

A novel device for inclined compaction test on soils

Panu Promputthangkoon^{1,*} and Tavorn Kuasakul²

¹Natural Disaster Prevention and Control for Sustainable Environment Research Unit, Faculty of Engineering, Rajamangala University of Technology Srivijaya, Songkhla, Thailand

²Civil Engineering Department, Faculty of Engineering, Rajamangala University of Technology Srivijaya, Songkhla, Thailand

Abstract. It can be said that the soil compaction test is currently the standard method for obtaining the right amount of water to be added in order to achieve a maximum dry density. Then, the water content obtained from laboratory work, known as optimum moisture content, is utilised in the field for compacting the soil. It should be noted that the compaction test is carried out on a soil sample prepared in a mould horizontally laid. In the field, however, quite often the compaction is done on side embankments or sloping grounds. Hence, using the laboratory result to control the field density for such cases is problematic. Therefore, this study developed a device that could be used to conduct the compaction test concerning the following conditions: (1) compaction is vertically applied to a soil sample inclined at various angles (VC), and (2) compaction is normal to an inclined soil sample (IC). Some initial tests on lateritic soil using both methods developed showed that at the same energy applied the densities are quite different. These results confirm that, in the case of sloping ground, the standard compaction test may not be appropriate.

1 Introduction

Lateritic soil has continuously been employed for road and embankment constructions because of its abundant quantity around the world (see Fig 1 [1]). In addition, its basic and engineering properties are both desirable and suitable for construction projects. Holland [2] reported that the lateritic soil is created in tropical climate, as evident in Fig. 1. Note that the tropical climate occurs in regions within the equatorial belt, experiencing hot and humid weather with abundant rainfalls.

According to [3], lateritic soils are simply residual soils having Silicon dioxide (Silica) to Sesquioxide ratio between 1.33 to 2.00. One distinct aspect of the soil is its red colour. As such, Blight described the term lateritic soil as reddish tropically weathered geomaterials [4]. Its engineering properties are the mix of fine-grained sands, gravels, and soft rock. Even though it visually looks strong, but some particles tend to easily crush under impact. Besides, some particles left after crushing may exhibit plastic behaviour.



Fig. 1. Distribution of lateritic soil around the world [1]

The engineering properties of the laterite in Thailand were extensively studied in 1969 by U.S. Agency for International Development [5]. According to Brown et. al. [6], Thailand can be divided into five physiographic regions: (1) Northwest Highland, (2) Chao Phraya Plain, (3) Khorat Plateau, (4) Chanthaburi District, and (5) Peninsular Area. Of all of those five regions, lateritic soils are most found in the Khorat Plateau and Chanthaburi District.

The study concerning the quantity and sources of lateritic soil is important for developing a country. The soil is one of the main sources for road construction. The more the road is constructed the more economy is foreseen thereby increasing the wealth of people. Quite often a source of lateritic soil is far from a construction site, resulting in the need for transportation. This practice has led to the study for soil compaction. This is because it is well known that soil when excavated will be looser than that of its original state. Thus, when transported and filled in another location the soil must be compacted.

The maximum dry density of a lateritic soil when compacted in the field can be obtained with the right amount of added water. In addition, suitable compacting machines are also important. The standard practice concerning the soil compaction test currently carried out in the laboratory is performed on a soil being horizontal. In the field, however, in some situations the ground may be sloped thereby applying a laboratory result for a field operation is problematic. Therefore, this study attempted to overcome this problem by developing a device that can conduct the compaction test on a soil sample being non-horizontal.

* Corresponding author: [panu pptk@hotmail.com](mailto:panu_pptk@hotmail.com)

2 Development of the device

2.1. Design principles

The design of this device was based on the following assumptions: (1) applied energy can be generated from the standard impact hammer used in the compaction test, (2) a mould has a rectangular shape of 15 by 15 cm with around 4.10 cm high, (3) the mould must be able to support a collar in order to be able to apply the inclined compaction effort, and (4) comprises a base that can be adjusted to incline at various angles.

Fig 2 displays the schematic diagram of the mould developed. Basically, it comprises a steel plate supporting the mould having the dimensions of 15.00 by 15.00 by 4.10 cm. One important aspect of this design was that the top of the mould is recessed such that it can support a collar shown in Fig 3. The steel plate shown in Fig 2 was drilled such that it can be attached to the base shown in Fig 4 using bolts and nuts. The two vertical frame components shown in Fig 4 were also drilled so that the base can be lifted at a specified angle thereby enabling the inclined compaction test carried out.

