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Strength Amplification of Expansive Soil Using Phosphogypsum

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ABSTRACT

This research highlights the effectiveness of phosphogypsum in reducing the expansive nature of A-6 soil. This paper includes a thorough analysis into the usage of phosphogypsum as a soil stabilisation material for A-6 soil, which is classified as clayey soil as per AASHTO classification system. The study looks at how different percentages of phosphogypsum (3%, 6%, 9%, 12%, and 15%) affect many critical soil parameters, including Atterberg's limits, compaction, hydraulic conductivity and CBR. The experimental results reveal that phosphogypsum greatly enhances soil properties. The liquid limit decreased from 69% to 58%, but the plastic limit climbed slightly from 25.17% to 25.94%. As a result, the plastic index improved, and the optimal moisture level increased from 10.4% to 11.4%. The maximum dry density dropped from 1820 kg/m³ to 1500 kg/m³. The hydraulic conductivity of soil fell from 9.67E-07 cm/s to 5.7E-07 cm/s. The California Bearing Ratio (CBR) values also improved, rising from 4.61% to 7.95%. The variation in values shows that phosphogypsum is an effective soil stabilisation material in civil engineering applications.

KEYWORDS: Expansive soil, Phospogypsum, CBR, Hydraulic Conductivity.

1. INTRODUCTION

Soil stabilisation is most commonly exercised in embankment, foundation, and pavement projects, particularly road construction [1]. Soil stabilization improves the machinal and physical properties of natural soil. These attributes primarily include strength, volume, stability, and durability [2]. It also helps to reduce the entire cost of the project, as economy is a crucial element in determining the pace and quality of work. Most pavement building operations are hampered by poor soil [3]. Such soil, due to its composition and particle size distribution, might cause extra engineering issues that must be addressed. AASHTO classifies this type of soil in categories ranging from A-4 to A-7 [4]. Soil stabilisation is vital in any construction project since soil is the primary foundation material upon which the entire structure is built. As a result, any construction must have a material that is strong enough to carry its load [5]. The primary goal of soil stabilisation is to increase the bearing capacity of soil. Several additives have been used in soil stabilization like lime, stone dust, tyre shreds, salts, rice husk, plastic bags and mixture of more than one of the above [1]. The use of waste products like waste plastic materials [4], waste beverage cane [5], glass waste [6], cement waste dust [7] is analyzed as a soil stabilization material by several researchers. This work focuses on the use of an industrial waste like PG as a soil stabilization material. Earlier work on PG shows that it has been used as filler for bricks [8] and as a binder [9]. PG is a waste product which is produced during the production of phosphoric acid from phosphate rock in the fertilizer companies in the production of fertilizers. Approximately 300 million tonnes of PG are produced annually worldwide, and it is primarily disposed of in enormous stockpiles or released into aquatic bodies [10]. The production of 1 ton of fertilizer produces 5 tons of PG as a by waste product [11]. The Large amounts of leftover PG can be reused by mixing it with weak soil for strength improvement. This material includes naturally occurring radioactivity, and 226Ra is the primary source of radiation. [8]. The use of PG, which is an unconventional material, in soil will not only improve the strength characteristics of soil but will also utilize the mammoth dumps of PG because it is more environmentally sound to use waste and hazardous products rather than dump it.

2. MATERIALS AND METHODOLIGY

2.1 Materials Used

Following materials are used in this research work.

2.1.1 Soil

In this investigation, A-6 Soil (according to AASHTO classification) was used. The soil was gathered from Chakwal District in Punjab, Pakistan. This region's soil is predominantly A-6 according to the AASHTO classification. The soil sample (A-6 soil) contains approximately 29% sand and 60% fines (silt and clay).

Table 1: Properties of Soil

Soil Properties	Specifications
AASTHO Classification	A-6
Liquid Limit (%)	34.6
Plastic Limit (%)	17.96
Plasticity Index	16.59
OMC (%)	10.63
Max. Dry Density (kg/m3)	2039

2.1.2 Phosphogypsum

In this investigation, PG is used an admixture for stabilization of A-6 soil. PG is a waste product resulted in the production of fertilizer. PG was obtained from fertilizer industry and was sun dried before use.

