A Study on Subgrade Quality Improvement using Recycled Waste Polypropylene Nodules

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ABSTRACT

Scarcity of traditional construction materials has motivated researchers to explore alternatives, and besides crushed glass, reclaimed asphalt pavement, and scrap tires, to name a few, plastic waste (unwanted or unusable plastic objects) has also gained attention in recent years. Plastic waste is traditionally re-used or recycled, but it often ends up as trash on curbside, in landfills, or in our seas and oceans. The substantial amount of plastic waste produced annually worldwide, and its environmental repercussions are the rationale for exploring alternatives in order to recycle plastic waste into construction materials. This exploration can also benefit many industries and would help minimizing adverse environmental impacts associated with dumping tones of plastic waste in landfills. Using plastic waste material with soil for soil reinforcement purposes has revealed some improvements in terms of strengths of materials, but nevertheless, this potentiality has not been fully assessed for different types and forms of plastic waste with natural subgrade soil in the road industry. In this paper, recycle polypropylene nodules [diameter: 3-4 mm] is combined with clayey silt and used as a ground improvement material. Soil subgrade is mixed with 1-5% polypropylene nodules (by dry weight of soil sample). Various geotechnical properties have been assessed thoroughly. Tie investigation process entails assessing compaction, California Bearing Ratio (CBR), shear strength parameters and permeability properties for both natural sub-grade soil and plastic-mixed sub-grade soil. The results obtained show that the addition of plastic wastes decrease the maximum dry densities of the subgrade soils because of the lower relative density of the plastic material compared to the soil particles. It is also found that the addition of plastic wastes increase the CBR values. Values of cohesion increased up to addition of 2.5% polypropylene nodules; further addition of pp nodules, leads to decrease the cohesion values.Values of angle of internal friction was decreased up to addition of 1.5% pp nodules, then increased.Values of coefficient of permeability are decreased up to 1.5% addition of plastic grains, then increased. The results of this research suggest that partial replacement of subgrade soil material with plastic waste may prove useful in road subgrade applications.

1. INTRODUCTION

1.1. General

Soil stabilization is the process of refining the physical and chemical characteristics of soil up to a suitable extent where soil can show significant enhancement in parameters like bearing capacity, shear strength, etc. All these properties of soil are very important for soil as a foundation material. Soil stabilization includes procedure such as mixing different types of additives in soil such as plastic strips, moorum husk, rice husk, jute fiber, fly ash, etc. in order to increase it's physical and chemical properties. Shrinkage, shear strength, bearing capacity are improved by addition of such ground improvement materials.

Plastic is a synthetic, non-renewable material which has a very negative impact on the natural environment. Plastic is the most common type of solid waste contributing almost 90% of total solid waste, and most of it being non-renewable in nature. Instead of dumping such kind of wastes into the clean environment, various industries uses processes such as remolding of plastic and creating new articles out of it. But certainly all of the plastic can not be treated in the same way. Using these remolded and non-remolded plastics for the stabilization of naturally occurring soil to increase its physical parameters and properties is one of a revolutionary method of reusing the waste plastic and reducing its content from nature. Stabilized soil is the one which has higher shear strength, higher California bearing ratio (CBR Value), and high bearing strength. Such type of soil is very useful in construction of different types of foundation works. If the foundation of a structure is strong, the structure will be less susceptible to a collapse.

1.2. Adverse Effects of Plastic Wastes

The uses of plastic wastes in the form of plastic wrappers, bottles, straws and carry bags are increasing day by day. 350 million metric tons of plastic wastes are generated every year in the world, among this only 9% of plastic wastes are recycled and the existing may disposed in land-fills or in water bodies (mainly ocean). According to the report (2019-20) of The Central Pollution Control Board, India generates 3.5 million metric tons of plastic wastes every year, among which 30% are recycled. According to UNESCO, over 1 million marine animals are killed due to plastic wastes. Plastics are classified into 7 different types (PET, HDPE, PVC, LDPE, Polypropylene(PP), polystyrene and others). In India 45% of PET, 25% of HDPE, 20% of Polypropylene, 7.6% of Polymers and 2.4% of polystyrene are recycled every year. Plastic waste is fast becoming a widely recognized problem. While it is an important material for our economy, providing multiple benefits to modern day living, plastic can take thousands of years to biodegrade. It takes up valuable space in landfill sites and is polluting the natural environment, having a significant impact on our oceans.

1.3. Motivation

For many years, road engineers have used additives such as lime, cement and cement kiln dust to improve the qualities of readily available local soils. Laboratory and field performance tests have confirmed that the addition of such additives can increase the strength and stability of such soils. However, the cost of introducing these additives has also increased in recent years. This has opened the door widely for the development and introduction of other kinds of soil additives such as plastics, bamboo, liquid enzyme soil stabilizers etc. Soil stabilization using raw plastic bottles, and recycled plastic fibers are an alternative method for the improvement of sub grade soil of pavement. It can significantly enhance the properties of the soil used in the construction of road infrastructure. Results include a better and longer lasting road with increased loading capacity and reduced soil permeability. This new technique of soil stabilization can be effectively used to meet the challenges of society, to reduce the quantities of waste, producing useful material from non-useful waste materials that lead to the foundation of sustainable society.

Around the globe, thousands of people are working on the ideas of sustainable development. One of the youngest activists, Licipriya Kangujan from Delhi has started a shop where a person can get 2 kgs of rice/ 2 notebooks/ 2 pencil boxes/ 1 plant sapling in exchange of 1 kg of single use plastic. A Pune based organization " Eco-Kaari" has started an initiative to make hand bags, fashion accessories, home decors from single used plastic wrappers. This organization has already recycled 15 lakh plastic wrappers. This research study in inspired from these ideas.

Study may be conducted using recycled polypropylene nodules as a ground improvement material. This is likely to enhance the properties of soil like permeability, shear strength parameters and CBR value and increase the recycle rate of PP via demand and supply policy. At the same time it is likely to improve the strength of the weak soils and increase the recycle rate by utilizing the remolded plastic waste in granule form for stabilizing the subgrade layer of the road pavements

2. LITERATURE REVIEW

In this chapter, a review of available literature relevant to this research are to be furnished. In most of the research studies, recycled plastics strips were used as ground improvement material. The review has been presented for different methodologies in chronological order.

2.1. Review papers of plastic-mixed soil samples

Setty and Rao (1987) carried out triaxial tests and CBR tests on silty sand, reinforced with randomly distributed polypropylene fibers. The test results of the soils sample indicated significant increased values in cohesion intercept (up to 5.7 times) and a slight decreased values in angle of internal friction (i.e. overall effect is to increase shear strength), with an increase in fiber content up to 3% (by weight). Adding fibers up to 2% improves dry strength, but afterwards there is a decrease in dry strength. Addition of 1-2% PP fibers was recommended for this case study.

M.S. Dixit and S.H Pawar (2009) observed improvement of silty clay by mixing with polypropylene fibre up to a certain percentage. In this study author selected polypropylene fibers of 25, 50 and 75 aspect ratios and 0.3 mm diameter. Plastic fibers were thoroughly mixed with natural soil (specific gravity- 2.61, liquid limit- 57%, plastic limit- 29%, M.D.D.- 1.54 gram/cc, O.M.C.- 21.2%, cohesion- 30 KN/m^2, angle of internal friction- 17^o, C.B.R.- 5.26% and U.C.S. value- 3.5 kg/cm^2). Plastic fibers were added 0%, 0.75%, 1.5% and 2.25% of dry weight of soil. For all aspect ratios, MDD and angle of internal friction decreased up to addition of 2.25% pp fibre afterwards increased. OMC and cohesion increased up to addition of 2.25% pp fibre then reverse graph was observed. When soil was mixed with 2.25% pp strips, optimum values of CBR and UCS were observed. The C.B.R. value increased in the range of 11% to 47% for addition up 2.25% of polypropylene fibers and decreased afterwards. The value of unconfined compressive strength increased in the range 17% to 46% up to 2.25% addition of fibers. As compared to natural soil, CBR and UCS values increased to 47% and 45% simultaneously when 2.25% pp strips (aspect ratio- 75) was used. From this experimental study, it can be concluded that 2.25% addition of polypropylene fibers in the soil can be considered as an optimum mix for design purposes.

Choudhary et al. (2010) carried out a series of CBR tests on randomly reinforced soil by varying percentage of HDPE with different length and proportion. The following conclusion was drawn from the results-

(i) Addition of HDPE strips to local sands increased the CBR values.

(ii) The maximum improvement in CBR was obtained when the strip content is 4% and the aspect ratio 3.

(iii) The reinforcement benefit increases with an increase in waste plastic strip content and length. The maximum CBR value of a reinforced soil system is approximately 3 times of the natural soil.

Addition of 4% HDPE strips (aspect ratio- 3) was considered as optimum percentage.

Babu and Chouksey (2010) carried out experiments on stress-strain response of plastic waste mixed soil. Based on test results, improved shear strength and reduced compressibility were observed significantly with addition of a small percentage of plastic waste to the soil and there by bearing capacity improvement and settlement reduction in the design of shallow foundation. Previous studies have shown that in general, fiber inclusion improves the overall engineering behavior of soils by increasing the compressive and tensile strength, peak friction angle, and cohesive intercept , while contributing to an increase in residual strength, ductility, energy absorption capacity, CBR and resistance to cyclic loading. Hence it appears that there is scope of study of behavior of clay mixed with randomly distributed plastic fiber obtained from waste PET bottle which likely to reduce environmental hazard to a great extent. Hence, there will be recycling of plastic waste.

Arpan Laskar and Dr Sujit Kumar Pal (2013) conducted laboratory tests to examine the effect of waste plastic fibers on compaction and consolidation behaviors of reinforced soil. In this experimental study, raw plastic bottle fibers was cut and used in three different sizes, i.e.,10mm X 5 mm (AspectRatio= 2), 10mm X 2.5mm (A.R.= 4) and size=10 mm X 1.25 mm (A.R.= 8). These different sizes of plastic strips was mixed with local soil (Fine Sand = 40.15%, Silt = 30.90%, and Clay = 28.95%) with 0%, 0.25%, 0.50% and 1.00% by dry weight of the soil. At first the maximum dry density (MDD) and optimummoisture content (OMC) was determined for different sizes and content of plastic fiber. From this experiment on remolded fiber reinforced soils, it was found that compression index (Cc) and coefficient of volume change (mv) values decreased with the increase of fibers in soil from up to 0.50% but the values increased with further increase of plastic fibers up to 1.00% in soil. 90% of total compression tookplace within 96 seconds for 800 K N/m2 load with mixing of the plastic fibers in soil with aspect ratio 8 and plastic fiber content of

1.00%. This study concluded that plastic strips can be utilized as ground improvement material in soil used for effective stability and consolidation.

Bala Ramudu Paramkusam et al. (2013) studied the effective use of waste plastic fibers on the properties of the mixture of red mud and fly ash. CBR, MDD, OMC were determined after adding 0.5%, 1%, 2%, 3% and 4% plastic fiber content with mixed soil. MDD values increased up to the addition of 2% plastic fiber content afterward decreased. OMC values were same in each case. Improved CBR vales were obtained in the cases of adding 0.5%, 1% and 2% plastic fiber content. Improved values were observed and considered for addition of 0.5% - 2.0% plastic content. Particularly this range of values was considered as optimum percentage.

Akshat Malhotra and Hadi Ghasemain (2014) analyzed strength parameters of soil using HDPE plastic waste fibers (40 micron), in proportion of 1.5%, 3%, 4.5% and 6% of the weight of dry black cotton soil. In the test results, it was glorified that the UCS values increased up to use of 4.5% plastic content then decreased. Mixed subgrade consist of 4.5% plastic fiber content and 95.5% soil had shear strength of 287.32 KN/m2 which was almost 4 times of normal subgrade soil. Soil stabilized with 4.5% plastic fiber content was considered as optimum percentage for this case study.

Mercy Joseph Poweth et al. (2014) investigated the effect of plastic granules on weak soil sample, where recycled waste plastic granules were used in varying percentage. The percentage of waste plastic was taken as 0.25%, 0.5 %, 0.75%. Maximum dry density was obtained when 0.25 % plastic was added and OMC was less than the soil without plastic for this percentage of soil. Further CBR value decreased when 0.25 % plastic was added but it was found to be increased for 0.75 % of plastic. Sag curve was observed when author plotted the CBR curve. Author also observed that, for the same percentage of plastic, shear stress was maximum. 0.75% addition of waste plastic nodules by dry weight of soil was considered as optimum.

Jasmin Varghese Kalliyath et.al. (2016) studied the effect of plastic fibers on natural soil. Various tests such as Standard Proctor, UCS were carried out with different samples of silty clay. Authors observed that the replacement of 0.5 % waste plastic fiber to the expansive clayey soil reduce its OMC and increased maximum dry density. UCS of the soil was found to be increased for this particular proportion. The test results also showed that with 1% replacement, MDD and UCS were less than the 0.5 % replacement but greater than the natural untreated soil. MDD and UCS graph had shown convexity. The increase in the MDD of the soil with 1% replacement is due to the decrease in number of voids with the addition of plastic which leads to effective compaction and also increase in the cohesion. Thus authors concluded that optimum percentage addition of plastic should be 0.5-1% for optimum results.

Feroz Hanif Khan (2016) performed soil testsby varying 0% - 6% HDPE plastic strips with 100% - 94% pure soil. Soil for this research work was collected from Trimurti Nagar square, Nagpur. Laboratory tests were conducted to determine the various properties of soil. Test results are given below-

i. Fine Content (particle size < 75 micron) - 74.69%
ii. Specific Gravity (G) - 2.65
iii. Liquid Limit - 56.50%
iv. Plastic Limit - 29.10%
v. Free Swell Index - 30
vi. O.M.C. - 20.2%
vii. M.D.D. - 1.63 gm/cc
viii. C.B.R. - 2.33%
ix. U.C.S. at O.M.C. - 2.69 kg/cm^2

Waste plastic fibers (HDPE) were used as a reinforcement material to improve the strength of soil-subgrade. Plastic fibers were cut manually from HDPE bottles. Thesizes of those strips were 12mm*12mm (Aspect Ratio= 1), 24mm*12mm (A.R.= 2), 36mm*12mm (A.R.= 3). Optimum CBR and secant modulus values were found for the mixture of 5% HDPE plastic content (36mm*12mm) with 95% subgrade soil. The CBR value and secant modulus values of the mixed soil having 5% HDPE plastic fiber content with aspect ratio 3 (36mm*12mm) were almost 2.85 times and 2.2 times simultaneously of pure subgrade soil. The decreased values of maximum dry density was observed when soil was stabilized with HDPE nodules. Mixing of 5% HDPE plastic fiber content (size-36mm*12mm) with natural subgrade was recommend for that particular type of soil.

H. B. Suralkar and R.R. Kshatriya (2020) performed experimental analysis on lime stabilized clayey subgrade soil mixed with polypropylene (pp) fibre. The soil was collected from Maharashtra area, having specific gravity 2.653, liquid limit- 71.1%, plastic limit- 40.80%, M.D.D.- 1.298 gram/cc, O.M.C.-35.2%, C.B.R.- 5.26% and U.C.S. value0 3.73 kg/cm^2. The length of polypropylene fibre was 24 mm, having specific gravity 0.91 gram/cc and breaking elongation 20%. Various laboratory tests were performed and the test results are tabulated in table 2.

Table 2.1 - Test Results from the paper of H.B. Suralkar and R.R. Kshatriya (2020)							
Test Cases	MDD (KN/m^3)	OMC (%)	CBR (unsoaked) (%)	CBR (soaked) (%)	UCS value (Kg/cm^2)	Cohession (KN/m^2)	angle of internal friction (ϕ^O)
Soil + 8% Lime	12.48	33.19	3.84	15.09	0.82	47.69	25.76
Soil + 8% Lime + 0.2% Fibre	13.45	31.96	4.28	17.08	0.908	51.5	28.43
Soil + 8% Lime + 0.4% Fibre	13.63	30.87	11.97	26.56	2.494	47.5	32.16
Soil + 8% Lime + 0.6% Fibre	12.8	30.95	9.81	24.08	1.468	38.74	34.61
Soil + 8% Lime + 0.8% Fibre	12.49	34.50	5.48	16.81	0.648	40.98	37.7

Due to addition of polypropylene strips, MDD and cohesion values increased up to certain percentage afterward decreased. OMC decreased up to addition of 0.4% pp strips then reverse curve was observed. CBR and UCS values increased up to addition of 0.4% pp strip then decreased. More friction is introduced with increased percentage of pp fibre content. Lime stabilized soil, thoroughly mixed with 0.4% pp fibre is recommended for the ground improvement for this particular type of soil.

Nitin Tiwari and Neelima Satyam (2021) performed various mechanical strength tests such as unconfined compressive strength (UCS) and large direct shear box tests to evaluate the mechanical interaction between the system of expansive soil subgrade, polypropylene fiber and geogrid at the interface. Polypropylene fiber of 12-mm length was used in the proportion of 0.25%, 0.5%, and 1.0% of dry weight of soil and a single geogrid layer at mid-depth. The result showed that the shear strength of reinforced subgrades with a layer of biaxial/triaxial geogrid and polypropylene fiber increased significantly. It is also observed that the unconfined compressive strength of the expansive soil increased with the inclusion of polypropylene fiber and geogrid. The combined reinforcement method showed an effective treatment methodology to improve the engineering property of expansive soil subgrades.

Sikander Zamen et al. (2021) performed tests by mixing different concentrations of polypropylene fibers and cement with black cotton soil. The strength of PP fiber and cement-based soil samples was measured in terms of unconfined compressive strength

(UCS) and California Bearing ratio (CBR). Specimens for UCS and CBR tests were prepared at 2%, 4%, 6% and 8% of cement (by dry weight of soil) and seven percentages of polypropylene fibers i.e. 0.0%, 0.1%, 0.2%, 0.3%, 0.4%, 0.5% and 0.6% (by dry weight of soil). Fourier transform infrared (FTIR) analysis confirmed the presence of polypropylene and cement contents in the soil samples by detecting vibration modes of additives/admixtures components. Unconfined compressive strength tests were conducted on prepared soil samples at three different curing times as 7 days, 14 days, and 28 days. Tests results depicted that unconfined compressive strength was increased due to prolonged curing time and axial strains of expansive soil specimens were reduced accordingly. On the other hand, increased in fiber content induced ductility and increased the residual strains of the soil specimen. It had also been observed that increased in cement content increased the unconfined compressive strength of the expansive soil and reduced the axial strain of the soil specimen. For UCS tests, addition of 6% cement and 0.3% polypropylene fibers by dry weight of soil was found to be the most effective for use in subgrades as it yields greater strength and is rendered economical as well. In case of CBR tests, addition of 4% cement and 0.3% PP fibers with soil had given 6.67 times improved than natural soil of Nandipur area. The optimum combinations of cement and polypropylene fibers to stabilize soils had proven to be a unique technique as compared to the other treatment attempts made so far.

