STABILIZING SLOPES USING WASTES FROM INDUSTRIES

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Abstract - *Increasing industrialization leads to larger quantity of waste getting accumulated leading to environmental degradation. The use of industrial wastes has shown effective results in accordance with stabilizing the soil as well as slope. In this study the slope is analyzed using Geo Studio, a slope modeling software and the soil is stabilized using additive method of stabilization. All the necessary inputs are provided into the software. The use of industrial wastes such as Ground granulated blast furnace slag(GGBS), Glass powder, Hypo sludge have shown effective results in accordance with stabilizing the soil as well as slope. GGBS is a byproduct from the iron and steel making, Glass powder is obtained from powdering the waste glass material, Hypo sludge is waste obtained from paper industries. The Slope/W function in Geo Studio provides analysis of slopes based on various methods. Morgenstern and Price method is used here which can be carried out under both normal and pore water pressure conditions. The cohesion of soil increased significantly with addition of industrial wastes. A maximum factor of safety of 1.05 (Normal condition) is obtained when 10% GGBS is added to soil. A maximum dry density of 19.5 KN/m^3 is obtained when 4% Glass powder is added to soil.*

Key Words: **Industrial waste, Morgenstern and Price, Slope Stabilization, Geo Studio, Hypo sludge, GGBS**

1.INTRODUCTION

Slopes either occur naturally or are engineered by humans. Slope stability problems have been faced throughout history. Furthermore, the increasing demand for engineered cut and fill slopes on construction projects has only increased the need to understand analytical methods, investigative tools, and stabilization methods to solve slope stability problems. Slope stabilization methods involve specialty construction techniques that must be understood and modeled in realistic ways. An understanding of geology, hydrology, and soil properties is central to applying slope stability principles properly. Analyses must be based upon a model that accurately represents site subsurface conditions, ground behavior, and applied loads. Judgments regarding acceptable risk or safety factors must be made to assess the results of analyses. In most applications, the primary purpose of slope stability analysis is to contribute to the safe and economic design of excavations, embankments, earth dams, landfills, and spoil heaps. Slope stability evaluations are concerned with identifying critical geological, material, environmental, and economic parameters that will affect the project, as well as understanding the nature, magnitude, and frequency of slopes.

1.1 FACTORS AFFECTING SLOPE

Failure of Slope occurs because of the downward movements of material due to gravity and when shear stresses exceeds the shear strength. Therefore, factors that tend to increase the shear stresses or decrease the shear strength increase the chances of failure of a slope. Different processes can lead to reduction in the shear strengths of rock mass. Increased pore pressure, cracking, swelling, decomposition of clayey rock fills, creep under sustained loads, leaching, strain softening, weathering and cyclic loading are common factors that decrease the shear strength of rock mass. In contract to this the shear stress in rock mass may increase due to additional loads at the top of the slope and increase in water pressure in cracks at the top of the slope, increase in soil weight due to increased water content, excavation at the bottom of the slope and seismic effects. In addition to these reasons factor contributing in failure of slope are properties of rock mass, (slope geometry), state of stress, temperature and erosion.

Plane failure   Wedge failure

Circular failure   Toppling failure
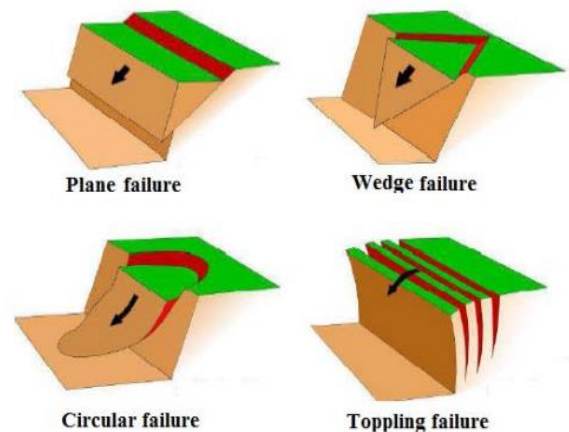
1.2 SOIL STABILIZATION

Soil stabilization is the process of altering some soil properties by different methods, mechanical or chemical in order to produce an improved soil material which has all the desired engineering properties. Soils are generally stabilized to increase their strength and durability or to prevent erosion and dust formation in soils. The simplest method for developing strength of soil to drained out water after compaction of the soil. The other method is adding binder like fly ash, lime, bituminous and cements etc. material to the weak soils for improving geotechnical properties of soil

1.3 METHODS OF STABILIZATION

1. Mechanical method of Stabilization

In this procedure, soils of different gradations are mixed together to obtain the desired property in the soil. This may be done at the site or at some other place from where it can be transported easily. The final mixture is then compacted by the usual methods to get the required density.

2. Additive method of stabilization

It refers to the addition of manufactured products into the soil, which in proper quantities enhances the quality of the soil. Materials such as cement, lime, bitumen, fly ash, GGBS are used as chemical additives. Sometimes different fibers are also used as reinforcements in the soil.

2. TEST RESULTS:

2.1 SOIL PROPERTIES

Soil characteristics were determined using Atterberg limits, Specific gravity, Sieve analysis, Standard proctor compaction test.

