The Influence of Fines Content on Compaction Characteristics of Poorly-Graded Sands

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***Abstract*—In civil engineering, soil compaction refers to the process of raising soil density by reducing the volume of voids or air spaces inside it. This is done to improve the soil's engineering properties, making it more stable and capable of bearing heavy loads. Compacted soils are common foundation materials for buildings, roads, embankments and other infrastructure projects. Most construction projects use sand as a filling or foundation material because of its cost-effectiveness. But pure sand is difficult to get good compaction because sand grains are not sensitive to the compaction that causes their strong structure. According to previous researchers, the maximum dry density can be increased and the optimum moisture content can be decreased by increasing the fine content of sands. This means that increasing the fines percentage helps reach the densest state with the least water content. However, previous researchers have used fines that were sieved from the original sandy soil in the tests they performed. Hence, this research was focused on observing the variation of compaction characteristics by mixing a natural clay soil at different percentages and performing standard proctor tests in the laboratory. According to the standard proctor compaction test results, increasing the fines content increased both the maximum dry density and the optimum moisture content. But both the measured parameters were observed to have a decreasing trend for fine percentages beyond 15%.**

Keywords—Compaction characteristics, maximum dry density, optimum moisture content, standard proctor compaction test

I. INTRODUCTION

Compaction is a widely used simple ground improvement technique in the construction field. Soil will compact naturally by itself but the main purpose of the compaction is to get the required maximum dry density of soil quickly. It also improves the soil properties, reducing or preventing settlement, increasing soil strength, improving bearing capacity, controlling volume changes and also lowers the permeability. There are different methods that can be used for compact soil such as impact-sharp blow, pressure static weight, vibration shaking, kneading manipulation or re-arranging and different machineries are available such as sheep foot rollers, temping rollers, smooth-drum vibratory soil compactors, pad-vibratory soil compacters and pneumatic-tired rollers etc.

However, the variation of compaction characteristics depends on the soil types, and therefore, the methods and machines that should be used for soil compaction at the site will be varied. Furthermore, doing laboratory testing for compaction will help to study the effect of soil type on compaction characteristics [1]. There are two laboratory tests for compaction: standard and modified proctor compaction tests. According to ASTM D698 and AASHTO T99, for standard Proctor, the hammer weight is 5.5lb (2.5kg) and the drop height is 12 inches (305mm). According to ASTM D1557 and AASHTO T180-D, the modified Proctor method uses a 10 lb. (4.5kg) hammer with an 18-inch (457 mm) drop height for compaction. Therefore, the compaction energy that is applied by the modified proctor test is higher than the standard proctor test. However, based on a past research study, the correlation between maximum dry density and optimum moisture contents is unique for both proctor and modified proctor energy levels. [2]

If we collect a sand sample, it naturally contains some fines. Those fines can go through the voids and fill the voids effectively when compacting the soil sample. Also, water should be added to compact soil because it reduces the frictional force between soil grains. But soils will bounce back if we add more water content. According to past findings, an increase in the fines percentage increases the maximum dry density and requires less water content to reach the densest stage because the voids fill with fines and the volume of the voids decreases. Also, with an increase in fines, the optimum moisture content decreases because the voids to fill with water will decrease [3]. According to the Atterberg limit, fines can be categorized as plastic or non-plastic. Plastic fines give a higher percentage increase in maximum dry unit weight as compared to non-plastic fines [4]. Moreover, their experiment results show the percentage increase in maximum dry unit weight for plastic fines was more than twice that of non-plastic fines.

If the soil properties of sand can be improved by combining it with another type of soil, it will be beneficial for the whole construction process. However, either dynamic compaction or vibro-compaction should be used at the construction site for compacting sandy soils, and both of these methods involve high costs. If we can improve compaction characteristics by adding a proper content of fines, it will become more efficient to select the ideal sandy soil when selecting filling material for the construction. Therefore, it is needed to establish a relationship between the compaction characteristics of sands with different fine contents In this research, the variation of compaction characteristics of poorly graded sands with different fine contents will be discussed, the relationship between maximum dry density and optimum moisture content with different fine contents will be developed and finally, the effectiveness of fine content for sandy soils for proper compaction in the construction industry will be assessed.