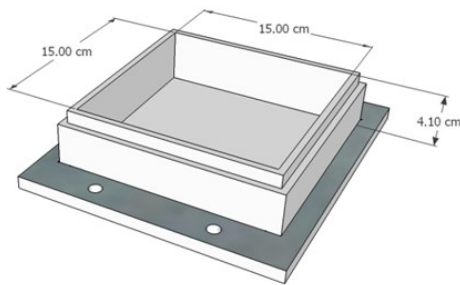


Fig. 2. Mould developed for inclined compaction test

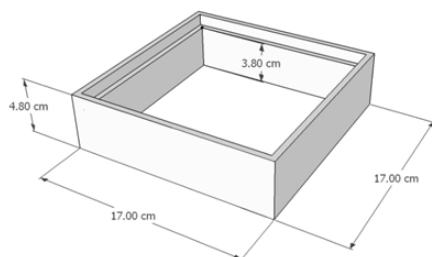


Fig. 3. Collar of the mould



Fig. 4. Picture of the base for supporting the mould

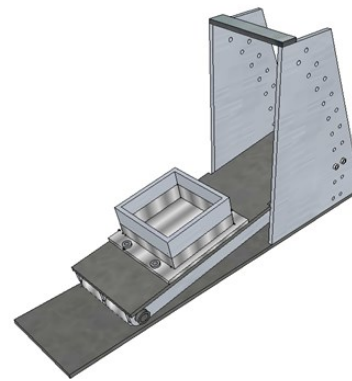


Fig. 5. Schematic diagram of the full system

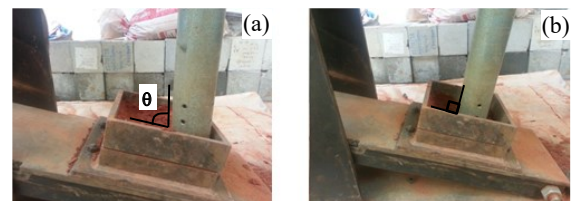


Fig. 6. Vertical compaction on inclined mould, VC (a) inclined compaction on inclined mould, IC (the energy applied is normal to the mould) (b)

Fig 5 illustrates the schematic diagram of the full system developed by the authors. The two rows of holes at the two vertical frames were drilled such that they can lift the base at the angles of 5, 10, 15, 20, 25, 30, 35, 40, and 45°, meaning the inclined compaction test could be carried out corresponding to these pre-set inclined angles.

2.2 Mechanism of inclined compaction

This study attempted to make the following tests applicable: (1) compaction energy is vertically applied to a soil sample inclined at various angles, and (2) compaction effort is normal to an inclined soil sample. The former is schematically depicted in Fig 6 (a); while the latter can be done according to the illustration in Fig 6 (b). It should be noted herein that as an inclined angle is greater the collar must be attached so that the compaction could be carried out.

As the mould used in this study was not the same as the standard mould normally employed in the compaction test according to the ASTM D1557-12 [7], the number of blows, NL , must be first determined. Because the mould developed was just 4.10 cm high, the number of layers for compaction was just two, instead of three as used in the standard compaction that uses the 4.584 in high mould (11.64 cm). This was accomplished by using the following equation

$$NL = \frac{\text{Energy (from ASTM)} \times \text{Soil Volume}}{\text{Ram Wt. (kg)} \times 9.81 \times \text{Drop height} \times \text{Layers}} \quad (1)$$

where energy = 2,700 kN.m/m³, soil volume = 0.15×0.15×0.041 m³, ram weight = 4.54 kg, drop height = 0.457 m, and layers of compaction = 2. This resulted in the NL of 63 blows per layer.

Table 1. Soil properties and classification results

Property	Value
Texture Composition:	
Gravel, > 75 – 4.75 mm, %	36
Sand, 4.75 – 0.075 mm, %	59
Silt and Clay, < 0.075 mm, %	5
Physical Properties:	
Liquid Limit (LL), %	31
Plastic Limit (PL), %	18
Plastic Index (PI), %	13
Specific Gravity (G_s)	2.70
Classification:	
AASHTO	A-2-6
Unified Soil Classification System	SC

3 Inclined compaction tests

3.1. Soil sample

The soil sample employed for this investigation was laterite of which is the most common material for the road construction in Thailand. It was obtained from Moo 8, Ban Bangonaetae, Korlortanyong Subdistrict, Nongjig District, Pattani Province, Southern Thailand.

