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Effect of Soil-Fly Ash Mix on the Stability of Pavement Subgrade

Javeed Ahmad Wani[1], Er Rajat Balyan[2]
[1]M.Tech Scholar, Dept. of Civil Engineering, Desh Bhagat University, Gobindgarh Punjab, India
[2]Professor, Dept. of Civil Engineering, Desh Bhagat University, Gobindgarh Punjab, India

Abstract: The overall performance of pavement is very much responsive to the characteristics of the soil subgrade. For that reason, weak subgrades are augumented by adopting the most efficient and profitable stabilization techniques. The subgrade soil stabilization is one of the principal and major processes in the construction of any highway. The whole aim of this thesis is to investigate the effect on the stability of pavement subgrade by the application of soil-fly ash mix. In this regard a laboratory experimental program was considered to study the effect caused by the action of fly ash stabilization on the geotechnical trademarks of expansive subgrade soils. Expansive soil treated with different percentages of fly ash i:e 10, 20, 30, and 40 percent were taken into account. For analysis of stabilization of soil using fly ash, CBR, Compaction, specific gravity, sieve analysis, water absorption tests are performed. Properties used for investigating are Liquid Limit, Plastic Limit, Optimum Moisture Content and California Bearing Ratio. The experimental data reveals that addition of fly ash admixture to the soil has a great influence on its properties. Fly ash has been used successfully in many projects to improve the strength characteristics of soils. Fly ash can be used to stabilize bases or subgrades, to stabilize backfill to reduce lateral earth pressures and to stabilize embankments to improve slope stability.
Keywords: Flexible pavement, Soil, Fly-ash, stabilization techniques, CBR, OMC.

I. INTRODUCTION

Fly ash, also known as "pulverized fuel ash" in the United Kingdom, is a coal combustion product that is composed of the particulates (fine particles of fuel) that are driven out of coal-fired boilers together with the flue gases. Fly ash is a byproduct of the powdered coal combustion process usually connected with electric power generating plants. Fly ash is a fine dust which is pozzolanic in nature and composed of alumina, silica and various alkalies and oxides.

The soil stabilization is the modification of soil properties to meliorate the engineering performance of soils. The properties most often modified are water content, density strength and plasticity. Modification of soil properties is the temporary enhancement of sub grade stability to expedite construction.

Fly ash can be used to stabilize the subgrades and also to stabilize backfill to minimize the lateral earth pressures. Fly ash can also be used to stabilize embankments to meliorate slope stability. Fly ash has been used successfully in many projects to meliorate the strength characteristics of soils. Typical stabilized soil depths are 15 to 46 centimeters (6 to 18 inches).

The overall strength and performance of a pavement is dependent not only upon its design (including both structural design and mix design) but also on the load-bearing capacity of the subgrade soil. Thus, the techniques that can be done to increase the load-bearing capacity (or structural support) of the subgrade soil will most likely meliorate the pavement load-bearing capacity and pavement performance and strength. The greater subgrade structural capacity can result in thinner and more economical pavement structures. Finally, the finished subgrade layer should meet grades, elevations and slopes specified in the contract base. This subsection covers:

A. Increasing Subgrade Support-Compaction

In order to provide maximum structural support (as measured by MR, CBR or R-value), a subgrade soil must be compacted to an adequate density (see Figure 1). If it is not, the subgrade will continue to compress, deform or erode after construction, causing pavement cracks and deformation. Generally, adequate density is specified as a relative density for the top 150 mm (6 inches) of subgrade of not less than 95 percent of maximum density determined in the laboratory. In fill areas, subgrade below the top 150 mm (6 inches) is often considered adequate if it is compacted to 90 percent relative density. In order to achieve these densities the subgrade must be at or near its optimum moisture content (the moisture content at which maximum density can be achieved). Usually compaction of in situ or fill subgrade will result in adequate structural support.

B. Increasing Subgrade Support-Alternative Means

If the structural support offered by the in situ compacted subgrade is evaluated to be inadequate, there are three options to increase the structural support (any one or combination of the three can be used):

1) *Stabilization:* The binding characteristics of the materials generally increase subgrade load-bearing capacity. Typically, cement is used with less plastic soils (plasticity index less than 10), lime is used with highly plastic soils (plasticity index greater than 10) and emulsified asphalt can be used with sandy soils. For flexible pavements, a prime coat is not effective on silt clay or clay soils because the material cannot be absorbed into such a fine soil.
2) *Over-excavation:* The general principle is to replace poor load-bearing in situ subgrade soil with better load-bearing fill. Typically, 0.3-0.6 m (1 – 2 ft.) of poor soil may be excavated and replaced with better load-bearing fill such as gravel borrows.
3) *Add a base course and perhaps a subbase course over the subgrade:* A base course offers additional load-bearing capacity. New pavement structural designs often use some sort of granular base course unless subgrade structural support is extremely good and expected loads are extremely low. Base courses are subjected to the same compaction and elevation requirements as subgrade soils.