Mukhtar Abukhettala and Mamadou Fall (2021) performed laboratory tests on subgrade soil with recycled plastic waste in different forms. Soil sample used for this experimental study was classified as A-2-7, according to AASHTO classification system. This soil consists of 1% gravel, 97% sand and 2% clay & silt. Different types of plastic nodules in different percentages was used to improve the properties of soil. Various geotechnical laboratory tests were carried out by varying the plastic nodules of 0%, 1%, 2%, 3%, 4%, 5% & 6%. Mixing of 1-2% pelleted HDPE or 1% flaky PET nodules in soil subgrade increased the maximum dry density values. All the other cases, MDD values had been decreased. Soil mixed with 1-3% pelleted HDPE/ 3% flaky PP/ 2-3% pelleted PP had shown improved values in permeability. UCS value in soil subgrade was decreased in all test categories. When HDPE nodules were used in pelleted form in the range of 1-3% with soil subgrade, the modulus of resilience value increased. Improved CBR values were observed when 3% ground HDPE/ 1% pelleted PET/ 1-3% pelleted PP were mixed with pure soil. As a summary HDPE in pelleted form (1-2%) with subgrade soil (98-99%) had improved the subgrade soil properties impressively for this particular type of soil.

Shalema Amena (2022) analyzed different properties of soil subgrade reinforced with wasted plastic strips. Plastic fibers were mixed in different percentages (0, 0.25, 0.50, 1.00, 1.50 and 2.00%) with expansive soil (100%, 99.75%,99.50%, 99%. 98.50% and 98%) to improve the subgrade soil properties. Soil was collected from a particular site of Jimma town, Ethiopia and plastic bottles were collected randomly from open spaces and cut manually in sizes of 5mm*8mm, 8mm*15mm and 15mm*25mm. According to Unified Soil Classification System, the soil was classified as fine grained soil (liquid limit = 88.5%, plastic limit = 43.6%, MDD = 1.375 gram/cc, OMC = 37.5%). CBR value of the mixed soil sample, consist of 2% plastic strips (5mm*8mm) and 98% soil was more than two times of pure subgrade soil. Optimum CBR value was noticed for the mixture of 1.5% plastic content (8mm*15mm) and 98.5% soil was almost 1.75 times of normal subgrade soil. Highest CBR value was observed for the mixture of 1.4% plastic strips (15mm*25mm) and 98.6% pure soil, which was almost 1.925 times of the CBR value of normal subgrade soil. UCS values was increased up to addition of 0.5% plastic content, then the values decreased. Cohesion was increased up to addition of 1.5% plastic content, then the values decreased. Free swell was decreased with increasing sizes and rates of adding plastic strips with subgrade soil. With increasing proportion of plastics strips, the MDD had been decreased but the graphs did not show any particular pattern. Addition of 1.5-2% plastic strips was recommended to used for ground improvement.

Worku Firomsa Kabeta (2022) performed laboratory tests on clayey subgrade stabilized with waste plastic strip having sizes 1 cm, 2 cm, 3 cm. Clayey soil sample is thoroughly mixed with 0.1%, 0.2%, 0.3% and 0.4% plastic strips by dry weight of soil. The soil was collected from Ethiopia, having specific gravity 2.8, liquid limit- 49%, plastic limit- 32%, M.D.D.- 1.51 gram/cc, fine content (finer than 0.075 mm) - 95%. Maximum dry density was slightly increased up to 0.3% plastic fibre content then decreased for 1 cm and 2 cm strips. In case of using 3 cm plastic strip the observed maximum dry density was maximum for 4% addition plastic strips with soil. The CBR and UCS values increased to 289% and 1.97% simultaneously when soil was stabilized with 2 cm plastic strip (0.4% of dry weight of soil), as compared to natural subgrade. Natural subgrade mixed with 0.3% plastic strip of 2 cm size was considered as the optimum percentage in this study.

Tewodros Tsegaye Woldesenbet (2023) conducted test to improve the strength of black cotton soil for its suitability for road subgrade construction using wastes from plastic bottles and glass waste powders. the wastes were used to replace cement, since the cost of cement raised due to energy and raw material to use as stabilizer in weak soil. Te glass powder (WGP) and the plastic chips were mixed with the soil sample with 6%, 12%, 18%, and 24% of WGP and 2%, 4%, 6%, and 8% of plastic chips, respectively by dry weight of soil. Physical properties and strength parameters test were conducted in laboratory. Soil sample was classified to A-7-5 as per the AASHTO Soil Classification System and CH as per the Unified Soil Classification System (USCS). The properties of soil subgrade was increased with increased ratios of powder glass and plastic strips. Te soil had high value of percent swell (128%), and the addition of 8%, 16%, 24%, 32% of the stabilizers reduces the range to 84.3%, 55.7%, 32.5%, and 18.4%, respectively. The UCS value of the combined system [soil + 24 % glass powder + 8 % plastic chips] was 7.27 time of normal subgrade. The CBR value of the combined system [soil + 24 % glass powder + 8 % plastic chips] was 7.27 time of normal subgrade. The results indicated that the two stabilizers were very effective in improving strength parameters and index parameters. Optimum results were found when soil was stabilized with 24% glass and 8% plastic chips.

2.2. Summary of reviewed literature

Many researchers have found, plastic as a good ground improvement material. In previous research studies, plastic was mixed with different types of weak and expansive soil in different forms (strips, nodules etc.). For those experiments, plastic strips were directly cut from the waste plastic bottles and sometimes recycled plastic nodules were used in granular form. Some researchers also mixed other type of soil stabilizing material (lime, glass powder, fly ash etc) with plastic and used as ground improvement material. When plastic was used as a ground modifier, optimum values of plastic content depends upon the type of soil, type & form of plastic. In most of research studies, compaction, CBR and UCS tests were conducted to analyze the strength characteristics of plastic-mixed soil subgrade and improved values were observed for addition of 1-5% plastic (by weight of dry soil) with natural subgrade.

3. OBJECTIVE & SCOPE OF WORK

3.1. Overview

Researchers have found that different recycled plastic fibers (PET, HDPE, PP etc.) in different forms (strips, pelleted, flaky & nodules form) can be used as a good material for ground improvement when it was mixed with subgrade soil.
In this research work, recycled polypropylene nodules is used as ground improvement material. Here, polypropylene fibers are used for its high strength, density, durability. It is also preferred for it's low recycle rate in India.

3.2. Gap of Past Research

Although polypropylene is a good ground improvement material but optimum percentages were not specifically mentioned in many research papers. At a particular percentage of adding waste plastic fibers in a particular form with subgrade soil had given some improved test results. Even sometimes, the results were almost same as obtained from pure subgrade soil. There were only few cases where all the test results were satisfying. Polypropylene fibers were mostly used in strip format. 1-2% was considered as optimum values when the pp strips were mixed with soil subgrade. Optimum range was not concluded for other forms of pp strips.

3.3. Problem Identification

Polypropylene fibers in nodules form were rarely used by the past researchers for the quality improvement of natural subgrade where plastic nodules can easily mixed with natural soil rather than plastic strips.
In this research study, 0-3% recycled polypropylene nodules [3-4 mm diameter] will be mixed with dry soil and different strength parameter tests will be performed to obtain the optimum percentage to improve the natural subgrade. Further variations by addition of pp nodules can be performed if the optimum values and reverse curves were not obtained in different strength parameter graphs obtained from laboratory tests.

3.4. Objective of Work

To study the potential of using waste recycled polypropylene nodules for quality improvement of natural subgrade soil and to determine optimum percentage of waste plastic to be used. This research study has focused on recycle and reuse of already generated plastic wastes.

3.5. Scope of Work

- Quality assessment of natural subgrade should be done to know the characteristics of the soil.
- Quality assessment of different plastic mixed subgrade soil have to be done by varying percentage of polypropylene nodules.
- To determine optimum proportions of plastic nodules which improves quality of natural subgrade.

4. METHODOLOGY

4.1. Sample Collection

Around 80 kgs of soil sample is collected from a river side area of South 24 Parganas. From the visual observation, it is interpreted that the soil is silty clay or clayey silt.

Plastic nodules (polypropylene) are bought from a small scale industry which sells recycled plastic granules. Polypropylene has specific gravity- 0.91 grams per cc, softening point- 140^{o}C, melting point- 165^{o}C and tensile modulus of elasticity- 1300 mega-pascal. Polypropylene fibers breaks when it is 70-100% elongated . It normally shows very good resistance to chemicals and bacteria. It has good toughness & abrasion resistance value. Polypropylene fibers absorbs 0-0.05% moisture content.

4.2. Sample Preparation

When the soil sample was collected from ground, it was wet and lumped in nature. The whole sample is oven dried and pulverized. The soil sample is seived through 4.75 mm sieve and the passing samples are mixed uniformly. For pure soil sample tests, oven dried soil samples are used. For mixed sample preparation, percentage weight of plastic granules are mixed with dry weight of soil . As an example, it is assumed that 2.5 kg dry soil sample is taken for a proctor test and 3% plastic content will be used for this test. 3% weight of 2.5 kg sample is 75 gram. 75 gram plastic is mixed with 2.5 kg soil sample to prepare the desired plastic-mixed sample.

Table 4.1.- Details of Samples

Sample Identifier No.	Percentage (of soil) of PP nodules	Percentage of Dry Soil	Percentage (of mix) Addition of Polypropylene Nodules
1	0.0%	100.00%	0.00%
2	1.0%	99.01%	0.99%
3	1.5%	98.52%	1.48%
4	2.0%	98.04%	1.96%
5	2.5%	97.56%	2.44%
6	3.0%	97.09%	2.91%
7	5.0%	95.24%	4.76%
8	10.0%	90.91%	9.09%

4.3. Sample Testing

4.3.1. General

Natural subgrade soil should be crushed properly and oven dried at 100-degree Celsius for at least 24 hours. Grain size distribution, specific gravity, shrinkage limit, plastic limit, liquid limit tests are to be performed for natural subgrade soil for the classification of soil. Further laboratory tests like compaction, permeability, CBR, UU triaxial tests of plastic mixed soil samples have to done for obtaining the improved subgrade characteristics. For the mixed samples, desirable percentage of polypropylene nodules are mixed with oven dried soil sample. Brief Discussion of the different pure soil and plastic mixed soil tests are given below.

4.3.2. Determination of Atterberg Limits

4.3.2.1. Liquid Limit Test [IS 2720-5 (1985)]

It determines the moisture content at which soil changes from a plastic to a liquid state. The apparatus required includes a Casagrande's apparatus, grooving tool, porcelain dish, balance sensitive to 0.01 g, spatula, air-tight containers, and an oven capable of maintaining 105-110°C. The test begins with a representative soil sample passing through a 425 µm IS sieve. About 120 grams of the soil is mixed with distilled water to form a uniform paste. This paste is then placed in the Casagrande's cup, and a groove is cut through the center using the grooving tool. The cup is lifted and dropped from a height of 10 mm at a rate of 2 drops per second until the groove closes over a length of 12 mm. The number of drops is recorded, and a sample of the soil is taken to determine its moisture content by drying it in an oven at 105-110°C for 24 hours. This process is repeated with varying moisture contents to obtain at least four sets of data. The moisture content is plotted against the number of drops on a semi-logarithmic graph, and the moisture content corresponding to 25 drops is interpolated as the liquid limit. The results are reported as a percentage of the dry soil weight. Consistent preparation of the soil paste, uniform application of drops, and careful handling of the apparatus are essential for accurate and reliable results.

4.3.2.2. Plastic Limit Test [IS 2720-5 (1985)]

This limit lies between the plastic and semi-solid state of the soil. This test apparatus includes a porcelain or noncorroding mixing dish, spatula, flat glass plate, air-tight container, balance sensitive to 0.01 g, and an oven capable of maintaining 105-110°C. First, a representative soil sample passing through a 425 µm IS sieve is taken, and about 30 grams of it is mixed with distilled water to form a uniform paste. This paste is then rolled into a thread on a glass plate until it reaches a uniform diameter of about 3 mm. The rolling continues until the thread crumbles and cannot be re-rolled into a 3 mm thread. The crumbled soil is then collected and placed in an air-tight container, weighed, and dried in the oven at 105-110°C for 24 hours. The plastic limit is the average moisture content at which the soil threads crumble at a 3 mm diameter, and it is reported as a percentage of the dry soil's weight. It is crucial to ensure the soil paste is homogeneous and uniformly mixed, roll the threads uniformly, and handle the apparatus with care to obtain accurate and reliable results.

4.3.2.3. Shrinkage Limit Test [IS 2720-6 (1972)]

This limit is achieved when further loss of water from the soil does not reduce the volume of the soil. It can be more accurately defined as the lowest water content at which the soil can still be completely saturated. Evaporating dish, glass cup, glass plates, sieves and graduated glass is used in this test. Take about 100 gm of soil sample from a thoroughly mixed portion of the material passing through 425-mieron I.S. sieve. Place about 30 gm the above soil sample in the evaporating dish and thoroughly mixed with distilled water and make a creamy paste. Fill the dish in thrice layers by placing approximately 1/3 rd of the amount of wet soil with the help of spatula. Tap the dish gently on a fin base until the soil lows over the edges and no apparent air bubbles exist. Repeat this process for 2nd and 3rd layers also till the dish is completely filled with the wet soil. Strike off the excess soil and make the top of the dish smooth.Weigh immediately, the dish with wet soil and record the weight. Air- dry the wet soil cake for 6 to 8 hours, until the colour of the pat turns from dark to light. Then oven-dry to constant weight at 105°C to 110°C say about 12 to 16 hrs. Determine the weight of the empty dish and record. Determine the volume of shrinkage dish which is evidently equal to volume of the wet soil as follows. Place the shrinkage dish in an evaporating dish and fill the dish with mercury till it overflows slightly. Press it when plain glass plate firmly on its lop to remove excess mercury. Pour the mercury from the shrinkage dish into a measuring jar and find the volume of the shrinkage dish directly. Record this volume as the volume of the wet soil pat. Place the dry soil pat on the mercury. It floats submerge it with the pronged glass plate which is again made flush with top of the cup. The mercury spills over into the larger plate. Pour the mercury that is displayed by the soil pat into the measuring jar and find the volume of the soil pat directly. Shrinkage limit and volumetric shrinkage is calculated from the calculation part of IS 2720-6 (1972).

4.3.3. Specific gravity Tests [IS 2720-3-1 (1980)]

The Specific Gravity Test using a density bottle, determines the specific gravity of soil particles. The apparatus includes a 50 ml density bottle, a balance sensitive to 0.01 g, a vacuum desiccator, distilled water, and an oven capable of maintaining 105-110°C. First, clean and dry the density bottle thoroughly and weigh it (W1). Take approximately 15-20 grams of oven-dried soil passing through a 2 mm IS sieve and place it in the density bottle, then weigh the bottle with the soil (W2). Add distilled water to the bottle to fill it about half, ensuring no air bubbles remain, and then place the bottle in a vacuum desiccator to remove any entrapped air. After de-airing, fill the bottle to the calibration mark with distilled water and weigh it again (W3). Empty the bottle, clean it, fill it only with distilled water to the calibration mark, and record the weight (W4). This test should be conducted at a temperature of 27°C, and if the temperature deviates, appropriate corrections should be applied. Accurate removal of air bubbles, precise measurements, and careful handling of the density bottle are essential for reliable results. The specific gravity is reported to the nearest 0.01.

Almost 10-15 grams of polypropylene nodules are used to determine the specific gravity of polypropylene sample and all the other procedures are same as above.

4.3.4. Grain Size Analysis Test [IS 2720-4 (1985)]

In this experimental study, wet sieve analysis and hydrometer method is used to determine the particle size distribution curve. Wet sieve analysis method is used to analyse the particle distribution curve for the particle size larger than 0.075 mm. Hydrometer method is based on the principle of sedimentation, which is useful for determination of the particle size distribution curve for the particle size smaller than 0.075 mm.

4.3.4.1. Wet Sieve Analysis Test

This test is used to determine the particle size distribution of coarse-grained soils (gravel and coarse sand) through wet sieving. This technique is particularly useful for soils with particles larger than 0.075 mm. Set of sieves (4.75 mm, 2.36 mm, 1.18 mm, 600 μm, 300 μm, and 150 μm sieves and pan), mechanical shaker, continuous water supply, balance and drying oven is used for this test. Sieve is cleaned and weight of sieves are taken. Sample is placed on the top sieve and pour water over it to wash the material through the sieves. Sieves are agitated manually. Set of sieves are separated and placed in oven for 24 hours at 105-110°C. Weight of each sieve is noted down. Percentage of the total sample mass retained on each sieve is calculated. Graph between cumulative percentage retained and particle size should be determined. This method ensures accurate particle size distribution measurement for fine or cohesive materials.

4.3.4.2. Hydrometer Test

A hydrometer analysis is the process by which fine-grained soils, silts and clays, are graded. Hydrometer analysis is performed if the grain sizes are too small for sieve analysis. The basis for this test is Stoke's Law for falling spheres in a viscous fluid in which the terminal velocity of fall depends on the grain diameter and the densities of the grain in suspension and of the fluid. The grain diameter thus can be calculated from a knowledge of the distance and time of fall. The hydrometer also determines the specific gravity (or density) of the suspension, and this enables the fraction of particles of a certain equivalent particle diameter to be calculated. Balance, Mixer (blender), hydrometer (152H model preferably), sedimentation cylinder (1000 ml cylinder), graduated 1000 ml cylinder for control jar, dispersing agent [sodium hexametaphosphate (NaPO3) or sodium silicate (NaSiO3)], control cylinder, thermometer, beaker and timing device is used for conducting the test. Test procedure is followed by the clause 5.2.4 of IS: 2720 (pat4) - 1985. Meniscus, temperature and dispersing agent correction is done during test process. Grain size curve versus the adjusted percent finer graph is plotted on the semi-logarithmic sheet.

4.3.5. Indian Standard Light Compaction Test [2720 (Part 7) – 1980]

It determines the compaction characteristics of soil. The apparatus includes a Proctor mould, proctor rammer, proctor mould (1000cc), balance, oven, 4.75 mm sieve, spatula, measuring cylinder and 5-6 small containers. This compaction test is conducted for the soil mixed with 0%, 1%, 1.5%, 2%, 2.5%, 3%, 5% and 10% polypropylene fibers by dry weight of soil. First, the test sample is sieved through a 4.75 mm sieve, and approximately 2.5 kg of it is mixed with water to reach a moisture content 4-6%. The soil is divided into three parts, and each part is compacted in the mould with 25 blows from the 2.6 kg rammer. After compaction, collar is removed and the excess soil is trimmed with the spatula and the mould with compacted soil is weighed. A sample of the compacted soil is taken in a container to determine its moisture content by oven-drying at 105-110°C for 24 hours. This process is repeated with 4% increase of moisture content. The repeated tests should be conducted until the compacted soil's weight decreases. Bulk density is calculated by dividing the mass of compacted soil by the mould volume, and dry density is obtained by adjusting for moisture content. These values are plotted to create a compaction curve, with the peak indicating the Maximum Dry Density (MDD) and corresponding Optimum Moisture Content (OMC). The results, MDD in kg/m³ and OMC as a percentage, are reported.

