

# Sustainable Solutions for Clayey Soil Improvement: A Study of Steel Slag and Glass Powder

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## Abstract

This study uses glass powder and steel slags, two industrial wastes, to examine various soil parameters, including the California bearing ratio, unconfined compressive strength, plasticity index, and maximum dry density. Both glass powder and steel slags significantly impact different soil characteristics for both soil samples. When glass powder and steel slag were added to soil samples, the PI values dropped from 13.7% to 10.1%, and for steel slag, they fell from 13.1% to 8.3%. The PI was similarly decreased when both were combined in the specified percentage content; the most significant reduction, 1.4%, was seen at 10% GP and 20% SS. In a similar vein, the MDD value rose as the SS and GP contents increased; the highest increases were noted for 10% SS, at 1.92 g/cc, and 10% GP, at 1.96 g/cc, respectively. However, the highest growth, 2.21 g/cc, occurred when 10% GP and 20% SS were combined with steel slag and glass powder. Both steel slag and glass powder raise the CBR value; the highest increases were observed for 10% SS, which was 8.7%, and 10% GP, which was 9.6%, respectively. The most significant growth, 17.6%, was observed when 10% G.P. and 20% SS were combined with steel slag and glass powder. The percentage increased by almost 183.8% from its initial amount. Thus, the use of steel slag and glass powder in stabilization is a common and economical way to improve the soil's qualities for stabilization.

**Keywords:** Steel slags, Glass powder, California bearing ratio, Plasticity index, and Maximum dry density.

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## INTRODUCTION

Since certain soil defects may create delays in human activities and properties, the idea of stabilizing soil has existed for thousands of years [1-2]. Various stabilizers use various methods to avoid these problems. Soil improvement is a grouping of many methods to change the mechanical or chemical properties of soil to improve its function [3-5]. In reality, the phrase "soil improvement" encompasses a wide range of engineering projects, including building construction, road paving, and airport runways, where the main goal is to enhance the soil and reduce construction costs by utilizing local resources [6]. In civil engineering projects, such as dam construction and highway foundation laying, an understanding of soil stabilization is crucial [7]. In its natural form, soil with too much clay loses strength and bearing capacity. Consequently, it is essential to improve the strength and stability of the soil, which is why many studies recommend the use of easily accessible and affordable stabilizers [8-9]. For this reason, numerous researchers have used several stabilizers to increase the strength of the soil [10-17]. The available stabilizers could be industrial raw materials or agricultural waste. To improve the geotechnical properties of soil for a range of civil engineering projects, including building, road, and dam construction, the researchers use industrial and agricultural raw materials. To improve the geotechnical properties, researchers are focusing on affordable stabilizers [18].

Natural disasters are a worldwide problem. The main distinction is the extent of the shift, which varies according to the location and can have catastrophic effects on the local ecology and population. Currently, increasing industrial production with available natural resources is challenging, which in turn hinders the

growth of industrial manufacturing and the rate at which natural resources are being depleted. Glass powder and steel slag are among the industrial raw products that are produced, which are detrimental to the environment [19]. These fundamental components can be added to soil to enhance its properties and, to a certain degree, control unfavourable environmental circumstances. Researchers have previously discovered that specific stabilizers have an impact on soil stabilization. In 1950, a French engineer named Henry Vidal introduced the idea of stability. Steel reinforcement was utilized periodically in Vidal's stabilization approach to boost the tensile strength of a cohesively non-cohesive material. The goals of soil stabilization are to decrease permeability and increase soil strength and durability. Glass powder has been shown to enhance the properties of clayey soil. This involves raising the optimal moisture content, Atterberg's limits, and maximum dry density.

The addition of glass powder increases the CBR value of clayey soil. The ability of clayey soil to swell can be decreased by using glass powder. When 12% glass powder was added to clayey soil, the swell value decreased from 5.5% to 1.65%. When the curing period is prolonged from three to twenty-eight days, the hydration process increases the UCC strength of the clayey grains and glass powder. The addition of glass powder increases the CBR value of clayey soil. Clayey soil can be made less prone to swelling by applying glass powder [20]. The study discovered that the test results showed both an increase in workability and an improvement in the MDD score. In addition to the California bearing ratio value improving and increasing when 12% of the soil was replaced with glass, the UCS value climbed dramatically as well. The amount of glass powder in the soil had a significant effect on the swell index, which decreased from 5.5% to 1.65%. Following the addition of 12% glass powder, the soil's behaviour much improved [21].

The prime objectives of the research study are as follows:

- To improve the soil's geotechnical qualities
- To use inexpensive stabilizers to make soil stabilization cost-effective

## MATERIALS AND METHODS

The following are the materials utilized in this investigation.

### Steel Slag

Because of its high calcium and silica content, steel slag, a by-product of the steel industry, can be utilized to increase the strength and longevity of soil. It enhances long-term stability by promoting pozzolanic reactions, decreasing flexibility, and increasing bearing capacity when combined with soil. Additionally, its angular particle structure promotes interlocking, which improves shear strength and compaction.

