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Soil Stabilisation Using Ground Granulated Blast Furnace Slag

Ashish Kumar Pathak[1], Dr. V. Pandey[2], Krishna Murari[3]. J.P.Singh[3]
[1]Asst. Prof, Dept of civil engineering, NSIT Bihta, Patna (India).
[2]HOD, Dept of civil engineering, B.I.T Sindri, Dhanbad (India).
[3]Asst. Prof, Dept of civil engineering, B.I.T Sindri, Dhanbad (India).

ABSTRACT
Stabilisation is a broad sense for the various methods employed and modifying the properties of a soil to improve its engineering performance and used for a variety of engineering works. In today's day soil stabilisation is the major problem for civil engineers, either for construction of road and also for increasing the strength or stability of soil and reduces the construction cost.
In this thesis the soil are stabilised by ground granulated blast furnace slag (GGBS) and this material is obtained from the blast furnace of cement plant, which is the byproduct of iron (from ACC plant, sindri). It is generally obtained in three shaped one is air cooled, foamed shaped and another is in granulated shaped. The use of by-product materials for stabilisation has environmental and economic benefits. Ground granulated blast furnace slag (GGBS) material is used in the current work to stabilise soil (clay). The main objectives of this research were to investigate the effect of GGBS on the engineering property (optimum moisture content and maximum dry density, plastic limit, liquid limit, compaction, unconfined compressive strength, triaxial and California bearing ratio test) of the soil and determine the engineering properties of the stabilised.
Granulated shaped blast furnace slag is most suitable for increasing the strength of the soil and for this we check the following property of soil. GGBS are added from 0% to 25% by dry weight of soil, first of all check the all soil property at 0 % (no GGBS) and then compare after addition of GGBS from 5% to 25%.
The investigations showed that generally the engineering properties which improved with the addition of GGBS. The addition of GGBS resulted in a dramatic improvement within the test ranges covered in the programme. The maximum dry density increased and the optimum moisture content decreased with increasing GGBS content and at 25% we got the maximum value of dry density.
Keywords: Soil Stabilisation, GGBS, Mohr circle, Unconfined compression test, CBR test.

I. INTRODUCTION

1.1 General

Economic development of any country is controlled to a great extent by the highway and airport networks. This is becoming particularly apparent in the developing countries, where tremendous lengths of roads need to be constructed in order to facilitate the development of agriculture, commerce and industry. The cost of any road pavement project includes initial costs and subsequent maintenance costs. The initial costs include many items such as land, accommodation works, bridges and subways, drainage, pavement construction etc. The type and the thickness of the pavement construction determine a large percentage of the initial cost of any road project. Therefore, the development and use of methods to decrease the cost of pavement construction is very beneficial. It is essential to take into consideration the conditions of the sub grade soil before designing the type and the thickness of the pavement, as the sub grade carries the traffic loads as well as the pavement loads. The major function of the pavement is to reduce stresses in the sub grades so that there is little or no deformation in the sub grade. Therefore, the more the sub grade is resistant to deformation the thinner the pavement will be, thus reducing the construction cost of the road.

Good qualities of sub grade soils are preferable for durable road but not always available for highway construction. The highway engineer designing a road pavement may be faced by weak or unsuitable sub grade. In this case the following methods to overcome this problem can be considered. First improve in-situ materials by normal compaction methods and design for the modified properties.
Second, import the suitable materials from the nearest convenient source and replace the site materials. Third, improve the properties of the existing materials by incorporating some other materials; this process is known as "soil stabilisation".

The most appropriate method will usually be determined by economic considerations, for example it may be cheaper to stabilise a soil using relatively expensive additives rather than excavate and dispose of unsuitable materials and place suitable fill, as well as the properties of the sub grade.

1.2 Soil Stabilisation

Soil stabilisation in its general meaning considers every physical and chemical method employed to make a soil suitable for its required engineering purpose. In its specific meaning in road engineering, soil stabilisation is a process to improve the soil strength by using additives in order to use as a base or sub base courses and carry the expected traffic and pavement loads.