4.3.6. California Bearing Ratio Test [2720 (Part 16) – 1979]

Plastic-mixed soil samples are prepared with mixing the soil sample with desired percentages of pp nodules and water by dry weight of soil. For a good subgrade, the soil should be compacted such a way that the moisture content lies on the right side of the optimum in compaction graph. Soil samples are compacted in CBR mould (volume= 2250 cm^3) using light compaction rammer (weight= 2.6 kg, height of fall= 310 mm) in 3 layers of 55 blows. After removing the collar, weight the top surface of the mould is leveled using spatula and the remaining soil is collected in a container & oven-dried for determination of moisture content. Then weight of the mould (after removing collar) is taken for determination of bulk & dry density. Base plate and spacer disk are separated from the mould and rotated to 180 degree. Then one filter, rotated mould,another filter paper and spacer disc are placed one above another and assembled. Then the compacted soil is soaked in water for 96 hours.After soaking, the sample is removed from the mold and placed in a testing machine. A surcharge weight is applied to the sample to simulate the load of the pavement.The sample is then subjected to a penetration load at a constant rate of penetration (1.25 mm/min) until a specified penetration depth (12.5 mm) is reached.Loads for each 0.5 mm penetration are noted down.The loads at 2.5 mm and 5.0 mm penetration depths are compared with those required for a standard crushed rock sample.For the standard crushed rock, the loads are 1370 kg and 2055 kg for 2.5 mm and 5 mm penetrations, respectively. The CBR value is calculated using the formula:

CBR= [Load on soil sample / Load on standard sample] * 100%

The CBR value at 2.5 mm penetration is typically used for evaluating soil strength. When CBR value at 5.0 mm penetration is more than the CBR value at 2.5 mm penetration, the test is repeated. If same result is obtained from the repeated test, CBR value at 5.0 mm penetration is used for evaluating soil strength.

4.3.7. UU Triaxial Test [2720 (Part 11) – 1978]

Pure soil sample and plastic-mixed samples are compacted in proctor mould to achieve the desired dry density. Soil samples should be compacted such a way that the moisture content lies on the right side of the optimum in compaction graph. Representative samples are extracted using triaxial sample tubes by extracting machines. The dimensions of the samples are 38 mm in diameter and 76 mm in height.The sample is placed in a triaxial cell. This cell includes a rubber membrane that isolates the soil from the cell's fluid. At first the confining stress is applied then the deviatoric stress is applied. In both cases, drainage is not permitted. Set of three UU triaxial tests were done for the confining pressure of 100 kpa, 200kpa and 300kpa. The load is applied at a constant rate of strain of 2.5 mm per minute. From the test data, deviatoric stress vs axial strain graph is plotted for the confining pressure of 100 kpa, 200kpa and 300kpa. Proof stresses for this three cases are calculated from this graph. Shear stress vs normal stress graph is plotted and mohr-coulomb failure envelope is drawn. Cohesion and angle of internal friction values are determined from the failure envelope.

4.3.8. Falling Head Permeability Test [2720 (Part 17) – 1986]

Soil sample is compacted by Indian standard light compaction and placed in a permeameter [100 mm diameter & 127 mm height], which is a cylindrical device with a known cross-sectional area. 2.5 kg of representative soil sample is taken and desired amount of pp nodules and water is added to prepare the mixed sample. Permeameter is assembled for dynamic compaction. Grease the inside of the mould and place it upside down on the dynamic compaction base. Weigh the assembly correct to a gram (w). Put the collar to the other end. Now, wet soil is compacted in 3 layers with 25 blows to each layer with a 2.6 kg dynamic tool. Collar is removed and excess amount of soil is trimmed off. Mould assembly with the soil is weighted. Filter paper is placed on the top of the soil specimen and he perforated base plate is fixed on it. Assembly is turned upside down and the compaction plate is removed. Insert the sealing gasket and place the top. perforated plate on the top of soil specimen and fix the top cap. The bottom tap is be closed and the test assembly is leaved for 4 days for complete saturation of soil sample. After 4 days, water is filled up to a certain height of stand pipe. The reading on stand pipe is noted for each 1 hour interval for 5 times and reading after 24 hours is noted down. Permeability is measure using the formula-

$$k_T = \frac{2.303 a L}{A t} \log_{10} \frac{h1}{h2}$$

k = coefficient of permeability (hydraulic conductivity) (m/s).
a = the inside area of the standpipe (standpipe).
L = Length of the sample.
A =the inside area of specimen.
d= inside diameter of.
D= inside diameter of permeameter).
t = elapsed time of test (s).
h1 = the elevation of water in the standpipe at time t=0.
h2 = the elevation I water in the standpipe at time equal to t.

Temperature at the time of test is calculated. After temperature correction, permeability at 27°C is calculated.

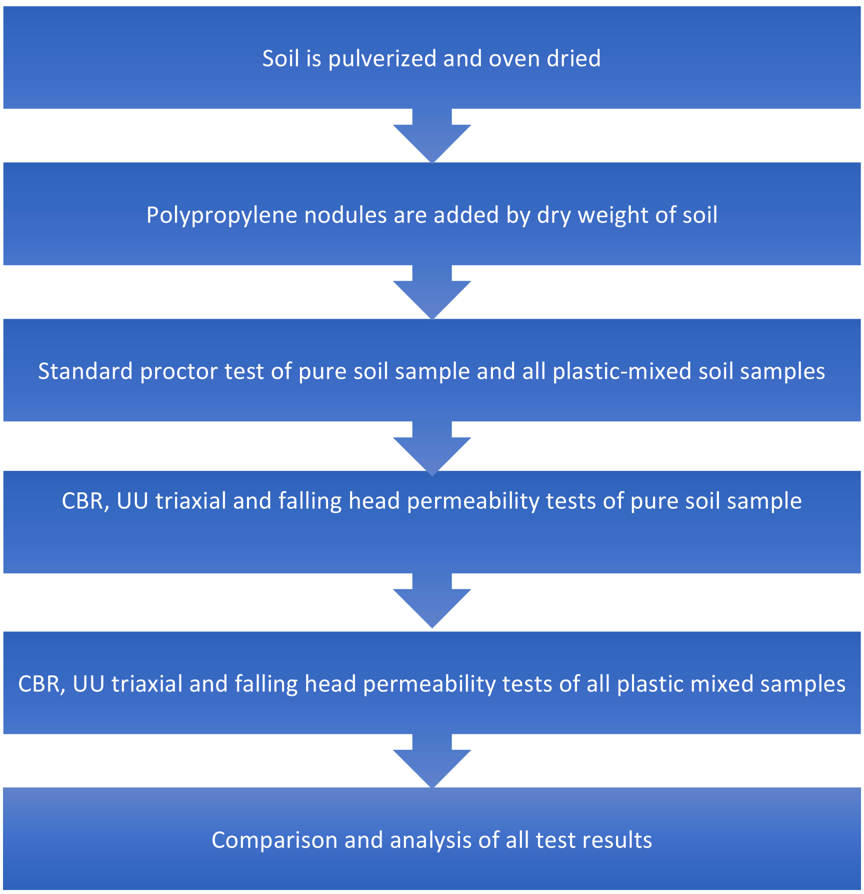


Figure 1- Work plan and flow chart

5. RESULTS & DISCUSSION

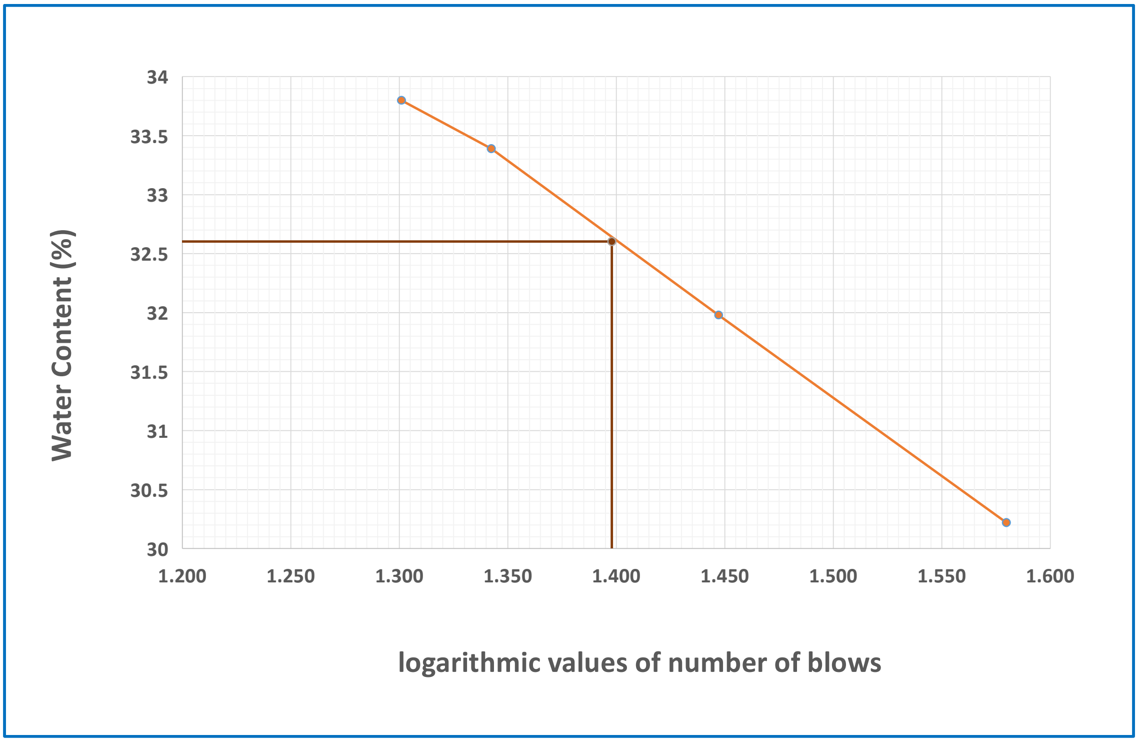
Laboratory tests for pure soil samples and plastic-mixed samples are conducted with minimum error. The test results has been presented in chronological order.Relationships of different percentages of plastic granules and changes in soil properties are explained.

5.1. Atterberg's Limits

These tests are an inexpensive and well documented way of predicting the engineering properties of soil sample. From this laboratory experiment, it was found that the liquid limit, plastic limit and shrinkage limit are 32.60%, 25.04% and 10.23% respectively. For this particular soil, the percentage of volume shrinkage is 13.32%.

Figure 2- Atterberg limit test apparatus and sample

The graph for determination of liquid limit is shown below-



Graph 1- Determination of liquid limit

The plasticity index of the soil is (LL - PL) = (32.60 - 25.04)% = 7.56% (>7%). According to Atterberg chart, the soil is classified as clayey soil with low plasticity.

5.2. Specific Gravity Test (G)

Pycnometer was used for determination of specific gravity of soil sample and polypropylene granules. The specific gravity of soil solids and polypropylene nodules are 2.465 and 0.888 respectively. According to Wikipedia, specific gravity of polypropylene is 0.91 which is almost similar of our result. The graphs related to this test are tabulated below.

Table 5.1- Determination of Specific Gravity of Soil

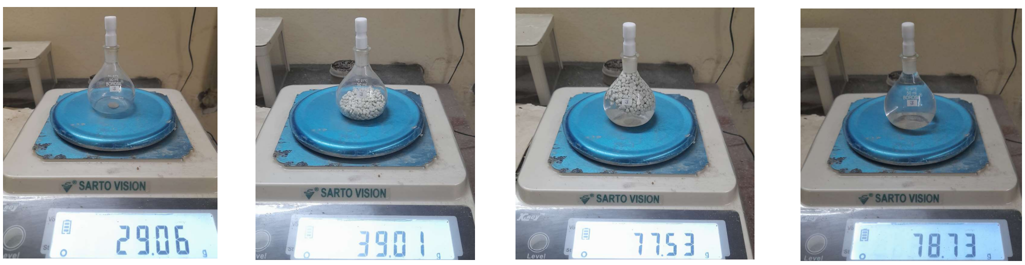
Specimen No	Weight of Empty Pycnometer (W1)	Weight of Pycnometer + Dry Soil (W2)	Weight of Pycnometer + Dry Soil+ Water (W3)	Weight of Pycnometer + Water (W4)	W2-W1	W3-W4	Specific Gravity (G) (gram /cm3)
1	31.98	43.48	89.63	82.78	11.5	6.85	2.473
2	29.14	44.8	88.05	78.71	15.66	9.34	2.478
3	32.6	46.88	91.66	83.17	14.28	8.49	2.466
4	28.28	42.11	87.01	78.81	13.83	8.2	2.456
5	31.84	42.99	87.15	80.55	11.15	6.6	2.451
							Specific Gravity = 2.465

W1 W2 W3 W4

Figure 3- Specific gravity test apparatus with soil sample

Table 5.2- Determination Specific Gravity of Plastic Granules

Specimen No	Weight of Empty Pycnometer (W1)	Weight of Pycnometer + Dry Soil (W2)	Weight of Pycnometer + Dry Soil+ Water (W3)	Weight of Pycnometer + Water (W4)	W2-W1	W3-W4	Specific Gravity (G) (gram /cm3)
1	32.43	42.36	81.49	82.69	9.93	-1.2	0.892
2	30.27	40.54	79.16	80.58	10.27	-1.42	0.879
3	29.06	39.01	77.53	78.73	9.95	-1.2	0.892
							Specific Gravity= 0.888



W1 W2 W3 W4

Figure 4- Specific gravity test apparatus with polypropylene nodules

5.3. Grain Size Distribution

This test is usually presented in a grain size curve obtained from sieve analysis and sedimentation analysis methods. This curve plots particle size against the cumulative percentage by weight, showing the proportion of soil particles within each size range. Understanding grain size distribution helps determine soil characteristics such as permeability, cohesiveness, and suitability for construction. For example, soils with a high proportion of sand drain quickly but may lack cohesion, while soils with significant clay content can retain water well but may become easily compacted.

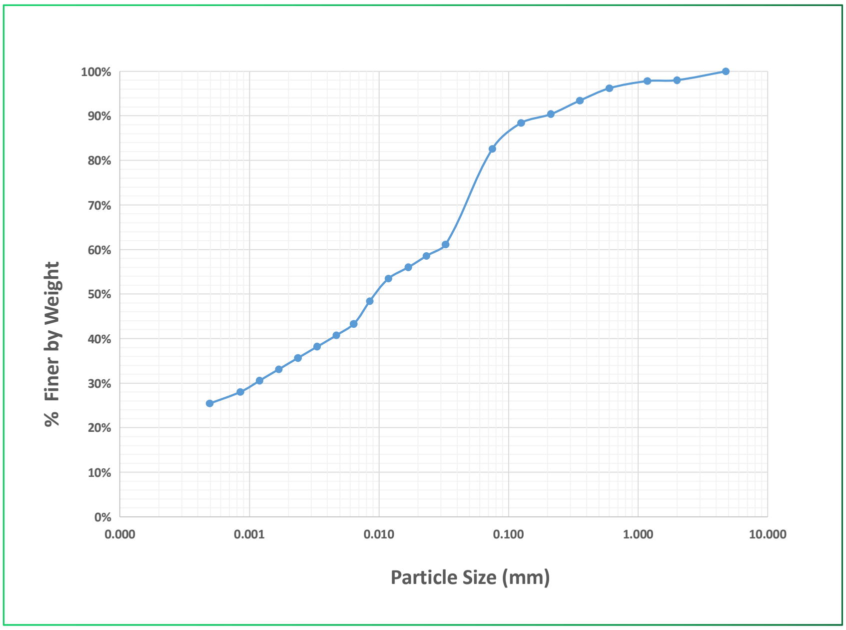
Figure 5- Wet sieve analysis apparatus and sample

Figure 6- Hydrometer test apparatus and sample

The data table and graph of grain size distribution analysis are plotted below.

Table 5.3.- Grain Size Distribution Analysis

Grain Size Distribution Analysis			
Wet sieve analysis results		Hydrometer Test Results	
Sieve Size (mm)	% Finer	Sieve Size (mm)	% Finer
4.750	100.00%	0.03264	61.11%
2.000	98.00%	0.02323	58.56%
1.180	97.80%	0.01685	56.02%
0.600	96.20%	0.01184	53.47%
0.355	93.40%	0.00848	48.38%
0.212	90.40%	0.00638	43.29%
0.125	88.40%	0.00468	40.74%
0.075	82.60%	0.00333	38.19%
		0.00237	35.65%
		0.00168	33.10%
		0.00120	30.56%
		0.00085	28.01%
		0.00049	25.46%



Graph 2- Particle Size Distribution Curve

From wet sieve analysis and hydrometer test results, it is calculated that the soil sample consist of 17.40% sand, 48.32% silt and 34.28% clay. The soil is classified as clayey silt.

5.4. Compaction Test

Standard proctor tests had been carried out for the soil samples mixed with 0%, 1%, 1.5%, 2%, 2.5%, 3% pp nodules by dry weight of soil for determination of maximum dry density and optimum moisture content. Significant changes were not observed in permeability and UU triaxial tests, for this particular range of addition of plastic nodules, further standard proctor tests were carried out by 5% & 10% addition of plastic nodules. Optimum moisture content and maximum dry density were determined from the graph for each cases.

Figure 7- Standard Proctor Apparatus and Sample

Variations of dry density with water content is shown below for individual mixed soil sample.