3. METHODOLOGY

The study focused on soil classification and selecting the desired A-6 type for further tests. Sieve analysis and Atterberg's limits tests were conducted on oven-dried soil, while hydrometer analysis was performed to determine particle sizes and percentage passing. The Modified Proctor Test was conducted to determine the Optimum Moisture Content and Maximum Dry Density for each proportion of PG. A falling head permeability test was conducted on bare, and soil supplemented with PG, using the standard approach outlined in ASTM D5084. Soaked California Bearing Ratio tests were conducted on bare and PG-amended soil samples, using a 5mm sieve. Sample moulds for CBR were prepared at the calculated optimum moisture content. All samples were placed in a water tank for 96 hours to determine the swell index. After draining completely, each sample was placed in a test assembly, allowing a 50mm diameter plunger to penetrate the surface at a deformation rate of 1.25mm per minute.

4. RESULTS AND DISCUSSIONS

This section demonstrates the geotechnical properties of the A-6 soil tested with 0%, 3%, 6%, 9%, 12% and 15% of PG. The soil used has a specific gravity of 2.63 and percentage passing through sieve No. 200 is 74.99%.

4.1 Modified Compaction Test

A modified compaction test was carried out on A-6 soil with varied PG percentages (0%, 3%, 6%, 9%, 12%, 15%) to investigate the relationship between moisture content and dry density. The results showed that increase in the PG percentage the OMC fluctuate but does not increase or decrease linearly. Results described in figure 1. Because of the fine particles of PG, PG treated soil has almost same water holding capacity like pure soil. However, the maximum dry density decreased due to lighter particles. Results are shown in figure 2.

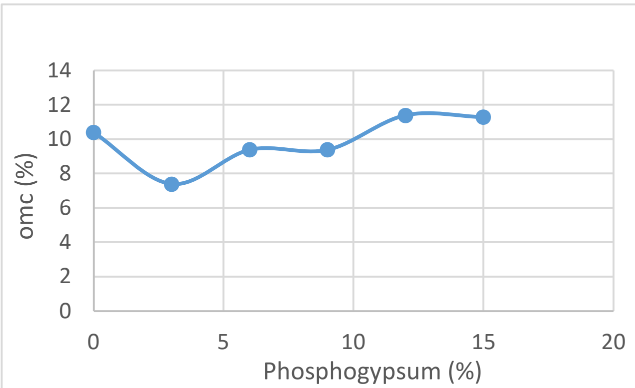

Figure 1:PG (%) vs OMC (%)

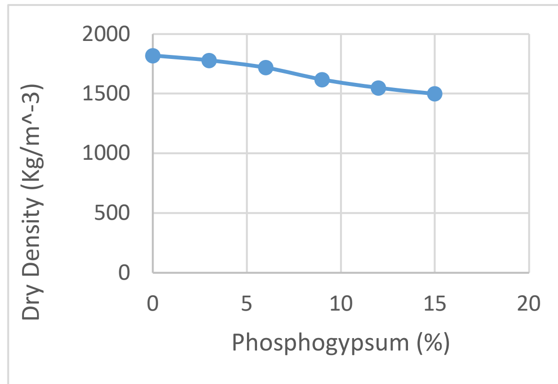

Figure 2: PG (%) vs Dry Density

4.2 Atterberg's Limits

The Atterberg's limits (Liquid limit, Plastic limit, and Plasticity Index) test is performed on pure soil for AASTHO soil classification and on PG treated soil with varying percentages of PG (3%, 6%, 9%, 12%, 15%) to investigate the variation of Atterberg's limit with varying PG content. A soil sample passing through a 5 mm sieve was used to estimate the liquid limit, plastic limit, and plasticity index. The test findings demonstrate that the liquid limit decreases with increasing PG content. Figure 3 depicts the variance of liquid limits. An increase in PG % has no significant effect on plastic limit. Figure 4 shows the results.

