PERFORMANCE ASSESSMENT OF THREE-RING COMPACTION AND DIRECT SHEAR TESTING DEVICE

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Engineering in Geotechnology

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การประเมินประสิทธิภาพของแบบหล่อทดสอบการบดอัดและกำลังเฉือนแบบสามวงแหวน

นางสาวปิยวรรณ สนสกุล

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
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PERFORMANCE ASSESSMENT OF THREE-RING COMPACTION AND DIRECT SHEAR TESTING DEVICE

Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for a Master's Degree.

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แบบหล่อทดสอบการบดอัดและกำลังเฉือนแบบสามวงแหวนได้พัฒนาขึ้นเพื่อใช้ทดสอบความชื้นที่ความหนาแน่นสูงสุด ความหนาแน่นแห้งและกำลังเฉือนของตัวอย่างดิน อุปกรณ์สามารถทดสอบกำลังเฉือนของตัวอย่างดินที่มีขนาดเม็ดดินใหญ่กว่า 10 มิลลิเมตรและสามารถใช้เป็นแบบหล่อทดสอบการบดอัดและเป็นแบบหล่อทดสอบกำลังเฉือนโดยไม่ต้องนำตัวอย่างดินออกมาดังนั้นตัวอย่างจึงไม่ถูกรบกวน ดินเบนโทไนต์ (ผสมน้ำบริสุทธิ์) ใช้ทดสอบเพื่อยืนยันว่าแบบหล่อทดสอบแบบสามวงแหวนให้ผลเทียบเท่ากับการใช้อุปกรณ์ทดสอบตามมาตรฐาน ASTM ตัวอย่างดิน 5 ชนิด ประกอบด้วย ดินตะกอนประปา ดินเบนโทไนต์ (ผสมน้ำเกลืออิ่มตัว) ทรายที่มีดินเหนียวปน ทรายที่คละขนาดไม่ดี และทรายที่มีขนาดเม็ดคละดีนำมาทดสอบเพื่อประเมินประสิทธิภาพการทำงานของอุปกรณ์ ผลที่ได้จากแบบหล่อทดสอบแบบสามวงแหวนสอดคล้องกับผลที่ได้จากอุปกรณ์ตามมาตรฐาน ASTM ผลการทดสอบระบุว่ากำลังเฉือน ความหนาแน่นแห้งสูงสุด และความชื้นที่ความหนาแน่นสูงสุดของดินเบนโทไนต์ผสมน้ำบริสุทธิ์ที่ได้จากแบบหล่อทดสอบแบบสามวงแหวนและแบบหล่อทดสอบแบบมาตรฐาน มีผลการทดสอบใกล้เคียงกันมาก สำหรับตัวอย่างดิน 5 ชนิด ยกเว้นดินเบนโทไนต์ผสมกับน้ำเกลืออิ่มตัว แบบหล่อทดสอบแบบสามวงแหวนให้ค่าความหนาแน่นสูงสุดสูงกว่าที่ได้จากแบบหล่อทดสอบแบบมาตรฐาน ค่ากำลังเฉือนที่ได้จากแบบหล่อทดสอบแบบสามวงแหวนมีค่าสูงกว่าที่ได้จากการอุปกรณ์ทดสอบกำลังเฉือนตามมาตรฐาน ซึ่งเป็นผลมาจากแบบหล่อทดสอบแบบสามวงแหวนสามารถใช้ทดสอบกำลังเฉือนของดินที่มีอนุภาคเม็ดดินสูงถึง 10 มิลลิเมตรดังนั้นจึงทำให้ค่ากำลังเฉือนมีค่าสูงซึ่งใกล้เคียงกับพฤติกรรมจริงของดินที่อยู่ภายใต้สภาวะในภาคสนาม

สาขาวิชา เทคโนโลยีธรณี ลายมือชื่อนักศึกษา ____________

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PIYAWAN SONSAKUL : PERFORMANCE ASSESSMENT OF THREE-RING COMPACTION AND DIRECT SHEAR TESTING DEVICE. THESIS ADVISOR : ASSOC. PROF. KITTITEP FUENKAJORN, Ph.D., P.E., 36 PP.

DIRECT SHEAR TEST/SHEAR STRENGTH/COMPACTION

A three-ring compaction and direct shear test mold has been developed to obtain the optimum water content, dry density and shear strength of compacted soil samples. The device can shear the soil samples with grain size up to 10 mm. It can be used as a compaction mold and direct shear mold without removing the soil sample, and hence eliminating the sample disturbance. Commercial grade bentonite (mixed with distilled water) is tested to verify that the three-ring mold can provide the results comparable to those obtained from the ASTM standard testing device. Five types of soil, including sludge, bentonite (mixed with brine), clayey sand, poorly-graded sand and well-graded sand, are tested to assess the performance of the device. Their results are compared with those obtained from the ASTM standard test device. The results indicate that the shear strength, maximum dry density and optimum water content of the bentonite (mixed with distilled water) obtained from the three-ring mold and the ASTM standard mold are virtually identical. Except for the bentonite mixed with brine the three-ring mold yields a higher maximum dry density of the soils than that from the standard mold. The shear strengths obtained from the three-ring mod are also higher than those from the standard shear test device. This is primarily because the three-ring mold can accommodate the soil particles up to 10 mm for the shear test,

and hence resulting in higher shear strengths that are closer to the actual behavior of the soil under in-situ conditions.

School of Geotechnology　　　　Student's Signature______________________

Academic Year 2012　　　　Advisor's Signature______________________

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LIST OF SYMBOLS AND ABBREVIATIONS

σ	=	Normal Stress
τ	=	Shear Stress
c	=	Cohesion
ϕ	=	Friction Angle

CHAPTER I

INTRODUCTION

1.1 Rationale and background

Mechanical properties of soil are necessary for the design and analysis of earth structures. Soil strength indicates the ability of the soil to carry load. Direct shear testing is one of the popular test methods to obtain such properties. The method has been standardized by the American Society for Testing of Materials (ASTM D3080). The standard method has however limited the maximum particle size of 4.75 mm which is about one-tenth of the mold diameter. The soil samples are normally sieved to exclude the large particles. The obtained results therefore may not truly represent the actual in-situ properties of soils of which contain larger particle sizes. Another disadvantage of the standard direct shear test method is that the soil samples may be disturbed while they are pushed out of the compaction mold and trimmed before direct shear testing.

1.2 Research objectives

The objective of this study is to design and invent a new device for compaction and shear tests of soil and particulate samples in the laboratory. It is called here as three-ring compaction and direct shear testing device. The performance of the new device will be assessed by testing five soil types with different properties. The test results from the three-ring compaction and direct shear testing will be compared with those obtained from the ASTM standard compaction and direct shear test methods.

1.3 Scope and limitations

1) The collected soil samples include.

   - bentonite of American colloid company
   - soil at Phu Thap Pah gold mine, Loei province.
   - soil at Chai Mongkhon sub district, Nakhon Ratchasima province (zone 48P UTM 189749/1643411).
   - soil at Suranaree sub district, Nakhon Ratchasima province (zone 48P UTM 181504/1645294).

2) The basic properties of the soils are determined including specific gravity, Atterberge's limits, grain size analysis (wet sieve analysis and hydrometer analysis), and consolidation test.

3) Compaction testing uses standard mold (ASTM D1557) and three-ring mold.

4) Direct shear testing uses standard mold (ASTM D3080) and three-ring mold.

5) Normal stresses used in the direct shear are from 0.2, 0.4, 0.6, 0.8 to 1 MPa.

1.4 Research methodology

Figure 1.1 shows the research plan.

1.4.1 Literature review

Literature review will be carried out to study the determination of soil strength parameters and the relevant theory of direct shear test. The results of laboratory test of direct shear test. The sources of information are from text books, journals, technical reports and conference papers. A summary of the literature review will be given in the thesis.

