

## CORRELATION BETWEEN MAXIMUM DRY DENSITY AND SOIL PARTICLES' SIZE USING MODIFIED PROCTOR TEST: A CASE STUDY

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### Abstract

Soils are aggregates of mineral particles, along with air and water in the voids. Soil compaction is the most vital factor in any earthwork's construction. Compaction improves the engineering properties of the soil. Experience and experimentation have shown us that compacting the soils we use makes the infrastructure more sustainable, along with some other advantages. In this study, a particular amount of soil samples was collected in a large bag to find out the maximum dry density of the soil specimen, and several numbers of soil samples were collected from various point locations. The dry density of the soil samples was determined by calculating the moist density and moisture of the specific soil samples. Then, the performance of soil compaction work was determined by calculating the degree of compaction. There were four locations on the site in Kushtia. The average degree of compaction at each of the four locations was above ninety percent, which was in the acceptance range. From the regression graph of the maximum dry density and percentage of particle size, it is clear that the maximum dry density will increase with the increase of the clay and silt portion. With the expansion of the smaller particles, the value of maximum dry density will rise. There were a very small numbers of research work on correlating the dry density with the soil particle characteristics. In this work, the variation of the dry density of soil samples with the types and sizes of the particles is described vividly.

**Keywords:** *Compaction test, Dry density, Modified Proctor test, Moisture, Soil particles, Strength.*

### Introduction

In order to get a high density, filling material for road embankments, railway subgrade, earth-dams must be compacted. Compaction reduces the soil's permeability and water-absorbing propensity while increasing the soil's shear strength and decreasing its tendency to settle (Spagnoli, 2020). Soil compaction works against the undesirable soil subsidence of an embankment (Anggraini *et al.*, 2023). The aim of every compaction specification is to attain a certain value of dry unit weight. The first and foremost benefit of soil compaction is to increase the bearing capacity of the soil and decrease the chance of settlement. The effect of compaction effort is represented by the soil's moisture content and dry density in reference to optimum moisture content and maximum dry density. Sufficient time and effort are needed in laboratory experiments in order to obtain compaction properties (Ng *et al.*, 2015). The main objective of soil compaction is to create a soil material that can meet three essential requirements. First, reduce the subsequent settlement of the soil mass under live loads. Second, the reduction in permeability will gradually prevent the development of enormous water stresses, causing liquefaction issues, and containing water in the case of earth dams. Finally, the soil material's shear resistance is enhanced (Fondjo *et al.*, 2021).

A systematic approach to examining the compaction ability of disturbed soils over a range of soil water contents is provided by the Proctor test. (Aragon, *et al.*, 2000). In 1933, Ralph R. Proctor started a research work that effectively identifies the practical highest density of a soil sample along with the optimum moist situation needed to achieve that density. That idea is referred to in the present time as the moisture content-density kinship test, laboratory compaction qualities of soils, or just the standard Proctor test, and is point by point in ASTM D698 and AASHTO T 99 test procedure. The modified Proctor test was established in 1958 as ASTM D1557 and AASHTO T 180 to accelerate the testing procedure at higher loads effects of soil types (Benjamin, 2023). During construction, the geotechnical engineers assess the unit weight of compacted soil in the field to verify the