Table 5.4.- Data obtained from all proctor tests

PURE SOIL	
Moisture Content (%)	Dry Density (KN/m3)
6.51	14.858
10.73	15.384
15.01	15.974
19.33	16.335
23.41	15.780
27.56	14.626

SOIL WITH 1% PLASTIC GRANULES	
Moisture Content (%)	Dry Density (KN/m3)
11.49	15.218
15.20	15.606
19.07	16.115
22.80	15.426
26.75	14.425

SOIL WITH 1.5% PLASTIC GRANULES	
Moisture Content (%)	Dry Density (KN/m3)
11.19	15.036
15.26	15.487
18.95	15.974
23.49	15.212
27.76	14.149

SOIL WITH 2% PLASTIC GRANULES	
Moisture Content (%)	Dry Density (KN/m3)
10.84	15.042
14.59	15.381
18.59	15.858
22.23	15.427
25.85	14.581

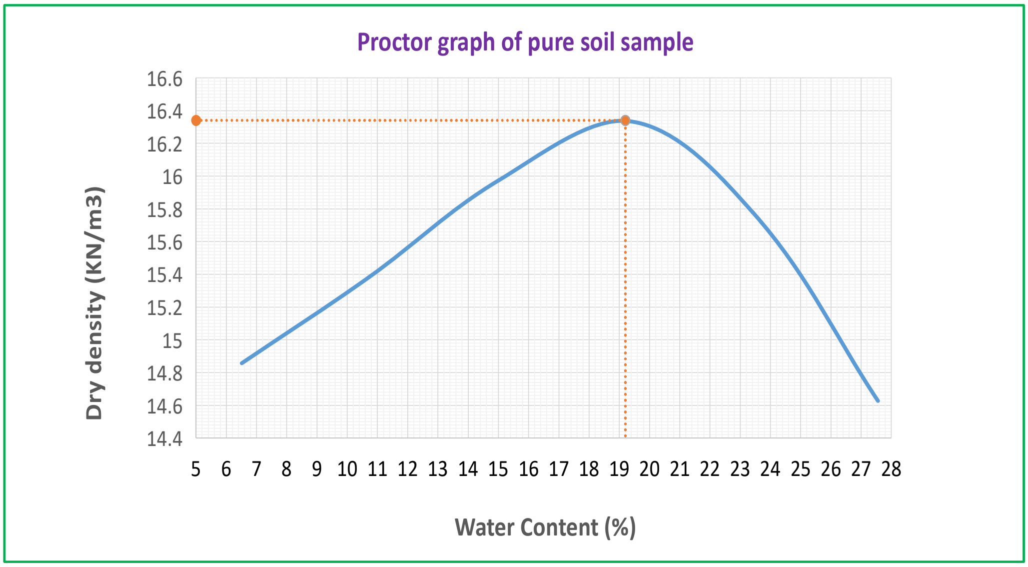
SOIL WITH 2.5% PLASTIC GRANULES	
Moisture Content (%)	Dry Density (KN/m3)
10.50	14.793
14.40	15.217
18.35	15.781
22.23	15.336
26.30	14.251

SOIL WITH 3% PLASTIC GRANULES	
Moisture Content (%)	Dry Density (KN/m3)
10.33	14.610
14.32	15.030
18.29	15.690
22.59	14.955
26.62	13.740

SOIL WITH 5% PLASTIC GRANULES	
Moisture Content (%)	Dry Density (KN/m3)
6.38	14.395
10.78	14.826
14.99	15.507
19.16	15.534
24.81	14.404

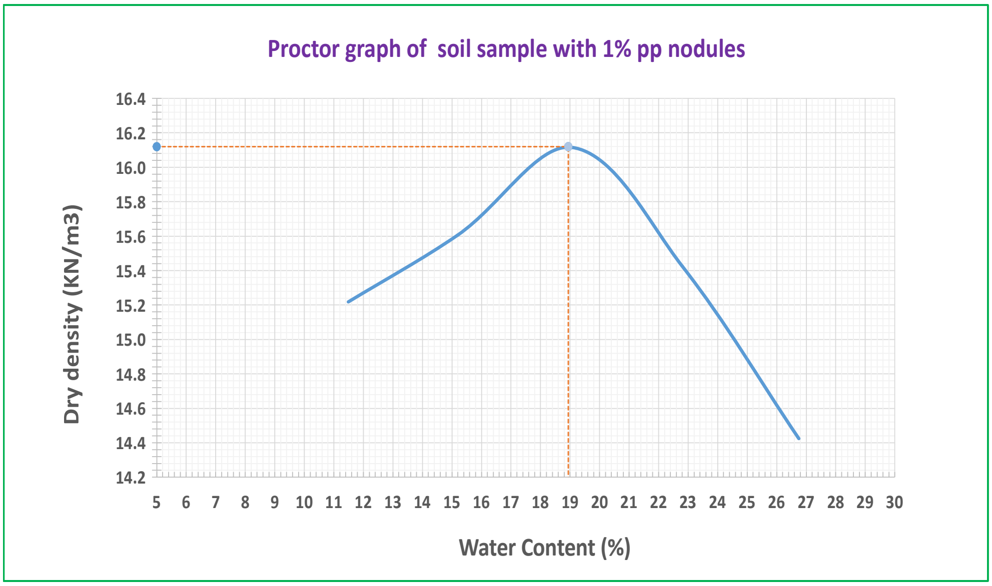
SOIL WITH 10% PLASTIC GRANULES	
Moisture Content (%)	Dry Density (KN/m3)
6.34	14.122
10.90	14.580
15.40	15.255
20.58	14.788
25.02	13.916

Pure soil sample- For this case, the maximum dry density is 16.34 KN/m^3 and optimum moisture content is 19%.



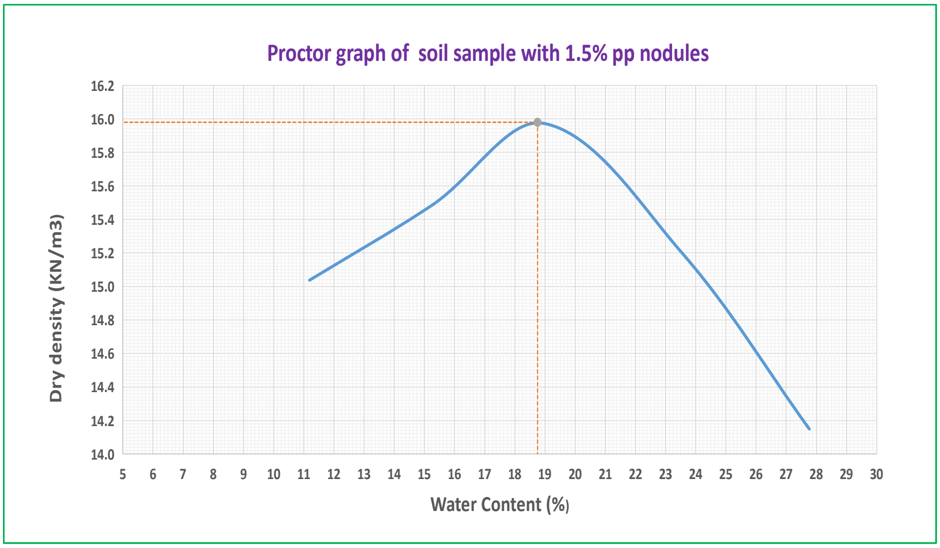
Graph 3- Proctor graph of pure soil sample

Soil sample mixed with 1% pp nodules- For this case, the maximum dry density is 16.12 KN/m^3 and optimum moisture content is 18.94%.



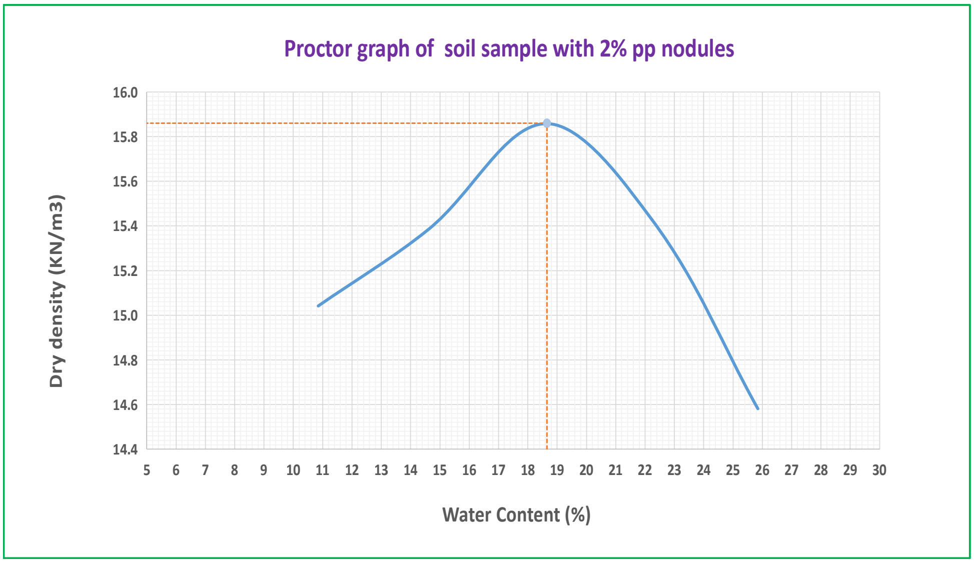
Graph 4- Proctor graph of soil sample mixed with 1% pp nodules

Soil sample mixed with 1.5% pp nodules- For this case, the maximum dry density is 15.98 KN/m^3 and optimum moisture content is 18.75%.



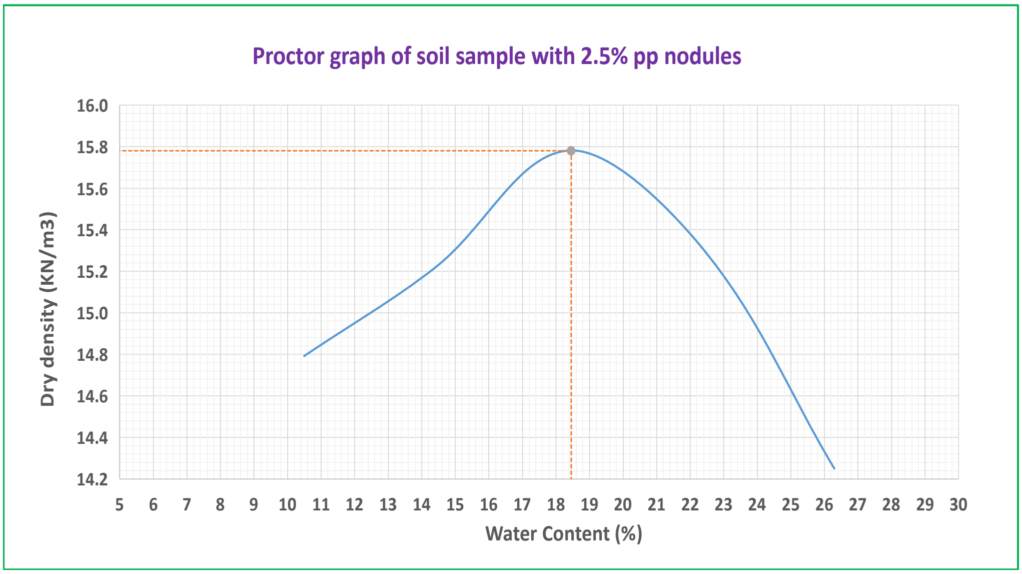
Graph 5- Proctor graph of soil sample mixed with 1.5% pp nodules

Soil sample mixed with 2% pp nodules- For this case, the maximum dry density is 15.86 KN/m^3 and optimum moisture content is 18.65%.



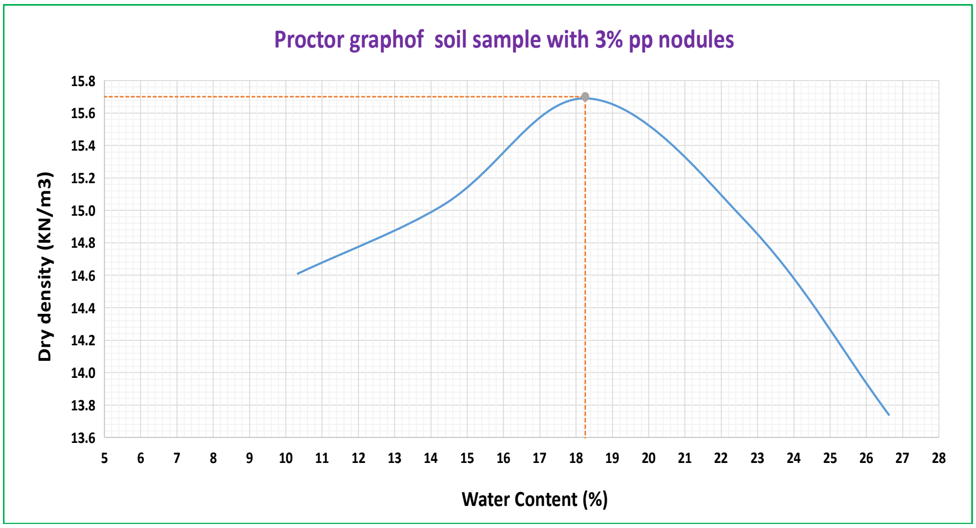
Graph 6- Proctor graph of soil sample mixed with 2% pp nodules

Soil sample mixed with 2.5% pp nodules- For this case, the maximum dry density is 15.78 KN/m^3 and optimum moisture content is 18.45%.



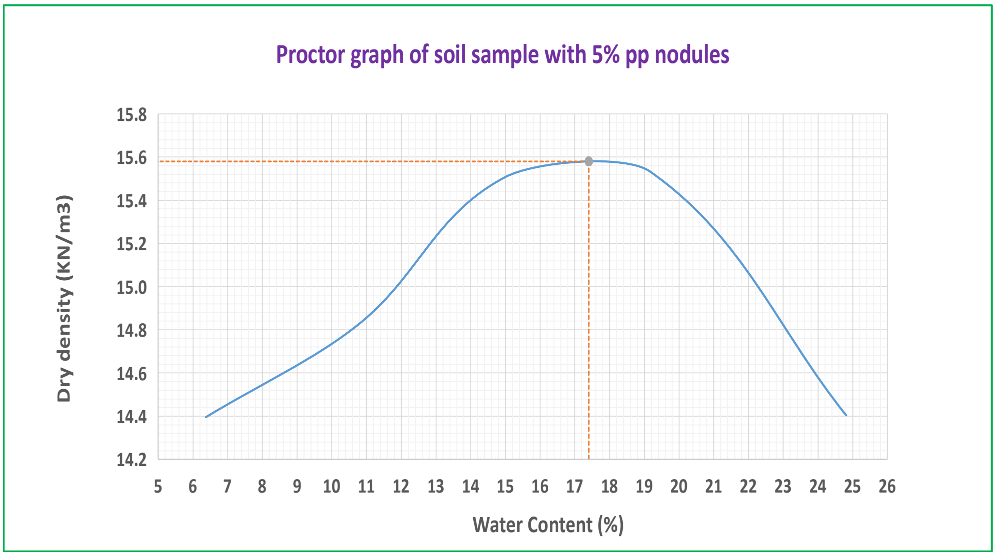
Graph 7- Proctor graph of soil sample mixed with 2.5% pp nodules

Soil sample mixed with 3% pp nodules- For this case, the maximum dry density is 15.78 KN/m^3 and optimum moisture content is 18.45%.



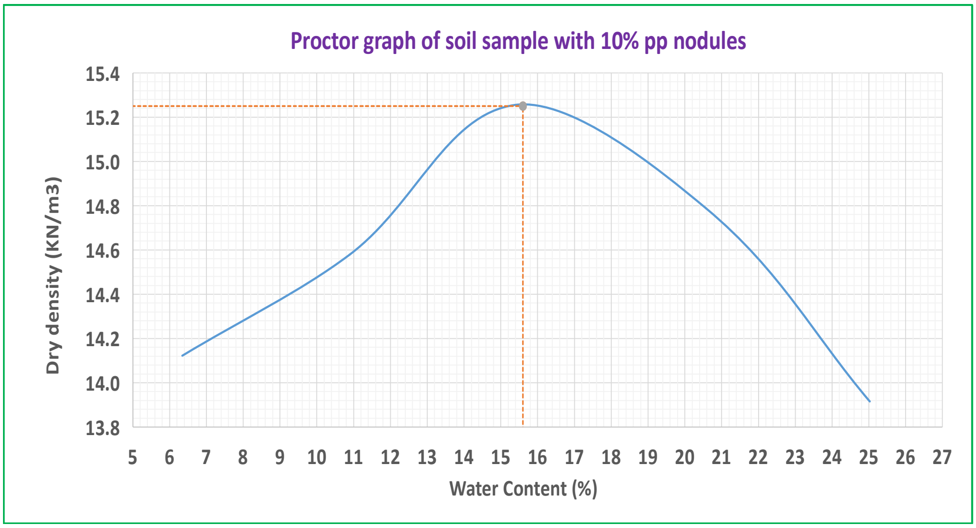
Graph 8- Proctor graph of soil sample mixed with 3% pp nodules

Soil sample mixed with 5% pp nodules- For this case, the maximum dry density is 15.58 KN/m^3 and optimum moisture content is 17.40%.



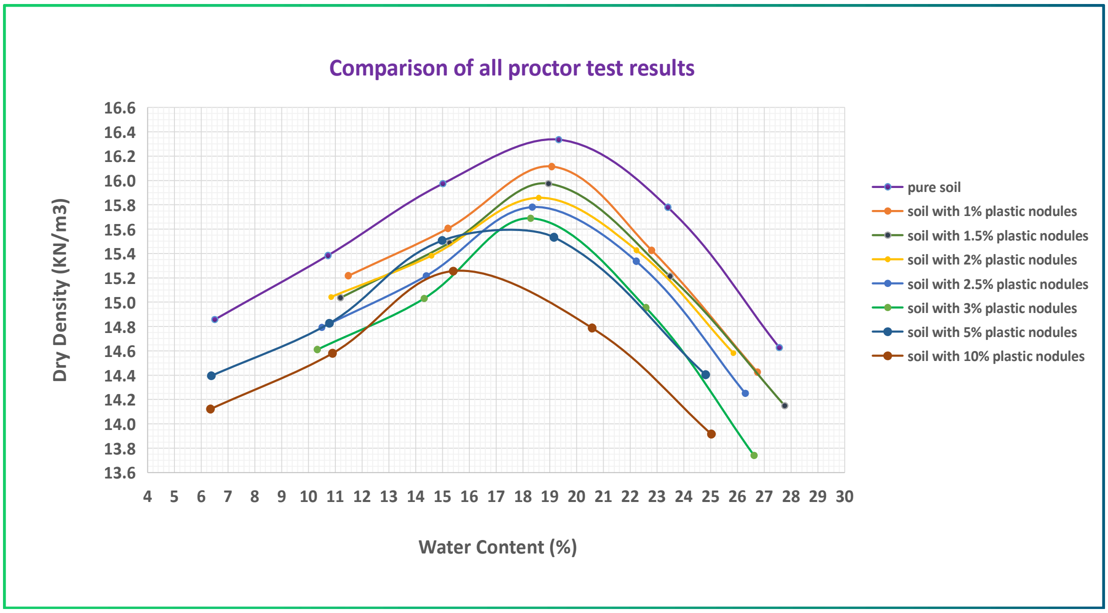
Graph 9- Proctor graph of soil sample mixed with 5% pp nodules

Soil sample mixed with 10% pp nodules- For this case, the maximum dry density is 15.25 KN/m^3 and optimum moisture content is 15.60%.