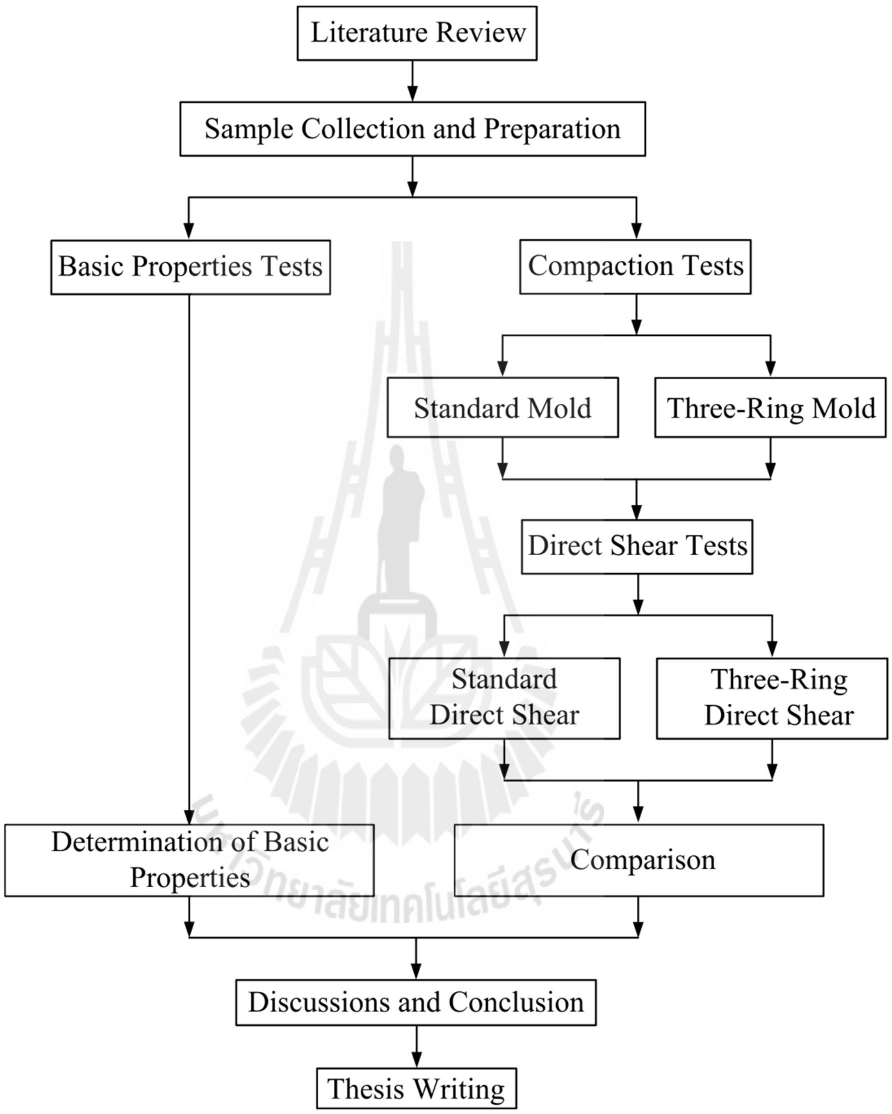

Figure 1.1 Research methodology.

1.4.2 Soil collection and preparation

Four soil samples used in this study are the bentonite from American colloid company, soil at Phu Thap Pah gold mine in Loei province, soil at Chai Mongkhon sub district, Nakhon Ratchasima province (UTM 189749/1643411) and soil at Suranaree district, Nakhon Ratchasima province (UTM 181504/1645294). The soil sample will be tested to determine the basic properties. Sample preparation will be carried out in the laboratory at the Suranaree University of Technology.

1.4.3 Basic properties of soil

Basic properties of soil will be determined for use as a data basis. Atterberge's limit will be determined according to the ASTM (D4318-05), as an indicator of changes in volume when the water content changes. Specific gravity will be determined in according to the ASTM (D854-00). Grain size analysis will be performed according to the ASTM (D422-07). Compaction test will be performed according to the ASTM (D1557-09), using a mold with diameter of 4 in (standard mold) and 4 in (three-ring mold). Consolidation test will be performed in according to the ASTM (D2435-04) to find the maximum past pressure of soil compaction.

1.4.4 Direct shear test

The direct shear test method follows the ASTM (D3080-04) standard practice which will be compared with the three-ring direct shear test. The constant normal stresses are varied from 0.2, 0.4, 0.6, 0.8 to 1 MPa.

1.4.5 Determination of basic properties

Determination of the Atterberge's limit follows Casagrande method, including plastic limit (PL), liquid limit (LL), and plasticity index (PI). Grained size analysis, using wet sieve and hydrometer analysis will show grain size distribution relation between percent finer as a function of particle sizes. Compaction test shows relation between water content with dry density and know a value OWC (optimum water content) maximum dry density.

1.4.6 Comparison

The results of compaction and direct shear testing between three-ring mold and standard mold will be compared.

1.4.7 Discussions and conclusion

Results from laboratory testing will be used to assess the performance assessment of the three-ring mold device. Similarity and discrepancies will be discussed.

1.4.8 Thesis writing

All research activities, methods, and results will be documented and complied in the thesis. This research is application to design mine backfill which soil strength parameter of direct shear test. The research or findings will be published in the conference proceedings or journals.

1.5 Thesis contents

Chapter I states the objectives, rationale, and methodology of the research. **Chapter II** summarizes results of the literature review on direct shear and laboratory testing. **Chapter III** describes the test materials and testing devices. **Chapter IV** presents the verification test method, the performance assessment and test results. Conclusions and recommendations for future research needs are given in **Chapter V**. **Appendix A** provides detailed results of Atterberg's limit, cone penetration and consolidation tests.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

Topics relevant to this research are reviewed to improve an understanding of laboratory testing methods of soils. Results from the review are summarized as follows.

2.2 Direct Shear Test

Das (2008) states that the direct shear method is the oldest and simplest form of shear test arrangement. A diagram of the direct shear test apparatus is shown in Figure 2.1 the test equipment consists of a metal shear box in which the soil specimens may be square or circular. The size of the specimens generally used is about 3 to 4 in^2 across and 1 in high. The box is split horizontally into halves. Normal force on the specimen is applied from the top of shear box. The normal stress on the specimens can be as 150 psi. Shear force is applied by moving one half of the box relative to the other to cause failure in the soil specimen. Depending on equipment, the shear test can be either stress-controlled or strain-controlled. In stress-controlled tests, the shear force is applied in equal increments until the specimen fails. The failure takes place along the plane of split of shear box. After the application of each incremental load, the shear displacement of the top half of the box is measured by a horizontal dial gauge.

The change in the height of the specimen (and thus the volume change of the specimen) during the test can be obtained from the reading of the dial gauge that measures the vertical movement of the upper loading plate. In stain-controlled tests, a constant rate of shear displacement is applied to one half of the box by a motor is applied to one half of the box by a motor that act through gears. The constant rate of shear displacement is measured by a horizontal dial gauge. The resisting shear force of the soil corresponding to any shear displacement can be measured by a horizontal proving ring or load cell. The volume change of the specimen during the test is obtained in a manner similar to the stress-controlled test.

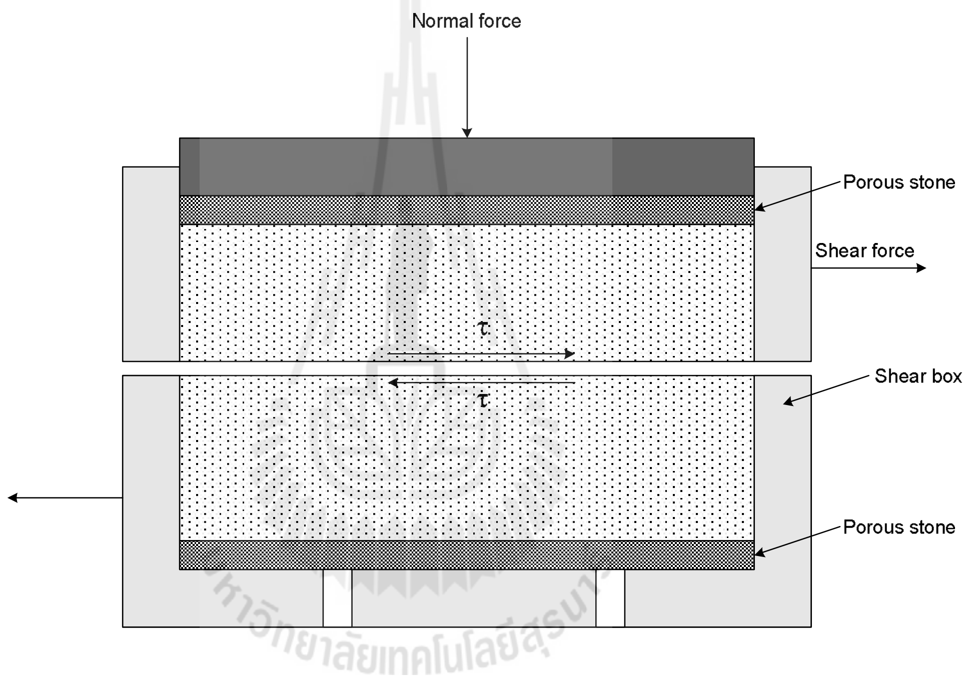

Figure 2.1 Typical direct shear test arrangement (Das, 2008)

2.3 Laboratory testing

ASTM (D422) determines the percentage of different grain sizes contained within a soil. The mechanical or sieve analysis can be performed to determine the distribution of the coarser, larger-sized particles, and the hydrometer method is used to determine the distribution of the finer particles. The distribution of different grain sizes affects the engineering properties of soil. Grain size analysis provides the grain size distribution, and it is required in classifying the soil.

ASTM (D854-00) determines the specific gravity of soil by using a pycnometer. Specific gravity is the ratio of the mass of unit volume of soil at a stated temperature to the mass of the same volume of gas-free distilled water at a stated temperature. The specific gravity of a soil is used in the phase relationship of air, water, and solids in a given volume of the soil.

ASTM (D1557) determines the relationship between the moisture content and the dry density of a soil for a specified compactive effort. The compactive effort is the amount of mechanical energy that is applied to the soil mass. Several different methods are used to compact soil in the field, and some examples include tamping, kneading, vibration, and static load compaction.

This laboratory will employ the tamping or impact compaction method using the type of equipment and methodology developed by R. R. Proctor (1933), therefore, the test is also known as the Proctor test. Two types of compaction tests are routinely performed: (1) the Standard Proctor test, and (2) the Modified Proctor test. Each of these tests can be performed in three different methods as outlined in the attached Table 1. In the Standard Proctor test, the soil is compacted by a 5.5 lb hammer falling a distance of one foot into a soil filled mold. The mold is filled with three equal layers of soil, and each layer is subjected to 25 drops of the hammer. The Modified Proctor test is identical to the Standard Proctor test except it employs, a 10 lb hammer falling a distance of 18 inches, and uses five equal layers of soil instead of three. There are two types of compaction molds used for testing. The smaller type is 4 inches in diameter and has a volume of about 1/30 ft^3 (944 cm^3), and the larger type is 6 inches in diameter and has a volume of about 1/13.333 ft^3 (2,123 cm^3). If the larger mold is used each soil layer must receive 56 blows instead of 25 (See Table 2.1).