relative soil compaction percentage. The Proctor test is the most usual laboratory soil test and the basis for compacted soil placements for embankments, pavements, and structural fills. The process of compaction involves rearranging the particle locations to reach a higher density by figuring out the maximum dry density (MDD) and optimum moisture content (OMC) (ASTM, 2012). The process of compaction takes a lot of time and effort. To reduce time and effort for getting desired MDD, many studies were conducted to correlate the MDD with different index of soil properties. Six parameters such as, liquid limit, plastic limit, specific gravity, fine content, gravel content and sand content are correlated to the MDD (Gunaydin, 2009). Typically, all compaction specifications depend on gaining a certain value of dry unit weight. During construction, the geotechnical experts measure the in situ dry unit weight of compacted soil in the field to verify the results with the requirements (Rahman *et al.*, 2011). Soil compaction involves the mechanical process of bringing soil grains closer together, decreasing soil volume and pore space. However, the volume occupied by the soil grains remains the same. Engineers often consider soil compaction when designing construction projects, utilizing techniques such as grinding or compression. By controlling the dry soil density and moisture content within specific limits, essential soil properties can be determined, including density, California Bearing Ratio (CBR), consolidation, permeability, shear strength, and more. Soil compaction plays a vital role in the construction of many structures, such as roads, airports, embankments, and other infrastructural projects (Analysis of Soil Compaction using Proctor Standards in Highway Construction Design, 2021). From several reviews, it is confirmed that a certainly viable correlation exists between maximum dry density versus optimum water content. The kinship between an optimum degree of saturation and optimum moisture content (OMC) shows that OMC is lower for soils with higher maximum dry density, because the rising value of OMC results in increasing porosity, and there exists a negative relationship between porosity and MDD (Udom, 2018). The soil type concerning the grain-size distribution, the shape of the soil grains, the specific gravity of soil solids, and the presence of fine particles offer a great effect on the maximum dry unit weight

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and optimum moisture content (Guerrero, 2004). For certain moisture contents, when soil compaction is greatest, clay achieves theoretical saturation, whereas sand does not (Ren et al., 2015). Testing methods for the standard and modified Proctor test procedures are the American Association of State Highway and Transportation Officials (AASHTO) T99 and T180 respectively. The proportionate American Society for Testing and Materials (ASTM) testing procedures are D 698 and D 1557 respectively (Connelly, 2008).

**Table 1.** Difference between standard and modified Proctor tests.

Test procedure	Standard Proctor test (AASHTO T99)	Modified Proctor test (AASHTO T180)
Hammer weight (lb)	5.5	10
Falling distance of the hammer (inch)	12	18
Numbers of layer	3	5
Energy (ft-lb.ft <sup>-3</sup> )	12375	56250

(Note: There are fundamental differences between standard and modified proctor tests (**Table 1**)).

To verify the degree of compaction, the in-place field density of fillings and maximum dry density is determined. Besides compaction, consolidation is also important to increase dry density. Compaction is a dynamic application of load, whereas consolidation is a static process of loading.

**Table 2:** Location and chainage of the study area.

Region no.	Chainage	Length covered along the bank (m)	Location
01	Km 15.50 to km 16.25	750	Right bank of the Gorai River, Khoksha, Kushtia.
02	Km 16.25 to km 17.00	750	
03	Km 25.00 to km 26.00	1000	
04	Km 26.00 to km 27.00	1000	

#### Test for determination of maximum dry density

This work was divided in two stages. The first one was to determine the maximum dry density of soil sample from selected region, and the second one was to find field density of different spots from same region. In order to determine the degree of compaction of the earthen embankment, firstly, 12 kg of moist soil samples from each region were collected. Four regions were selected in the project area to find out the degree of compaction. Then the collected samples were carried to the laboratory. In the lab, samples were air-dried to the desired moisture, usually around 10% or more below the anticipated optimum moisture. For soil having more moisture, quick moisture can be achieved by using a heater. This can be accelerated for cohesive and high plastic soils by breaking down clumps and spreading the sample out on open trays. The breakdown may be continued more thoroughly when the soil was friable enough. For the standard and modified Proctor test, the finer materials to pass through either a 4.75mm (#4) sieve were taken for the compaction test. From 12kg soil sample, a minimum of four specimens of 2000g soils were prepared for the compaction

Compaction is to be done for the exclusion of air, and consolidation is done for the expulsion of water. The aim of compaction is to attain the maximum dry density of the soil sample. Maximum dry density depends on different factors, especially on types and sizes of soil particles. This paper presents a case study about the determination of field density of earth filling works and the effect of some properties of soil sample on its maximum dry density. This will help experts to predict the soil properties requirements for earth filling works requiring a particular maximum dry density.