1.3 Types of Stabilisation

There are different types of stabilisation, each having its own benefits and potential problems. The types described below are those most frequently used.

1.3.1 Mechanical Stabilisation:-

The most basic form of mechanical stabilisation is compaction, which increases the performance of a natural material. The benefits of compaction however are well understood and so they will not be discussed further in this report. Mechanical stabilisation of a material is usually achieved by adding a different material in order to improve the grading or decrease the plasticity of the original material. The physical properties of the original material will be changed, but no chemical reaction is involved. For example, a material rich in fines could be added to a material deficient in fines and in order to produce a material nearer to an ideal particle size distribution curve. This will allow the level of density achieved by compaction to be increased and hence improve the stability of the material under traffic. The proportion of material added is usually from 10 to 50 per cent. Mechanical stabilisation is usually the most cost-effective process for improving poorly-graded materials. This process is usually used to increase the strength of poorly-graded granular material up to the well-graded granular material. The stiffness and strength will generally be lower than that achieved by chemical stabilisation and would often be insufficient for heavy traffic pavements. It may also be necessary to add a stabilising agent to improve the Final properties of the mixed material.

1.3.2 Cement Stabilisation:-

Any cement can be used for stabilisation, but Ordinary Portland cement is the most widely used throughout the world. The addition of cement material, in the presence of moisture, produces hydrated calcium aluminate and silicate gels, which crystallize and bond the material particles together. Most of the strength of a cement-stabilized material comes from the hydrated cement. A chemical reaction also takes place between the material and lime, which is released as the cement hydrates leading to a further increase in strength. Granular materials can be improved by the addition of a small proportion of Portland cement, generally less that 10 per cent. The addition of more than 15 per cent cement usually results in conventional concrete. In general the strength of the material will steadily increase with a rise in the cement content.

There are three main types of cement stabilised materials:-

(a) **Soil Cement**

Soil cement usually contains less than 5 per cent cement. It can be either mixed in-situ (usually up to 300mm layer at a time) or mixed in plant. The technique involves breaking the soil sample and mixing in the cement, then adding water and compacting in the usual way. In (1998) croney recommends that a minimum strength should be 2.5 Mpa (7 days cube crushing strength) or, if this material is used to replace the sub-base then strength requirement should be increased to 4 MPa.

(b) **Cement bound granular Material (CBM)**

This can be regarded as a stronger form of soil-cement which uses granular aggregate (crushed rock or natural gravel) rather than a soil. The process works best if the natural granular material has limited fines content. This is always mixed in plant and the strength requirement is 5-7 MPa (7 days cube crushing strength).

(c) **Lean concrete**

This material has low cement content and hence looks and behaves as concrete of a CBM. It is usually made from batched coarse and fine crushed aggregate, but natural washed aggregate (e.g. river gravels) can also be used.

1.3.3 Lime Stabilisation:-

The stabilisation of pavement materials is not new, with examples of lime stabilisation being recorded in the construction of early Roman roads. However, the invention of Portland cement in the 19th Century resulted in cement replacing lime as the main type of stabiliser. Lime stabilisation will only be effective with materials which contain enough clay for a positive reaction to take place. Lime is produced from chalk or limestone by heating and combining with water. The term ‘lime’ is broad and covers the following three main types:

a) Quicklime i.e. calcium oxide (CaO),
b) Slaked or hydrated lime, i.e. calcium hydroxide $Ca(OH)_2$ and
c) Carbonate of lime, i.e. calcium carbonate ($CaCO_3$).

Only quicklime and hydrated lime are used as stabilisers in road construction. They are usually added in solid form but can also be mixed with water and applied as slurry. It must be noted that there is a violent reaction between quicklime and water and consequently operatives exposed to quicklime can experience several external and internal burns, as well as blinding.

Hydrated lime is used extensively for the stabilisation of soil, especially soil with a high clay content where its main advantage is in raising the plastic limit of the clayey soil. Very rapid stabilisation of water-logged sites has been achieved with the use of quicklime.