Table 2.1 Alternative proctor test methods (Reddy, 2002)

	Standard Proctor ASTM 698			**Modified Proctor ASTM 1557**		
	Method A	**Method B**	**Method C**	**Method A**	**Method B**	**Method C**
Material	≤ 20% Retained on No.4 Sieve	>20% Retained on No.4 ≤ 20% Retained on 3/8"Sieve	>20% Retained on No.3/8" <30% Retained on 3/4"Sieve	≤ 20% Retained on No.4 Sieve	>20% Retained on No.4 ≤ 20% Retained on 3/8"Sieve	>20% Retained on No.3/8" <30% Retained on 3/4"Sieve
For test sample, use soil passing	SieveNo.4	3/8"Sieve	3/4"Sieve	SieveNo.4	3/8"Sieve	3/4"Sieve
Mold	4" DIA	4" DIA	6" DIA	4" DIA	4" DIA	6" DIA
No. of layers	3	3	3	5	5	5
No. of blows/layer	25	25	56	25	25	56

Note: Volume of 4" diameter mold = 944 cm^3, Volume of 6" diameter mold = 2,123 cm^3 (verify these values prior to testing)

Mechanical compaction is one of the most common and cost effective means of stabilizing soils. An extremely important task of geotechnical engineers is the performance and analysis of field control tests to assure that compacted fills are meeting the prescribed design specifications. Design specifications usually state the required density (as a percentage of the "maximum" density measured in a standard laboratory test), and the water content. In general, most engineering properties, such as the strength, stiffness, resistance to shrinkage, and imperviousness of the soil, will improve by increasing the soil density. The optimum water content is the water content that results in the greatest density for a specified compactive effort. Compacting at water contents higher than (wet of) the optimum water content results in a relatively dispersed soil structure (parallel particle orientations) that is weaker, more ductile, less pervious, softer, more susceptible to shrinking, and less susceptible to swelling than soil compacted dry of optimum to the same density. The soil compacted lower than (dry of) the optimum water content typically results in a flocculated soil structure (random particle orientations) that has the opposite characteristics of the soil compacted wet of the optimum water content to the same density.

ASTM (D2435) determines the magnitude and rate of volume decrease that a laterally confined soil specimen undergoes when subjected to different vertical pressures. From the measured data, the consolidation curve (pressure-void ratio relationship) can be plotted. This data is useful in determining the compression index, the recompression index and the preconsolidation pressure (or maximum past pressure) of the soil. In addition, the data obtained can also be used to determine the coefficient of consolidation and the coefficient of secondary compression of the soil. The consolidation properties determined from the consolidation test are used to estimate the magnitude and the rate of both primary and secondary consolidation settlement of a structure or an earth fill. Estimates of this type are of key importance in the design of engineered structures and the evaluation of their performance.

ASTM (D3080) determines the consolidated-drained shear strength of a sandy to silty soil. The shear strength is one of the most important engineering properties of a soil, because it is required whenever a structure is dependent on the soil's shearing resistance. The shear strength is needed for engineering situations such as determining the stability of slopes or cuts, finding the bearing capacity for foundations, and calculating the pressure exerted by a soil on a retaining wall. The direct shear test is one of the oldest strength tests for soils. In this laboratory, a direct shear device will be used to determine the shear strength of a cohesionless soil (angle of internal friction (ϕ)). From the plot of the shear stress versus the horizontal displacement, the maximum shear stress is obtained for a specific vertical confining stress. After the experiment is run several times for various vertical-confining stresses, a plot of the maximum shear stresses versus the vertical (normal) confining stresses for each of the tests is produced. From the plot, a straight-line approximation of the Mohr-Coulomb failure envelope curve can be drawn, ϕ may be determined, and, for cohesionless soils ($c = 0$), the shear strength can be computed from the following equation:

$$\tau = \sigma \tan \phi \tag{2.1}$$

ASTM (D4318) determines the plastic and liquid limits of a fine grained soil. The liquid limit (LL) is arbitrarily defined as the water content, in percent, at which a pat of soil in a standard cup and cut by a groove of standard dimensions will flow together at the base of the groove for a distance of 13 mm (1/2 in.) when subjected to 25 shocks from the cup being dropped 10 mm in a standard liquid limit apparatus operated at a rate of two shocks per second. The plastic limit (PL) is the water content, in percent, at which a soil can no longer be deformed by rolling into 3.2 mm (1/8 in.) diameter threads without crumbling. The Swedish soil scientist Albert Atterberg originally defined seven “limits of consistency” to classify fine-grained soils, but in current engineering practice only two of the limits, the liquid and plastic limits, are commonly used. (A third limit, called the shrinkage limit, is used occasionally.) The Atterberg limits are based on the moisture content of the soil. The plastic limit is the moisture content that defines where the soil changes from a semi-solid to a plastic (flexible) state. The liquid limit is the moisture content that defines where the soil changes from a plastic to a viscous fluid state. The shrinkage limit is the moisture content that defines where the soil volume will not reduce further if the moisture content is reduced. A wide variety of soil engineering properties have been correlated to the liquid and plastic limits, and these Atterberg limits are also used to classify a fine-grained soil according to the Unified Soil Classification system or AASHTO system.

Ahad and Ali (2008) studied the effects of particle size on macro and micro mechanical behavior of coarse-grained soils, using both experimental tests and numerical simulations, on a series of both small (6cm×6cm×2cm) and large (30cm×30cm×15cm) scale direct shear tests on selected coarse-grained soils to determine the effect of stress level on the relationship between particle size and friction angle and behavior of samples. Approaches showed that the behavior of the coarse grained soil changes from strain hardening to softening during shearing as vertical stress increases. The internal friction angle reduces with increasing the stress level. Results show that particle size greatly influences the mechanical behavior of the coarse-grained soils. The internal friction angle and the sample's dilation increase with growing the particle size. An increase in the specimen scale leads to reduction of the apparent cohesion. Comparison of experimental and numerical tests reveals that the numerical simulation exaggerates the effect of particle size on the mechanical behavior.

Nam et al. (2011) studied the undisturbed soil samples for direct shear tests which extruded from Shelby tubes and block soil samples obtained from the study site. Disturbed soil samples were also collected and tested for grain size distribution, Atterberg limits, specific gravity, and classification by the United Soil Classification System (USCS). A representative soil profile of the riverbank, where the soil samples were collected, consists of: silty sand SM (0–0.6 m), low plasticity clay CL (0.6–2.5 m), high plasticity silt MH (2.5–3.8 m), and low plasticity clay CL (3.8–4.5 m). Conventional direct shear test procedures followed ASTMD 3080 (2004) the soil sample was sheared at a rate of 0.005 mm/min for silt (MH) and clay (CL), and 0.008 mm/min for silty sand (SM). The volume changes during the suction-controlled tests were different from those in the saturated direct shear tests. The samples typically contracted during shearing in the saturated soil samples, where as the samples seemed to be initially contracted then dilated under unsaturated conditions regardless of the soil type.

Bergado et al. (2006) studied the laboratory tests for both index and engineering properties of the soil used as the compacted clay liner (CCL) and uniform gravel used as the protective layer between the lining system and the waste have been conducted. The soil used as the CCL has a specific gravity of 2.70, liquid limit of 67%, plastic limit of 31%, maximum dry density of 1.75 g/cm^3 and optimum moisture content of 14.5% as per standard proctor test. For soils, the failure envelope may show slight curvature, particularly under low normal stress. The shear stress versus displacement and shear stress versus normal stress curves for CCL are expected, the shear strength of the compacted clay is dependent on the applied normal stress. The internal friction angle for the compacted clay is high at low normal stress and decreases with increasing normal stress. For normal stresses below 200 kPa, the compacted clay yields a friction angle of 33 and for normal stresses above 200 kPa, the internal friction angles of the compacted clay is 19.24 degrees.

CHAPTER III

TEST MATERIALS AND TESTING DEVICES

3.1 Introduction

This chapter describes the materials and testing devices. A three-ring compaction and direct shear mold has been developed to obtain the optimum water content, dry density and shear strength of compacted soil samples.

3.2 Test materials

Bentonite obtained from the American Colloid Company is selected for the verification test of the three-ring mold. This is primarily because it is highly uniform and consistent in engineering properties. It is prepared for the compaction tests and direct shear test for both the three-ring mold and the ASTM standard mold. Its maximum dry density, optimum water content, and shear strengths are determined. Table 3.1 shows some basic properties of the materials. Sludge from to Metropolitan Waterworks Authority, bentonite (mixed with brine), clayey sand from Loei province, poorly-graded sand from Chai Mongkon district and well-graded sand from Suranaree district are collected and prepared to assess the performance of the three-ring mold. They are tested to determine the maximum dry density, optimum water content, and shear strengths. The results are compared with those of the ASTM standard method and device. Table 3.1 gives some engineering properties of the materials. Figure 3.1 shows the particle size distribution of the soils. It should be noted that the maximum particle size used for the compaction test (ASTM D 1557) and shear test

(ASTM D3080) is less than 4.75 mm while for the three-ring mold test is up to 10 mm. Bentonite is cannot test to particle-size analysis because particle size is smaller.

Table 3.1 Properties and classification of five soils used in this study.