### Glass Powder

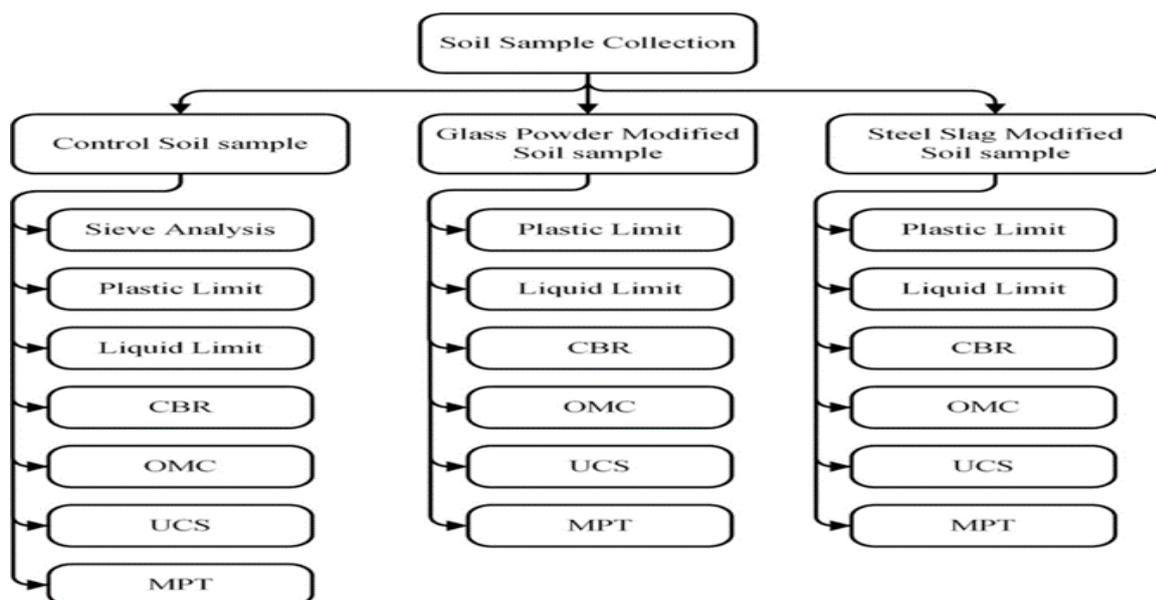
The soil becomes more cohesive and durable when calcium hydroxide reacts with glass powder, which is mainly made of amorphous silica. By recycling waste and reducing environmental impact, their use not only improves geotechnical performance but also encourages sustainable building practices.

The methods used for this study are listed below.

About eight trial pits were considered for the soil sample collection, and two samples were taken from a 3x3-foot pit throughout this study project. The soil samples were taken into the lab for additional analysis. The complete flowchart for the entire research project is displayed in the diagram below. ASTM Standards carried out every test.

**Table 1: Test with ASTM Standards**

S. No.	Test Name	ASTM Standards
1.	Liquid Limit Test	ASTM- D4318
2.	Plastic Limit Test	ASTM- D4318
3.	Modified Proctor Test	ASTM- D698
4.	Moisture Content Test	ASTM-D1557
5.	CBR Test	ASTM- D1883



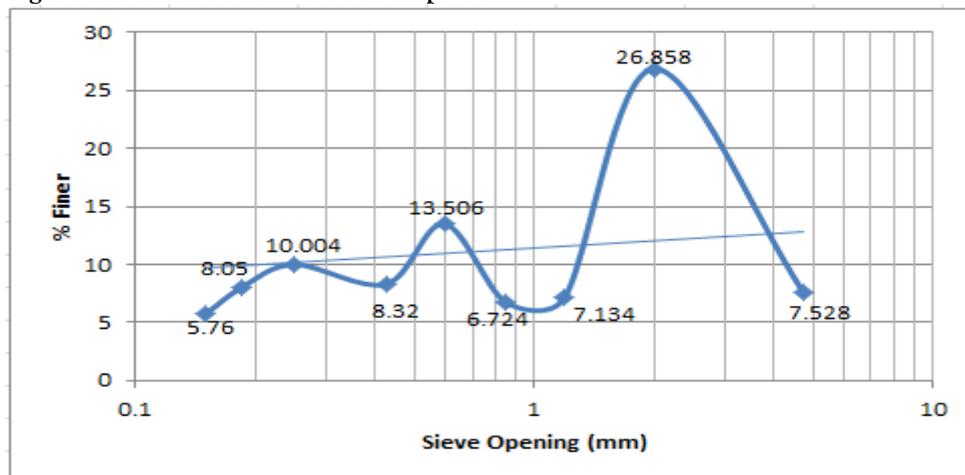
**Figure: Experimental Flowchart Diagram**

After drying overnight, the soil sample was run through a 3/8" sieve to separate the materials. These soil samples were split to pass through a 3/8" sieve after being air dried for the entire night in a large container. The soil sample was then subjected to several tests, as indicated in the flow chart above. The table and graph below show the results of the sieve examination of the two soil samples that were taken from two distinct locations.

The gradation curves for the soil samples collected for the sieve analysis test from samples 1 and 2 are displayed in the figures. The soil taken from site one was classified as A-6 clayey soil components by the AASHTO. In contrast, the soil collected from site two was classified as A-2-6 silty or clayey sand material. After adding steel slag and glass powder, the soil at Site 1 is categorized as A-4 silty.



