Development of Three-Ring Compaction and Direct Shear Test Mold for Soils with Oversized Particles

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Abstract

A three-ring compaction and direct shear mold has been developed to determine the optimum water content, maximum dry density and shear strength of compacted soil samples with particle sizes up to 10 mm. It is designed to be used as a compaction mold and direct shear mold without removing the soil sample, and hence eliminating the sample disturbance. Commercial grade bentonite is tested to verify that the three-ring mold can provide the results comparable to those obtained from the ASTM standard test methods. Clayey sand, poorly-graded sand and well-graded sand with oversized particles are tested to assess the performance of the device. Their results are also compared with those obtained from the ASTM standard methods. The results indicate that the shear strength, maximum dry density and optimum water content of the bentonite obtained from the three-ring mold and the ASTM standard mold are virtually identical. For the soils with oversized particles the three-ring mold yields higher maximum dry densities than those obtained from the ASTM mold. The shear strengths obtained from the three-ring mold 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 soils under field conditions.

1. Introduction

Shear strength of soil is an important design parameter for geotechnical engineering work. The method of determine the shear strength has been standardized by the ASTM. One of its applications is to determine the shear strength of compacted soil samples. A disadvantage of the standard shear test method and equipment is that the compacted soil samples need to be removed from the 100-mm diameter compaction mold, trimmed and installed into the smaller shear mold (60-mm diameter). The process could disturb the samples physical properties [1]. The relatively small shear mold also limit the maximum particle size of the test samples [2-3]. This calls for a new device and method for soil compaction and shear tests in order to determine the compacted soil properties that are close to there under field conditions.

The objective of this study is to develop a new test method and device for the soil compaction and shear tests. The newly developed mold is intent to serve as both compaction mold and shear box. It is called here as "three-ring compaction and shear mold." This new approach not only eliminates the sample disturbance, but also allows shearing the soil sample with larger particle size (up to 10 mm). This paper describes the verification and performance of the new test method and device.

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, and hence the test results are isolated

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from the intrinsic variation of the material. The bentonite will be prepared for the compaction test and direct shear test using both the three-ring mold and the ASTM standard mold. Its maximum dry density, optimum water content, and shear strengths will be determined. Table 1 shows some basic properties of the tested bentonite.

Clayey sand (SC) from Loei province, poorly-graded sand (SP) from Chai Mongkon district and well-graded sand (SW) 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 1 gives some engineering properties of the materials. Figure 1 shows the particle size distribution of the soils. It should be noted that the maximum particle size used for the compaction test [4] and shear test [5] is 4.75 mm while for the three-ring mold test is 10 mm.

Table 1 Properties and classification of four soil samples used in this study.

Materials	S.G.	LL (%)	PL (%)	PI (%)
Bentonite	2.50	357.00	43.67	313.33
Clayey sand (SC)	2.43	36.30	26.80	9.50
Poorly graded sand (SP)	2.64	27.30	19.00	8.30
Well-graded sand (SW)	2.66	21.70	14.00	7.70

3. Compaction and Shear Molds

The ASTM standard compaction mold consists of top ring and bottom ring. The diameter is 10.16 cm and height is 17.3 cm. The two rings are held in-place with locking edges and secured on the base plate using bolts (Figure 2 - right).

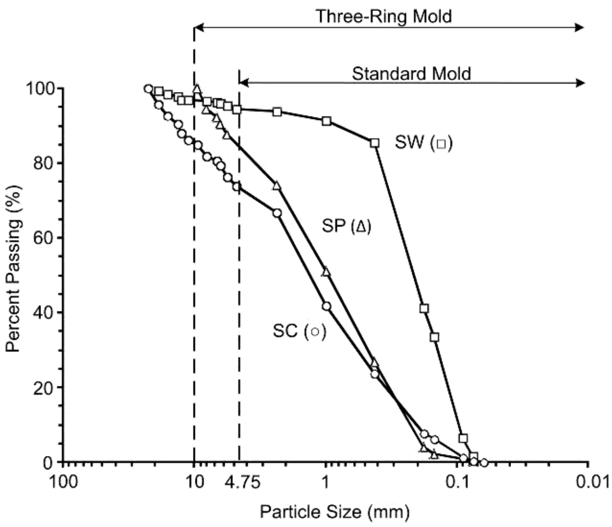

Figure 1 Particle size distribution of the tested soils.