Materials	Specific gravity	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)	Classification soil
Bentonite (mixed with distilled water)	2.50	357.00	43.67	313.33	-
Bentonite (mixed with brine)	2.50	108.00	48.99	59.01	-
Sludge	2.53	55.00	21.50	23.50	Silt of high plasticity (MH)
Soil at Phu Thap Pah, Loei	2.43	36.30	26.80	9.50	Clayey sand (SC)
Soil at Chai Mongkhon, Nakhon Ratchasima	2.64	27.30	19.00	8.30	Poorly-graded sand (SP)
Soil at Suranaree, Nakhon Ratchasima	2.66	21.70	14.00	7.70	well-graded sand (SW)

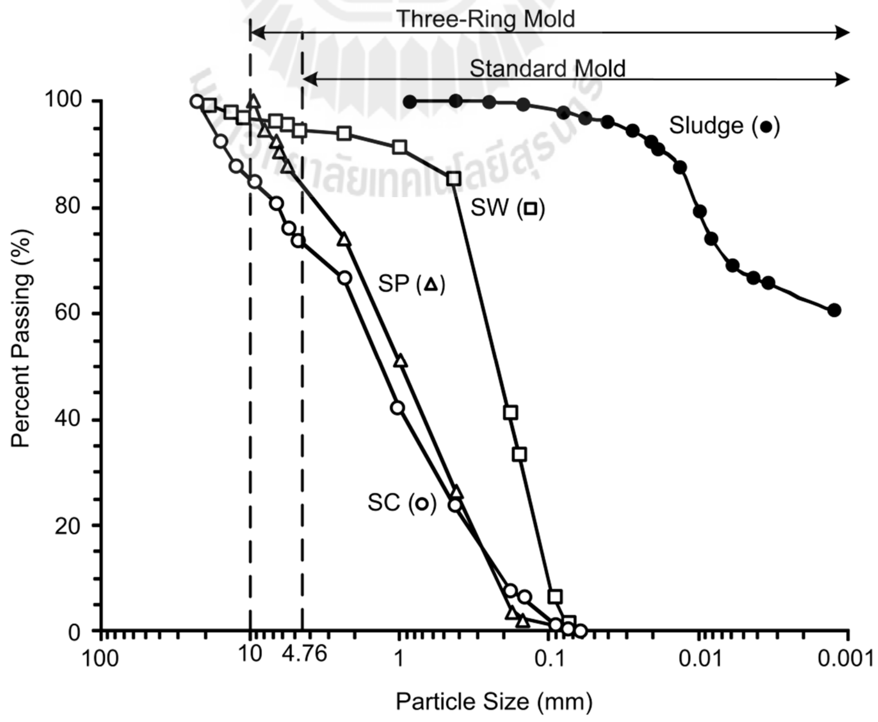

Figure 3.1 Particle size distribution of the tested materials.

3.3 Devices used in testing

3.3.1 ASTM standard mold

The ASTM standard compaction mold consists of top ring and bottom ring. The inner diameter is 10.16 cm, outer diameter is 10.76 cm, and height is 11.64 cm. The two rings are secured on the base plate using bolts. The two rings of the standard mold cannot be laterally displaced due to the locking edges at the rims of the rings (Figure 3.2). Each sample is compacted in the ASTM standard mold following the ASTM (D1557). For direct shear test after compaction, the soil sample is removed and trimmed to provide a diameter of 2.5 inches and thickness 1 inch. The sample is then installed into the direct shear mold (ASTM D3080).

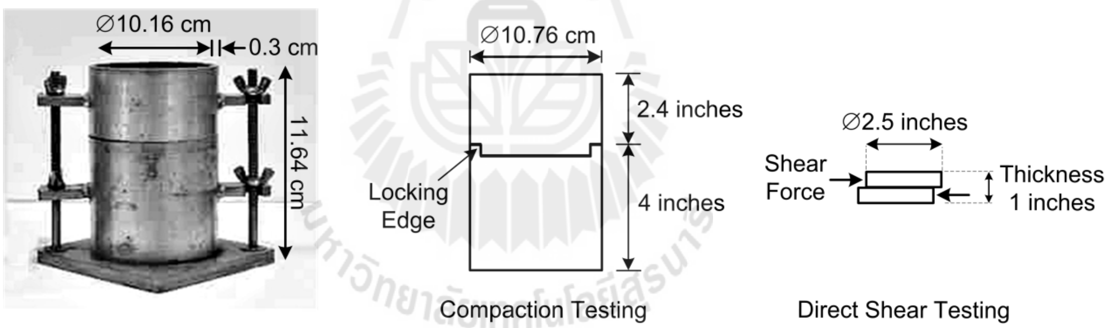

Figure 3.2 The ASTM standard mold.

3.3.2 Three-ring compaction mold

The three rings are secured on the base plate using steel bolts and two steel clamps. The inner diameter is 10.16 cm, outer diameter is 10.76 cm, and the combined height is 15.19 cm. The clamps prevent the rings from displacing during compaction. These clamps are removed when the mold is placed into a direct shear load frame, and hence they can be displaced (sheared) when the lateral force is applied during shear test. This means that the mold will become a shear box (Figure 3.3).

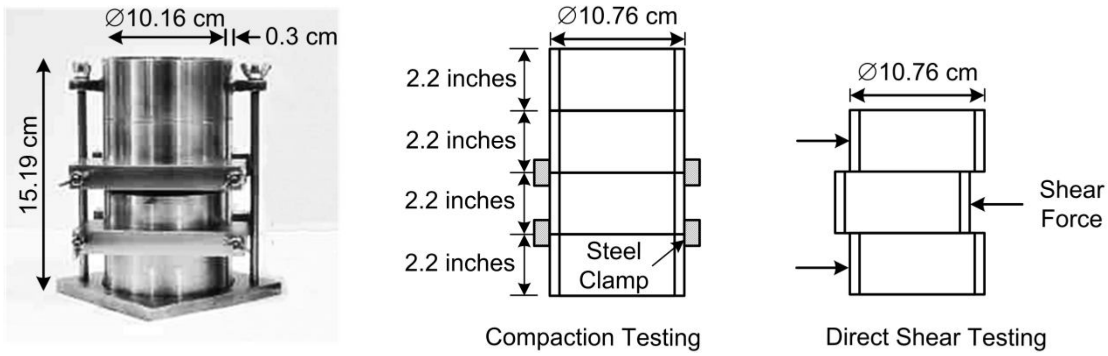

Figure 3.3 Three-ring mold.

The three-ring mold requires a new shear test frame. Since there are two incipient shear planes of the compacted soil sample, one between the top and middle rings, and the other between the middle and bottom rings. The main components for the shear test frame are the lateral load system for pushing the middle ring, and the vertical load system for applying a constant normal stress on the compacted soil sample (Figure 3.4). The applied loads are obtained from two 20-ton hydraulic load cells, connected to separated hydraulic hand pumps. Pressure gages are used to measure the load. The shear and normal displacements are monitored by high precision dial gages.

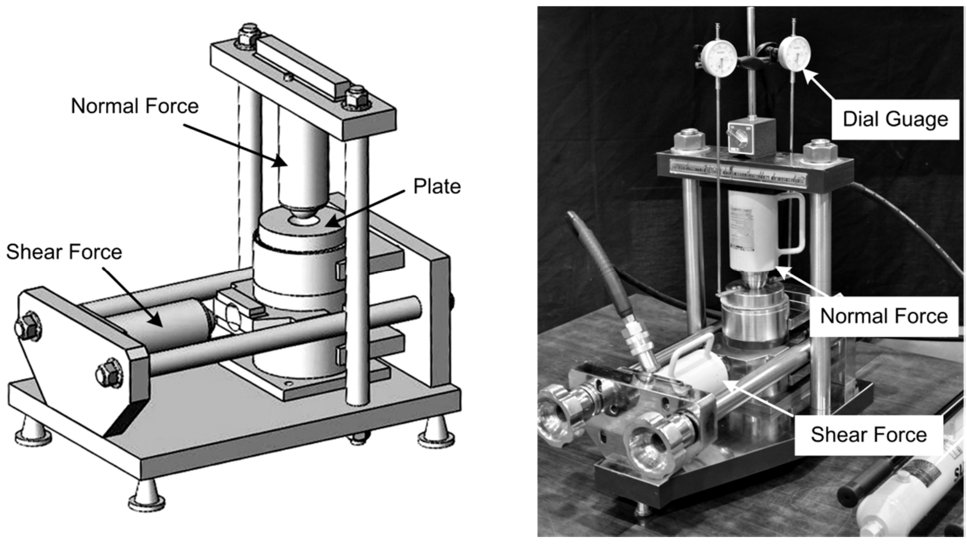

Figure 3.4 Direct shear test frame developed for use with the three-ring mold.

CHAPTER IV

VERIFICATION TEST AND PERFORMANCE ASSESSMENT

4.1 Introduction

The objective of this study chapter is to verify the performance of the three-ring mold. This chapter describes the verification test method, the performance assessment and test results. Results obtained from the three-ring mold and ASTM standard mold, are compared.