Properties	Values
Specific gravity	2.38
Optimum moisture content	10.8%
Maximum Dry Density (γ_{dmax})	19.1 KN/m³
Liquid limit	31
Plastic limit	28.57
Plasticity Index (I_P)	2.43
Uniformity coefficient	7.5

Table -1: Native soil properties

Based on the liquid limit and plastic limit values the soil is classified as follows:
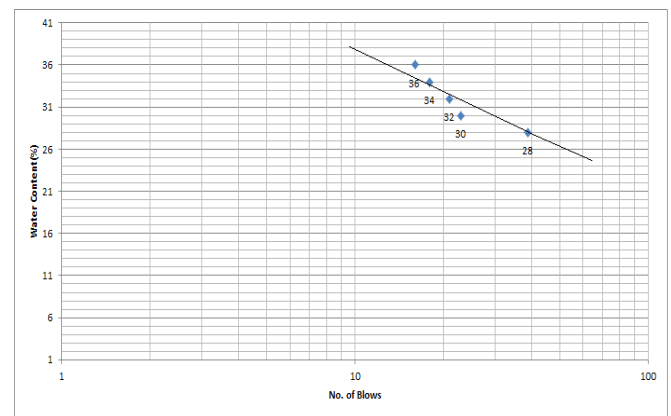
IS Classification of Soil
I_P = 0.73 x (W_L-20)
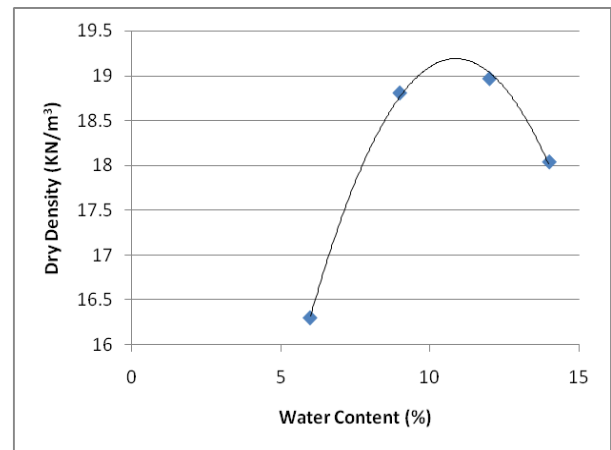   = 0.73 x (31-20)
   = 8.03

Hence the soil is classified as low compressible silt as per IS classification
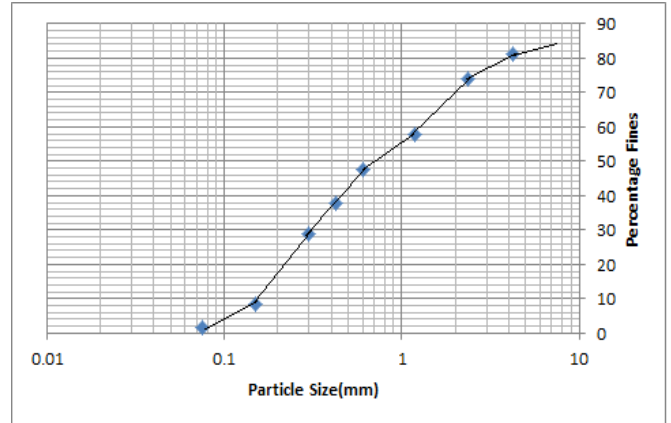
Fig -1: Particle Size Distribution for Plain Soil

Figure -2: Liquid limit for the soil

Figure 4.3 Proctor compaction test curve

2.2 MAXIMUM DRY DENSITY AND OPTIMUM MOISTURE CONTENT

2.2.1 GROUND GRANULATED BLAST FURNANCE SLAG

The native soil has a maximum dry density and optimum moisture content of 19.1KN/m³ and 10.8% respectively on adding GGBS it was seen that the maximum

dry density and optimum moisture content has increased to 19.8 KN/m^3 and 11%. The maximum dry density is obtained by adding 10% GGBS.

Table 4.2 Proctor compaction for GGBS

Admixture Percentage	Maximum Dry Density (KN/m^3)	Optimum Moisture Content (%)
Soil + 2% GGBS	19	12
Soil + 4% GGBS	19.02	9
Soil + 6% GGBS	18.84	9
Soil + 8% GGBS	19.51	12
Soil + 10% GGBS	19.8	11
Soil + 12% GGBS	19.65	12

2.2.2 GLASS POWDER

The native soil has a maximum dry density and optimum moisture content of 19.1KN/m^3 and 10.8% respectively on adding Glass powder it was seen that the maximum dry density has increased to 20.2 KN/m^3 and optimum moisture content has decreased to 9%. The maximum dry density is obtained by adding 4% Glass powder.