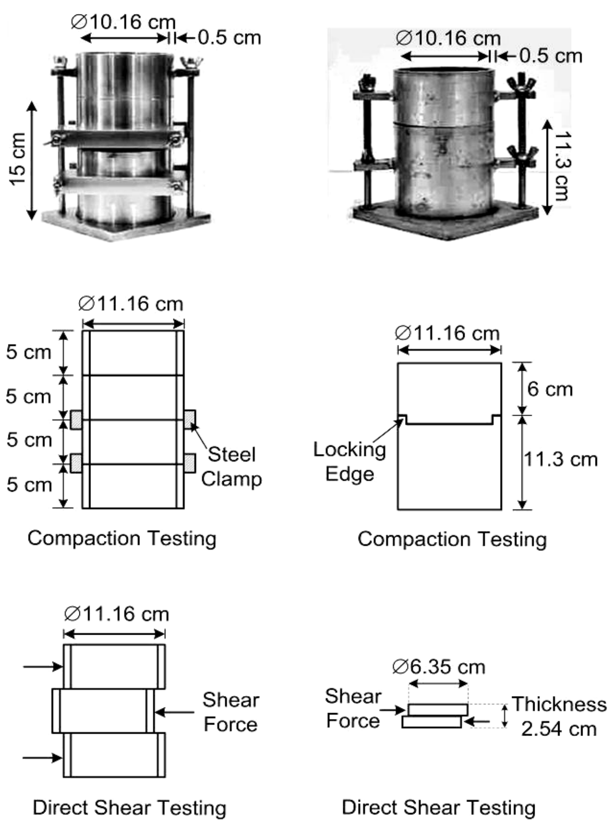

Figure 2 Three-ring mold (left) and ASTM standard mold (right).

Unlike the standard compaction mold the proposed three-ring mold consists of top, middle and bottle rings (Figure 2 – left). The inner diameter is 10.16 cm, outer diameter is 11.2 cm and the combined height is 20 cm. The three rings are secured on the base plate using steel bolts and two steel clamps. The top and bottom rims of the rings have no locking edge. The steel clamps are used to 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 laterally displaced (sheared) when the lateral force is applied during shear test. This means that the mold will become shear box in the shear frame. Note that the two rings of the standard mold cannot be laterally displaced due to the locking edges at the rims of the rings (Figure 2 – right).

The three-ring mold is designed to be used with a new shear test frame for the direct shear test. There are two incipient shear planes of the compacted soil sample in the three-ring mold, 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 load on the compacted soil sample (Figure 3). The applied loads are obtained from two 20-ton hydraulic load cells connected to hydraulic hand pumps. Pressure gages are used to measure the loads. The shear and normal displacements are monitored by high precision dial gages.

4. Verification Test

The verification of the test results obtained from the proposed three-ring mold is made by performing compaction and the direct shear tests of the bentonite sample. Figure 4 compares the results of the compaction tests between the application of the three-ring mold and the ASTM standard test mold. The maximum dry densities and the optimum water contents of the bentonite obtained for both methods are virtually identical. The results from the direct shear tests of the compacted bentonite from the two techniques are very similar (Figures 5 and 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 2 and 3.

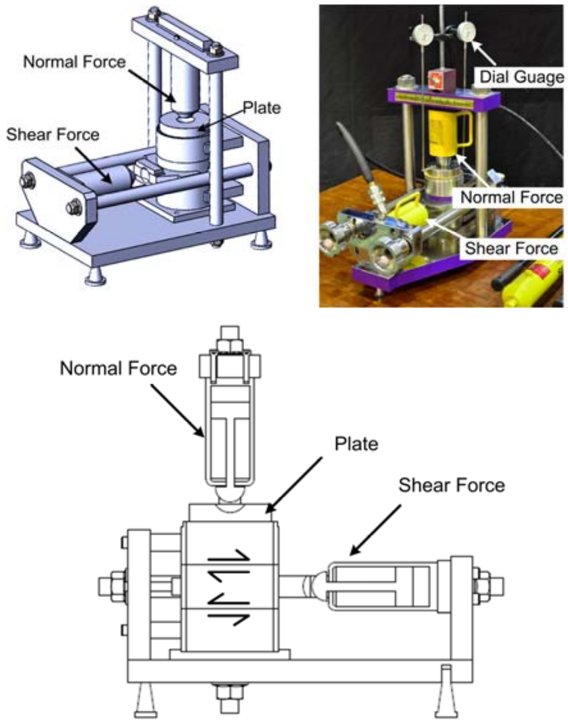

Figure 3 Direct shear test frame developed for use with the three-ring mold.