## Methodology

### Study area

The study area is located at the bank of River Gorai in Kustia. As a part of bank protective work, an embankment has been constructed on the right bank of Gorai River. This embankment was constructed by holding layers of soils and other fills, one above another, and compacting them using a heavy rolling plant until adequate strength has been achieved. To verify the degree of compaction, the in-place field density of fillings and maximum dry density was determined. The execution and supervision works of this embankment was done by Jaduboyra O & M Sub-division, Kushtia O & M Division, Bangladesh Water Development Board, Kushtia. A team from Geo-technical Research Directorate, River Research Institute, Faridpur was directed to measure the relative compaction of that earth filling works and particle analysis of soil sample of this embankment. In the project area there were four regions, these four regions covered different chainage sections. (**Table 2**).

with increasing moisture content that will cover the realized optimum water content. Then each of the five specimens were placed in a mould. The diameter and height of the mould were 4 inches and 4.6 inches respectively. Then water was added to each of four specimens and mixed thoroughly with it. The amount of added water to the next specimen was increased by 2% than that of previous one. Here 2% of the weight of soil samples was 40gm that means 40ml water. The prepared specimens were stored in closed containers for curing for 16 hours for proper moisture conditioning. Next, the prepared samples were compacted in a mould of 1/30 ft<sup>3</sup> by a hammer of 10lb falling from 18inch, the number of blows was 25, and the mould was vertically divided into five parts, and the mould was filled by the soil sample in five layers and compacted each layer cumulatively (Reddy, 2023). So, the compaction effort in the modified proctor test was 56,250 ft-lbft<sup>-3</sup>. After compaction, the collar was removed carefully, and the compacted soil was trimmed off so that the surface was completely flat with the top of the mould. Replace small bits of a soil sample to fill the little shortage created during the trimming process.



Fig. 1. Water added soil sample, mold, and hammer.



Fig. 2. Automatic soil compaction machine.

Then the weight of the compacted soil including mould (with base and without collar) was recorded. The weight of the mould was known. Next the wet weight of the compacted soil sample was calculated, and the wet density of the soil samples was determined, and a small portion of this sample was taken to a pot, and the weight of the soil plus pot was measured. Next, the can with soil was placed in an oven for the next 24 hours. After 24 hours, the weight of the soil plus the container was taken. Thus, the percentage of the water content in the compacted soil sample was determined. Then, the process was repeated for the rest of the four previously prepared and cured specimens. From the wet density and moisture content of compacted soil specimens, dry density of every specimen was calculated, and the values of the dry density of soil and perspective water content (%) were plotted on a simple graph (Fig. 3, 4, 5, and 6).

#### Test for determination of field dry density

Then, calculation of the field density of various points in one the four particular regions of the embankment was taken into account. For that reason, a small amount, approximately 200g of soil samples were taken. The weight of each moist sample was recorded, and the wet unit weight of these samples was determined [Eq. (1)].

$$\gamma_{moist} = W/V \quad \text{Eq. (1)}$$

The samples were dried in an oven for 24 hours at 110°C (Rasti et al., 2020). From the difference between the two results percentage of moisture was calculated and the dry densities of the soil samples were determined [Eq. (2)].

$$\gamma_d = \gamma_{moist} / (1 + \frac{w\%}{100}) \quad \text{Eq. (2)}$$

By dividing the dry density of each soil sample by the maximum dry density of the soil specimen of the same region, the degree of compaction was derived [Eq. (3)].

$$\text{Relative Compaction} = \left( \frac{\text{Field dry density}}{\text{Maximum dry density}} \right) \times 100\% \quad \text{Eq. (3)}$$

The higher value of degree of compaction means the better performance of the compaction work.

For determining particle sizes of soil sample a Particle Size Analyser (Mastersizer 3000) was used. Using this analyser, percentages of soil particles and the values of  $D_{50}$ ,  $D_{90}$ ,  $D_{10}$ , etc were found directly. In this study, soil particles from 4.76 mm to 0.074mm are treated as sand portion and soil particles from 0.074mm to 0.002mm are taken as silt and particles less than 0.002mm are treated as clay portion.

