Effect of Coarse Content on Compaction Test

Badee Alshameri

National University of Sciences and Technology (NUST), Pakistan

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Compaction,
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Maximum dry density,
Optimum moisture content,
Specific gravity

Abstract

The compaction is a mechanism to densify the loose soils. The maximum soil densification can be achieved by optimization of the desirable optimum moisture content (OMC) and maximum dry density (MDD). The maximum dry density and the optimum moisture content were affected by several parameters. The coarse content (CC) is one of these parameters. This paper studied the effect of the coarse content on the compaction parameters (MDD, OMC). Several sand-kaolin mixtures had coarse content ranged from 30 % to 80 % and moisture content ranged from 12% to 20% were used to inspect the relationship between CC, specific gravity (Gs), MDD, OMC, and bulk density. The results presented five empirical correlations with coefficient of determination ($R^2 \geq 0.98$) between CC, Gs, MDD, OMC and bulk density. The comparison between the current study and previous researchers indicated that both soil type and moisture content have significant effect on the efficiency of the empirical correlation equations between the maximum dry density, specific gravity, and coarse content. The results indicated a linear relationship between coarse content toward maximum dry density and specific gravity where both MDD and Gs increased with an increase CC. In contrary, the results showed non-linear relationship between optimum moisture content and coarse content where OMC decrease with an increase CC.

1. Introduction

The compaction is a mechanism used to rearrange the positions of particles to achieve higher density. The compaction depends on several parameters [1] which can be classified into two main categories: (1) Procedure parameters and (2) Compacted material properties. In the procedure, the parameters were; the hammer weight, number of blows, high and inclination of drops, mould size and type of compaction [1]. The compacted material properties parameters can be included the particle size, the materials conditions and the moisture content [2–8]. Table 1 tabulated the effect of parameters on the maximum dry density (MDD) and optimum moisture content (OMC) from previous researchers.

According to Wang et al. [5,6], the coarse content showed curve relationship with the maximum dry density. The result on Wang et al. [6] showed that the MDD increased with the increment of the coarse content from 10 to 20% then MDD decreased with further increment of the coarse content from 40 to 80%. Similar behaviour observed on Wang et al. [5] where MDD increase with an increase CC from 10 to 50% then decrease with further increment of CC from 60 to 80%. In addition, Wang et al. [6] and Omotosho [9], indicated that the increment of the coarse content caused decrement of OMC. Wang et al. [5] stated that there is non-linear relationship between the increment of the coarse content and OMC. With the increment of the coarse content from 10 to 40% resulted decreased the OMC then with further increment on CC from 40% to 80%, the OMC increased.

The previous researchers studied the effect of the coarse content on compaction parameter using gravel size [5,9,10]. Other researchers correlated between CC and compaction parameters using different fine materials such as bentonite [11], Fly ash with soil mixture [12–14]. While other researchers did not include the fine material on the their studies [6]. This study, focus on the effect of wide range of coarse content (coarse content ranged from 20% to 80%) on the maximum dry density MDD and optimum moisture content OMC by using sand-kaolin mixtures in standard compaction effort as well as present a

new empirical correlation between coarse content, maximum dry density, optimum moisture content, bulk density, and specific gravity.

2. Materials and test procedures

Six sand-kaolin mixtures were used and tested under different moisture content. Those mixtures were as the followings: 80–20, 70–30, 60–40, 50–50, 40–60, 30–70 (where the first number represented the coarse content and the second one represented the fine content). In these mixtures, the sand with particle size less than 3.35 mm was used as coarse materials and the fine material was a kaolin. The kaolin had minimum 40% particle size < 2 μ m, and maximum 0.05% 325 of 45 μ m mesh residues. Figure 1 showed the grain size distribution for coarse materials.