Graph 10- Proctor graph of soil sample mixed with 10% pp nodules

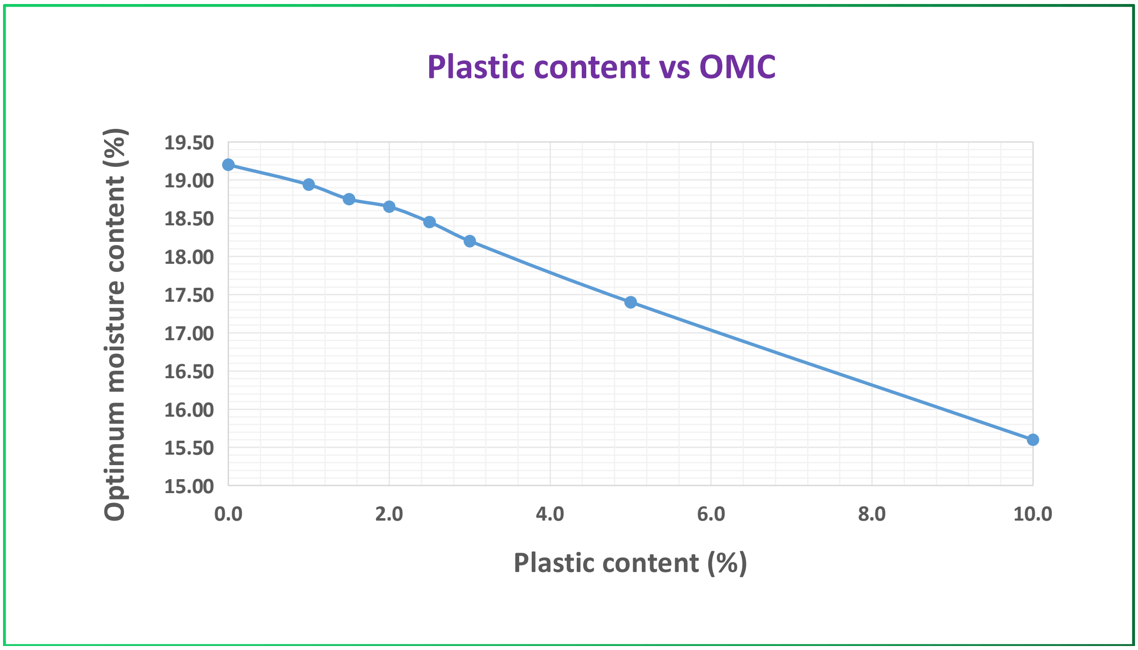
Curves obtained from different proctor graphs are plotted in a single graph. The change in dry density for varying plastic content is observed for different moisture content.



Graph 11- All proctor test results

Table 5.5.- Plastic content vs OMC graph

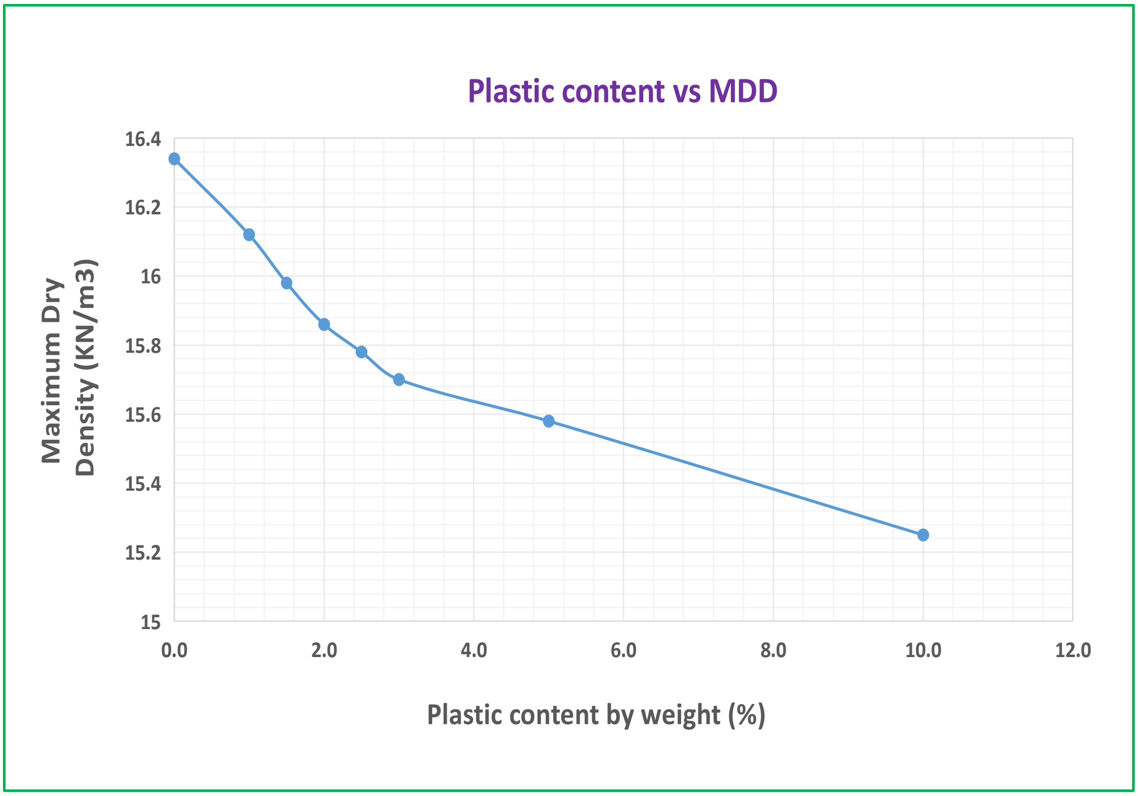
Plastic content by weight (%)	**OMC (%)**
0.0	19.20
1.0	18.94
1.5	18.75
2.0	18.65
2.5	18.45
3.0	18.20
5.0	17.40
10.0	15.60



Graph 12- Plastic content vs OMC

Table 5.6.- Plastic content vs MDD graph

Plastic content by weight (%)	Maximum Dry Density (KN/m^3)
0.0	16.34
1.0	16.12
1.5	15.98
2.0	15.86
2.5	15.78
3.0	15.70
5.0	15.58
10.0	15.25



Graph 13- Plastic content vs MDD

Compaction characteristics of different plastic-mixed soil samples are observed to improve the quality of subgrade. Series of standard proctor test trials are done to measure the compaction parameters by varying the proportion of polypropylene (pp) nodules. The addition of pp nodules with soil sample revealed the decrease in OMC in a linear pattern. MDD values also decrease with increase in plastic proportion. The specific gravity of pp nodules is much lesser than soil solids. When plastic is added to the natural soil, pp nodules replaces the position of soil solids, so the MDD values decreased. The more plastic content will added the amount of soil solids will be lesser for a fixed volume of mould. When more plastic nodules are added, lesser amount of water is required to achieve the optimum moisture content.

5.5. California Bearing Ratio Test

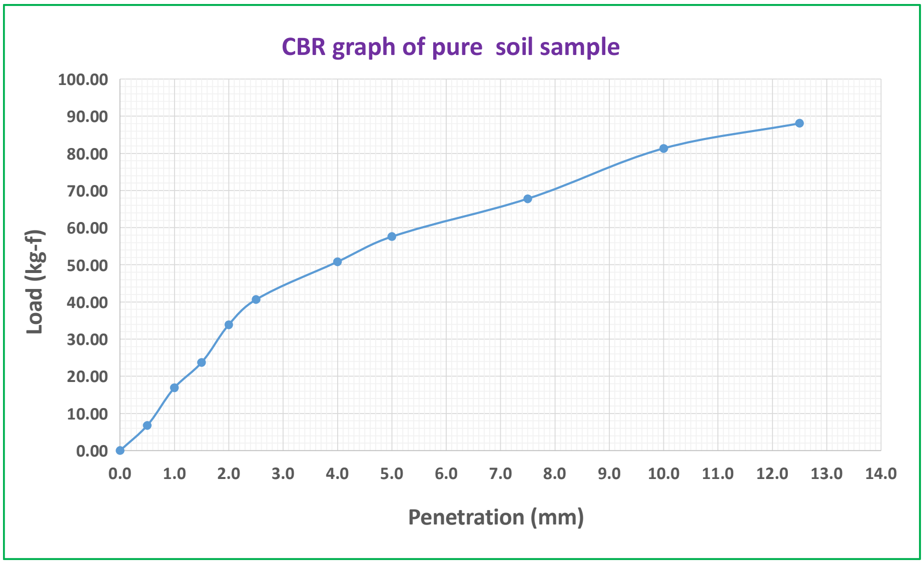
Once the OMC and MDD values were obtained from the compaction test, The CBR specimens were prepared by subjecting them to standard compaction. For a good subgrade, the soil should be compacted such a way that the moisture content lies on the right side of the optimum in compaction graph. In this eight test cases, it was ensured that the moisture content of the soil samples were more than OMC. Soaked CBR tests were carried out for the mixed soil samples. Desired amount of water and pp nodules were added to oven dried soil for preparation of mixed soil samples. Moisture content and dry density of each test cases are shown below.

Table 5.7.- MDD and OMC of all CBR test samples

Type of Sample	MDD (KN/m3)	Dry density obtained at the time of test (KN/m^3)	Density obtained as compared to MDD (%)	OMC (%)	Moisture content at the time of test
Pure Soil Sample	16.34	15.95	97.61%	19.20%	20.02%
Soil Sample + 1% pp	16.12	15.81	98.08%	18.94%	19.56%
Soil Sample + 1.5% pp	15.98	15.62	97.75%	18.75%	19.54%
Soil Sample + 2% pp	15.86	15.61	98.42%	18.65%	19.22%
Soil Sample + 2.5% pp	15.78	15.39	97.53%	18.45%	19.08%
Soil Sample + 3% pp	15.70	15.29	97.39%	18.25%	18.87%
Soil Sample + 5% pp	15.58	15.31	98.27%	17.40%	18.26%
Soil Sample + 10% pp	15.25	14.87	97.51%	15.60%	16.36%

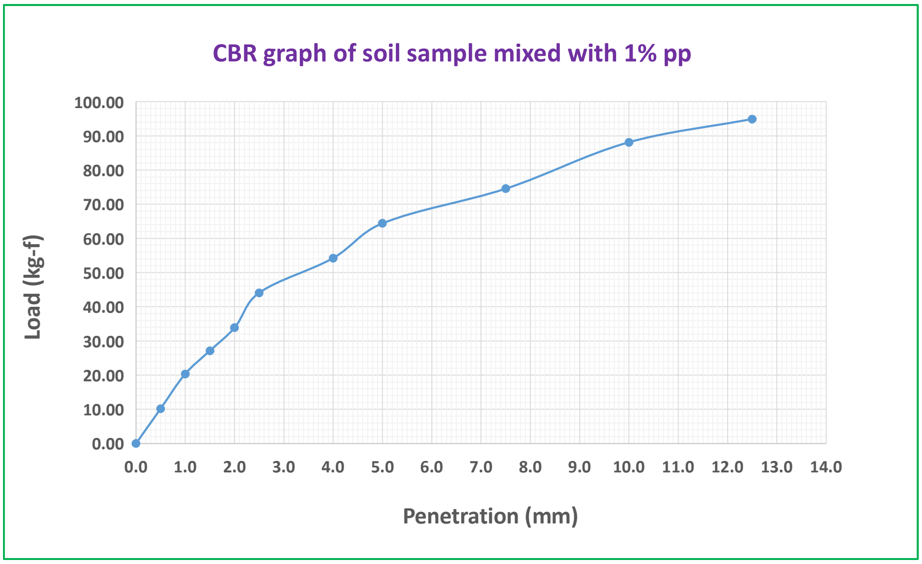
Figure 8- CBR Apparatus and Sample

Pure soil sample- For2.5mm and 5.0 mm penetration, soaked CBR values are 2.97% and 2.80% respectively.



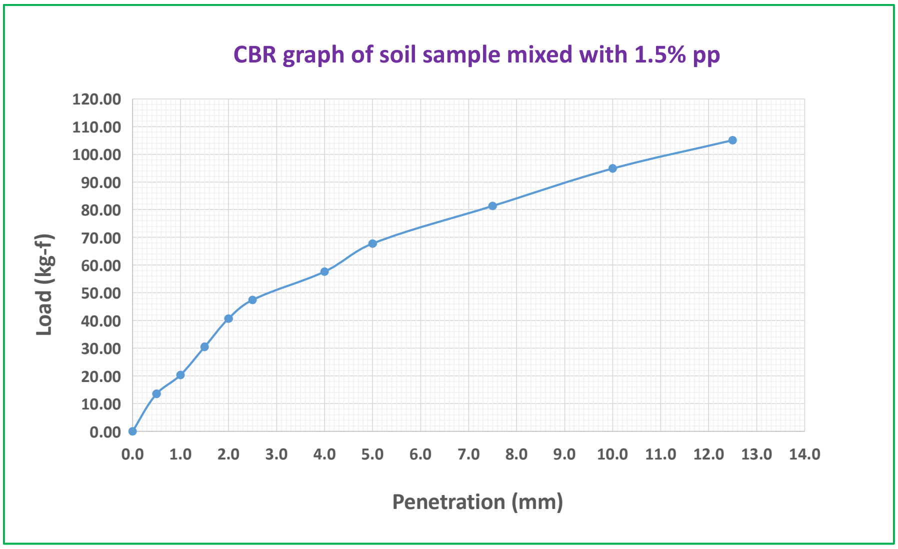
Graph 14- CBR graph of pure soil sample

Soil sample mixed with 1% pp nodules- Soaked CBR values are 3.22% and 3.13% for 2.5mm and 5.0 mm penetration respectively.



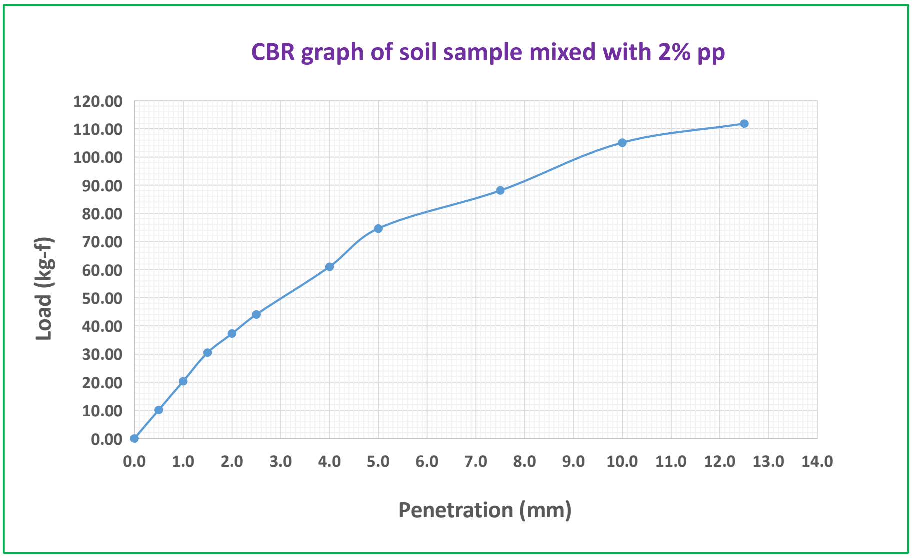
Graph 15- CBR graph of soil sample mixed with 1% pp nodules

Soil sample mixed with 1.5% pp nodules- For 2.5mm and 5.0 mm penetration, soaked CBR values are 3.46% and 3.30% respectively.



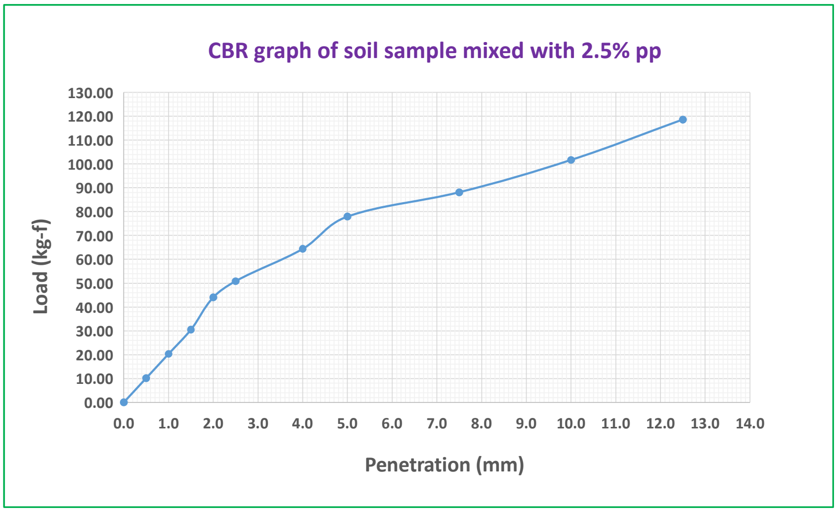
Graph 16- CBR graph of soil sample mixed with 1.5% pp nodules

Soil sample mixed with 2% pp nodules- Soaked CBR values are 3.22% and 3.63% for 2.5 mm and 5.0 mm penetration respectively. In this case, CBR value for 5.0 mm penetration is more than the CBR value of 2.5 mm penetration. The test was repeated and similar values were observed.



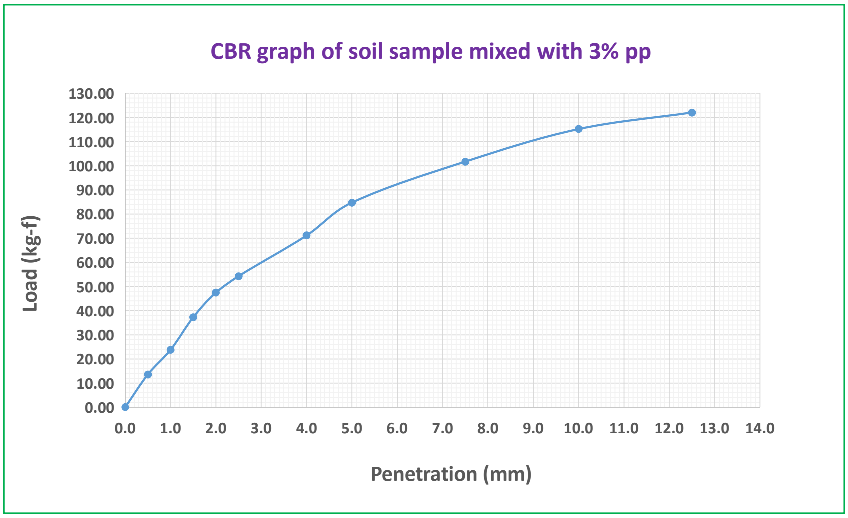
Graph 17- CBR graph of soil sample mixed with 2% pp nodules

Soil sample mixed with 2.5% pp nodules- For 2.5 mm and 5.0 mm penetration, soaked CBR values are 3.71% and 3.79% respectively. In this case, CBR value for 5.0 mm penetration is more than the CBR value of 2.5 mm penetration. The test was repeated and similar values were observed.



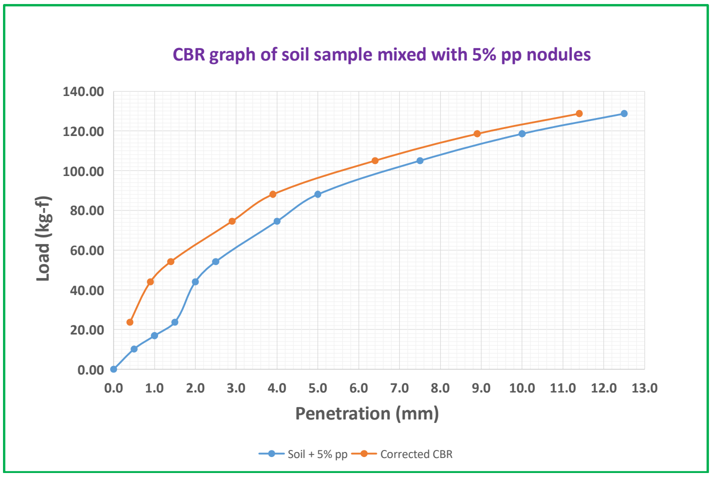
Graph 18- CBR graph of soil sample mixed with 2.5% pp nodules

Soil sample mixed with 3% pp nodules- Soaked CBR values are 3.96% and 4.12% for 2.5mm and 5.0 mm penetration respectively. For this case, CBR value for 5.0 mm penetration is more than the CBR value of 2.5 mm penetration. The test was repeated and similar values were observed.