Table 4.3 Proctor compaction for Glass powder

Admixture Percentage	Maximum Dry Density (KN/m^3)	Optimum Moisture Content (%)
Soil + 1% HS	19.45	10.4
Soil + 2% HS	18.99	12
Soil + 4% HS	18.32	15

2.2.3 HYPO SLUDGE

The native soil has a maximum dry density and optimum moisture content of 19.1KN/m^3 10.8% respectively on adding Hypo Sludge it was seen that the maximum dry density has increased to 19.45 KN/m^3 and Optimum moisture content has decreased to 10.4%. The maximum dry density is obtained by adding 1% Hypo Sludge.

**Table 4.4** Proctor compaction for Hypo sludge

| Admixture Percentage	Maximum Dry Density (KN/m^3)	Optimum Moisture Content (%)
Soil + 2% GP	19.45	12
Soil + 4% GP	20.02	9
Soil + 6% GP	19.6	11

4.2.4 MIX PROPORTIONS

The maximum dry density of soil and optimum moisture content has increased from 19.1 KN/m^3 and 10.8% to 19.44 KN/m^3 and 15% respectively on adding optimum percentage of Glass powder and GGBS.The maximum dry density of soil and optimum moisture content has increased from 19.1 KN/m^3 and 10.8% to 19.37 KN/m^3 and 15% respectively on adding optimum percentage of Glass powder, GGBS, and Hypo sludge.

Table 4.5 Proctor compaction for Mix proportions

Admixture Percentage	Maximum Dry Density (KN/m^3)	Optimum Moisture Content (%)
Soil + 4%GP + 10% GGBS	19.44	15
Soil + 4%GP + 10% GGBS +1% HS	19.37	15
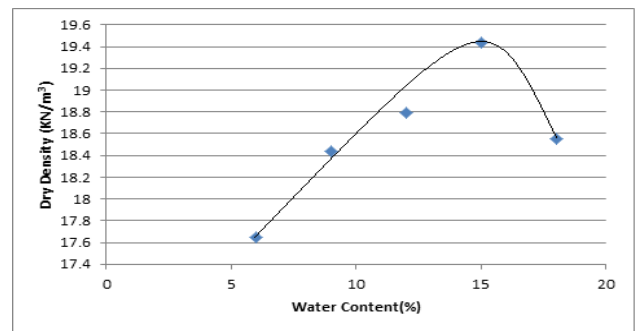
Figure 4.4 Proctor Compaction Test Curve for S+GGBS+GP
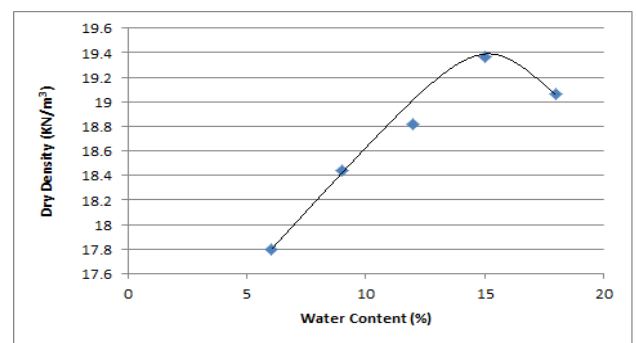
Figure 4.5 Proctor Compaction Test Curve for S+GGBS+GP+HS

## 4.3 DIRECT SHEAR TEST

The table shows the shear stress of soil of native soil and with admixtures. On adding glass powder it is seen that the shear stress is increased from 0.048 Kg/cm^2 to 0.084 Kg/cm^2 for normal stress of 0.5 Kg/cm^2. On adding GGBS the shear stress increases from 0.048Kg/cm^2 to 0.080Kg/cm^2 for normal stress of 0.5 Kg/cm^2. On adding Hypo sludge the

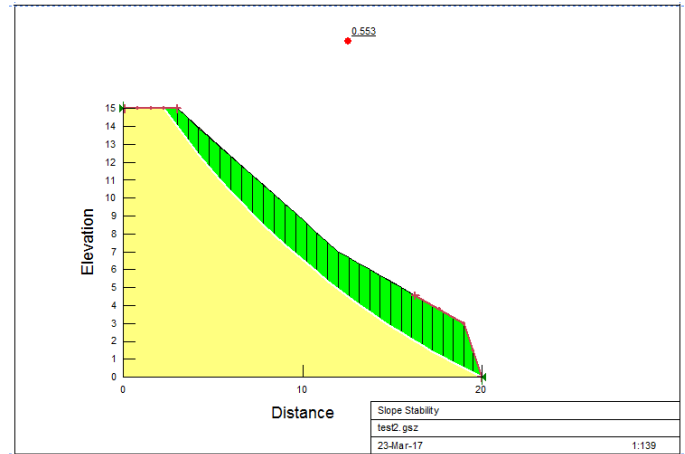shear stress increases from 0.048Kg/cm² to 0.091Kg/cm² for normal stress of 0.5 Kg/cm².