4.2 Verification test

The verification of the three-ring mold is made for the compaction test and the direct shear test by using the bentonite (mixed with distilled water) as a reference sample. The bentonite is mixed with the distilled water with percentages of bentonite of 15, 20, 25, 30, 35 and 40%. The mixtures are compacted in the mold (ASTM D1557) for compaction test. The compacted bentonite is dynamic compaction with a release of weight steel hammer 10 pounds in mold of 27 times per layer in six layers of three-ring compaction test. The standard compaction bentonite is dynamic compaction with a release of weight steel hammer 10 pounds in mold of 25 times per layer in five layers. Compaction test apparatus with the three-ring mold and the ASTM standard mold is shown in Figure 4.1. Figure 4.2 compares the results between the application of the three-ring mold and the ASTM standard test mold. The maximum dry densities and optimum water contents of the bentonite obtained for both methods are very similar.

Figure 4.1 Compaction test with three-ring mold (left) and ASTM standard mold (right).

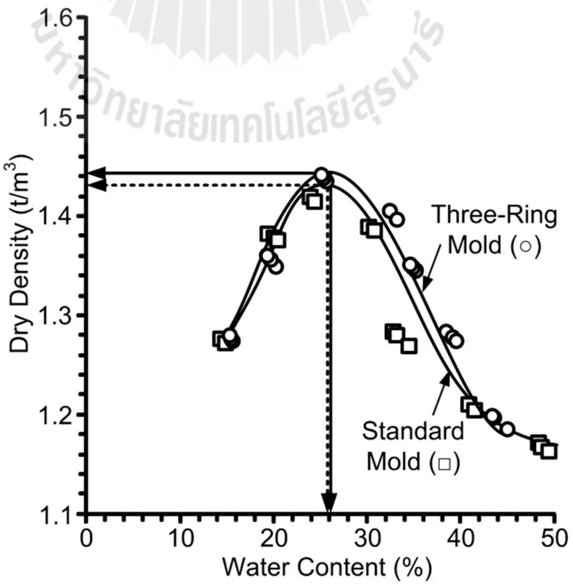

Figure 4.2 Maximum dry density and optimum water content of bentonite obtained from the three-ring mold and ASTM standard mold.

4.3 Performance assessment

The sludge, bentonite (mixed with brine), clayey sand, poorly-graded sand, and well-graded sand are prepared for the compaction and shear tests by using both the three-ring mold and the ASTM standard test mold. The mixtures are compacted in the mold (ASTM D1557) for compaction tests. The compacted materials are dynamic compaction with a release of weight steel hammer 10 pounds in mold of 27 times per layer in six layers of three-ring compaction test. The standard compaction materials are dynamic compaction with a release of weight steel hammer 10 pounds in mold of 25 times per layer in five layers. The direct shear test normal force is applied by the vertical hydraulic load cell. Normal stresses used are 0.2, 0.4, 0.6, 0.8 and 1 MPa for the three-ring mold and the ASTM standard mold. Shear force is applied by a horizontal hydraulic load cell. The peak shear strength is used to calculate the cohesion and friction angle. Figure 4.3 show direct shear test apparatus (ASTM D3080) and Figure 4.4 is shows three-ring compaction and direct shear test device.

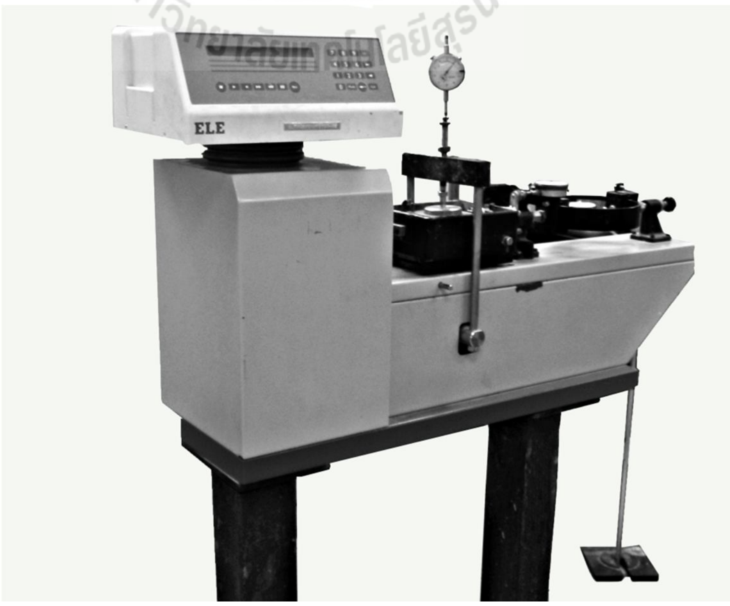

Figure 4.3 Direct shear test apparatus for standard ASTM D3080.

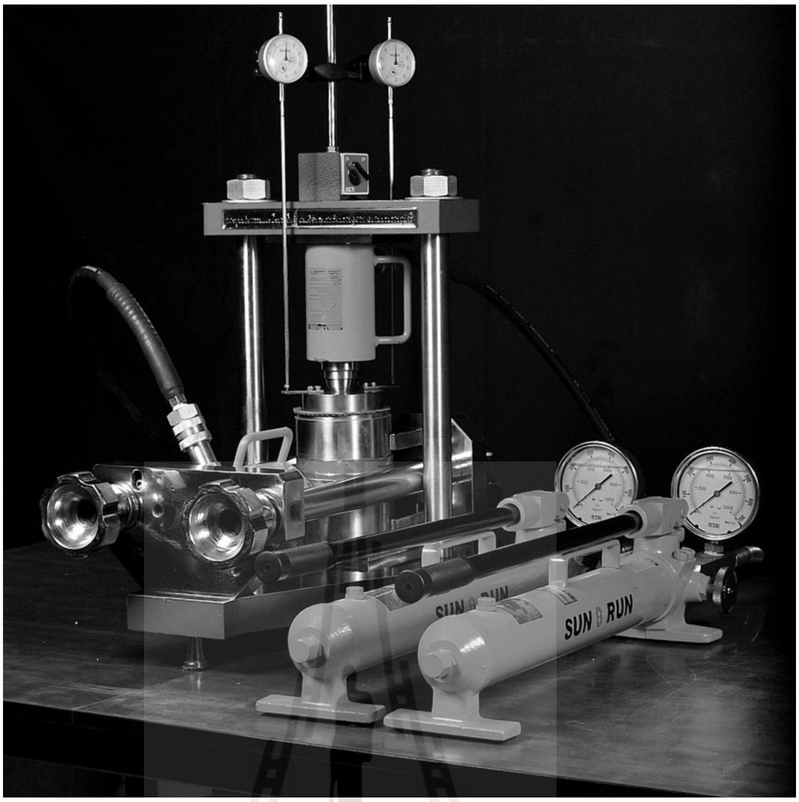

Figure 4.4 Three-ring compaction and direct shear test device.

4.4 Test results

The results from the direct shear tests of the compacted bentonite from the two techniques are very similar (Figures 4.5 and 4.6). These suggest that the three-ring mold can provide the results that are comparable to those of the ASTM standard test mold. The numerical values for the relevant properties obtained from the two tests on the bentonite are given in Tables 4.1 and 4.2. The compaction test results indicate that the three-ring mold that can accommodate larger particle sizes of the soil yields higher maximum dry density values for all tested soils (Table 4.1). The optimum water contents obtained from both methods are similar. The three-ring mold however gives a higher maximum dry density than those obtained from the ASTM standard mold (Figure 4.7). Figures 4.8 and 4.9 plot the results from the direct shear testing for both methods.

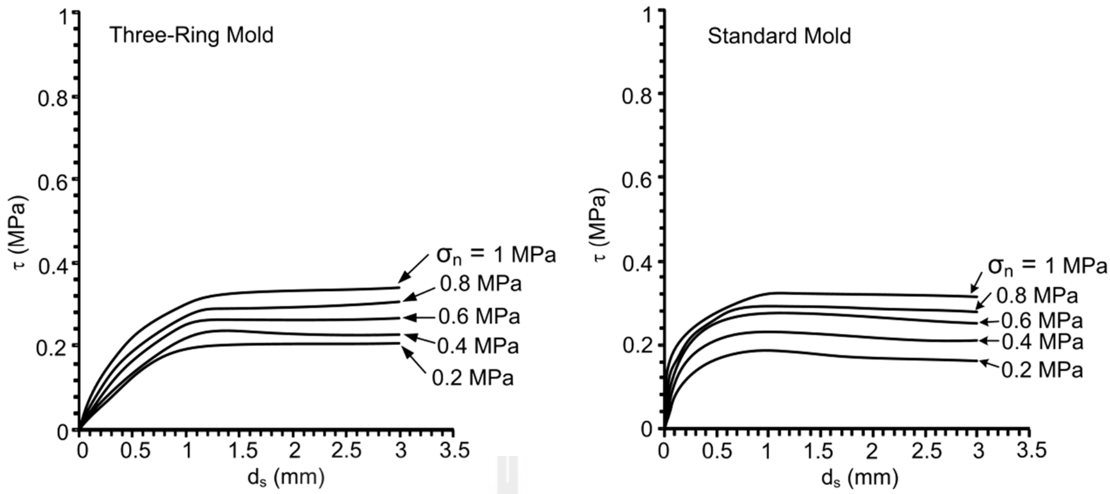

Figure 4.5 Shear stresses as a function of shear displacement of compacted bentonite from three-ring mold (left) and ASTM standard mold (right).

