1.3 Objective

The research work presented in this dissertation concerns itself with the prediction of CBR values from soil parameters in an attempt to reduce the amount of CBR testing done in industry.

Definition of California Bearing ratio (CBR)

California division of highways in 1929 firstly developed California Bearing Ratio test to classify the suitability of soil for use as sub-grade or base course material in highway construction. During World War II, the US corps of engineers adopted the test for use in airfield construction. This test measures the shearing resistance of soil under controlled moisture and density conditions.

The California bearing ratio test is penetration test meant for the evaluation of sub-grade strength of roads and pavements. The results obtained by these tests are used with the empirical curves to determine the thickness of pavement and its component layers. This is the most widely used method for the design of flexible pavement.

The CBR test is obtained as the ratio of the unit load required to affect a certain depth of penetration in to a compacted sample at desired water content and density to the standard unit load required to obtain the same depth of penetration on a standard sample of crushed stone. The equation is as follows:

$$\text{CBR} = \frac{\text{test unit load}}{\text{standard unit load}} * 100$$

From the above equation, it shows that CBR number is a percentage of the standard unit load. In general practice, the percentage symbol; is dropped and the ratio is used as a number, e.g. 4, 6 or 4.5.

The CBR number is generally based on the load ratio for a penetration of 2.5mm. However, if the CBR value at penetration of 5mm is larger, the test should be

redone. If a second test yields also a large number at 5 mm penetration, the CBR for 5 mm shall be used.

1.4 Soil

Like other construction materials soils has its own scientific analysis with regards to its abilities on dealing with forces. Being the oldest construction and probably engineering material soil is one of the most complex fields in civil engineering to the point that when it comes to the factor of safety in design whatever has direct contact with soils, e.g. foundations, or soil based constructions, e.g. embankments, require a significantly higher safety factor compare with other construction materials, i.e. the uncertainty in soil analysis and design is higher. After all today soil and rock are still one of the most important materials used in construction. It is used or on its natural state or with improvements, such as compaction, reinforcement and etc., as the main component such as in dams, embankments and highways or as supporter element in every construction, i.e. foundation support.

1.5 Properties of soil

1.5.1 Physical properties

The physical properties of soil are texture, density, structure, porosity, consistency, temperature and colour. These properties determine the aeration of the soil and the ability of water to infiltrate and to be held in the soil. Soil texture is determined by the relative proportion of the three kinds of soil particles, called soil "separates": sand, silt, and clay. Soil density, mainly bulk density, is a measure of soil compaction. Soil porosity is that part of the soil volume which is occupied by water and gases. The ability of soil to stick together is soil consistency. Soil temperature and colour are self-defining. The properties may vary through the depth of a soil profile.

- **Density**

It is the weight per unit volume of an object. Particle density is equal to the mass of solid particles divided by the volume of solid particles - it is the density of only the mineral particles that make up a soil; i.e., it

excludes pore space and organic material. Soil particle density is typically 2.60 to 2.75 grams per cm³ and is usually unchanging for a given soil. Soil bulk density is equal to the dry mass of the soil divided by the volume of the soil; i.e., it includes air space and organic materials of the soil volume.

- **Consistency**

Consistency is the ability of soil to stick to itself or to other objects (cohesion and adhesion respectively) and its ability to resist deformation and rupture. It is of rough use in predicting cultivation problems and the engineering of foundations. Consistency is measured at three moisture conditions: air-dry, moist and wet; and in those conditions the qualities depend upon the clay content. In the wet state, the two qualities of stickiness and plasticity are assessed. A soil's resistance to fragmentation and crumbling is assessed in the dry state by rubbing the sample. Its resistance to shearing forces is assessed in the moist state by thumb and finger pressure. Finally, a soil's plasticity is measured in the wet state by moulding with the hand.

1.6 Classification of soils

Soil classification is the arrangement of soils into different groups such that the soils in a particular group have similar behaviour. As there are a wide variety of soils covering earth, it is desirable to systematize or classify the soils into broad groups of similar behaviour. Soils, in general, may be classified as cohesion-less and cohesive or as coarse-grained and fine-grained. These terms, however, are too general and include a wide range of engineering properties.

1.6.1 Requirements for a Soil Classification System:

For a soil classification system to be useful to the geotechnical engineers, it should have the following basic requirements:

- It should have a limited number of groups.
- It should be based on the engineering properties, which are most relevant for the purpose for which the classification has been made.

- It should be simple and should use the terms, which are easily understood.

1.6.2 Soil Classification Systems:

Several classification systems were evolved by different organizations having a specific purpose as the object. The two classification systems, which are adopted by the US engineering agencies and the State Departments, are the Unified Soil Classification (UCCS) and the American Association of State Highway and Transportation Officials (AASHTO) system. Other countries, including India, have mostly the USCS with minor modifications.

For general engineering purposes, soils may be classified by the following systems

- Particle size classification
- Textural classification
- Highway Research Board (HRB) classification
- Unified Soil Classification
- Indian Soil Classification

1.6.2.1 Particle size classification

As per I.S. Classification (IS: 1498-1970) the soil is divided into six groups:

- Boulders, particle size greater than 300 mm
- Cobble, particle size between 80 mm to 300 mm
- Gravel, particle size between 4.75 mm to 80 mm
- Sand, particle size between 0.075 mm to 4.75 mm
- Silt, particle size between 0.002 mm to 0.075 mm
- Clay, particle size smaller than 0.002 mm (2 μm)

1.7 Outline of Thesis

- Chapter 1 deals with general introduction of CBR.
- Chapter 2 is the literature review of the research work conducted on prediction of CBR.
- Chapter 3 consists of the experimental work done for this study and its results.
- In Chapter 4 the analysis of the results is done.
- Chapter 5 consists of conclusion of the dissertation.

Aggarwal and Ghanekar (1970) performed their research on 48 samples of fine-grained soils found in India, on the basis of which they had tried to develop a correlation between CBR values and either liquid limit, plastic limit or plasticity index. But in that case they failed to find any strong or significant correlation between them. Instead, they found a better correlation when they include the optimum moisture content and liquid limit. The correlation developed is as below:

$$\text{CBR} = 2 - \log(\text{OMC}) + 0.07 * \text{L.L.} \quad [2.1]$$

OMC-optimum moisture content, L.L=Liquid limit

The 48 soil samples tested by them had CBR values not exceeding 9% and the standard deviation obtained was 1.8. Hence, they suggested that the correlation is only of sufficient accuracy for preliminary identification of material. They also recommended that this correlation may be of more use of derived for specific geological regions.

Patel et al. (2010) proposed a method for correlating CBR values with the LL, PL, PI, OMC and Maximum dry density of cohesive soils of various zones of Surat city of Gujarat state. The correlation is established in the form of an equation of CBR as a function of different soil properties by the method of regression analysis.

- **CBR (Unsoak)** = 54.247 - 212.216 (LL) + 212.18 (PL) +211.937 (Ip) - 0.467 (SL) -20.903 (MDD) + 0.159 (OMC) [2.2]

- **CBR (Soak)** = 53.783 - 103.571 (LL) + 103.447 (PL) +103.443 (Ip) - 0.077 (SL) -21.782 (MDD) - 0.304 (OMC) [2.3]

- **CBR (Unsoak)** = 17.009 - 0.0696 (Ip) - 6.296 (MDD) +0.0648 (OMC) [2.4]

- **CBR (Soak)** = 43.907 - 0.093 (Ip) - 18.78 (MDD) - 0.3081(OMC) [2.5]

OMC-Optimum Moisture content, MDD-Maximum dry density, Ip-Plasticity index, LL-liquid limit, PL- Plastic limit

The first preferable model is in the form of equation [2.4] and [2.5] which shows the relation between plasticity index, optimum moisture content, maximum dry density and CBR(soak) value with an error of -2.5% for equation 3 and -5% for equation [2.5].

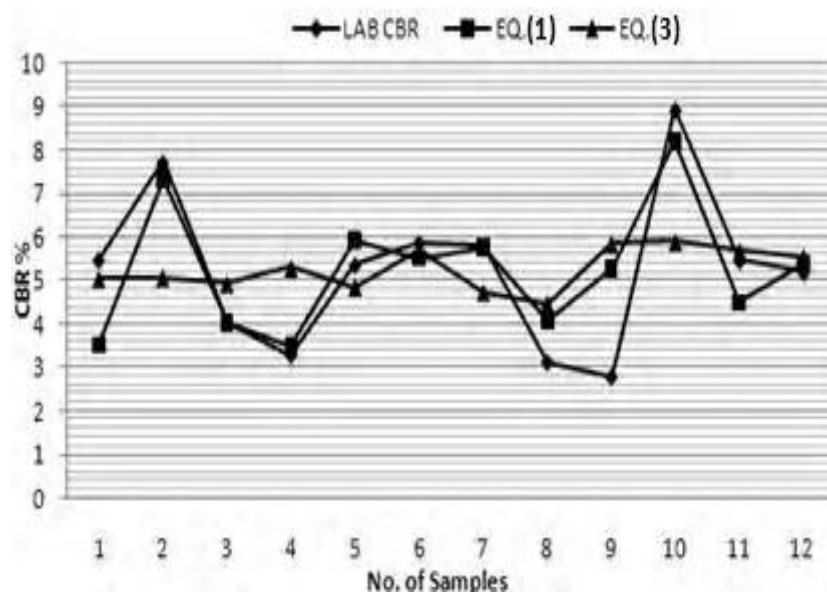


Fig. 2.1: Comparison between laboratory CBR and CBR value obtained from equation [2.1] & [2.3] in unsoaked condition [Patel et al. (2010)]

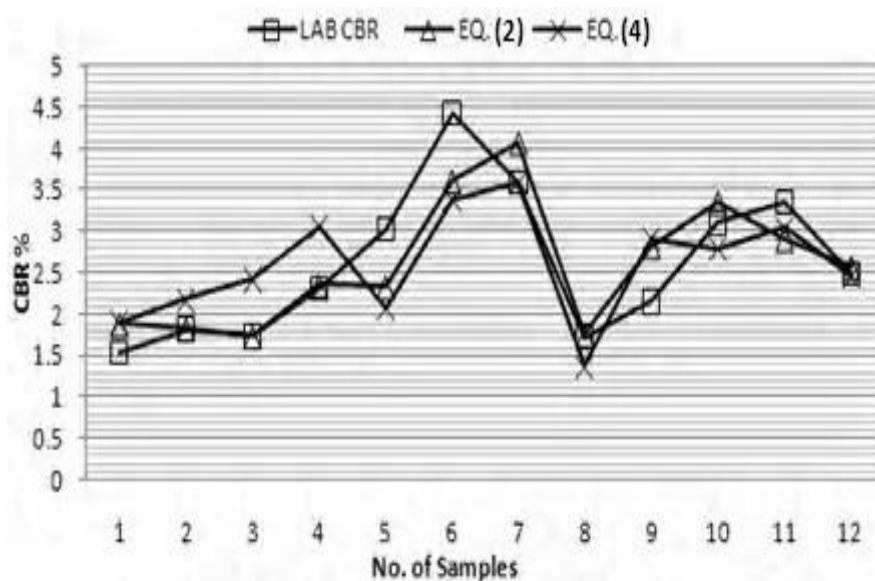


Fig. 2.2 Comparison between laboratory CBR and CBR value obtained from equation [2.2] & [2.4] in soaked condition [Patel et al. (2010)]

The second preferable model is in the form of equation [2.2] and [2.3]. In these equations the correlation is developed between CBR value and the group of soil index properties which include, liquid limit, plastic limit, plasticity index, shrinkage limit, maximum dry density and optimum moisture content. For the fine grained soil ranges unsoaked CBR ranges from 2.5 % to 9.0 % and soaked CBR ranges from 1.5 % to 4.5 %. Effect of soil properties on CBR value can be explained as Liquid Limit and Plastic Limit has low influence on CBR value. But CBR value varies with Plasticity Index, when Plasticity Index increases CBR value decreases and when Plasticity Index decreases CBR value increases. This shows that there is relation between CBR value and Clay content of the soil.

Venkatasubramanian et al. (2011) proposed a method for correlating CBR values with the liquid limit, plastic limit, plasticity index, OMC, Maximum dry density, UCC values of various soils taken from in and around three different districts in Tamil-Naidu. The relation was made with the help of artificial neural network system and multiple regression analysis. The tests were performed as per I.S. code specification. The results showed that the specific gravity for 15 samples varied from 1.609 to 2.55 and plasticity index varied from 5 to 9. All samples had good amount of sand content which ranged from 28% to 86%. Unsoaked CBR value is around 2-3 times the soaked CBR value. Unconfined compressive strength varied from 66.2KN/m² to 183.90KN/m² for different samples. From the results it was observed that samples 1, 2, 5, 8, 9, 10, 11, 12 and 15 multiple linear regression analysis under estimates actual CBR values and for remaining samples it over estimates. Similarly for samples 1, 2, 4, 5, 6, 9, 11, 14 and 15 neural network model under estimates CBR value and for remaining samples it over estimated.

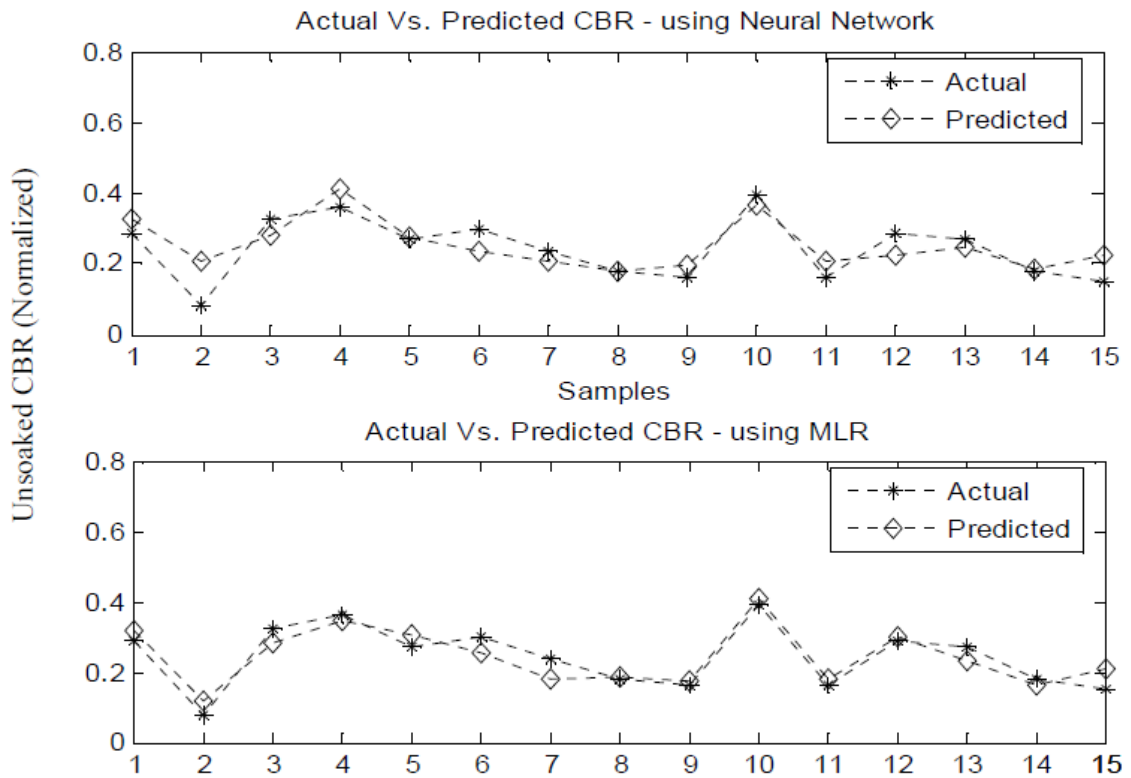


Fig. 2.3 Comparison of un-soaked CBR actual Vs predicted from ANN and MLR [Venkatasubramanian et al. (2011)]

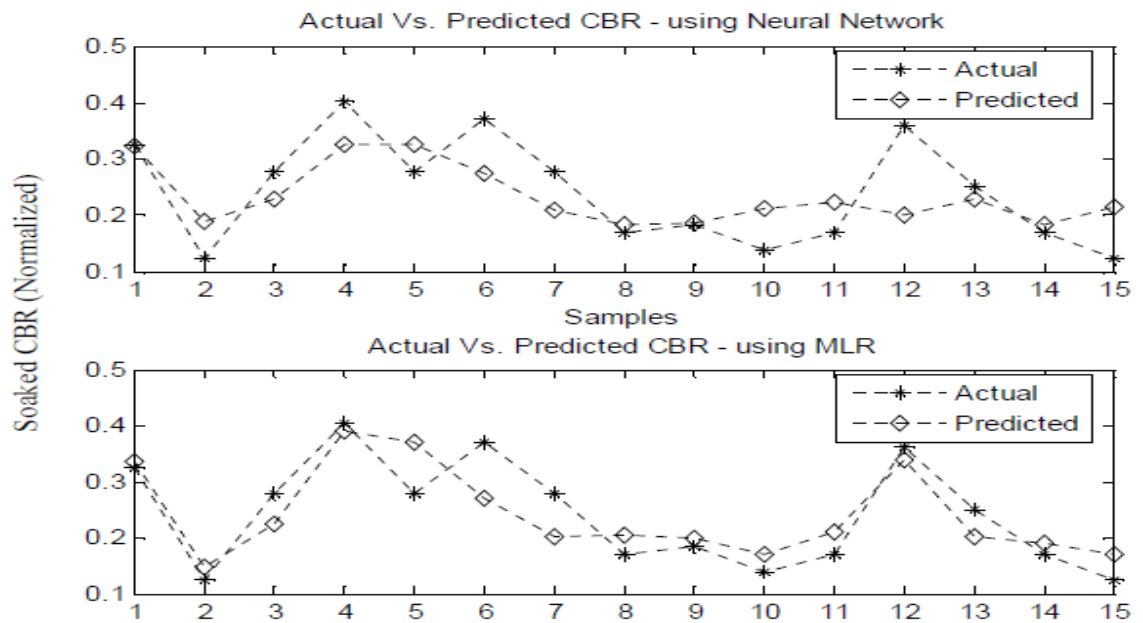


Fig. 2.4: Comparison of soaked CBR actual Vs predicted from ANN and MLR [Venkatasubramanian et al. (2011)]

It was also concluded from this research that the CBR prediction model based on multiple linear regression performs better than neural network model and hence recommended to predict CBR values.

Saklecha et al. (2011) presents the application of artificial neural networks to study the strength characterization of foundation soils in a basaltic terrain. In this research, a total of 387 laboratory test data sets were collected for different locations in Wardha district in the state of Maharashtra, India. To get successful network, five models of neural network of neural network with diverse topologies were developed.

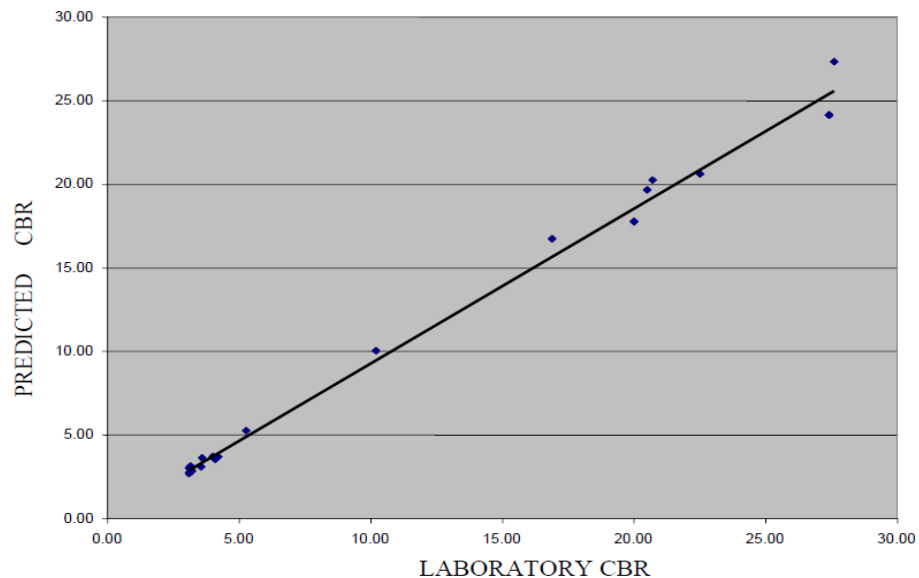


Fig. 2.5: Linear correlation graph between predicted CBR and Laboratory CBR [Saklecha et al. (2011)]

The models were trained and cross validated until the convergence was achieved in the mean sum of squares of the network errors. The correlation coefficient between predicted CBR and desired CBR was found to be 0.88, which showed a good learning of ANN model. Consequently it could be concluded that the ANNs are found to be able to learn the relation between the strength parameter CBR and mechanical properties of foundation soil.

Datta and Chottopadhyay (2011) checked the validity and applicability of correlation which were used for prediction of CBR for their acceptance in general

practice. The predicted and tested values of CBR of various soils were used to check the applicability and limitations of available methods and were presented in this research.

It was found that the correlation given by Vinod and Cletus (2008) seems to give good agreement of tested values and predicted values of CBR for CI soils but in case of CL soils, the predicted values are much higher than the experimental values.

$$\text{CBR} = -0.889(\text{LL}) + 45.616 \quad [6]$$

In another case the predicted values from correlation given by Patel and Desai (2010) agree with the tested values particularly for CI soils. But for other soils the predicted values are much lower than the tested values.

Ramasubbarao and Sankar (2013) conducted tests to determine grain size, liquid limit, plastic limit, MDD and OMC. In this study a correlation was established in the form of equation of soaked CBR value as a function of different soil properties by regression analysis in which regression models of both simple linear and multiple linear were developed. The range of parameters studied in this investigation is: Gravel (0-24)%, sand(0-40.14)%, Fines(50-100)%, LL(24.6-94)%, PL(11.9-36)%, MDD(1.25-1.85)gm/cc, OMC(12.3-35.4)% and soaked CBR(.8-5.86)%. Validity of the proposed model was verified by data of soil properties reported by few investigators. The statistical parameters indicated that better performance can be obtained from the model developed using MLRA by showing the highest R-value of 0.96 and R²-value of 0.92 and the lowest error of 0.97. It was observed that the use of index properties appears to be reasonable in the estimation of soaked CBR value of fine grained soils.

Talukdar (2014) conducted index tests on 16 different samples collected from different districts of Assam. The correlation was developed between fine-grained soil (ML and MI) and PI, MDD and OMC. It was observed that the CBR value decreases with the increase in the plasticity index and optimum moisture content of soil but increases with the increase in the maximum dry density.

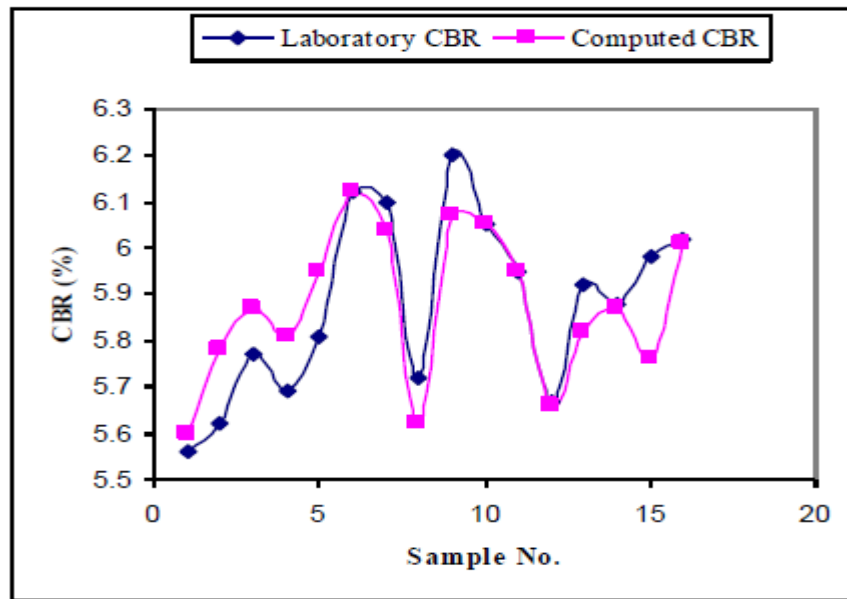


Fig. 2.6: Comparison of laboratory and computed CBR value [Talukdar (2014)]

There was a slight difference between the CBR value determined in the laboratory and computed by multiple regression models which involves LL, PI, MDD and OMC. The comparison also show that there were some soil samples which have no difference in the laboratory and the computed value of CBR, but the maximum difference observed was 3.67%.