Admixture Percentage	Normal Stress (Kg/cm²)	Shear Stress (Kg/cm²)
Plain soil	0.2	0.035
	0.5	0.048
	0.7	0.091
Soil + 4% Glass powder	0.2	0.041
	0.5	0.084
	0.7	0.11
Soil + 10% GGBS	0.2	0.033
	0.5	0.080
	0.7	0.112
Soil + 1% HS	0.2	0.037
	0.5	0.091
	0.7	0.114

Table 4.6 Direct shear test for soil and industrial wastes
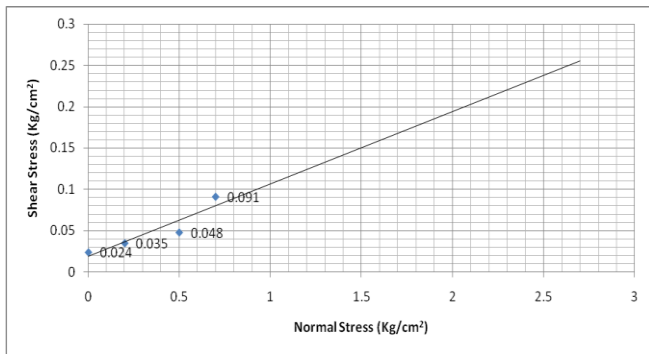
Figure 4.6 Mohr coulomb envelopes for plain soil

From Graph,
Cohesion, C = 0.014 kg/cm²
        = 1.37 KN/m²
Angle of Internal Friction, ϕ = 20°
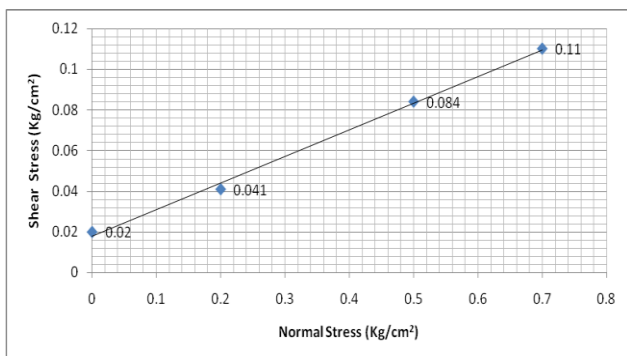
Figure 4.7 Mohr coulomb envelope for soil with glass powder

From Graph,
Cohesion, C = 0.02 kg/cm²
        = 1.96 KN/m²
Angle of Internal Friction, ϕ = 33°
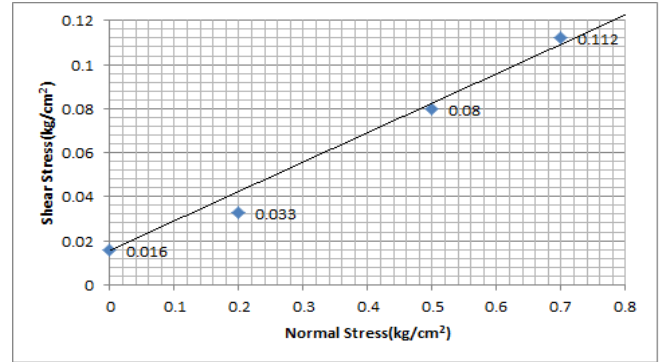
Figure 4.9 Mohr coulomb envelope for soil with GGBS

From Graph,
Cohesion, C = 0.016 kg/cm²
        = 1.56 KN/m²
Angle of Internal Friction, ϕ = 36°
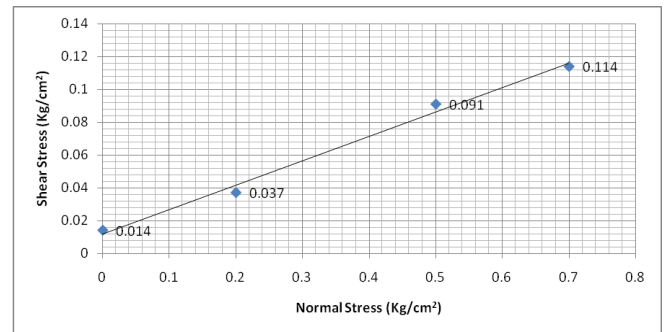
Figure 4.10 Mohr coulomb envelope for soil with Hypo sludge

From Graph,
Cohesion, C = 0.014 kg/cm²
        = 1.37 KN/m²
Angle of Internal Friction, ϕ = 34°

4.3.1 MIX PROPORTIONS

The table shows the shear stress of soil of native soil and with admixtures. On adding glass powder and GGBS it is seen that the shear stress is increased from 0.048 Kg/cm² to 0.081 Kg/cm² for normal stress of 0.5 Kg/cm². On adding GGBS+GP+HS the shear stress increases from 0.048Kg/cm² to 0.080Kg/cm² for normal stress of 0.5 Kg/cm².