C. Subgrade Elevation

The subgrade elevation should generally adjust closely to the construction plan subgrade elevation after final grading (often called fine-grading). Large elevation divergence should not be remunerated for by varying pavement or base thickness because in the case of HMA pavements, HMA compacts differentially and HMA, PCC and aggregate are more expensive than subgrade soil. Thicker areas compact more than thinner areas which will result in the subgrade elevation discrepancies affecting final pavement smoothness.

II. FLEXIBLE PAVEMENT

The flexible pavements are so named because the total pavement structure flexes or deflects under loading. A flexible pavement structure is typically combination of different layers of material. Each layer resists the loads from the above layer and spreads them out and then passes these loads to the next layer below. Typical flexible pavement structure shown in fig. 1 consisting of:-

1) *Surface course:* This is the top layer and the layer that comes in contact with traffic. It may be combination of one or different HMA sub-layers. HMA is a mixture of fine aggregates, coarse aggregates and asphalt binders with or without additives.
2) *Base course:* This is the layer just below the HMA layer and it contains of aggregate (either un-stabilized or stabilized).
3) *Sub-base course:* This is the layer (or layers) under the base layer. A sub-base is not always needed.

a) *Subgrade course:* The subgrade is the material upon which the pavement layer is situated. Although it is desirable to look at pavement performance in terms of pavement crust structure material, thickness and mix design but the sub-grade can often be the overriding factor in the overall pavement performance. The CBR value of the subgrade.

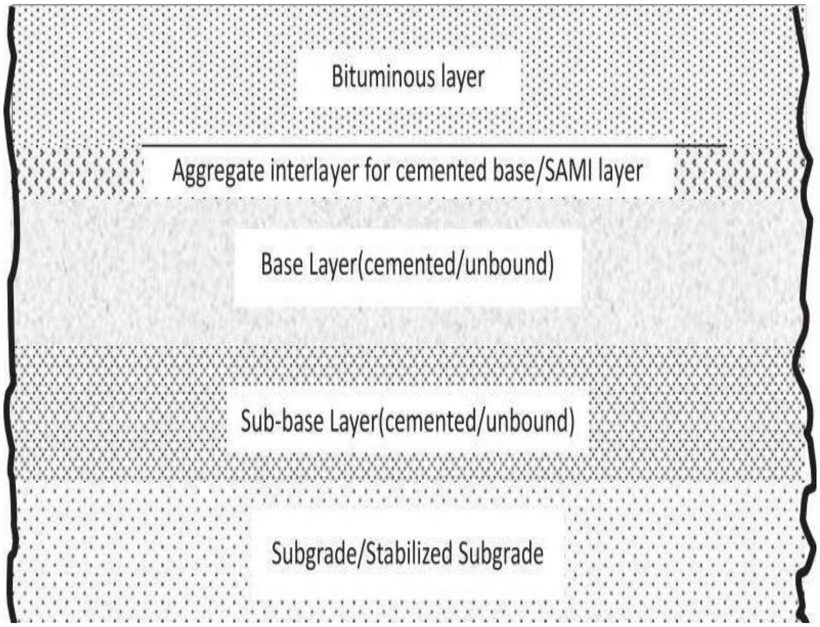

Figure 1: Different layers of the Flexible Pavement (Source: IRC: 37-2012)

III. MATERIALS USED

A. *Fly Ash*

Fly ash, also known as "pulverised fuel ash" in the UK, is a coal combustion product that is composed of the particulates (fine particles of burned fuel) that are driven out of coal-fired boilers together with the flue gases. Ash that falls to the bottom of the boiler is called bottom ash. In modern coal-fired power plants, fly ash is generally captured by electrostatic precipitators or other particle filtration equipment before the flue gases reach the chimneys.

Two classes of fly ash are defined by ASTM C618: Class F fly ash and Class C fly ash. The chief difference between these classes is the amount of calcium, silica, alumina, and iron content in the ash.