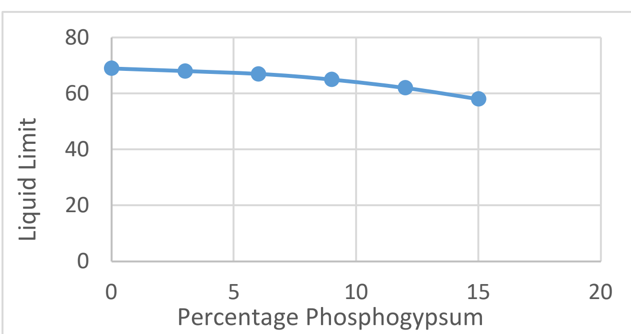

Figure 3: PG (%) vs Liquid Limit (%)

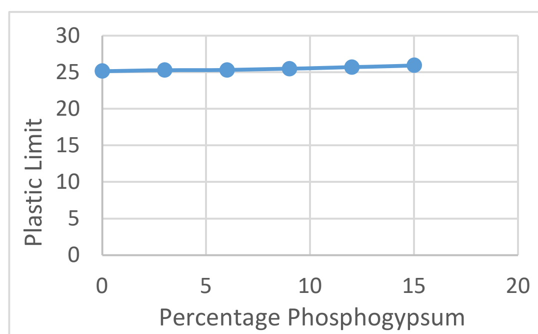

Figure 4: PG (%) vs Plastic Limit (%)

4.3 Hydraulic Conductivity:

The hydraulic conductivity coefficient is determined by a falling head permeability test on pure and PG treated soil, using ASTM D: 5084-10 protocol. Soil was treated with varying PG concentrations (3%, 6%, 9%, 12%, 15%) and remoulded at 90% relative maximum dry density.

Results show that increasing PG percentage decreases hydraulic conductivity and the soil will have less permeability, as shown in Figure 5.

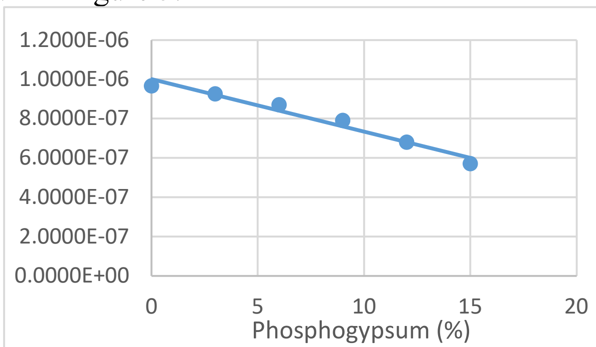

Figure 5: PG (%) vs Permeability (cm/s)

4.4 California bearing ratio:

California bearing ratio experiments were performed on soil treated with PG at various percentages (3%, 6%, 9%, 12%, and 15%) in accordance with ASTM D1883-16. Three CBR moulds were prepared and submerged in water for 96 hours. The results demonstrated an increase in CBR value with increasing PG percentage, with a maximum value at 12% and then start decreasing.

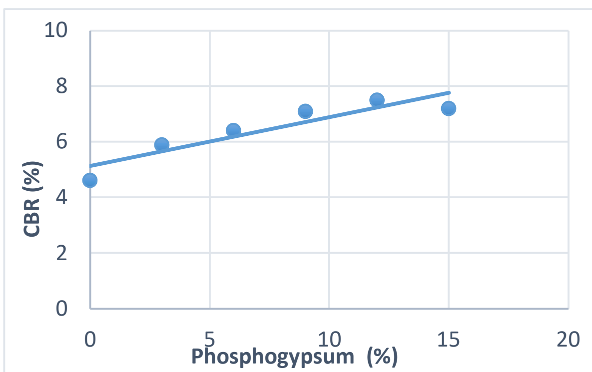

Figure 6: PG (%) vs CBR (%)

5. CONCLUSION

- The liquid limit decreased from 69% to 58% but the plastic limits of the soil increased from 25.17% to 25.94% which is not a notable change. This shows water holding capacity of soil was decreased.
- Addition of PG results in a decrease in the maximum dry density (from 1820 kg/m3 to 1500 kg/m3) and increase in the optimum moisture content of soil (from 10.4% to 11.4%).

- Due to highly fine particles of PG, the addition of PG has decreased Hydraulic Conductivity of soil from $9.67E^{-07}$ cm/s to $5.7E^{-07}$ cm/s.
- The California Bearing Ratio value of soil was increased from 4.61% to 7.5% with the increase in PG concentration from 0% to 12%.

6. REFERENCES

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