



Use of bitumen emulsion in gravel road: A laboratory study

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Abstract

The objective of this experimental study is to improve the properties of the gravel soil by adding bitumen emulsion. An attempt has been made to use emulsion for improving the strength of gravel soil expressed in terms of CBR values which may prove to be economical. By adding 8% 10% 12% and 14% of bitumen emulsion to gravel soil the strength property of is increased. The characteristic properties of soil i.e. specific gravity, plastic limit, liquid limit, plasticity index and CBR values of gravel soil with bitumen emulsion was studied. From tests it is observed that excellent soil strength results by using bitumen emulsion. A little cement added to provide better soil strength. It is observed that excellent soil strength results by using cationic bitumen emulsion (CMS) with little quantity of cement used as filler. The appropriate mixing conditions for gravelly soil with CMS Bitumen emulsion have been first attempted. This is followed by deciding four particular material conditions to show the variation in dry density and CBR value to achieve the best possible strength properties of gravel soil. The result shows the best strength properties (CBR) of gravel soil at 14% of adding bitumen emulsion.

Keywords: subgrade soil, CBR, stabilization, bitumen emulsion

Introduction

The study aimed to assess the appropriateness of bitumen emulsion for stabilization of gravel soil or clayey soil. Many researchers resolute more on resources which are locally available so that we are able to enhance the properties of poor soil in excess of addition of industrially made stabilizing agents (cement, lime, etc.) had kept construction cost of structures very high. Most of the stabilization has to be undertaken in soft soils (silty, clayey, peat, or organic soils) in order to achieve desirable engineering properties. Fine grained granular materials are the easiest to stabilize due to their large surface area in relation to their particle diameter. A clay soil compared to others have a large surface area due to flat and elongated particles shapes. On the other hand, silty materials can be sensitive to small change in moisture and therefore, may prove difficult during stabilization. Organic and peat soils are high in water content and high porosity. The uniformity of peat soil can differ from mucky to stringy. The deposit may be shallow, or it can extend to several depths below the ground level. Whereas organic soil due to high exchange capacity can delay the process of hydration by retaining the calcium ions which are liberated while hydration of calcium aluminates and calcium silicate in cement to make balance by adjusting the exchange capacity.

Principle of Soil Stabilization

Soil stabilization is the process of enhancing the engineering characteristics of soil by amalgamating the stabilizers to increase the load carrying capacity, and resistance to weathering. A binding material or a chemical is mixed with raw soil for the stabilization. It is required to improve the natural soils for increasing the bearing capacity of soils carrying heavy loads, reduce permeability, compressibility,

durability and resistance to weathering. The principle of soil stabilization are used for controlling the grading of soil and aggregates in the construction of bases and sub bases of highway.

Components of soil stabilization

Stabilization of soil is done by using stabilizers in soft soil to enhance the geotechnical features such as bearing capacity, permeability and compressibility. The parts of soil stabilization include soils or soil minerals and stabilizing agents or binders. By stabilizing soil, this made the soil more stable thus enhancing bearing capacity of soil.

Soil

Most of the stabilization has to be undertaken in soft soils (silty, clayey, peat, or organic soils) in order to achieve desirable engineering properties. Fine grained granular materials are the easiest to stabilize due to their large surface area in relation to their particle diameter. A clayey soil compared to others has a large surface area due to flat and elongated particle shapes. On the other hand, silty materials can be sensitive to small change in moisture and therefore, may prove difficult during stabilization. Organic and peat soils are high in water content and high porosity. The uniformity of peat soil can differ from mucky and stringy. The deposit may be shallow, or it can extend to several depths below the ground level. Whereas organic soil due to high exchange capacity can delay the process of hydration by retaining the calcium ions which are liberated while hydration of calcium aluminates and calcium silicates cement to make balance by adjusting the exchange capacity.

Stabilizing Agents

Different stabilizing agents are used to enhance the

engineering properties of the soil. these are primary binders (hydraulic) and secondary binders(non-hydraulic) additives which when comes in contact with pozzolanic materials and water reacts with it to form composite of cementitious characteristics. The usually used binders are:

Cement: It is a binder, a substance used for construction that sets, hardens and adheres to other materials, binding them together. Cement is seldom used on its own, but rather to bind sand and gravel together. Cement is used with fine aggregates to produce mortar for masonry, or with sand and gravel aggregates to produce concrete.

Lime: Lime is a calcium containing inorganic mineral in which carbonates, oxides, and hydroxides predominate. In general lime is calcium oxide or calcium hydroxide.

