Experimental Study on Stabilization of Expansive Soil Using Steel Slag and Bitumen Emulsion

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ABSTRACT: *Starting from the base, soil is one of natural most construction material. Almost all type of construction is built with or upon the soil. The most important part of a road pavement is subgrade soil and its strength. If strength of soil is poor, then stabilization is normally needed. Subgrade is sometimes stabilized or replaced with stronger soil material so as to improve the strength. Such stabilization is also suitable when the available subgrade is made up of weak soil. Increase in sub grade strength may lead to economy in the structural thicknesses of a pavement. The main objective of this experimental study is to improve the properties of the expansive soil by adding steel slag, bitumen emulsion. An attempt has been made to use steel slag, bitumen emulsion for improving the strength of expansive soil expressed in terms of CBR values which may prove to be economical. In this study, the whole laboratory work revolves around the basic properties of soil and its strength in terms of CBR. It is observed that excellent soil strength results by using steel slag (SS) as well as bitumen emulsion (BE). In this project the strength of soil is increased by adding steel slag, bitumen and both steel slag and bitumen emulsion instead of replacing with stronger soil. The initial strength of the soil is determined by conducting soil tests such as specific gravity, plastic limit, liquid limit, standard proctor compaction test, unconfined compressive strength and California bearing ratio tests. The steel slag used in two sizes less than 4.75mm and size between 4.75mm to 10mm which is known as Steel Slag type A and B. The results obtained are then compared with the soil treated with 5%, 10%, 15%, 20% and 25% of steel slag. Also the results obtained are then compared with the soil treated with 2.5%, 5%, 7.5%, 10%, 12.5% of bitumen emulsion. Further the optimum percentage of steel slag of both types and bitumen emulsion is mixed with soil together with different combination.*

Keywords: Bitumen Emulsion, CBR, Expansive Soil, Steel slag, SPT, Unconfined Compressive Strength

1. INTRODUCTION

Nearly 51.8 million hectares of land area in India are covered with Expansive soil (mainly Black Cotton soil). The property of these expansive soils, in general, is that they are very hard when in dry state, but they lose all of their strength when in wet state. In light of this property of expansive soils, these soils pose problems worldwide that serve as challenge to overcome for the Geotechnical engineers. Starting from the base, soil is a standout amongst the most abundant construction materials of nature. Just about all kind of construction is based with or upon the soil. Long term performance of pavement structures is altogether affected by the strength and durability of the subgrade soils. Presently every road construction project will use one or both of these stabilization strategies. The most well-known type of mechanical soil stabilization is compaction of the soil,

ISBN : 978-93-87793-89-7

while the addition of cement, lime, bituminous or alternate executors is alluded to as a synthetic or added substance strategy for stabilization of soil. American Association of State Highway and Transportation Officials (AASHTO) classification system is a soil classification system specially designed for the construction of roads and highways used by transportation engineers. The system uses the grain-size distribution and Atterberg limits, such as Liquid Limits and Plasticity Index to classify the soil properties. There are different types of additives available. Not all additives work for all soil types. Generally, an additive may be used to act as a binder, after the effect of moisture, increase the soil density. Following are some most widely used additives. In countries with large population like India, it is a challenge to lay road networks of thousands of kilometers. Hence searching for economical methods of road construction is necessary. One of such desirable idea is to partially replace soil with locally abundant materials so that soil cost may reduce. The construction cost can considerably decreased by partially replacing local materials in soil at lower layers of road pavements like sub-base course. Disposal of waste materials from industries is resulting in direct or indirect pollution on environment. Engineering use of such wastes like steel slag is always an acceptable criteria.

The Indian Road Congress encodes the accurate outline methodologies of the pavement layers based upon the subgrade quality. Subgrade quality is generally communicated as far as CBR. That is the California Bearing Ratio communicated in rate. Consequently, in all, the pavement and the subgrade together must sustain the activity volume. In this project locally available black cotton soil type is taken as experimenting material. Medium setting bitumen emulsion and the steel slag used in two sizes less than 4.75mm and size between 4.75mm to 10mm which is known as Steel Slag type A and B is used as stabilizing agent in this particular study. Bitumen emulsion stabilization is an effective process as bitumen makes soil stronger and improves resistance capacity against water and frost. Actually bitumen is a very effective agent for stabilization but for soil stabilization it is being costly. This experiment study deals with some specific tests like Modified Compaction Test, CBR Test and the main objective is to optimize the strength of soil or improve the dry density property. In this project also attempt was made to maximize optimizing stability changing the mixing process with bitumen emulsion as well as steel slag. Partial replacement of expansive soil by bitumen emulsion and steel slag is the solution for problems mentioned above. In this research work, expansive soil is replaced with bitumen emulsion 3%, 6%, 9%, 12%, 15%, and steel slag at 5%,10%,15%, 20%, 25% and 30%. Then finally both bitumen emulsion and steel slag is used together with optimum percentage. All the key geo-technical tests like plastic limit, liquid limit, standard proctor and California bearing tests and unconfined compressive strength were conducted as per IS codes. The results of soil at different replacement percentages were compared to conclude the overall optimum percentage of that particular material in expansive soil.