Harini and Naagesh (2014) present the application of ANN and MLR to estimate the CBR of of fine-grained soils. The prediction models were developed to correlate CBR with the basic properties of soil i.e. optimum moisture content, maximum dry density, liquid limit, plastic limit, plasticity index and percentage fines.

A total 40 soil samples were collected from the surroundings of Bangalore city. Out of total 40 soils sample data, 30 were used for training and 10 were used for testing. The research showed that the CBR is best correlated with the liquid limit and percent fines, this model had a high correlation coefficient (CC=0.86) with

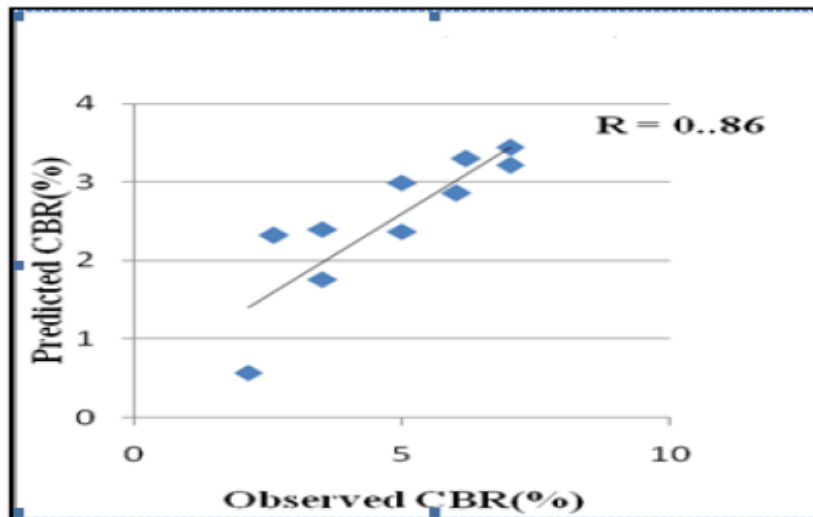


Fig. 2.7: Scattered plot of observed Vs predicted CBR for the best model by MLR [Harini and Naagesh (2014)]

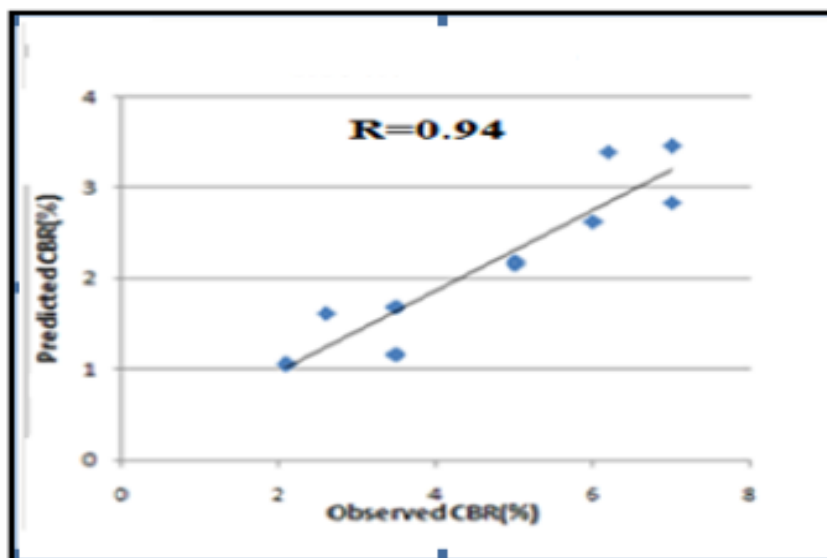


Fig. 2.8: Scattered plot of observed Vs predicted CBR by ANN [Harini and Naagesh (2014)]

least RMSE values. It was concluded from the research that Neural network models, which can incorporate additional model parameters, give less scattered parameters than those given by MLR. Therefore ANN model and MLR can be used for correlation of CBR with index properties.

Experimental Program and Results

Eleven different soil samples were collected from Patiala, Derabassi, Bhawanigarh, Kurali, Khurana village, Adampur, Nabha, Devigarh, Banur, Rajpura and Tangori. These soil samples were tested for CBR value, OMC, Maximum Dry Density, Grain size analysis, PL, LL, PI and Unconfined compression test. These tests were performed as per I.S. code specification.

| | |
|--------------------------------|---|
| Number of Samples | 11 |
| Parameters Analysed | Grain Size Analysis |
| | Liquid Limit |
| | Plastic Limit |
| | Plasticity index |
| | Maximum Dry Density |
| | Optimum Moisture Content |
| | Unconfined Compressive Strength |
| | California Bearing Ratio (Soaked and Unsoaked) |

Test Methods**3.1 Index properties of soil**

These are the properties of soil, which are used to characterize soil and determine their basic properties such as moisture content, particle size distribution, specific gravity, consistency and moisture-density relationships.

3.1.1 Sieve Analysis

Sieve analysis is done to determine the percentage of various grain sizes. The grain size distribution helps in determining the textural classification of soils whether it is gravel, sand, silt, clay, etc. which is then useful in evaluating the engineering characteristics such as permeability, strength, swelling potential and

susceptibility to frost action. The sieves for soil tests used are 4.75 mm to 75 microns. The test is performed as per IS: 2720-Part IV (2006).

3.1.2 Atterberg limit

This limit describes the plasticity and consistency of fine-grained soils with varying degrees of water content. For the portion of soil passing 425 micron I.S. sieve, the moisture content is varied to determine the three stages of soil behaviour in terms of consistency. These stages are generally known as liquid limit (LL), plastic limit (PL) and shrinkage limit (SL) of soils.

3.1.2.1 Liquid limit test

The liquid limit is defined as the water content at which part of soil, cut by a groove of standard dimension will flow together for a distance of 1.25 cm under an impact of 25 blows in a standard liquid limit apparatus. The soil at that water content has some strength which is about 0.17 N/cm^2 (17.6gm/cm^2). At this water content soil just passes from liquid state to plastic state. The test is performed as per IS: 2720-PartV (1985).

3.1.2.2 Plastic limit test

The moisture at which soil has the smallest plasticity is known as the plastic limit. Just after plastic limit the soil displays the properties of a semi-solid. For determination purpose, the plastic limit is defined as the water content at which soil will just begin to crumble when rolled into a thread of 3mm in diameter. The difference in moisture content or interval between the liquid and plastic limits is termed as the plasticity index. The values of liquid limit and plastic limit are directly used for classifying the fine grained cohesive soil according to Indian standard on soil classification.

3.2 Compaction test

It is the process of densification of soils. Compaction is the application of mechanical energy to a soil so as to rearrange its particles and reduce the void ratio. It is applied to improve the properties of an existing soil or in the process of placing fill such as in the construction of embankments, road bases, runways,

earth dams, and reinforced earth walls. Compaction is also used to prepare a level surface during construction of buildings. There is usually no change in the water content and in the size of the individual soil particles. The test is performed as per IS: 2720-Part VIII (1995).

3.3 Unconfined compression test

This test is done to determine the shear parameters of cohesive soil. It may not always be possible to conduct the bearing capacity test in the field. Therefore it is sometimes easier to take the undisturbed soil sample and test its strength in the laboratory and also to choose the best material for the embankment; one has to conduct strength tests on the samples selected. Under these circumstances it is easy to perform the unconfined compression test on undisturbed or remoulded soil sample.

3.4 California Bearing Ratio

It is the ratio of force per unit area required to penetrate a soil mass with standard circular piston at the rate of 1.25 mm/min. to that required for the corresponding penetration of a standard material.

3.4.1 Laboratory test

In the laboratory CBR tests are usually made on test specimens at the optimum moisture content value for the soil as determined using the standard or modified compaction test. California Bearing Ratio is the ratio of force per unit area required to penetrate a soil mass with standard circular piston at the rate of 1.25 mm/min. to that required for the corresponding penetration of a standard material. The test can be performed on remoulded specimens and on undisturbed specimens which may be compacted either statically or dynamically. The standard loads adopted for different penetrations for the standard material with a CBR value of 100% are shown in the table below: The test is performed as per IS: 2720-Part XVI (2002).

Table 3.1: Loads adopted for different penetrations

| Penetration of Plunger (mm) | Standard load (kg) |
|-----------------------------|--------------------|
| 2.5 | 1370 |
| 5.0 | 2055 |
| 7.5 | 2630 |
| 10.0 | 3180 |
| 12.5 | 3600 |

3.4.2 Equipments and tool required:

1. Cylindrical mould having inside diameter 150 mm and height 175 mm, provided with a detachable extension collar 50 mm height and a detachable perforated base plate 10 mm thick.
2. Spacer disc with diameter 148 mm and 47.7 mm in height along with handle.
3. Metal rammers weighing 2.6 kg with a drop of 310 mm (or) weight 4.89 kg a drop 450 mm.
4. Weights. One annular metal weight and several slotted weights each weighing 2.5 kg, 147 mm in diameter, with a central hole of 53 mm in diameter.
5. Loading machine shall have a capacity of 5000 kg and equipped with a movable base or head that travels at a uniform rate of 1.25 mm/min. Complete with load indicating device.
6. The metal penetration piston shall be 50 mm in diameter and minimum of 100 mm in length.
7. I.S. sieves. 4.75 mm and 20 mm.
8. Miscellaneous apparatus such as a mixing bowl, straight edge, scales soaking tank or pan, drying oven, containers and filter paper.

3.4.3 Preparation of the specimen

Prepare the remoulded soil specimen at maximum dry density or any other density at which C.B.R test has performed. Maintain the specimen at optimum moisture content or the field moisture as required.



Fig.3.1: CBR apparatus (Digital)

3.4.4. Compaction

Take about 4.5 to 5.5 kg of soil and mix it thoroughly with the required water. Compact the sample in the mould using either light compaction or heavy compaction. In light compaction test, we compact the soil in 3 equal layers, in which each layer is given 55 blows by 2.6 kg rammer and in heavy compaction we compact the soil in 5 layers, 56 blows to each layer by the 4.89 kg rammer. Remove the collar and trim off soil. Turn the mould upside down and then remove the base plate and displacer disc. Weigh the mould with compacted soil and then determine the bulk density and dry density. Place filter paper on top of the compacted soil (collar side) and clamp the perforated base plate on to it.

3.5 Test results for Sample number-1

Location- Patiala city

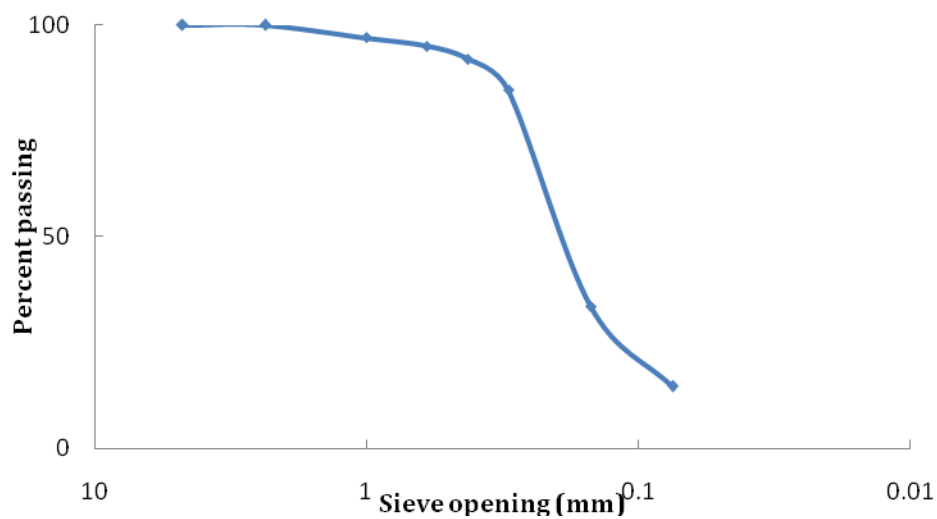


Fig. 3.2: Gradation curve for sieve analysis

The soil was found to be SC type (Clayey sand). The Fines content was 14.6% and sand content was 85.4%.

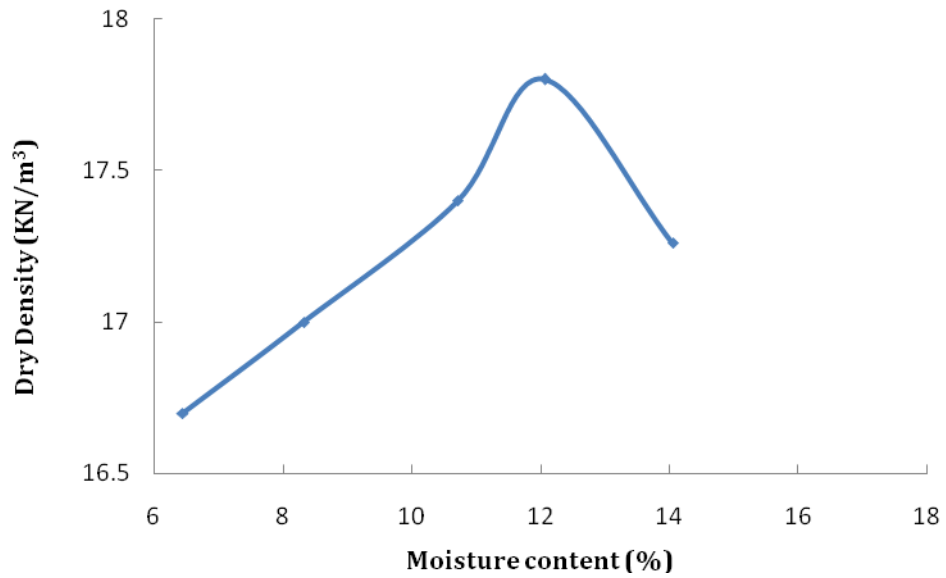


Fig. 3.3: Compaction curve for determination of MDD and OMC

From the plot of Dry density versus moisture content we obtained Max dry density and optimum moisture content as 17.8KN/m³ and 12% respectively.

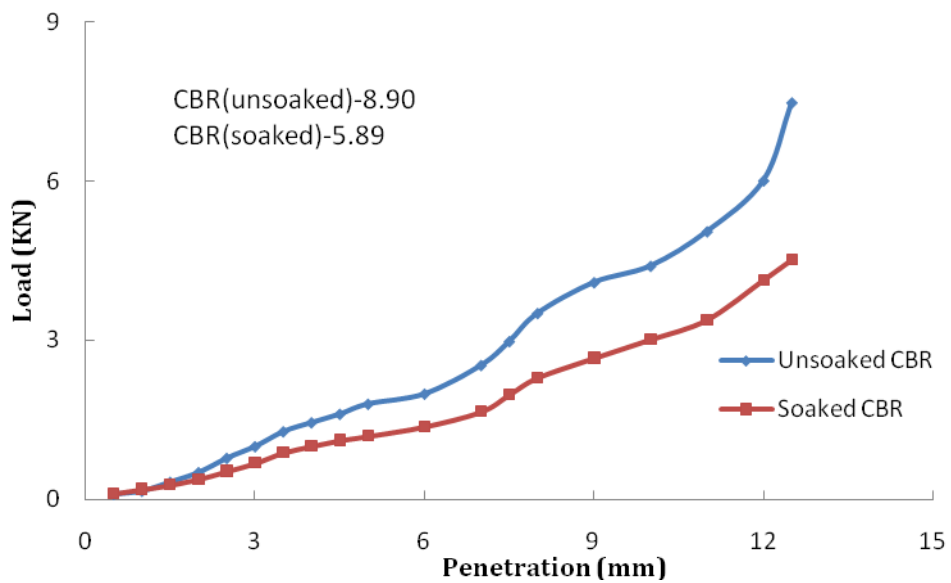


Fig. 3.4: Graph showing load Vs penetration for determination of CBR value

3.6 Test results for Sample number-2

Location-Derabassi

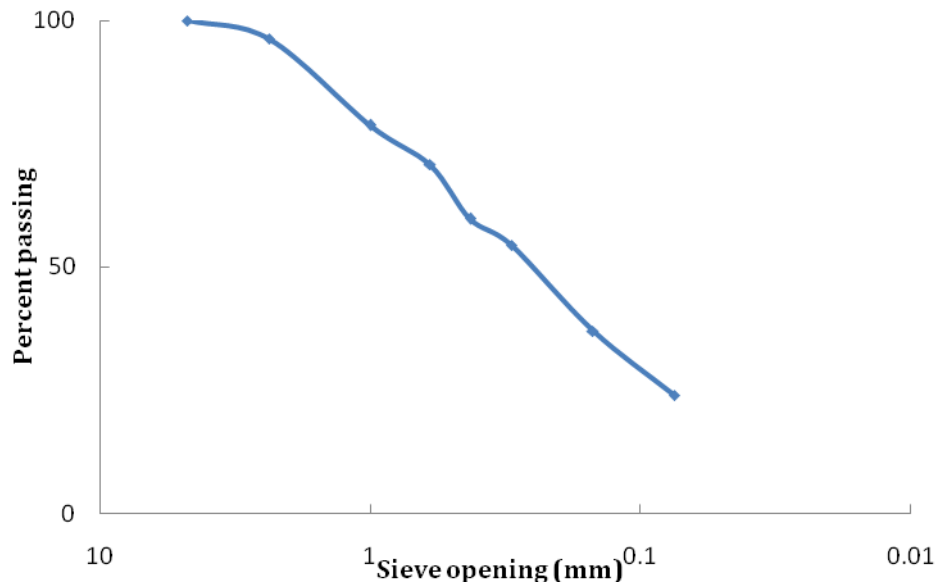


Fig. 3.5: Gradation curve for sieve analysis

The soil was found to be SC type (Clayey sand). The Fines content was 24% and sand content was 76%.

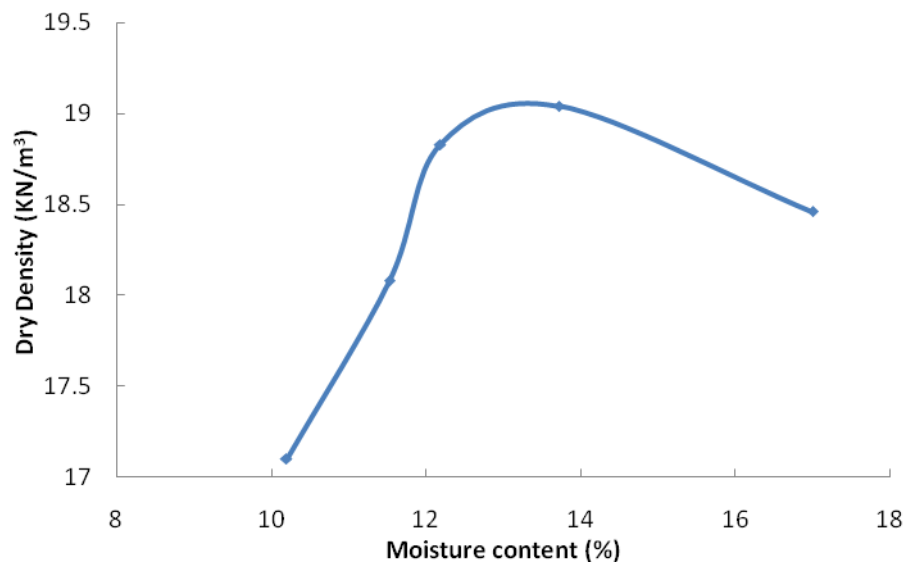


Fig. 3.6: Compaction curve for determination of MDD and OMC

From the plot of Dry density versus moisture content we obtained Max dry density and optimum moisture content as 19.04KN/m³ and 14% respectively

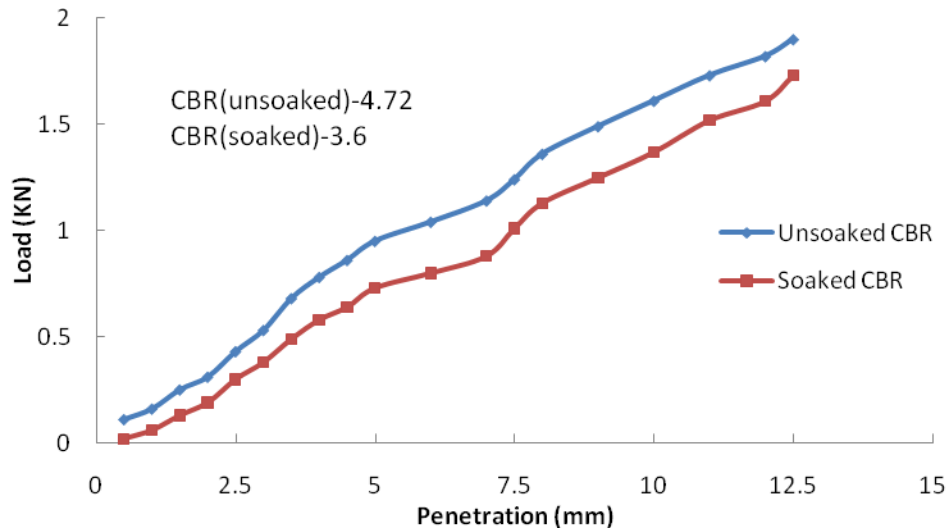


Fig. 3.7: Graph showing load Vs penetration for determination of CBR value

3.7 Test results for Sample number-3

Location-Bhawanigarh

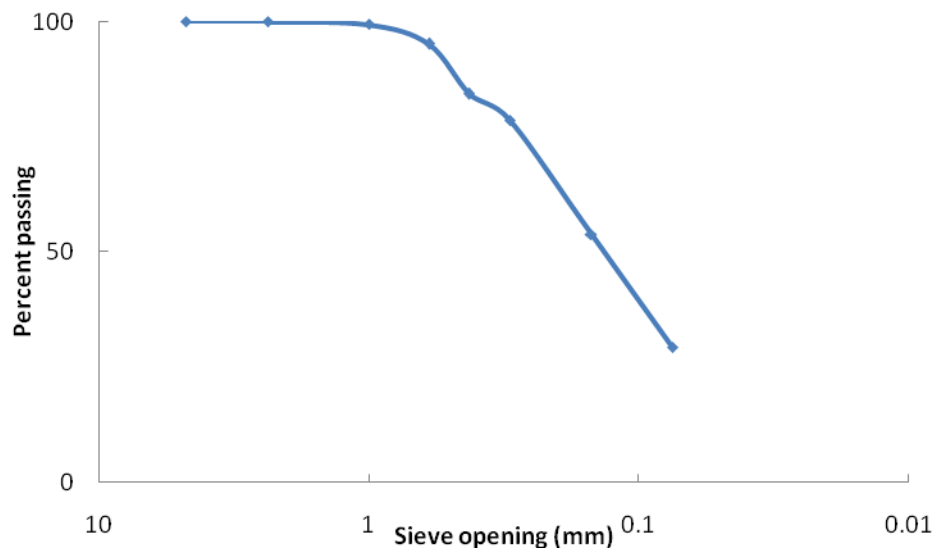


Fig. 3.8: Gradation curve for sieve analysis

The soil was found to be SC type (Clayey sand). The Fines content was 29.4% and sand content was 70.6%.