Bitumen: It is a black or dark-color, amorphous, material that can be found in different forms (solid, semi-solid, viscous) such as rock asphalt, natural bitumen, tar and bitumen derived from petroleum. Bituminous stabilization is best for soils which are sandy or poor-quality base course materials.

Fly-Ash: It is obtained as by product from blast furnace and is normally rich in alumina and silica. Though, the amount of fly ash essential for sufficient stabilization is fairly high, making its use limited to areas with ease of using large amount of fly ash at comparatively low cost.

Methods of soil stabilization

Mechanical stabilization

Mechanical stabilization involves physically changing the property of the soil somehow, in order to affect its gradation, solidity, and other characteristics. To achieve the desired grading, sometimes the soils with coarse particles are added or the soils with fine particles are removed. It is also known as granular stabilization. The grading of the soil-aggregate mixture must be such that a dense mass is produced when it is compacted. Before compaction extra aggregates may be mixed so that soil- aggregate mixture became uniform, well-graded dense after compaction. Uniformly mixing the materials and compacting the mix can finish mechanical stabilization. This method is simplest and is usually used to get better sub-grades which are having low bearing capacity. It is widely utilized in the construction of sub-bases, bases and surfacing of roads.

Cement Stabilization

Cement stabilization is done by mixing pulverized soil and Portland cement with water and compact the mix to stain a strong material. The material obtained by mixing soil and cement is known as soil-cement. There are three types of soil-cement like normal, plastic and cement-modified. Normal soil-cement contain 5 to 14 % of cement by volume. It is quite strong and weather resistant. It is commonly used for stabilizing low plastic and sandy soil. Plastic soil-cement contains about 5 to 14% of cement by volume, but it has more quantity of water to have wet uniformity. It is used on step or irregular slopes where it is difficult to use normal road making equipment. Cement modified soil contain less than about 5% of cement by volume. It is a semi-hardened product of soil-cement. It is quite inferior to the other two types.

Lime Stabilization

It is done by adding lime to the soil. It is useful for the stabilization of clayey soils. When lime reacts with soil, there is exchange of cation in the absorbed water layer and a decrease in plasticity of soil occurs. The resulting material is more fragile than the original clay, and is therefore, more suitable sub-grade. The quick lime is more effective as stabilizer than the hydrated lime, but the latter is more safe and convenient to handle.

Bituminous Stabilization

Bituminous non-aqueous system of hydrocarbons that are soluble in carbon disulfide. It is generally done with asphalt as binder. As asphalts are normally too viscous to be used directly, these are used as cutback with some solvent such as gasoline. Organic soil which can be mixed with bitumen (asphalt) is used for bituminous stabilization. For sandy soils, asphalt binds particles of soil together and thus used as bonding or cementing agent whereas in cohesive soils, asphalt give protection to soil by plugging voids thus made it water-proof. It allows the cohesive soil to maintain low water content and increase the bearing capacity. The total bitumen essential usually varies among 4 to 7% by weight.

Chemical Stabilization

In chemical stabilization, soils are stabilized by adding different chemicals. The main advantage of chemical stabilization is that setting time and curing time can be controlled, but it is however more expensive than other methods.

Calcium Chloride: the soils treated with this do not easily pick up water, the method is effective foe stabilization of slit and clay which having low strength while increase in moisture content. The quantity of this required is one and a half percentage of the weight of soil. It is used for construction of roads in stabilizing bases and sub-bases.

Factors affecting the strength of stabilized soil

Organic Matter

In many cases, the top layers of most soil constitute large amount of organic matters. However, in well drained soils organic matter may extend to a depth of 1.5 m (Sherwood, 1993). Soil organic matters react with hydration product e.g. calcium hydroxide ($\text{Ca}(\text{OH})_2$) resulting into low pH value. The resulting low pH value may retard the hydration process and affect the hardening of stabilized soils making it difficult or impossible to compact.

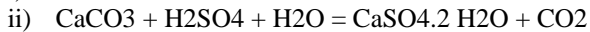
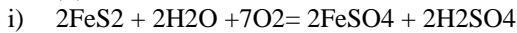
Sulphates

The use of calcium-based stabilizer in sulphate-rich soils causes the stabilized sulphate rich soil in the presence of excess moisture to react and form calcium sulphoaluminate (ettringite) and or thamausite, the product which occupy a greater volume than the combined volume of reactants. However, excess water to one initially present during the time of mixing may be required to dissolve sulphate in order to allow the reaction to proceed.