## Results and discussions

Using modified Proctor test, maximum dry density was determined for the soil samples of each region. For determining the relative compaction of the embankment, field density has determined. For each location various number of sites were selected for collecting a few gram of soil samples for determining field density. The inner volume of the mould used for modified Proctor test was 947.59 cm<sup>3</sup>. Applying the test procedure of determining the maximum dry density using modified Proctor test, the values of maximum dry density of the soil samples of the four regions were determined, and the corresponding points of the optimum moisture content were found out by plotting the values of dry density verses corresponding values of moisture content in a plain graph (Fig. 3, 4, 5, and 6).

After determining the maximum dry density, the dry densities of soil samples taken from different points of the same region were calculated from the moist density of in-situ soil sample and the moisture content, the field dry density was derived [Eq. (2)]. After finding the dry density, using the [Eq. (3)], the relative compactions of earth filling works of different points of all four regions were derived (Table 3, 4, 5, and 6).

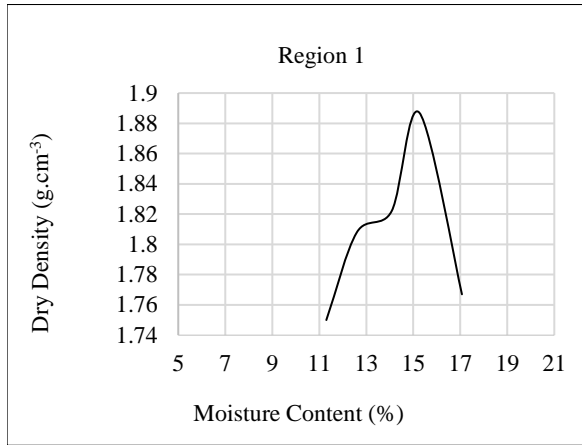


Fig. 3. Dry density vs moisture content curve.

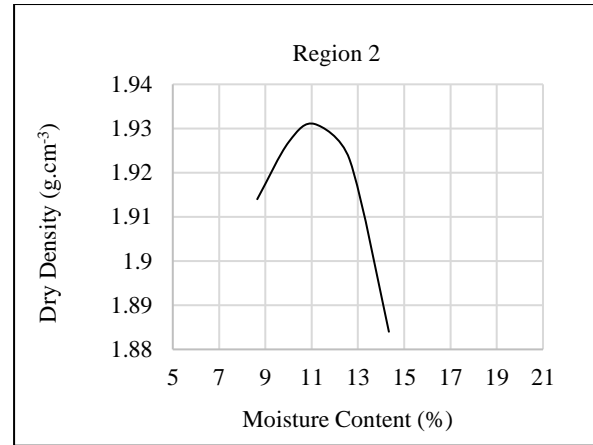


Fig. 4. Dry density vs moisture content curve.

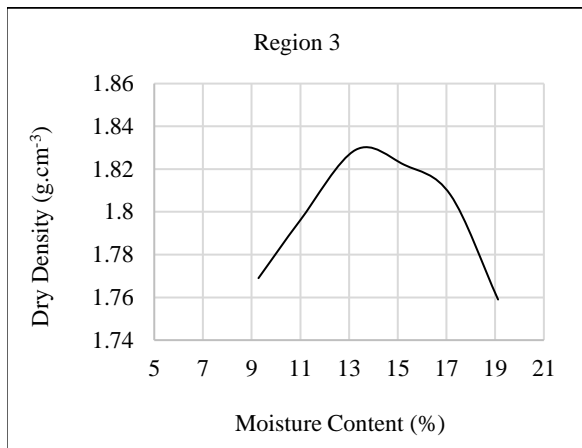


Fig. 5. Dry density vs moisture content curve.