The preparation of samples and the procedure of laboratory tests were one according to standard compaction effort in ASTM D698 [1] using 6" mould and procedure of method B. The dry density was calculated according to equations 1 and 2:

Table 1. Effect of coarse and fine content toward MDD and OMC

Content	Effect of CC toward MDD	Material	Refe.
CC	Increased MDD to the highest value at CC = 20% then decreased beyond this value	Decreases	Crushed mudstone [6]
CC	Increased MDD to the highest value at CC = 60% then decreased beyond this value	Decreases	Crushed sandstone [5]
CC	Increased MDD to the highest value at CC = 8% then decreased beyond this value	Decrease	lateritic soil [9]
FC	Increased MDD to the highest value at FC = 15% then decreased beyond this value	Increase	Bentonite sand mixture [11]
FC	Decrease	Increase	Fly ash-soil mixtures [12,13]
FC	Decrease	Increase	Mixture of gravel, sand, silt, clay, and ash [14]
FC	Decrease	Increase	Sand-kaolin [15]

CC: Coarse content, FC: fine content, OMC: optimum moisture content, MDD: maximum dry density

*Corresponding Author: badee.alshameri@yahoo.com

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Figure 1. Particle size distribution curve for coarse material (sand)

$$\rho_{wet} = \frac{(M_t - M_{md})}{V} \quad (1)$$

$$\rho_{dry} = \frac{\rho_{wet}}{\left[1 + \left(\frac{w}{100}\right)\right]} \quad (2)$$

Where ρ_{wet} is bulk density, M_t is the mass of moist soil in mould and mould, M_{md} is the mass of compaction mould, V is the volume of compaction mould. ρ_{dry} is the dry density of compaction point and w is the average water content of compaction point.

3. Results and Discussion

Table 2 showed the results of equivalent bulk density ρ_{wet} , maximum dry density and optimum moisture content at different coarse content. The results indicated the highest value of bulk density was 2.16 g/cm³ at CC = 80% and the lowest (i.e. ρ_{wet} = 1.9 g/cm³) at CC = 30%. In addition, table 2 showed that the highest specific gravity value (G_s = 2.61) was at CC = 80%, and the lowest value for the specific gravity (G_s = 2.553) at CC = 30%. Figure 2 showed linear relationship between MDD and CC. It is obvious that the highest value of maximum dry density (MDD = 1.93 g/cm³) was indicated in CC = 80% while the lowest value of maximum dry density (MDD = 1.58 g/cm³) was in CC = 30%. The equivalent bulk density (ρ_{wet}) corresponding to the highest MDD was 2.16 g/cm³. The equivalent bulk density (ρ_{wet}) of the lowest MDD was 1.90 g/cm³. This result was in compliance with the outcomes in Wang et al. [5,6] using clay, silt, sand and gravel, Abu-Farsakh [7] using clay, silt and sand, Dafalla [11] using clay-sand, Santos et al. [12] using ash-soil, Kim et al. [14] using ash-soil, Mir and Sridharan [13] using ash, clay, silt and sand, and Crispim et al. [16] using clay, silt, sand and gravel.

Table 2. The results of bulk density, MDD, and OMC at different coarse content

CC %	G_s	ρ_{wet} (g/cm ³)	MDD (g/cm ³)	OMC (%)
80	2.61	2.16	1.93	12
70	2.597	2.11	1.89	12
60	2.585	2.03	1.81	12
50	2.576	1.99	1.71	16
40	2.563	1.94	1.64	18
30	2.553	1.90	1.58	20

CC: Coarse content, G_s : Specific gravity, OMC: Optimum moisture content, MDD: Maximum dry density, ρ_{wet} : Bulk density

Figure 2 indicated two empirical correlations equations which linked coarse content toward the bulk density and maximum dry density as in the equation 3 and 4 respectively:

$$MDD = 0.0073 CC + 1.3566 \quad (4)$$

Where ρ_{wet} is the equivalent bulk density for the maximum dry density, MDD is the maximum dry density, and CC is the coarse content (i.e. sand content). Equations 3 and 4 has the coefficient of determination $R^2 = 0.98$. In addition, both equations 3 and 4 were

correlated only for sand kaolin mixture with percentage of sand% between 30% to 80%.