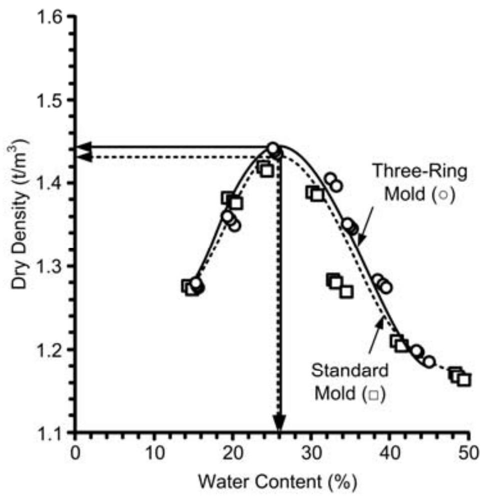

Figure 4 Maximum dry density and optimum water content of bentonite obtained from the three-ring mold and ASTM standard mold.

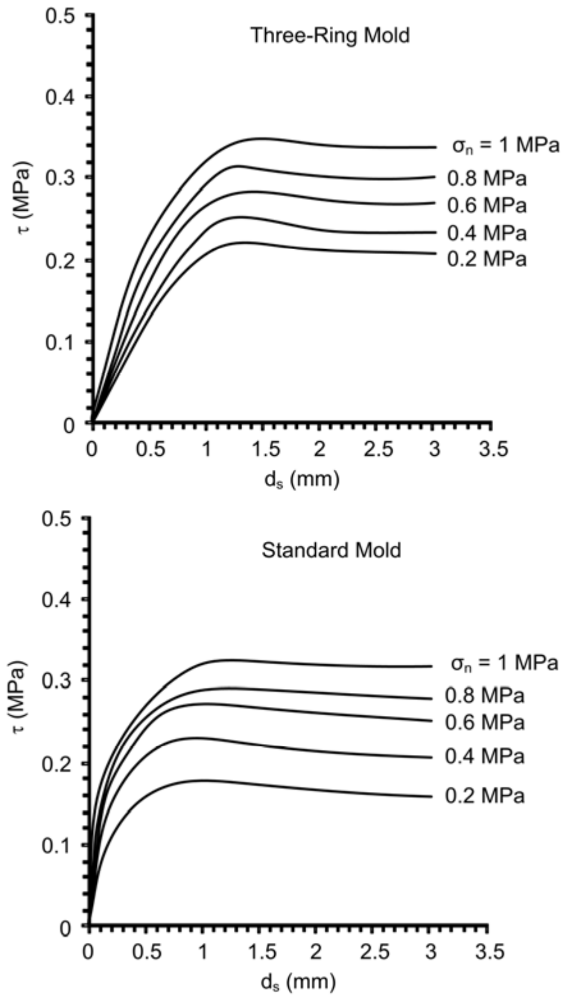

Figure 5 Shear stresses as a function of shear displacement of compacted bentonite from three-ring mold (Top) and standard mold (Bottom).

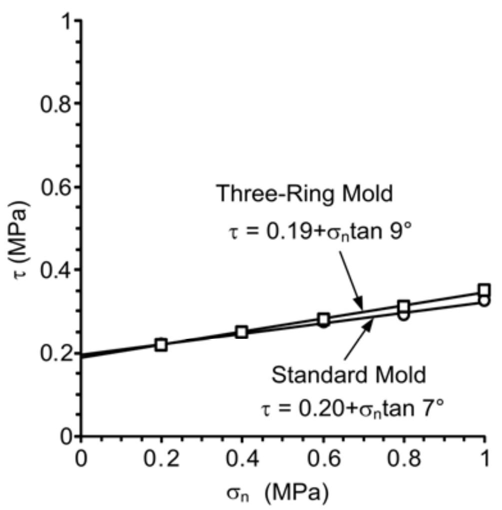

Figure 6 Shear strength as a function of normal stress of bentonite from three-ring and standard molds.

Table 2 Compaction test results.

Materials	Optimum Water Content (%)		Maximum Dry Density (t/m^3)	
	Three-Ring Mold	Standard Mold	Three-Ring Mold	Standard Mold
Bentonite	26	26	1.442	1.430
Clayey sand (SC)	15.7	15.2	1.760	1.670
Poorly-graded sand (SP)	9.1	9.3	2.120	1.910
Well-graded sand (SW)	10.7	11.1	1.905	1.860

Table 3 Direct shear testing results.

Materials	Cohesion		Friction Angle (degrees)	
	Three-Ring Mold	Standard Mold	Three-Ring Mold	Standard Mold
Bentonite	0.19	0.20	9	7
Clayey sand (SC)	0.24	0.24	20	15
Poorly-graded sand (SP)	0.09	0.09	42	23
Well-graded sand (SW)	0.06	0.06	34	27

5. Performance Assessment

The selected 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 compact test results indicate that the three-ring test mold that can accommodate the particle sizes up to 10 mm yields higher maximum dry density values for all tested soils (Table 2). The optimum water contents obtained from both methods are similar (Figure 7).