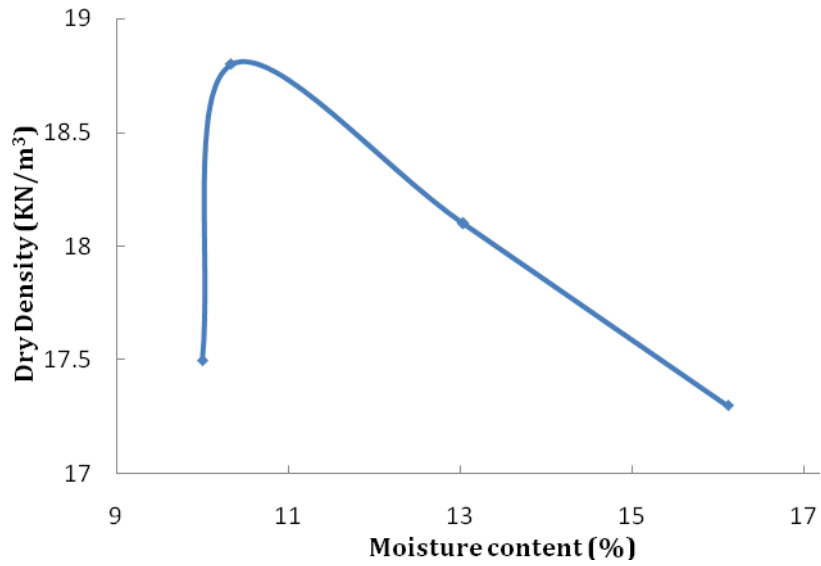


Fig. 3.9: Compaction curve for determination of MDD and OMC

From the plot of Dry density versus moisture content we obtained Max dry density optimum moisture content as 18.8KN/m³ and 10.34% respectively.

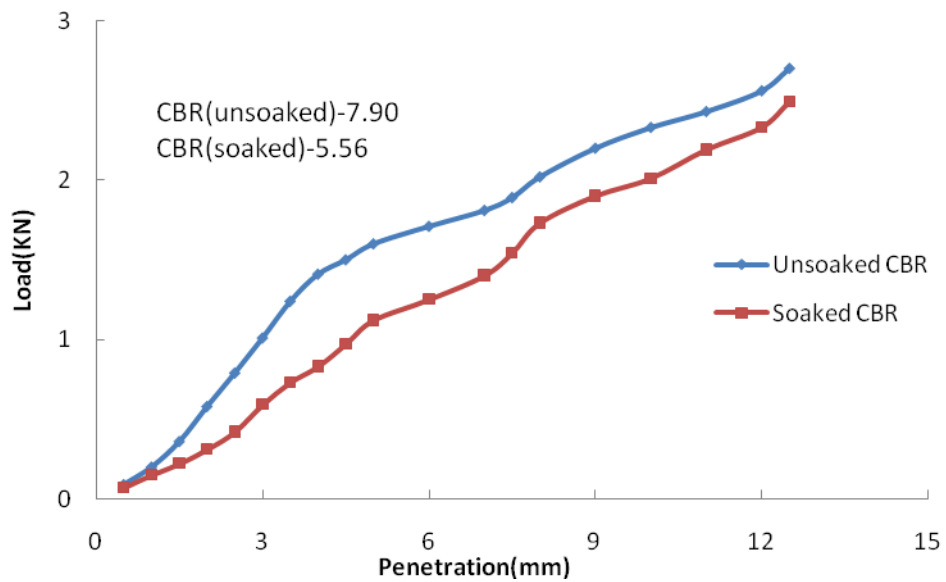


Fig. 3.10: Graph showing load Vs penetration for determination of CBR value

3.8 Test results for Sample number-4

Location-Kurali

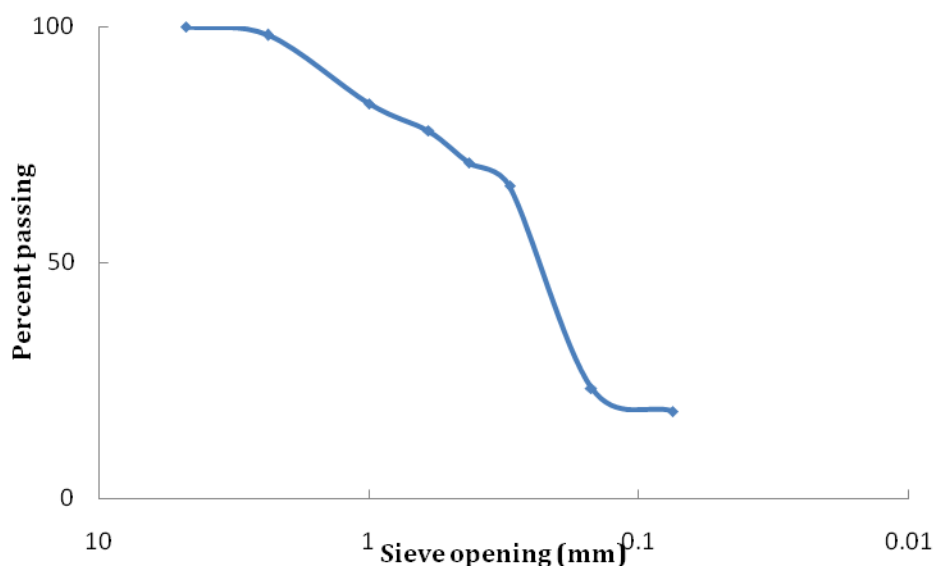


Fig. 3.11 Gradation curve for sieve analysis

The soil was found to be SC type (Clayey sand). The Fines content was 18.5% and sand content was 81.5%

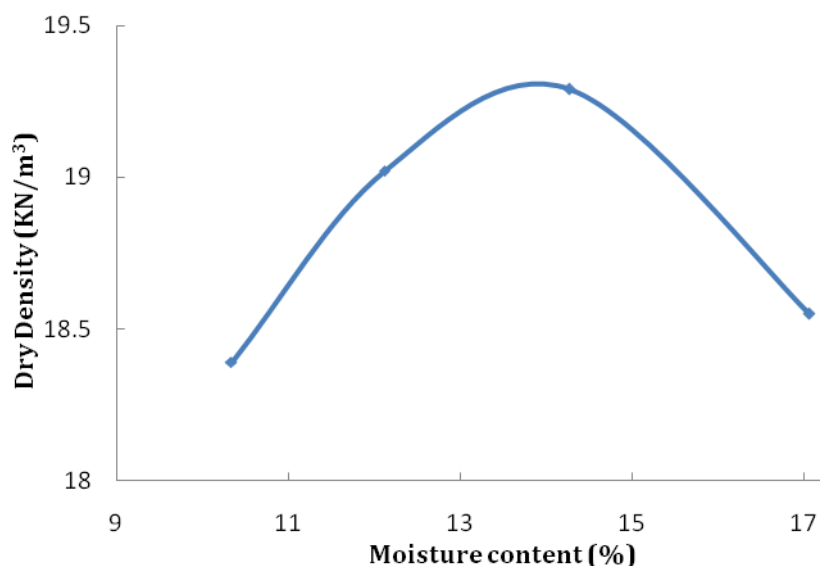


Fig. 3.12 Compaction curve for determination of MDD and OMC

From the plot of Dry density versus moisture content we obtained Max dry density and optimum moisture content as 19.29KN/m³ and 14.28% respectively

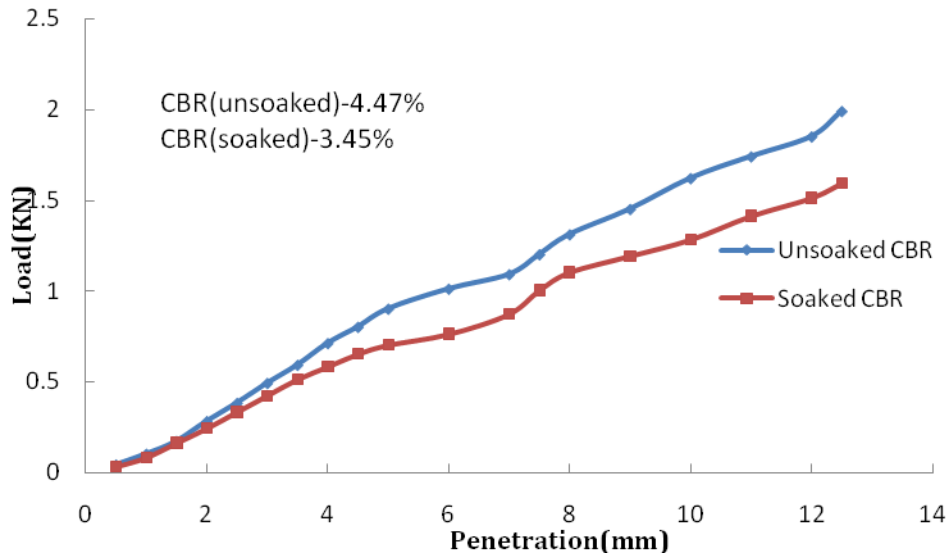


Fig. 3.13: Graph showing load Vs penetration for determination of CBR

3.9 Test results for Sample number-5

Location-Khurana village

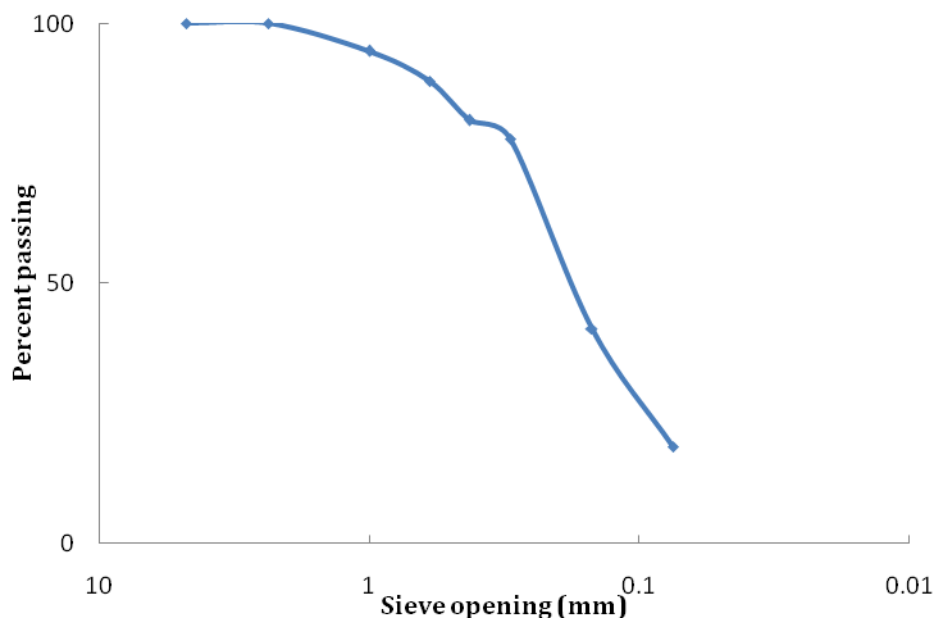


Fig. 3.14: Gradation curve for sieve analysis

The soil was found to be SC type (Clayey sand). The Fines content was 18.7% and sand content was 81.3%

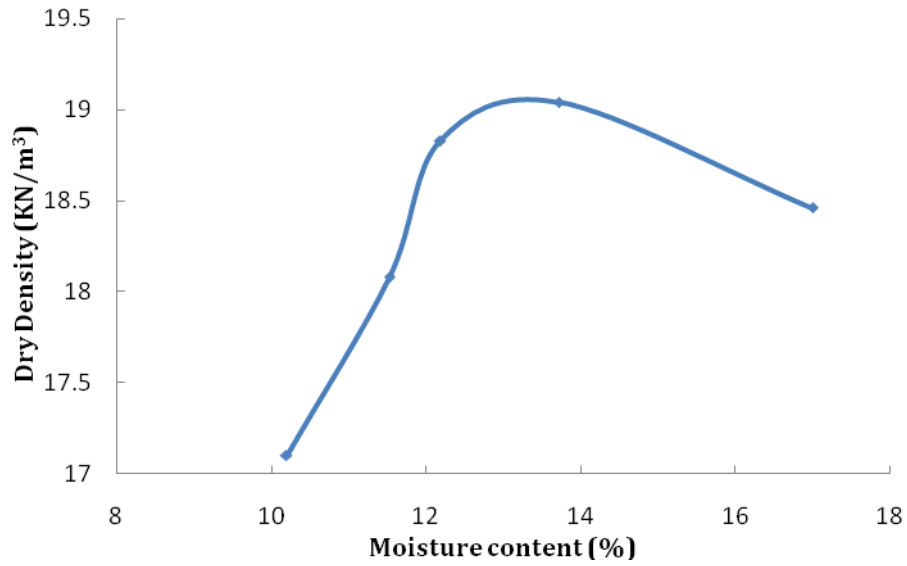


Fig. 3.15: Compaction curve for determination of MDD and OMC

From the plot of Dry density versus moisture content we obtain Max dry density and optimum moisture content as 18.8KN/m³ and 10.34% respectively.

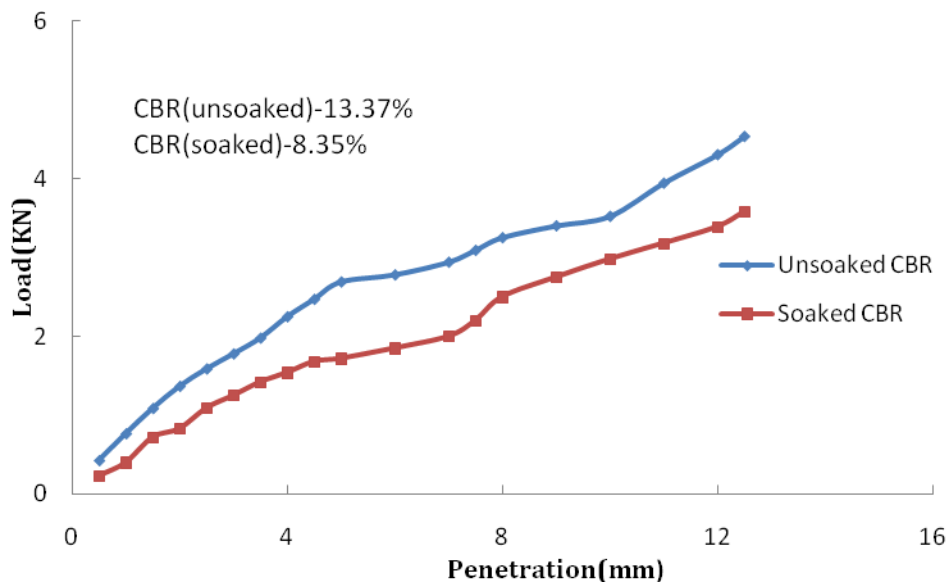


Fig. 3.16: Graph showing load Vs penetration for determination of CBR

3.10 Test results for Sample number-6

Location-Adampur

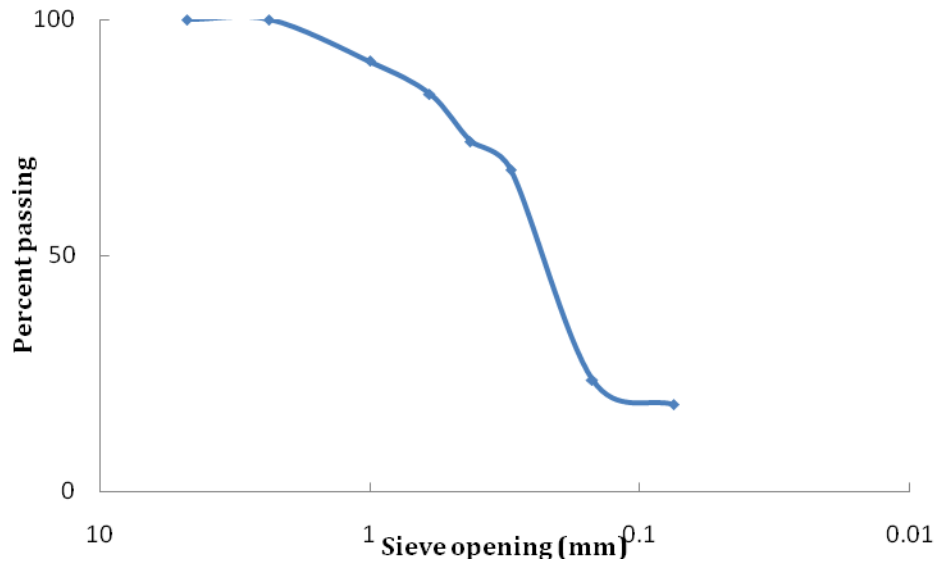


Fig. 3.17: Gradation curve for sieve analysis

The soil was found to be SC type (Clayey sand). The Fines content was 18.5% and sand content was 81.5%.

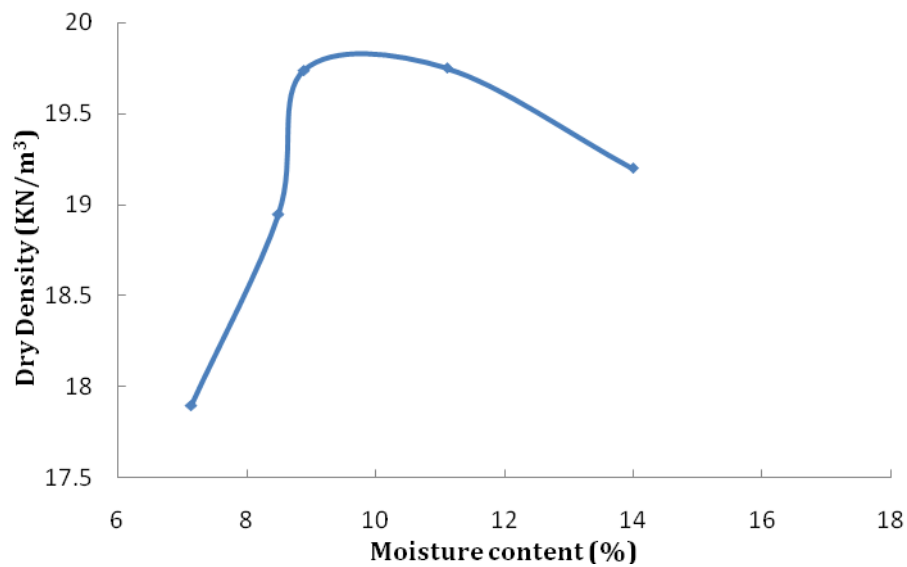


Fig. 3.18: Compaction curve for determination of MDD and OMC

From the plot of Dry density versus moisture content we obtained Max dry density and optimum moisture content as 19.75KN/m³ and 11.12% respectively.

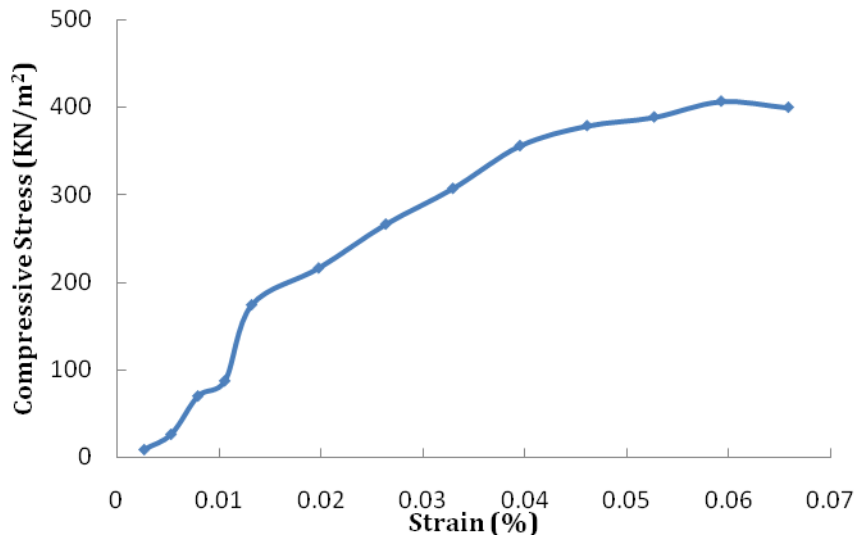


Fig. 3.19: Graph showing Compressive Stress Vs Strain

The Unconfined compressive strength was found to be 4.06 kg/cm² and the strain at failure was 6.57%.

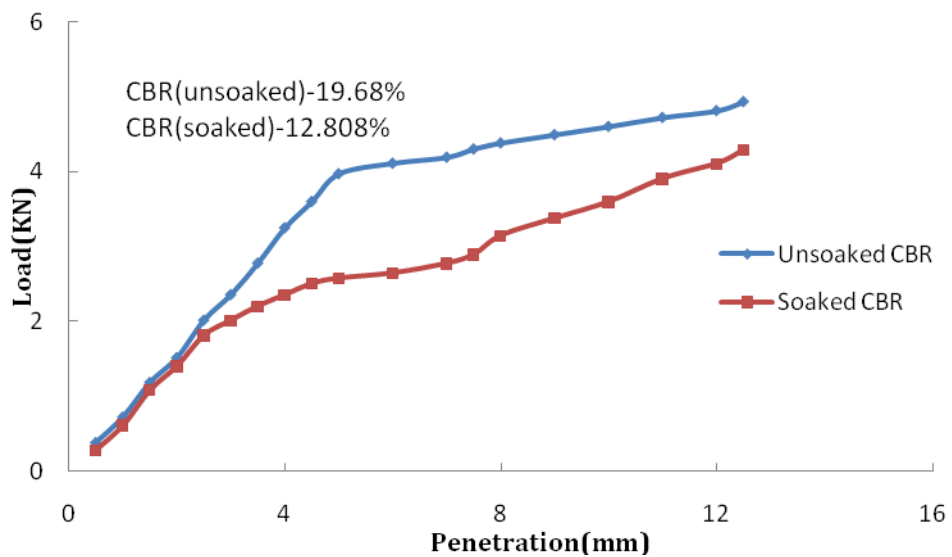


Fig. 3.20: Graph showing load Vs penetration for determination of CBR

3.11 Test results for Sample number-7

Location-Devigarh

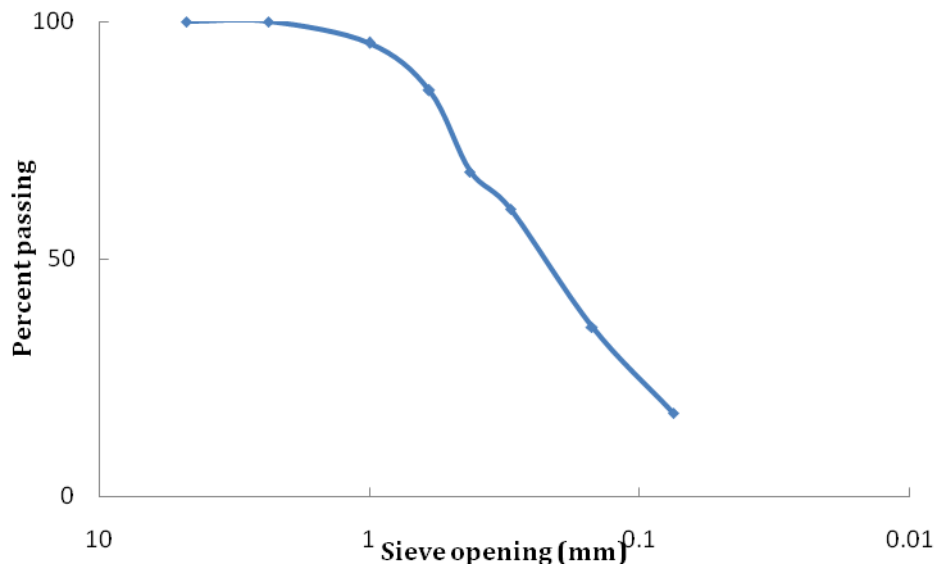


Fig. 3.21: Gradation curve for sieve analysis

The soil was found to be SC type (Clayey sand). The Fines content was 16% and sand content was 84%.