Sulphides

In many of waste materials and industrial by-product, sulphides in form of iron pyrites (FeS_2) may be present. Oxidation of FeS_2 will produce sulphuric acid, which in the presence of calcium carbonate, may react to form gypsum

(hydrated calcium sulphate) according to the reactions (i) and (ii) below



The hydrated sulphate so formed, and in the presence of excess water may attack the stabilized material in a similar way as sulphate. Even so, gypsum can also be found in natural soil.

Compaction

In practice, the effect of addition of binder to the density of soil is of significant importance. Stabilized mixture has lower maximum dry density than that of unstabilized soil for a given degree of compaction. The optimum moisture content increases with increasing binders. In cement stabilized soils, hydration process takes place immediately after cement comes into contact with water. This process involves hardening of soil mix which means that it is necessary to compact the soil mix as soon as possible. Any delay in compaction may result in hardening of stabilized soil mass and therefore extra compaction effort may be required to bring the same effect. That may lead to serious bond breakage and hence loss of strength. Stabilized clay soils are more likely to be affected than other soils due to alteration of plasticity properties of clays. In contrary to cement, delay in compaction for lime-stabilized soils may have some advantages. Lime stabilized soil require mellowing period to allow lime to diffuse through the soil thus producing maximum effects on plasticity.

Moisture Content

In stabilized soils, enough moisture content is essential not only for hydration process to proceed but also for efficient compaction. Fully hydrated cement takes up about 20% of its own weight of water from the surrounding. On other hand, Quicklime (CaO) takes up about 32% of its own weight of water from the surrounding. Insufficient moisture content will cause binders to compete with soils in order to gain these amounts of moisture. For soils with great soil-water affinity (such as clay, peat and organic soils), the hydration process may be retarded due to insufficient moisture content, which will ultimately affect the final strength.

Temperature

Pozzolanic reaction is sensitive to changes in temperature. In the field, temperature varies continuously throughout the day. Pozzolanic reactions between binders and soil particles will slow down at low temperature and result into lower strength of the stabilized mass. In cold regions, it may be advisable to stabilize the soil during the warm season.

Freeze-thaw and dry-wet effect

Stabilized soils cannot withstand freeze-thaw cycles. Therefore, in the field, it may be necessary to protect the stabilized soils against frost damage. Shrinkage forces in stabilized soil will depend on the chemical reactions of the binder. Cement stabilized soil are susceptible to frequent dry-wet cycles due to diurnal changes in temperature which may give rise to stresses within a stabilized soil and, therefore, should be protected from such effects.

Literature Review

L. Lauren performed an experimental take a shot at soil

stabilization products like the polymer emulsion for having all the earmarks of being the stabilization executors for what's to come. Every one of the three polymer-emulsions was utilized as a part of this testing project performed eminently making solid examples that all gave suitable CBR qualities to ways. The CBR test was utilized for this venture on the grounds that it has been effectively related with quality capability of the subgrade, subbase, and base course material for utilization in street and runway development.

Martin *et al.* developed a paper deals with foam bitumen stabilization. Foamed bitumen is a mixture of bitumen, air and water. Here 2 percent of cement and 3.5 percent of bitumen foam was used. From here it has been found that Rehabilitation using foamed bitumen had proved to be successful because of its ease and speed of construction, its compatibility with a wide range of aggregate types and its relative immunity to the effects of weather.

A. P. Chritz discussed about performance evaluation of mixed in place bituminous stabilized shoulder gravel. Here it was showed an economical maintenance of gravel shoulders, a very common problem is facing by highway agencies.

Yuehuan *et al.* worked on foamed bitumen stabilization for Western Australian pavements. Currently, the popularity of soil cement stabilization had been challenged by anew innovative soil improvement technique, known as foamed bitumen stabilization. Very few of work have been done on it and application of this type of stabilization is currently applied in flexible pavement subgrade stabilization. Numerous Australian roadway and way offices have committed noteworthy investigation and stores to investigate this system so as to attain a more adaptable and weakness safe balanced out material suitable for an extensive variety of pavement conditions. Percent of froth bitumen utilized as 3 to 5 percent. It was one kind of mix design however here after the mix design process stabilization done and CBR quality tried.

Nikraz worked on Bitumen-cement Stabilized Layer in Pavement Construction Using Indirect Tensile Strength (ITS) Method. In this study, the goal was to mix and blend Portland concrete and bitumen emulsion with soil for upgrading the quality, strength and durability of the dirt. So as to upgrade the soil quality and decrease its weakness to water, soil stabilization is obliged to be connected to the soil. In accordance with this, enhanced burden exchange was added to the asphalt establishment by having the bond impact which really supports the firmness and Bitumen emulsion impacts which enhance versatility and soil penetrability of the settled layer.

