



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

IJRSET

International Journal of Innovative Research in
SCIENCE | ENGINEERING | TECHNOLOGY



INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 13, Special Issue 3, May 2024

ISSN INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA

Impact Factor: 8.423

 9940 572 462

 6381 907 438

 ijirset@gmail.com

 www.ijirset.com

Experimental Investigations on Stabilization of Expansive Soil in Subgrade Layer by using Waste Plastic and Fly Ash

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ABSTRACT: This study investigates the use of plastic strips and fly ash to improve the engineering properties of black cotton soil for plastic road construction. Experimental investigations were conducted on specimens with varying sizes and percentages of plastic strips, as well as different proportions of fly ash. The objectives focused on evaluating the influence of these materials on the soil's plasticity index, compaction characteristics, and strength properties. The findings contribute to sustainable practices by enhancing soil behavior, stability, and strength, while effectively utilizing plastic waste in road construction.

KEYWORDS: Flyash, Plastic, Black Cotton Soil

I. INTRODUCTION

1.1 Background:

Pollution is a major global concern, with conventional plastic being a significant contributor to environmental degradation. In India alone, plastic waste generation reaches 3.36 million tons annually, while recycling remains insufficient with only 4773 registered units. The growing production and consumption of plastic products have resulted in an exponential increase in non-decomposable waste. Conventional plastic poses severe challenges due to its non-biodegradable nature and harmful emissions when incinerated. Therefore, developing new applications for plastic waste is crucial to mitigating its adverse environmental impacts. One promising approach involves using waste plastic in geotechnical applications, such as stabilizing expansive soils in subgrade layers of pavements and foundations. This technique not only reduces the accumulation of high-density polyethylene (HDPE) waste but also enhances soil properties, making it a cost-effective and sustainable practice. Black cotton soil, known for its problematic swelling and shrinkage, can be significantly improved in terms of bearing capacity, California bearing ratio (CBR), compaction, and shear strength by incorporating waste plastic strips. In addition to plastic waste, fly ash, an industrial byproduct, presents disposal challenges and environmental risks. Fly ash has been shown to improve the plasticity index and strength characteristics of soils, making it an effective stabilizing agent. Combining waste plastic and fly ash offers a dual solution: enhancing the strength of expansive soils for construction purposes and addressing disposal issues of both waste materials. This study focuses on the innovative use of waste plastic and fly ash to stabilize expansive soils, particularly black cotton soil, for pavement subgrade layers. This approach not only provides an eco-friendly solution for waste disposal but also enhances the durability and stability of geotechnical structures, demonstrating significant potential for field application in India and beyond.

The typical cross section of road with application of waste plastics in the subgrade pavement layer is shown in Fig-1.

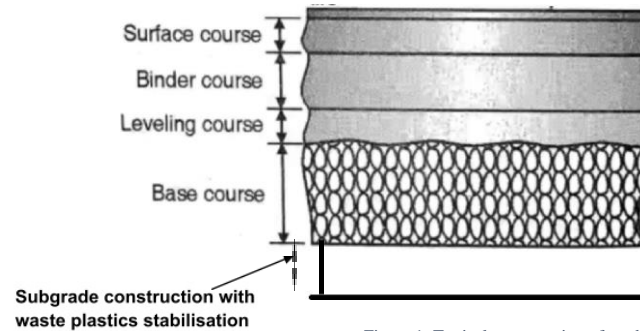


Figure 1: Typical cross section of road

1.2 Borrow Area :

Borrow area means an area from which earthen material is excavated for the purpose of constructing roadways. Excavation of natural earth will result in frequent sliding, loss of life and ecosystem services, groundwater contamination, and loss of arable land. Instead of using borrowed material and creating borrow pits, if we can stabilize the expansive soil by treating it with other inert materials it would decrease the cost and will also be beneficial for the environment as it reduces many risk factors that harms the environment and natural soil conditions. The below figure 2 shows the picture of the borrow pit.



