# Laboratory Evaluation of CBR Values in Geopet-Reinforced Sandy Soils: Modeling with the RSM Method

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## Abstract

**The increasing production of solid waste has become an international concern for engineers. One effective approach to addressing this issue is the reuse of solid waste for the improvement of construction sites and loose soils. Among the methods of soil reinforcement or stabilization is the use of polyethylene terephthalate (PET) and fly ash (FA), both of which are derived from industrial and urban waste. In this study, the California Bearing Ratio (CBR) test was conducted on both unreinforced and reinforced sands from Bandar Anzali, using Geopet with mesh sizes of 1×1, 2×2, and 3×3 cm. The sands were also stabilized with fly ash at weight percentages of 5%, 10%, and 15%, with sodium hydroxide as a fly ash activator. Additionally, in the current analysis, the Response Surface Methodology (RSM) was employed to determine the significant relationships between the percentage of fly ash, Geopet layers, and their interactions on CBR. Ultimately, RSM was used to evaluate CBR in a consistent and efficient manner in this study. The P-value in the applied model is less than 0.0001, indicating the model's effectiveness. The results show that the optimal scenario involves the use of Geopet with a mesh size of 1×1 cm combined with 15% fly ash, in which the CBR value increased by 2.7 times compared to the unreinforced condition.**

## KEYWORDS

**Bandar Anzali sand, Geopet, fly ash, California Bearing Ratio (CBR), Response Surface Methodology (RSM)**

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## ۱. Introduction

Various mechanical methods and natural or synthetic materials are available to improve soil behavior, with the selection depending on factors such as environmental considerations, economic viability, and structural aspects [1]. One method of soil improvement is reinforcement using fibers and filaments. Since the disposal of plastic waste without harming the ecosystem has become increasingly challenging [2], the reuse of polyethylene terephthalate (PET) waste in soil stabilization can significantly reduce its environmental impact [3, 4]. Increasing the soil's bearing capacity using natural or synthetic fibers is a suitable approach for soil reinforcement and improvement [5]. Plastic, as a synthetic fiber, has been consistently used for soil reinforcement .

To evaluate the obtained response expressed through various parameters, researchers utilize a mathematical model [6, 7]. Branches of Design of Experiments (DOE) aim to create a precise experimental design using a set of mathematical and statistical techniques. In recent years, Response Surface Methodology (RSM) has been actively applied to engineering problems and is considered a key component of DOE [8]. By integrating mathematics and statistics, RSM not only reflects the outcomes derived from various experiments but also visualizes the correlation effects between variables through 3D plots. The assessment of the mechanical properties of soil and concrete has thoroughly confirmed the efficiency of this method [9, 10]. Ultimately, RSM has been selected to evaluate the California Bearing Ratio (CBR) of soils stabilized with fly ash and Geopet.

## ۲. Materials and Methods

### ۲,۱. Geopet

PET (Polyethylene Terephthalate) is the most common form of plastic waste found on land. It is essentially a polyester polymer with a transparent surface, resistant to chemicals, easily producible, and economically viable [11]. In this study, Geopet sheets with mesh sizes of 1×1, 2×2, and 3×3 cm² and a thickness of 0.8 mm were used. The PET sheets were produced in rolls at a manufacturing plant, and then Geopet sheets were cut using laser cutting equipment with an accuracy of 0.1 mm, as shown in Figure 1.

### 2.2. Sample Preparation

The CBR test was conducted on soil with moisture content below the optimum level. The soil was compacted in four layers, with each layer compacted to 70% of the dry density to ensure the total mass of the soil in the mold reached a specified volume. After compacting each layer, a plastic sheet was horizontally placed within the sample. The diameter of the plastic sheet was slightly smaller than that of the sample. All unreinforced and reinforced samples were subjected to rupture at a strain level of 15% with a strain rate of 0.5% per hour. Modifications were made for permeability and membrane strength, cell swelling, and cross-sectional area. Geogrid with dimensions of 1×1, 2×2, and 3×3 cm² was used in three layers at different heights.

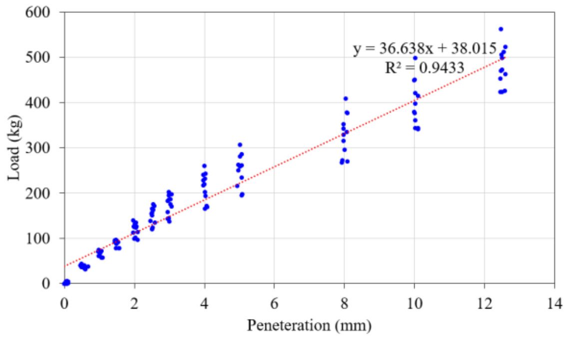


**Figure 1. Relationship between penetration and bearing capacity ($R^2$ = 0.94)**

## 3. Discussion and Results

The results indicated that an increase in the penetration of the steel plunger into the soil leads to increased tensile force; initially, there is a sharp increase (up to about 4 mm of penetration), after which the slope of the load-penetration curves gradually decreases beyond 4 mm of penetration. This behavior reflects the gradual penetration of the plunger into the soil. The load-penetration curves demonstrate that the use of Geopet prevents the failure of the samples by restricting the movement of soil particles. As the load penetrates the soil surface, the Geopet layers in the sand are gradually subjected to tensile stress, and due to the stiffness of Geopet, the layers deform and apply an upward force to support the load. This mutual loading (by the steel plunger and Geopet) causes greater interlocking of soil particles with the Geopet apertures. Moreover, the tension in the Geopet layers shows that their resistance to the applied load has been mobilized. Table 1 presents the CBR values of various soil samples.

**Table 6. CBR Values of Reinforced and Unreinforced Soil**

| CBR Value | | | Sample |
|---|---|---|---|
| ۱۰/۵۴ | | | Unreinforced Soil |
| One Layer of Geopet | | | Reinforced Soil |
| Size of Aperture (cm²) | | | |
| ۳x۳ | ۲x۲ | ۱x۱ | |
| ۱۱/۸۹ | ۱۲/۶۳ | ۱۳/۶۹ | |
| two Layers of Geopet | | | |
| Size of Aperture (cm²) | | | |
| ۳x۳ | ۲x۲ | ۱x۱ | |
| ۱۳/۵ | ۱۳/۹۸ | ۱۴/۹۹ | |
| three Layers of Geopet | | | |
| Size of Aperture (cm²) | | | |

| | | | |
|---|---|---|---|
| ۳x۳ | ۲x۲ | ۱x۱ | |
| ۱۳/۹۶ | ۱۵/۲۹ | ۱۶/۲ | |

## 4. Conclusion

- Curing for seven days resulted in an increase in penetration strength with longer curing times. This allowed the internal reactions within the material to progress further, enhancing the strength of the samples. Additionally, over time, the water within the geopolymer gradually evaporates, leading to the collapse of capillary pores and the formation of a denser structure, which increases compressive strength and subsequently improves CBR values. As the results indicate, the CBR of the uncured sample under similar conditions was 15.3% lower .
- The mathematical models based on RSM (Response Surface Methodology) demonstrated a strong correlation with the experimental findings. These results provide clear evidence that the proposed approach for estimating the CBR of soil stabilized with fly ash and Geopet is promising and highly valuable.

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