1.3.4 Bitumen or Tar stabilisation:-

Bitumen or tar are too viscous to use at ambient temperatures and must be made into either cut-back bitumen (a solution of bitumen in kerosene or diesel) or a bitumen emulsion (bitumen particles suspended in water). When the solvent evaporates or the emulsion ‘breaks’ the bitumen is deposited on the material, the bitumen merely acts as a glue to stick the material particles together and prevent the ingress of water. In many cases the bituminous material acts as an impervious layer in the pavement, preventing the rise of capillary moisture. In a country where bitumen is relatively expensive compared to cement and where most expertise is in cement construction, it appears more reasonable to use a cement stabiliser rather than a bitumen/tar based product.

1.3.5 Chemical stabilisation:-

Stabilization of moisture in soil and cementation of particles may be done by chemicals such as calcium chloride, sodium chloride etc. Although all the method is well versed for the soil stabilization but these all require money to spend. Hence to study the stabilization of soil “GROUD GRANULATED BALLAST FURNANCE SLAG (GGBS)” may be used as an admixture which is easily available. The general objectives of mixing chemical additive with soil are to improve or control volume stabilities, strength and stress-strain properties, permeability and durability. Volume stabilities namely control of swelling and shrinkage can be improved by replacement of high hydration of cations such as calcium, magnesium, aluminium or iron. It can also be improved by cementation and by water proofing chemicals. The development and maintenance of high strength and stiffness is achieved by elimination of large pores by bonding particles and aggregates together by maintenance of flocculent particle arrangement by prevention and swelling.

1.3.6 Geosynthetic stabilisation:-

Geosynthetic in general can be defined as a generic term which includes geotextiles, geomembranes, geocomposites and these material used by civil engineers to improve soil behaviour. The American society for Testing and materials has defined geosynthetics as a product manufactured from polymeric materials. Earth and any other geotechnical engineering materials is an integral part of manmade project and structures. Geosynthetics are almost exclusively manufactured from polymeric materials such as polypropylene, polyester, and polyethylene.

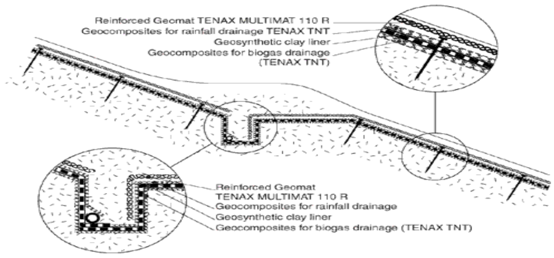

Fig: - 1. Details of geosynthetics

II. EXPERIMENTAL PROGRAM

2.1 General

To study about the soil stabilisation, soil is mixed with GGBS and their engineering properties were determined. The test procedure adopted has been presented in this chapter in details. The experimental setup and the test procedure have been planned in such a way that it takes into account all the related aspects, such as related proportion are mixed at calculated O.M.C and soil are replaced according to the proportion of GGBS.

2.2 Specific Gravity Test

The appropriate method for determining the specific gravity of the soil is the pycnometer test. Specific gravity of the soil particles is the ratio of weight of given volume of soil solids to the weight of an equal volume of water at 4°c.

i.e G = □s /□w

Specific gravity as such does not indicate the behavior of a soil mass under external load, but it is an important factor which is used in computing other soil properties. For example soil particle size determination by means of the hydrometer method .It is also used in consolidation studies of clay in calculating the degree of saturation of a soil and in other calculation.

2.3 Soil Compaction Test (standard proctor test)

There are many situations in engineering practice when the soil itself used as construction material. In the construction of engineering structure such as highway embankment or earth dams for example: - loose fills required to be compacted to increase the soil density and improving their strength characteristics in order to enhance the engineering performance of the soil compaction is must for the appropriate compaction of the soil we need to require optimum moisture content. This optimum moisture content corresponding to the max Compaction can be found by Standard Procter Compaction Test. Compaction is the densification of the soil by the application of the mechanical energy. It is the process by which the soils grains get arrange more closely, the volume of air void get reduced and the density of soil increase. For the heavier standard compaction for airfield construction the optimum moisture content corresponding to maximum compaction is derived by the Modified Procter Compaction Test.