1.3 Processing Technique of Mixing Plastic and Fly ash:

Plastic and fly ash can be blended together by mixing fly ash into melted plastic. Another way is to use plastic in granular form, here approach is to stabilize expansive soil by mixing plastic strips (containing LDPE, HDPE and PET) of varying sizes along with varying percentages of fly ash.

1.4 Present Scope of Study:

In order to reduce the accumulation of waste plastic on mother earth and also encourage its use for stabilisation of expansive soil in the subgrade layer. Many researchers have found that the use of plastic fibers significantly improves the engineering properties of soils

Studies have revealed that, the addition of waste plastic strips with cement kiln (Shafat, 2019), waste plastic strips with lime (Venkata et al., 2017), waste plastic strips with brick powder (Amena, 2021), waste brick powder mixed with lime (Reddy et al., 2018), and randomly distributing fiber as reinforcement (Rabindra Kar, 2011) caused an increase in strength properties, swelling potential, and frictional resistance of fine-grained soil. But only few studies have been reported in literature where stabilisation of expansive soil with use of High-Density Polythene (HDPE) plastic waste plastic bags and fly ash used for construction of subgrade layer.

Hence attempt will be made to investigate various properties enhancement of expansive soil after addition of waste plastics and fly ash. Also compare the cost of stabilisation with plastic and with conventional stabilisation techniques.

II. LITERATURE REVIEW

2.1 General

All the research paper gave a brief idea about the building concept and analysis method which can be implemented in our project and gives better results.

2.2 Literature Review: Shelema Amena (1) : The present study investigated the utilisation of plastic wastes as reinforcement to improve the strength and swelling behaviour of weak subgrade expansive soils and reduce plastic pollution. Expansive soils are known for their volume change during different seasons, while plastic waste is the most hazardous waste pollutant material that causes damage to the environment and organisms.

Utilising plastic wastes in subgrade construction reduces the quantity of waste and improves the problematic behaviour of expansive soils. The studied soil is categorised as expansive clay soil according to the AASHTO soil classification system.

Various geotechnical laboratory tests were conducted by varying the plastic strip sizes with treatment percentages of 0%, 0.25%, 0.5%, 1%, 1.5% and 2%. The study found that swelling percentages and compaction parameters were decreased with an increase in plastic waste strips.

As percentages of plastic strips increase, CBR values increase while unconfined compressive strength increases up to 0.5% addition of plastic strips and then slightly decreasing. The cohesion of the soil increases up to 1.5% of plastic strips addition.

The study recommends that the utilisation of plastic waste in subgrade road construction is the best alternative to improve the strength of expansive soils and reduce environmental pollution. The studies on the effect of HDPE plastic waste on some soil concluded that constructing flexible pavement to improve the subgrade soil of pavement using waste plastic bottles chips is an alternative method (Niteen, 2018).

Studies done on polyethylene, bottles, and shopping bags as reinforcement mixed with lime and rice husk ash (Muntohar et al., 2013), and crushed waste glass (Fauzi et al., 2016) found that the unconfined compressive strength and CBR values improved slightly.

The present study was conducted using rectangular plastic strip sizes of 5*8 mm, 8*15 mm, and 15*25 mm at 0.25%, 0.5%, 1%, 1.5%, and 2% percentages of plastic waste strips

to introduce the usage of plastic waste chips as a reinforcement to improve the strength of the flexible pavement's subgrade layer.

Abhishek Dixit (2) : In this study, soil samples from two locations of Bhauti regions of Kanpur (PSIT campus and new transport Nagar) were collected and analyzed for different geotechnical properties like specific gravity, plastic limit, liquid limit, plasticity index, optimum moisture content, maximum dry density and California bearing ratio (CBR).

Waste polyethene collected from Kanpur city were cut into different sizes, mixed in different proportions with the soils, compacted at optimum moisture content and California bearing ratio were assessed. Plastic wastes were mixed with soil in the proportions of 0%, 1%, 2%, 3%, 4% and 5%. € analysis showed that PSIT campus soil mixed with 4% plastic waste and new transport Nagar soil with 3% plastic have higher CBR values compared to raw soil. Based on the CBR values, total thickness as well as individual layer of flexible pavement for two lane carriage way was designed.