1.1 Objective and Scope of Work

The main objective of this experimental study is to improve the properties of the expansive soil by adding bitumen emulsion and steel slag as stabilizing agent. An attempt has been made to use emulsion for improving the strength and geotechnical properties of gravel soil. Very mostly, use of use of bitumen emulsion is

ISBN : 978-93-87793-89-7

environmentally accepted. To achieve the whole project some experimental investigation is needed in laboratory. The experiments which to be conducted are Specific Gravity of the soil sample, Grain size Distribution of soil sample and liquid limit plastic limit test to identify the material and Standard Proctor test to obtain maximum dry density and optimum moisture content of soil sample, CBR test of soil sample mixing with emulsion and steel slag. So the main objective is to maximize the CBR value by checking some conditions to increase the CBR value of soil subgrade. The objectives of this study are,

1. Improvement in engineering property of locally available soil.
2. Reducing the plasticity of soil to achieve more stable soil.
3. Utilization of waste material like steel slag in road constitution.
4. Improve the properties of soil using bitumen emulsion and steel slag.
5. To improve the structural integrity of soils in roadways.
6. To reduce pavement thickness and subsequently the cost of project.
7. Utilization of land which is not adequate for road pavement.

2. LITRATURE REVIEW

Shubham Langar et al. (2018)[1] studied on Enhancement of Shear Strength of Soil Using Bitumen, in this study he disused that to improve the properties of the gravely soil by adding bitumen emulsion as stabilizing agent and little bit cement as filler. An attempt has been made to use emulsion for improving the strength and geotechnical properties of gravel soil. Very mostly, use of use of bitumen emulsion is environmentally accepted.

Olumide Moses Ogundipe(2014)[2] had proposed about strength and compaction characteristics of bitumen-stabilized granular soil. In his study, he was discussed about the investigation of the stabilization of granular soil with bitumen. The strength and compaction characteristics of the natural and stabilized granular soil were determined.

Deby Linsha et al. (2016)[3] proposed about performance evaluation of improvement of shear strength of soil using bitumen emulsion the strength of soil is increased by adding bituminous emulsion instead of replacing with stronger soil. The initial strength of the soil is determined by conducting soil tests such as sieve analysis, plastic limit, liquid limit, shrinkage limit, Modified proctor compaction test and California bearing ratio tests.

Paul et al. (2011)[4] suggested an introduction to soil stabilization in pavement taking a mixture of bitumen and well-graded gravel or crushed aggregate. After compaction it gave an exceedingly steady waterproof mass of sub base or base course quality. The fundamental system involved in asphalt stabilization of fine-grained soils is a waterproofing wonder. Soil particles or soil agglomerates were covered with asphalt that forestalls or abates the entrance of water which could regularly bring about abatement in soil quality. **Martin et al. (2009)**[5] 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.

Yuehuan et al. (2010)[6] He 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.

Satyendra kumar verma (2015)[7] directed a test research on a laboratory study on use of bitumen emulsion in black soil. The whole laboratory work revolves around the basic properties of soil and its strength in terms of CBR. A little cement added to provide better soil strength.

Shashank, et al (2017)[8] studied on application of steel slag as an effective construction material in pavements. He was found that, the powdered steel slag acts as a good binding material in the pavements. The steel slag is replacing the aggregates for about 20-30%, hence this makes the construction as an economical construction.

Chippada Srinivas (2017)[9] carried out an excellent work to establish the experimental investigation on expansive soil stabilization by using steel slag. He conclude that Steel slag is a by product of steel manufacturing industry which is dumped in large quantities every year. It is desirable to partially replace expansive soil with steel slag. In his research work, expansive soil is partially replaced with steel slag at different percentages. Tests like plastic limit, liquid limit, standard proctor and California bearing ratio have been conducted to derive such optimum percentage of steel slag in expansive soil.