1) *Class F fly ash:* The burning of harder, older anthracite and bituminous coal typically produces Class F fly ash. This fly ash is pozzolanic in nature, and contains less than 7% lime (CaO). Possessing pozzolanic properties, the glassy silica and alumina of Class F fly ash requires a cementing agent, such as Portland cement, quicklime, or hydrated lime—mixed with water to react and produce cementitious compounds.
2) *Class C fly ash:* Fly ash produced from the burning of younger lignite or sub-bituminous coal, in addition to having pozzolanic properties, also has some self-cementing properties. In the presence of water, Class C fly ash hardens and gets stronger over time. Class C fly ash generally contains more than 20% lime (CaO).

Table: 2 Physical properties of fly ash

Colour	Dark gray
Specific gravity	2.74
Liquid limit	27%
Plastic limit	Non plastic
Maximum dry density	1.1g/cc
Optimum moisture content	32%
Swelling pressure	0.124kg/cm2

Table: 3 Chemical composition of fly ash

Sl. No.	Chemical component	Chemical content by wt.%	
		Class C	Class F
1	Silica(SiO2)	40	55
2	Alumina(Al2O3)	16.5	26
3	Ferric Oxide(Fe2O3)	6.5	7
4	Calcium Oxide(CaO)	24	9
5	Magnesium Oxide(MgO)	2.3	2
6	Sulfate Oxide(SO3)	3	1
7	Loss of Ignition(LOI)	6	6

B. *Soil Properties*

People describe soil types in all kind of ways such as light, heavy, poor or good, clay and loam. Soil scientist distinguishes the soil type by how much clay, silt and sand are present is called as texture. It is possible to change the texture by adding several additives. Changing texture can help in providing the right condition needed for plant growth.

Silts are soil particle whose size is between sand and clay. Silt feels smooth and powdery. Clay is the smallest part of particles. Clay is smooth when dry and sticky when wet. Soils are called heavy soils if it is high in clay content. Clay also holds a lot of nutrients but doesn't let air and water through it well.

One approach is to use fly ash to stabilize the soft sugared. The strength values of the soil-fly ash mixtures were evaluated to characterise the performance of stabilized soil as a road subbase. California bearing ratio (CBR) and unconfined compression strength tests were executed to determine the optimum mixture contents and strength properties of the soil-fly ash mixtures for construction.

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Table: 1 Geotechnical properties of unmodified soil

Sl. No	Property	Value
1	Gravel	1.5%
2	Sand	32.5%
3	Fines	66.3%
4	Bulk Density	2.3g/cc
5	Specific gravity	2.66
6	Liquid limit	35.8%
7	Plastic limit	22.3%
8	Plasticity index	13.5%
9	Optimum moisture content	10.6%
10	Maximum dry density	19.3kN/m3

C. Additives

Additives when added to the soil in the proper quantities in manufactured commercial products that improve plasticity (Gordon R. Sullivian, 1994) and some engineering characteristic. Additives addressed in this research are limited and only focus on the fly ash.

IV. MODIFICATION

Modification relates to the stabilization process that results in melioration in some properties of the soil but thus not by design result in a significant increase in soil and durability (William E Wildman, 1981).

A. Mechanical Stabilization

Mechanical stabilization is effected by mixing or blending soil of two or more gradations to find a material meeting the required specification. The soil blending may take place at the construction site, a central plant, or a borrow area. The blended material is then disperses and compacted to required densities by the conventional means (Gordon R. Sullivan, 1994).

B. Mechanisms of Stabilization

The stabilization mechanism may vary from the constitution of new compounds binding the finer soil particles to coating particle surfaces by the additive to limit the moisture sensitivity. Therefore, a basic understanding of the stabilization mechanisms convoluted with each additive is mandatory before selecting an efficient stabilizer entourage for a specific application. Chemical stabilization convoluted mixing or injecting the soil with chemically active compounds such as Portland cement, calcium or sodium chloride or with viscoelastic materials such as bitumen, lime and fly ash. Chemical stabilizers can be generally divided in to three groups: (1) Traditional stabilizers such as hydrated lime, Portland cement and Fly ash. (2) Non-traditional stabilizers contains sulfonated oils, ammonium chloride, enzymes, polymers, and potassium compounds and (3) By-product stabilizers that contains cement kiln dust, lime kiln dust etc. Among these, the most widely used chemical additives are lime, Portland cement and fly ash. Although stabilization with fly ash may be more economical when compared to the other two, the constitution of fly ash can be highly variable.