**Figure: Gradation curve of soil sample -1**



**Figure: Gradation curve of soil sample -2**

## RESULTS AND DISCUSSIONS

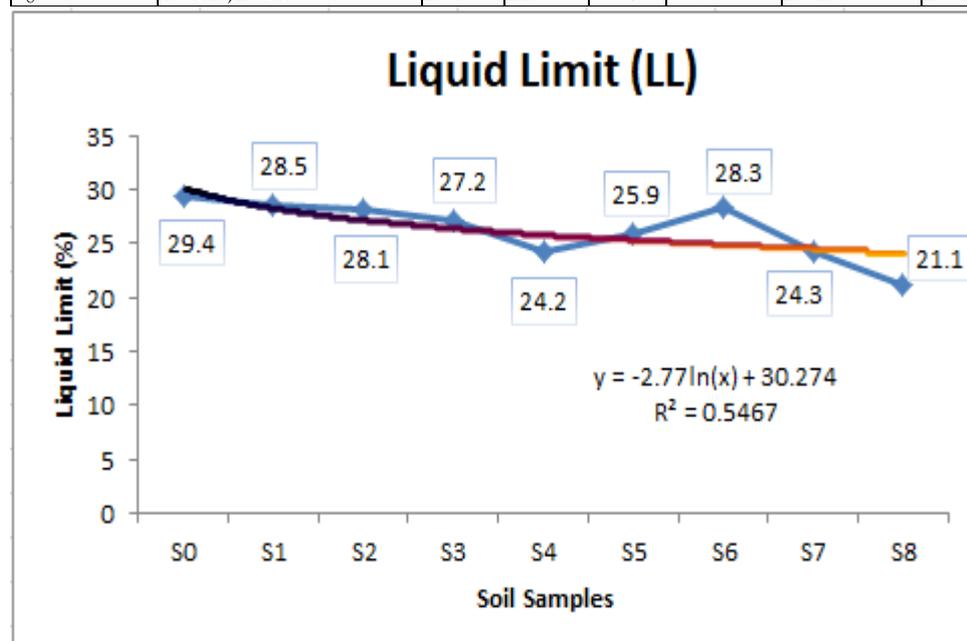
To achieve the goals of this research project, this section of the study focuses on the analysis of the results that were recorded during the project. These results were then tabulated as indicated in the tables below and plotted for both soil samples, referred to as soil samples 1 and 2. With the use of the test findings listed in the table below, the following geotechnical properties: liquid limit, plastic limit, plasticity index, maximum dry density, optimal moisture content, and California bearing ratio have been thoroughly examined.

**Table 1: Laboratory tests outcomes for soil sample 1**

Soil Sample	Addition of Stabilizers	LL (%)	PL (%)	PI (%)	OMC (%)	MDD (g/cc)	CBR (%)	Increase in CBR (%)
S <sub>0</sub>	Control	29.4	16	13.7	10.21	1.81	6.2	-
S <sub>1</sub>	5GP	28.5	18	11.4	9.94	1.89	7.4	19.35
S <sub>2</sub>	10GP	28.1	19.5	10.1	9.11	1.92	8.7	40.32
S <sub>3</sub>	10SS	27.2	18.5	9.3	12.3	1.96	9.6	54.84
S <sub>4</sub>	20SS	24.2	17.8	8.2	15.21	2.02	9.9	59.68
S <sub>5</sub>	5GP,10SS	25.9	19.8	6.8	11.87	2.01	10.1	62.9
S <sub>6</sub>	5GP,20SS	28.3	16	3.3	14.9	2.1	14.7	137
S <sub>7</sub>	10GP,10S	24.3	19	5.1	11.01	2.05	12.5	101.6
S <sub>8</sub>	10GP,20SS	21.1	20	1.4	13.7	2.21	17.6	183.8

**Table 2: Laboratory tests outcomes for soil sample 2**

Soil Sample	Addition of Stabilizers	LL (%)	PL (%)	PI (%)	OMC (%)	MDD (g/cc)	CBR (%)	Increase in CBR (%)
S <sub>0</sub>	Control	30	20	11.2	7.65	2.2	10.3	-
S <sub>1</sub>	5GP	29.1	19	10.8	7.1	2.21	10.9	5.8
S <sub>2</sub>	10GP	27.4	19	9.7	6.8	2.22	11.5	11.65
S <sub>3</sub>	10SS	26.3	18	8.5	9.2	2.225	11.9	15.53
S <sub>4</sub>	20SS	24.5	18	7.1	10.1	2.24	12.6	22.33
S <sub>5</sub>	5GP,10SS	26.3	20	5.5	9.01	2.23	12.5	21.35
S <sub>6</sub>	5GP,20SS	27.5	16	1.05	9.7	2.29	18.7	81.55
S <sub>7</sub>	10GP,10SS	22.6	19	3.72	8.64	2.25	15.6	51.45
S <sub>8</sub>	10GP,20SS	20.8	21	0.57	9.3	2.32	20.1	95.14