Different geotechnical properties like specific gravity, liquid limit, plastic limit, plasticity index, maximum dry density and optimum water content of soils, collected from the both locations of the Kanpur city were determined. The California bearing ratio was also assessed. CBR increased by 22.7% with PSIT campus soil at 4% of plastic waste whereas it increased by 34% with new transport Nagar at 3%. Therefore, more amount of plastic wastes can be used with PSIT campus soil compared to new transport Nagar soil²⁴, found unsoaked CBR value increased by 30% at 5% of plastic waste and hence plastic waste as strips/chips can be used for soil reinforcement/stabilization for the subgrade.

Form the study, it is found that the use of plastic waste in soil stabilization cannot only enhance the CBR value of soils but it can also be considered as a most suitable disposal technique for the protection of environment.

Mantu Kumar Et. Al (3) : The present study proposes to utilize waste plastic bags as a reinforcing material for soil supporting the concept of sustainable engineering practices. It is worthy to note that several researchers have utilized industrial waste products such as fly ash, phosphogypsum and others as soil stabilizer for ground improvement.

Only a few studies have been reported in literature where waste plastic bags are considered as a soil-reinforcing material. Therefore, the present study includes the laboratory experiments where specimens of composite black cotton soil mixed with different sizes and percentage of plastic strips by mass were performed.

The results were analyzed to study the influence of plastic strips of different aspect ratio for various properties such as compaction characteristics, California bearing ratio (CBR) and shear strength of the expansive soil. Moreover, the study shows the feasibility of using waste plastic bag's strips as reinforcing material in the expansive soil to improve its engineering properties.

In the present experimental study, the black cotton soil used has plasticity index as 35%, shrinkage index as 39.2% and free swell index as 49.8%; hence, the soil taken may be categorized as the expansive soil with high degree of expansion.

The sample soil reinforced with waste plastic bag strips (HDPE plastic-sizes 1 cm × 3 cm, 2 cm × 3 cm, 3 cm × 3 cm, thickness = 40 micron) have shown improvement in its engineering properties such as compaction, CBR and shear strength characteristics.

The range of plastic strip content to be mixed with the sample soil chosen is 0.1%, 0.4%, 0.7% and 1% by weight, and the maximum observed improvement in the soil is found at 0.4% strip content with the strip of size 3 cm × 3 cm.

The analysis of experimental results reveals that the maximum increase in MDD of the soil is 5% (17 to 17.87 kN/m²) and the corresponding OMC has reduced from 18 to 14.4%, the unsoaked CBR value has increased by 32% (from 8.1 to 10.75%) and soaked CBR is enhanced by 223% (from 1.98 to 6.41%), the shear strength parameter cohesion has shown a rise of 50% (from 0.8 to 1.2 kg/cm²) and the angle of internal friction is increased by 60% (from 15° to 24°).

The overall increase in shear strength is found to be 56%. Subsequently, the regression models have also been presented for response variables MDD, unsoaked CBR, soaked CBR, cohesion and angle of internal friction in terms of two independent variables: aspect ratio (h) and plastic strip content (α). The models are applicable only in the range of the experimental investigation presented here and may be referred directly for similar field situations. It is obvious that the proposed additive, the waste plastic carry bags, is an eco-friendly and cost-effective material for stabilization of expansive soils and may find its use in stabilization of weak subgrade soil.

Amena Oljira (4) : The present study investigated the utilization of plastic wastes as reinforcement to improve the strength and swelling behavior of weak subgrade expansive soils and reduce plastic pollution.

Expansive soils are known for their volume change during different seasons, while plastic waste is the most hazardous waste pollutant material that causes damage to the environment and organisms. Utilizing plastic wastes in subgrade construction reduces the quantity of waste and improves the problematic behavior of expansive soils.

