# Bearing capacity of mixed soil model

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**ABSTRACT.** The main objective of this research is the improvement of red soil by the addition of construction materials. This method could provide a scientific way to create a soil foundation with sufficient stability against geo-technical problems or instabilities. Laboratory tests have been conducted to characterize the behavior of red soil when amended with different types of gravels, soils and sand under compacted conditions with Optimum Moisture Content (OMC). Safe bearing capacity of all models have been calculated to identify the best and worst soil mixed model.

**KEYWORDS.** Red soil; shear stress; soil improvement; bearing capacity

## INTRODUCTION

Soil mixing to stabilize soft or loose soils is considered a fairly new technology in the United States. This technique has been applied to improve and stabilize cohesive and cohesion-less soils under static loads. Successful applications include liquefaction mitigation, steel reinforced retaining walls, groundwater cutoff walls, and stabilization of contaminated soils. Applications of this technology have recently expanded to settlement control of soils, slope stabilization and the formation of composite gravity structures. Design for these applications requires the unconfined compressive strength, elastic modulus and shear strength of the soil and soil-cement columns must be determined or estimated. On a recent project in Honolulu, Hawaii, loose soils were sufficiently stabilized with a 23% treatment ratio, and at a site in Lakeland, Florida, a very soft and compressible clay layer was sufficiently stabilized with only a 12% treatment ratio. In slope stability applications, soil mixing improves the overall shear strength of the soil to adequately increase the factor of safety, and also the soil-cement columns can force the potential failure surface deeper. Lastly, soil mixing has been applied to construct in-situ gravity structures where its composite action design assumption was confirmed with an instrumented test wall, and used in two recent commercial applications [1]. Another soil-cement mixing method uses jet grouting as a technique to improve the bearing capacity of sub-base foundation. This method reduces total settlement and increases shear strength of the soil foundation [2]. Soil amendment is one of the economic techniques to improve soil bearing capacity and it guarantees achievement of safe soil bearing capacity in any situation with minimum time consumption. Wide ranges of soils have shown improved soil characteristics based on application of the technique of soil mixing. In this regard, laboratory testing plays a critical role in assessing soil properties. This investigation is invaluable in terms of providing recommendations concerning site improvement. Several laboratory experiments are required for developing the soil-mixing model necessary for reliable field application (a rational assessment selecting soil property for improvement of soil bearing capacity should include a logical investigation in laboratory testing method for accurate interpretation of results providing feasible data in field application).

The research presented is the state of-the-practice for soil foundation bearing capacity over a wide range of soil foundation improvements.

## METHODOLOGY AND EXPERIMENT

The experiments are conducted by the direct shear test method, in the Geo-technical Engineering Laboratory of S. J. College of Engineering- Mysore, to evaluate mixed soil characteristics. Using the current experiments, several models have been developed to improve red soil (plastic soil) by mixing with sand, gravels and non-plastic soils. In this investigation liquid limit, plastic limit, wet sieve analysis, standard compaction test and direct shear test have been employed to characterize accurate behavior of models in the laboratory. Calculation of the safe bearing capacity of any mixed soil is done using the Terzaghi calculation method. The necessary factors to characterize soil foundation include, C, Φ, moisture and unit weight of the soil, which are used to find the best safe bearing capacity of soil. Materials have been used for creation of the model illustrated in Table. 1. All models have an assumed depth of 1.5 m and widths of 2.5 x 2.5 ft$^2$, that are used in calculation of safe bearing capacity.