**Figure: Effect of SS & G.P on LL of soil sample 1**

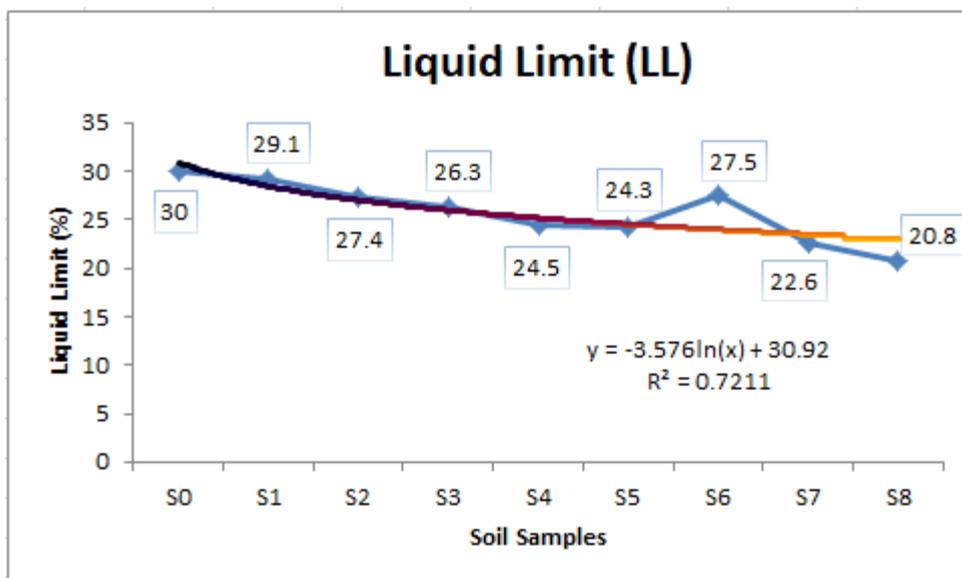


Figure: Effect of SS & G.P on LL of soil sample 2

### DISCUSSION

The liquid limit (LL) results graphs for the two soil sample sets all have a downward trend, from S0 to S8, as shown in the figure. It means that as the number of samples increases, the plasticity properties of soils decrease gradually. The figure shows that the LL values in both the LL datasets start from around 30% for S0, which reduces even further up to almost 21.1% and 20.8 % for S8, as illustrated by the graphs above. It may be due to a decrease in clay content or an increase in coarser-grained particles, such as silt and sand, which has resulted in the change in nature. It's also vital to remember that both graphs change over time. For example, the LL values of samples S5 and S6 increase briefly before returning to their original levels. These localized increases might be due to changes in the soil's organic matter, moisture content, or mineralogy, which may have temporarily changed the liquid limit. To find out what caused these differences, additional investigation is needed. In general, the fact that LL values are decreasing indicates that the soil is becoming less pliable and more solid, which is beneficial for building purposes. Lower LL values are generally linked to less compressibility and less possibility for shrinkage and swelling. This makes the soil better for engineering needs.

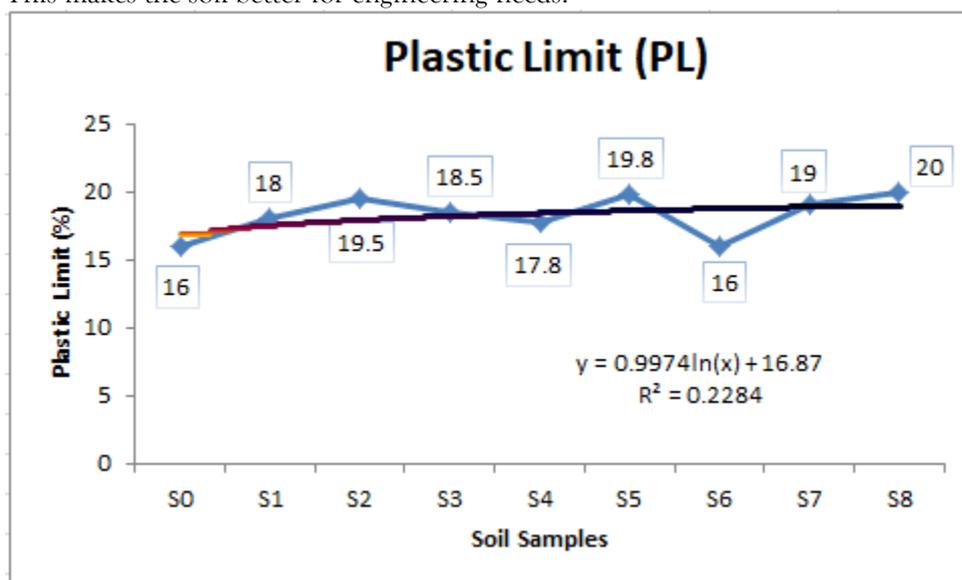


Figure: Effect of SS & G.P on PL of soil sample 1

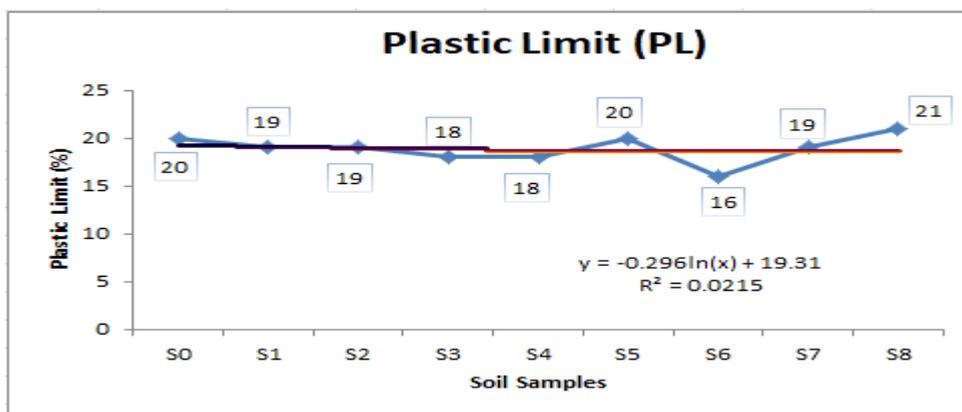


Figure: Effect of SS & G.P on PL of soil sample 2

### DISCUSSION

The fact that Soil Sample 1's plastic limit is slightly higher than that of Soil Sample 2 means that Soil Sample 1 has more clay or is more plastic. The lower plastic limit of Sample 2 suggests that the soil is coarser or less cohesive. Changes in plastic limitations can affect how soils perform and how they behave when they are under stress, especially when designing roads or buildings. The results indicate that different stabilizing or treatment methods are necessary, depending on the plastic characteristics of each sample. Geotechnical investigation should take into consideration the inherent mineralogical or compositional disparities between the two soils, as evidenced by these variations.