C. Additive Stabilization

Additive stabilization is accomplished by the addition of proper percentage of cement, lime, fly ash, bitumen, or combination of these materials to the soil. The selection of determination of the percentage and type of additive to be used is depending upon the soil classification and the degree of improvement in soil quality coveted (Gordon R. Sullivan, 1994).

Generally, smaller amounts of additives are required when it is simply coveted to modify soil properties such as workability, gradation and plasticity. When it is coveted to meliorate the strength and durability significantly, larger quantities of additives are used. After the additive has been combined with the soil, scattering and compaction are accomplished by conventional means.

V. PROJECT OBJECTIVE

Soil stabilization can be explained as alteration of the soil properties by chemical or physical means in order to improve the engineering properties of the soil. The main objectives of this project i: e, subgrade soil stabilization (by means of fly-ash) is to increase the bearing capacity of the soil and its resistance to weathering process and soil permeability. The long-term functioning of any construction project reckons on the firmness of the rudimentary soils.

VI. LITERATURE REVIEW

Joel H. Beeghly, 2003, "Recent Experiences with stabilization using fly ash of Pavement Subgrade Soils, Base, and reprocessed asphalt"……as per author HIghway engineers have long recognized remote future benefits of increasing the strength and durability of pavement subgrade soil by mixing fly ash with subgrade soil during new construction. Federal and state highway engineers have a revived interest in "perpetual pavement" which will befit from "perpetual foundations". For a low cohesive, silty soil or for converting full depth asphalt pavement recent investigations and some recent experiments demonstrated that lime and F class fly ash stabilization can be economically engineered for long-term performance. For relevant soils, LFA is able to provide cost savings by minimizing material cost by up to 50% as compared to Portland cement stabilization.

David J. White, 2013, "Fly Ash Stabilization of Subgrade"……according to the author the Iowa subgrade soils rate generally from fair to poor with the majority of soils classifying as AASHTO A-4 to A-7-6, these soils show low bearing strength, high volumetric instability, and freezing and thawing durability problems. Stabilization gives different options to improve such soil conditions. ASTM class C self-cementing fly ash has been used on a limited scale in state to treat or stabilize unstable/wet subgrade. Primarily, stabilization play the purpose of forming a construction base in wet soils for embankment fill construction, soft subgrades, or temporary roadway foundations. The Fly ash stabilization is not used currently to improvise the strength and stiffness of pavement foundations, this review set out to investigate its applications and usage for pavement thickness design optimization.

Mohd Ashraf bin MohdHussin, 2010, "stabilization of subgrade by using fly ash related to road Pavement thickness design at jalanjaya gad1ng"…… This project aims to study the effectiveness of adding fly ash by percentage to the subgrade with increasing the California Bearing Ratio (CBR) value. The fly ash will be added to the plain soil (subgrade) by using 4% and 8% fly ash and tested by following ASSHTO as guidance steps. California Bearing Ratio (CBR) is a commonly used directly as to assess the stiffness modulus and shear strength of subgrade in pavement design work. If the CBR value is increasing by adding the fly ash to the soils it's shown its effectiveness in increasing soil strength and vice versa. Overall, when California Bearing Ratio (CBR) value increases, the thickness of pavement design can be reduced and subsequently the road construction of the affected road section will be more economically.

Cetin Bora et al. (2010): Roadways are one of the largest construction fields, and use of suitable waste materials in construction projects can provide serious cost savings while meeting the agenda of the United States Federal Highway Administration Green Highways Partnerships initiative. A laboratory study was carried out to investigate the effectiveness of reusing chemically stabilized pavement surface materials in construction of highway bases. Non-cementitious high carbon fly ash was activated with lime kiln dust and used to stabilize an unpaved road material (URM) collected from Maryland. The effects of lime kiln dust (LKD) and fly ash addition, and curing time on strength and stiffness of highway bases were studied. The effects of winter conditions on stiffness were examined by performing resilient modulus tests on the specimens after a series of freeze–thaw cycles. The thicknesses of base were calculated for all design mix by using their CBR and summary resilient moduli (SMR) values.