Saurabh Kumar et al. (2016)[10] concentrated on the stabilization of clayey soil using steel slag. In his project, strength characteristics of clayey soil with steel slag have been studied. With the addition of slag percentage in the soil the maximum dry density in increasing order and the optimum moisture content start decreasing at both slag passed through 180 μ and 300 μ sieves.

Dr. B. M. Patil (2018)[11] directed a test research on effect of steel slag on CBR value of black cotton soil. The evaluate effect of addition of steel slag with various percentages to stabilize the black cotton soil and to verify its suitability to be used as a construction material for road, embankment and structural fills.

3. SYSTEM DEVELOPMENT

3.1 Sample Collection

3.1.1 Black Cotton Soil

The black cotton soil used in the present study is locally available soil taken from near Everrest Engineering College, Jatwada Road, Aurangabad. The material was excavated from 1m below the ground surface. Soil is the principal material for the construction of embankment and subgrade of highways. The design and performance of the pavement, particularly the flexible pavement, depends on the type of subgrade soil and its properties. Some of the essential laboratory tests were carried out to determine the engineering properties

ISBN : 978-93-87793-89-7

i.e. index properties, atterbarge limits and strength characteristics of the soils. Laboratory tests were carried out as per relevant IS codes.

Table No.1 Properties of Soil

Sr. No.	Properties	Value
1	Specific Gravity	2.42
2	Maximum Dry Density (MDD)	1.5 gm/cc
3	Optimum Moisture Content (OMC)	18.82%
4	Liquid Limit (LL)	48%
5	Plastic Limit (PL)	25.64%
6	Plasticity Index (Ip)	22.36
7	CBR (UnSoak)	3.85
8	CBR (Soak)	1.85
9	Unconfined Compressive Strength	1.052 Kg/cm^2
10	IS Classification	Inorganic clay soil

3.1.2 Steel Slag

Steel slag, a by-product of steel making, is produced during the separation of the molten steel from impurities in steel-making furnaces. The slag occurs as a molten liquid melt and is a complex solution of silicates and oxides that solidifies upon cooling. Virtually all steel is now made in integrated steel plants using a version of the basic oxygen process or in specialty steel plants (mini-mills) are using an electric arc furnace process. In present project work the steel slag is used in two types according to their size. First type is steel stag which is passing through 4.75 mm IS sieve which is known as Steel Slag Type A. The second type is Steel slag which is passing through 10 mm IS sieve and retained on 4.75 mm IS sieve which is known as Steel slag Type B. The steel slag is used for experiment in 5%, 10%, 15%, 20%, etc. with soil.

3.1.3 Bitumen emulsion

Bitumen emulsion is a mixture of fine droplets of bitumen and water. But as the bitumen is a petroleum product it doesn't mix with water and as it is sticky in nature, it doesn't easily gets disintegrated into fine droplets. To overcome this problem an emulsifier is used. Emulsifier can be defined as a surface-active agent. Emulsifier keeps the bitumen in its fine droplet state by disallowing it to mix with other droplets. As the droplets are very fine they suspend in water. In this present study the thinner is used as emulsifier. The bitumen emulsion is used for experiment in 2.5%, 5%, 7.5%, 10%, etc. with soil.

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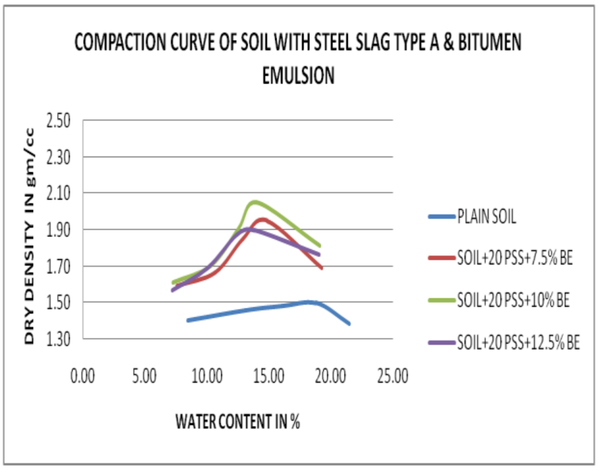
4. PERFORMANCE ANALYSIS

4.1 Compaction Test

The standard proctor test is carried out on plain soil, plain soil and steel slag type A(PSS) i.e. steel slag passing through 4.75mm IS sieve, Plain soil and Steel Slag type B (RSS) i.e. steel slag passing through 10mm IS sieve and retained on 4.75 mm Is Sieve, bitumen Emulsion (BE). The focus on the combination of both steel slag and bitumen emulsion with different percentage