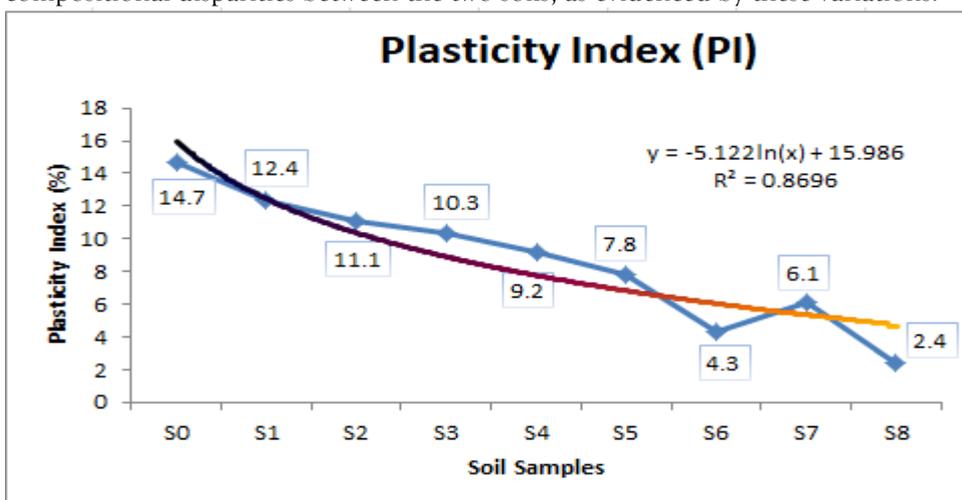


Figure: Effect of SS & G.P on PL of soil sample 1

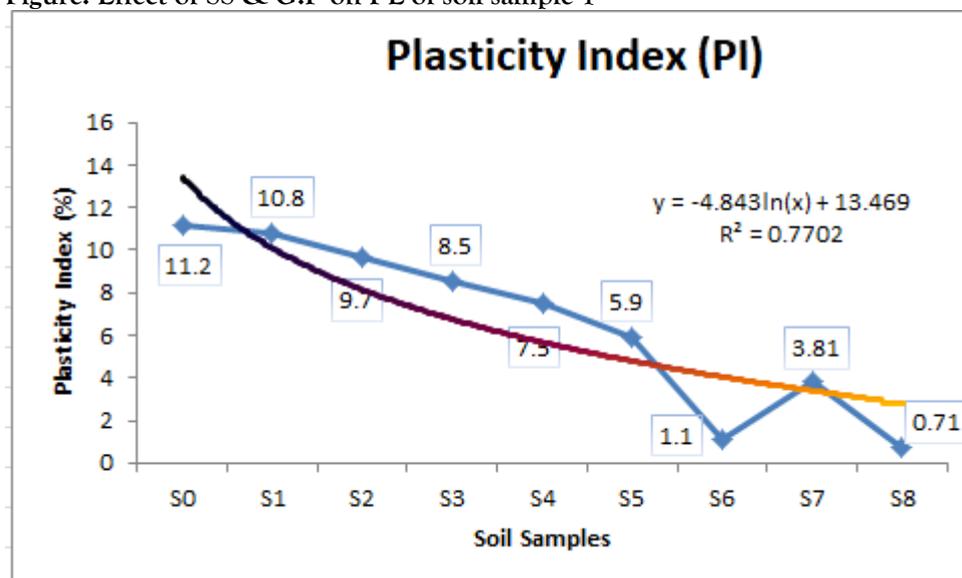


Figure: Effect of SS & G.P on PL of soil sample 2

**DISCUSSION:**

The Plasticity Index (PI) shows a clear decreasing trend from S0 to S8 across all of the soil samples. This means that the soil's plastic behaviour has undergone significant changes. The PI shows a shift from soils that are moderately plastic to nearly non-plastic soils. It goes from 11.2% at S0 to barely 0.71% at S8. A lower PI means that the soil is easier to deal with, more stable, and has a higher swelling potential. This is because the silt and sand fractions are higher, and the clay content is lower. Small changes, such as the 3.81% rise at S6, might be due to differences in moisture or mineral composition in different areas and need additional study.