Fig: - 2. Mixing of soil for determining the OMC and MDD

2.3.1 Test procedure:

Take approximately 10 lb. (4.5 kg) of air-dried soil in the mixing pan, break all the lumps so that it passes (4.75mm sieve) and add approx amount of water to increase the moisture content by about **5**%. Clean the mould fix it to the base and take the empty mass of mould attach the collar to the mould and inside the mould greased thoroughly. Place the first portion of the soil in the Proctor mould and compact the layer applying 25 blows. Scratch the layer with a spatula forming a grid to ensure uniformity in distribution of compaction energy to the subsequent layer. Place the second layer, apply 25 blows, place the last portion and apply 25 blows. The final layer should ensure that the compacted soil is just above the trim of the compaction mould. Detach the collar carefully without disturbing the compacted soil inside the mould and using a straight edge trim the excess soil levelling to the mould. Determine the weight of the mould with the moist soil, Extrude the sample and break it to collect the sample for water content determination preferably from the middle of the specimen. Repeat the process with increases water content by 2% until the wt. of mould is decreases.

2.4 Atterberg's limit test

Consistency is a term which used to describe the degree of fineness of a soil is in a qualitative manner by using descriptions such as soft, medium, firm, stiff or hard. It indicates the relative is with which a soil can be deformed generally the properties of consistency associated only with fine grained soil especially clay.

The engineering properties of clay are considerably influence by the amount of water present in them depending upon the water content the four stage and stages namely liquid stage, plastic stage, semi-solid stage and solid stage of the consistency are used to describe consistency of a clay soil. The boundary water content at which the soil undergoes a change from one state to another is called consistency or Atterberg's limits. In 1911 a Swedish soil scientist Atterberg's first demonstrate the significance of these limit on the basis of change of state there are mainly three consistency limit.

(a) Liquid limit test

Liquid limit is the water content of soil which changes its state from liquid to plastic state. It is defined as the minimum water content at which the soil is still in the liquid state but has small shearing strength against flowing and a part of soil cut by a groove of standard dimension will flow together for a distance of 12 mm under an impact of 25 blows in a device which is called casagrande appratus.

(b) Plastic limit test

Plastic limit is the water content corresponding to an arbitrary limit between the plastic and the semi soild states of consistency of soil. It is defined as the minimum water content at which a soil will just begin crumble when rolled into a thread approximately 3 mm in diameter.

2.5 Sieve Analysis

The sieve analysis is the true representative of grain size distribution, since the test is not affected by temperature. The complete sieve analysis can be divided into two parts coarse analysis and fine analysis the portion retained on 4.75 mm is termed as coarse analysis and passed from that is fine analysis and in this project we use for soil that means fine analysis and for that the setup is arranged as 4.75mm, 2mm, 1mm, 600,425,300,212, 150 and 75 micron is sieves.

Sieving is performed by arranging the various sieves one over another in the order of their mesh openings a large aperture is kept at top and the smallest at the bottom the soil sample is put on the top sieve, and the whole assembly is fitted on a sieve shaking machine. The amount of shaking depends upon the shape and the amount of particle at least 10 minutes of shaking is desirable for soils with small particle.

Fig: - 3. Experimental setup for sieve test

2.6 Shear strength of soil

The shear strength of soil is the resistance to deformation by continuous shear displacement of soil particles or on masses upon the action of a shear stress. Shear resistance can be determined in laboratory by the following four methods and in this project the soil property is check by two methods
(a) Triaxial shear test
(b) Unconfined compression test

2.6.1 Tri-axial test:

PREPARATION OF TEST SPECIMEN:-

Remould sample may be prepared, the soil which is passes from 4.75mm is mixed at calculated O.M.C at compacted into mould with three layers and a thin walled tube having the same internal diameter is pushed into the mould. The sample should be extruded from the tube pushing from the cutting edge side. The ends of the specimen are trimmed flat and normal to its axis the split mould should be lightly oiled from inside. The specimen is then taken out carefully from the split mould so that length and diameter are not affected. The specimen is then on one of the end caps and the other end cap is put on the top of the specimen. The rubber membrane is then placed around the specimen above and below so that water is not affect the specimen. The specimen is ready to use for the calculation of dial gauge and proving ring reading.