Kota prudhvi teja *et al.* directed the improvement of silty soil as subgrade material by stabilizing with bituminous emulsion. The first part of investigation was to identify the soil classification of the selected soil according to USCS (Unified soil classification system) by conducting Atterberg's limit test, after soil is classified sieve analysis was done to know the Coarse fraction and Fine fraction of the soil to determine whether the soil is well graded. The second part of the investigation was to identify the specific gravity of the soil which helps to determine the dry density of the soil, by using modified proctor test the maximum dry density (MDD) of the soil is concluded with different concentrations of water and optimum moisture content is observed by plotting a graph between dry density and moisture content. The final part of the investigation was to

discriminate the changes in General, physical and mechanical properties of soil. The second part and third part of investigation found that soil physical and mechanical properties of stabilized soil are improved with reference to, CBR and Maximum dry density. In final investigation the correlation with different emulsion concentrations with cohesion, internal shear angle and three parameters of Atterberg's limits are increased.

Habiba Afrin stated the Different Types Soil Stabilization Techniques. The main objective of this study is to review the physical and chemical properties of soil in different types of stabilization methods. Stabilization and its effect on soil indicate the reaction mechanism with additives, effect on its strength, improves and maintains soil moisture content and suggestion for construction systems. Soil stabilization can be accomplished by several methods. All these methods fall into two broad categories namely mechanical stabilization and chemical stabilization. As technology advances and economic conditions change, many more chemical agents will be introduced into subgrades to improve their compactability, durability, and strength. At the same time, more performance-based testing will be necessary to prove the effectiveness of these stabilization agents. In addition, there are chemicals being used today in the petrochemical industry whose use in soils is as yet unexplored. Another area for research is such processes as injection and spray-on techniques for more economical treatment. Global climate change may affect the durability and application of stabilizers.

N. Vijay Kumar *et al.* studied the strength of Laterite soil using bitumen emulsion and ESP, CSA. In this research study, the admixture bitumen emulsion is added at 5%, 10%, & 15% proportions. Similarly egg shell powder and coconut shell ash are also added at the same proportions. The initial strength of the Laterite soil is determined through various tests like Sieve Analysis, Plastic Limit, Liquid Limit, Specific Gravity, Compaction, Unconfined Compression, California Bearing Ratio and Direct Shear tests. The same tests have been conducted with Laterite soil added with bitumen emulsion and Laterite soil added with egg shell powder and coconut shell ash. The results obtained are then compared with initial Laterite soil and Laterite soil added with admixtures. This study made a comprehensive examination of the effectiveness of soils on the performance of bitumen emulsion. The characteristics of soil sample were known from the tests conducted and the similar tests are conducted for the soil sample mixed with three different proportions of bitumen emulsion.

Maheshwari G. Bisanal *et al.* stated the Stabilization of Soil Using Sea Shell and Bitumen Emulsion. In this study an attempt has been made to stabilize the black cotton soil with sea shell and bitumen emulsion. Soil stabilization is a technique aimed at increasing or maintaining the stability of soil mass and chemical alteration of soils to enhance their Engineering Properties. These curiosity factors influenced us to determine the significant results for proposed combination of work and are described in this paper. Stabilization can be used to treat a wide range of subgrade materials from expansive clay to granular materials. This

allows for the establishment of design criteria as well as the determination of the proper chemical additive and admixture rate to be used in order to achieve the desired engineering properties. Benefits of the stabilization process can include higher resistance values, reduction in plasticity, lower permeability, reduction of pavement thickness, elimination of excavation material hauling or handling. Stabilization of expansive soils with admixtures controls the potential of soils for a change in volume, and improves the strength of soils.

Objective of the study

1. The unconfined compressive strength of soil increased by the addition of admixtures such as bitumen emulsion.
2. Addition of bitumen emulsion with soil reduces their plastic indices significantly.
3. Specific gravity of the soil is increased when the bitumen emulsion is mixed with gravel soil.
4. The use of bitumen emulsion to stabilize uniform grained soil can create improved ground layer but also a surface base.
5. Observing its economic cost and quality of stabilization improvement, it is clear that this type of stabilization may be applicable in gravel soil road or in shoulder portion of highways.

Framework of the Study

This study has been done by taking into consideration various studies as well as tests. The experimental results are for the type of stabilizers used and test methods that have been done for experiments. therefore conclusion should be considered perfect to some extent for given applications. To determine the maximum dry density of the material modified proctor test has been conducted. But the actual goal is to increase the strength. So CBR test are conducted in different cases and conditions and make a comparative experimental study. So the methodology is how to achieve maximum bearing capacity or maximize the CBR value.