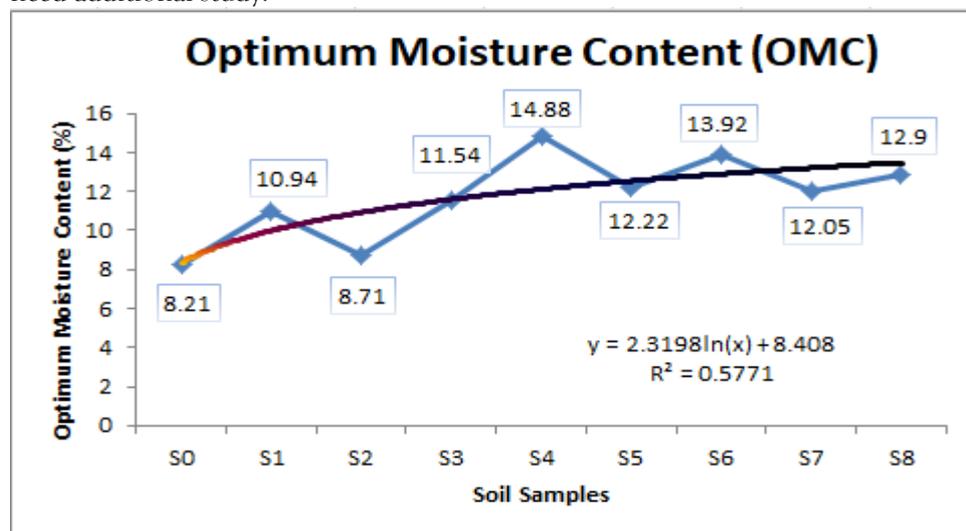


Figure: Effect of SS & G.S on OMC of soil sample-1

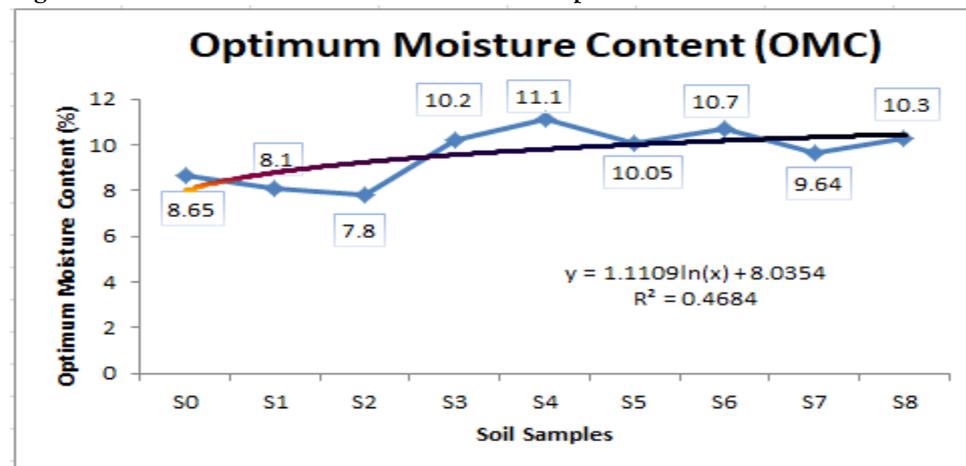


Figure: Effect of SS & G.S on OMC of soil sample-2

**Discussion:**

The two soil samples exhibited significant differences in compactness at their optimal moisture content (OMC). A comparative analysis shows that both soil types reduce OMC over the sample range, indicating increased compaction and composition changes. Clay reduction or an increase in non-cohesive elements like sand and silt, which need less water to reach maximum dry density, may explain this trend. The lower OMC values in both cases indicate improved compaction moisture efficiency, which is desirable for construction. Due to lower peak compaction water usage, managing less OMC is easier and cheaper. Individual sample variances may be related to regional soil gradation, organic matter, or mineralogy and should be investigated. Statistics show that stabilization or natural grading can modify soil structure and compaction moisture. This may affect foundation performance and site preparation.