The studied soil is categorized as expansive clay soil according to the AASHTO soil classification system. Various geotechnical laboratory tests were conducted by varying the plastic strip sizes with treatment percentages of 0%, 0.25%, 0.5%, 1%, 1.5% and 2%. The study found that swelling percentages and compaction parameters were decreased with an increase in plastic waste strips. As percentages of plastic strips increase, CBR values increase while unconfined compressive strength increases up to 0.5% addition of plastic strips and then slightly decreasing.

The cohesion of the soil increases up to 1.5% of plastic strips addition. The study recommends that the utilization of plastic waste in subgrade road construction is the best alternative to improve the strength of expansive soils and reduce environmental pollution.

As the sizes and percentage addition of plastic strips increases, the free swell values of the soil decrease. An increase in the size of the plastic strips creates a large gap between soil particles that alters interaction between soil particles.

In the same way, the mass of the soil decreases as the percentages of plastic increase waste which leads to a reduction in swelling

potential. Since plastic strips are chemically inactive to react with soil, there is no chemical reaction. As plastic strips alter the interaction between the soil particles so that swelling potential decreases.

Generally, based on the results of UCS, CBR, and swelling percentages to improve the difficulty of expansive soil properties, one can use 8*15 mm plastic size as an average. The study found that utilizing plastic waste strips as subgrade pavement material can open a door for proper plastic waste disposal methods and good soil improvements.

Hayden A. Hasan (5) : This paper investigated the effect of fly ash addition on geotechnical properties of expansive soil. Classification tests, consistency limits test, specific gravity test, compaction test, direct shear test, swell percentage, and swell pressure tests, were conducted on specimen of expansive soil.

Results of tests showed that soil was a clay high plasticity (CH) soil, according to the Unified Classification System (USCS) classification system. Liquid limit reduced from 74

% at 0 % fly ash to 56 % at 20 % fly ash content by dry weight of soil, the plastic limit reduced from 31 % at 0 % fly ash to 25 % at 20 % fly ash content, the plasticity index reduced from 44% at 0% fly ash to 31 % at 20% fly ash.

The maximum dry density reduced from 17.3 kN/m³ at 0% fly ash to 13 kN/m³ at 20 % fly ash and optimum moisture content increased from 19.2% at 0% fly ash to 29.3% at 20% fly ash. Shear strength parameters c and ϕ were measured after the addition of various contents of fly ash on curing days (7, 14 & 21).

The value of cohesion (c) increased with increasing the amount of fly ash added to 15% then decreases. The effect of curing time on cohesion increased until 14 days. While c is decreased at various contents of added fly ash at 0 time (no curing or immediately tested).

The increased internal friction angles (ϕ) with added fly ash in all samples are independent on curing time of the mixture. The increment in ϕ of all the mixtures for 7, 14 and 21 days cure time is more than that of no cure time.

Swell percentage decreased when fly ash content increased from 48% at 0% fly ash to 32% at 20% fly ash. Swell pressure decreased from 620 kN/m² at 0 % fly ash to 370 kN/m².

Akshat Mehrotra Et. Al (6) : Black Cotton soil which is a type of expansive soil, has the property of swelling excessively when wet and shrinks highly when exposed to dry conditions showing terrible surface cracks and due to this an uneven surface is created.

This condition arises due to a mineral known as montmorillonite and presence of fine clay particles. The soil changes its shape rapidly due to the addition of water. The soil occupies more than 20 % of the surface area of India. The aim of this research is to study the effect of HDPE plastic waste on the unconfined compressive strength of soil. The HDPE plastic (40 micron) waste was added at a proportion of 1.5%, 3%, 4.5% and 6% of the weight of dry soil. At the end of the study it was concluded that the addition of plastic waste had increased the unconfined compressive strength of black cotton soil. For the waste added, the maximum strength obtained at 4.5% was 287.32KN/m² and from natural soil it was 71.35KN/m².