Admixture Percentage	Normal Stress (Kg/cm²)	Shear Stress (Kg/cm²)
Soil + 4% Glass powder + 10% GGBS	0.2	0.043
	0.5	0.081
	0.7	0.12
Soil + 4% Glass powder + 10% GGBS + 1% Hypo sludge	0.2	0.036
	0.5	0.080
	0.7	0.119

Table 4.7 Direct shear test for mix proportions
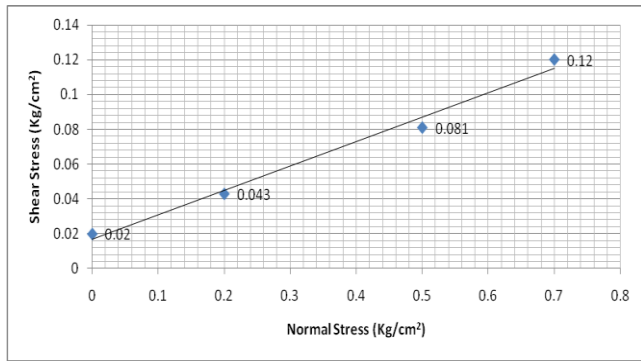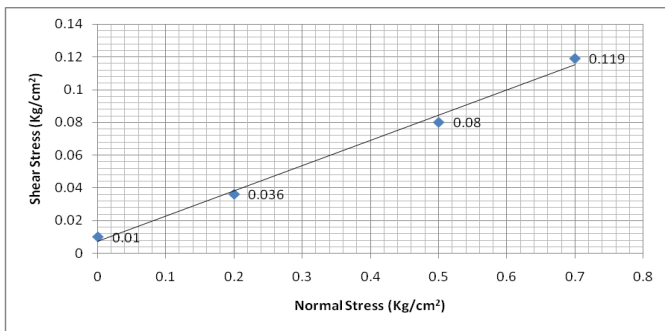
Figure 4.11 Mohr coulomb envelope for soil with GP and GGBS

From Graph,

Cohesion, C = 0.02 kg/cm²

= 1.96 KN/m²

Angle of Internal Friction, ф = 30⁰

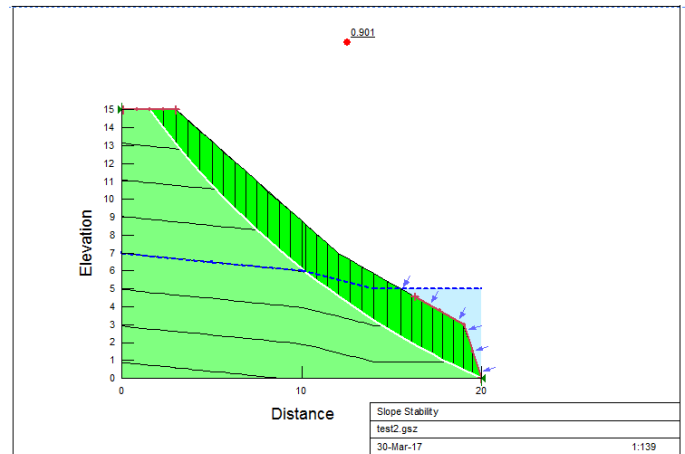**Fig 4.12** Mohr coulomb envelope for soil with GP, GGBS, and Hypo sludge

From Graph,

Cohesion, C = 0.01 kg/cm²
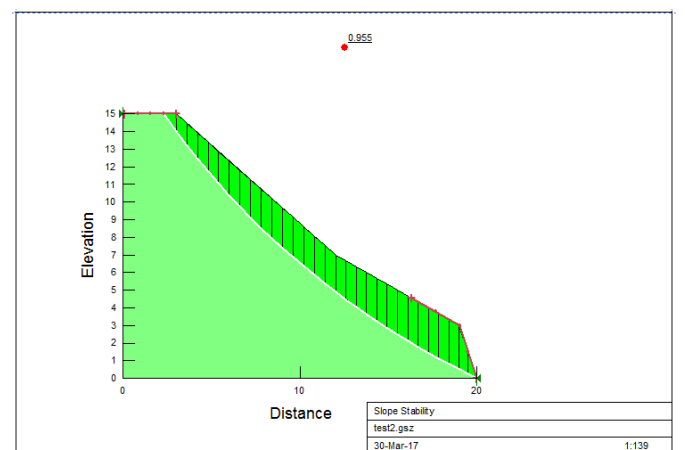
= 0.981 KN/m²

Angle of Internal Friction, ф = 33⁰

4.4 CRITICAL SLIP SURFACES

4.4.1 PLAIN SOIL
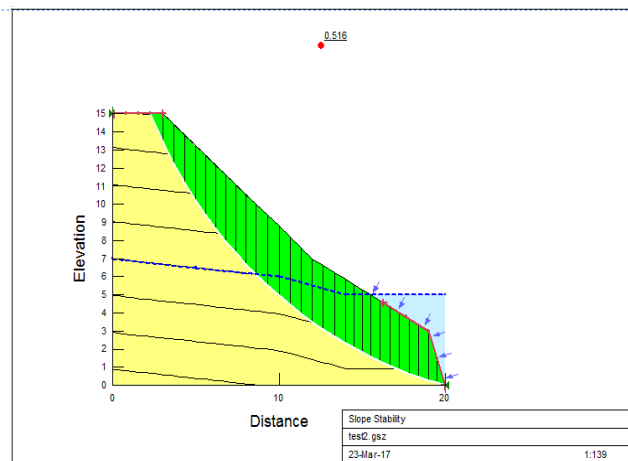
Fig 4.13 Critical Slip Surface with pore pressure for Plain soil