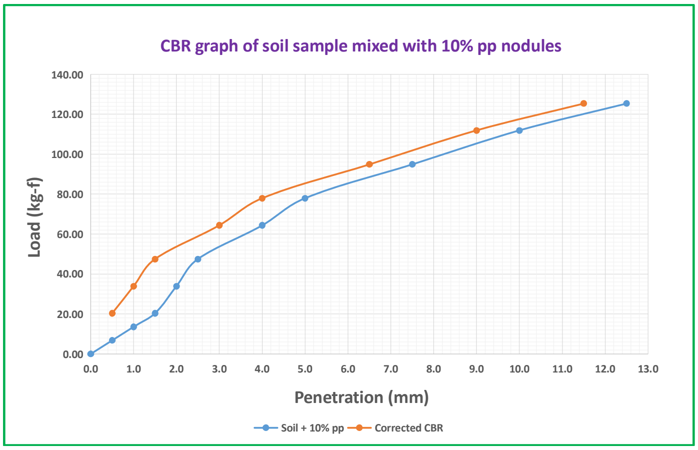
Graph 19- CBR graph of soil sample mixed with 3% pp nodules

Soil sample mixed with 5% pp nodules- After plotting the CBR graph, it was noticed that there was concavity in graph up to 1.1 mm penetration. Then concavity correction was done and soaked CBR values were obtained from corrected graph. Soaked CBR values are 5.05% and 4.65% for 2.5mm and 5.0 mm penetration respectively.



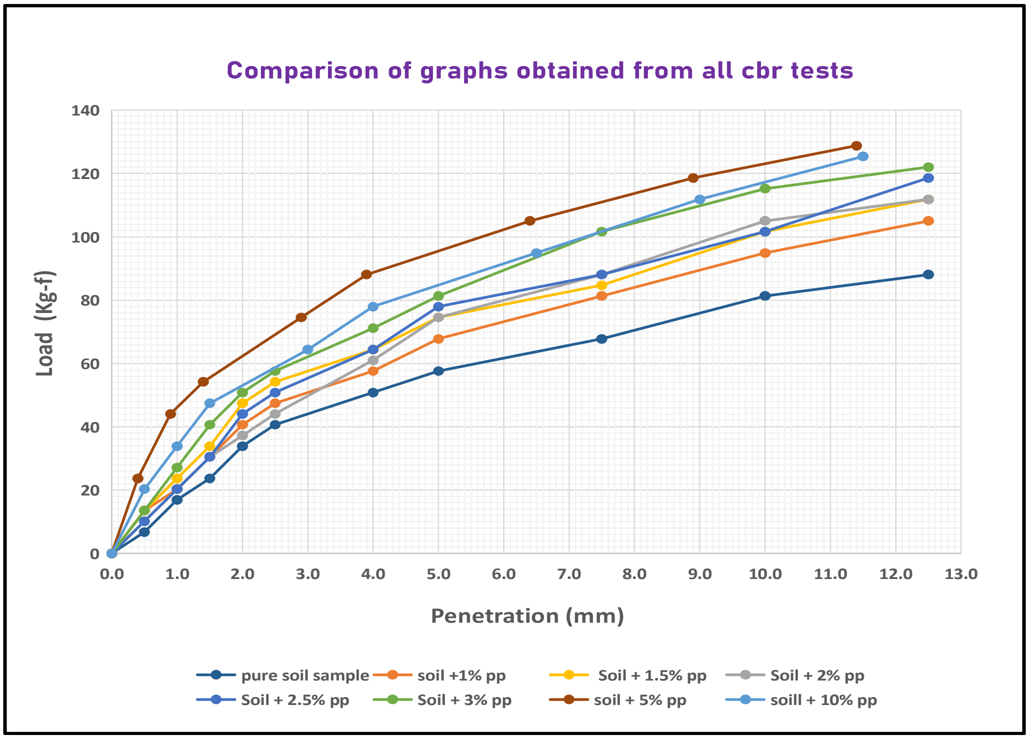
Graph 20- CBR graph of soil sample mixed with 5% pp nodules

Soil sample mixed with 10% pp nodules- After plotting the CBR graph, it was noticed that there was concavity in graph up to 1.0 mm penetration. Then concavity correction was done and soaked CBR values were obtained from corrected graph. Soaked CBR values are 4.29% and 4.12% for 2.5mm and 5.0 mm penetration respectively.



Graph 21- CBR graph of soil sample mixed with 10% pp nodules

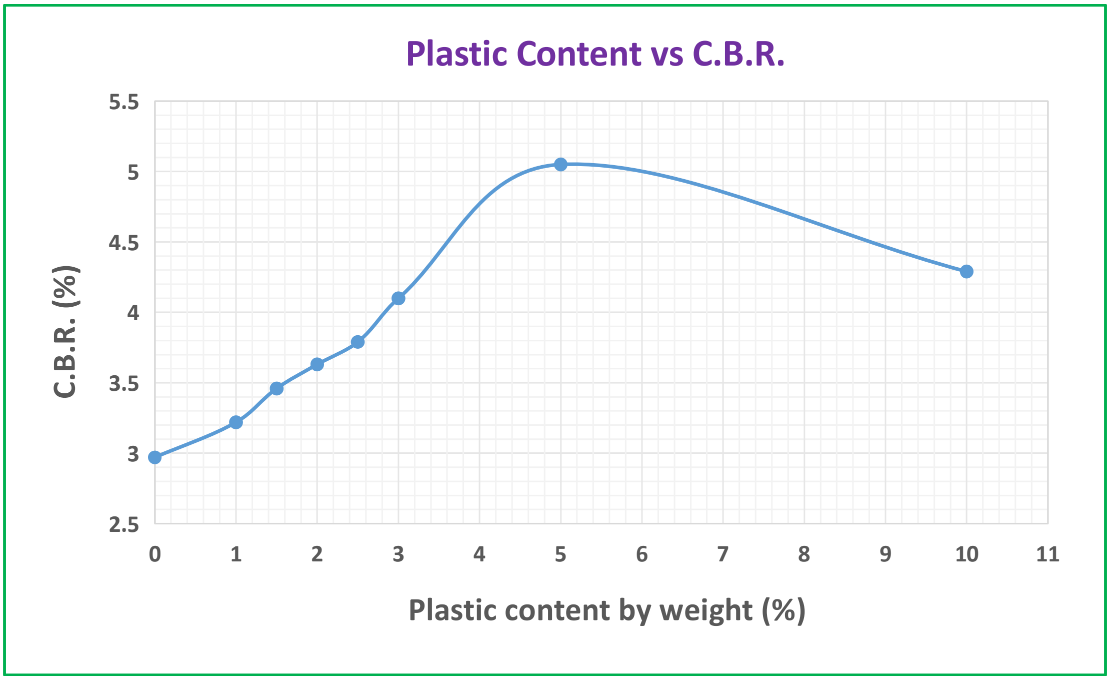
Curves obtained from different CBR graphs are plotted in a single graph. The change in load for varying plastic content is observed for different penetration values.



Graph 22- Comparison of load vs penetration graph of all CBR tests

Table 5.8.- Plastic content vs CBR value

Plastic content by weight	C.B.R. values (%) in soaked condition
0.0	2.97
1.0	3.22
1.5	3.46
2.0	3.63
2.5	3.79
3.0	4.10
5.0	5.05
10.0	4.29



Graph 23- Plastic content vs CBR graph

Soaked CBR is considered as the worst site condition. The results of this test are very helpful to understand the effect of water on the strength characteristics of weak soil subgrade. Improved CBR values are obtained for all plastic-mixed samples. It is clearly understood from Graph 23, that CBR values are increased up to addition of 5% pp grains, then decreased. Polypropylene is a very good material for its strength and durability. In all plastic-mixed samples, polypropylene nodules provided a greater strength against deformation. CBR value for 5% addition of pp nodules is 1.70 times of the CBR value of natural soil.

3-5% addition of plastic content is considered as optimum for this test case.

5.6. UU Triaxial Test

This test has been performed on pure soil sample as well as different plastic mixed samples to determine the shear strength parameters under undrained condition. These undrained shear strength parameters are useful in determination of bearing capacity of soil and stability analysis of highway embankments. For every case, mohr failure envelopes are plotted from series of unconsolidated undrained triaxial tests done for the confining pressure of 100 kpa, 200kpa and 300kpa. The failure envelopes are usually be a horizontal line for saturated specimens and curved line for partially saturated specimens. In our case, all the soil samples are partially saturated so 1 degree failure curve is obtained in all test cases. Cohesion (c_u) and angle of internal friction (φ_u) values are determined from mohr failure envelope. Moisture content and dry density of each test cases are shown below.

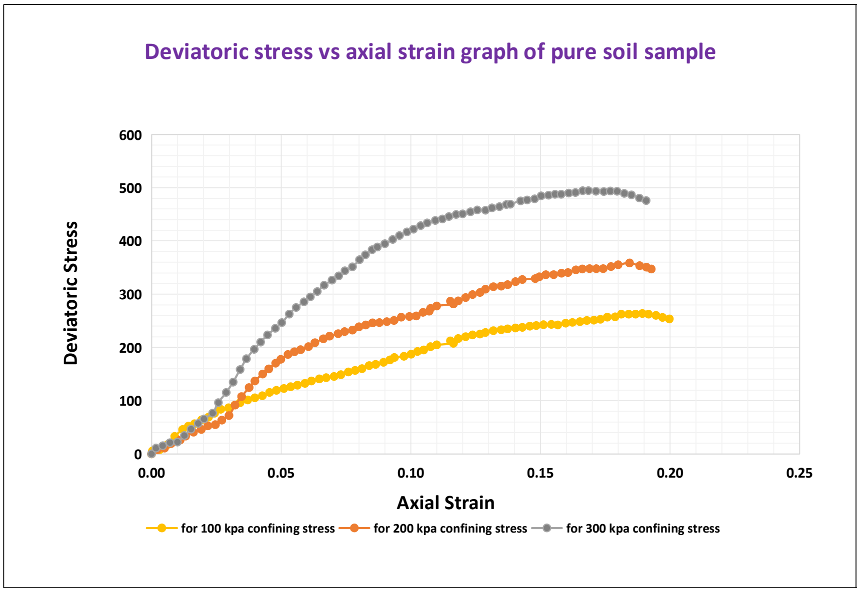
Table 5.9.- MDD and OMC of all triaxial test samples

Type of Sample	MDD (KN/m3)	Dry density obtained at the time of test (KN/m^3)	Density obtained as compared to MDD (%)	OMC (%)	Moisture content at the time of test
Pure Soil Sample	16.34	15.95	97.61%	19.20%	20.02%
Soil Sample + 1% pp	16.12	15.81	98.08%	18.94%	19.56%
Soil Sample + 1.5% pp	15.98	15.62	97.75%	18.75%	19.54%
Soil Sample + 2% pp	15.86	15.61	98.42%	18.65%	19.22%
Soil Sample + 2.5% pp	15.78	15.39	97.53%	18.45%	19.08%
Soil Sample + 3% pp	15.70	15.29	97.39%	18.25%	18.87%
Soil Sample + 5% pp	15.58	15.31	98.27%	17.40%	18.26%
Soil Sample + 10% pp	15.25	14.87	97.51%	15.60%	16.36%

Figure 9- UU Triaxial Apparatus and Sample

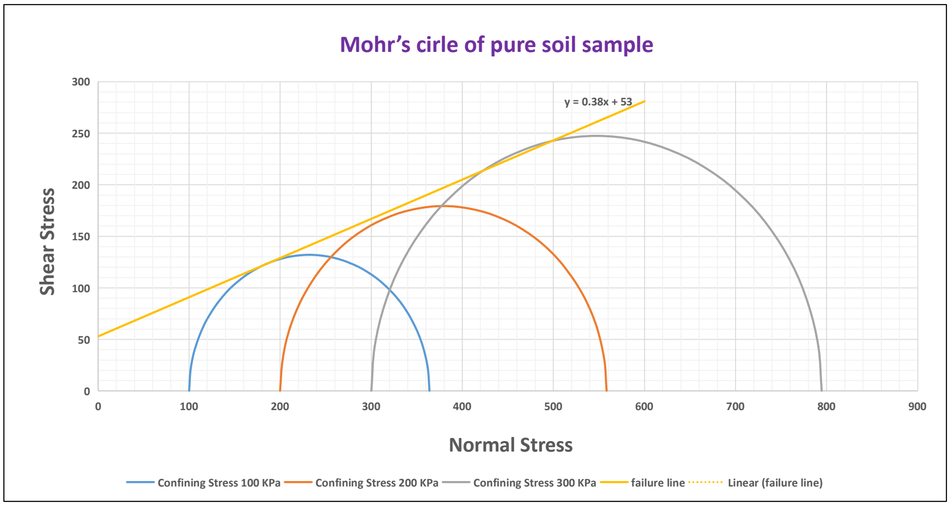
Pure Soil Sample-

For application of 100 kpa, 200 kpa and 300 kpa confining stresses, the maximum deviatoric stresses are obtained as 263.92 kpa, 358.53 kpa and 494.64 kpa respectively.



Graph 24- Deviatoric stress vs axial strain graph of pure soil sample

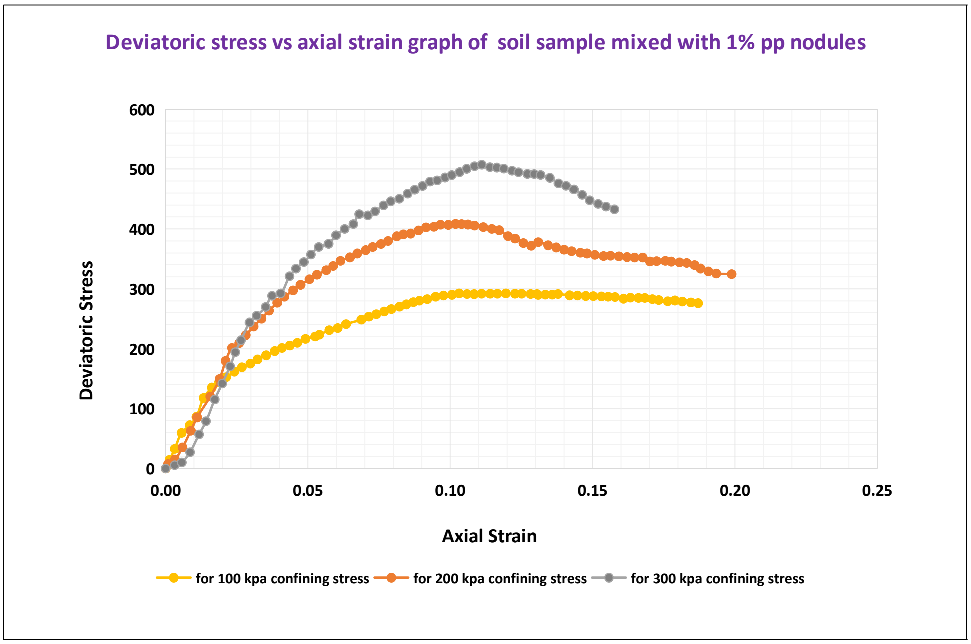
For this soil sample, cohesion is 53 kpa and internal friction is 20.80°.



Graph 25- Mohr's circle of pure soil sample

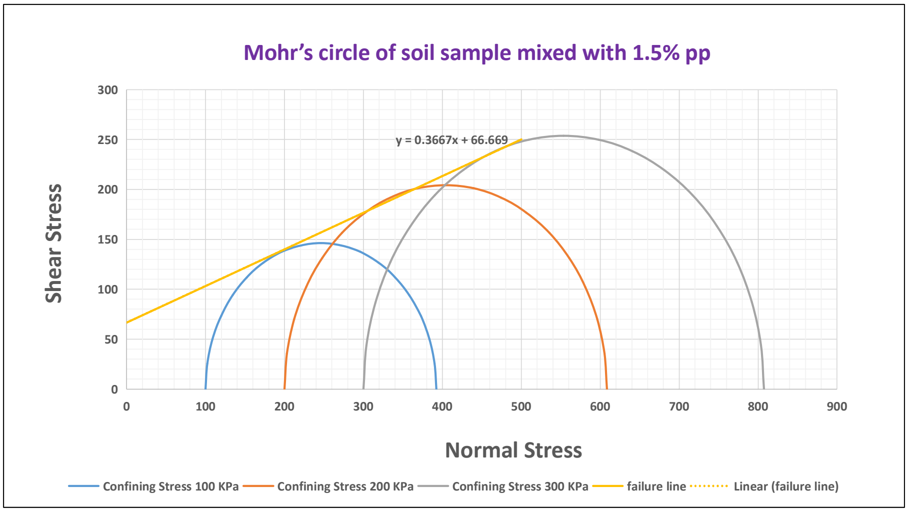
Soil sample mixed with 1% pp nodules-

When 100 kpa, 200 kpa and 300 kpa confining stresses are applied, the maximum deviatoric stresses are recorded as 292.32 kpa, 408.42 kpa and 507.36 kpa respectively.



Graph 26- Deviatoric stress vs axial strain graph of soil sample mixed with 1% pp nodules

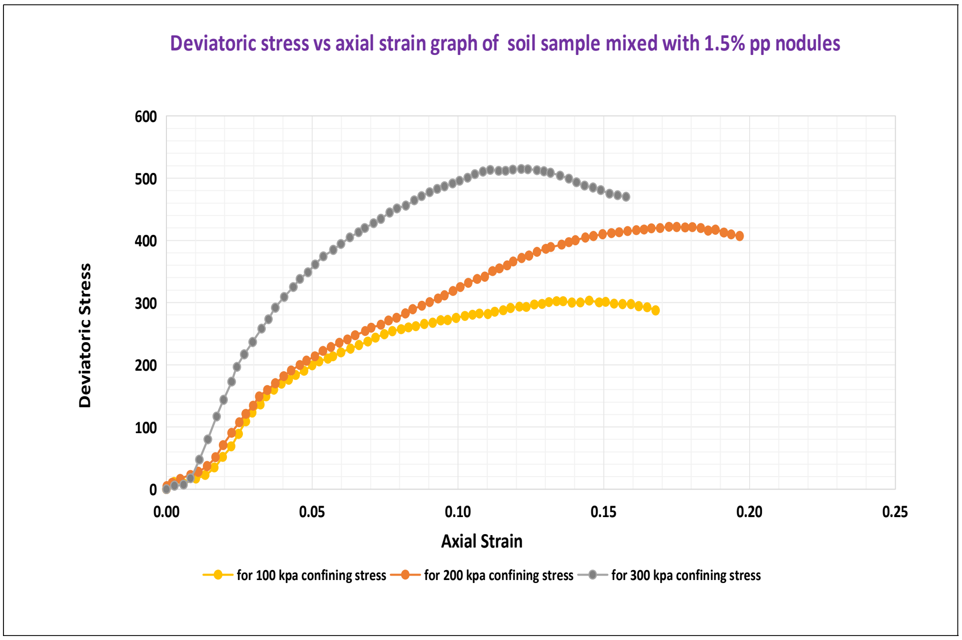
For this mixed soil sample, cohesion is 66.67 kpa and internal friction is 20.14°.