The soil was first sieved to determine its size distribution. It was found that the coefficients of uniformity (C_u) and curvature (C_g) are 23 and 0.98, respectively, indicating that it was well-graded. In addition, the permeability test revealed that the coefficient is 0.4212 mm/s. The atterberg test showed that the plasticity index is 13%; and, the specific gravity is 2.70. According to the AASHTO standard, these properties indicate that the soil is A-2-6, meaning very good for road construction. For the case of the USCS, it was classified as SC, clayey sand. Table 1 displays the summary of the laboratory test results as well as soil classification by both AASHTO and USCS.

3.1. Test programmes

To assess the performance of the device developed, two compaction methods were conducted: (1) compaction effort was vertically applied on an inclined soil sample, namely VC, and (2) applied compaction effort was normal to an inclined soil sample, namely IC. For both testing methods, the soil samples were inclined, with respect to the horizontal, at the angles of 5, 15, and 30°.

In order to obtain a consistency result, each test set-up was carried out twice. If the results were not much different, they were hold and averaged; otherwise, a third or even fourth test was conducted. These resulted in a total of 12 tests experimented: VC5-1, VC5-2, VC15-1, VC15-2, VC30-1, VC30-2, IC5-1, IC5-2, IC15-1, IC15-2, IC30-1, and IC30-2. Please note that the number just after the alphabets VC and IC indicate an inclined angle of a soil sample (see Fig 6), and the number after the dash indicates the sample number (1 or 2).

4 Results and discussion

Test results obtained from this study were simply the maximum dry densities, $\rho_{d,max}$ and their corresponding optimum moisture contents, OMC. Table 2 shows the compaction test results for the VC. For the IC, the compaction test results were summarised and shown in Table 3. To visually observe the results obtained, all of the testing data were plotted and shown in Fig 7.

For the VC samples, it was found that as the inclined angle is gradually increased the $\rho_{d,max}$ is steadily decreased, i.e., the $\rho_{d,max}$ values are 1.883, 1.800, and 1.764 g/cm³ with respect to the inclined angles of 5, 15, and 30°. Nonetheless, for the case of the OMC value, it was observed that the greater the inclined angle the higher the OMC value. Notice that these findings were also true for the case of the IC samples.

Even though the values of $\rho_{d,max}$ and OMC for both cases are very similar in terms of either increasing or decreasing, but their average values for the same inclined angle are quite different.

Table 2. Results for vertical compaction on inclined mould

Sample	$\rho_{d,max}$ (g/cm ³)	Avg. $\rho_{d,max}$ (g/cm ³)	OMC (%)	Avg. OMC (%)
VC5-1	1.870	1.883	15.20	15.00
VC5-2	1.895		14.80	
VC15-1	1.800	1.800	15.80	15.60
VC15-2	1.800		15.40	
VC30-1	1.765	1.764	17.20	16.90
VC30-2	1.762		16.60	

Table 3. Results for inclined compaction on inclined mould

Sample	$\rho_{d,max}$ (g/cm ³)	Avg. $\rho_{d,max}$ (g/cm ³)	OMC (%)	Avg. OMC (%)
IC5-1	1.890	1.890	14.30	14.15
IC5-2	1.890		14.00	
IC15-1	1.900	1.888	15.00	14.80
IC15-2	1.876		14.60	
IC30-1	1.810	1.819	17.40	16.00
IC30-2	1.828		14.60	

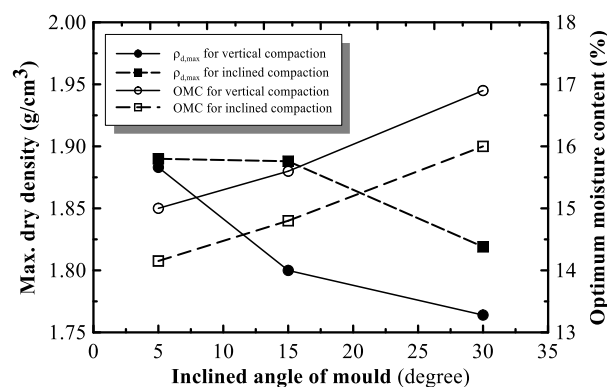


Fig. 7. $\rho_{d,max}$ and OMC of both vertical- and inclined compactions versus inclined angle of mould

Table 4. Differences of $\rho_{d,max}$ and OMC between inclined- and vertical compactions versus inclined angle of mould

Inclined angle (°)	Avg. $\rho_{d,max}$ (g/cm ³)		% Diff.	OMC (%)		% Diff.
	VC	IC		VC	IC	
5	1.883	1.890	0.37	15.00	14.15	-5.67
15	1.800	1.888	4.89	15.60	14.80	-5.13
30	1.764	1.819	3.12	16.90	16.00	-5.33