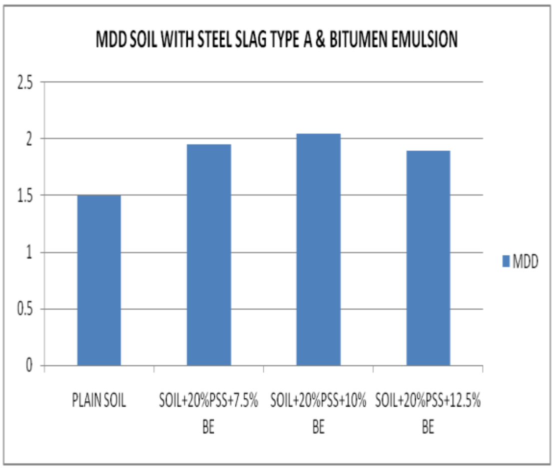
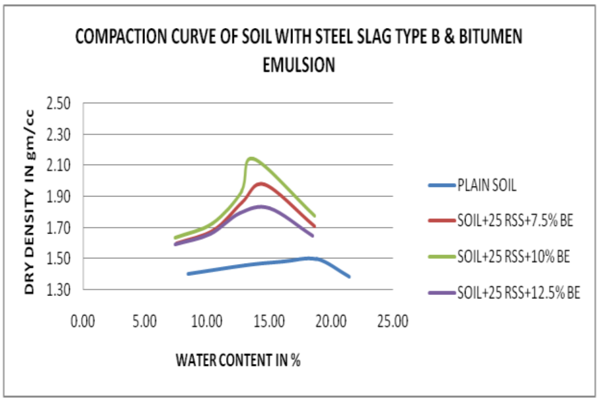


Fig. 1 Compaction curve with SS type A + BE **Fig. 2 MDD with SS type A + BE**

Above Fig.1 shows the compaction curve of plain soil and soil with different combination of steel slag type A and bitumen emulsion. Fig. 2 shows variation of dry density of soil with different combination of steel slag type A and bitumen emulsion



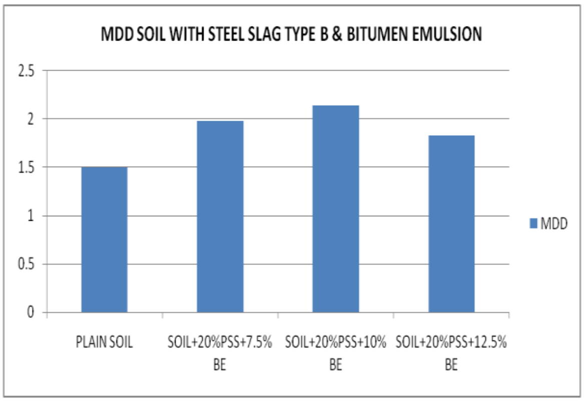


Fig. 3 Compaction curve with SS type B + BE **Fig. 4 MDD with SS type B + BE**

Above Fig.3 shows the compaction curve of plain soil and soil with different combination of steel slag type B and bitumen emulsion. Fig. 4 shows variation of dry density of soil with different combination of steel slag type B and bitumen emulsion.

4.2 CBR Test

The CBR is the measure of resistance of a material to penetration of a standard plunger under controlled density and moisture conditions. This is an extremely normal test to comprehend the subgrade strength before

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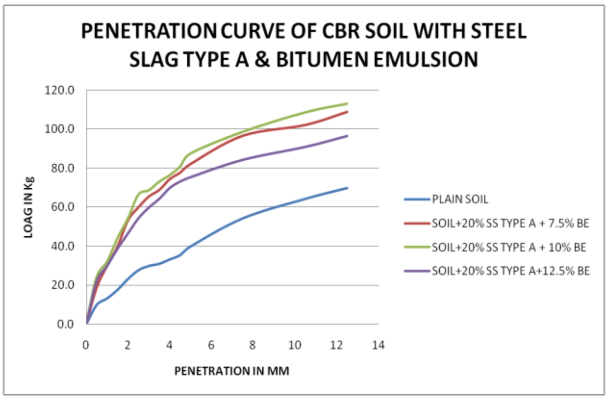
construction of roadways. The test has been broadly researched for the field connection of flexible pavement thickness necessity. Fundamentally testing is carried out taking after IS: 2720.