Graph 27- Mohr's circle of soil sample mixed with 1% pp nodules

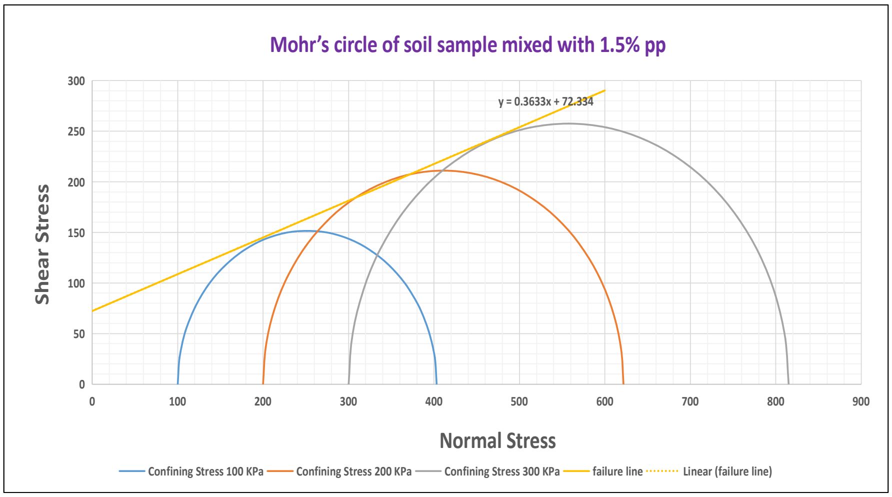
Soil sample mixed with 1.5% pp nodules-

For application of 100 kpa, 200 kpa and 300 kpa confining stresses, the maximum deviatoric stresses are obtained as 303.12 kpa, 4421.88 kpa and 514.91 kpa respectively.



Graph 28- Deviatoric stress vs axial strain graph of soil sample mixed with 1.5% pp nodules

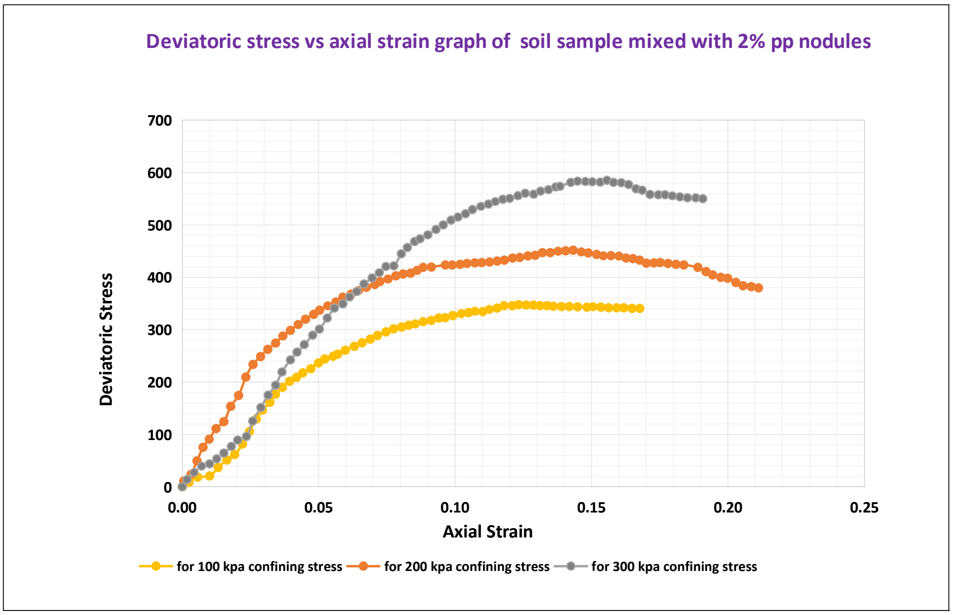
For this mixed soil sample, cohesion is 72.33 kpa and internal friction is 19.96°.



Graph 29- Mohr's circle of soil sample mixed with 1.5% pp nodules

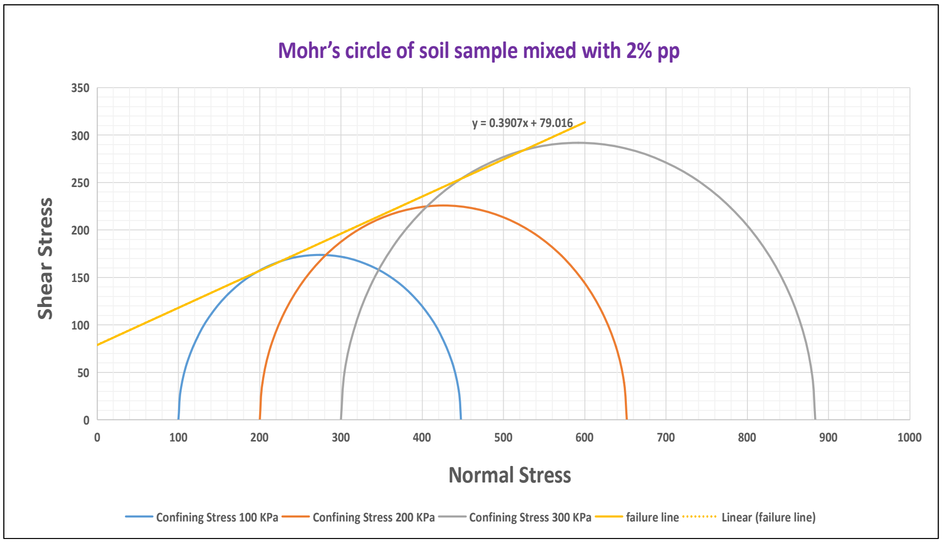
Soil sample mixed with 2% pp nodules-

When 100 kpa, 200 kpa and 300 kpa confining stresses are applied, the maximum deviatoric stresses are recorded as 347.67 kpa, 451.79 kpa and 583.7 kpa respectively.



Graph 30- Deviatoric stress vs axial strain graph of soil sample mixed with 2% pp nodules

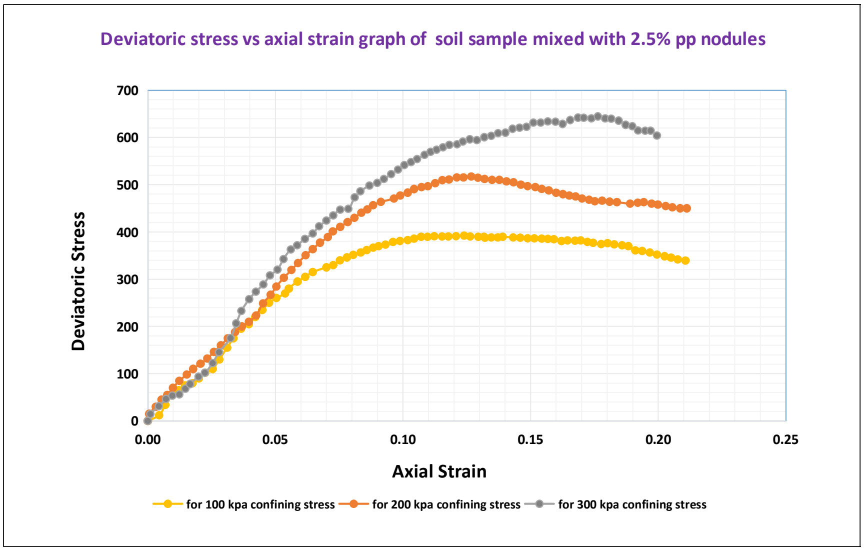
For this mixed soil sample, cohesion is 79.02 kpa and internal friction is 21.34°.



Graph 31- Mohr's circle of soil sample mixed with 2% pp nodules

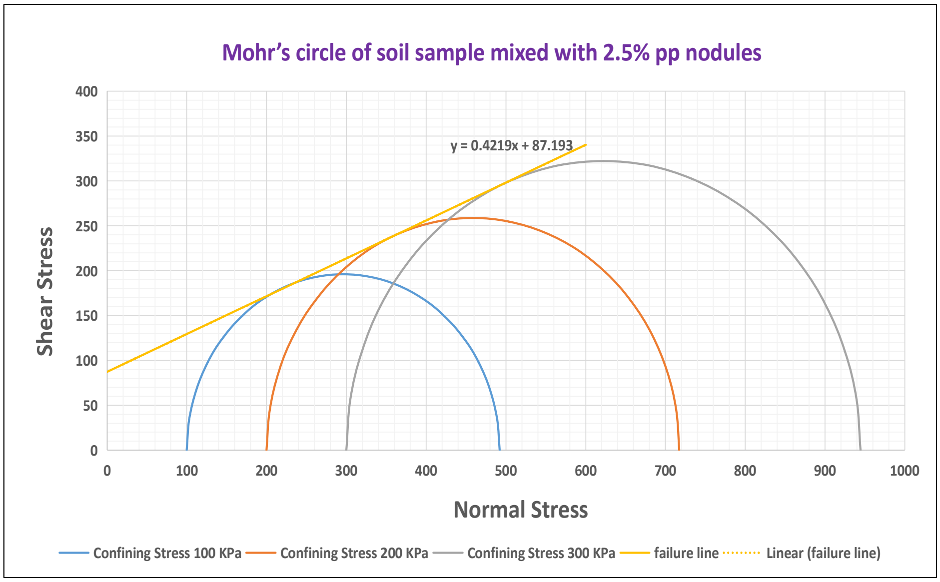
Soil sample mixed with 2.5% pp nodules-

For application of 100 kpa, 200 kpa and 300 kpa confining stresses, the maximum deviatoric stresses are obtained as 392.02 kpa, 517.39 kpa and 644.5 kpa respectively.



Graph 32- Deviatoric stress vs axial strain graph of soil sample mixed with 2.5% pp nodules

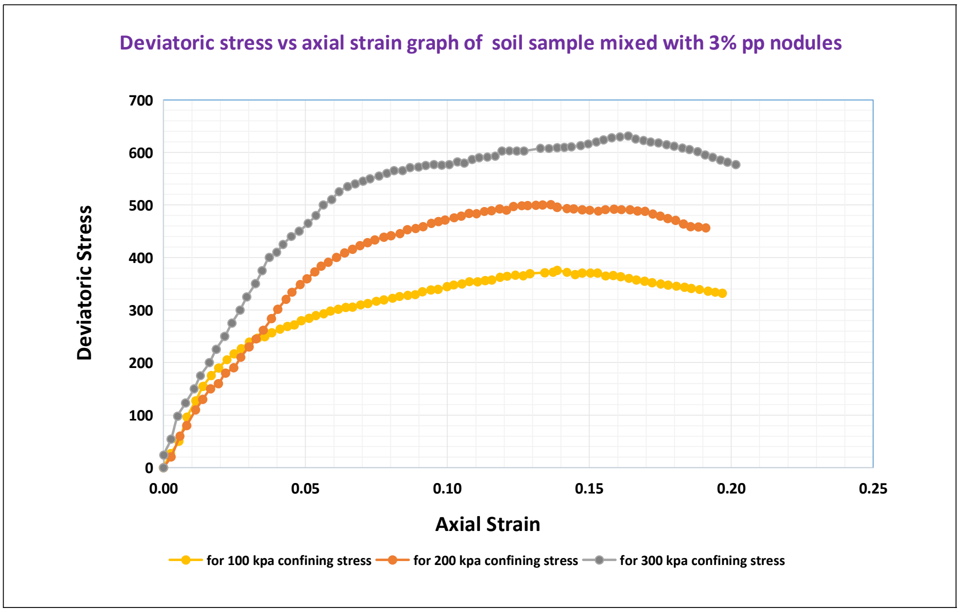
For this mixed soil sample, cohesion is 87.20 kpa and internal friction is 22.87°.



Graph 33- Mohr's circle of soil sample mixed with 2.5% pp nodules

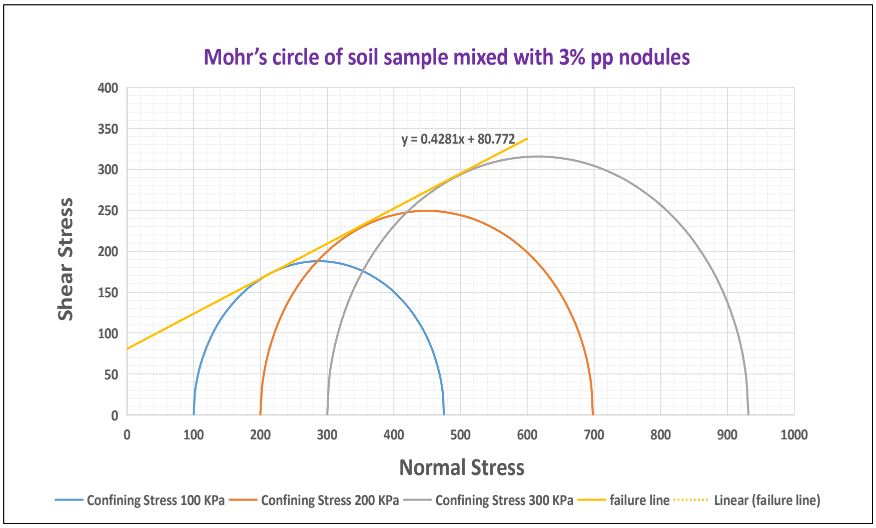
Soil sample mixed with 3% pp nodules-

When 100 kpa, 200 kpa and 300 kpa confining stresses were applied, the maximum deviatoric stresses are recorded as 375.26 kpa, 498.39 kpa and 631.37 kpa respectively.



Graph 34- Deviatoric stress vs axial strain graph of soil sample mixed with 3% pp nodules

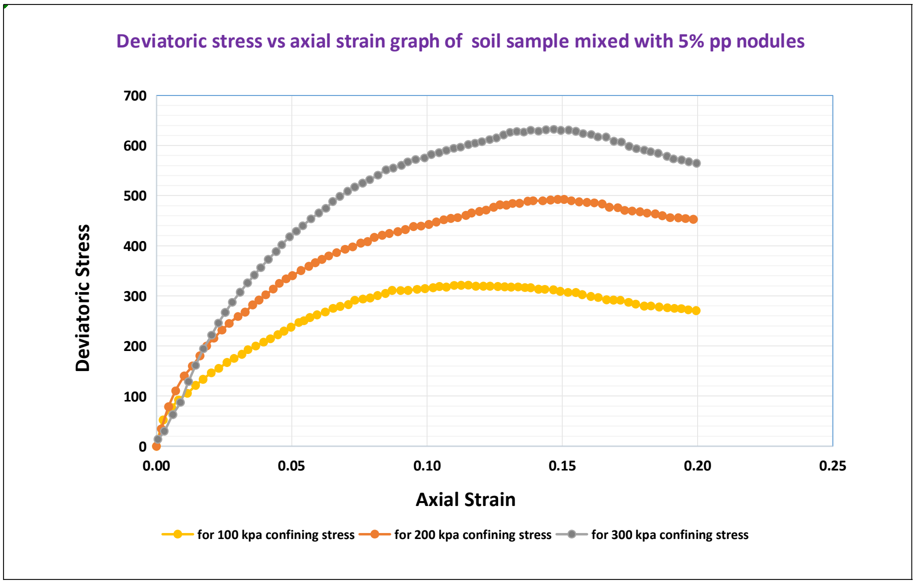
For this mixed soil sample, cohesion is 87.20 kpa and internal friction is 22.87°.



Graph 35- Mohr's circle of soil sample mixed with 3% pp nodules

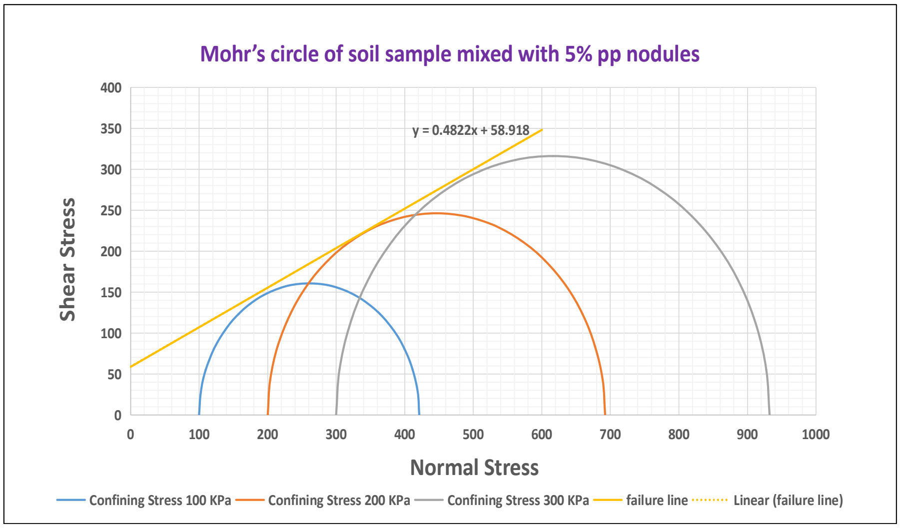
Soil sample mixed with 5% pp nodules-

For application of 100 kpa, 200 kpa and 300 kpa confining stresses, the maximum deviatoric stresses are obtained as 321.31 kpa, 492.43 kpa and 632.36 kpa respectively.