S. Kolias (2004): The effectiveness of using high calcium fly ash and cement in stabilising fine-grained clayey soils (CL, CH) was investigated in the laboratory. Strength tests in uniaxial compression, in indirect (splitting) tension and flexure were carried out on samples to which various percentages of fly ash and cement had been added. Modulus of elasticity was determined at 90 days with different types of load application and 90-day soaked CBR values are also reported. Pavement structures incorporating subgrades improved by in situ stabilisation with fly ash and cement were analyzed for construction traffic and for operating traffic. These pavements are compared with conventional flexible pavements without improved subgrades and the results clearly show the technical benefits of stabilising clayey soils with fly ash and cement. In addition TG–SDTA and XRD tests were carried out on certain samples in order to study the hydraulic compounds, which were formed. This work shows that the potential benefit of stabilising clayey soils with high calcium fly ash but this depends on the type of soil, the amount of stabilising agent and the age.

VII. METHODOLOGY

A. Mixing

One of the main concerns when using fly ash as a soil stabilizer is achieving thorough and uniform mixing with the soil to be stabilized. There are two approaches generally used in construction: (1) off-site mixing using continuous or batch type mixing and (2) on-site mixing. Off-site mixing operations have the advantage of achieving more uniform mixtures because the amount of materials batched can be controlled to a greater extent than with on-site mixing. A disadvantage in using self-cementing fly ash is that it can exhibit a relatively rapid set (as little as ten minutes), which can decrease strength with delayed compaction.

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B. Application of Water

The process of adding and monitoring the mixing water during the stabilization operation is one of the most important steps in the construction process. When using a mixing plant setup, general suggestions for water are that it should be between 80% and 110% of the optimum moisture content, based on the moisture-density relationship of the stabilized mixture, to obtain proper density at time of compaction.

Before adding fly ash, water can be added to the subgrade soils. However, a disadvantage to this approach is that the subgrade may become unstable, complicating the rest of the construction process. Water can be added after the fly ash has been incorporated into the soil, but more passes of the mixing equipment are generally required and strength loss can occur due to the hydration of the fly ash prior to final compaction. Further, the most effective method for controlling mixing water has been to add the water directly into the mixing drum of the pulvamixer. This procedure produces the most uniform mixing and the least amount of delay in the construction process.

1) Compaction of Fly Ash-Stabilized Soil

A variety of compaction equipment can be used to increase the relative compaction of fly ash soil mixtures, dependent on soil type. Due to its self-cementing properties, fly ash can be an effective stabilizer for granular and fine grained materials. Compaction delay time should also be considered because the stabilized material can lose strength gain capacity as the fly ash hydrates while in an uncompacted state. For Class F fly ash stabilization work, a maximum compaction delay time of up to four hours has been specified.

2) Different stabilization techniques for soil

As there are numerous way to stabilize Natural soil because it is a complex and irregular material, Yet because of its broad presence all around the world and its low cost it offers great pass for skilful use as an engineering material. The various types of stabilization techniques are:

a) Mechanical stabilization
b) Cement stabilization
c) Lime stabilization
d) Bitumen stabilization
e) Chemical stabilization
f) Thermal stabilization
g) Electrical stabilization
h) Stabilization by grouting
i) Stabilization By geotextiles and fabrics