Methodology

Specific Gravity

Specific gravity of soil is very important property to understand the soil condition. Tests were done for both the gravel soil and gravel soil with bitumen emulsion at different percentages. It is noted that the gravel soil when added with emulsion at different percentages, specific gravity gets increased with increasing percentage of bitumen emulsion. This increase in specific gravity may be due to the high specific gravity of bitumen emulsion.

Table 1: Specific gravity of gravel soil and bitumen emulsion mixed soil

Sr. No	sample	Specific gravity
1	Gravel soil	2.75
2	Gravel soil + 8% bitumen emulsion	2.97
3	Gravel soil + 10% bitumen emulsion	3.02
4	Gravel soil + 12% bitumen emulsion	3.08
5	Gravel soil + 14% bitumen emulsion	3.13

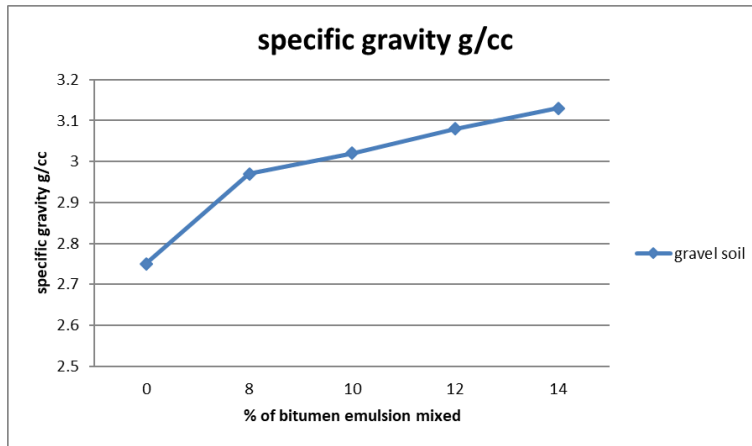


Fig 1: Specific gravity of soil sample

Liquid and plastic limit test

Liquid limit (LL), plastic limit (PL), and plasticity index (PI) of gravel soil and stabilized bitumen emulsion are evaluated. From the liquid limit and plasticity index of untreated gravel soil is found to be inorganic silts of low plasticity (ML) and stabilized gravel soil is found to be inorganic clays of high plasticity (CL) as per Indian

standard classification. It shows the plastic limit, liquid limit, plastic index of gravel soil and bitumen emulsion mixed sample results. There is an increase in the percentages of liquid and plastic limits as compared to the normal gravel soil without mixing with emulsion. Thus plasticity index also gets increased.

Table 2: Liquid limit, plastic limit, and plasticity index results

Sample	Liquid limit %	Plastic limit %	Plasticity index %
Gravel soil	29	22	7
Gravel soil + 8% bitumen emulsion	31.32	23.76	7.56
Gravel soil + 10% bitumen emulsion	31.9	24.2	7.70
Gravel soil + 12% bitumen emulsion	32.48	24.64	7.84
Gravel soil + 14% bitumen emulsion	33.06	25.08	7.98