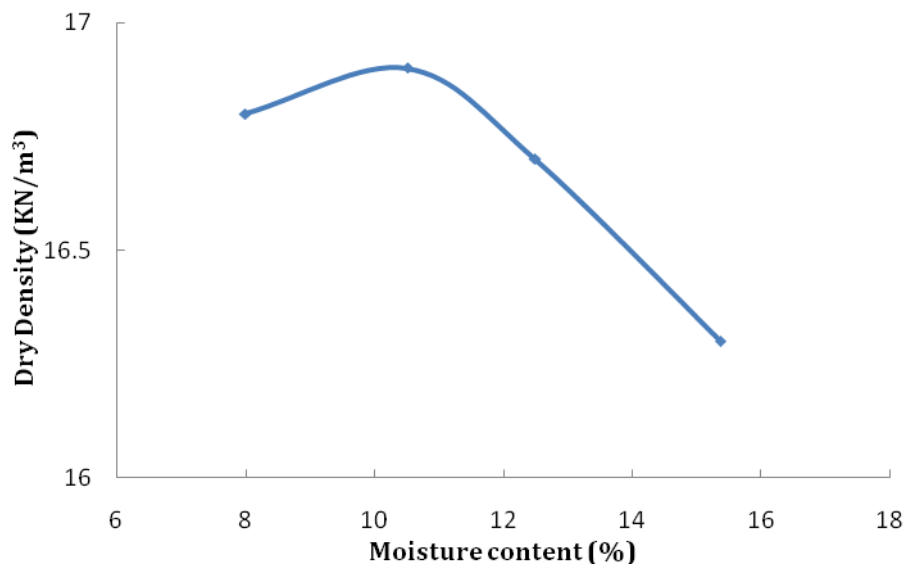


Fig. 3.22: Compaction curve for determination of MDD and OMC

From the plot of Dry density versus moisture content we can obtain Max dry density and optimum moisture content as 16.9KN/m³ and 10.52% respectively

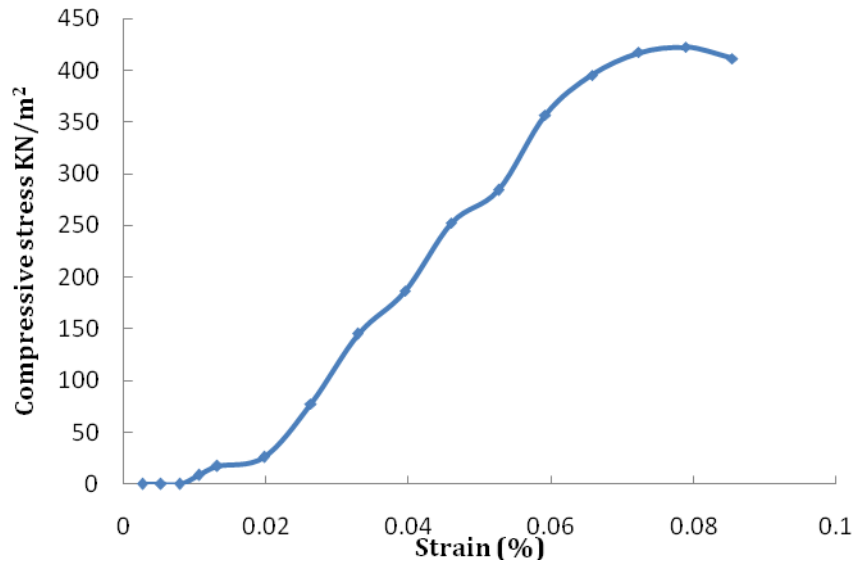


Fig. 3.23: Graph showing Compressive Stress Vs Strain

The Unconfined compressive strength was found to be 422 KN/ m² and the strain at failure was 8.55%.

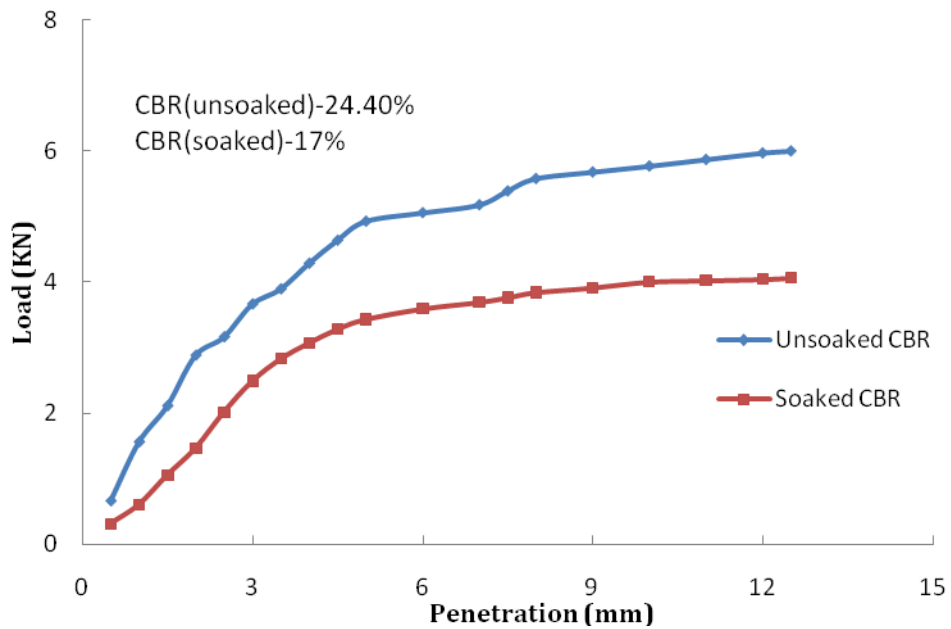


Fig. 3.24: Graph showing load vs penetration for determination of CBR value

3.12 Test results for Sample number-08

Location-Banur

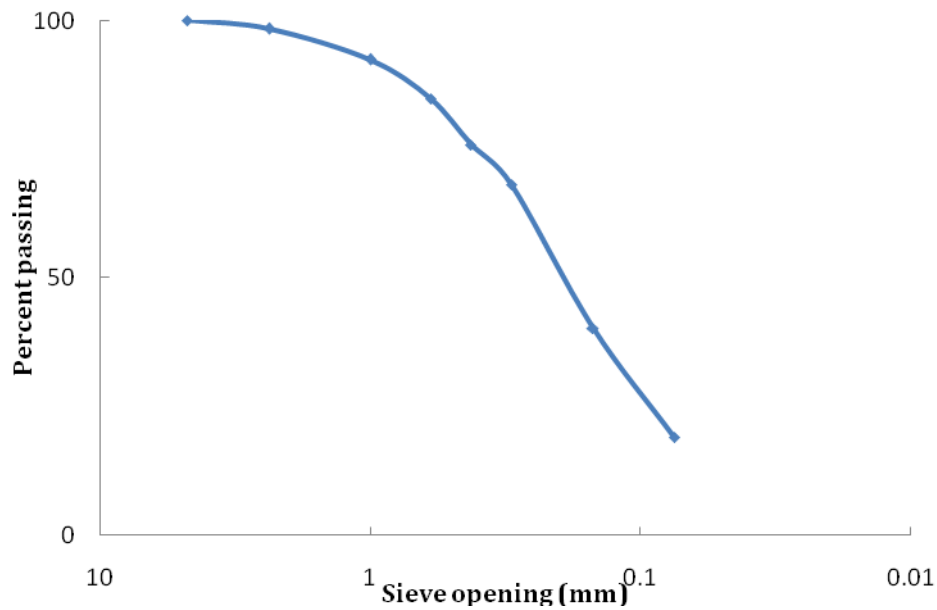


Fig. 3.25: Gradation curve for sieve analysis

The soil was found to be SC type (Clayey sand). The Fines content was 19% and sand content was 81%.

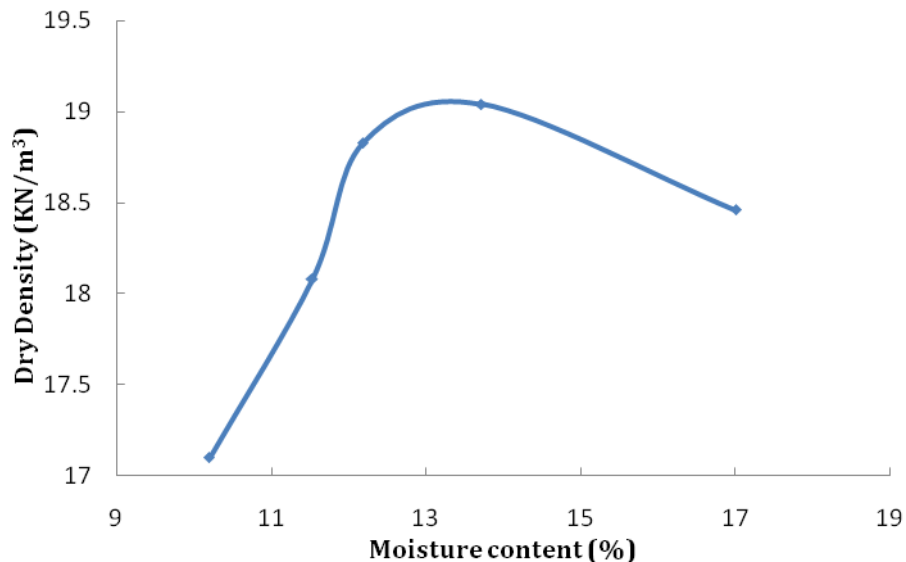


Fig. 3.26 Compaction curve for determination of MDD and OMC

From the plot of Dry density versus moisture content we obtained Max dry density and optimum moisture content as 19.2KN/m³ and 13.6% respectively.

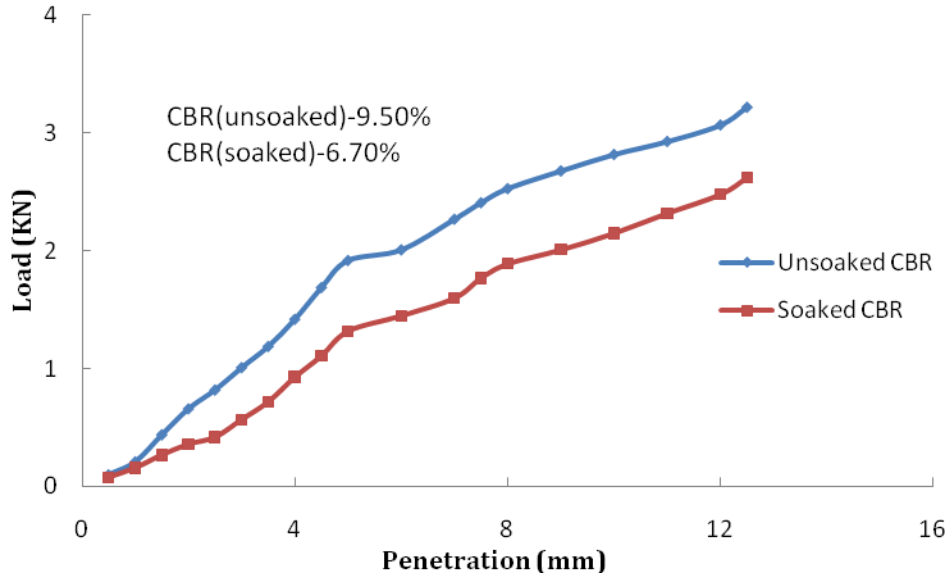


Fig. 3.27: Graph showing load Vs penetration for determination of CBR

3.13 Test results for Sample number-09

Location-Rajpura

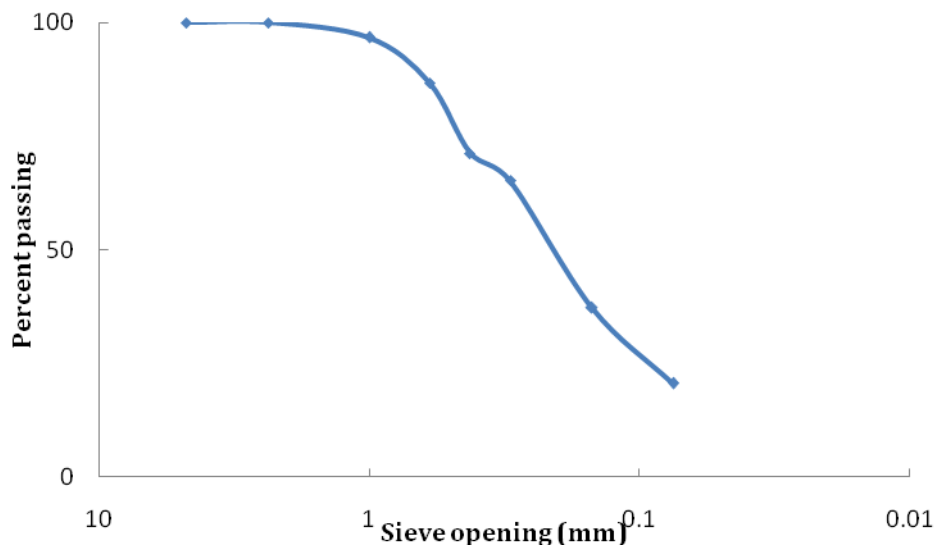


Fig. 3.28: Gradation curve for sieve analysis

The soil was found to be SC type (Clayey sand). The Fines content was 20.6% and sand content was 79.4%.

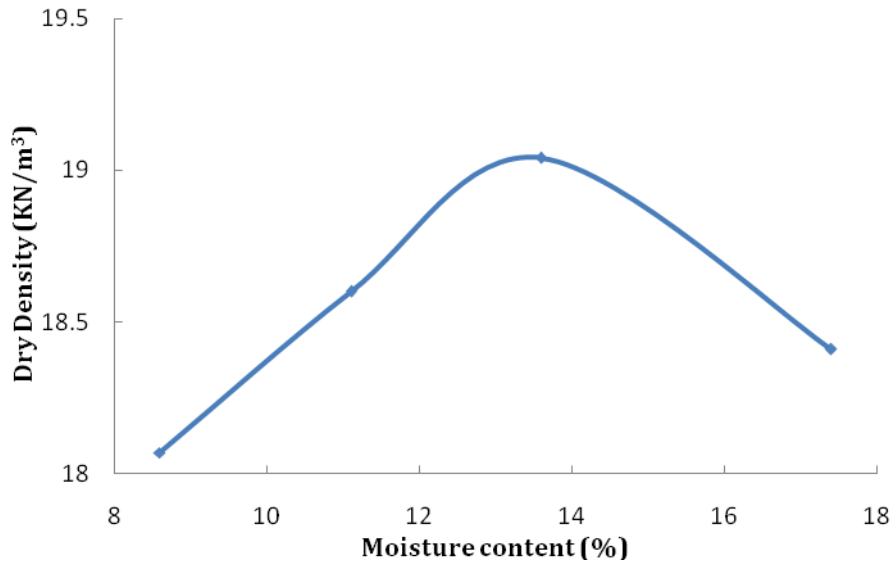


Fig. 3.29 Compaction curve for determination of MDD and OMC

From the plot of Dry density versus moisture content we obtained Max dry density and optimum moisture content as 19.04KN/m³ and 13.6% respectively.

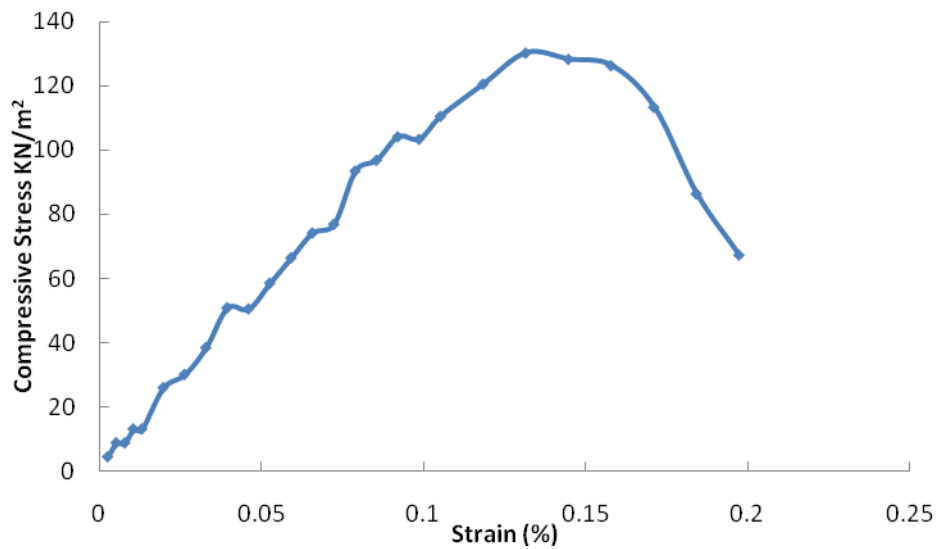


Fig. 3.30: Graph showing Compressive Stress Vs Strain

The Unconfined compressive strength was found to be 247 KN/m² and the strain at failure was 3.94%.

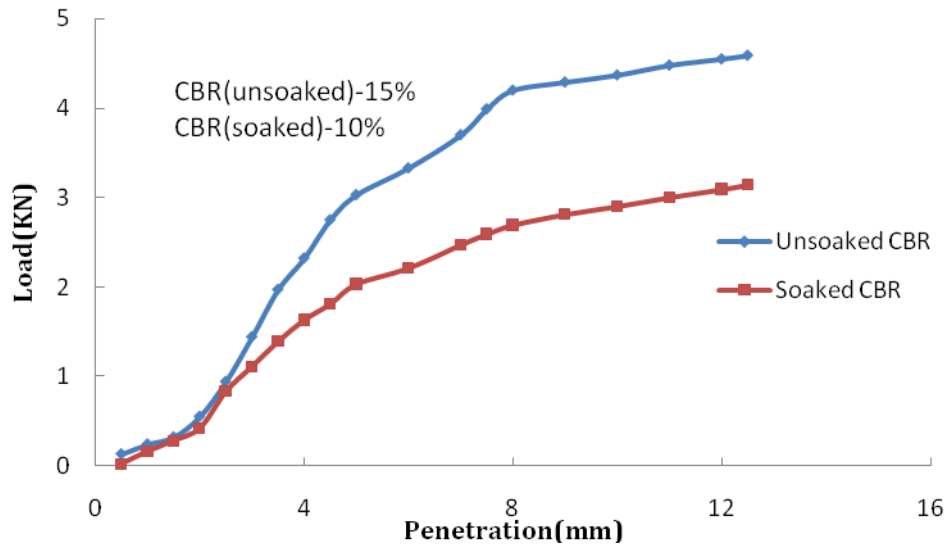


Fig. 3.31: Graph showing load Vs penetration for determination of CBR

Test results for Sample number-10

Location-Tangori

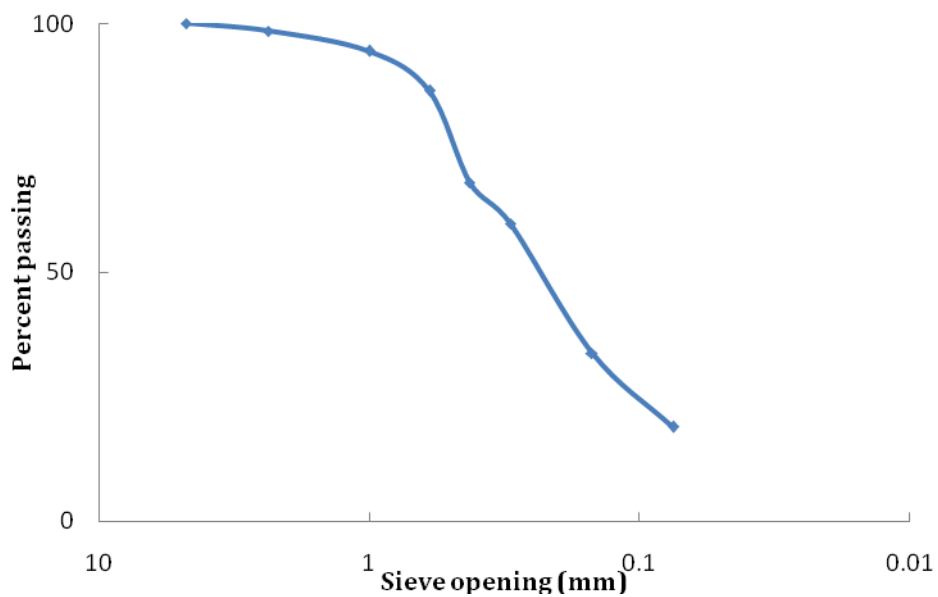


Fig. 3.32: Gradation curve for sieve analysis

The soil was found to be SC type (Clayey sand). The Fines content was 18.9% and sand content was 81.1%.

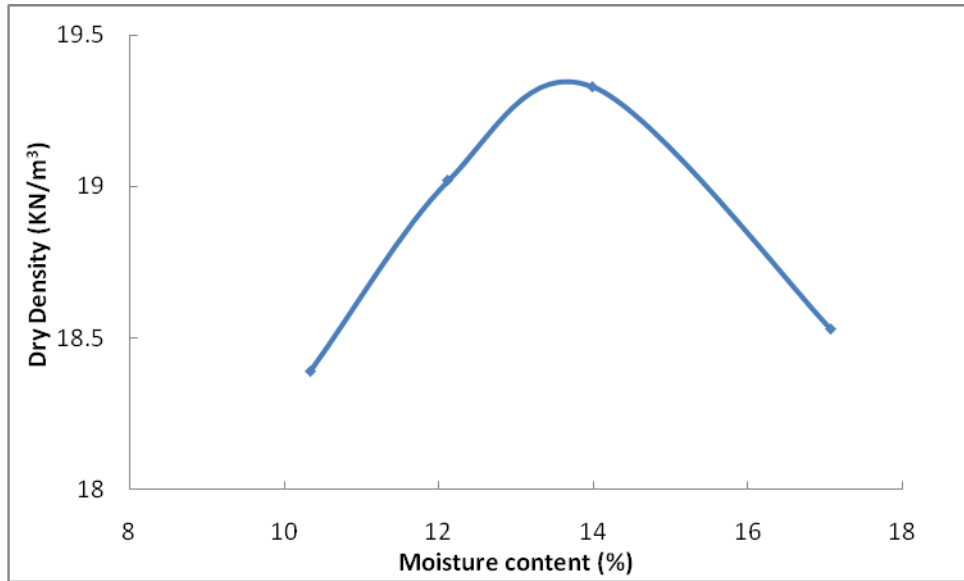


Fig. 3.33: Compaction curve for determination of MDD and OMC

From the plot of Dry density versus moisture content we obtained Max dry density and optimum moisture content as 19.33KN/m³ and 13.99% respectively

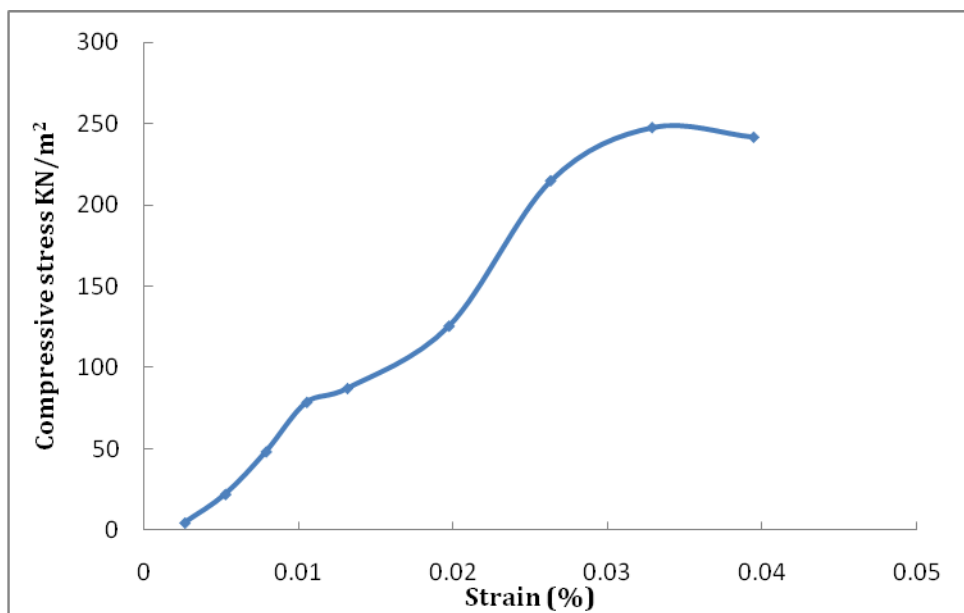


Fig. 3.34: Graph showing Compressive Stress Vs Strain

The Unconfined compressive strength was found to be 3.47 KN/m² and the strain at failure was 10.52%.