Fig 4.14 Critical Slip Surface without pore pressure for Plain soil

4.4.2 SOIL WITH GLASS POWDER

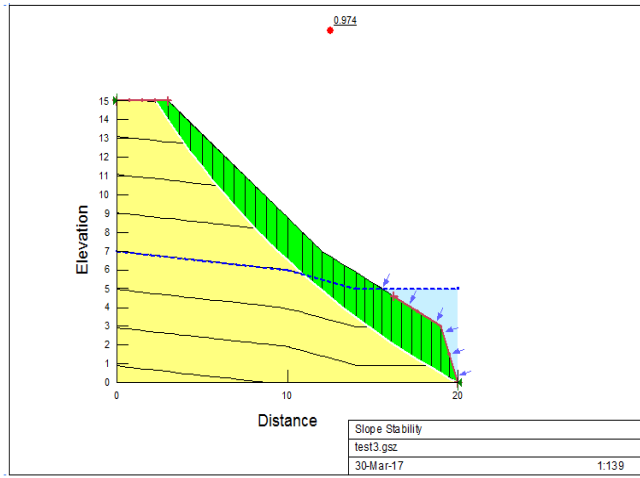**Fig 4.15** Critical Slip Surface with pore pressure for S+GP

Fig 4.16 Critical Slip Surface without pore pressure for S+GP

4.4.3 SOIL WITH GGBS

Fig 4.17 Critical Slip Surface with pore pressure for S+GGBS

Fig 4.18 Critical Slip Surface without pore pressure for S+GGBS

4.4.4 SOIL WITH HYPO SLUDGE
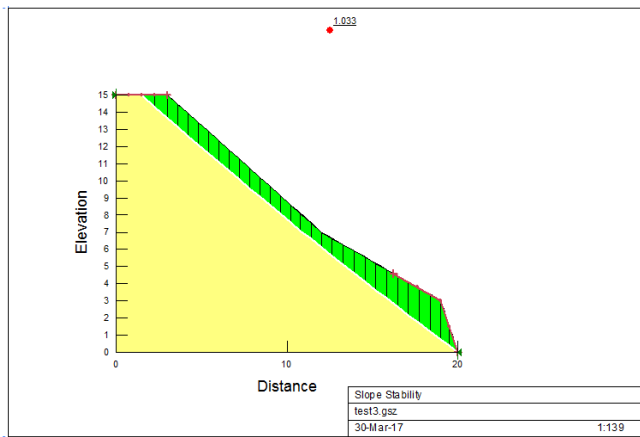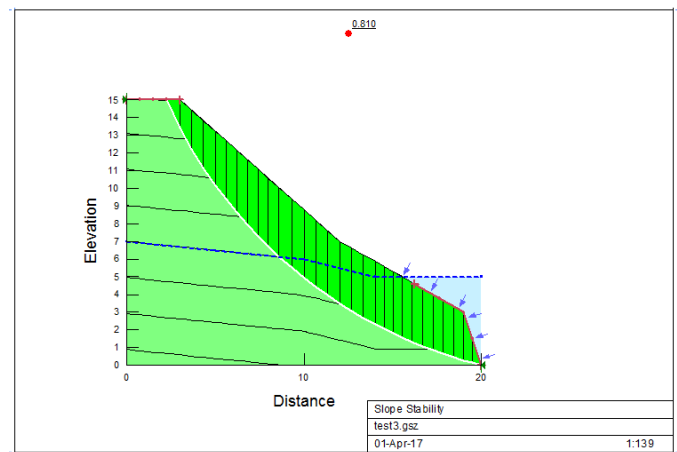

Fig 4.19 Critical Slip Surface with pore pressure for S+HS

Fig 4.20 Critical Slip Surface without pore pressure for S+HS
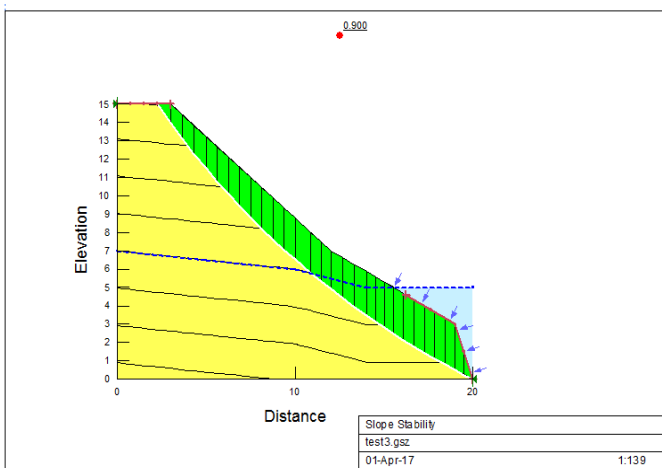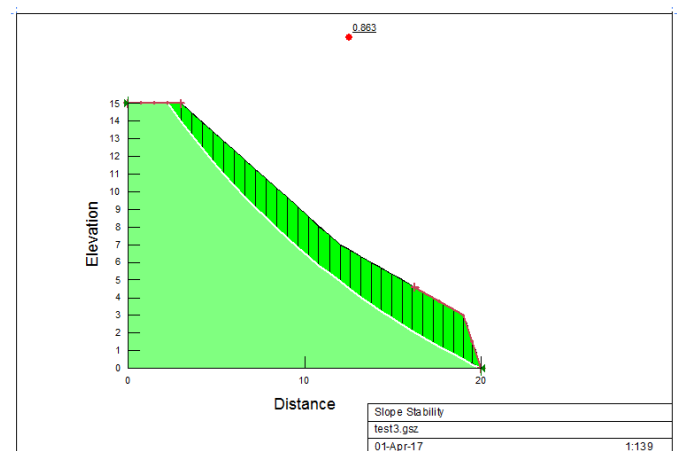
4.4.5 SOIL WITH GLASS POWDER AND GGBS