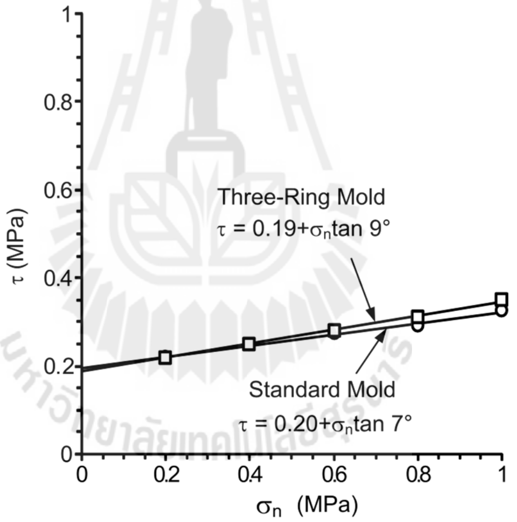

Figure 4.6 Shear strength as a function of normal stress of bentonite compared between three-ring and ASTM standard molds.

Under the same normal loads testing with the three-ring mold gives higher peak and residual shear stresses. The three-ring mold gives higher friction angle and cohesion than those obtained from the ASTM standard test mold (Figure 4.10 and Table 4.2). Again this is because of the larger particle sizes included in the compacted soil samples for the three-ring mold.

obtained from the ASTM standard test mold (Figure 4.10 and Table 4.2). Again this is because of the larger particle sizes included in the compacted soil samples for the three-ring mold.

Table 4.1 Compaction test results.

Type	Optimum water content (%)		Maximum dry density (t/m^3)	
	Three-Ring Mold	**Standard Mold**	**Three-Ring Mold**	**Standard Mold**
Sludge	26.00	26.30	1.442	1.358
Bentonite (Fresh water)	26.00	26.00	1.442	1.430
Bentonite (Brine)	20.00	20.00	1.520	1.500
Clayey sand (SC)	15.70	15.20	1.760	1.670
Poorly-graded sand (SP)	9.10	9.30	2.120	1.910
Well-graded sand (SW)	10.70	11.10	1.905	1.860

Table 4.2 Direct shear testing results.

Type	Cohesion		Friction Angle (degrees)	
	Three-Ring Mold	**Standard Mold**	**Three-Ring Mold**	**Standard Mold**
Sludge	0.12	0.14	32	26
Bentonite (Fresh water)	0.19	0.20	9	7
Bentonite (Brine)	0.14	0.11	9	8
Clayey sand (SC)	0.24	o.24	20	15
Poorly-graded sand (SP)	0.09	0.09	42	23
Well-graded sand (SW)	0.06	0.06	34	27

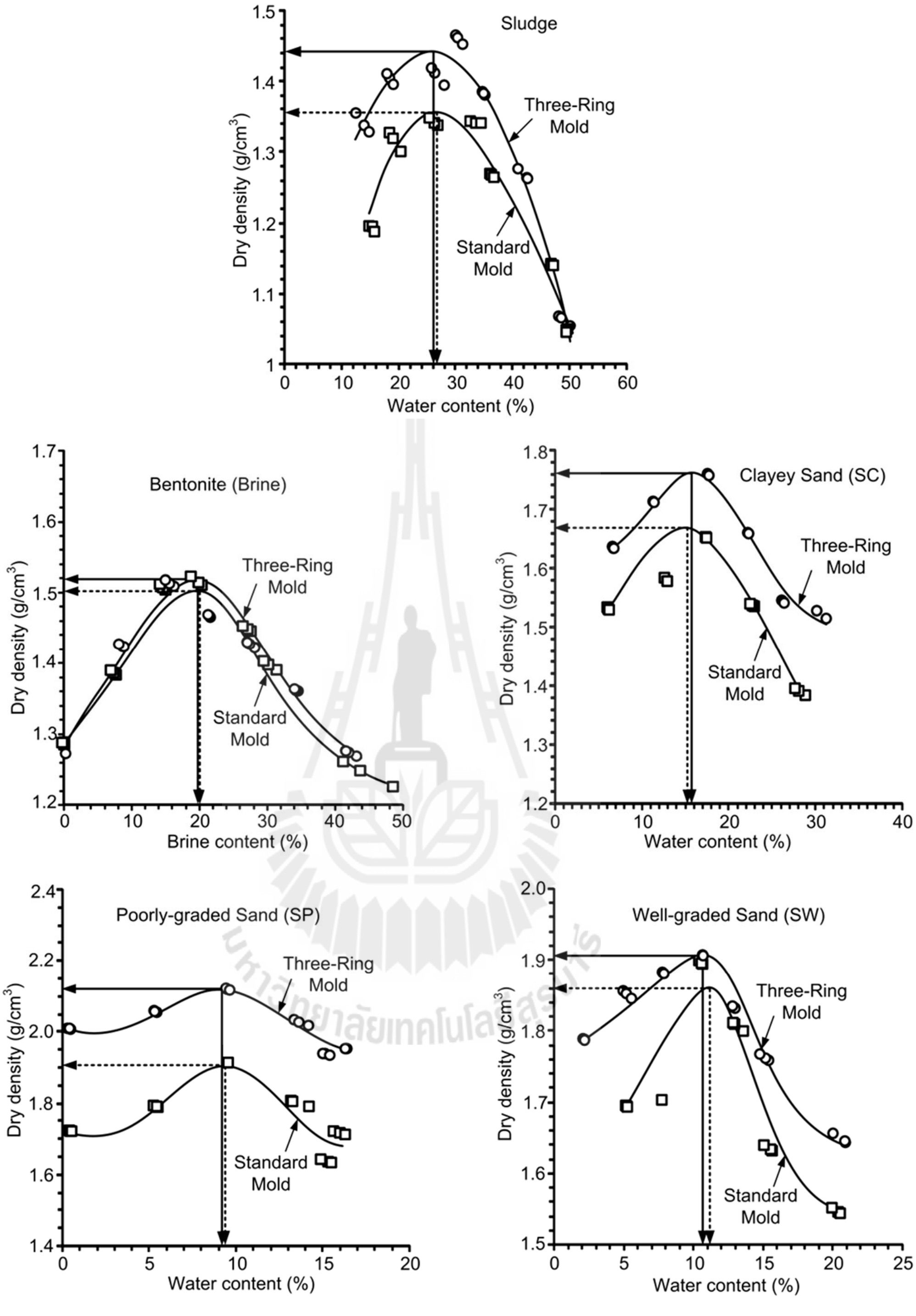

Figure 4.7 Maximum dry density and optimum water content of soils obtained from the three-ring mold and ASTM standard mold.

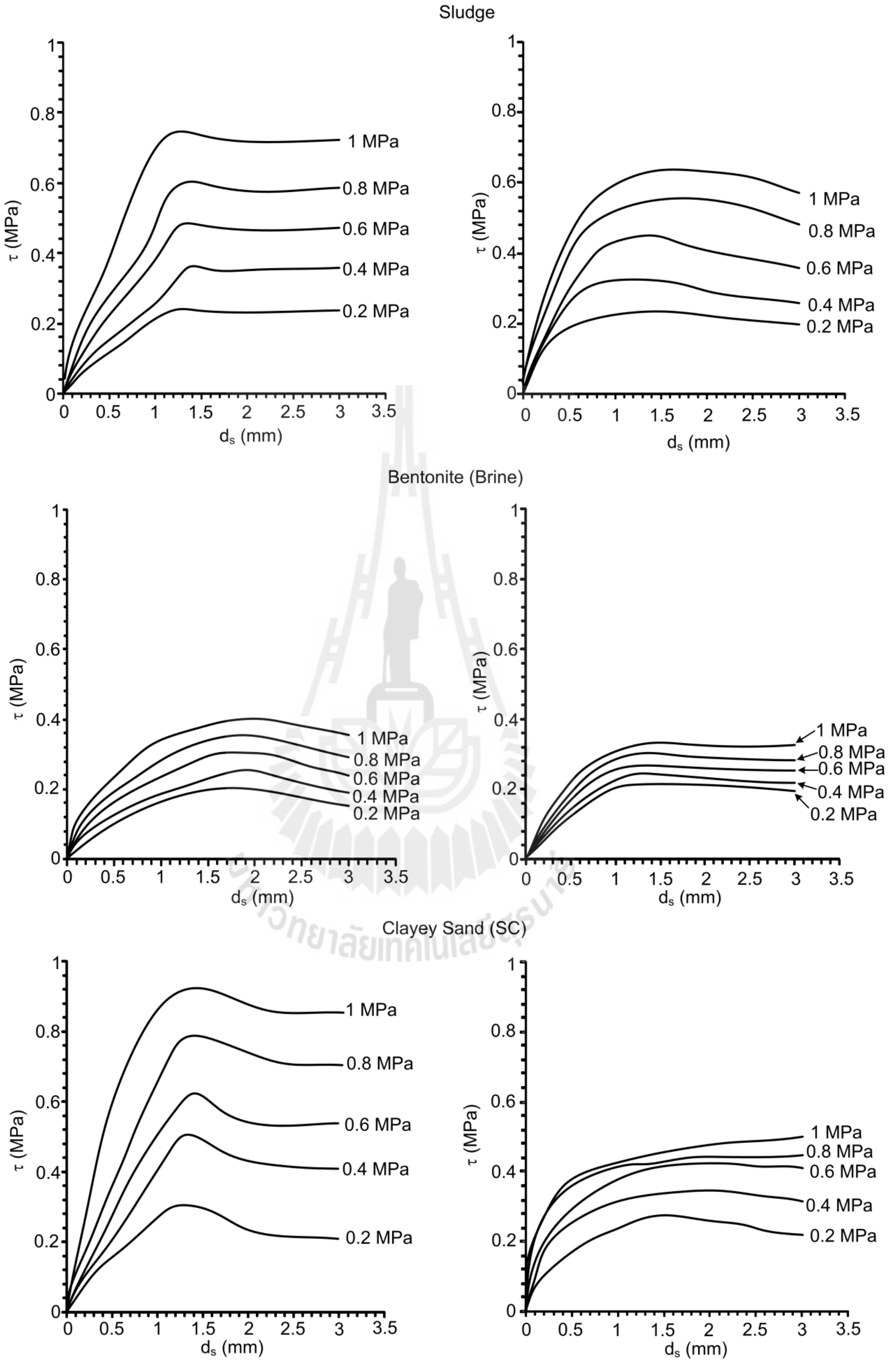

Figure 4.8 Shear stresses as a function of shear displacement of compacted sludge, bentonite (mixed with brine) and clayey sand from three-ring mold (left) and ASTM standard mold (right).