III. METHODOLOGY

3.1 GENERAL:

The material requirement and methodology of stabilisation of expansive soil with waste plastic are listed below:

3.1.1 Materials:

- a. Collecting the expansive soil from road construction area from a depth of 1 m below ground surface. Performing the tests for its properties.
- b. Collecting fly ash ('c' class). Mixing it with soil in 5%, 10%, 15%, 20% respectively and perform the laboratory experiments.
- c. Deciding the optimum percentage of fly-ash content among 5%, 10%, 15% and 20% depending upon the results obtained.
- d. Collecting the HDPE and PET plastics and cutting them in sizes of 1 cm × 3 cm, 2 cm × 3 cm and 3 cm × 3 cm.
- e. Making the mixture of black cotton soil with the optimum fly-ash percentage and then adding the plastic strips with varying percentage that is 0.5%, 1.0%, 1.5% and 2%.
- f. Performing the practical experimental tests with the above sample and writing the results.

3.1.2. Experimental program:

The following laboratory tests are conducted on mixed samples such as:

- a. Grain size analysis: The objective of grain size analysis is to determine the percentage of soils passing different sieve opening sizes.
- b. Atterberg limits: The purpose of conducting Atterberg limit test is to know the plasticity properties of soil and to use it as input index parameters for soil classification.
- c. Compaction characteristics: To study the compaction characteristics of soil and to identify the effect of plastic strip reinforcement on maximum dry density (MDD) and optimum moisture content (OMC).
- d. CBR & FSI (Soaked & Unsoaked): To evaluate the stability of soil sub grade and to measure of strength of subgrade soils for construction of the pavements.
- e. Triaxial compression test: Triaxial tests are used to determine the shear strength characteristics of soils subjected to a wide range of stress paths and loading conditions.

- f. Scanning Electron Microscopy (SEM) Analysis: In order to understand the mechanism of soil-plastic interaction, clay particle's alignment, number of pores. To understand the variation in the physical and mechanical behaviours of improved expansive soil before and after reinforcement.

The following laboratory tests are conducted on mixed samples such as:

- (a) **Grain size analysis:** The objective of grain size analysis is to determine the percentage of soils passing different sieve opening sizes.
- (b) **limits: Atterberg** The purpose of conducting Atterberg limit test is to know the plasticity properties of soil and to use it as input index parameters for soil classification.
- (c) **Compaction characteristics:** To study the compaction characteristics of soil and to identify the effect of plastic strip reinforcement on maximum dry density (MDD) and optimum moisture content (MC).

DETERMINATION OF SPECIFIC GRAVITY OF SOIL SOLIDS BY DENSITY BOTTLE METHOD

Aim:

To determine the specific gravity of soil solids by the Density bottle method. Specific gravity (G) is defined as the ratio of the weight of an equal volume of distilled water at that temperature, both weights taken in air.

Specification:

IS 2720 (Part III) – 1980 is the standard recommended to determine the specific gravity of fine-grained soils. The value ranges are the same as in the previous experiment. The average of the values obtained shall be taken as the specific gravity of the soil particles and reported to the nearest 0.01 precision. If the two results differ by more than 0.03 the tests shall be repeated.

Equipment Required:

1. ml capacity density bottle with stopper
2. 50 A constant temperature water bath (27 °C)
3. Oven with a range of 105 to 110 °C
4. Vacuum desiccators
5. Vacuum pump
6. Other accessories, such as weighing balance accurate to 0.001g, trays, wooden mallets, etc.

Theory:

Specific gravity of soil solids is defined as the weight of soil solids to the weight of an equal volume of water.