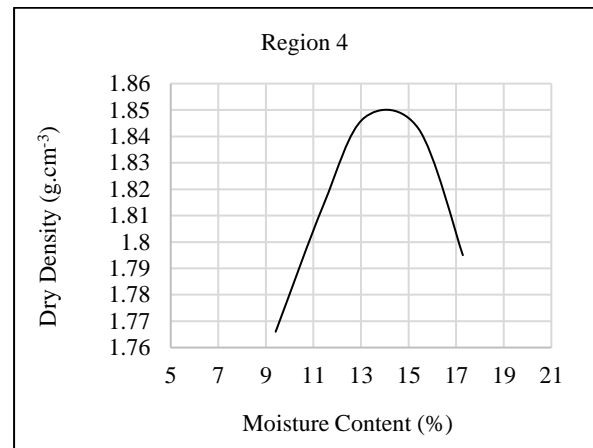


Fig. 6. Dry density vs moisture content curve.

After determining the maximum dry density, the dry densities of soil samples taken from different points of the same region were calculated from the moist density of in-situ soil sample and the moisture content, the field dry density was derived

[Eq. (2)]. After finding the dry density, using the [Eq. (3)], the relative compactions of earth filling works of different points of all four regions were derived (Table 3, 4, 5, and 6).

Table 3. Relative compaction of earth filling work of region no. 01 (MDD 1.883 g.cm<sup>-3</sup>).

Chainage km	15.500 km	15.550 km	15.600 km	15.700 km	15.750 km	15.800 km	16.050 km	16.100 km
MDD (g.cm <sup>-3</sup> )	1.883							
Dry Density (g.cm <sup>-3</sup> )	1.83	1.74	1.66	1.69	1.78	1.78	1.88	1.85
Relative Compaction in %	97.19	92.41	88.16	89.75	94.53	94.53	99.84	98.25

Table 4. Relative compaction of earth filling work of region no. 02 (MDD 1.934 g.cm<sup>-3</sup>).

Chainage km	16.330 km	16.350 km	16.710 km	16.715 km	16.720 km	16.800 km	16.850 km	16.900 km
MDD (g.cm <sup>-3</sup> )	1.934							
Dry Density (g.cm <sup>-3</sup> )	1.86	1.83	1.78	1.66	1.77	1.57	1.65	1.74
Relative Compaction in %	96.17	94.62	92.04	85.83	91.52	81.18	85.32	89.97

**Table 5.** Relative compaction of earth filling work of region no. 03 (MDD 1.829 g.cm<sup>-3</sup>).

Chainage	25.500 km	25.570 km	25.685 km	25.810 km	25.990 km
MDD (g.cm <sup>-3</sup> )	1.829				
Dry Density (g.cm <sup>-3</sup> )	1.48	1.42	1.55	1.43	1.53
Relative Compaction in %	80.92	77.64	84.75	78.18	83.65

**Table 6.** Relative compaction of earth filling work of region no. 04 (MDD 1.848 g.cm<sup>-3</sup>).

Chainage	26.300 km	26.500 km	26.700 km	26.825 km	27.000 km
MDD (g.cm <sup>-3</sup> )	1.848				
Dry Density (g.cm <sup>-3</sup> )	1.21	1.76	1.29	1.38	1.47
Relative Compaction in %	65.48	95.24	69.81	74.68	79.55

With the rising of clay and silt content of soil particles, the maximum dry density of soil is increasing and vice versa. Sensitivity analyses showed that while the gravel content is a major factor in predicting maximum dry density, the plastic limit has a significant impact on the optimum moisture content. Similar observation has found by Ali *et al.*, 2024. As

the plastic limit depends on the types of soil particles, both MDD and OMC depend on soil particles.

The percentage of soil particles and maximum dry density of the selected four locations soil samples are given below (**Table 7**).