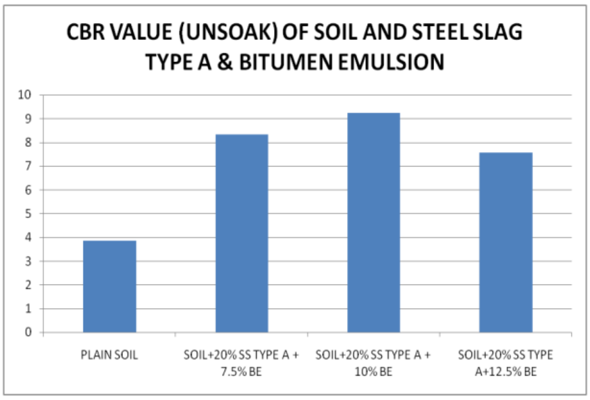
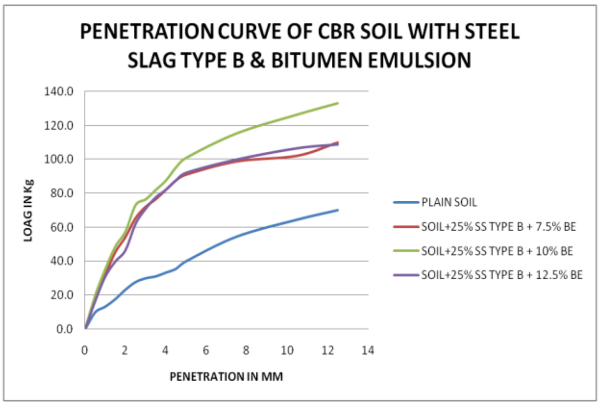


Fig. 5 penetration curve with SS type A + BE **Fig. 6 CBR (unsoak) with SS type A + BE**

Above Fig.5 shows the penetration curve of plain soil and soil with different combination of steel slag type A and bitumen emulsion. Fig. 6 shows variation of CBR (Unsoak) value of soil with different combination of steel slag type A and bitumen emulsion.



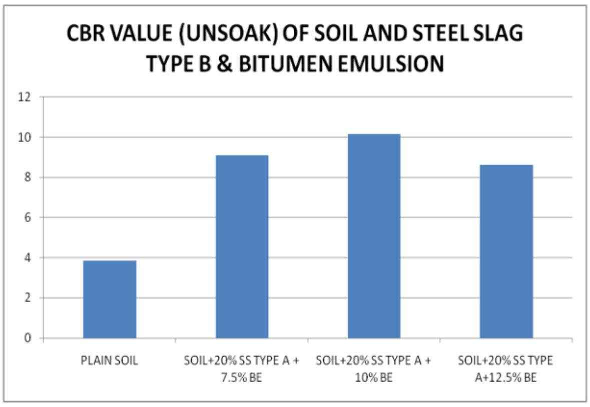
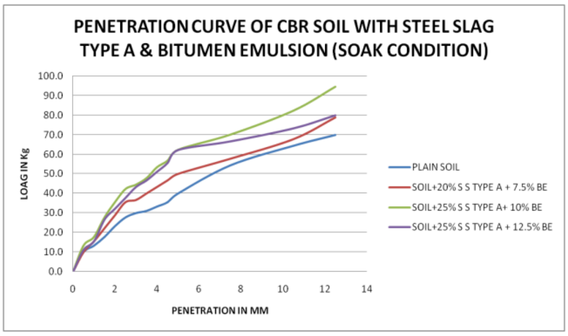


Fig. 7 penetration curve with SS type B + BE **Fig. 8 CBR (unsoak) with SS type B + BE**

Above Fig.7 shows the penetration curve of plain soil and soil with different combination of steel slag type B and bitumen emulsion. Fig. 8 shows variation of CBR (Unsoak) value of soil with different combination of steel slag type B and bitumen emulsion.



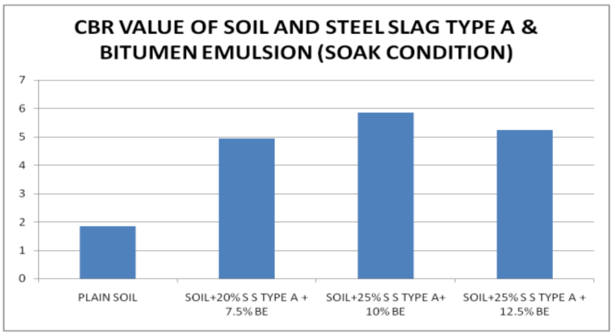


Fig. 9 penetration curve with SS type A + BE **Fig. 10 CBR (soak) with SS type A + BE**

