DRA-49. GOLDER LABORATORY DIRECT SHEAR TESTS RESULTS

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1. STATEMENT OF PROBLEM

What are the values of friction angle and cohesion intercept obtained from direct shear tests conducted by the Golder laboratory on Questa mine rock pile and analog samples? On the basis of these results how is the shear strength of Questa rock pile material affected by changing the water content of the material and what is the effect of shear box size and scalping on the shear strength? Shear strength is an important factor in controlling the gravitational slope stability of the rock piles. A set of five samples from the Questa rock piles and analog sites with different alteration and weathering mineral assemblages were collected and analyzed for geotechnical parameters to determine the range in values by different laboratory methods (shear box size and scalping) and with different water contents.

2. PREVIOUS WORK

Gutierrez (2006) performed laboratory direct shear tests on the Goathill North (GHN) rock pile material from the Questa mine. The shear tests were conducted on the air dried samples passed sieve No. 6, using 2-inch and 4-inch square shear boxes. A displacement rate of 8.5×10^{-3} mm/sec (0.02 in/min) and a normal stress range of 160 to 800 kPa were used for the tests. Gutierrez (2006) reported a residual friction angle (φ_r) ranging from 37º to 41º and a peak internal friction angle (φ) ranging from 40º to 47º. Note in Gutierrez's analysis, the Mohr-Coulomb failure envelope was assumed to pass through the origin; a zero cohesion intercept was used in her study.

URS Corporation (2003) reports the results of a number of direct shear tests on Questa mine material, using 12 inch square and 2.4 inch diameter shear boxes that were conducted by AMEC geotechnical laboratory and Advanced Terra Testing in Arizona and Colorado, respectively (refer to DRA 44). The tests were performed under different normal stresses ranging from 119.7 to 478.8 kPa and 98.6 to 526.7 kPa for 12-inch and 2.4-inch samples, respectively. The materials of minus 1.5 inch for the 12-inch box and minus No. 4 sieve for 2.4-inch diameter box were used for the shear tests. The materials for 12-inch samples were prepared under dry densities ranging from 1,522 to 1,682 kg/m^3 (95 to 105 pcf) at water contents ranging from 8 to 12%. The 2.4-inch samples had dry densities of 1,522 to 1,890 kg/m^3 (95 to 118 pcf) and water contents of 10 to 14%. The friction angle and cohesion intercept for 12-inch shear box ranged from 26° to 59^o (with an average value of 43.7^o) and 0 to 111 kPa, respectively. For the 2.4-inch shear box, the friction angle and cohesion intercept ranged from 30° to 41^o (with an average value of 35.2°) and 0 to 34 kPa, respectively. Based on the above shear test results, URS Corporation (2003) concluded that as larger particles are present in the shear box, higher shear strengths are obtained and that scalping of the Questa rock pile material causes reduction in the measured shear strengths.

3. TECHNICAL APPROACH

Five samples (called megasamples), were collected from the Spring Gulch (SPR) and Sugar Shack West (SSW) rock piles, and the Goat Hill debris flow (MIN) and Questa Pit alteration scar (QPS) analog sites of the Questa mine (Fig. 1). Note that two samples from the Sugar Shack West rock pile were collected at two different locations. Samples with different weathering intensity (based on the simple weathering index) were collected. Sample locations and descriptions are summarized in Appendix 1 and McLemore et al. (2008). From each location, the minus 1-inch material collected in the field was placed into three 30 gallon plastic drums and shipped to the Golder Associates-Burnaby Laboratory for triaxial and direct shear testing. A total of fifteen 30-gallon plastic drums of material were shipped to the Golder Associates-Burnaby Laboratory.

The gradation curves of the samples from wet sieving analysis are reported in Figures 2-1 to 2-5 (Appendix 2) and DRA-41. Two types of shear boxes were used for testing i.e. a square shear box 12 inch × 12 inch and 9 inch in height and a circular shear box, 2.4 inch in diameter and 1 inch in height. Each test series included four individual shear tests using different normal stresses. For the 12-inch shear box, minus 1-inch material was placed in the shear box and normal stresses of 50, 150, 250, and 400 kPa were used. Each specimen[1] was compacted to a dry density of 1,800 kg/m^3 at dry, moist, and wet conditions, corresponding to the water contents of 0 to 2%, 9 to 12% and 10 to 12%, respectively. For the 2.4 inch in diameter shear box, minus No. 6 sieve material was used under normal stresses of 50, 150, 400, and 700 kPa. The specimens were compacted to a dry density of 1,700 kg/m^3 at dry, moist, and wet conditions corresponding to the water content of 1 to 3%, 9 to 15%, and 9 to 16%, respectively. Testing was done at the compacted water content except for the wet specimens. These specimens were flooded and sheared under almost saturated conditions. The shear displacement rates for 12-inch and 2.4-inch shear tests were 0.01 mm/sec and 0.003 mm/sec, respectively. Specimens from the Debris flow sample were also tested using a 2.4-inch square direct shear box. The normal stresses used are similar to those for 2.4-inch diameter shear box.

Some direct shear tests on air dried megasample specimens were conducted at New Mexico Tech (NMT), using a 2-inch square shear box. Material passing the No. 6 sieve was compacted at the dry density of 1,700 kg/m^3 and was subjected to a shear displacement rate of 8.5×10^{-4} mm/sec. Two sets of shear tests were conducted; in the first set, four shear tests with the normal stress in the range of 50 to 150 kPa and in the second set, four shear tests with the normal stress of 50 kPa to 700 kPa were performed.