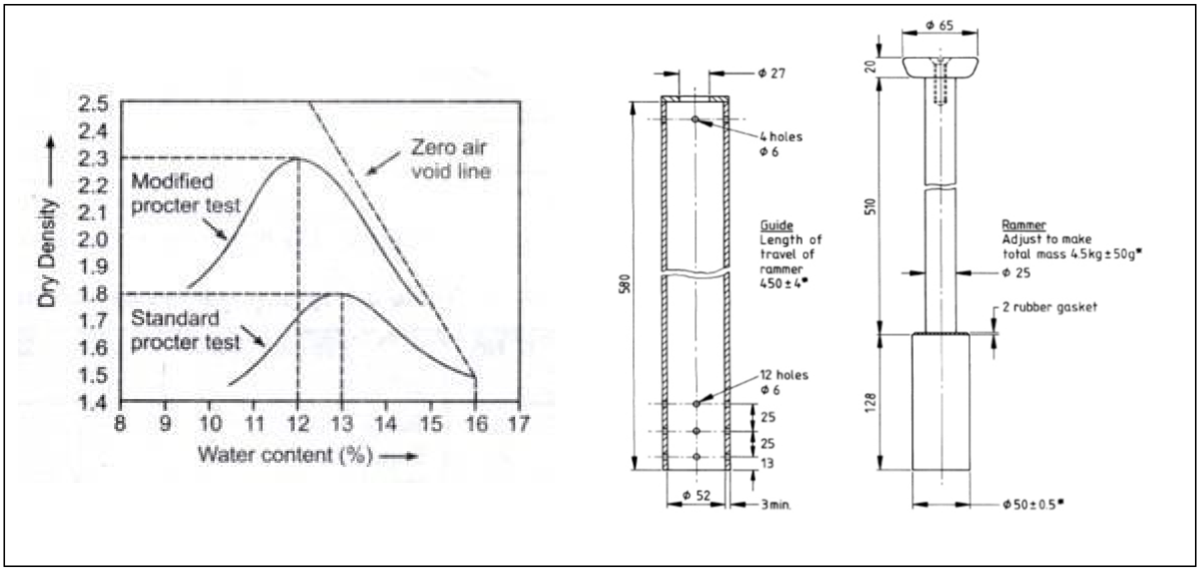
3) Fly ash stabilization

Erdalcokca used fly ash as a stabilizer with lime in 1998. In his research works lime is added to black cotton soils at 0 to 8% to establish datum values. Next fly ash is at 0 to 25% limit. The curing period is considered at 7 days age for his experiments. Fly ash is defined as the material collected from the flue gases of a furnace fired with coal. Fly ash consists of often hollow spheres of silicon aluminum, iron oxide and UN oxidized carbon. Thus , expansive soils likely to be stabilized effectively by cation exchange using fly ash. Addition of 20% fly ash can decreased the selling capability considerably. There is slight decrease in swelling potential from 20 to 25 % fly ash addition .therefore the optimum fly ash content is near 20% only. The plasticity index, activity, CBR, UCS, and swelling pressure etc. gave satisfactory results when black cotton soils are treated with fly ash. Thus fly ash is a good stabilizer now a day.

VIII. LABORATORY INVESTIGATION

A. Compaction Test

Compaction is the method for densification of soil mass by tightening the air voids. The purpose of laboratory compaction test is so obtain that the proper amount of water at which the weight of the soil grains in a unit volume of the compacted is maximum. The amount of water is called the Optimum Moisture Content (OMC). In the laboratory different values of moisture contents and the resulting dry densities are obtained after compaction and are plotted both to arithmetic scale. The former are as abscissa and the latter as ordinate. The points that observed are joined together as a curve. The maximum dry density and corresponding OMC are read from the curve.



The wet density of the compacted soil is calculated as below

$$\square c = \frac{W1 - W2}{V}$$

Where,
w1 = Weight of mould with moist compacted soil
w2 = Weight of empty mould.
V = Volume of mould.

B. California Bearing Ratio Test

The California Bearing Ratio (C.B.R.) test was conducted by California division of highway as a method of classifying and obtained the soil subgrade and base course materials for flexible pavements. The test is empirical and the results cannot be related to fundamental property of the material. The CBR is an evaluation of resistance of a material to penetration of standard plunger under restricted density and moisture conditions. The CBR test may be performed for undisturbed specimen in the laboratory. The test is performed by causing a cylindrical plunger of some diameter to penetrate a pavement component material at 1.25mm/minute. The loads for 2.5mm and 5mm are observed. This load is verbalized as a percentage of standard load value at a respective deformation level to obtain C.B.R. value. The values are given in the table 4. As per IRC recommendation the minimum value of C.B.R. required for a subgrade should be 8%.
It is defined as the ratio of force per unit area required to penetrate a soil mass with standard circular piston at the rate of 1.25 mm/min. to that required for the corresponding penetration of a standard material.

$$C.B.R. = \frac{TESTLOAD}{STANDARDLOADX\ 100\ \%}$$

The following table gives the standard loads adopted for different penetrations for the standard material with a C.B.R. value of 100%.

Table 4 Standard loads for different penetration value

Penetration of plunger (mm)	Standard load (kg)	Unit standard load, kg/cm2
2.5	1370	70
5.0	2055	105
7.5	2630	134
10.0	3180	162
12.5	3600	183