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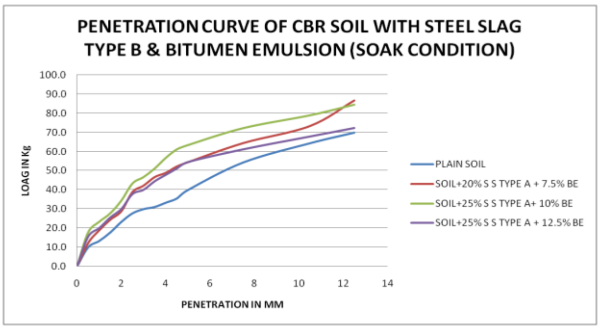
Above Fig.9 shows the penetration curve of plain soil and soil with different combination of steel slag type A and bitumen emulsion. Fig. 10 shows variation of CBR (soak) value of soil with different combination of steel slag type A and bitumen emulsion.



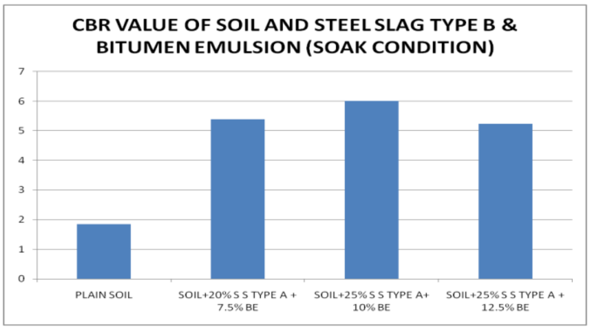


Fig. 11 penetration curve with SS type B + BE **Fig. 12 CBR (soak) with SS type B + BE**

Above Fig.11 shows the penetration curve of plain soil and soil with different combination of steel slag type B and bitumen emulsion. Fig. 12 shows variation of CBR (soak) value of soil with different combination of steel slag type B and bitumen emulsion.

4.3 Unconfined Compressive Strength

The compressive strength of original soil first calculated. With varying percentage of steel slag Type A and Type B, bitumen emulsion mix with soil the compressive strength of soil is calculated. After finding optimum percentage of both steel slag and bitumen emulsion different combination of both is used for calculation of unconfined compressive strength of soil.

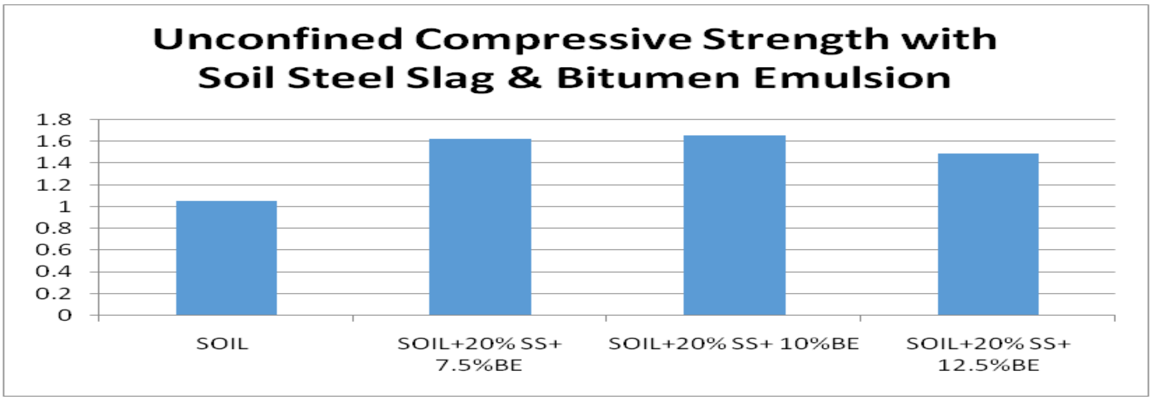


Fig. 13 Compressive Strength of Soil + Steel Slag + Bitumen Emulsion

The following table shows the calculated test result of soil with different combination of material

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Table No. 2 Test Result of Soil With Material

Sr. No.	Material	Tests				
		MDD (gm/cc)	OMC (%)	CBR(Unsoak)	CBR (Soak)	UCS (kg/cm^2)
1	Soil	1.50	18.82	3.85	1.85	1.052
2	Soil + 20% SSA + 7.5% BE	1.95	14.86	8.32	4.93	1.624
3	Soil + 20% SSA + 10% BE	2.05	14.00	9.24	5.85	1.661
4	Soil + 20% SSA + 12..5% BE	1.90	13.84	7.55	5,24	1.490
5	Soil + 25% SSB + 7.5% BE	1.98	14.63	9.09	5.39	-
6	Soil + 25% SSB + 10% BE	2.14	13.77	10.17	6.01	-
7	Soil + 25% SSB + 12.5% BE	1.83	13.05	8.62	5.24	-