| Sl. No | % Of Red Soil | % Of Sand | % Of Gravel 4.75 mm | % Of Gravel 2 mm | % Of Black Soil | % Of Green Soil | % Of Dark Brown Soil | % Of Yellow Soil | % Of Light Brown Soil |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 55 | 45 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 55 | 0 | 45 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 55 | 0 | 0 | 45 | 0 | 0 | 0 | 0 | 0 |
| 5 | 55 | 15 | 15 | 15 | 0 | 0 | 0 | 0 | 0 |
| 6 | 55 | 0 | 0 | 0 | 45 | 0 | 0 | 0 | 0 |
| 7 | 55 | 0 | 0 | 0 | 0 | 45 | 0 | 0 | 0 |
| 8 | 55 | 0 | 0 | 0 | 0 | 0 | 45 | 0 | 0 |
| 9 | 55 | 0 | 0 | 0 | 0 | 0 | 0 | 45 | 0 |
| 10 | 90 | 0 | 0 | 0 | 2 | 2 | 2 | 2 | 2 |
| 11 | 80 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 |
| 12 | 70 | 0 | 0 | 0 | 6 | 6 | 6 | 6 | 6 |
| 13 | 60 | 0 | 0 | 0 | 8 | 8 | 8 | 8 | 8 |
| 14 | 50 | 0 | 0 | 0 | 10 | 10 | 10 | 10 | 10 |
| 15 | 70 | 0 | 0 | 0 | 10 | 10 | 10 | 0 | 0 |
| 16 | 70 | 0 | 0 | 0 | 10 | 10 | 0 | 10 | 0 |
| 17 | 70 | 0 | 0 | 0 | 10 | 10 | 0 | 0 | 10 |
| 18 | 70 | 0 | 0 | 0 | 10 | 0 | 10 | 10 | 0 |
| 19 | 70 | 0 | 0 | 0 | 10 | 0 | 10 | 0 | 10 |
| 20 | 70 | 0 | 0 | 0 | 10 | 0 | 0 | 10 | 10 |
| 21 | 70 | 0 | 0 | 0 | 15 | 15 | 0 | 0 | 0 |
| 22 | 70 | 0 | 0 | 0 | 15 | 0 | 15 | 0 | 0 |
| 23 | 70 | 0 | 0 | 0 | 0 | 0 | 0 | 15 | 15 |
| 24 | 70 | 0 | 0 | 0 | 15 | 0 | 0 | 15 | 0 |
| 25 | 70 | 0 | 0 | 0 | 15 | 0 | 0 | 0 | 15 |
| 26 | 70 | 0 | 0 | 0 | 0 | 15 | 15 | 0 | 0 |
| 27 | 70 | 0 | 0 | 0 | 0 | 15 | 0 | 15 | 0 |
| 28 | 70 | 0 | 0 | 0 | 0 | 15 | 0 | 0 | 15 |
| 29 | 70 | 0 | 0 | 0 | 0 | 0 | 15 | 15 | 0 |
| 30 | 70 | 0 | 0 | 0 | 0 | 0 | 15 | 0 | 15 |
| 31 | 55 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 45 |

Table 1: Mixed soil models.

For all models, real soil characteristics were considered in order to assess soil foundation improvement. It has been done by performing laboratory tests thorough the interpreting of the test results. Formulas for calculation of safe bearing capacity, are the following:

$$q_f = 1.3C\,N_c + \gamma D\,N_q + 0.4\,\gamma B\,N_\gamma \quad (1)$$

$$q_{nf} = q_f - q_{nf} = q_f - \gamma D \quad (2)$$

$$q_s = (q_{nf} / F) + \gamma D \quad (3)$$

Also $N_q$, $N_c$ and $N_\gamma$ are the general bearing capacity factors and depending upon
1) Depth of footing;
2) Shape of footing;
3) Φ, friction angle.
These parameters have been used from suggestion by the Terzaghi calculation method [3].

## RESULT AND DISCUSSION

In order to determine soil morphological characteristics, wet sieve analysis has been employed. Morphology of seven soils have been used in developing models, as shown in Tab. 2 and Fig. 1. Among all soils, red and black soils have the most linear distribution of particles. Tests of liquid limit and plastic limit, indicated that black green, yellow, dark brown and light brown soils are not plastic soils, and only red soil is a plastic one. Results of liquid limit and plastic limit are mentioned in Tab. 3, 4 and Fig. 2. Red soil has liquid limit of 32.7% and plastic limit of 17.785%. Red soil has been selected for evaluation of its characteristics because of its plasticity. This will allow the eventual improvement of red soil as a construction and sub soil material.