II. Materials and Methods

A sandy soil sample was collected from a location in Meepe, Sri Lanka. Natural clay samples were collected from a paddy field located in Mirigama, Sri Lanka. Both the sandy soil sample and the clayey soil sample were dried for 24 hours at 100°C. Then, a sieve analysis test was done on the sandy soil sample to determine whether it was poorly graded or well graded. After clarifying the type of sandy soil, the entire sample was sieved to separate the sand grains by collecting the sand sieved in between the 4.75 mm and 0.075 mm sieves. Also, the oven-dried clay sample was crushed and sieved from the 0.075-mm sieve to separate pure fines. Then, after mixing 0%, 5%, 10%, 15% and 20% of clay soil into the sand, 25 standard proctor compaction tests were done for the sand sample according to ASTM D698. Finally, the moisture content and dry density values were measured to determine the relationship between them.

III. Results and Discussion

A. *Sieve Analysis Test*

Figure 1 shows the grain size distribution curve of the sandy soil sample taken for the experiment. This graph was used to determine the 10% passing (D_{10}), 30% passing (D_{30}) and 60% passing (D_{60}) grain sizes. Then the coefficient of uniformity (C_u) and the coefficient of curvature (C_c) were calculated.

The following equations (1) and (2) were used to find the values of C_u and C_c.

$$C_u = \frac{D_{60}}{D_{10}} \quad (1)$$

$$C_c = \frac{D_{30}^2}{D_{10} D_{60}} \quad (2)$$

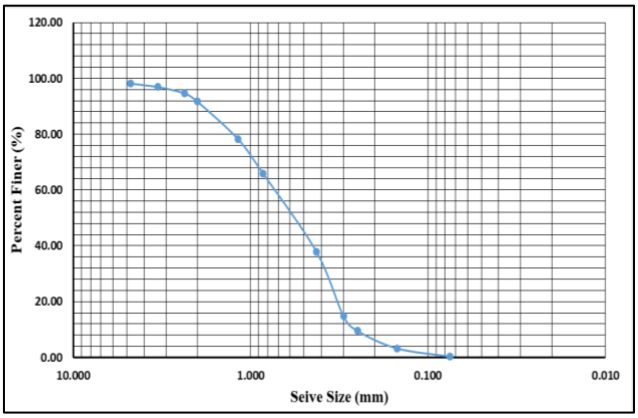

Fig. 1. Grain size distribution curve for sandy soil sample

The below Tab. 1 shows the values that were taken for the classification of the above sandy soil sample.

TABLE I. Important Values of Soil Classification for Sandy Soil Sample

Gravel %	1.98
Sand %	97.82
Fines %	0.29
D_{10}	0.255 mm
D_{30}	0.383 mm
D_{60}	0.762 mm
C_u	2.988
C_c	0.755
SG	2.6548

According to the Unified Soil Classification System (USCS), this sandy soil sample is a poorly graded sand.

B. *Standard Proctor Compaction Test*

Below Fig.2 illustrates the five compaction curves corresponding to the tests performed on the soil samples that were prepared by mixing different percentages of clay.

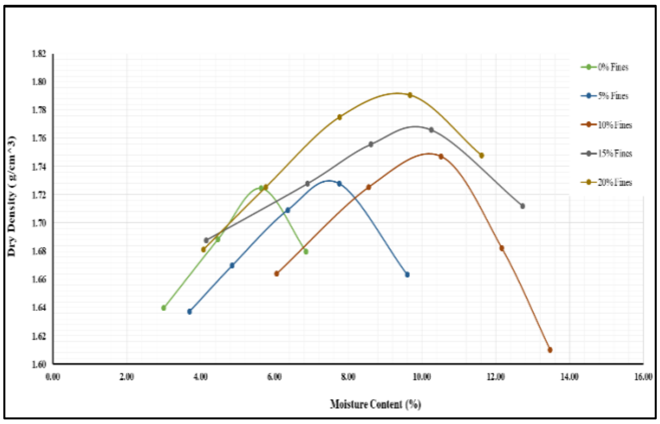

Fig. 2. Compaction curves for the sand sample

Figure 3 shows the variation of maximum dry density (MDD) with different percentages of clay content. The graph reveals that, the maximum dry density increases proportionally with the clay content.