2.6.2 Unconfined compression test:-

PREPARATION OF TEST SPECIMEN:

Remould sample may be prepared, the soil which is passes from 4.75mm by compacting the soil at the desired water content in a mould, and then cut by the sampling tube. The split mould is oiled lightly from inside and the sample is then pushed out of the tube into the split mould and the sample is carefully taken out from the split mould. A wire saw may be used to trim the ends parallel to each other a lathe or trimmer may be used to trim the specimen to circular cross section. The sample is ready to use for the find out the parameter for unconfined compressive strength.

2.7 California bearing ratio test:

This method was originally devised by O.J.Porter of the California state highway department. The method combines a load penetration test performed in the laboratory or in situ for the determination of thickness of pavement and of its constituent layers. This is probably the most widely used method for the design of flexible pavement. The CBR test is a small scale penetration test in which a cylindrical plunger of (5cm in dia.) cross section is penetrated into a soil mass at the rate of 1.25mm/min. observation are taken between the penetration resistance (test load) versus the penetration of plunger. The penetration resistance of the plunger into a standard sample of crushed stone for the corresponding penetration is called standard load. The CBR is defined as the ratio of test load to the standard load.

The CBR test is carried out on a compacted soil in a CBR mould 150mm in diameter and 175mm in height, provide with a detachable collar of 50 mm in height and a detachable perforated base plate. The moulding dry density and water content should be the same as would be maintained during field compaction. CBR values are determined for soaked and unsoaked samples, for soaked sample specimen are kept submerged in water for about 4 days before testing. The load reading is recorded at penetration, 0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, 10.0, and 12.5mm. the CBR value are generally calculated for penetration of 2.5mm and 5.0mm, and the CBR value at 2.5mm penetration are more than that at 5.0mm penetration and in such case the former is to be taken as the CBR value for design purpose. If the CBR value 5mm exceeds than from 2.5mm the test is repeated.

Fig: - 6. Experimental setup for California bearing ratio

2.7. (A) Preparation of test specimen:

Remould specimens may be prepared at the proctors maximum dry density and optimum moisture content. The material used should be passing through 4.75mm and also mix the proportion of GGBS at which we calculate. The specimen is prepared either by dynamic compaction or static compaction, but in this project specimen is prepared by dynamic compaction.

Take 4.5 to 5 kg oven dried soil and mix with water at calculated O.M.C of the given proportion, and mix with thoroughly and placed in mould. The soil is compacted in mould in three equal layers and each layer being given 56 blows by the 2.6 kg rammer. Remove the collar and trim the excess soil. Put the filter paper on the top of the compacted soil and placed the mould on the machine, in which the filter paper is placed the bottom side. The specimen placed in such a way that the penetration needle is at centre. The instrument is start and takes the parameter of CBR through which we find the test load at 2.5mm and 5mm.

III. RESULTS AND DISCUSSION

3.1 STANDARD PROCTOR TEST

Standard Proctor tests were used to establish the dry density-moisture content relationship and carried out the test of soil with various amounts of GGBS added consider the effect of GGBS on optimum moisture content and maximum dry density the test of soil with 0 % to 25% by dry weight of soil.