4.4 Flexible Pavement Design as per IRC-37-2001 Traffic Count Survey

The Calculation of vehicles is done with the traffic data and axle load survey as per IRC 37:2001. The design procedure given by IRC makes use of the CBR value, million standard axle concept, and vehicle damage factor. Traffic distribution along the lanes is taken into account. The design is meant for design traffic which is arrived at using a growth rate. Flexible pavements are considered to include the pavements which have bituminous surfacing and granular base and sub-base courses conforming to IRC/ MOST standards. These guidelines apply to new pavements.

1 Design Traffic

The design traffic is considered in terms of cumulative number of standard axles (in the lane carrying maximum traffic) to be carried during the design life of pavement using **N = {365×[(1+r)^n-1]/r}×{A×D×F) }**

The cumulative number of standard axles to be catered for in the design life in terms of msa**,** A= Initial traffic in the year of completion of construction in terms of the number of commercial vehicles per day

D= Lane distribution factor, F= Vehicle damage factor, n= Design life in years, r= Annual growth rate of commercial vehicles.

The traffic in the year of completion is estimated using

A = P (1+r)^x

P= Number of commercial vehicles as per last count, x= Number of years between the last count and the year of completion of construction

2. Traffic growth rate

Traffic growth rates should be estimated by studying the past trends of traffic growth, and by establishing econometric models, as per the procedure outlined in IRC:108 “Guidelines for traffic prediction on rural

ISBN : 978-93-87793-89-7

highways". If adequate data is not available, it is recommended that an average annual growth rate of 7.5 percent may be adopted.

3. Design Life

For the design of pavement, the design life is defined in terms of the cumulative number of standard axles that can be carried before strengthening of pavement is necessary. It is recommended that pavements for National Highways (NH) and State Highways (SH) should be design for a life of 15 years. Expressways and Urban roads nay be designed for a longer life of 20 years. For other categories of roads, a design life of 10 to 15 years may be adopted.

4. Vehicle Damage Factor

Sufficient information on axle loads is not available and project does not warrant conducting an axle load survey, the indicative values of vehicle damage factor as given below may be used.

Table No. 3 Indicative VDF Values (Table 1 of IRC:37-2001)

Initial traffic volume (CVPD)	Terrain	
	Rolling/Plain	Hilly
0-150	1.5	0.5
150-1500	3.5	1.5
More than 1500	4.5	2.5

5. Design Charts and Catalogue

Based on the performance of existing designs and using analytical approach, simple design charts (Figure 2.13 and 2.14) and a catalogue of pavement designs are added in the code. The pavement designs are given for subgrade CBR values ranging from 2% to 10% and design traffic ranging from 1 msa to 150 msa for an average annual pavement temperature of 35 C. The later thicknesses obtained from the analysis have been slightly modified to adapt the designs to stage construction. Using the following simple input parameters, appropriate designs could be chosen for the given traffic and soil strength

- Design traffic in terms of cumulative number of standard axles; and
- CBR value of subgrade.

The designs relate to ten levels of design traffic 1, 2, 3, 4, 5, 10, 20, 30, 50, 100 and 150 msa. For intermediate traffic ranges, the pavement layer thickness may be interpolated linearly. For traffic exceeding 150 msa, the pavement design appropriate to 150 msa may be chosen and further strengthening carried out to extend the life at appropriate time based on pavement deflection measurements as per IRC : 81.

Available Data:

1. Design of CBR of Subgrade Soil : 2% 2. Design Life of Pavement (n): 15 years

3. Annual Growth rate (r): 7.5 % 4. Distribution of Commercial vehicle for Single Lane (D): 0.75 (Double Lane) 5. No. of years between the last count and the year of completion of construction (x)= 1

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5. Design Calculation of Pavement thickness:

1. Commercial Vehicle at last count "P" =350 CV/Day

$A=P(1+r)^x = 376.2$

2. N = The cumulative no. of standard axles to be catered for in the design in terms of msa.

N= 9.413 (say 10).

Total thickness of pavement for design CBR 2% and Design traffic = design traffic 10 msa of IRC37, 2001 Total Thickness = 860 mm.