**Table 7:** Relationship between MDD and soil properties.

Location	Region 1	Region 2	Region 3	Region 4
% of clay	2.85	3.15	2.37	2.67
% of silt	89.0	90.99	84.16	87.24
% of sand	8.05	5.86	13.47	10.09
D <sub>50</sub> (µm)	13.62	9.73	20.06	19.01
Maximum dry density (g.cm <sup>-3</sup> )	1.883	1.934	1.829	1.848
Optimum moisture content	15.26	11.14	13.2	14.8

Dry density of compacted soil samples depends on moisture content, compaction energy and soil particles' sizes. As the maximum dry density is obtained by applying a certain compaction energy, so the maximum dry density depends on moisture content of soil sample and particle size of sample. Since moisture content also depends on particle size of soil, so the maximum dry density for a constant compaction energy depends on soil particle size. Finer particles have less voids and compacted soil will be denser, so the maximum dry density will be more (Alshameri, 2020). By plotting the values of the maximum dry density with the variations of soil particles the coefficients of determination were found (**Fig. 7, 8 and 9**).

From **Fig. 7, 8 and 9**, it can be decided that the maximum dry density of soil specimens is directly proportional to the percentage of clay and silt particles and inversely proportional to the percentage of sand particles. So, using that soil for subgrade, which has minimum sand content to achieve the maximum dry density, will be wise. Soil with a

large amount of sand content should be avoided as much as possible. Now, the values of the maximum dry density of soil specimens were plotted against the sizes of the soil particles below which 50% soil particles were finer (**Fig. 10**).

Regression analysis is a statistical apparatus that is for defining the functions between independent and independent variables. The power of dependence between variables is determined by using correlation research. If,  $R \leq 0.3$ , no significant correlation exists, if  $0.5 < R < 0.7$ , then significant correlation, and if  $0.7 < R < 0.9$ , then a strong correlation sustains (Djokovic, 2013). So, there is a strong relation between the maximum dry density of soil samples and the percentage of soil particles. Moreover, in the case of a number of soil specimens, there remains a significant correlation between the maximum dry density and optimum moisture content of the specific soil samples. Furthermore, the maximum dry density is also directly proportional to D<sub>50</sub> of the soil samples (**Fig. 10**). In the Proctor test the two

parameters such as the maximum dry density and optimum moisture content depend on hammer weight, the height of the hammer drop, and the number of blows. With the increase of hammer weight and the height of the hammer drop, the compaction effort will rise. As a result, maximum dry density will rise. Although, the number of blows on the soil and the dry density of the soil is directly proportional (Hussein, 2018).

So, it can be stated that, as the number of blows increases, the maximum dry density of that particular soil sample is increasing and vice versa. The method of compaction plays a vital role in determining maximum dry density. The highest dry density gained by the modified Proctor test will be more than that of the standard Proctor test. Not only that, the maximum dry density varies more than 5% from the result of the standard compaction test (Lvovska, 2018, pp. 636-641).

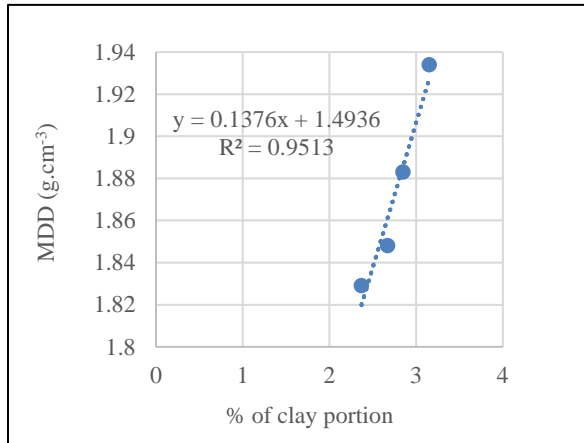


Fig. 7. Clay quantity and dry density relationship.