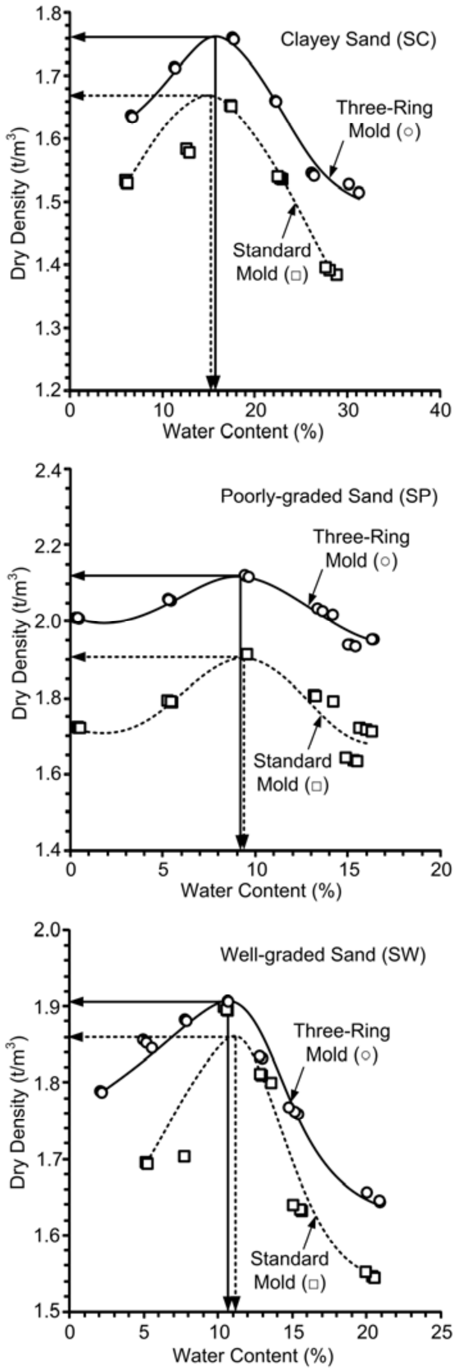

Figure 7 Dry densities and optimum water contents from compaction test from three-ring and standard compaction molds.

Figure 8 plots the results of direct shear testing for both methods. 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 9 and Table 3). Again this is because the particle sizes included in the compacted soil samples for the three-ring mold are up to 10 mm (mesh 3/8 in) while for the standard mold is up to 4.75 mm (mesh No. 4).

6. Discussions and Conclusions

The verification test 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 is shown during the direct shear testing. It allows testing the soil with the maximum particle sizes up to 10 mm (one-tenth of the ring diameter). As demonstrated by testing the three different soil samples, soils with larger maximum particle sizes yield higher maximum dry density and shear strengths. This is important for the design and stability analysis of the compacted slope embankments or backfills. It is true that the ASTM test method and its relevant device will give 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 developed for the three-ring mold can also 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.