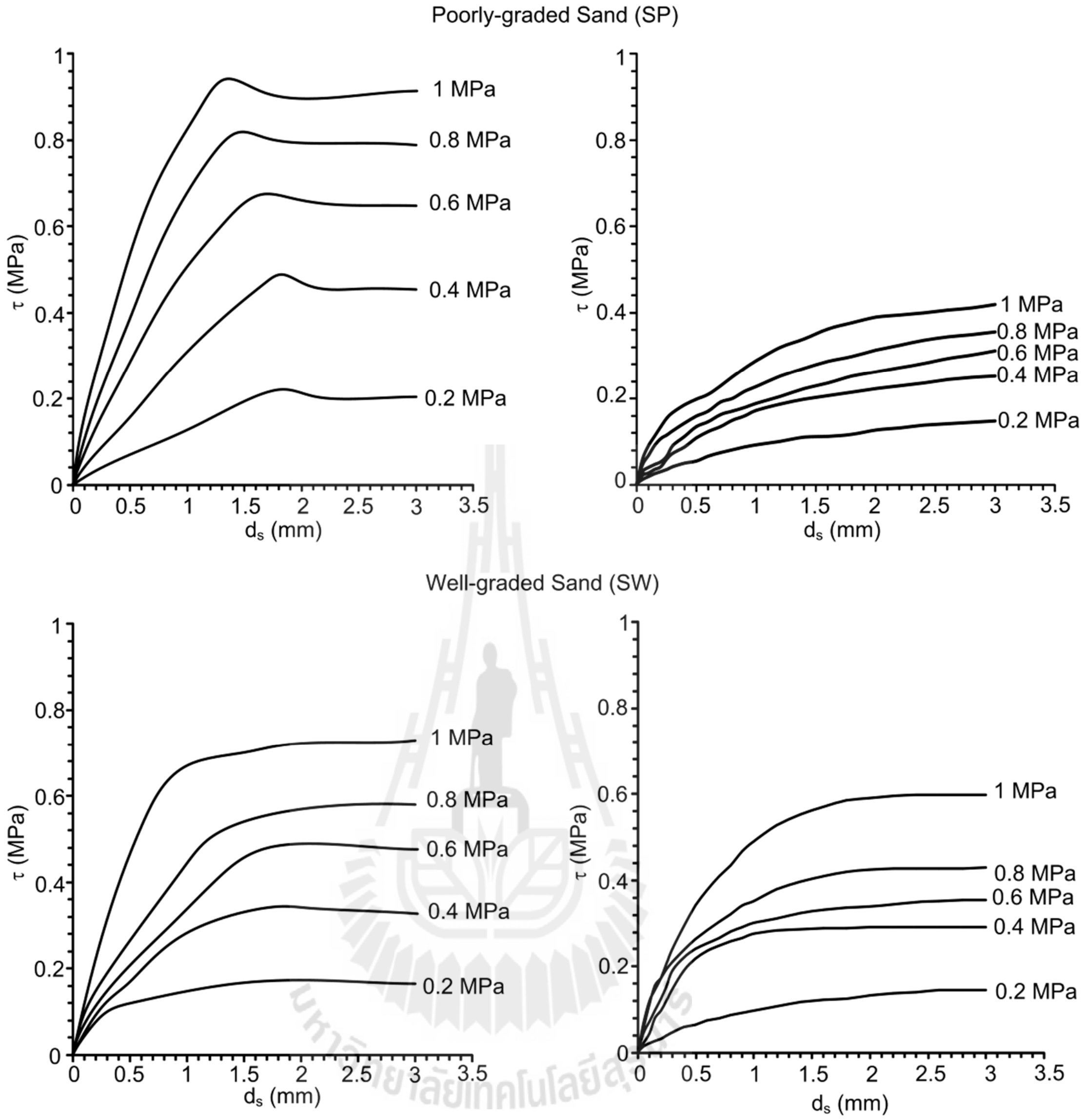

Figure 4.9 Shear stresses as a function of shear displacement of compacted poorly-graded sand and well-graded sand from three-ring mold (left) and ASTM standard mold (right).

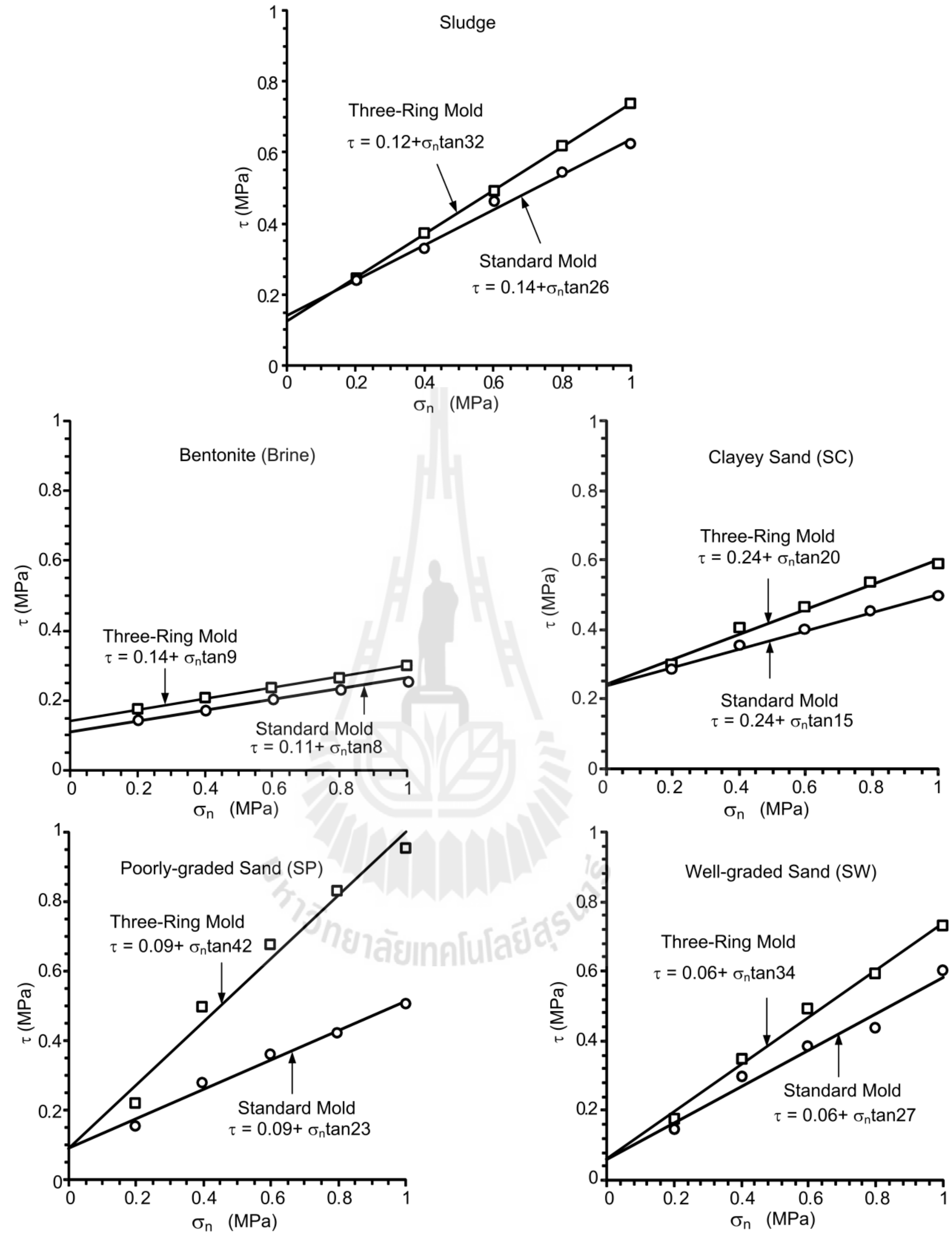

Figure 4.10 Shear strength as a function of normal stress of soils compared between three-ring and ASTM standard molds.

CHAPTER V

DISCUSSIONS, CONCLUSTIONS, AND RECOMMENDATIONS FOR FUTURE STUDIES

5.1 Discussions and conclusions

The verification test by using the compacted bentonite indicate that the three-ring mold can provide the maximum dry density, optimum water content and shear strengths comparable to those of the ASTM standard test mold. The advantage of the three-ring mold relates to the direct shear test allows testing the soil with the maximum particle size up to 10 mm (one-tenth of the ring diameter). The maximum dry density and optimum water contents of the bentonite (mixed with distilled water) obtained for both methods are very similar. Compaction test results of the five soil samples indicate that the three-ring mold which can accommodate larger particle sizes of the soils yields higher maximum dry density values for all tested soils. But the optimum water content obtained from both methods are similar. Results of direct shear testing for both methods under the same normal loads show that the three-ring mold gives higher peak and residual shear stresses. The three-ring mold gives higher friction angle and cohesion than those obtained from the ASTM standard test mold. The ASTM test method however gives a more conservative result. For the mining application however design of the compacted soil slopes with properties that are lower than the actual condition may make them economically not feasible. Due to the fact that the three-ring mold serves as both compact mold and shear box, the problem of sample disturbance which sometimes occurs in the standard testing, is eliminated. The direct shear load frame fabricated for the three-ring mold can maintain a true vertical load on the sample during shearing. Note that the vertical load (normal stress) for most commercially available direct shear devices will slightly tilt as the shear force applies on one of the shear box.