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C. Specific Gravity

Specific gravity of soil is defined as the ratio of the weight of an equal volume of distilled water at that temperature both weights taken in air. It is denoted by G. The Pycnometer method can be used for determination of the specific gravity of solid particles for both fine grained and coarse grained soils. The specific gravity of solids is determined using the relation:

$$G = \frac{M_2 - M_1}{(M_2 - M_1) - (M_3 - M_4)}$$

Where,

M1=mass of empty Pycnometer

M2= mass of the Pycnometer with dry soil

M3= mass of the Pycnometer and soil and water

M4 = mass of Pycnometer filled with water only

G= Specific gravity of solids

IX. EXPERIMENTAL RESULTS

A. Subgrade soil results

Table 5 Results of unmodified subgrade soil

Sl. No.	Property	Subgrade soil(S.S)
1	Liquid limit	35.8%
2	Plastic limit	22.3%
3	Plasticity index	13.5%
4	Shrinkage limit	25%
5	Average Grain Size D 50 (mm)	0.11
6	Coefficient of Uniformity Cu	2.75
7	Coefficient of Curvature Cc	1.45
8	Maximum dry density	19.3 kN/m3
9	O.M.C.	10.6%
10	U.M.C.	58.3 kN/m2
11	Classification As per Indian Standard Typical Soil Classification	SM Silty Sand

Table 6 Results of subgrade soil with 10% of fly ash

SL. NO.	PROPERTY	90% S. S. + 10% F. A.
1	Liquid limit	33.7%
2	Plastic limit	24.4%
3	Plasticity index	14.5%
4	Shrinkage limit	21%
5	Maximum dry density	17.2 kN/m3
6	O.M.C.	13.24%
7	U.C.S.	60 N/m2

Table 7 Results of subgrade soil with 20% of fly ash

SL. NO.	PROPERTY	80% S. S. + 20% F. A.
1	Liquid limit	31%
2	Plastic limit	23%
3	Plasticity index	11.95%
4	Shrinkage limit	18%
5	Maximum dry density	17.3 kN/m3
6	O.M.C.	13.75%
7	U.C.S.	90.5 kN/m2

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Table 8 Results of subgrade soil with 30% of fly ash

SL. NO.	PROPERTY	70% S. S. +30% F. A.
1	Liquid limit	32.7%
2	Plastic limit	25%
3	Plasticity index	10.15%
4	Shrinkage limit	24%
5	Maximum dry density	17.1 kN/m3
6	O.M.C.	14.25%
7	U.C.S.	88.8 kN/m2

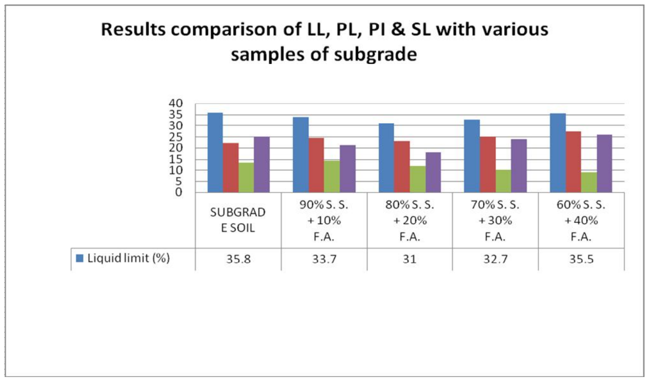

Fig. : Graphical comparison of subgrade soil to the stabilized subgrade soil

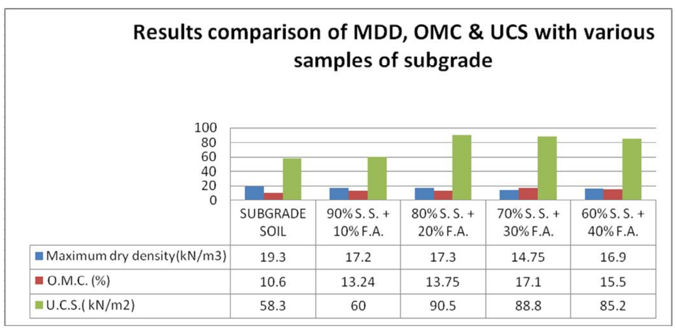

Fig.: Graphical comparison of subgrade soil to the stabilized subgrade soil(MDD, OMC & UCS)

X. CONCLUSIONS

A. It was observed that OMC increases and MOD decreases with increased percentage of fly ash mixed with silty sand. The optimum value of fly ash mix was obtained to be approximately 30%.

B. The variation of unconfined compressive strength (UCS) with percentage of fly ash mix expose that UCS increases up to 30% of fly ash mix and then it decreases.

C. Through this experimentation it is observed that the by-product fly ash is also good stabilizing compound.

D. The optimum proportions for the combination of subgrade soil + by product are 80% S.S + 20% F.A.

E. When the percentage of fly ash increased then the liquid limit increased and plastic limit decreased

F. With the addition of fly ash greater than 20%, the plasticity index of the soil is also decreased.

G. With the addition of fly ash greater than 20%, the optimum moisture content of the black cotton soil is increased while the maximum dry density of soil decreased.