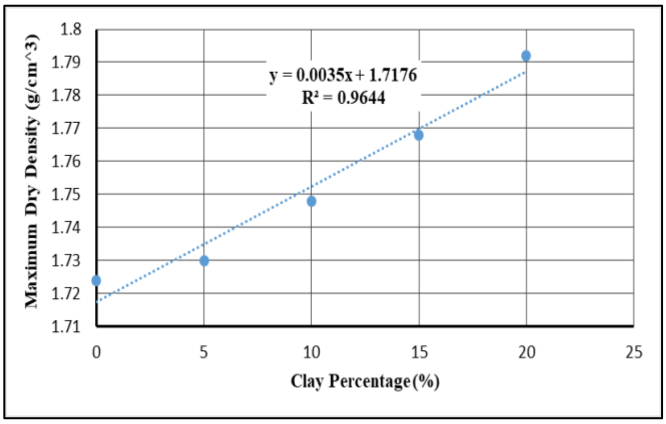

Fig. 3. The variation of MDD with different clay percentages

According to above figure, the relationship between the maximum dry density and clay percentage can be derived as a linear equation and the maximum dry density at 0% clay content, reads as $1.7176\,\mathrm{g/cm^3}$. The gradient of the line represents the increase of the MDD corresponding to the increase of the clay percentage.

Figure 4 shows the variation of optimum moisture content (OMC) with increasing percentages clay content.

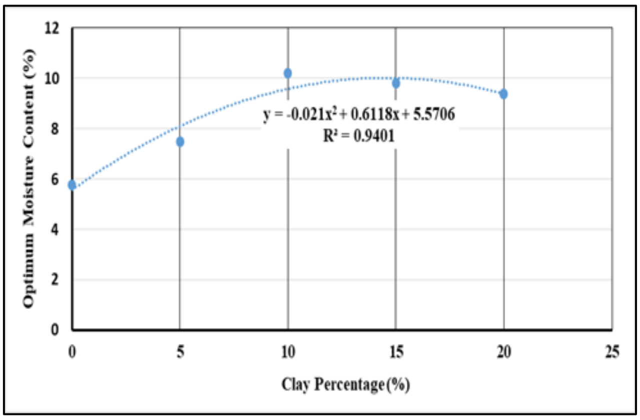

Fig. 4. The variation of OMC with different clay percentages

According to the above graph (Fig. 4), the optimum moisture content increases with the clay percentage up to a certain level and then commences a downward slope. The best fitting curve for the plotted data gives a 2nd degree polynomial with a R^2 value of 0.9401 (Equation 3), y being the OMC and x being the clay percentage.

$$y = -0.021x^2 + 0.6118x + 5.5706 \quad (3)$$

Hence, the clay percentage that gives the highest OMC, was derived (Equation 4 and 5) as 14.5667%.

$$\frac{dy}{dx} = -0.042x + 0.6118 = 0 \quad (4)$$

$$x = 14.5667 \quad (5)$$

IV. Conclusion

Based on the above standard Proctor test results, increasing the natural clay content caused an increase in maximum dry density because the voids were filled by fines going through the sand grains (refer figure 3). The main observation that can be seen in Figure 4 is that the moisture content increases until the added percentage of clay is at 14.5667% (refer equation 5) since the frictional forces between soil grains are reduced due to the water filling the voids. Then it starts to decrease when adding clay percentages beyond 14.5667%. This is due to the filling of voids by fines, causing to reduce the frictional forces and voids by adding more fines. Therefore, this helps to understand that the increased clay content of sandy soil is ideal for achieving better compaction with less water content. But the above equations, derived from the graphs shown in figures 3 and 4, are limited to poorly graded sands. Therefore, future development should be done for the well-graded sand.

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