5.2 Recommendations for future studies

More soil samples should be tested under a wider range of normal stress. The effect of sample disturbance due to cutting and trimming should be further investigated particularly on low cohesive soils. The effect of the large particle sizes (>10 mm) for the ASTM standard mold testing should also be further examined. For this test the higher percentage of the larger particle sizes may be used to enhance such effect.

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APPENDIX A

BASIC PROPERTIES TEST RESULTS OF SOIL SAMPLES

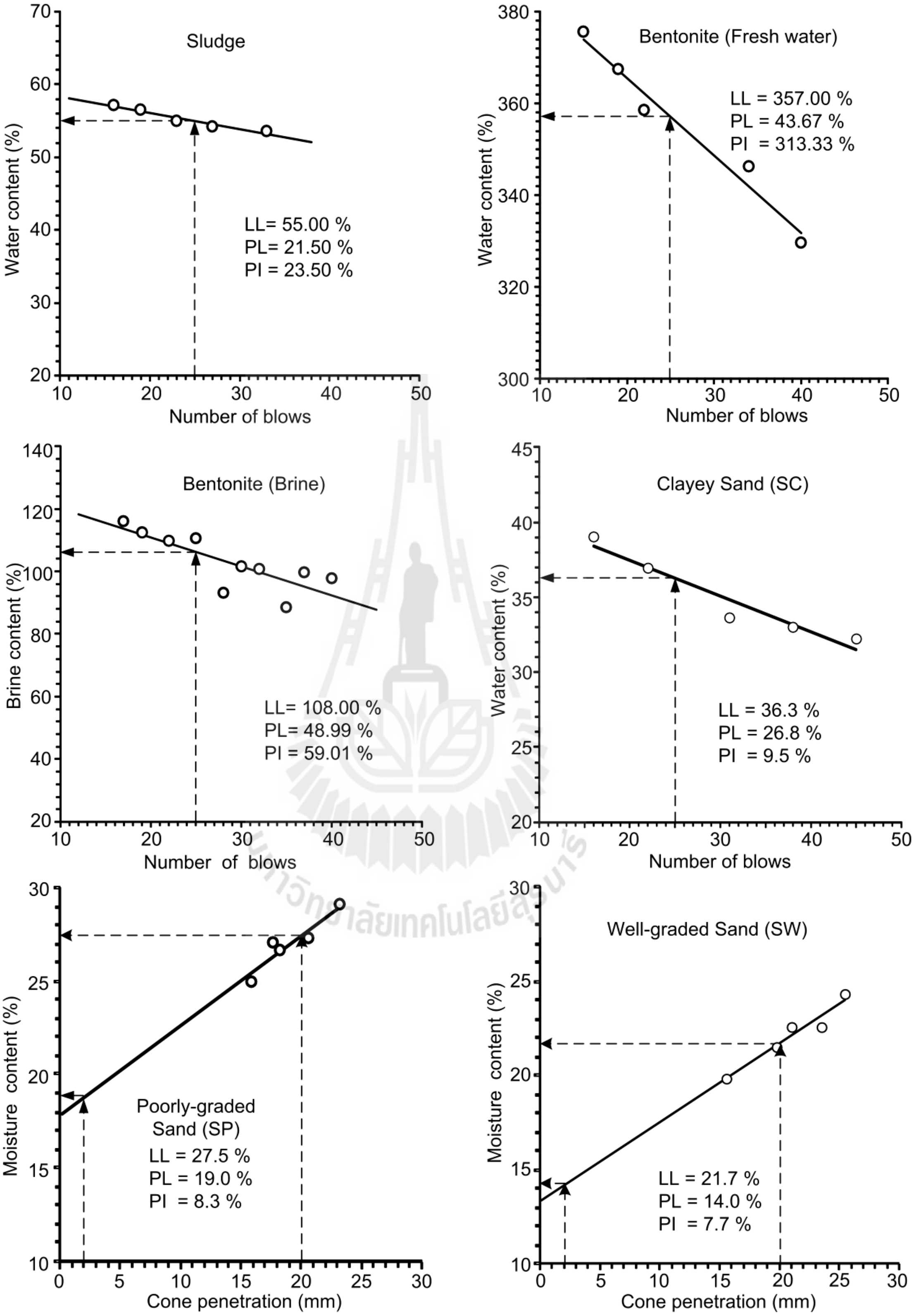

Figure A.1 Atterberg’s limit and cone penetration test result of soil samples.

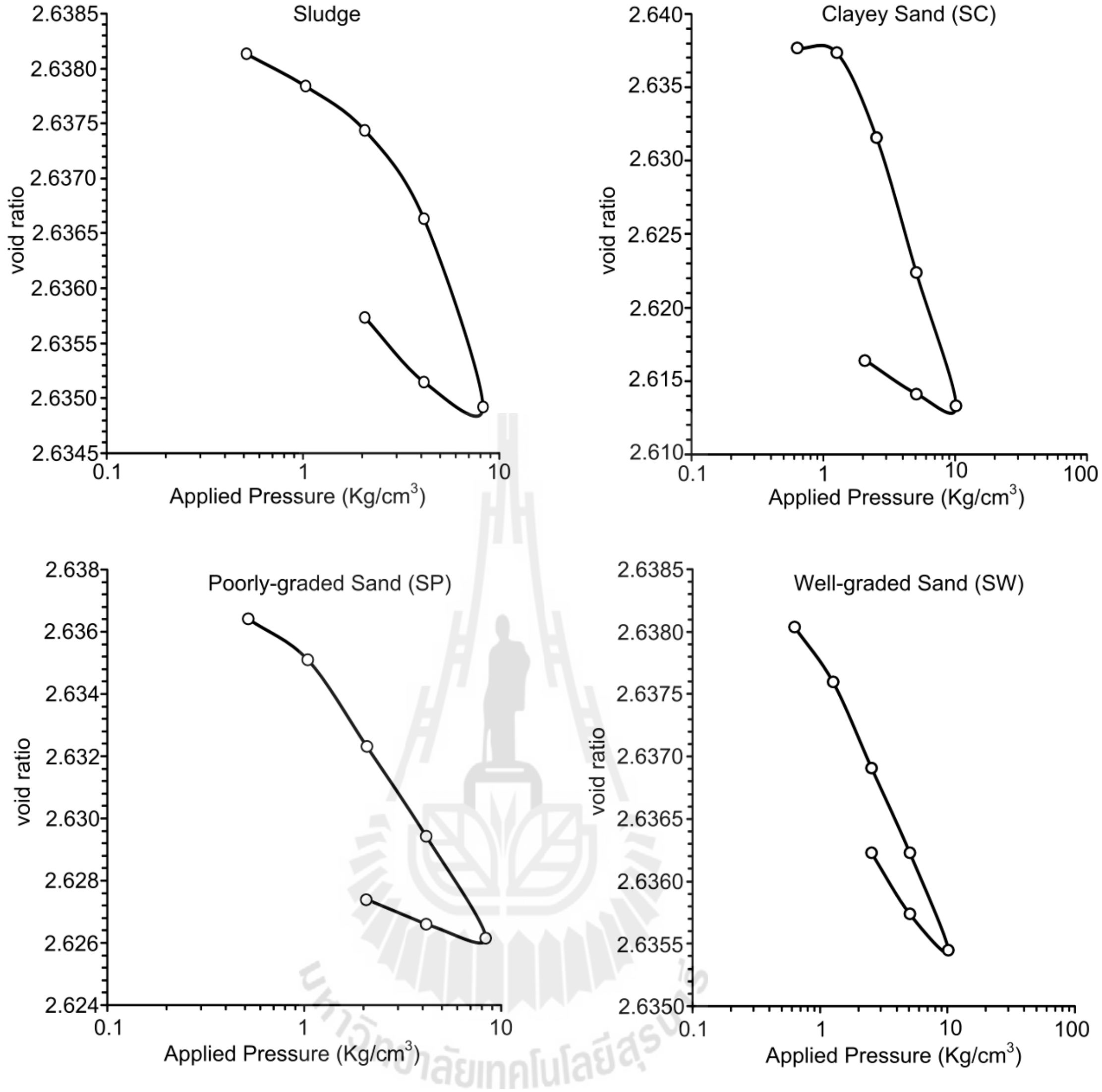

Figure A.2 Consolidation test result of four soil samples.

BIOGRAPHY

Ms. Piyawan Sonsakul was born on May 25, 1989 in Phitsanulok province, Thailand. She received her Bachelor's Degree in Engineering (Geotechnology) from Suranaree University of Technology in 2010. For her post-graduate, she continued to study with a Master's degree in the Geological Engineering Program, Institute of Engineering, Suranaree University of Technology. During graduation, 2010-2012, she was a part time worker in position of research assistant at the Geomechanics Research Unit, Institute of Engineering, Suranaree University of Technology.