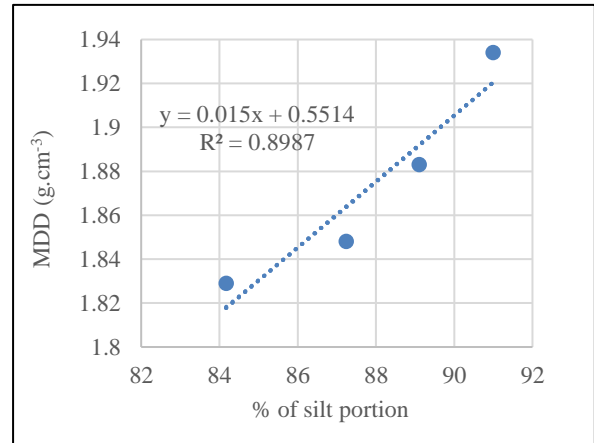


Fig. 8. Silt quantity and dry density relationship.

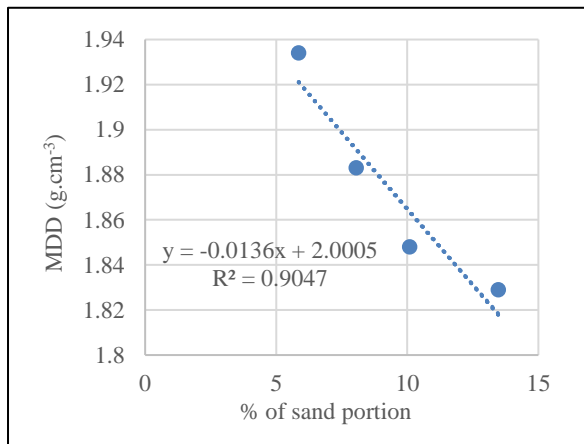


Fig. 9. Sand quantity and dry density relationship.

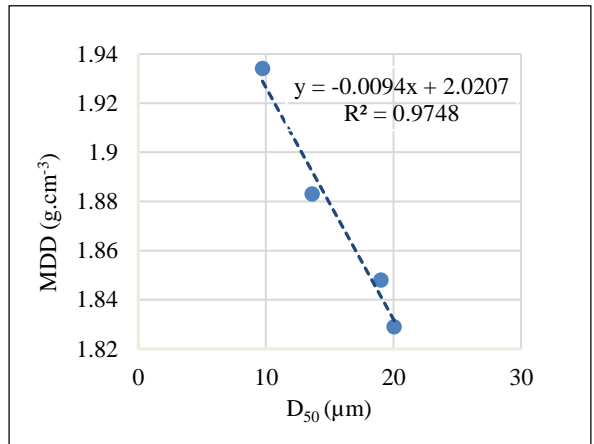


Fig. 10. Relationship between MDD and D<sub>50</sub>.

**Conclusions**

From the study, the moisture content and size of the soil particles are significant for the density of a compacted soil sample. The linear relationships showed excellent coefficient of determination values, presenting the magnitudes of the correlation between MDD and sand, silt and clay percentages of compacted soil samples. The values of R<sup>2</sup> for clay, silt and sand portion are 0.9513, 0.8987 and 0.9047 respectively. The soil sample of the four regions of the study area contains sand percentage from 5.86% to 13.47%, and the MDD of the soil sample of these four compacted regions varies from 1.829 to 1.934 gcm<sup>-3</sup>. For the presence of more voids in the sand portion, with the increase of sand particles, the value of MDD decreased. Engineers must choose a well-graded soil sample to construct a barrier to fill all the pores with finer particles. In the same way as the Proctor test, the embankment's compaction work should be done layer by layer, and the experts should design the compactor's load and the compaction work's duration. Even though variables like soil

type, moisture content, compaction energy, and compaction technique are essential, a whole picture can require more than just these. Because soil behaviour is complex, engineers must have a sophisticated grasp of it and use a variety of approaches to guarantee the best possible embankment performance. A comprehensive strategy and cutting-edge technologies will make more resilient and sustainable infrastructure possible.

**Acknowledgement**

We want to express our deep gratitude to Kushtia O & M Division, Bangladesh Water Development Board, Kushtia, for giving us a significant opportunity to be a part of the construction of an embankment along the right bank of Gorai River, Khoksha, Kushtia.

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