The equation for specific gravity, G: $G = \frac{W_2 - W_1}{(W_2 - W_1) - (W_3 - W_4)}$

Where

W1 = weight of the empty bottle

W2 = weight of bottle + dry soil



W3= weight of bottle + soil +
water
W4= weight of bottle +
water

Result:

AVERAGE G= 2.23

Detailed result is shown in annexure 1

Conclusion:

The experiment is conducted as per the procedure laid down. The specific gravity of soil solids=2.23

Observation table of specific gravity

Sr. No.	Particulars	Test No 1 (G1)	Test No 2 (G2)
1.	Weight of density bottle (W1), gm	23.75	23.75
2.	Weight of bottle +dry soil (W2), gm	49.04	47.33
3.	Weight of bottle + soil + water (W3), gm	89.13	87.09
4.	Weight of bottle + water (W4), gm	74.75	74.39
5.	Specific Gravity, G	2.31	2.16
6.	Average $G, (G1+G2+G3)/3$	2.23	

DETERMINATION OF ATTERBERG’S CONSISTENCY LIMITS

Introduction:

Water plays an important role in soil mechanics practice, when dealing with density, void ratio, settlement and strength characteristics of either disturbed or undisturbed soils. Fine grained soils in particular can exhibit several states depending on the amount of water in the soil system.

When water is added to dry soil, the individual particles are covered with adsorbed water forming a thin film around it. If the addition of water is continued the thickness of water film will continue to increase, thereby facilitating the sliding effect between adjoining particles.

Thus it is a fact that the behavior of the soil is related to the amount of water in the system. Atterberg defined boundaries of four states of soils in terms of limits

(a) Liquid limit: The boundary between liquid and plastic states

(b) Plastic limit: The boundary between plastic and semisolid state and

(c) Shrinkage limit: The boundary between semi solid and solid state.

The liquid limit is the water content which the soil has negligible shear strength, (10 to 15 gm/sq.cm) such that it flows to close the groove of standard width when agitated in the standard liquid apparatus.

The plastic limit is the water content at which the soil begins to crumble when rolled into threads of 3 to 4 mm dia.

The shrinkage limit is the water content that is just sufficient to fill the pores when the soil is at the minimum volume it will attain by drying. The amount of water which must be added to change the state of soil from a plastic limit to a liquid limit is known as plasticity.

The liquid limit minus the plastic limit is known as the plasticity index.

1) Determination of liquid limit of soil

Object and scope: The object of the test is to determine the liquid limit of the soil sample using Casagrande type mechanical liquid limit apparatus.

Material and equipment:

- i) Mechanical liquid limit device (Casagrande type) consisting of a brass cup and carriage,
- ii) grooving tool,
- iii) Porcelain evaporating dish, about 12 cm in diameter,
- iv) Flexural spatula, with blade about 8 cm along 2 cm wide, v)
Balance to weigh 0.01 gm.,
- vi) Air tight containers for moisture content determination,
- vii) 425 micron etc.

Calculations and results:

Plot the flow curve with water content as the ordinate and log of no of blows as abscissa. The water content corresponding to 25 blows is taken as the liquid limit of the soil.



2) Determination of plastic limit of soil

Object and scope: The object of the test is to determine the plastic limit of soil sample and then to calculate plasticity index, toughness index, liquidity index and consistency index of the soil.

Material and Equipment: Same as that of above experiment in addition to a rod of 3mmdiameter.

Results:

% fly ash added to soil	LL of soil	PL of soil	Plasticity Index
0%	53.5	25.23	28.27
5%	40.5	24.05	16.4
10%	32	23.65	8.35
15%	29	22.98	6.02
20%	26.5	21.53	4.97

Table 3: Results

Results of tests showed that soil was a clay high plasticity (CH) soil, according to the Unified Classification System (USCS) classification system. Liquid limit reduced from 53.5 % of 0% fly ash to 26.5% for 20% fly ash content by dry weight of soil.

Classification of soils as per IS 1498 (1970)

Cl. 3.2.2 Fine-Grained Soils -

The fine-grained soils shall be further divided into three subdivisions on the basis of the following arbitrarily selected values of liquid limit:

- a) Silts and clays of low compressibility - having a liquid limit less than 35 (represented by symbol L).

b) Silts and clays of medium compressibility - having a liquid limit greater than 35 and less than 50 (represented by symbol I).

c) Silts and clays of high compressibility - having a liquid limit greater than 50 (represented by symbol H).