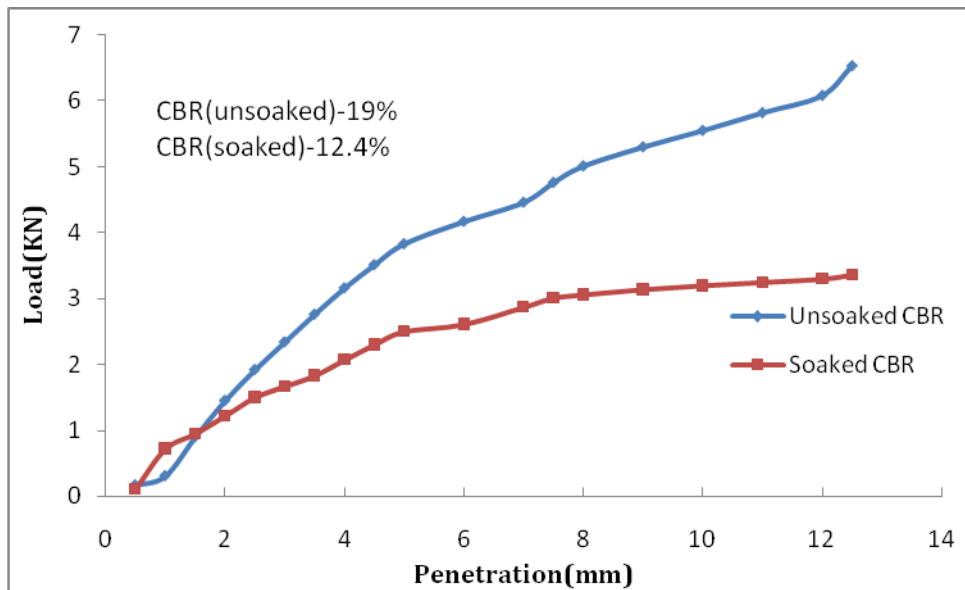


Fig. 3.35: Graph showing load Vs penetration for determination of CBR

3.14 Test results for Sample number-11

Location-Nabha

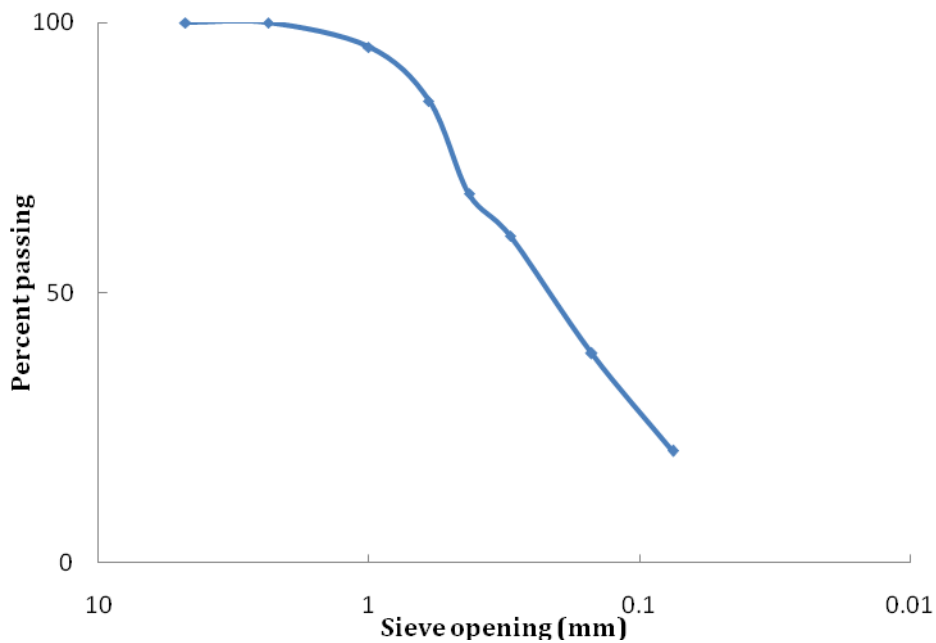


Fig. 3.36: Gradation curve for sieve analysis

The soil was found to be SC type (Clayey sand). The Fines content was 20.7% and sand content was 79.3%

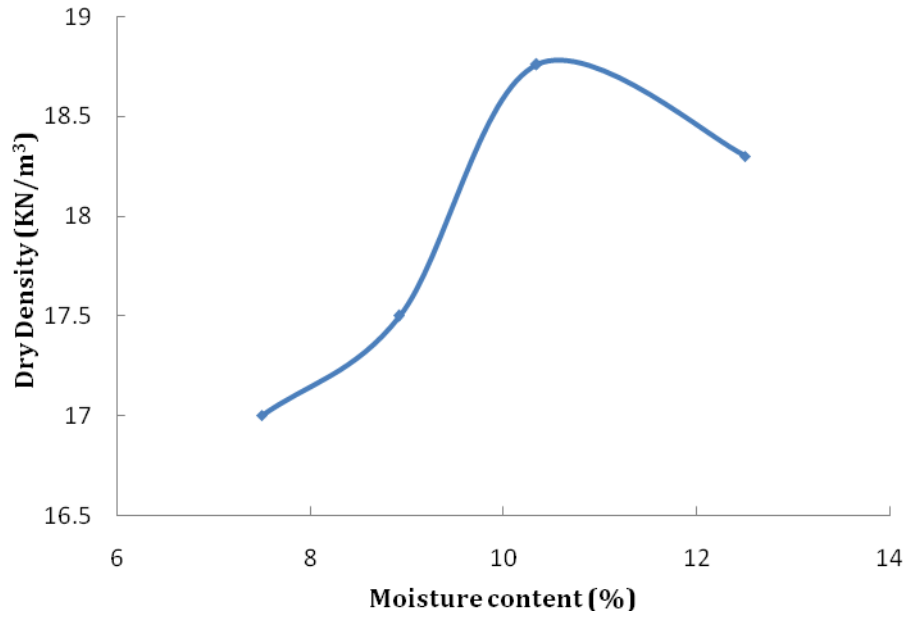


Fig. 3.37: Compaction curve for determination of MDD and OMC

From the plot of dry density versus moisture content we obtained Max dry density and optimum moisture content as 18.47 KN/m³ and 10.34% respectively.

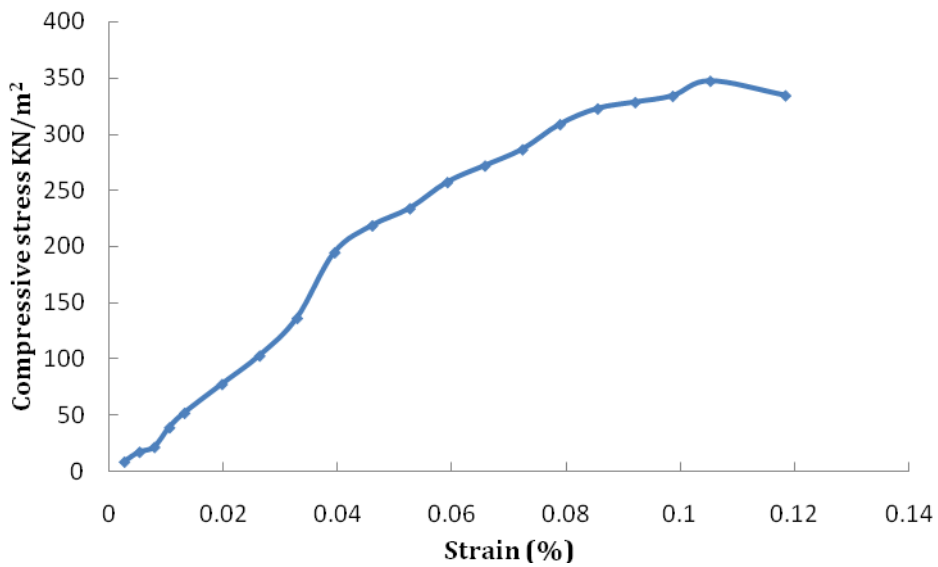


Fig. 3.38: Graph showing Compressive Stress Vs Strain

The Unconfined compressive strength was found to be 126 KN/ m² and the strain at failure was 17.10%.

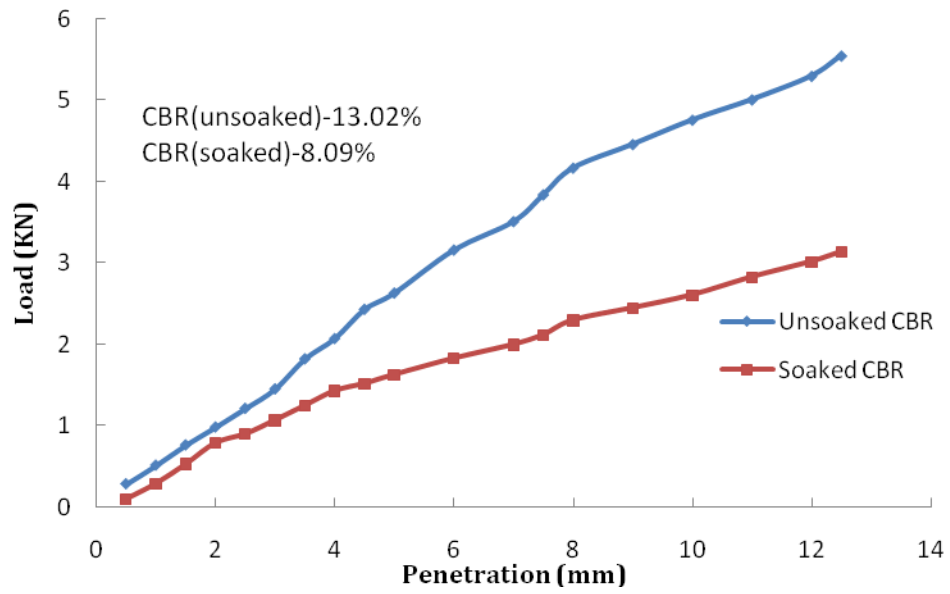


Fig. 3.39 Graph showing load Vs penetration for determination of CBR value

In this chapter the relation of CBR with different soil properties is established. The results of different tests conducted on soil were analysed and correlated with CBR using Multiple Linear Regression analysis. ANN (Artificial Neural Networks) model is also developed to determine the best linear fit. The software used in this Multiple Linear Regression analysis is MINITAB and for ANN is MATLAB.

4.1 Multiple Linear Regression analysis

Multiple linear regression attempts to model the relationship between two or more explanatory variables and a response variable by fitting a linear equation to observe data. It is a statistical technique that uses several explanatory variables to predict the outcome of a response variable. The main use of multiple linear regressions (MLR) is to model the relationship between the explanatory and response variables. Multiple linear regressions take a group of random variables and try to find a mathematical relationship between them. The model creates a relationship in the form of a straight line (linear) that best approximates all the individual data points.

4.2 Artificial Neural Networks

Artificial Neural Networks are relatively crude electronic models based on the neural structure of the brain. In this method the error function in the form of sum of squares of the errors between the actual outputs from the training sets and the computed outputs is minimized iteratively. It is natural proof that some problems that are beyond the scope of current computers are indeed solvable by small energy efficient packages. This brain modelling also promises a less technical way to develop machine solutions. This new approach to computing also provides a more graceful degradation during system overload than its more traditional counterparts.

4.3 Experimental results

The Table 4.1, 4.2 and 4.3 give the results of various soil properties from the experiments conducted in the laboratory for 11 samples taken for the present study. The properties include, maximum dry density, optimum moisture content, percentage fraction of sand and fines, unconfined compressive strength, liquid limit, plastic limit, and plasticity index. The tests were performed as per IS: Code. The summary of results obtained from laboratory test are tabulated below

Table 4.1: Properties of tested soil specimen

| | 1 | 2 | 3 | 4 |
|--------------------------|----------------|------------------|---------------------|---------------|
| | Patiala sample | Derabassi sample | Bhawani-garh sample | Kurali sample |
| Fines (%) | 14.6 | 24 | 29.4 | 18.5 |
| Sand (%) | 85.4 | 76 | 70.6 | 81.5 |
| Liquid limit (%) | 13.33 | 20 | 18.5 | 21.42 |
| Plastic limit (%) | Np | 18.18 | 13.25 | 17.62 |
| P.I. (%) | Np | 1.82 | 5.25 | 3.8 |
| MDD (KN/m ³) | 17.8 | 19.04 | 18.8 | 19.29 |
| OMC (%) | 12.068 | 13.72 | 10.34 | 14.28 |
| UCS (KN/m ²) | - | - | - | - |
| CBR Unsoaked (%) | 8.9 | 4.72 | 7.9 | 4.47 |
| CBR Soaked (%) | 5.89 | 3.6 | 5.56 | 3.45 |

Table 4.2: Properties of tested soil specimen

| | 5 | 6 | 7 | 8 |
|-------------------|----------------|----------------|-----------------|--------------|
| | Khurana Sample | Adampur Sample | Devigarh Sample | Banur Sample |
| Fines (%) | 18.7 | 18.5 | 16 | 19 |
| Sand (%) | 81.3 | 81.5 | 84 | 81 |
| Liquid limit (%) | 21 | 25 | 34.9 | 17 |
| Plastic limit (%) | 14.16 | 10.8 | 25 | 11 |
| P.I. (%) | 6.84 | 14.2 | 9.9 | 6 |

| | | | | |
|-------------------------------|-------|--------|-------|------|
| MDD (KN/m³) | 18.8 | 19.75 | 16.9 | 19.2 |
| OMC (%) | 10.34 | 11.12 | 10.52 | 13.6 |
| UCS (KN/m²) | - | 400 | 4.22 | - |
| CBR Unsoaked(%) | 13.37 | 19.68 | 24.4 | 9.5 |
| CBR Soaked (%) | 8.35 | 12.808 | 17 | 6.7 |

Table 4.3: Properties of tested soil specimen

| | 9 | 10 | 11 |
|-------------------------------|-----------------------|-----------------------|---------------------|
| | Rajpura sample | Tangori sample | Nabha sample |
| Fines (%) | 20.6 | 18.9 | 20.7 |
| Sand (%) | 79.4 | 81.1 | 79.3 |
| Liquid limit (%) | 29 | 32.33 | 20 |
| Plastic limit (%) | 19 | 19 | 11.68 |
| P.I. (%) | 10 | 13.33 | 8.32 |
| MDD (KN/m³) | 1.904 | 19.33 | 18.74 |
| OMC (%) | 13.6 | 13.99 | 10.34 |
| UCS (KN/m²) | 247 | 347 | 126 |
| CBR Unsoaked (%) | 15 | 19 | 13.02 |
| CBR Soaked (%) | 10 | 12.4 | 8.09 |

From the above table it is understood that maximum dry density for 11 samples varies from 16.9-19.75 KN/m³. Plasticity index ranged from 1.82-14.2. Among the different samples taken from study, fines content exceeds 20% for sample 2, 3, 9 and 11. Unconfined compressive strength for sample 6, 7, 9, 10 and 11 lied between 126 KN/m²- 422 KN/m².

4.4 ANN model to establish Best-linear fit between the experimental and literature values

The ANN model generated in this study is to determine that the best line fit can be established between trained and tested values. The basic neural network was trained with test values obtained from literature review and laboratory tests. The software used for the Artificial Neural Network is NN tools of MATLAB. The

model was trained with a set of 40 values obtained from the literature review. In an ANN model, the process of fitting a model to the data is called training. The model learns from the observations (data points) how the input parameters and output parameter relate.

Table 4.4: Results of trained data (Unsoaked CBR)

| Data set | Tuples | RMSE | Best Line Fit |
|----------|--------|--------|-------------------------|
| Train | 40 | 0.0095 | $A = (1)T + (-0.00357)$ |
| Test | 11 | 0.0079 | |

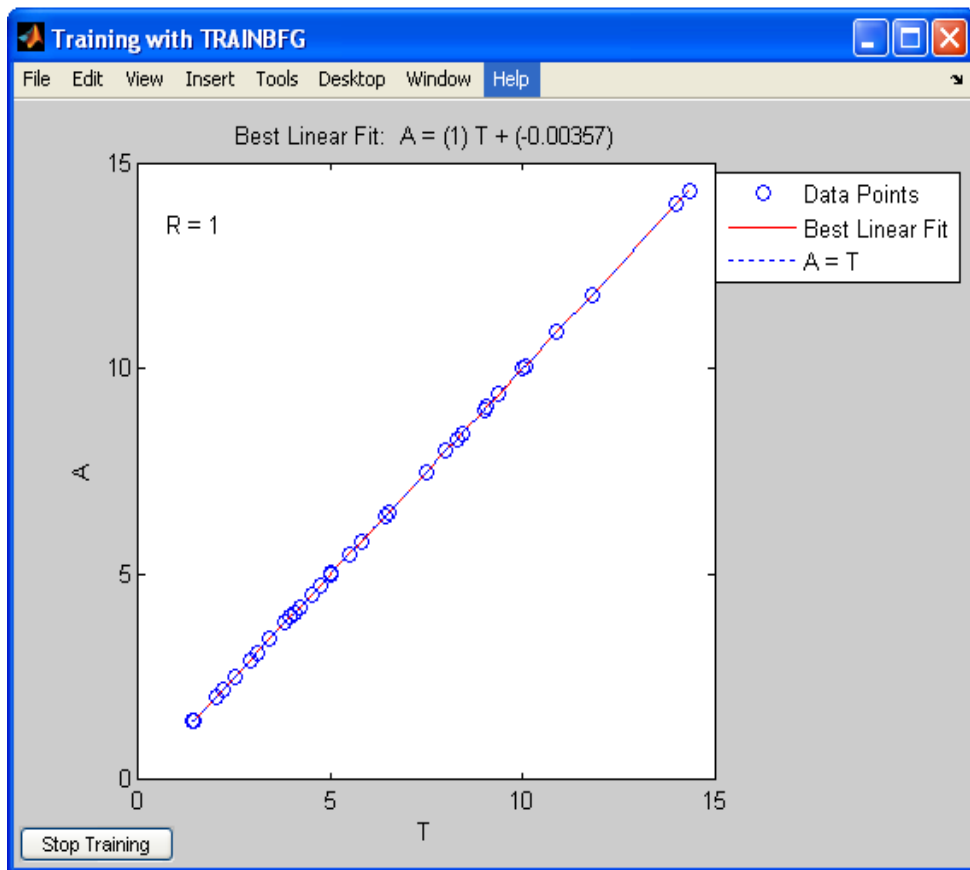


Fig. 4.1: Best-linear fit for experimental and literature values (Unsoaked CBR)

Table 4.5: Results of trained data (Soaked CBR)

| Data set | Tuples | RMSE | Best Line Fit |
|----------|--------|--------|---------------|
| Train | 40 | 0.0085 | $A = (1) T +$ |
| Test | 11 | 0.0120 | 0.000146 |

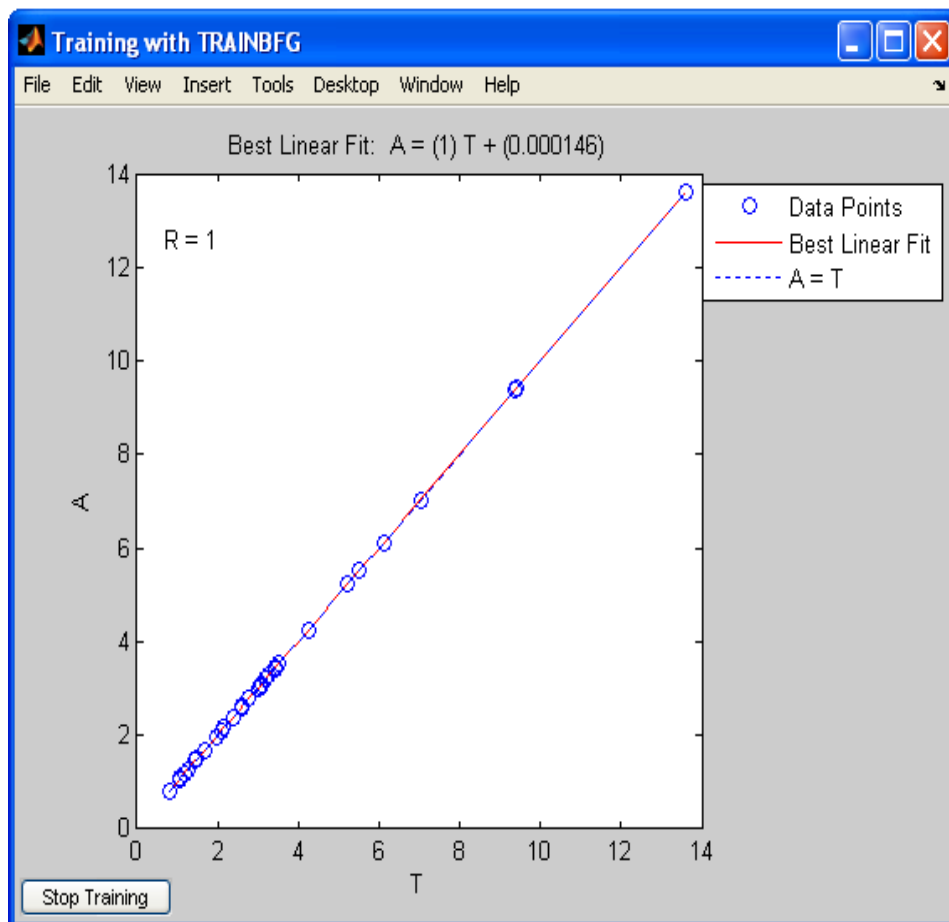


Fig. 4.2: Best-linear fit for experimental and literature values

ANN finds the general pattern between input and output using only data without necessity for any prior knowledge about the problem. The soil parameters analysed are similar to that analysed in MLR (%Fines, L.L., M.D.D., O.M.C. and CBR). The best line fit was obtained for both soaked and unsoaked CBR with value of $R=1$

$$A = (1) T + (-0.00357) \text{ UNSOAKED}$$

$$A = (1) T + (0.000146) \text{ SOAKED}$$

4.5 Correlation of CBR with soil parameters by Multiple Regression Analysis

After the results obtained from the laboratory, linear regression analysis was done to correlate CBR and soil properties. A total of three models are developed for both unsoaked and soaked CBR and the following equations are determined

$$\text{CBR (Unsoaked)} = 4.91 - 0.431 * \% \text{Fines} + 0.714 * \text{L.L.} \quad [4.1]$$

{R² = .622} {Relation between %Fines, L.L and CBR}

$$\text{CBR (Unsoaked)} = 52.2 - 1.42 * \text{M.D.D.} - 1.904 * \text{O.M.C.} \quad [4.2]$$

{R² = 0.156} {Relation between OMC, MDD and CBR}

$$\text{CBR (Unsoaked)} = 5.6 - (0.600 * \text{Fines}) + (0.745 * \text{L.L.}) + (1.37 * \text{M.D.D.}) - (1.95 * \text{OMC}) \quad [4.3]$$

{R² = 0.901} {Relation between %Fines, LL, MDD, OMC and CBR}

$$\text{CBR (Soaked)} = 2.81 - 0.272 * \% \text{Fines} - 0.485 * \text{L.L.} \quad [4.4]$$

{R² = 0.732} {Relation between %Fines, L.L and CBR}

$$\text{CBR (Soaked)} = 39.7 - 1.29 * \text{M.D.D.} - 0.576 * \text{O.M.C.} \quad [4.5]$$

{R² = 0.159} {Relation between OMC, MDD and CBR}

$$\text{CBR (Soaked)} = 9 - (0.347 * \% \text{fines}) + (0.499 * \text{L.L.}) + (0.453 * \text{M.D.D.}) - (1.11 * \text{O.M.C.}) \quad [4.6]$$

{R² = 0.897} {Relation between %Fines, L.L., M.D.D., O.M.C. and C.B.R}

From the above developed models it was observed that equation [4.3] for unsoaked and [4.6] for soaked are most significant with a R² -value of 0.901 and 0.897. Therefore the equation [4.3] developed for unsoaked CBR value is

$$\text{CBR (Unsoaked)} = 5.6 - (0.600 * \text{Fines}) + (0.745 * \text{L.L.}) + (1.37 * \text{M.D.D.}) - (1.95 * \text{OMC})$$

Table 4.6: Results of CBR (unsoaked) from experiments and analysis

| | CBR UNSOAKED (Experimental results) | CBR UNSOAKED (Predicted) | Difference In values |
|----|--|-------------------------------------|---------------------------------|
| 1 | 8.9 | 7.62 | 1.28 |
| 2 | 4.72 | 5.43 | -0.71 |
| 3 | 7.9 | 7.33 | 0.57 |
| 4 | 4.47 | 9.03 | -4.56 |
| 5 | 13.37 | 15.618 | -2.248 |
| 6 | 19.68 | 18.49 | 1.19 |
| 7 | 24.4 | 24.63 | -0.23 |
| 8 | 9.5 | 6.649 | 2.851 |
| 9 | 15 | 14.4 | 0.6 |
| 10 | 19 | 17.54 | 1.46 |
| 11 | 13.02 | 13.59 | -0.57 |

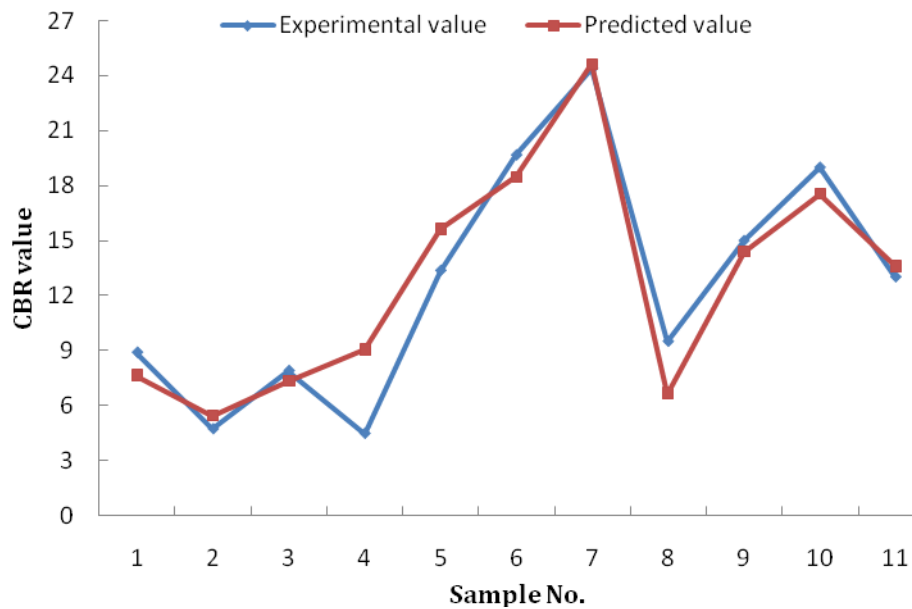


Fig. 4.3: Graph showing comparison of actual and predicted CBR value (unsoaked)

For unsoaked CBR values obtained from regression models, it is inferred that, for samples 1, 3, 6, 8, 9, 10 it under estimates the actual CBR value, but for other samples it over estimates. The figure depicts the results of Unsoaked CBR value obtained from laboratory results as well as regression. The R² value of the CBR prediction model from multiple regressions is 0.901.