| Sl. No | Diameter of Sieve | COF Red Soil | COF Sand | COF Dark Brown Soil | COF Yellow Soil | COF Green Soil | COF Light Brown Soil | COF Black Soil |
|---|---|---|---|---|---|---|---|---|
| 1 | 4.75 | 100 | 100 | 99.59 | 100 | 100 | 100 | 96.94 |
| 2 | 2 | 99.58 | 96 | 89.10 | 99.6 | 99.6 | 92.6 | 91.83 |
| 3 | 1 | 94.16 | 79.8 | 50.15 | 99 | 99.4 | 73 | 83.66 |
| 4 | 0.6 | 88.12 | 63.2 | 36.23 | 98.6 | 99 | 63.2 | 80.59 |
| 5 | 0.425 | 86.24 | 50.6 | 33.40 | 98.2 | 98.8 | 59.6 | 78.55 |
| 6 | 0.3 | 71.24 | 7.6 | 22.10 | 93.8 | 98.2 | 48.2 | 67.52 |
| 7 | 0.212 | 61.86 | 2.8 | 16.45 | 86.8 | 97.6 | 40.4 | 60.77 |
| 8 | 0.150 | 58.94 | 1.8 | 14.84 | 75.2 | 97 | 34.6 | 56.88 |
| 9 | 0.075 | 55.40 | 1.2 | 11.61 | 68 | 95.2 | 31.6 | 52.19 |
| 10 | Received | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Table 2: Result of sieve analysis of soils (COF=Community Passing Finer).

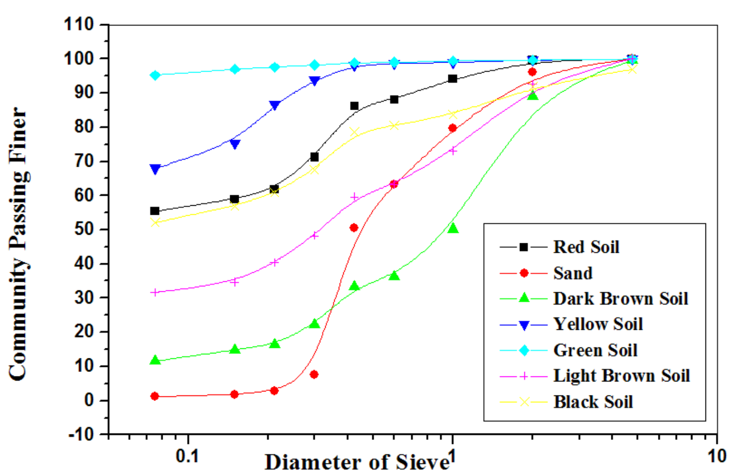


Figure 1: Result of soils sieve analysis.

Optimum Moisture Content (OMC) in all models ranges from 9.58 to 22.69. The maximum safe bearing capacity occurs when OMC is 10.72. It is shown that an increase of OMC is followed a decrease in safe bearing capacity. Model 3 has the best safe bearing capacity (3334.44 kN/m$^2$). It is made up of 55% red soil and 45% gravel with a diameter of 4.75mm. Model 29 has been developed from 70% red soil, 15% yellow and 15% dark brown soils and has a minimum safe bearing capacity (SBC) of 170 kN/m$^2$. Sand and gravels have the positive effect of increasing the angel of friction (Φ) in all models. Any model consisting of gravel has shown better unit weight (Tab. 5). The proper selection and evaluation of a soil improvement technique for a particular site is neither a simple nor a single out come proposition. Local conditions and judgment are integral parts in the decision making process [4]. Ground improvement by soil mixing has highly variable results, and this has a nonlinear impact on reliability analyses for soil foundation supported structures [5]. It is possible to study the influence of several factors affecting the mixing process simultaneously [6]. Deep soil mixing is an extremely valuable and competitive ground engineering technology if applied correctly, designed properly, and constructed efficiently [7]. The method has more engineering possibilities than many the competitive methods resulting in a great possibility for optimization of the ground improvement measure in the actual project [8]. Soil mixing provides an economical, reliable way of satisfying a difficult set of technical parameters [9]. The technique has also resulted in a shorter construction time schedule [10]. In Model 3 the maximum SBC is due to the combination of red soil and gravel 4.75 mm. The model shows good binding and cohesion of particles which lead to increasing the angle of friction, cohesion, unit weight and shear strength. These characteristics eventually decrease settlement, deformation and landslide of the soil foundation. Binding of particles in the model is dependent on particles shape as well as level of model compatibility, OMC and plasticity. Plasticity in the soil implies an increase of safe bearing capacity. If a model can achieve a high level of OMC, this could have less bearing capacity due to significant decreasing angle of friction in the model. Red soil's plasticity demonstrates good safe bearing capacity, while increased SBC has been shown from the addition of angular gravel.