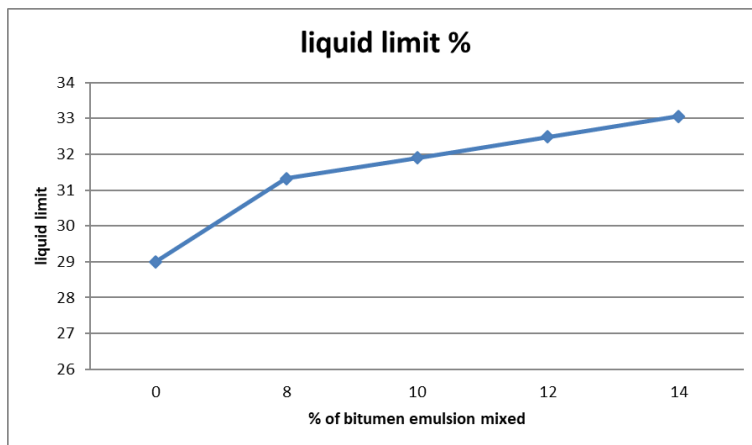


Fig 2: Liquid limit for soil sample

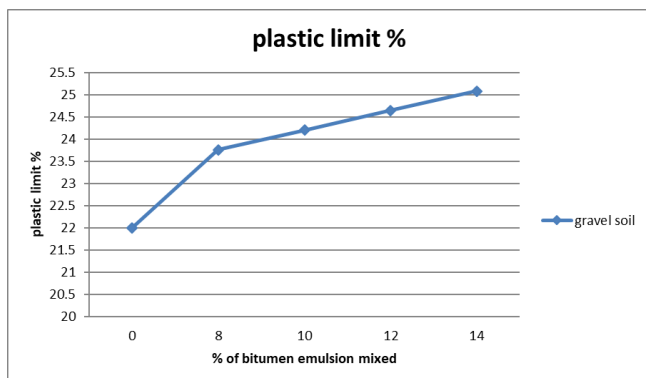


Fig 3: Plastic limit for soil sample

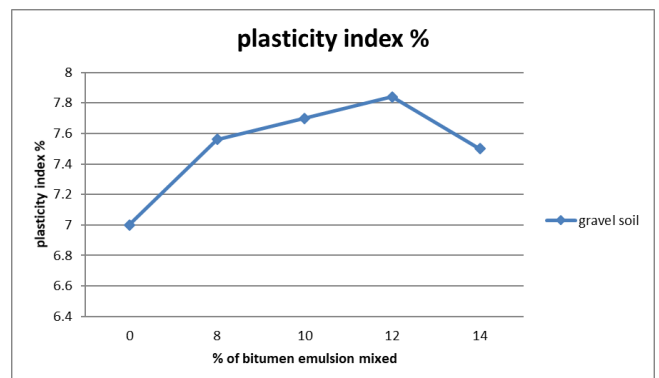


Fig 4: Plasticity index for soil sample

Compaction test

The compaction characteristics of gravel soil and bitumen emulsion mixture, showing optimum moisture content (OMC) and maximum dry density (MDD) of the compacted soils. OMC gets increased with increase in the bitumen

emulsion percentage. MDD values also gets increased with the bitumen percentage compared to the normal gravel soil. MDD is increased due to the high specific gravity of the mixture.

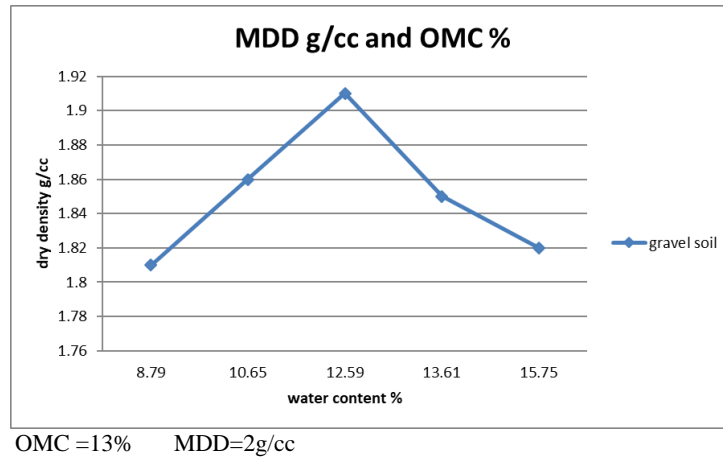


Fig 5: Compaction tests for MDD AND OMC

Table 3: OMC and MDD values of gravel soil and emulsion mixed with soil

Sr. No.	Sample	MDD g/CC	OMC%
1	Gravel soil	2	13
2	Gravel soil + 8% bitumen emulsion	2.16	14.04
3	Gravel soil + 10% bitumen emulsion	2.2	14.3
4	Gravel soil + 12% bitumen emulsion	2.24	14.56
5	Gravel soil + 14% bitumen emulsion	2.28	14.82