Similarly the equation [4.6] developed for Soaked CBR value is as follows

$$\text{CBR (Soaked)} = 9 - (0.347 * \% \text{ fines}) + (0.499 * \text{L.L.}) + (0.453 * \text{M.D.D.}) - (1.11 * \text{O.M.C.})$$

Table 4.7: Results of CBR (soaked) from experiments and analysis

| | CBR SOAKED (Experimental results) | CBR SOAKED (Predicted) | Difference In values |
|----|--|-----------------------------------|---------------------------------|
| 1 | 5.89 | 5.25 | 0.64 |
| 2 | 3.6 | 4.04 | -0.44 |
| 3 | 5.56 | 5.06 | 0.5 |
| 4 | 3.45 | 6.15 | -2.7 |
| 5 | 8.35 | 10.02 | -1.67 |
| 6 | 12.808 | 11.65 | 1.158 |
| 7 | 17 | 16.84 | 0.16 |
| 8 | 6.7 | 4.49 | 2.21 |
| 9 | 10 | 9.85 | 0.15 |
| 10 | 12.4 | 11.8 | 0.6 |
| 11 | 8.09 | 8.8 | -0.71 |

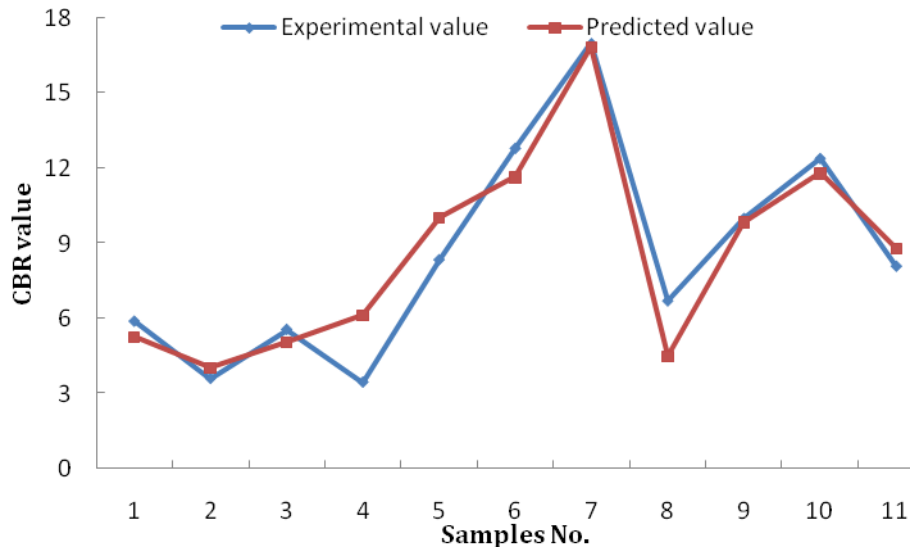


Fig.4.4: Graph showing comparison of actual and predicted CBR value

For soaked CBR values obtained from regression model, it is inferred that, for samples 1, 3, 6, 7, 8, 9, 10 it under estimates the actual CBR value, but for other samples it over estimates. The figure depicts the results of soaked CBR value obtained from laboratory results as well as regression. The R^2 value of the CBR prediction model from multiple regressions is 0.897.

From the above performed results it was determined that a significant correlation can be developed between among 4 parameters of soil and CBR. The parameters used in the development of model are Percent fines, L.L., M.D.D., O.M.C. and CBR.

CONCLUSIONS & FUTURE SCOPE

Eleven samples were collected from different locations within a radius of 50km of Patiala city. Multiple Linear Regression analysis and ANN on clayey sand soil was performed and the following conclusion is made:

- The tests performed on these soil samples were Grain size analysis, LL, PL, PI, UCS, Compaction test, MDD and CBR. The maximum dry density for 11 samples varied from 16.9-19.75 KN/m³. Plasticity index ranged from 1.82-14.2. Among the different samples taken from study, fines content exceeds 20% for sample 2, 3, 9 and 11. Unconfined compressive strength for sample 6, 7, 9, 10 and 11 lied between 126- 422 KN/m². CBR value of unsoaked soil sample lied between (4.72%-24.4%) and for soaked soil sample it lied between (3.6%-17%)
- The model developed by neural networks is trained with 40 values obtained from literature review and 11 values from laboratory tests for both soaked and unsoaked CBR.
- The best line fit is established for both unsoaked [$A=T+(-0.00357)$] and soaked CBR [$A=(1)T+0.000146$] with value of $R=1$.
- A total of six model were developed by MLR, three for unsoaked and three for soaked CBR, out of which two models showed a good correlation of CBR with Soil properties. It was found that CBR value of the soil bears a significant correlation with Percent fines, L.L., M.D.D and O.M.C. with R^2 value of 0.901(unsoaked) and 0.897(soaked).
- For unsoaked CBR values for samples 1, 3, 6, 8, 9, 10 it under estimates the actual CBR value, but for other samples it over estimates. In soaked condition, for samples 1, 3, 6, 7, 8, 9, 10 it under estimates the actual CBR value, but for other samples it over estimates.

Future Scope of work

The type of soil used in this study is SC type based on which the correlations were developed. Additional tests shall be performed on other types of soil so that the correlations can be updated if necessary to include a wider range of soil types.

REFERENCES

- Agarwal, K.B. and Ghanekar, K.D., (1970). "Prediction of CBR from plasticity characteristics of soil", proceedings of 2nd south-east Asian conference on soil engineering, Singapore, June 11-15, pp.571-6.
- Datta, T., & Chattopadhyay, B. C. (2011). "Correlation between CBR and index properties of soil." In Proceedings of Indian Geotechnical Conference, Kochi.
- Harini, H., & Naagesh, S. (2014). "Predicting CBR Of Fine Grained Soils By Artificial Neural Network And Multiple Linear Regression." International Journal of Civil Engineering.
- IS: 2720-Part IV (2006) Grain size analysis, Bureau of Indian Standard, New Delhi, India.
- IS: 2720-Part V (1985) Determination of Liquid limit & Plastic limit, Bureau of Indian Standard, New Delhi, India.
- IS: 2720-Part VIII (1995) Determination of Water content, Bureau of Indian Standard, New Delhi, India.
- IS: 2720-Part XVI (2002) Determination of CBR, Bureau of Indian Standard, New Delhi, India.
- IRC: 37-2012 " Guidelines for design of Flexible pavement"
- Kaur,S., Boveja, V.B., and Agarwal, A. (2011),"Artificial Neural Network Modeling for Prediction of CBR" , Indian Highways, Vol. 39 , No 1, 31-38
- Mouratidis, A., (2004). "Correlations for Soil Bearing Capacity Parameters." Proceedings of International Seminar on Geotechnics in Pavement and Railway Design and Construction, 143 -148.
- Patel, R. S., & Desai, M. D. (2010). "CBR predicted by index properties for alluvial soils of South Gujarat." In Proceedings of the Indian Geotechnical conference, Mumbai (pp. 79-82).
- Ramasubbarao, G.V., and Sankar, S., (2013). "Predicting Soaked CBR Value of Fine Grained Soils Using Index and Compaction Characteristics." Jordan Journal of Civil Engineering, Volume 7, No.
- Reddy, K.V., "Correlation Between California Bearing Ratio and Shear Strength on Artificially Prepared Soils with Varying Plasticity Index",

International Journal of Civil Engineering & Technology (IJCIET), Volume 4, Issue 6, 2013, pp. 61 – 66.

- Roy, T.K, Chattapadhyay, B. C and Roy, S. K. (2010). “California Bearing Ratio, Evaluation and Estimation.” A Study of Comparison. IGC, IIT, Mumbai, pp 19-22.
- Saklecha, P. P., Katpatal, Y. B., Rathore, S. S., & Agarawal, D. K. (2011). “Correlation of Mechanical Properties of weathered Basaltic Terrain for strength Characterization of foundation using ANN.” International Journal of Computer Applications-Nov.
- Satyanarayana Reddy, C.N.V. and Pavani, K. (2006). “Mechanically Stabilised Soils-Regression Equation for CBR Evaluation, Proceedings of Indian Geotechnical Conference-2006, Chennai, India. Dec. 14-16, 731-734.
- Talukdar, (2014) D. K. “A Study of Correlation Between California Bearing Ratio (CBR) Value With Other Properties of Soil.” International journal of emerging technology and Advanced Engineering. Volume 4.
- T. Taskiran (2010).”Prediction of California bearing ratio (CBR) of fine grained soils by AI methods.” journal of Advances in Engineering Software, 41, 886–892.
- Venkatraman, T.S., Samson ,M. And Ambili , T.S.(1995), “Correlation between CBR and Clegg Impact Value” , Proc. Nat. Sem. On emerging trends in Highway Engineering, Centre for Transportation Engineering, Bangalore, Vol. I , 25.1-25.5
- Venkatasubramanian, C., & Dhinakaran, G. (2011). “ANN model for predicting CBR from index properties of soils.” International Journal of Civil & Structural Engineering, 2(2), 614-620.
- Vinod, P. and Reena, C. (2008). “Prediction of CBR Value of Lateritic Soils Using Liquid Limit and Gradation Characteristics Data.” Highway Research Journal, IRC, 1 (1): 89-98.
- Yildirim, B. and Gunaydin, O. (2011). “Estimation of CBR by Soft Computing Systems.” Expert Systems with Applications, ELSEVIER, 38: 6381-6391.

Location: Patiala city

Sample No.:1

GRAIN SIZE ANALYSIS OF SOIL

| IS Sieve Designation | Weight of Soil Retained in Grams | Cumulative weight retained in grams | Cumulative percentage retained | Percentage passing |
|----------------------|----------------------------------|-------------------------------------|--------------------------------|--------------------|
| 4.75 mm | 0 | 0 | 0 | 100 |
| 2.36 mm | 0 | 0 | 0 | 100 |
| 1.0 mm | 30 | 30 | 3.0 | 97 |
| 0.60 mm | 20 | 50 | 5.0 | 95 |
| .425mm | 30 | 80 | 8.0 | 92 |
| 0.30 mm | 74 | 154 | 15.4 | 84.6 |
| 0.15 mm | 490 | 664 | 66.4 | 33.6 |
| 0.075 mm | 190 | 854 | 85.4 | 14.6 |
| Retainer | 146 | 1000 | 100.0 | 0 |

DETERMINATION OF COMPACTION PROPERTIES FOR SOIL USING STANDARD PROCTOR TEST

| | | 1 | 2 | 3 | 4 | 5 |
|-----|--|-------|------|-------|-------|-------|
| 1. | Mass of Mould W1 in gm | 5060 | 5060 | 5060 | 5060 | 5060 |
| 2. | Mass of Mould + Wet Soil W2 in gm | 6846 | 6909 | 6989 | 7060 | 7033 |
| 3. | Mass of Wet Soil W2-W1 in gm | 1786 | 1849 | 1929 | 2000 | 1973 |
| 4. | Volume of Mould V in c.c. | 1000 | 1000 | 1000 | 1000 | 1000 |
| 5. | Bulk Density $r_m = (W2-W1)/V$ gm/cc | 1.786 | 1.84 | 1.929 | 2.0 | 1.973 |
| 6. | Container No. | 38 | 21 | 46 | 24 | 5 |
| 7. | Mass of Container + Wet soil W3 in gm | 78 | 95 | 105 | 78 | 120 |
| 8. | Mass of Container + Oven dried soil W4 | 76 | 91.5 | 99 | 74.5 | 111 |
| 9. | Mass of moisture W3-W4 in gm | 2 | 3.5 | 6 | 3.5 | 9 |
| 10. | Mass of Container W5 in gm | 45 | 50 | 43 | 46 | 47 |
| 11. | Mass of Oven dried soil W4-W5 in gm | 31 | 42 | 56 | 26 | 64 |
| 12. | Water Content in % | 6.45 | 8.33 | 10.71 | 12.06 | 14.06 |
| 13. | Dry Density | 1.67 | 1.7 | 1.74 | 1.78 | 1.729 |

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT FOR SOIL USING CASAGRANDE'S APPARATUS

| | Description | Liquid limit | | |
|-----------|--|--------------|-------|-------|
| | | 1 | 2 | 3 |
| 1. | Penetration D in mm/no of Blows (N) | 3 | 6 | 27 |
| 2. | Container No. | 33 | 77 | 37 |
| 3. | Mass of Container + Wet Soil W2 in gm | 120 | 101 | 111 |
| 4. | Mass of Container + Oven Dried Soil | 106 | 91 | 103 |
| 5. | Mass of Moisture W2-W3 in gm | 14 | 10 | 08 |
| 6. | Mass of Container W1 in gm | 44 | 42 | 43 |
| 7. | Mass of Oven Dried Soil W3-W1 in gm | 62 | 49 | 60 |
| 8. | Moisture content | 22 | 20.40 | 13.33 |

DETERMINATION OF C.B.R.

| Penetration (mm) | Load on Plunger(Unsoaked) | Load on Plunger(Soaked) |
|-----------------------|---------------------------|-------------------------|
| 0.5 | .10 | .11 |
| 1 | .16 | .19 |
| 1.5 | .33 | .27 |
| 2 | .51 | .38 |
| 2.5 | .78 | .53 |
| 3 | 1.0 | .68 |
| 3.5 | 1.28 | .88 |
| 4 | 1.45 | 1 |
| 4.5 | 1.61 | 1.11 |
| 5 | 1.80 | 1.19 |
| 6 | 1.99 | 1.37 |
| 7.5 | 2.98 | 1.97 |
| 8 | 3.51 | 2.29 |
| 10 | 4.40 | 3.01 |
| 12 | 6.01 | 4.13 |
| 12.5 | 7.48 | 4.51 |
| CBR (Unsoaked) | | 8.90 |
| CBR (Soaked) | | 5.89 |

Location: Derabassi

Sample No: 2

GRAIN SIZE ANALYSIS OF SOIL

| IS Sieve Designation | Weight of Soil Retained in Grams | Cumulative weight retained in grams | Cumulative percentage retained | Percentage passing |
|----------------------|----------------------------------|-------------------------------------|--------------------------------|--------------------|
| 4.75 mm | 0 | 0 | 0 | 100 |
| 2.36 mm | 38 | 38 | 3.8 | 96.2 |
| 1.18 mm | 175 | 213 | 21.3 | 78.7 |
| 0.60 mm | 80 | 293 | 29.3 | 70.7 |
| .425 mm | 110 | 403 | 40.3 | 59.7 |
| 0.30 mm | 53 | 456 | 45.6 | 54.4 |
| 0.15 mm | 174 | 630 | 63.0 | 37 |
| 0.075 mm | 130 | 760 | 76.0 | 24 |
| Retainer | 240 | 1000 | 100.0 | 0 |

DETERMINATION OF COMPACTION PROPERTIES FOR SOIL USING STANDARD PROCTOR TEST

| | | 1 | 2 | 3 | 4 | 5 |
|-----|--|-------|-------|-------|-------|-------|
| 1. | Mass of Mould W1 in gm | 4320 | 4320 | 4320 | 4320 | 4320 |
| 2. | Mass of Mould + Wet Soil W2 in gm | 6177 | 6301 | 6396 | 6448 | 6444 |
| 3. | Mass of Wet Soil W2-W1 in gm | 1857 | 1981 | 2076 | 2128 | 2124 |
| 4. | Volume of Mould V in c.c. | 982 | 982 | 982 | 982 | 982 |
| 5. | Bulk Density $r_m = (W2-W1)/V$ gm/cc | 1.89 | 2.017 | 2.113 | 2.166 | 2.162 |
| 6. | Container No. | 77 | 20 | 3 | 21 | 43 |
| 7. | Mass of Container + Wet soil W3 in gm | 65 | 58 | 51 | 59 | 73 |
| 8. | Mass of Container + Oven dried soil W4 in gm | 62.5 | 58 | 51 | 59 | 73 |
| 9. | Mass of moisture W3-W4 in gm | 2.5 | 3 | 2.5 | 3.5 | 7 |
| 10. | Mass of Container W5 in gm | 28 | 29 | 28 | 30 | 25 |
| 11. | Mass of Oven dried soil W4-W5 in gm | 24.5 | 26 | 20.5 | 25.5 | 41 |
| 12. | Water Content in % | 10.20 | 11.53 | 12.19 | 13.72 | 17.01 |
| 13. | Dry Density | 1.71 | 1.808 | 1.883 | 1.904 | 1.846 |

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT FOR SOIL USING CASAGRANDE'S APPARATUS

| | Description | Liquid Limit | | | | Plastic limit |
|-----------|--|--------------|----|-------|-------|---------------|
| | | 1 | 2 | 3 | 4 | |
| | | 16 | 26 | 30 | 39 | - |
| 1. | Penetration D in mm/no of Blows (N) | | | | | |
| 2. | Container No. | 47 | 29 | 45 | 26 | 17 |
| 3. | Mass of Container + Wet Soil W2 in gm | 80 | 87 | 60 | 77 | 56 |
| 4. | Mass of Container + Oven Dried Soil | 72 | 80 | 56 | 70 | 54 |
| 5. | Mass of Moisture W2-W3 in gm | 8 | 7 | 4 | 7 | 2 |
| 6. | Mass of Container W1 in gm | 42 | 45 | 38 | 40 | 43 |
| 7. | Mass of Oven Dried Soil W3-W1 in gm | 30 | 35 | 18 | 30 | 11 |
| 8. | Water Content in % | 26.67 | 20 | 22.22 | 23.33 | 18.18 |

DETERMINATION OF C.B.R.

| Penetration (mm) | Load on Plunger(Unsoaked) | Load on Plunger(Soaked) |
|-----------------------|---------------------------|-------------------------|
| 0.5 | 0.11 | 0.02 |
| 1 | 0.16 | 0.06 |
| 1.5 | 0.25 | 0.13 |
| 2 | .31 | 0.19 |
| 2.5 | 0.43 | 0.3 |
| 3 | 0.53 | 0.38 |
| 3.5 | 0.68 | 0.49 |
| 4 | 0.78 | 0.58 |
| 4.5 | 0.86 | 0.64 |
| 5 | 0.95 | 0.73 |
| 7.5 | 1.24 | 1.01 |
| 8 | 1.36 | 1.13 |
| 10 | 1.61 | 1.37 |
| 11 | 1.73 | 1.52 |
| 12.5 | 1.90 | 1.73 |
| CBR (Unsoaked) | | 4.72 |
| CBR (Soaked) | | 3.6 |

Annexure-3**GRAIN SIZE ANALYSIS OF SOIL**

Location: Bhawanigarh

Sample No: 3

| IS Sieve Designation | Weight of Soil Retained in Grams | Cumulative weight retained in grams | Cumulative percentage retained | Percentage passing |
|----------------------|----------------------------------|-------------------------------------|--------------------------------|--------------------|
| 4.75 mm | 0 | 0 | 0 | 100 |
| 2.36 mm | 0 | 0 | 0 | 100 |
| 1.18 mm | 6 | 6 | .6 | 99.4 |
| 0.60 mm | 42 | 48 | 4.8 | 95.2 |
| .450 mm | 109 | 157 | 15.7 | 84.3 |
| 0.30 mm | 56 | 213 | 21.3 | 78.7 |
| 0.15 mm | 249 | 462 | 46.2 | 53.8 |
| 0.075 mm | 244 | 706 | 70.6 | 29.4 |
| Retainer | 294 | 1000 | 100.0 | 0 |

DETERMINATION OF COMPACTION PROPERTIES FOR SOIL USING STANDARD PROCTOR TEST

| | | 1 | 2 | 3 | 4 |
|-----|--|-------|-------|-------|-------|
| 1. | Mass of Mould W1 in gm | 5060 | 5060 | 5060 | 5060 |
| 2. | Mass of Mould + Wet Soil W2 in gm | 6969 | 7140 | 7110 | 7078 |
| 3. | Mass of Wet Soil W2-W1 in gm | 1909 | 2080 | 2050 | 2018 |
| 4. | Volume of Mould V in c.c. | 1000 | 1000 | 1000 | 1000 |
| 5. | Bulk Density $r_m = (W2-W1)/V$ gm/cc | 1.909 | 2.080 | 2.050 | 2.018 |
| 6. | Container No. | 40 | 45 | 03 | 30 |
| 7. | Mass of Container + Wet soil W3 in gm | 52 | 57 | 54 | 63 |
| 8. | Mass of Container + Oven dried soil W4 in gm | 49 | 54 | 51 | 58 |
| 9. | Mass of moisture W3-W4 in gm | 3 | 3 | 3 | 5 |
| 10. | Mass of Container W5 in gm | 24 | 25 | 28 | 27 |
| 11. | Mass of Oven dried soil W4-W5 in gm | 25 | 29 | 23 | 31 |
| 12. | Water Content in % | 10 | 10.34 | 13.04 | 16.12 |
| 13. | Dry Density | 1.75 | 1.88 | 1.81 | 1.73 |