Graph 36- Deviatoric stress vs axial strain graph of soil sample mixed with 5% pp nodules

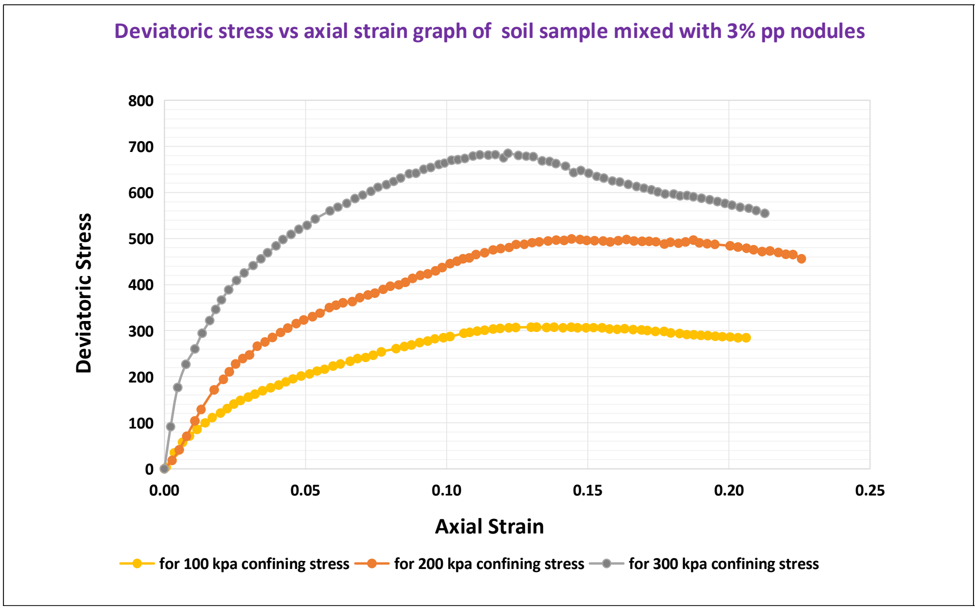
For this mixed soil sample, cohesion is 58.92 kpa and internal friction is 25.74°.



Graph 37- Mohr's circle of soil sample mixed with 5% pp nodules

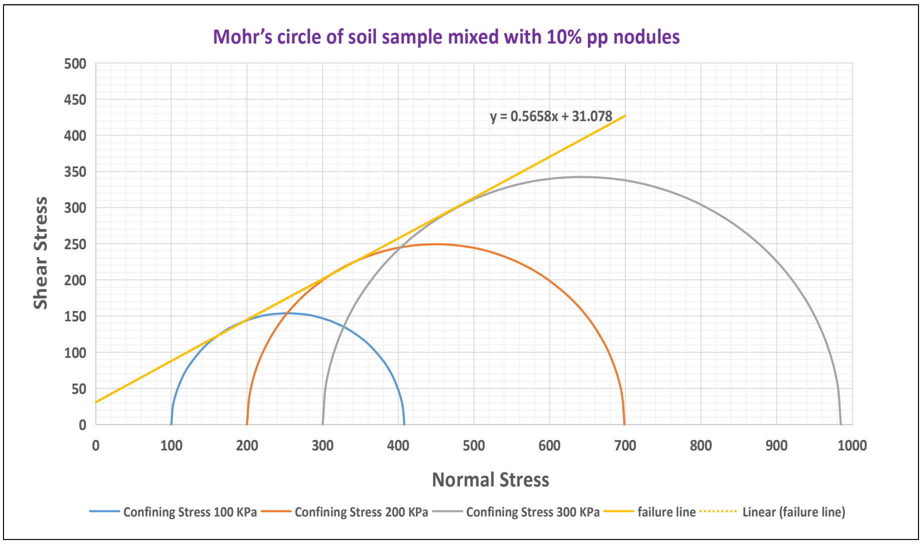
Soil sample mixed with 10% pp nodules

When 100 kpa, 200 kpa and 300 kpa confining stresses are applied, the maximum deviatoric stresses are recorded as 307.73 kpa, 498.88 kpa and 684.88 kpa respectively.



Graph 38- Deviatoric stress vs axial strain graph of soil sample mixed with 10% pp nodules

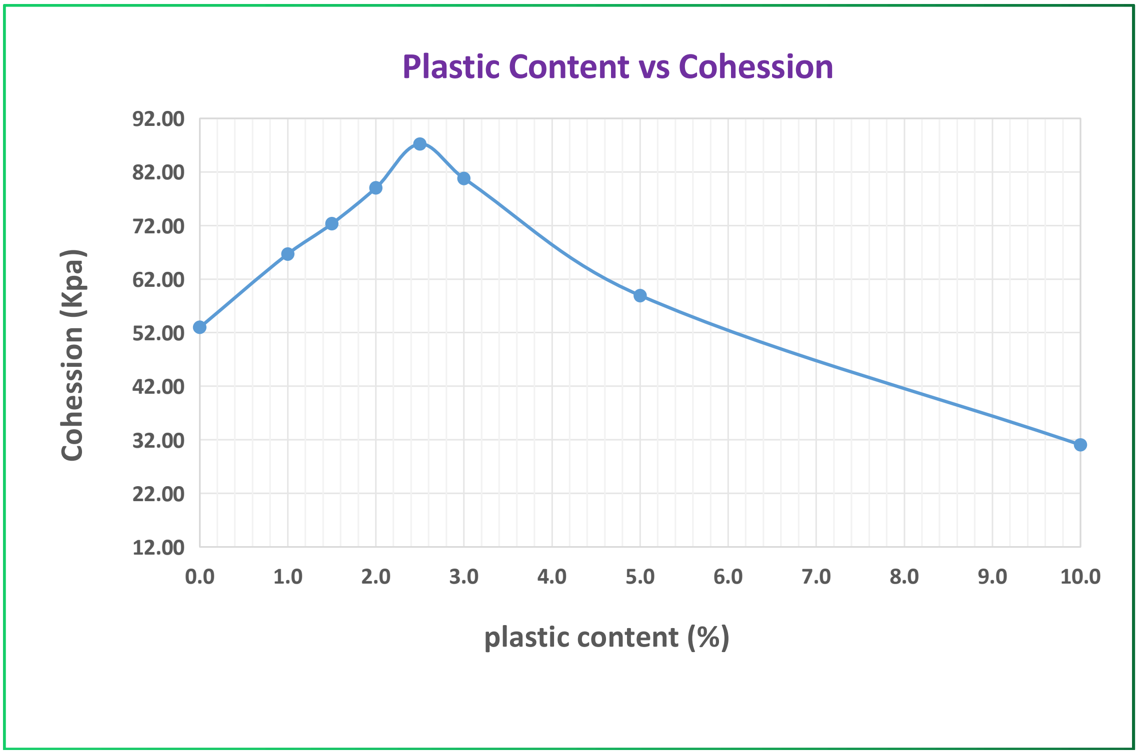
For this mixed soil sample, cohesion is 31.08 kpa and internal friction is 29.50°.



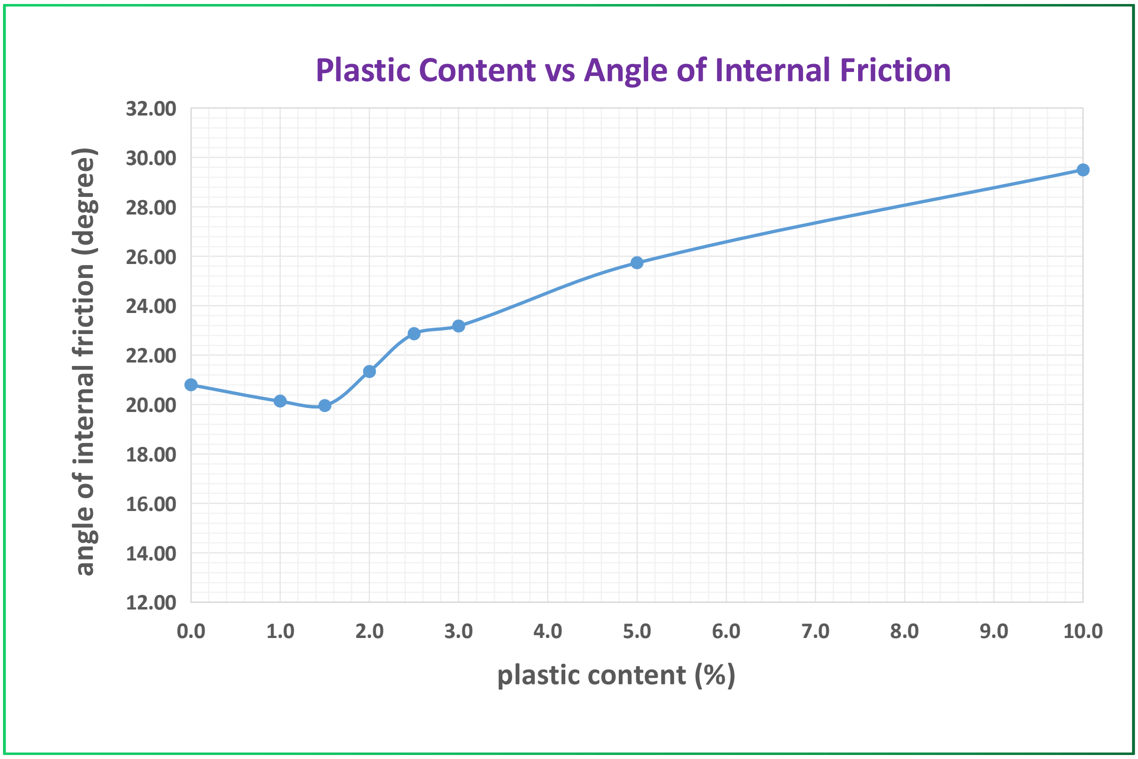
Graph 39- Mohr's circle of soil sample mixed with 10% pp nodules

Table 5.10.- Plastic content vs shear strength parameters

Plastic content by weight (%)	Cohession (Kpa)	Angle of Internal Friction (degree)
0.0	53.00	20.80
1.0	66.67	20.14
1.5	72.33	19.96
2.0	79.02	21.34
2.5	87.20	22.87
3.0	80.77	23.18
5.0	58.92	25.74
10.0	31.08	29.50



Graph 40- Plastic content vs cohesion



Graph 41- Plastic content vs angle of internal friction

UU triaxial tests are conducted to understand the behaviour of shear strength parameters for pure and plastic-mixed soil samples. All the soil samples are compacted in proctor mould at around OMC. Tested soil samples are partially saturated. Values of cohesion increased up to addition of 2.5% polypropylene nodules; further addition of pp nodules, leads to decrease the cohesion values. Plastic content vs cohesion graph is convex in nature, presented in Graph 40. Values of angle of internal friction was decreased up to addition of 1.5% pp nodules, then increased. For 2.5% addition of pp nodules, optimum cohesion value is observed, which is 1.66 times of pure subgrade soil. Cohesion is predominant, when the soil is mixed with 1-3% pp nodules. Frictional resistance increased drastically while 3-10% pp nodules are added.

5.7. Falling Head Permeability Test

It is desired to have a good permeable layer in modified subgrade. Falling head permeability test has been done for one pure soil sample and seven plastic-mixed samples. In different days, in different weather condition the lab tests have been done. To calculate permeability, 27°C is considered as the standard temperature for all test samples for omitting the dis-similarity in test temperature. Moisture content and dry density obtained from laboratory tests are shown below.

Table 5.11.- MDD and OMC of all permeability test samples

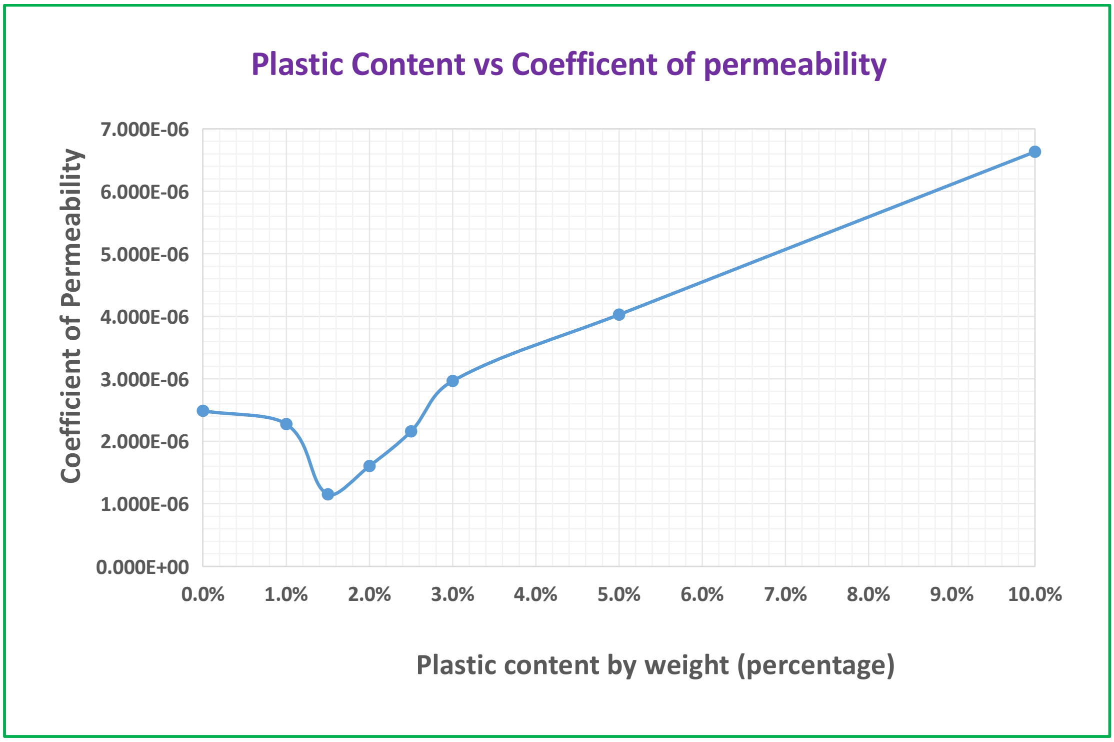
Type of Sample	MDD (KN/m3)	Achived Dry density (KN/m3)	Density obtained as compare to MDD (%)	OMC (%)	Moisture content at the time of test (%)
Pure Soil Sample	16.34	15.47	94.68%	19.20%	19.90%
Soil Sample + 1% pp	16.12	15.28	94.79%	18.94%	19.56%
Soil Sample + 1.5% pp	15.98	15.11	94.56%	18.75%	19.41%
Soil Sample + 2% pp	15.86	14.91	94.01%	18.65%	19.17%
Soil Sample + 2.5% pp	15.78	14.81	93.85%	18.45%	19.03%
Soil Sample + 3% pp	15.7	14.84	94.52%	18.25%	18.88%
Soil Sample + 5% pp	15.58	14.66	94.09%	17.40%	18.37%
Soil Sample + 10% pp	15.25	14.32	93.90%	15.60%	16.29%

Figure 10- Falling head permeability apparatus and Sample

- **Pure soil sample-** For this sample, permeability at 27°C is 2.487*10^{-6} cm/sec.
- **Soil sample mixed with 1% pp nodules-** For this sample, permeability at 27°C is 2.275*10^{-6} cm/sec.
- **Soil sample mixed with 1.5% pp nodules-** For this sample, permeability at 27°C is 1.154*10^{-6} cm/sec.
- **Soil sample mixed with 2% pp nodules-** For this sample, permeability at 27°C is 1.606*10^{-6} cm/sec.
- **Soil sample mixed with 2.5% pp nodules-** For this sample, permeability at 27°C is 2.162*10^{-6} cm/sec.
- **Soil sample mixed with 3% pp nodules-** For this sample, permeability at 27°C is 2.967*10^{-6} cm/sec.
- **Soil sample mixed with 5% pp nodules-**For this sample, permeability at 27°C is 4.027*10^{-6} cm/sec.
- **Soil sample mixed with 10% pp nodules-** For this sample, permeability at 27°C is 6.632*10^{-6} cm/sec.

Table 5.12.- Plastic content vs co-efficient of permeability

Plastic content by weight (%)	Coefficient of permeability (cm/sec)
0.0%	2.487E-06
1.0%	2.275E-06
1.5%	1.154E-06
2.0%	1.606E-06
2.5%	2.162E-06
3.0%	2.967E-06
5.0%	4.027E-06
10.0%	6.632E-06



Graph 42- Plastic content vs co-efficient of permeability

The changes in co-efficient of permeability for all combinations of mixed samples are presented in Table 5.12.. Values of coefficient of permeability are decreased up to 1.5% addition of plastic grains, then increased. Improved values are observed for addition of 3%, 5% and 10% pp nodules. When 10% pp nodules are added to soil, 2.67 times improved permeable layer is created compared to natural subgrade layer. 3-10% addition of pp nodules are recommended to obtain the good subgrade layer.

6. CONCLUSION AND FUTURE SCOPE OF WORK

6.1. Summary

This study aims to improve the strength of the weak soils and increase the recycle rate by utilizing the remolded plastic waste in granule form for stabilizing the subgrade layer of the road pavements. The study can have two purposes. One, creating a proper disposal method of plastic wastes and the second is to improve the subgrade layer properties of road pavements.

6.2. Conclusion

Based on the analysis and interpretations, following conclusions are drawn.

a) The specific gravity of pp nodules is much lesser than soil solids. When plastic is added to the natural soil, pp nodules replaces the position of soil solids, so the MDD values decreased. When polypropylene of different percentages are added to soil, polypropylene nodules occupy the place of soil and reduction in OMC values are observed. Decrement in the density of pavement layer materials has an advantage in some engineering works, such as lightweight embankment construction.

b) The addition of plastic waste strips improves the CBR value of the soil significantly. Improved CBR values are obtained for all plastic-mixed samples. CBR values are increased up to addition of 5% pp grains, then decreased.Optimum values of CBR test results are obtained for 3-5% addition of plastic content with subgrade soil.

c) Values of cohesion increased up to addition of 2.5% polypropylene nodules; further addition of pp nodules, leads to decrease the cohesion values. For 2.5% addition of pp nodules, optimum cohesion value is observed, which is 1.66 times of pure subgrade soil. Values of angle of internal friction was decreased up to addition of 1.5% pp nodules, then increased. When the soil is mixed with 2-3% pp nodules, improved values of cohesion and internal friction are observed.

d) Values of coefficient of permeability are decreased up to 2.5% addition of plastic grains, then increased. When 3%, 5% and 10% pp nodules are added with pure soil, permeability of soil samples have been increased.

The study found that utilizing plastic nodules as subgrade pavement material can open a door for proper plastic waste recycle & disposal methods and also utilized as a ground improvement material. For this type of soil (clayey silt), natural subgrade can be improved by addition of 3-5% polypropylene nodules.

6.3. Future Scope of Work

To further build on the findings of this study, the following areas of research can be suggested:

a) Particular form of plastic: Nodules form of plastic gives more homogeneous mixture than any other form of plastic. So similar study may be conducted with varying types and form of plastic.

b) Environmental Impact Assessments: Given the environmental concerns associated with plastic fibers, comprehensive environmental impact assessments should be conducted. These assessments should explore the long-term ecological effects of plastic fibers in the soil and investigate potential mitigation strategies, such as using recycled or biodegradable alternatives.

c) Cost Effectiveness: Cost analysis of the plastic-mixed subgrade of the model road should be done. This model should be cost effective and sustainable.

d) Long-Term Field Studies: Future research should focus on long-term field studies to assess the performance of lime and plastic fiber-stabilized soils under varying environmental conditions. These studies should consider factors such as temperature fluctuations, moisture variations, and the effects of load-bearing over time.

e) Optimization of Stabilization Techniques: Further research is needed to optimize the mix proportions of lime and plastic fiber for various types of expansive soils. Advanced modeling techniques and experimental approaches could help develop guidelines for proportioning that maximize soil stabilization performance.

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