Figure 2. MDD and bulk density versus the coarse content C

Figure 3 showed the results of optimum moisture content versus the coarse content. The results indicated non-linear relationship between the OMC and coarse content. The highest value of OMC was 20% at coarse content equals to 30%, the lowest one of OMC = 12% was at three values coarse content from 60, 70 and 80%. The similarity in the OMC at CC from 60 to 80 can be related to the interface between the fine content and soil structural. At low fine content (i.e. CC = 80%) the moisture content lubricating the contact between the coarse particles and lead to reach the MDD at OMC equal to 12%. However, by increment the fine content, the fine particles will act as lubricating agent side by side with the moisture content which lead to reach MDD at CC= 80% using the same moisture content (i.e. OMC = 12%). On the other hand, at CC = 50%, the fine particles reduce the effect of the moisture content and produce higher cohesion force which require more moisture content to reposition the coarse particles and reach higher MDD [17,18]. The OMC results agreed with outcomes from Wang et al. [5,6], Abu-Farsakh [7] and Omotosho [9]. However, the regressive relationship between OMC and CC can be related to the fine content where the highest fine content, the highest water required to minimizing the effect of the cohesion thus achieving the MDD point [17].

Figure 3. OMC versus the coarse content

The comparison between the current study and previous outcomes from different researchers at Figures 4 and 5 indicated the follows:

- All studies showed the same patterns where the CC has progressive and regressive relationships toward MDD and OMC respectively [5,9,11,12].
- At MDD results, the outcomes from Santos et al. (2011) showed close pattern to the current study compare with Wang et al. [5]. This can be related to use crushed sandstone with higher density

in Wang et al. [5] compare with mixture of soil and ash at Santos et al. [12].

- In the OMC comparison, the outcomes from Omotosho [9] and Dafalla [11] showed close value to the current study where the moisture content was less than 30% compare with 45.5 % in Santos et al. [12] results. And the material which used in both Omotosho [9] and Dafalla [11] were close the material in current study compare with the ash soil mixture from Santos et al. [12].

On the other hand, the results at figure 6 showed progressive relationship between the specific gravity (G_s) and the coarse content. Figure 7 showed the progressive relationship between the bulk density and maximum dry density with the specific gravity. The increment of MDD with the increasing the coarse content (see figure 2) can be related to the specific gravity where the increasing in coarse content resulted an increment the density (Table 2).

Figure 4. Comparison MDD from current study with previous researchers

Figure 5. Comparison OMC from current study with previous researchers

Figure 6. Specific gravity G_s versus the coarse content

By refereeing to Figures 6 and 7, the empirical correlations equations linked the specific gravity toward the coarse content, bulk density, and MDD which list in equations 5, 6 and 7 respectively:

$$G_s = 0.0011 \text{ CC} + 2.5184 \quad (5)$$

$$\rho_{\text{wet}} = 4.7573 G_s - 10.256 \quad (6)$$

$$\text{MDD} = 6.4601 G_s - 14.91 \quad (7)$$

Where G_s is specific gravity, CC is the coarse content (i.e. sand content), ρ_{wet} is the equivalent bulk density for the maximum dry density, and MDD is the maximum dry density. The coefficient of determination (R^2) for equation 5, 6, and 7 were $R^2 = 0.99$, 0.98 and 0.98 respectively. All of equations 5, 6 and 7 were correlated only for sand-kaolin mixture with percentage of sand% between 30% to 80%. The comparison between the G_s , MDD, and CC results from current study and the outcomes from Kulkarni et al. [19] indicated similarity between both results and conform the progressive relationships between G_s , MDD, and CC (see Figure 8).

Figure 7. Maximum dry density MDD and bulk density ρ_{wet} versus the specific gravity G_s

Figure 8. Comparison MDD, Gs, CC from current and previous study

4. Conclusion

The effect of coarse content in the maximum dry density MDD, bulk density ρ_{wet} and OMC was inspected under different mixtures of sand-kaolin.

- The study presented five empirical correlation between coarse content, specific gravity, maximum dry density, optimum moisture content and bulk density with coefficient of determination ($R^2 \geq 0.98$)
- The comparison between the current study and previous researchers indicated that both material type and moisture content have significant effect on the efficiency of the empirical correlation equations between the MDD, ρ_{wet} and G_s toward coarse content.
- linear relationship between the MDD, ρ_{wet} , and specific gravity G_s toward the coarse content.
- Non-linear relationship between the OMC and coarse content.
- The higher fine content the more moisture mould content requires to achieve MDD.

Nomenclature

CC : Coarse content
 FC : Fine content
 G_s : Specific gravity
 OMC : Optimum moisture content
 MDD : Maximum dry density
 ρ_{wet} : the equivalent bulk density

Declaration of Conflict of Interests

The author declares that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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