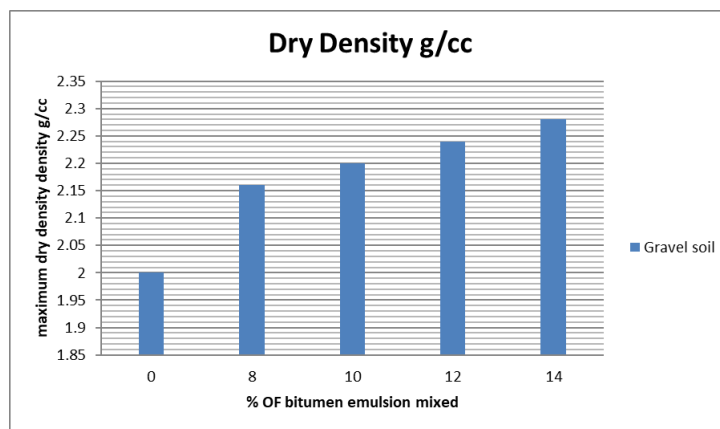


Fig 6: Variation of Maximum Dry Density value

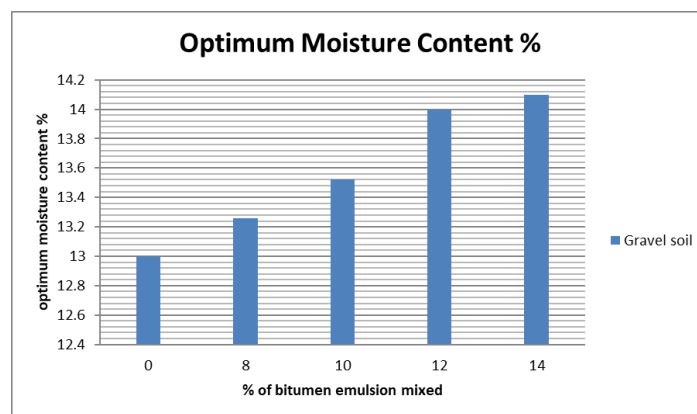


Fig 7: Variation of Optimum Moisture Content value

California bearing ratio test

The data collected for the determination of California bearing ratio of soil with different percentages of bitumen emulsion are tabulated below:

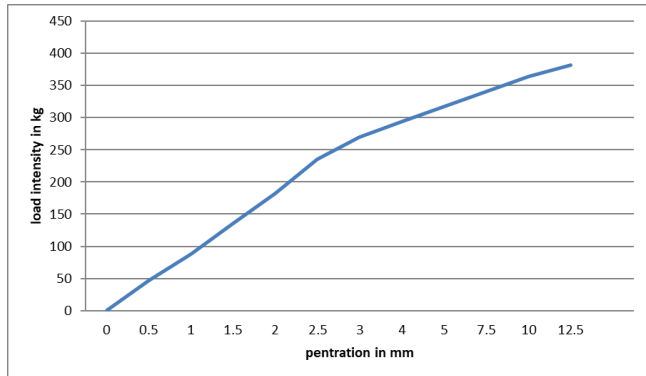
MDD g/cc = 2

OMC % = 13

Weight of original sample = 6.800 kg

Surcharge = 5kg

Soaking hours = 96hrs



CBR at 2.5mm = 17.15%

CBR at 5.0mm = 15.43%

Fig 8: plot for CBR data for normal available soil

Case A

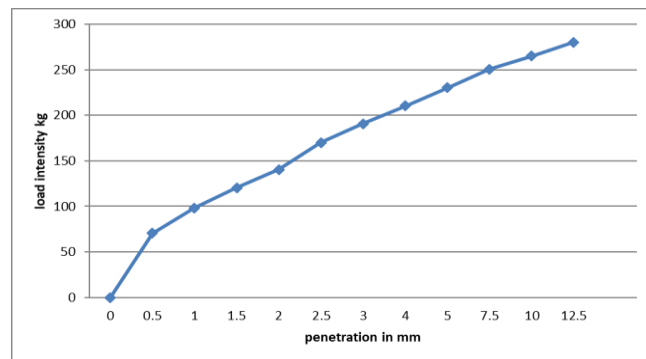
Mould size: standard volume 2250cc

Normal available soil tested with 8% of bitumen emulsion (soaked)

MDD = 2g/cc

OMC = 13%

CBR values at 2.5mm penetration and 5.0mm penetration is calculated



1. Soaked CBR value of soil with 8% B.E at 2.5mm penetration is 12.42 %

2. Soaked CBR value of soil with 8% B.E at 5.0mm penetration is 11.21%

Fig 9: Plot for CBR of soil with 8% bitumen emulsion

Case B

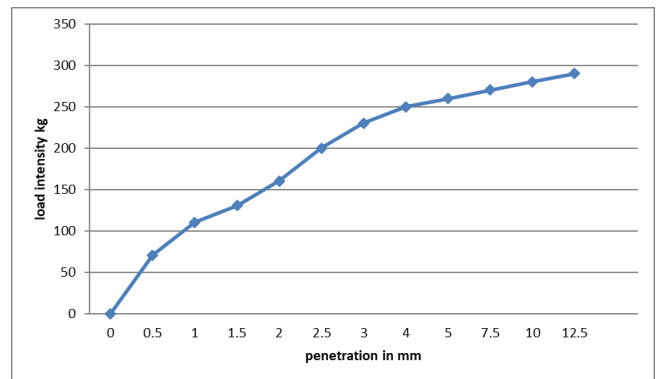
Mould size: standard volume 2250cc

Normal available soil tested with 10% of bitumen emulsion (soaked)