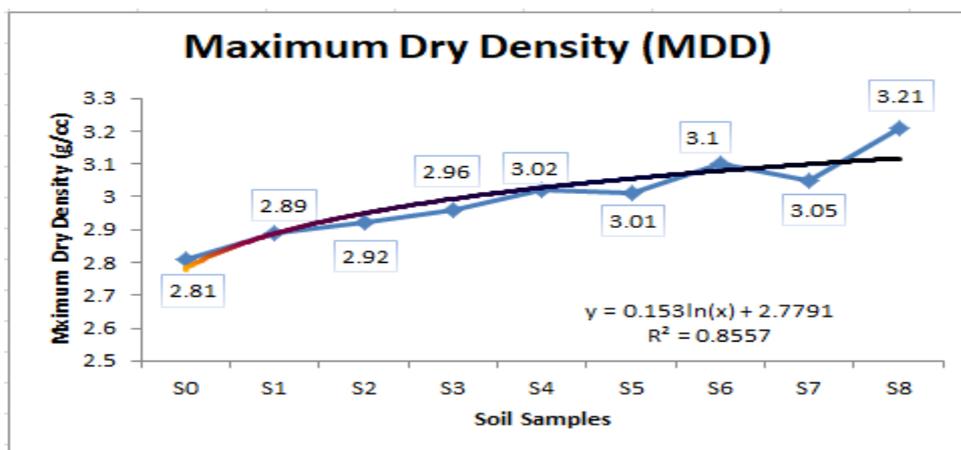


Figure: Effect of SS & G.S on MDD of soil sample-1

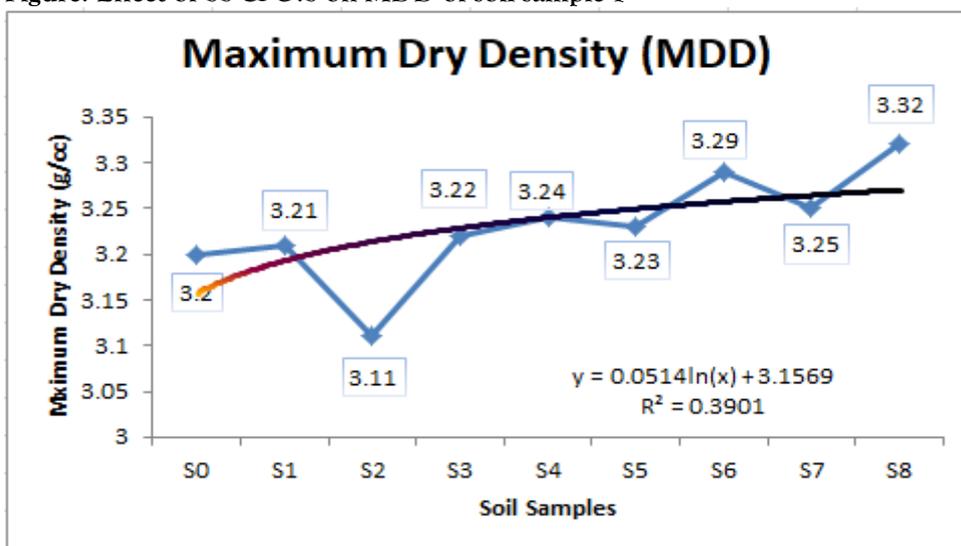


Figure: Effect of SS & G.S on MDD of soil sample-2

**Discussion:**

The comparison of MDD values shows that Sample 1 has a higher maximum dry density than Sample 2. This means that Sample 1 has a denser and more compactable soil structure. The difference in MDD might be due to differences in the mineral content, plasticity, and particle size distribution of the two soil samples. Sample A's larger MDD suggests that it can hold more weight and may not settle as much under structural pressures. The lower MDD in Sample 2 might be due to the presence of more organic material or small particles, which makes it difficult to compress. These results are essential for picking the right soils for subgrade, embankment, and earthworks projects because density has a direct effect on how well they operate.

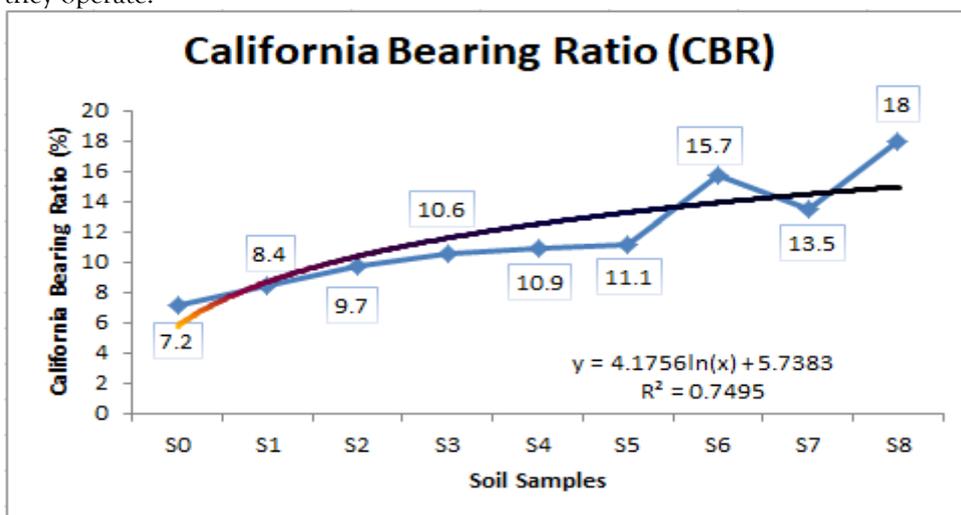


Figure: Effect of SS & G.S on CBR of soil sample 1

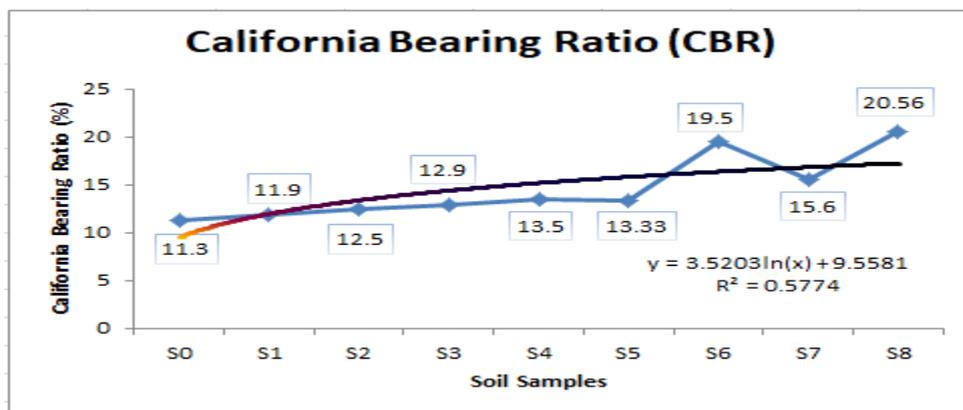


Figure: Effect of SS & G.S on CBR of soil sample-2

**Discussion:**

Soil Sample 1's CBR value was much greater or lower than Soil Sample 2's, which means that it could hold more or less weight. The fact that the CBR value increased as the penetration depth increased showed that Soil Sample 1 was more solid and compacted than Soil Sample 2. The discrepancies in CBR values are due to differences in the kind of soil, the way it is graded, the amount of moisture it has, and the amount of effort put into compacting it. A higher CBR value in one of the samples meant that it may be used for subgrade or sub-base layers in pavement construction. A lower value, on the other hand, suggested that stabilization or soil improvement was needed. These data are beneficial for making geotechnical decisions and designing pavements for different types of sites.