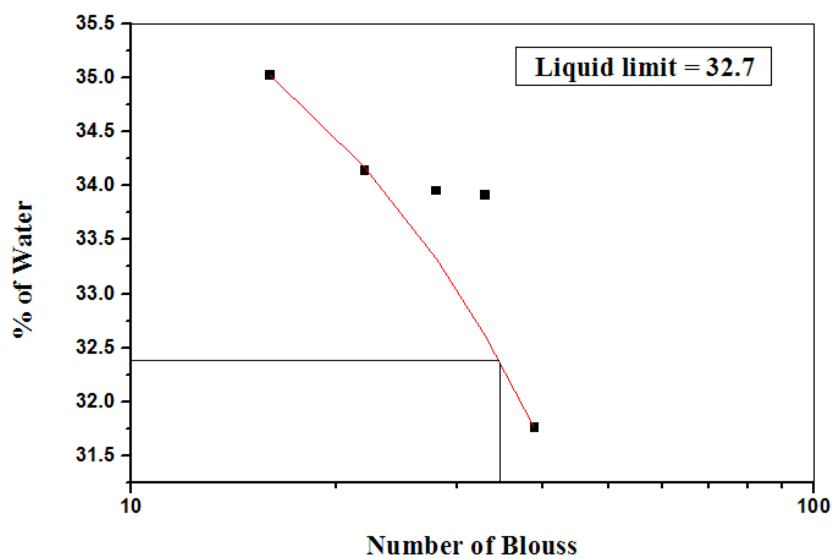


Figure 2: Result of liquid limit of red soil.

| Sl. No | Reading number | Cup number | Weight of wet sample | Weight of dry sample | Weight of cup | Weight of dry soil | Weight of water | % of water |
|---|---|---|---|---|---|---|---|---|
| 1 | 16 | 75 | 39.7 | 35.43 | 23.24 | 12.19 | 4.27 | 35.02 |
| 2 | 22 | 41 | 37.6 | 34.11 | 23.89 | 10.22 | 3.49 | 34.14 |
| 3 | 28 | 103 | 34.92 | 32 | 23.4 | 8.6 | 2.92 | 33.85 |
| 4 | 33 | 61 | 37.7 | 33.83 | 22.42 | 11.41 | 3.87 | 33.91 |
| 5 | 39 | 1 | 51.14 | 48.24 | 39.11 | 9.13 | 2.9 | 33.76 |

Table 3: Result of liquid limit of red soil

| Sl. No | Cup number | Weight of wet sample | Weight of dry sample | Weight of cup | Weight of Water | Weight of dry soil | % of water | Average % of water |
|---|---|---|---|---|---|---|---|---|
| 1 | 86 | 25.75 | 25.2 | 22.68 | 0.46 | 2.61 | 17.62 | 17.785 |
| 2 | 7 | 39.55 | 39.11 | 36.66 | 0.44 | 2.45 | 17.95 | |

Table 4: Result of liquid plastic of red soil (Plastic limit of red soil is 17.785%).

| Sl. No | Model No 1 | Optimum Moisture Content | γ [kN/m³] | Φ [°] | C [kN/m²] | S. B. C [kN/m²] |
|---|---|---|---|---|---|---|
| 1 | 1 | 11.2 | 21.94 | 38 | 21 | 2036.22 |
| 2 | 2 | 10.61 | 21.83 | 39 | 12 | 1926.51 |
| 3 | 3 | 10.72 | 23.46 | 39 | 46 | 3334.44 |
| 4 | 4 | 12.15 | 23.82 | 36 | 28 | 1833.97 |
| 5 | 5 | 9.58 | 23.02 | 40 | 8 | 2060.95 |
| 6 | 6 | 22.39 | 20.09 | 32 | 20 | 888.70 |
| 7 | 7 | 18.86 | 20.95 | 32 | 26 | 1026.83 |
| 8 | 8 | 14.56 | 23.35 | 18 | 44 | 427.74 |
| 9 | 9 | 14.23 | 20.96 | 30 | 28 | 718.00 |
| 10 | 10 | 16.83 | 21.61 | 36 | 22 | 1567.43 |
| 11 | 11 | 18.27 | 21.56 | 15 | 47 | 349.69 |
| 12 | 12 | 16.76 | 21.07 | 22 | 49 | 608.36 |
| 13 | 13 | 20.21 | 21.83 | 21 | 33 | 431.67 |
| 14 | 14 | 18.68 | 21.179 | 27 | 38 | 786.91 |
| 15 | 15 | 19.34 | 20.96 | 29 | 8.5 | 487.99 |
| 16 | 16 | 16.55 | 20.31 | 31 | 22 | 834.95 |
| 17 | 17 | 21.14 | 21.18 | 20 | 27 | 341.94 |
| 18 | 18 | 20.79 | 21.18 | 20 | 23 | 311.26 |
| 19 | 19 | 16.31 | 20.96 | 33.5 | 12 | 879.86 |
| 20 | 20 | 20.88 | 20.96 | 24 | 23 | 439.56 |
| 21 | 21 | 23.00 | 21.5 | 23 | 10 | 287.22 |
| 22 | 22 | 20.06 | 22.05 | 23 | 32 | 503.18 |
| 23 | 23 | 20.11 | 21.07 | 23 | 22 | 398.52 |
| 24 | 24 | 20.75 | 20.41 | 19 | 22 | 280.01 |
| 25 | 25 | 22.69 | 20.748 | 22 | 16 | 310.33 |
| 26 | 26 | 18.87 | 21.72 | 21 | 28 | 389.32 |
| 27 | 27 | 20.31 | 21.94 | 24 | 26 | 479.81 |
| 28 | 28 | 19.51 | 21.72 | 17.5 | 28 | 298.58 |
| 29 | 29 | 20.52 | 22.59 | 17 | 9 | 170.00 |
| 30 | 30 | 18.99 | 22.47 | 18 | 24 | 286.20 |
| 31 | 31 | 14.56 | 21.61 | 28 | 26 | 700.05 |