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT FOR SOIL USING
CASAGRANDE'S APPARATUS

| | Description | Liquid Limit | | | | | Plastic limit |
|----|-------------------------------------|--------------|----|-------|-------|-------|---------------|
| | | 1 | 2 | 3 | 4 | 5 | |
| 1. | Penetration D in mm/no of Blows (N) | 33 | 16 | 38 | 35 | 23 | 1 |
| 2. | Container No. | 45 | 21 | 29 | 24 | 09 | 22 |
| 3. | Mass of Container + Wet Soil W2 | 45 | 48 | 48 | 43 | 58 | 42 |
| 4. | Mass of Container + Oven Dried | 42 | 45 | 45 | 41 | 54 | 40 |
| 5. | Mass of Moisture W2-W3 in gm | 3 | 3 | 3 | 2 | 4 | 2 |
| 6. | Mass of Container W1 in gm | 25 | 30 | 29 | 28 | 32 | 25 |
| 7. | Mass of Oven Dried Soil W3-W1 | 17 | 15 | 16 | 13 | 22 | 15 |
| 8. | Water Content | 17.64 | 20 | 18.75 | 15.38 | 18.58 | 13.33 |

DETERMINATION OF C.B.R. TEST ON SOIL

| Penetration (mm) | Load on Plunger(Unsoaked) KN | Load on Plunger(Soaked) KN |
|-----------------------|------------------------------|----------------------------|
| 0.5 | .09 | .07 |
| 1 | .20 | .15 |
| 1.5 | .36 | .22 |
| 2 | .58 | .31 |
| 2.5 | .79 | .42 |
| 3 | 1.01 | .59 |
| 3.5 | 1.24 | .73 |
| 4 | 1.41 | .83 |
| 4.5 | 1.50 | .97 |
| 5 | 1.60 | 1.12 |
| 7.5 | 1.89 | 1.54 |
| 9 | 2.20 | 1.90 |
| 10 | 2.33 | 2.01 |
| 12 | 2.56 | 2.33 |
| 12.5 | 2.70 | 2.49 |
| CBR (Unsoaked) | | 7.90 |
| CBR (Soaked) | | 5.56 |

GRAIN SIZE ANALYSIS OF SOIL

Location: Kurali

Sample No: 04

| IS Sieve Designation | Weight of Soil Retained in Grams | Cumulative weight retained in grams | Cumulative percentage retained | Percentage passing |
|----------------------|----------------------------------|-------------------------------------|--------------------------------|--------------------|
| 4.75 mm | 0 | 0 | 0 | 100 |
| 2.36 mm | 18 | 18 | 1.8 | 98.2 |
| 1.18 mm | 145 | 163 | 16.3 | 83.7 |
| 0.60 mm | 58 | 221 | 22.1 | 77.9 |
| .450 mm | 68 | 289 | 28.9 | 71.1 |
| 0.30 mm | 49 | 338 | 33.8 | 66.2 |
| 0.15 mm | 329 | 667 | 66.7 | 23.3 |
| 0.075 mm | 148 | 815 | 81.5 | 18.5 |
| Retainer | 185 | 1000 | 100.0 | 0 |

DETERMINATION OF COMPACTION PROPERTIES FOR SOIL USING STANDARD PROCTOR TEST

| | | 1 | 2 | 3 | 4 |
|-----|--|-------|-------|-------|-------|
| 1. | Mass of Mould W1 in gm | 4320 | 4320 | 4320 | 4320 |
| 2. | Mass of Mould + Wet Soil W2 in gm | 6314 | 6415 | 6486 | 6454 |
| 3. | Mass of Wet Soil W2-W1 in gm | 1994 | 2095 | 2166 | 2134 |
| 4. | Volume of Mould V in c.c. | 982 | 982 | 982 | 982 |
| 5. | Bulk Density $r_m = (W2-W1)/V$ gm/cc | 2.030 | 2.133 | 2.205 | 2.172 |
| 6. | Container No. | 47 | 77 | 23 | 20 |
| 7. | Mass of Container + Wet soil W3 in gm | 59 | 65 | 60 | 77 |
| 8. | Mass of Container + Oven dried soil W4 in gm | 56 | 61 | 56 | 70 |
| 9. | Mass of moisture W3-W4 in gm | 3 | 4 | 4 | 7 |
| 10. | Mass of Container W5 in gm | 27 | 28 | 28 | 29 |
| 11. | Mass of Oven dried soil W4-W5 in gm | 29 | 33 | 28 | 41 |
| 12. | Water Content in % | 10.34 | 12.12 | 14.28 | 17.07 |
| 13. | Dry Density | 1.839 | 1.902 | 1.929 | 1.855 |

**DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT FOR SOIL USING
CASAGRANDE'S APPARATUS**

| | Description | Liquid Limit | | | | Plastic Limit |
|----|--|--------------|-------|-------|-------|---------------|
| | | 1 | 2 | 3 | 4 | |
| | | 1 | 2 | 3 | 4 | 1 |
| 1. | Penetration D in mm/no of Blows (N) | 38 | 28 | 25 | 13 | |
| 2. | Container No. | 28 | 6 | 2 | 77 | 43 |
| 3. | Mass of Container + Wet Soil W2 in gm | 52 | 43 | 44 | 41 | 39 |
| 4. | Mass of Container + Oven Dried Soil W3 | 49 | 41 | 41 | 39 | 37 |
| 5. | Mass of Moisture W2-W3 in gm | 3 | 2 | 3 | 2 | 2 |
| 6. | Mass of Container W1 in gm | 29 | 29 | 27 | 28 | 25 |
| 7. | Mass of Oven Dried Soil W3-W1 in gm | 20 | 12 | 14 | 11 | 12 |
| 8. | Water Content in % | 15 | 16.66 | 20.46 | 18.18 | 16.66 |

DETERMINATION OF C.B.R.

| Penetration (mm) | Load on Plunger(Unsoaked) | Load on Plunger(Soaked) |
|-----------------------|---------------------------|-------------------------|
| 0.5 | .04 | .03 |
| 1 | .10 | .08 |
| 1.5 | .17 | .16 |
| 2 | .28 | .24 |
| 2.5 | .38 | .33 |
| 3 | .49 | .42 |
| 3.5 | .59 | .51 |
| 4 | .71 | .58 |
| 4.5 | .80 | .65 |
| 5 | .90 | .70 |
| 7.5 | 1.20 | 1.0 |
| 9 | 1.45 | 1.19 |
| 10 | 1.62 | 1.28 |
| 11 | 1.74 | 1.41 |
| 12.5 | 1.99 | 1.59 |
| CBR (Unsoaked) | | 4.47 |
| CBR (Soaked) | | 3.45 |

GRAIN SIZE ANALYSIS OF SOIL

Location : Khurana village

Sample No: 5

| IS Sieve Designation | Weight of Soil Retained in Grams | Cumulative weight retained in grams | Cumulative percentage retained | Percentage passing |
|----------------------|----------------------------------|-------------------------------------|--------------------------------|--------------------|
| 4.75 mm | 0 | 0 | 0 | 100 |
| 2.36 mm | 0 | 0 | 0 | 100 |
| 1.18 mm | 53 | 53 | 5.3 | 94.7 |
| 0.60 mm | 58 | 111 | 11.1 | 88.9 |
| .450 mm | 75 | 186 | 18.6 | 81.4 |
| 0.30 mm | 35 | 221 | 22.1 | 77.9 |
| 0.15 mm | 366 | 587 | 58.7 | 41.3 |
| 0.075 mm | 226 | 813 | 81.3 | 18.7 |
| Retainer | 187 | 1000 | 100.0 | 0 |

DETERMINATION OF COMPACTION PROPERTIES FOR SOIL USING STANDARD PROCTOR TEST

| | | 1 | 2 | 3 | 4 |
|-----|--|-------|-------|-------|-------|
| 1. | Mass of Mould W1 in gm | 5060 | 5060 | 5060 | 5060 |
| 2. | Mass of Mould + Wet Soil W2 in gm | 6969 | 7140 | 7110 | 7078 |
| 3. | Mass of Wet Soil W2-W1 in gm | 1909 | 2080 | 2050 | 2018 |
| 4. | Volume of Mould V in c.c. | 1000 | 1000 | 1000 | 1000 |
| 5. | Bulk Density $r_m = (W2-W1)/V$ gm/cc | 1.909 | 2.080 | 2.050 | 2.018 |
| 6. | Container No. | 40 | 45 | 03 | 30 |
| 7. | Mass of Container + Wet soil W3 in gm | 52 | 57 | 54 | 63 |
| 8. | Mass of Container + Oven dried soil W4 in gm | 49 | 54 | 51 | 58 |
| 9. | Mass of moisture W3-W4 in gm | 3 | 3 | 3 | 5 |
| 10. | Mass of Container W5 in gm | 24 | 25 | 28 | 27 |
| 11. | Mass of Oven dried soil W4-W5 in gm | 25 | 29 | 23 | 31 |
| 12. | Water Content in % | 10 | 10.34 | 13.04 | 16.12 |
| 13. | Dry Density | 1.75 | 1.88 | 1.81 | 1.73 |

**DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT FOR SOIL USING
CASAGRANDE'S APPARATUS**

| | Description | Liquid Limit | | | | Plastic limit |
|----|---|--------------|----|-------|----|---------------|
| | | 1 | 2 | 3 | 4 | |
| 1. | Penetration D in mm/no of Blows (N) | 16 | 20 | 41 | 27 | - |
| 2. | Container No. | 5 | 28 | 20 | 39 | 09 |
| 3. | Mass of Container + Wet Soil W2 in gm | 40 | 39 | 42 | 38 | 39 |
| 4. | Mass of Container + Oven Dried Soil W3 in gm. | 38 | 38 | 40 | 36 | 38 |
| 5. | Mass of Moisture W2-W3 in gm | 2 | 1 | 2 | 2 | 3 |
| 6. | Mass of Container W1 in gm | 29 | 29 | 29 | 26 | 32 |
| 7. | Mass of Oven Dried Soil W3-W1 in gm | 09 | 09 | 11 | 10 | 6 |
| 8. | Water Content in % $W_n = (w_2 - w_3 / w_3 - w_1) * 100$ | 22.22 | 16 | 18.18 | 21 | 14.16 |

DETERMINATION OF C.B.R.

| Penetration (mm) | Load on Plunger(Unsoaked) KN | Load on Plunger(Soaked) KN |
|-----------------------|---------------------------------|----------------------------|
| 0.5 | .43 | .23 |
| 1 | .77 | .40 |
| 1.5 | 1.09 | .72 |
| 2 | 1.37 | .83 |
| 2.5 | 1.59 | 1.09 |
| 3 | 1.78 | 1.25 |
| 3.5 | 1.98 | 1.42 |
| 4 | 2.25 | 1.54 |
| 4.5 | 2.47 | 1.68 |
| 5 | 2.69 | 1.72 |
| 7.5 | 3.09 | 2.20 |
| 10 | 3.52 | 2.98 |
| 12 | 4.30 | 3.39 |
| 12.5 | 4.53 | 3.58 |
| CBR (Unsoaked) | | 13.37 |
| CBR (Soaked) | | 8.35 |

GRAIN SIZE ANALYSIS OF SOIL

Location: Adampur

Sample No: 06

| IS Sieve Designation | Weight of Soil Retained in Grams | Cumulative weight retained in grams | Cumulative percentage retained | Percentage passing |
|----------------------|----------------------------------|-------------------------------------|--------------------------------|--------------------|
| 4.75 mm | 0 | 0 | 0 | 100 |
| 2.36 mm | 0 | 0 | 0 | 100 |
| 1.18 mm | 88 | 88 | 8.8 | 91.2 |
| 0.60 mm | 70 | 158 | 15.8 | 84.2 |
| 0.450 mm | 100 | 258 | 25.8 | 74.2 |
| 0.30 mm | 60 | 318 | 31.8 | 68.2 |
| 0.15 mm | 346 | 664 | 66.4 | 23.6 |
| 0.075 mm | 151 | 815 | 81.5 | 18.5 |
| Retainer | 185 | 1000 | 100.0 | 0 |

DETERMINATION OF COMPACTION PROPERTIES FOR SOIL USING STANDARD PROCTOR TEST

| | | 1 | 2 | 3 | 4 | 5 |
|-----|---|-------|-------|-------|-------|-------|
| 1. | Mass of Mould W1 in gm | 5060 | 5060 | 5060 | 5060 | 5060 |
| 2. | Mass of Mould + Wet Soil W2 in gm | 6992 | 7117 | 7210 | 7254 | 7249 |
| 3. | Mass of Wet Soil W2-W1 in gm | 1932 | 2057 | 2150 | 2190 | 2189 |
| 4. | Volume of Mould V in c.c. | 1000 | 1000 | 1000 | 1000 | 1000 |
| 5. | Bulk Density $r_m = (W2-W1)/V$ gm/cc | 1.932 | 2.057 | 2.150 | 2.190 | 2.189 |
| 6. | Container No. | 39 | 5 | 77 | 20 | 09 |
| 7. | Mass of Container + Wet soil W3 in gm | 47.5 | 46 | 53 | 68 | 81 |
| 8. | Mass of Container + Oven dried soil W4 in gm | 46 | 45 | 51 | 64 | 75 |
| 9. | Mass of moisture W3-W4 in gm | 1.5 | 1 | 2 | 4 | 6 |
| 10. | Mass of Container W5 in gm | 26 | 29 | 28 | 29 | 32 |
| 11. | Mass of Oven dried soil W4-W5 in gm | 20 | 16 | 23 | 35 | 43 |
| 12. | Water Content in % | 7.15 | 8.5 | 8.9 | 11.12 | 14 |
| 13. | Dry Density $r_d = (100 r_m)/(100 + w)$ in gm/cc | 1.79 | 1.895 | 1.974 | 1.975 | 1.92 |

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT FOR SOIL USING
CASAGRANDE'S APPARATUS

| | Description | Liquid Limit | | | Plastic Limit |
|----|---|--------------|-------|----|---------------|
| | | 1 | 2 | 3 | |
| | | 1 | 2 | 3 | 1 |
| 1. | Penetration D in mm/no of Blows (N) | 26 | 37 | 17 | - |
| 2. | Container No. | 3 | 77 | 40 | 45 |
| 3. | Mass of Container + Wet Soil W2 in gm | 38 | 42 | 35 | 34 |
| 4. | Mass of Container + Oven Dried Soil W3 in gm. | 36 | 40 | 34 | 33 |
| 5. | Mass of Moisture W2-W3 in gm | 2.1 | 2 | 1 | 1 |
| 6. | Mass of Container W1 in gm | 28 | 28 | 24 | 25 |
| 7. | Mass of Oven Dried Soil W3-W1 in gm | 8 | 12 | 10 | 8 |
| 8. | Water Content in % | 26.7 | 16.66 | 20 | 12.5 |

DETERMINATION OF CBR

| Penetration (mm) | Load on Plunger(Unsoaked) KN | Load on Plunger(Soaked) KN |
|-----------------------|---------------------------------|----------------------------|
| 0.5 | .39 | .29 |
| 1 | .73 | .62 |
| 1.5 | 1.19 | 1.09 |
| 2 | 1.52 | 1.41 |
| 2.5 | 2.02 | 1.82 |
| 3 | 2.36 | 2.02 |
| 3.5 | 2.78 | 2.21 |
| 4 | 3.25 | 2.36 |
| 4.5 | 3.60 | 2.51 |
| 5 | 3.97 | 2.58 |
| 7.5 | 4.3 | 2.90 |
| 10 | 4.60 | 3.60 |
| 12 | 4.81 | 4.11 |
| 12.5 | 4.93 | 4.29 |
| CBR (Unsoaked) | | 19.68 |
| CBR (Soaked) | | 12.808 |

UNCONFINED COMPRESSION TEST

| Deformation | | Strain | Corrected Area | Load | | Compressive Stress |
|-------------|------|----------|----------------|------|------|--------------------|
| Div. | mm | | | Div. | Kg | Kg/cm ² |
| 0 | 0 | 0 | | 0 | 0 | |
| 20 | .20 | 0.002632 | 11.370 | 0.2 | 1 | 0.087951 |
| 40 | .40 | 0.005263 | 11.400 | 0.6 | 3 | 0.263158 |
| 60 | .60 | 0.007895 | 11.430 | 1.6 | 8 | 0.699913 |
| 80 | .80 | 0.010526 | 11.461 | 2 | 10 | 0.872524 |
| 100 | 1.00 | 0.013158 | 11.491 | 4 | 20 | 1.740493 |
| 150 | 1.50 | 0.019737 | 11.568 | 5 | 25 | 2.161134 |
| 200 | 2.00 | 0.026316 | 11.646 | 6.2 | 31 | 2.661858 |
| 250 | 2.50 | 0.032895 | 11.726 | 7.2 | 36 | 3.070101 |
| 300 | 3.00 | 0.039474 | 11.806 | 8.4 | 42 | 3.557513 |
| 350 | 3.50 | 0.046053 | 11.887 | 9 | 45 | 3.785648 |
| 400 | 4.00 | 0.052632 | 11.970 | 9.3 | 46.5 | 3.884712 |
| 450 | 4.50 | 0.059211 | 12.054 | 9.8 | 49 | 4.065041 |
| 500 | 5.00 | 0.065789 | 12.139 | 9.7 | 48.5 | 3.995387 |

GRAIN SIZE ANALYSIS OF SOIL

Location : Devigarh

Sample No: 07

| IS Sieve Designation | Weight of Soil Retained in Grams | Cumulative weight retained in grams | Cumulative percentage retained | Percentage passing |
|----------------------|----------------------------------|-------------------------------------|--------------------------------|--------------------|
| 4.75 mm | 0 | 0 | 0 | 100 |
| 2.36 mm | 0 | 0 | 0 | 100 |
| 1.18 mm | 45 | 45 | 4.5 | 95.5 |
| 0.60 mm | 100 | 145 | 14.5 | 85.5 |
| 0.450 mm | 172 | 317 | 31.7 | 68.3 |
| 0.30 mm | 78 | 395 | 39.5 | 60.5 |
| 0.15 mm | 248 | 643 | 64.3 | 35.7 |
| 0.075 mm | 181 | 824 | 82.4 | 17.6 |
| Retainer | 160 | 1000 | 100.0 | 0 |

DETERMINATION OF COMPACTION PROPERTIES FOR SOIL USING STANDARD PROCTOR TEST

| | | 1 | 2 | 3 | 4 |
|-----|--|-------|-------|-------|-------|
| 1. | Mass of Mould W1 in gm | 5060 | 5060 | 5060 | 5060 |
| 2. | Mass of Mould + Wet Soil W2 in gm | 6889 | 6928 | 6938 | 6950 |
| 3. | Mass of Wet Soil W2-W1 in gm | 1829 | 1868 | 1878 | 1890 |
| 4. | Volume of Mould V in c.c. | 1000 | 1000 | 1000 | 1000 |
| 5. | Bulk Density $r_m = (W2-W1)/V$ gm/cc | 1.829 | 1.868 | 1.878 | 1.890 |
| 6. | Container No. | 38 | 36 | 32 | 3 |
| 7. | Mass of Container + Wet soil W3 in gm | 56 | 45 | 61 | 58 |
| 8. | Mass of Container + Oven dried soil W4 in gm | 54 | 43 | 57 | 54 |
| 9. | Mass of moisture W3-W4 in gm | 2 | 2 | 4 | 4 |
| 10. | Mass of Container W5 in gm | 29 | 23 | 25 | 28 |
| 11. | Mass of Oven dried soil W4-W5 in gm | 25 | 19 | 32 | 26 |
| 12. | Water Content in % | 8 | 10.52 | 12.5 | 15.38 |
| 13. | Dry Density | 1.68 | 1.690 | 1.67 | 1.63 |

**DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT FOR SOIL USING
CASAGRANDE'S APPARATUS**

| | Description | Liquid Limit | | | | Plastic Limit |
|----|---|--------------|-------|------|------|---------------|
| | | 1 | 2 | 3 | 4 | |
| | | 1 | 2 | 3 | 4 | 1 |
| 1. | Penetration D in mm/no of Blows (N) | 42 | 35 | 15 | 23 | - |
| 2. | Container No. | 29 | 15 | 77 | 18 | 9 |
| 3. | Mass of Container + Wet Soil W2 in gm | 39 | 43 | 50 | 58 | 37 |
| 4. | Mass of Container + Oven Dried Soil W3 in gm. | 37 | 38 | 44 | 49 | 35 |
| 5. | Mass of Moisture W2-W3 in gm | 2 | 5 | 6 | 9 | 2 |
| 6. | Mass of Container W1 in gm | 29 | 25 | 28 | 25 | 27 |
| 7. | Mass of Oven Dried Soil W3-W1 in gm | 8 | 13 | 16 | 24 | 8 |
| 8. | Water Content in % | 25.5 | 38.46 | 37.5 | 34.9 | 25 |

DETERMINATION OF CBR

| Penetration (mm) | Load on Plunger(Unsoaked) KN | Load on Plunger(Soaked) KN |
|--|---------------------------------|----------------------------|
| 0.5 | 0.66 | .32 |
| 1 | 1.56 | .61 |
| 1.5 | 2.11 | 1.06 |
| 2 | 2.88 | 1.47 |
| 2.5 | 3.16 | 2.02 |
| 3 | 3.66 | 2.49 |
| 3.5 | 3.89 | 2.83 |
| 4 | 4.28 | 3.07 |
| 4.5 | 4.63 | 3.28 |
| 5 | 4.92 | 3.43 |
| 7.5 | 5.38 | 3.76 |
| 9 | 5.67 | 3.91 |
| 10 | 5.76 | 4.0 |
| 11 | 5.86 | 4.02 |
| 12.5 | 5.99 | 4.06 |
| CBR at 5mm penetration (Unsoaked) | | 24.4 |
| CBR at 5mm penetration (Soaked) | | 17 |

UNCONFINED COMPRESSION TEST

| Deformation | | Strain | Corrected Area | Load | | Compressive Stress |
|-------------|------|----------|----------------|------|----|--------------------|
| Div. | mm | | | Div. | Kg | Kg/cm ² |
| 0 | 0 | 0 | | 0 | 0 | 0 |
| 20 | .20 | 0.002632 | 11.370 | 0 | 0 | 00 |
| 40 | .40 | 0.005263 | 11.400 | 0 | 0 | 00 |
| 60 | .60 | 0.007895 | 11.430 | 0 | 0 | 00 |
| 80 | .80 | 0.010526 | 11.461 | 0.2 | 1 | 0.087252 |
| 100 | 1.00 | 0.013158 | 11.491 | 0.4 | 2 | 0.174049 |
| 150 | 1.50 | 0.019737 | 11.568 | 0.6 | 3 | 0.259336 |
| 200 | 2.00 | 0.026316 | 11.646 | 1.8 | 9 | 0.772798 |
| 250 | 2.50 | 0.032895 | 11.726 | 3.4 | 17 | 1.44977 |
| 300 | 3.00 | 0.039474 | 11.806 | 4.4 | 22 | 1.863459 |
| 350 | 3.50 | 0.046053 | 11.887 | 6 | 30 | 2.523765 |
| 400 | 4.00 | 0.052632 | 11.970 | 6.8 | 34 | 2.840434 |
| 450 | 4.50 | 0.059211 | 12.054 | 8.6 | 43 | 3.567281 |
| 500 | 5.00 | 0.065789 | 12.139 | 9.6 | 48 | 3.954197 |
| 550 | 5.50 | 0.072368 | 12.225 | 10.2 | 51 | 4.171779 |
| 600 | 6.00 | 0.078947 | 12.312 | 10.4 | 52 | 4.223522 |
| 650 | 6.50 | 0.085526 | 12.401 | 10.2 | 51 | 4.112572 |

GRAIN SIZE ANALYSIS OF SOIL

Location: Banur

Sample No:08

| IS Sieve Designation | Weight of Soil Retained in Grams | Cumulative weight retained in grams | Cumulative percentage retained | Percentage passing |
|----------------------|----------------------------------|-------------------------------------|--------------------------------|--------------------|
| 4.75 mm | 0 | 0 | 0 | 100 |
| 2.36 mm | 16 | 16 | 1.6 | 98.4 |
| 1.18 mm | 60 | 76 | 7.6 | 92.4 |
| 0.60 mm | 76 | 152 | 15.2 | 84.8 |
| 0.425 mm | 89 | 241 | 24.1 | 75.9 |
| 0.30 mm | 78 | 319 | 31.9 | 68.1 |
| 0.15 mm | 279 | 598 | 59.8 | 40.2 |
| 0.075 mm | 212 | 810 | 81.0 | 19 |
| Retainer | 190 | 1000 | 100.0 | 0 |