3. Total thickness to be provided = 860 mm

4. Pavement composition interpolated as per MORT&H (IRC37-2001 page 28 plate 1)

(a) Granular Sub-base = 470 mm, (b) Base course (wmm) = 250 mm, (c) Binder Course (DBM) = 100 mm

(d) Wearing Course (BC) = 40 mm

Similarly the thickness of different material with soil can be calculated as below,

Table No. 4 Total Thickness of Pavement with Different Material

Sr. No.	Material	Design CBR (%)	Total Pavement Thickness (mm)	Wearing Course (mm)	Binder Course (mm)	Granular Base (mm)	Granular Sub-base (mm)
1	Soil	1.85	860	40	100	250	470
2	Soil + 20% SSA + 10% BE	5.85	620	40	70	250	260
3	Soil + 25% SSB + 10% BE	6.01	610	40	65	250	255

RESULT AND DISCUSSION

The strength and compaction properties of black cotton soil stabilized with steel slag and bitumen emulsion were investigated. From this study it is clear that there is a considerable improvement in maximum dry density, California Bearing Ratio (CBR) and unconfined compressive strength of black cotton soil due to use of steel slag and bitumen emulsion if proper mixing is done.

The dry density of plain soil is 1.5 gm/cc and optimum moisture content is 18.82%. After the mixing of steel slag and bitumen emulsion the MDD increase and OMC decreases. The optimum percentage of mixing is 20% steel slag type A and 10% bitumen emulsion, the MDD increases upto 2.05gm/cc with decrease in OMC upto 14%. Similarly the optimum percentage of mixing is 25% steel slag type B and 10% bitumen emulsion, the MDD increases upto 2.14gm/cc with decrease in OMC upto 13.77%.

The CBR value of plain soil is 3.85 in Unsoak condition and 1.85 in soak condition. With addition of steel slag and bitumen emulsion the CBR value of soil increase. At optimum percentage of 20% steel slag type A and 10% bitumen emulsion the CBR value is 9.24% at Unsoak Condition and 5.85% in soak condition. Similarly At

ISBN : 978-93-87793-89-7

optimum percentage of 25% steel slag type B and 10% bitumen emulsion the CBR value is 10.17% at Unsoak Condition and 5.24% in soak condition.

The unconfined compressive strength of plain soil is 1.0252 kg/cm^2. With addition of steel slag and bitumen emulsion the unconfined compressive strength is increases. At optimum percentage of 20% steel slag type A and 10% bitumen emulsion the unconfined compressive strength is 1.661 kg/cm^2.

If we design pavement by using original plain soil the total thickness of pavement is 860 mm. whereas by using stabilized soil the total thickness of pavement is 620mm and 610mm for steel slag type A and bitumen emulsion, steel slag type B and bitumen emulsion respectively. Hence cost of construction of pavement will be minimised.

5. CONCLUSION

On the basis of experimental study, the following conclusion can be drawn,

- Steel Slag can be effectively mixed in Expansive type of soils to improve engineering properties. The powdered steel slag acts as a good binding material in the pavements.
- By using bitumen emulsion with steel slag the CBR value of soil can be increase in greater quantity, hence the thickness of pavement can be reduced.
- By reducing the thickness of pavement the quantity of material is also reduced. Hence the const of material is minimised and indirectly cost of construction is minimum. Also steel slag is a waste product of the major industries it can be obtained for lower cost.

6.1 Scope of Further Studies

We know a major problem associated with socio-economic development of a country is waste disposal. Safer disposal of Industrial waste has become a challenging job. Improving properties of soil become an important matter today. There are many alternatives available in doing the same. Here are some suggestions made for further studies using steel slag and bitumen emulsion.

1) Steel Slag size and percentage of bitumen emulsion can be made varying in results.

2) Other type of soil can be used for further studies.

3) Different waste material from agricultural land, municipality or industrial can be used to improve the soil characteristics.

7. ACKNOWLEDGEMENT

It was great experience for me to be associated with **Dr. S. S. KORANNE** Associate Professor in Civil Engineering Department, my Seminar guide during this work. I would like to express our deep gratitude to him for his valuable guidance, encouragement and moral support. Here I take an opportunity to convey my sincere thanks to Head of Department **Dr. R. M. DAMGIR** to support me. **Dr. P. B. MURNAL** Principal, Government College of Engineering, has been indeed a great source of inspiration for all of us in the campus, so it gives me an immense pleasure in expressing my indebtedness to him for his kindness and moral support. Finally, I would like to express my deep, incomparable appreciation and gratitude to my family for giving constant spiritual support and encouragement to pursue the higher technical education.

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