Table 5: Experiments Results.

## CONCLUSION

Red soil mixed angular gravel, 4.75mm, has a positive effect on increasing cohesion, angle of friction and unit weight of soil. These characteristics could increase soil foundation stability. Plasticity, morphology, compatibility and Optimum Moisture Content are the main factors involved in the soil safe bearing capacity. Proper morphology, plasticity, optimum moisture content in any soil mixed model could support stability of the soil foundation and disable forces applied to the soil mixed model.

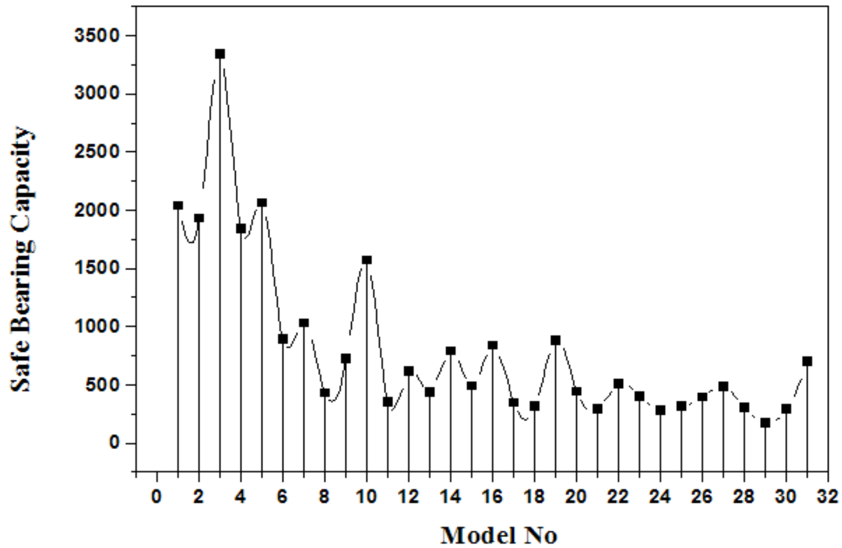


Figure 3: Model No vs Safe Bearing Capacity

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## NOMENCLATURE

| | |
|---|---|
| $\Phi$ [°] | = Friction Angle |
| C [kN/m²] | = Soil Cohesivity |
| OMC % | = Optimum Moisture Content % |
| SBC [kN/m²] | = Safe Bearing Capacity |
| $\gamma$ [kN/m³] | = Unit Weight |
| $q_f$ [kN/m²] | = Ultimate Bearing Capacity |
| $q_{nf}$ [kN/m²] | = Net Ultimate Bearing Capacity |
| $q_s$ [kN/m²] | = Safe Bearing capacity |
| $N_c$ | = General Bearing Capacity Factor |
| $N_q$ | = General Bearing Capacity Factor |

$N_{\gamma}$ = General Bearing Capacity Factor
B [m] = Foundation Width
D [m] = Foundation Depth
F = Safety Factor = 3