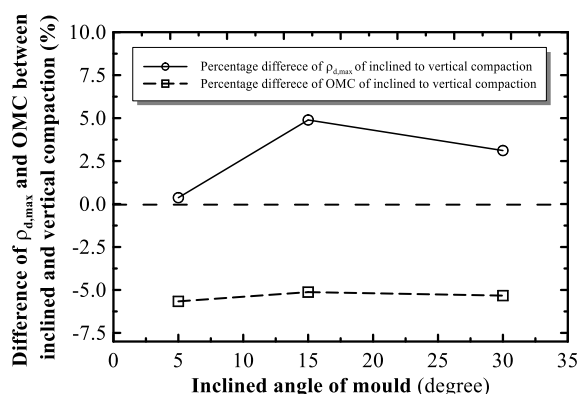


Fig. 8. Differences of $\rho_{d,max}$ and OMC between inclined- and vertical compactions versus inclined angle of mould

For instance, in the case of IC, when the inclined angle was changed from 5 to 15°, the average $\rho_{d,max}$ values were also changed, but just from 1.890 to 1.888 g/cm³. Comparing this result with the case of VC, it can be seen that at the same inclined angle change the average values are changed from 1.883 to 1.800 g/cm³, which is quite larger.

Furthermore, when the inclined angle was 5°, the difference of $\rho_{d,max}$ between the VC and IC samples is just 0.37%. This finding suggests that when a soil sample is almost horizontal the angle of the hammer relative to a soil sample has very little effect on the energy transferred to the soil being compacted.

Another point should be noted from this experiment is that the difference of the OMC values between the VC and IC samples when the inclined angles were gradually changed is almost constant: they are -5.67, -5.13, and -5.33% with respect to the inclined angles of 5, 15, and 30°. Thus, it may be concluded that the inclined angle of soil sample has no effect on the OMC value.

5 Conclusions

Lateritic soil is one of the most sought after material for road construction, especially in Thailand. The common practice is first looking for a material source. If the material is in accordance with the requirements, it is then excavated and transport to a construction site. To obtain a desired density, however, some kinds of compaction effort are essential.

Normally, the compaction test, either standard or modified, is carried out in a mould being horizontally laid. Then, the results were employed for quality control in the field. In the case of the ground is not horizontal

this practice may raise a problem in terms of getting a correct result. As such, a device has been developed in order to observe the compaction behaviour of the ground not being horizontal. The compaction test then was carried out on a soil sample laid at various inclined angles with two conditions: (1) compacting effort was vertical to a soil sample (VC) and (2) compacting effort was normal to a soil sample (IC). From the experiment, the following points have been drawn:

- 1) for all inclined angles, the IC yields greater maximum density,
- 2) when the inclined angle is just 5° the difference of $\rho_{d,max}$ between VC and IC is minimal,
- 3) when the inclined angles are greater than 5°, the difference of $\rho_{d,max}$ between the two methods is more obvious, and
- 4) in the case of OMC, it may be concluded that the two testing methods have no effect on the result because the percentage differences of the OMCs between those two methods are relatively consistent.

6 Acknowledgements

The authors wish to thank RMUTSV for their financial aid and support. Laboratory work was carried out by Mr. N. Inchana, Mr. P. Mongkol, and Mr. A. Binborsor, of which is kindly acknowledged.

References

1. M.D. Gidigasu, *Laterite Soil Engineering*, Elsevier Scientific Publishing Company, (1976)
2. T.H. Holland, *Geol. Mag.*, 4(10), (1903)
3. A. G/medhin, *Compaction properties of lateritic soils (The Case of Assossa)*, Master Thesis, Addis Ababa Uuniversity, (2008)
4. G.E. Blight, *Mechanics of Residual soils*. A.A Balkema, the Netherlands, (1997)
5. B.A. Vallerga, J.A. Shuster, A.L. Love, C.J. Van Til, *Engineering Study of Laterite & Lateritic Soils in Connection with Construction of Roads, Highways, & Airfields*, U.S. Agency for International Development, (1969)
6. G.F. Brown, and others, *Geological Reconnaissance of the Mineral Deposits of Thailand*, U.S. Geological Survey Bulletin No. 894. Washington, (1951)
7. ASTM D1557-12, Standard test methods for laboratory compaction characteristics of soil using modified effort (56,000 ft-lbf/ft³(2,700 kN-m/m³))