H. With the addition of 20% of fly-ash, the shrinkage limit of the stabilized subgrade soil is also reduced as compare to the subgrade soil.

I. With the addition of 20% of fly-ash, the unconfined compressive strength (UCS) of the stabilized subgrade soil is increased as compared to the subgrade soil.

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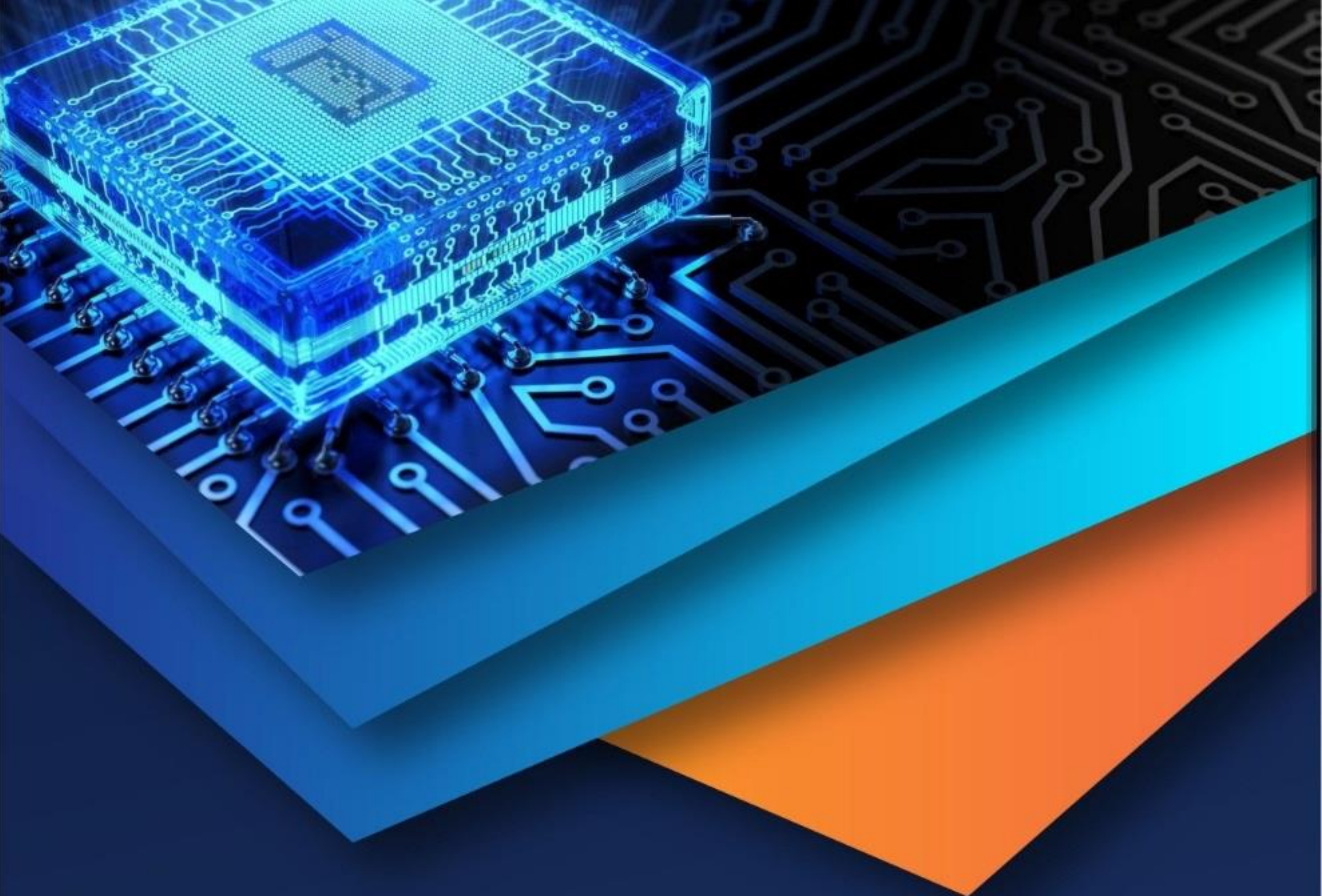
BIOGRAPHIES

Javeed Ahmad Wani is a student of M.Tech Transportation at Desh Bhagat University, Gobindgarh Punjab.
Email: wanijaveed007@gmail.com



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