Fig 4.21 Critical Slip Surface with pore pressure for S+GP+GGBS

Fig 4.22 Critical Slip Surface without pore pressure for S+GP+GGBS

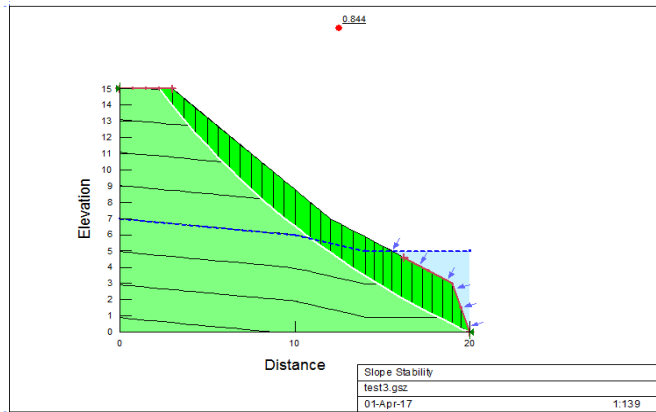#### 4.4.6 SOIL WITH GLASS POWDER + GGBS + HYPO SLUDGE

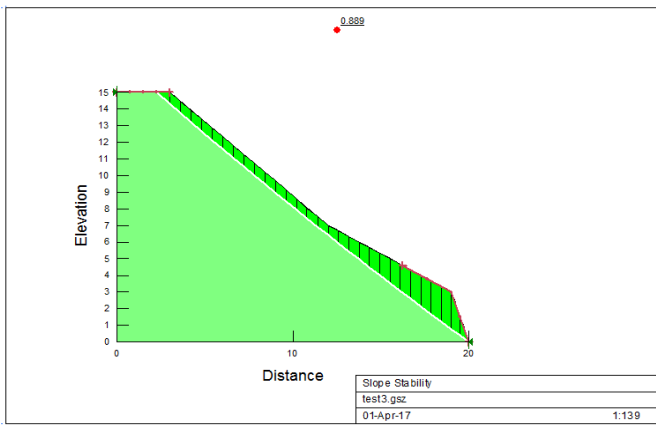**Fig 4.23** Critical Slip Surface with pore pressure for S+GP+GGBS+HS

Fig 4.24 Critical Slip Surface without pore pressure for S+GP+GGBS+HS

4.5 DISCUSSIONS

1. Comparison between MDD of Soil with Industrial Wastes

The maximum dry density was obtained when 4% of glass powder was added. Other wastes showed significant increase in dry density with respect to that of native soil. This is due to excessive bonding of glass powder with soil
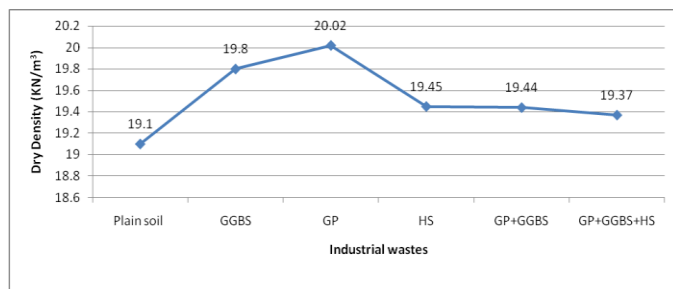

Chart -1: Variation of Max dry density of Soil with Industrial Wastes

2. Variation of Cohesion of soil with Industrial wastes

Maximum cohesion value of 1.96 KN/m² is obtained while adding glass powder and GP+GGBS. This is due to less optimum moisture content of glass powder with soil. While adding it along with GGBS it showed similar values of cohesion. Hypo sludge and its combinations were not significant they had same cohesion values as that of native soil.
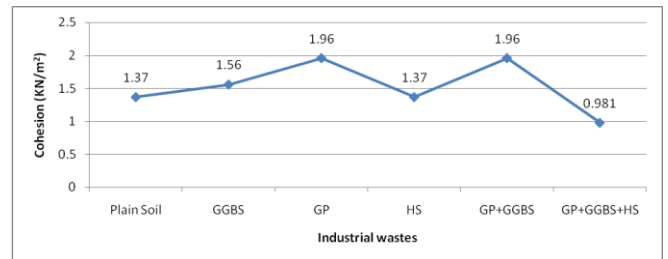