Table3.1 . EFFECT OF GGBS ON OMC AND MDD

GGBS (%)	O M C (%)	M DD (gm/cc)
0	14.33	1.710
5	14.13	1.726
10	13.54	1.735
15	13.15	1.750
20	12.75	1.756
25	12.46	1.765

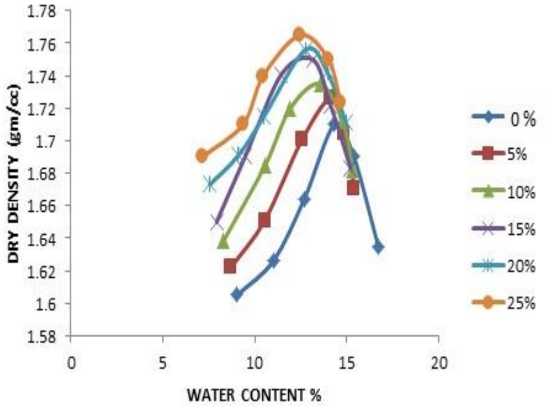

Fig: -7. OMC and MDD from 0% to 25 %

3.2 SPECIFIC GRAVITY TEST

Soil with various amounts of GGBS added to determine the effect on specific gravity of soil with 0 % to 25% by dry weight of soil.

TABLE 3.2 EFFECT OF GGBS ON SPECIFIC GRAVITYOF SOIL

GGBS (%)	SPECIFIC GRAVITY
0	2.56
5	2.58
10	2.59
15	2.60
20	2.61
25	2.63

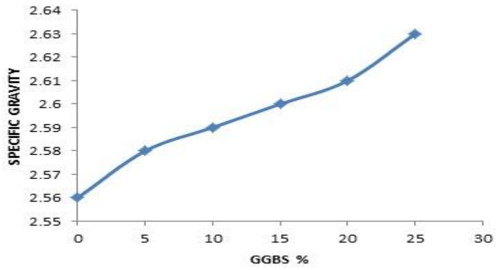

Fig: - 8. Specific gravity value (0% to 25%)

3.3 EFFECT OF GGBS ON UNCONFINED COMPRESSIVE STRENGTH

Soil with various amounts of GGBS added to determine the effect on compressive strength of soil with 0 % to 25% by dry weight of soil.

Table3.3 EFFECT OF GGBS ON COMPRESSIVE STRENGTH OF SOIL

GGBS (%)	UNCONFINED COMP. STRENGTH (kg/cm^2)
0	1.92
5	1.99
10	2.24
15	2.32
20	2.42
25	2.56

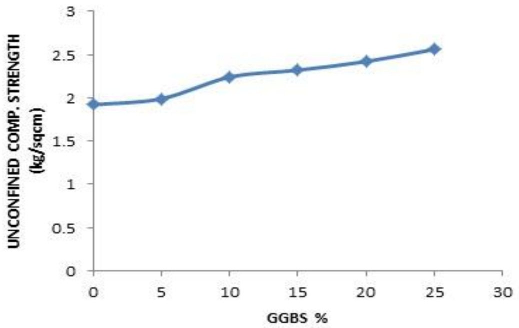

Fig: - 9. Unconfined compressive strength (0% to 25%)

3.4 TRI-AXIAL TEST

Soil with various amounts of GGBS added to determine the effect on shear parameter of soil with 0 % to 25% by dry weight of soil.

Table 3.4. EFFECT OF GGBS ON SHEAR PARAMETER OF SOIL

GGBS (%)	COHESION (C) (kg/cm^2)	ANGLE OF SHEARING RESISTANCE (Ø) IN DEGREE
0	1.45	17.26
5	1.37	18.43
10	1.30	19.23
15	1.20	20.13
20	1.10	21.03
25	1.00	21.96

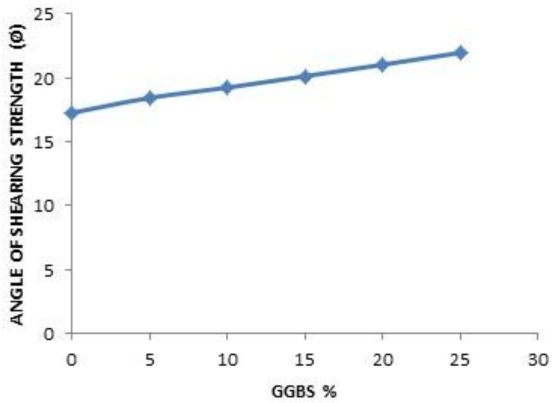

Fig: - 10. Angle of shearing resistance (0% to 25%)

3.5 CALIFORNIA BEARING RATIO TEST

Soil with various amounts of GGBS added to determine the effect on California bearing ratio test of soil with 0 % to 25% by dry weight of soil.