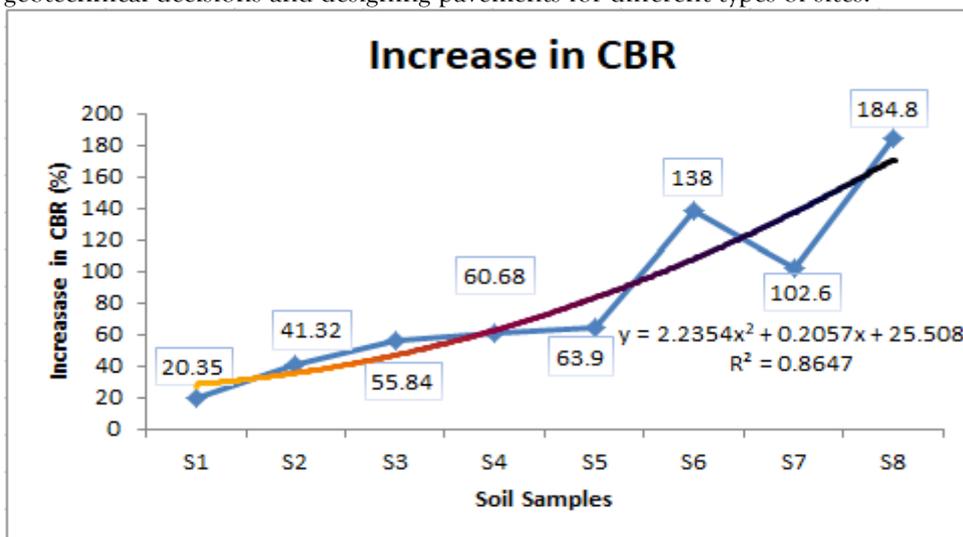


Figure: Effect of SS & G.S on CBR Increase of soil sample-1

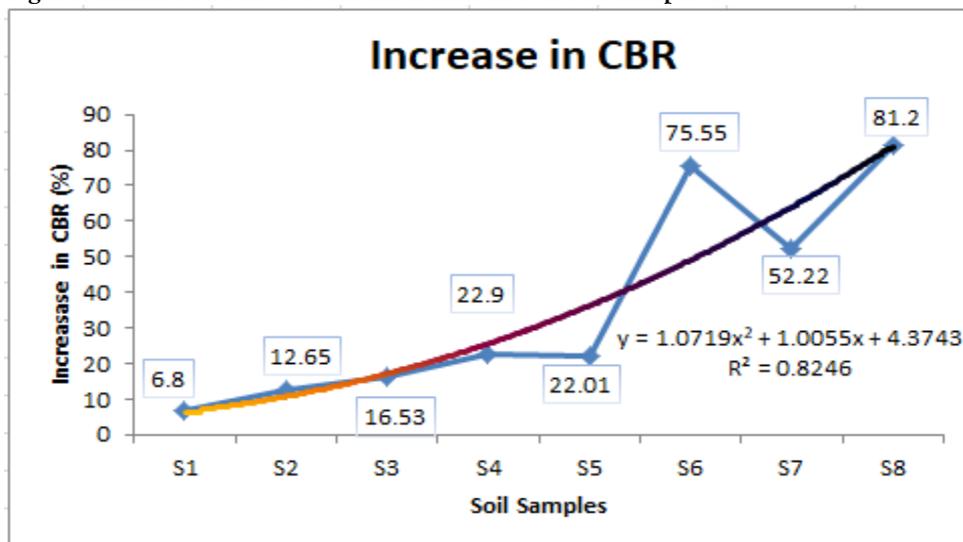


Figure: Effect of SS & G.S on CBR Increase of soil sample-1

## DISCUSSION:

The CBR values of both soil samples revealed an apparent increase, which suggests that the study's procedures for treating or changing the soil had made it better able to hold loads. Soil sample 2 reacted better to the stabilization method used, as evidenced by its CBR improving by a larger proportion than sample 1. The rise in CBR values shows that the stabilization approach worked (for example, lime, cement, or an additive), which made the subgrade much stronger. The post-treatment CBR values of both soils are within the acceptable range for pavement subgrade design, which makes them more suitable for building roads. The differences in CBR improvements highlight the importance of evaluating the site before stabilization and demonstrate the distinct characteristics of the two soil types.

## CONCLUSION

- This study sought to ascertain the effects of glass powder and steel slag on the geotechnical characteristics of soil mixtures. In this case, steel slag was added to the soil in different proportions as aggregate with a diameter of about 12 mm, and glass powder was added as filler after going through filter # 200. The following are the main conclusions drawn from this study:
- Because GP and SS are pozzolanic and cementitious ingredients, the plasticity index dropped as the amount of steel slag and glass powder rose. Because it contains amorphous silica and other oxides, it tends to increase the packing capacity of soil particles. 20% SS and 10% GP experienced the most considerable PI reduction. The results showed that as the steel slag level increased, OMC rose at 5% glass powder content but decreased at 10% glass powder content. Because SS absorbs more water than GP, it takes more water to reach MDD. The maximum dry density increased when both GP and SS improved. This is because the soil combination becomes denser due to the cementitious and binding properties of SS and GP. The most significant increase in MDD was observed at 10% GP content and 20% SS content.
- Since GP and SS are cementitious and pozzolanic, adding more of both increases the California bearing ratio. Because it contains amorphous silica and other oxides, it tends to increase the packing capacity of soil particles. The most significant increases in CBR were observed at 10% GP and 20% SS content.

## Recommendations

The substantial use of glass powder and steel slag in soil to lessen environmental issues is demonstrated by this experimental investigation. Because the maximum UCS was found at 5% GP and 20% SS addition in the soil, and because the CBR and MDD were also sufficiently increased at this ratio, the building manufacturing industry is strengthened by using 5% GP and 20% steel slag in soil mixtures as filler material and aggregates, respectively, with only minor effects on other soil properties.

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