DETERMINATION OF COMPACTION PROPERTIES FOR SOIL USING STANDARD PROCTOR TEST

| | | 1 | 2 | 3 | 4 | 5 |
|-----|--|-------|-------|-------|-------|-------|
| 1. | Mass of Mould W1 in gm | 4320 | 4320 | 4320 | 4320 | 4320 |
| 2. | Mass of Mould + Wet Soil W2 in gm | 6248 | 6349 | 6500 | 6444 | 6407 |
| 3. | Mass of Wet Soil W2-W1 in gm | 1928 | 2029 | 2180 | 2124 | 2087 |
| 4. | Volume of Mould V in c.c. | 982 | 982 | 982 | 982 | 982 |
| 5. | Bulk Density $r_m = (W2-W1)/V$ gm/cc | 1.963 | 2.065 | 2.180 | 2.164 | 2.124 |
| 6. | Container No. | 43 | 3 | 9 | 77 | 28 |
| 7. | Mass of Container + Wet soil W3 in gm | 50 | 48 | 57 | 55 | 76 |
| 8. | Mass of Container + Oven dried soil W4 in gm | 48 | 46 | 54 | 51 | 69 |
| 9. | Mass of moisture W3-W4 in gm | 2 | 2 | 3 | 4 | 7 |
| 10. | Mass of Container W5 in gm | 25 | 28 | 32 | 28 | 29 |
| 11. | Mass of Oven dried soil W4-W5 in gm | 23 | 18 | 22 | 23 | 40 |
| 12. | Water Content in % | 8.6 | 11.11 | 13.6 | 17.4 | 17.5 |
| 13. | Dry Density | 1.807 | 1.86 | 1.92 | 1.841 | 1.807 |

**DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT FOR SOIL
CASAGRANDE'S APPARATUS**

| | Description | Liquid Limit | | | | Plastic limit |
|----|-------------------------------------|--------------|-------|-------|-------|---------------|
| | | 1 | 2 | 3 | 4 | |
| 1. | Penetration D in mm/no of Blows | 27 | 30 | 40 | 15 | - |
| 2. | Container No. | 77 | 06 | 40 | 43 | 11 |
| 3. | Mass of Container + Wet Soil W2 | 70 | 76 | 57 | 55 | 38 |
| 4. | Mass of Container + Oven Dried Soil | 64 | 68 | 52 | 50.5 | 37 |
| 5. | Mass of Moisture W2-W3 in gm | 06 | 08 | 05 | 4.5 | 01 |
| 6. | Mass of Container W1 in gm | 28 | 29 | 24 | 25 | 28 |
| 7. | Mass of Oven Dried Soil W3-W1 | 36 | 39 | 28 | 25.5 | 09 |
| 8. | Water Content in % | 17 | 20.51 | 17.85 | 17.09 | 11 |

DETERMINATION OF CBR

| Penetration (mm) | Load on Plunger(Unsoaked) KN | Load on Plunger(Soaked) KN |
|-----------------------|------------------------------|----------------------------|
| 0.5 | 0.10 | .08 |
| 1 | 0.21 | .16 |
| 1.5 | 0.44 | .27 |
| 2 | 0.66 | .36 |
| 2.5 | 0.82 | .42 |
| 3 | 1.01 | .57 |
| 3.5 | 1.19 | .72 |
| 4 | 1.42 | .93 |
| 4.5 | 1.69 | 1.11 |
| 5 | 1.92 | 1.32 |
| 7.5 | 2.41 | 1.77 |
| 10 | 2.82 | 2.15 |
| 12 | 3.07 | 2.48 |
| 12.5 | 3.22 | 2.62 |
| CBR (Unsoaked) | | 9.50 |
| CBR (Soaked) | | 6.7 |

GRAIN SIZE ANALYSIS OF SOIL

Location: Rajpura

Sample No:09

| IS Sieve Designation | Weight of Soil Retained in Grams | Cumulative weight retained in grams | Cumulative percentage retained | Percentage passing |
|----------------------|----------------------------------|-------------------------------------|--------------------------------|--------------------|
| 4.75 mm | 0 | 0 | 0 | 100 |
| 2.36 mm | 0 | 0 | 0 | 100 |
| 1.0 mm | 33 | 33 | 3.3 | 96.7 |
| 0.60 mm | 110 | 133 | 13.3 | 86.7 |
| 0.425 mm | 155 | 288 | 28.8 | 71.2 |
| 0.30 mm | 60 | 348 | 34.8 | 65.2 |
| 0.15 mm | 280 | 628 | 62.8 | 37.2 |
| 0.075 mm | 166 | 794 | 79.4 | 20.6 |
| Retainer | 206 | 1000 | 100.0 | 0 |

DETERMINATION OF COMPACTION PROPERTIES FOR SOIL USING STANDARD PROCTOR TEST

| | | 1 | 2 | 3 | 4 | 5 |
|-----|--|-------|-------|-------|-------|-------|
| 1. | Mass of Mould W1 in gm | 5060 | 5060 | 5060 | 5060 | 5060 |
| 2. | Mass of Mould + Wet Soil W2 in gm | 6248 | 6349 | 6446 | 6444 | 6407 |
| 3. | Mass of Wet Soil W2-W1 in gm | 1928 | 2029 | 2126 | 2124 | 2087 |
| 4. | Volume of Mould V in c.c. | 982 | 982 | 982 | 982 | 982 |
| 5. | Bulk Density $r_m = (W2-W1)/V$ gm/cc | 1.963 | 2.065 | 2.164 | 2.162 | 2.124 |
| 6. | Container No. | 43 | 3 | 9 | 77 | 28 |
| 7. | Mass of Container + Wet soil W3 in gm | 50 | 48 | 57 | 55 | 76 |
| 8. | Mass of Container + Oven dried soil W4 in gm | 48 | 46 | 54 | 51 | 69 |
| 9. | Mass of moisture W3-W4 in gm | 2 | 2 | 3 | 4 | 7 |
| 10. | Mass of Container W5 in gm | 25 | 28 | 32 | 28 | 29 |
| 11. | Mass of Oven dried soil W4-W5 in gm | 23 | 18 | 22 | 23 | 40 |
| 12. | Water Content in % | 8.6 | 11.11 | 13.6 | 17.4 | 17.5 |
| 13. | Dry Density | 1.807 | 1.86 | 1.904 | 1.841 | 1.807 |

**DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT FOR SOIL USING
CASAGRANDE'S APPARATUS**

| | Description | Liquid Limit | | | | Plastic limit |
|----|--|--------------|------|----|----|---------------|
| | | 1 | 2 | 3 | 4 | |
| 1. | Penetration D in mm/no of Blows (N) | 10 | 19 | 26 | 35 | - |
| 2. | Container No. | 36 | 21 | 20 | 22 | 48 |
| 3. | Mass of Container + Wet Soil W2 in gm | 43 | 41 | 38 | 38 | 60 |
| 4. | Mass of Container + Oven Dried Soil W3 | 39 | 39 | 36 | 36 | 56 |
| 5. | Mass of Moisture W2-W3 in gm | 4 | 2 | 2 | 2 | 4 |
| 6. | Mass of Container W1 in gm | 23 | 30 | 29 | 26 | 35 |
| 7. | Mass of Oven Dried Soil W3-W1 in gm | 16 | 9 | 7 | 10 | 21 |
| 8. | Water Content in % | 25 | 22.2 | 29 | 20 | 19 |

DETERMINATION OF CBR

| Penetration (mm) | Load on Plunger(Unsoaked) KN | Load on Plunger(Soaked) KN |
|-----------------------|------------------------------|----------------------------|
| 0.5 | 0.13 | 0.02 |
| 1 | 0.24 | 0.16 |
| 1.5 | 0.32 | 0.28 |
| 2 | 0.55 | 0.42 |
| 2.5 | 0.94 | 0.83 |
| 3 | 1.44 | 1.11 |
| 3.5 | 1.97 | 1.39 |
| 4 | 2.32 | 1.63 |
| 4.5 | 2.75 | 1.81 |
| 5 | 3.03 | 2.03 |
| 7.5 | 3.99 | 2.59 |
| 8 | 4.20 | 2.69 |
| 10 | 4.37 | 2.90 |
| 12 | 4.55 | 3.09 |
| 12.5 | 4.59 | 3.14 |
| CBR (Unsoaked) | | 15 |
| CBR (Soaked) | | 10 |

UNCONFINED COMPRESSION TEST

| Deformation | | Strain | Corrected Area | Load | | Compressive Stress |
|-------------|------|----------|----------------|------|------|--------------------|
| Div. | mm | | | Div. | Kg | Kg/cm ² |
| 0 | 0 | 0 | | 0 | 0 | 0 |
| 20 | .20 | 0.002632 | 11.370 | 0.1 | 0.5 | 0.043975 |
| 40 | .40 | 0.005263 | 11.400 | 0.5 | 2.5 | 0.219298 |
| 60 | .60 | 0.007895 | 11.430 | 1.1 | 5.5 | 0.48119 |
| 80 | .80 | 0.010526 | 11.461 | 1.8 | 9 | 0.785272 |
| 100 | 1.00 | 0.013158 | 11.491 | 2 | 10 | 0.870246 |
| 150 | 1.50 | 0.019737 | 11.568 | 2.9 | 14.5 | 1.253458 |
| 200 | 2.00 | 0.026316 | 11.646 | 5 | 25 | 2.14666 |
| 250 | 2.50 | 0.032895 | 11.726 | 5.8 | 26 | 2.473137 |
| 300 | 3.00 | 0.039474 | 11.806 | 5.7 | 28.5 | 2.414027 |

GRAIN SIZE ANALYSIS OF SOIL

Location: Tangori

Sample No:10

| IS Sieve Designation | Weight of Soil Retained in Grams | Cumulative weight retained in grams | Cumulative percentage retained | Percentage passing |
|----------------------|----------------------------------|-------------------------------------|--------------------------------|--------------------|
| 4.75 mm | 0 | 0 | 0 | 100 |
| 2.36 mm | 15 | 15 | 1.5 | 98.5 |
| 1.0mm | 40 | 55 | 5.5 | 94.5 |
| 0.60 mm | 80 | 135 | 13.5 | 86.5 |
| 0.425 mm | 185 | 320 | 32.0 | 68 |
| 0.30 mm | 82 | 402 | 40.2 | 59.8 |
| 0.15 mm | 260 | 662 | 66.2 | 33.8 |
| 0.075 mm | 149 | 811 | 81.1 | 18.9 |
| Retainer | 189 | 1000 | 100.0 | 0 |

DETERMINATION OF COMPACTION PROPERTIES FOR SOIL USING STANDARD PROCTOR TEST

| | | 1 | 2 | 3 | 4 |
|-----|--|-------|-------|-------|-------|
| 1. | Mass of Mould W1 in gm | 4320 | 4320 | 4320 | 4320 |
| 2. | Mass of Mould + Wet Soil W2 in gm | 6314 | 6415 | 6486 | 6454 |
| 3. | Mass of Wet Soil W2-W1 in gm | 1994 | 2095 | 2166 | 2134 |
| 4. | Volume of Mould V in c.c. | 982 | 982 | 982 | 982 |
| 5. | Bulk Density $r_m = (W2-W1)/V$ gm/cc | 2.030 | 2.133 | 2.205 | 2.172 |
| 6. | Container No. | 47 | 77 | 23 | 20 |
| 7. | Mass of Container + Wet soil W3 in gm | 59 | 65 | 60 | 77 |
| 8. | Mass of Container + Oven dried soil W4 in gm | 56 | 61 | 56 | 70 |
| 9. | Mass of moisture W3-W4 in gm | 3 | 4 | 4 | 7 |
| 10. | Mass of Container W5 in gm | 27 | 28 | 28 | 29 |
| 11. | Mass of Oven dried soil W4-W5 in gm | 29 | 33 | 28 | 41 |
| 12. | Water Content in % | 10.34 | 12.12 | 13.99 | 17.07 |
| 13. | Dry Density | 1.839 | 1.902 | 1.933 | 1.855 |

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT FOR SOIL USING CASAGRANDE'S APPARATUS

| | Description | Liquid Limit | | | | Plastic limit |
|----|-------------------------------------|--------------|-------|-------|-----|---------------|
| | | 1 | 2 | 3 | 4 | |
| 1. | Penetration D in mm/no of Blows | 15 | 20 | 24 | 30 | - |
| 2. | Container No. | 18 | 45 | 09 | 31 | 20 |
| 3. | Mass of Container + Wet Soil W2 | 77 | 60 | 80 | 120 | 50 |
| 4. | Mass of Container + Oven Dried Soil | 67 | 54.5 | 71 | 106 | 48 |
| 5. | Mass of Moisture W2-W3 in gm | 10 | 5.5 | 09 | 14 | 02 |
| 6. | Mass of Container W1 in gm | 40 | 38 | 43 | 44 | 37.5 |
| 7. | Mass of Oven Dried Soil W3-W1 | 27 | 16.5 | 28 | 62 | 10.5 |
| 8. | Water Content in % | 37.0 3 | 33.33 | 32.33 | 22 | 19 |

DETERMINATION OF CBR

| Penetration (mm) | Load on Plunger(Unsoaked)KN | Load on Plunger(Soaked)KN |
|-----------------------|-----------------------------|---------------------------|
| 0.5 | 0.17 | 0.11 |
| 1 | 0.31 | 0.72 |
| 1.5 | 0.90 | 0.95 |
| 2 | 1.45 | 1.22 |
| 2.5 | 1.92 | 1.5 |
| 3 | 2.34 | 1.67 |
| 3.5 | 2.76 | 1.83 |
| 4 | 3.16 | 2.07 |
| 4.5 | 3.51 | 2.3 |
| 5 | 3.83 | 2.50 |
| 7.5 | 4.76 | 3.01 |
| 8 | 5.01 | 3.06 |
| 9 | 5.30 | 3.14 |
| 10 | 5.55 | 3.20 |
| 12 | 6.08 | 3.30 |
| 12.5 | 6.53 | 3.36 |
| CBR (Unsoaked) | | 19 |
| CBR (Soaked) | | 12.4 |

UNCONFINED COMPRESSION TEST

| Deformation | | Strain | Corrected Area | Load | | Compressive Stress |
|-------------|------|----------|----------------|------|-----|--------------------|
| Div. | mm | | | Div. | Kg | Kg/cm ² |
| 0 | 0 | 0 | | 0 | 0 | 0 |
| 20 | .20 | 0.002632 | 11.370 | 0.2 | 1 | 0.087951 |
| 40 | .40 | 0.005263 | 11.400 | 0.4 | 2 | 0.175439 |
| 60 | .60 | 0.007895 | 11.430 | 0.5 | 2.5 | 0.218723 |
| 80 | .80 | 0.010526 | 11.461 | 0.9 | 4.5 | 0.392636 |
| 100 | 1.00 | 0.013158 | 11.491 | 1.2 | 6 | 0.522148 |
| 150 | 1.50 | 0.019737 | 11.568 | 1.8 | 9 | 0.778008 |
| 200 | 2.00 | 0.026316 | 11.646 | 2.4 | 12 | 1.030397 |
| 250 | 2.50 | 0.032895 | 11.726 | 3.2 | 16 | 1.364489 |
| 300 | 3.00 | 0.039474 | 11.806 | 4.6 | 23 | 1.948162 |
| 350 | 3.50 | 0.046053 | 11.887 | 5.2 | 26 | 2.187263 |
| 400 | 4.00 | 0.052632 | 11.970 | 5.6 | 28 | 2.339181 |
| 450 | 4.50 | 0.059211 | 12.054 | 6.2 | 31 | 2.57176 |
| 500 | 5.00 | 0.065789 | 12.139 | 6.6 | 33 | 2.718511 |
| 550 | 5.50 | 0.072368 | 12.225 | 7 | 35 | 2.862986 |
| 600 | 6.00 | 0.078947 | 12.312 | 7.6 | 38 | 3.08642 |
| 650 | 6.50 | 0.085526 | 12.401 | 8 | 40 | 3.225546 |
| 700 | 7.00 | 0.092105 | 12.49 | 8.2 | 41 | 3.282626 |
| 750 | 7.5 | 0.098684 | 12.582 | 8.4 | 42 | 3.338102 |
| 800 | 8.0 | 0.105263 | 12.674 | 8.8 | 44 | 3.471674 |
| 900 | 9.00 | 0.118421 | 12.863 | 8.6 | 43 | 3.342922 |

GRAIN SIZE ANALYSIS OF SOIL

Location: Nabha

Sample No:11

| IS Sieve Designation | Weight of Soil Retained in Grams | Cumulative weight retained in grams | Cumulative percentage retained | Percentage passing |
|----------------------|----------------------------------|-------------------------------------|--------------------------------|--------------------|
| 4.75 mm | 0 | 0 | 0 | 100 |
| 2.36 mm | 0 | 0 | 0 | 100 |
| 1.18 mm | 45 | 45 | 4.5 | 95.5 |
| 0.60 mm | 100 | 145 | 14.5 | 85.5 |
| 0.425 mm | 172 | 317 | 31.7 | 68.3 |
| 0.30 mm | 78 | 395 | 39.5 | 60.5 |
| 0.15 mm | 217 | 612 | 61.2 | 38.8 |
| 0.075 mm | 181 | 793 | 79.3 | 20.7 |
| Retainer | 207 | 1000 | 100.0 | 0 |

DETERMINATION OF COMPACTION PROPERTIES FOR SOIL USING STANDARD PROCTOR TEST

| | | 1 | 2 | 3 | 4 |
|-----|--|-------|-------|-------|-------|
| 1. | Mass of Mould W1 in gm | 5060 | 5060 | 5060 | 5060 |
| 2. | Mass of Mould + Wet Soil W2 in gm | 6895 | 6969 | 7137 | 7120 |
| 3. | Mass of Wet Soil W2-W1 in gm | 1835 | 1909 | 2077 | 2060 |
| 4. | Volume of Mould V in c.c. | 1000 | 1000 | 1000 | 1000 |
| 5. | Bulk Density $r_m = (W2-W1)/V$ gm/cc | 1.835 | 1.909 | 2.077 | 2.060 |
| 6. | Container No. | 20 | 28 | 26 | 2 |
| 7. | Mass of Container + Wet soil W3 in gm | 72 | 90 | 56 | 63 |
| 8. | Mass of Container + Oven dried soil W4 in gm | 69 | 85 | 53 | 59 |
| 9. | Mass of moisture W3-W4 in gm | 3 | 5 | 3 | 4 |
| 10. | Mass of Container W5 in gm | 29 | 29 | 24 | 27 |
| 11. | Mass of Oven dried soil W4-W5 in gm | 40 | 56 | 29 | 32 |
| 12. | Water Content in % | 7.5 | 8.92 | 10.34 | 12.5 |
| 13. | Dry Density | 1.70 | 1.75 | 1.876 | 1.83 |

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT FOR SOIL USING CASAGRANDE'S APPARATUS

| | Description | Liquid Limit | | | | | Plastic limit |
|----|---------------------------------|--------------|-------|----|------|------|---------------|
| | | 1 | 2 | 3 | 4 | 5 | |
| 1. | Penetration D in mm/no of Blows | 21 | 16 | 37 | 22 | 26 | - |
| 2. | Container No. | 15 | 33 | 47 | 46 | 3 | 36 |
| 3. | Mass of Container + Wet Soil | 38 | 43 | 38 | 40 | 46 | 32 |
| 4. | Mass of Container + Oven Dried | 36 | 40 | 36 | 38 | 43 | 31 |
| 5. | Mass of Moisture W2-W3 in gm | 2 | 3 | 2 | 2 | 3 | 1 |
| 6. | Mass of Container W1 in gm | 25 | 29 | 27 | 23.5 | 28 | 23 |
| 7. | Mass of Oven Dried Soil W3-W1 | 11 | 11 | 09 | 14.5 | 15 | 8 |
| 8. | Water Content in % | 22.22 | 27.27 | 15 | 21 | 20.5 | 12.18 |

DETERMINATION OF CBR

| Penetration (mm) | Load on Plunger(Unsoaked)KN | Load on Plunger(Soaked)KN |
|-----------------------|-----------------------------|---------------------------|
| 0.5 | 0.28 | 0.10 |
| 1 | 0.51 | 0.29 |
| 1.5 | 0.76 | 0.53 |
| 2 | 0.98 | 0.79 |
| 2.5 | 1.21 | 0.90 |
| 3 | 1.45 | 1.07 |
| 3.5 | 1.82 | 1.25 |
| 4 | 2.07 | 1.43 |
| 4.5 | 2.43 | 1.52 |
| 5 | 2.63 | 1.63 |
| 7.5 | 3.84 | 2.12 |
| 8 | 4.17 | 2.3 |
| 10 | 4.76 | 2.61 |
| 12 | 5.30 | 3.02 |
| 12.5 | 5.55 | 3.14 |
| CBR (Unsoaked) | | 13.02 |
| CBR (Soaked) | | 8.09 |

UNCONFINED COMPRESSION TEST

| Deformation | | Strain | Corrected Area | Load | | Compressive Stress |
|-------------|-------|----------|----------------|------|------|--------------------|
| Div. | mm | | | Div. | Kg | Kg/cm ² |
| 0 | 0 | 0 | | 0 | 0 | 0 |
| 20 | .20 | 0.002632 | 11.370 | 0.1 | 0.5 | 0.043975 |
| 40 | .40 | 0.005263 | 11.400 | 0.2 | 1 | 0.087719 |
| 60 | .60 | 0.007895 | 11.430 | 0.2 | 1 | 0.087489 |
| 80 | .80 | 0.010526 | 11.461 | 0.3 | 1.5 | 0.130879 |
| 100 | 1.00 | 0.013158 | 11.491 | 0.3 | 1.5 | 0.130537 |
| 150 | 1.50 | 0.019737 | 11.568 | 0.6 | 3 | 0.259336 |
| 200 | 2.00 | 0.026316 | 11.646 | 0.7 | 3.5 | 0.300532 |
| 250 | 2.50 | 0.032895 | 11.726 | 0.9 | 4.5 | 0.383763 |
| 300 | 3.00 | 0.039474 | 11.806 | 1.2 | 6 | 0.508216 |
| 350 | 3.50 | 0.046053 | 11.887 | 1.2 | 6 | 0.504753 |
| 400 | 4.00 | 0.052632 | 11.970 | 1.4 | 7 | 0.584795 |
| 450 | 4.50 | 0.059211 | 12.054 | 1.6 | 8 | 0.66368 |
| 500 | 5.00 | 0.065789 | 12.139 | 1.8 | 9 | 0.741412 |
| 550 | 5.50 | 0.072368 | 12.225 | 1.9 | 9.5 | 0.777096 |
| 600 | 6.00 | 0.078947 | 12.312 | 2.3 | 11.5 | 0.934048 |
| 650 | 6.50 | 0.085526 | 12.401 | 2.4 | 12 | 0.967664 |
| 700 | 7.00 | 0.092105 | 12.49 | 2.6 | 13 | 1.040833 |
| 750 | 7.5 | 0.098684 | 12.582 | 2.6 | 13 | 1.033222 |
| 800 | 8.0 | 0.105263 | 12.674 | 2.8 | 14 | 1.104624 |
| 900 | 9.00 | 0.118421 | 12.863 | 3.1 | 15.5 | 1.205007 |
| 1000 | 10 | 0.131579 | 13.058 | 3.4 | 17 | 1.301884 |
| 1100 | 11.00 | 0.144737 | 13.259 | 3.4 | 17 | 1.282148 |
| 1200 | 12.00 | 0.157895 | 13.466 | 3.4 | 17 | 1.262439 |
| 1300 | 13.00 | 0.171053 | 13.68 | 3.1 | 15.5 | 1.133041 |
| 1400 | 14.00 | 0.184211 | 13.901 | 2.4 | 12 | 0.863247 |
| 1500 | 15.00 | 0.197368 | 14.129 | 1.9 | 9.5 | 0.672376 |