Table 3.5. EFFECT OF GGBS ON C B R VALUE FOR UNSOAKED SOIL

GGBS (%)	CBR IN (%) AT 2.5 (mm) PENETRATION	CBR IN (%) AT 5 (mm) PENETRATION
0	4.28	4.10
5	4.78	4.41
10	5.17	4.50
15	5.58	5.30
20	6.01	5.79
25	6.35	6.21

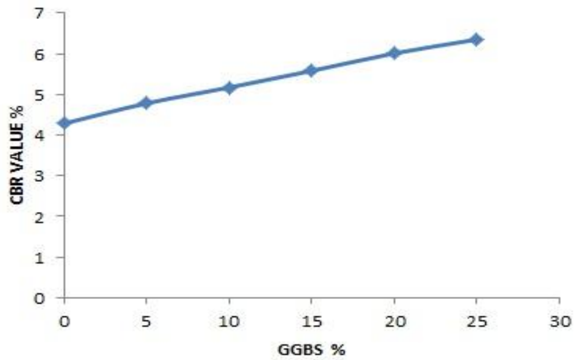

Fig: - 11. C B R value for 2.5mm Unsoaked (0% to 25%)

Table 3.6 EFFECT OF GGBS ON C B R VALUE FOR SOAKED SOIL

GGBS (%)	CBR IN (%) AT 2.5 (mm) PENETRATION	CBR IN (%) AT 5 (mm) PENETRATION
0	2.84	2.69
5	3.13	2.94
10	3.44	3.21
15	3.77	3.50
20	4.06	3.88
25	4.41	4.28

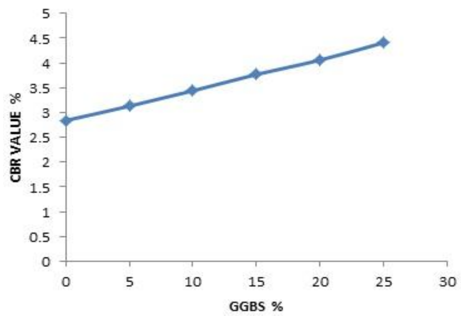

Fig: - 12. C B R value for 2.5mm soaked (0% to 25%)

IV. CONCLUSIONS

By analysis of result the following conclusions may be drawn:

1. With the increases of GGBS percentage optimum moisture content goes on decreasing while maximum dry density goes on increasing, hence compactibility of soil increases and making the soil more dense and hard.
2. With percentage increases of GGBS specific gravity goes on increasing, thus making the soil denser.
3. With the increases of GGBS percentage, percentage finer goes on decreases, which strengthens the soil.
4. With the increases of GGBS percentage liquid limit, plastic limit and plasticity index decreases,

which makes the soil less plastic and hence plasticity index reduces.

5. With the increases of GGBS percentage compressive strength increases that means arrangement of soil particles are very closely, which reduces the voids.
6. C B R value for soaked and unsoaked increases with increases in percentage of GGBS that show the densification of soil takes place and more suitable for pavement thickness.
7. Triaxial test result indicates that with the increases of GGBS percentage cohesion (C) decreases while angle of internal friction (Ø)increases considerably, thus making the soil less cohesive and more resistant.

FINALLY A GENERAL CONCLUSION ON THE BASIS OF TEST RESULTS CAN BE GIVEN AS...

Densification of soil (clay) takes place with increases in percentage of GGBS and plasticity index reduces from high plastic range i.e. more than 17 % to medium plastic range (7-17), thus making the soil suitable for embankment and for pavement of light and medium traffic. The pavement thickness will be reduced considerably with increases in percentage of GGBS With the increases in % of coarse particles causes increases in permeability and reducing the influence of pore water pressure and enhance the self-strength of soil, so stability of soil increases.

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