Chart -2: Variation of Cohesion of soil with Industrial wastes

3. Variation of Angle of Internal friction of soil with Industrial wastes

Maximum angle of internal friction of 36^0 is obtained when GGBS is added to soil. This is generally due to low optimum moisture content of GGBS with soil. Even in case of glass powder there was only a fraction of decrease in angle. The angle increased variably with respect to native soil on adding other admixtures.
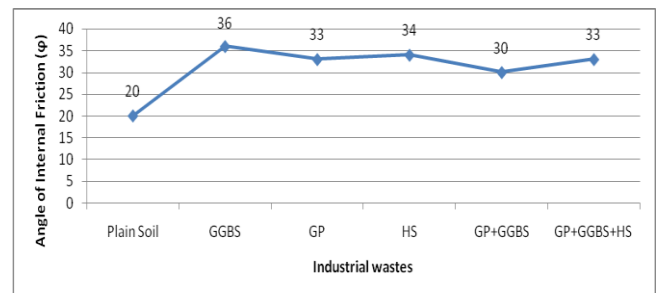

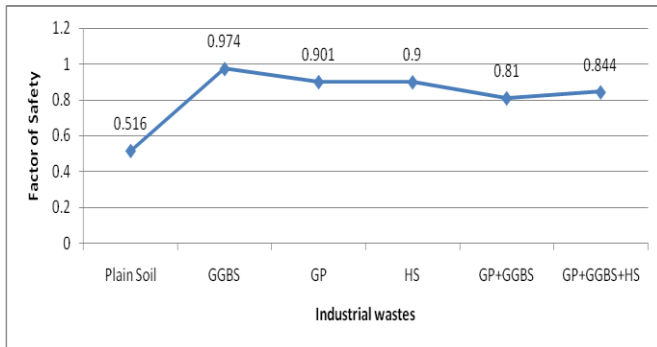**Chart -3:** Variation of Angle of internal friction of soil with Industrial wastes

4. Variation of Factor of safety of slope with Industrial waste (With pore pressure)

Maximum factor of safety of 0.974 is obtained when 10% of GGBS is added to soil. This is due to the larger angle of internal friction values of the admixture with soil. The factor of safety increased significantly on adding admixtures.

Chart -4: Variation of factor of safety of slopes with industrial wastes under pore water pressure conditions

5. Variation of Factor of safety of slope with Industrial waste (Without pore pressure)

Maximum factor of safety of 1.033 is obtained when 10% of GGBS is added to soil.This is due to the larger angle of internal friction values of the admixture with soil. The factor of safety increased significantly on adding ad mixtures.
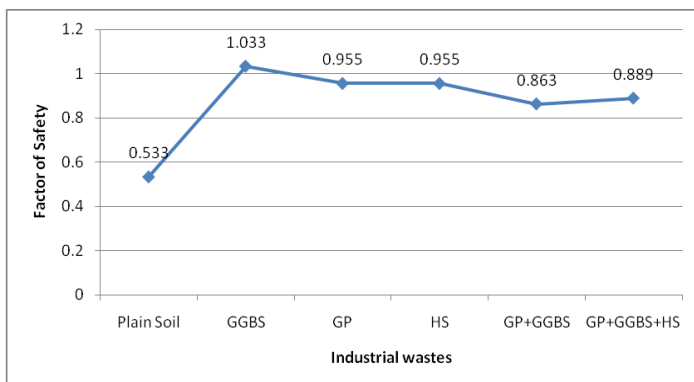
Chart -5: Variation of factor of safety of slopes with industrial wastes under normal conditions

3. CONCLUSIONS

1. Based on proctor compaction of soil with industrial wastes, it was found that the Maximum dry density of soil increased by 3.66%, 4.81%, and 0.89% on adding GGBS, Glass powder, Hypo sludge respectively. When these were used in combinations the maximum dry density increased on a small margin viz. 1.78% and 1.41% for GGBS+GP and GGBS+GP+HS respectively.

2. Based on Direct Shear tests with the industrial wastes, the cohesion value increased by 13.86%, 43.06%, 0%, 43.06% for GGBS, Glass powder, Hypo Sludge, GGBS+GP respectively. In case of GP+GGBS+HS the cohesion value decreased by 28.39%. The angle of internal friction increased by 80%, 65%, 70%, 50%, and 65% for GGBS, Glass powder, Hypo Sludge, GGBS+GP, GGBS+GP+HS respectively.

3. On determining the factor of safety of soil with industrial wastes from geo studio under pore waster

pressure conditions it was found that the factor od safety increased by 88.75%,74.61%, 74.41%, 56.97%, and 63.56% for GGBS, Glass powder, Hypo Sludge, GGBS+GP, GGBS+GP+HS respectively. In case of normal conditions the factor of safety increased by 93.80%, 79.17%, 79.17%, 61.91%, and 66.79% GGBS, Glass powder, Hypo Sludge, GGBS+GP, GGBS+GP+HS respectively.

Over all it can be concluded that on using industrial wastes with soil it provides a significant increase in factor if safety, hence they can be used for small slopes along such as railways embankments, along river banks etc. Since they also have good Maximum Dry Density they can be used for construction of small structures.

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