MDD = 2g/cc

OMC = 13%

CBR values at 2.5mm penetration and 5.0mm penetration is calculated



1. Soaked CBR value of soil with 10% B.E at 2.5mm penetration is 14.61%

2. Soaked CBR value of soil with 10% B.E at 5.0mm penetration is 12.66%

Fig 10: Plot for CBR of soil with 10% bitumen emulsion

Case C

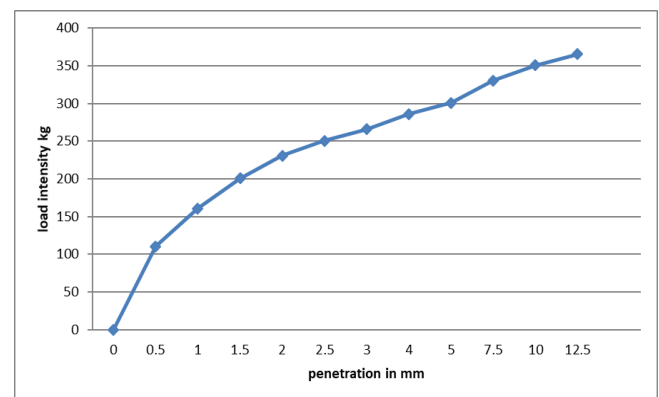
Mould size: standard volume 2250cc

Normal available soil tested with 12% of bitumen emulsion (soaked)

MDD = 2g/cc

OMC = 13%

CBR values at 2.5mm penetration and 5.0mm penetration is calculated



1. Soaked CBR value of soil with 12% B.E at 2.5mm penetration is 18.29%

2. Soaked CBR value of soil with 12% B.E at 5.0mm penetration is 14.63%

Fig 11: Plot for CBR of soil with 12% bitumen emulsion

Case C

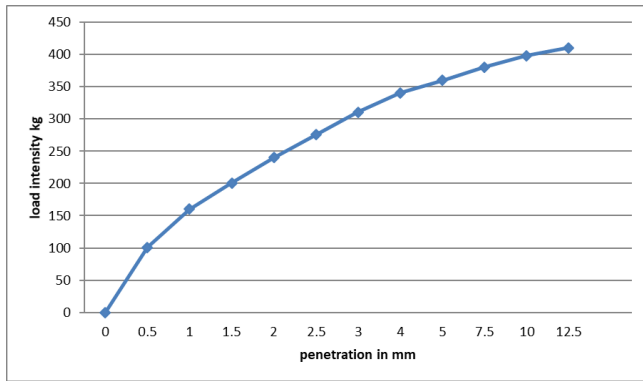
Mould size: standard volume 2250cc

Normal available soil tested with 14% of bitumen emulsion (soaked)

MDD = 2g/cc

OMC = 13%

CBR values at 2.5mm penetration and 5.0mm penetration is calculated



1. Soaked CBR value of soil with 14% B.E at 2.5mm penetration is 20.10%
2. Soaked CBR value of soil with 14% B.E at 5.0mm penetration is 17.52%

Fig 12: Plot for CBR of soil with 14% bitumen emulsion

Conclusions

Based on analysis and interpretation of experimental investigation following conclusions are drawn

1. Maximum dry density and Optimum moisture content

To study the effect of addition of bitumen emulsion in soil on MDD and OMC relationship different percentages of bitumen emulsion is added and optimised. It is interpreted that there is increase in MDD and OMC with addition of bitumen emulsion. The maximum dry density is occurred at 13% optimum moisture content from compaction test.

2. California bearing ratio (soaked)

1. The addition of 8% bitumen emulsion gives CBR values as 12.42% and 11.21% for soaked tests at 2.5mm and 5.0mm penetration respectively.
2. The addition of 10% bitumen emulsion gives CBR values as 14.61% and 12.66% for soaked tests at 2.5mm and 5.0mm penetration respectively.
3. The addition of 12% bitumen emulsion gives CBR values as 18.29% and 14.63% for soaked tests at 2.5mm and 5.0mm penetration respectively.
4. The addition of 14% bitumen emulsion gives CBR values as 20.10% and 17.52% for soaked tests at 2.5mm and 5.0mm penetration respectively.

The best results are obtained when the soil is left for soaking after mixing with bitumen. The soaked CBR values of soil samples increases considerably with addition of bitumen emulsion as compared to the normal soil.

The stabilization of gravel soil with bitumen emulsion gives better strength to subgrade soil in pavement design.

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