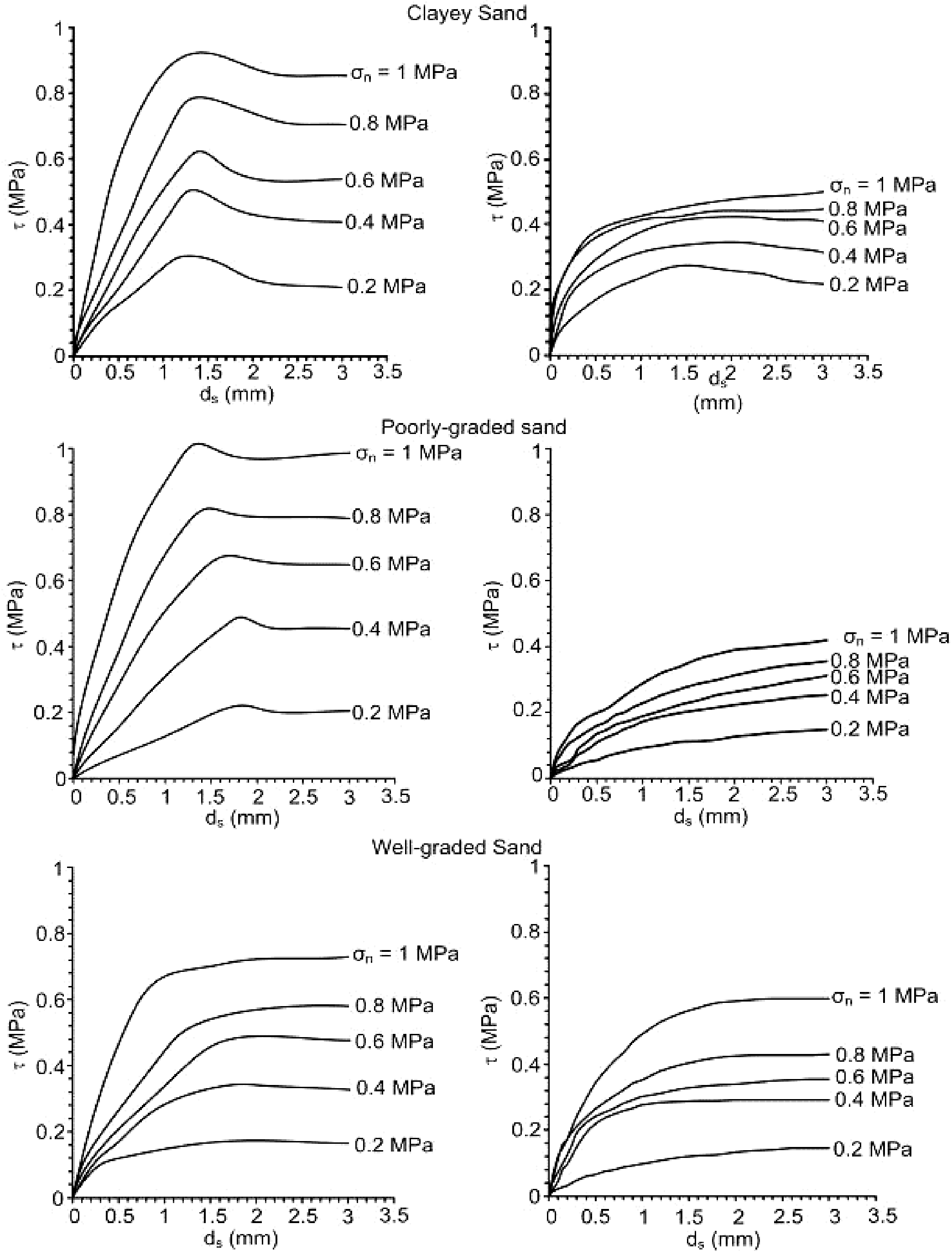

Figure 8 Shear stresses as a function of shear displacement from three-ring mold (left) and standard mold (right).

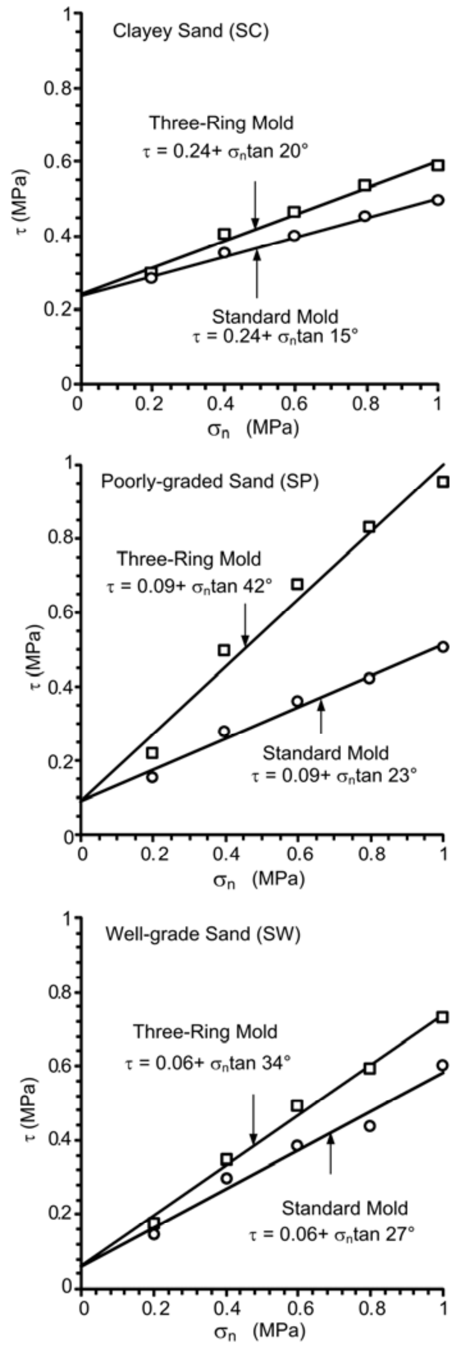

Figure 9 Shear strength as a function of normal stress from the three-ring and standard mold.

7. Acknowledgements

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