Note: In this system, fine-grained soils are not divided according to particle size but according to plasticity and compressibility. The term ‘compressibility’ here shall imply volume change, shrinkage during dry periods, and swelling during wet periods.

Cl. 3.5.3 Classification of fine-grained soils:

The laboratory classification criteria for classifying the fine-grained soils are given in the plasticity chart shown in Fig. 1 and Table 4 of IS 1498 (1970). The ‘A’ line has the following linear equation between the liquid limit and the plasticity index:

$$IP = 0.73(WL - 20)$$

Where,

IP = Plasticity Index

WL = Liquid limit

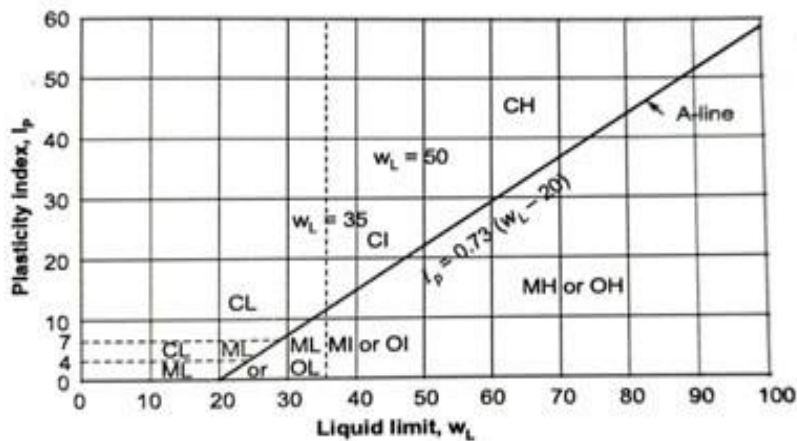


Figure: Plasticity Chart

In reference to IS 1498 (1970) Table 1:

Cl.3.5.4 Boundary Classification for Fine-Grained Soils-

The fine-grained soils whose plot on the plasticity chart falls on, or practically on:

- a) 'A' line .
- b) 'wL = 35 ' line
- c) 'wL = 50 ' line shall be assigned the proper boundary classification.

Soils that plot above the 'A' line, or practically on it, and which have plasticity index between 4 and 7 are classified ML-CL.

CI 3.6

Black Cotton Soil - Black cotton soils are inorganic clays of medium to high compressibility and form a major soil group in India. They are predominantly montmorillonitic in structure and black or blackish-grey in colour. They are characterized by high shrinkage and swelling properties. The majority of the soils, when plotted on the plasticity chart, lie along a band above the 'A' line. The plot of some of the black cotton soils is also found to lie below the 'A' line. Care should therefore be taken in classifying such soils.

Conclusion: In reference with IS 1498 (1970) it is observed that soil is characterized by high shrinkage and swelling properties, when plotted on the plasticity chart, lie along a band above the 'A' line.
(WL=53.5, PI=28.27)

V.CONCLUSION

- In reference with IS 1498 (1970) it is observed that soil is characterized by high shrinkage and swelling properties, when plotted on the plasticity chart, lie along a band above the 'A' line. (WL=53.5, PI=28.27)
- Results of tests showed that soil was a clay high plasticity (CH) soil, according to the Unified Classification System (USCS) classification system.
- Liquid limit of black cotton soil kept on reducing for varying fly ash content i.e. from 53.5 % for no fly ash, 40.5% for 5% fly ash, 32% for 10% fly ash, 29% for 15% fly ash, 26.5% for 20% fly ash content by dry weight of soil.
- MDD increased from 1.33 for 0% to 1.73 for 15%. OMC decreased from 25% for 0% fly ash to 16% for 15% fly ash.
- The California Bearing Ratio (CBR) for black cotton soil increased from 2.06% for without reinforcement to 2.89% for 15% fly ash content.
- The optimum plastic percentage works out to be 1.5% based on the obtained experiment.
- The CBR increased to 3.89 for the mix of 15% flyash and 1.5% plastic

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