All the shear tests were performed in accordance with the general guidelines of ASTM (1998) D-3080 standard and project SOPs (SOP-50).

[1] Note that the customary geotechnical terminology “specimen” is used to identify the portion of the sample that was used in the test. In other disciplines this maybe referred to a “sub-sample” or other similar terminology.

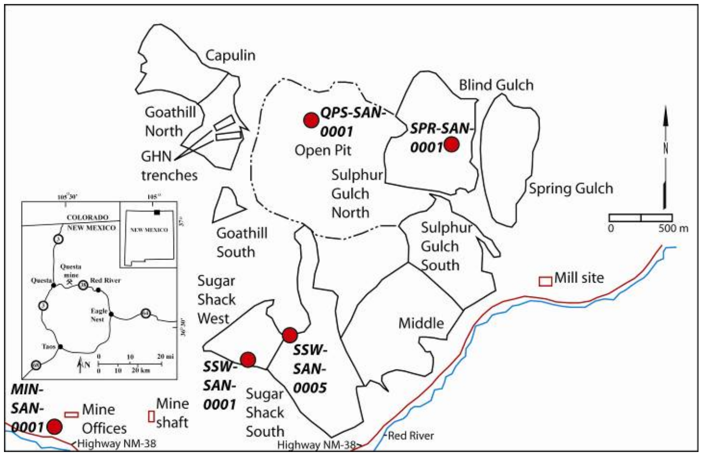


FIGURE 1. Location of megasamples, Questa mine, New Mexico.

4. CONCEPTUAL MODEL

The well known Mohr-Coulomb failure criterion was used to interpret the shear tests results. This failure criterion has two constants namely cohesion intercept (c) and friction angle (φ). The non-linear Coulomb failure criterion (Equation 1) was also used to interpret the shear strength of the specimens from the test results (Charles and Watts, 1980):

$$\tau = A\sigma_n^{\,b} \tag{1}$$

where A and b are material constants derived from the test results and σ_n is the applied normal stress in a shear test. This failure criterion is especially more practical when a wide range of normal stresses is being used; as the normal stress increases, the corresponding shear strength does not grow linearly possibly due to particle breakage. This non-linear failure criterion was successfully used by Linero et al (2007) in describing the shear strength of some rock piles in Chile from triaxial testing under a broader range of cell pressures than the normal stresses reported in this DRA.

5. STATUS OF COMPONENT INVESTIGATION

The shear stress versus shear displacement, and normal (vertical) displacement versus shear displacement results for the low and high normal stresses of the direct shear tests are reported in Appendix 3 and McLemore et al (2008). It is clear from the results in Appendix 3 that under the given normal stresses and the dry densities used, the material behavior is close to a perfectly plastic material i.e. the post peak softening is negligible for the maximum shear displacement used in these series of tests. The shear tests results in terms of nonlinear Coulomb failure envelopes of the megasamples are shown in Figures 4-1 through 4-3 (Appendix 4) of this DRA.

Cohesion intercept and friction angle parameters for each rock pile material were obtained by drawing the best fit straight line (failure envelope) through the four shear stress-normal stress points in the shear stress vs. normal stress plot. The shear strength parameters for air dried specimens from Golder and NMT are reported in Table 1. The Golder results for 12-inch and 2.4-inch shear boxes are in Tables 2, 3 and 4. These results suggest that:

- The measured peak friction angles from the 12-inch box are above 40° except for the specimens tested under moist and wet conditions from the Sugar Shack West rock pile.
- The friction angles from 12-inch box are in general higher than those measured using 2.4-inch box, suggesting the size effect in the measurement. One reason for the lower friction angles for the smaller box is the presence of higher percentage of fines in the samples.
- The results in Table 1 show a fairly good agreement between the friction angles obtained by the Golder Laboratory and NMT.

Note moist and wet specimens show lower friction angles compared to those from dry specimens suggesting moisture softening of Questa rock pile materials (Appendix 5).

Figures 2 and 3 illustrate the relationship between cohesion intercept and friction angle with the water content. The cohesion intercept and friction angles reported in these figures were obtained by using the four shear strength-normal stress points in plotting the Mohr-Coulomb failure envelope, corresponding to normal stresses of 50 to 700 kPa for 2.4-inch and 50 to 400 kPa for 12-inch boxes. It is clear from Figure 3 that the friction angle reduces as the water content increases. The plot in Appendix 5 also emphasizes this observation. The situation is similar for the case of cohesion intercept, even though the data is more scattered in this case, especially for the cohesion intercept values from the 12-inch shear box.

In general, water can act as a lubricating agent between the rock particle surfaces and change the strength and compressibility of rock fill material. Studies by Zellar and Wullimann (1957) on non-cohesive gravelly sand and boulder material have shown that the shear strength decreases with increasing water content; a shear strength loss of 10% to 15% was found as the rock fill material became wet. Douglas and Bailey (1982) also showed that the friction angle of rock pile material reduces as water content increases.

Additional data are in Nunoo (2009).

6. **RELIABILITY ANALYSIS**

Based on the results presented here it is expected that the overall shear strength performance of the system is better represented by the large shear box test results, however this should be reviewed when all the shear strength data obtained at the Questa mine from the present and previous work are combined. The cohesion intercept values reported in this DRA are not reliable compared to those obtained by the in situ tests data (DRA-47); disturbed material can not be used for reliable measurement of cohesion values. Although this sample set was limited to five samples, the results provide a basis for understanding effects of moisture, size of the shear box, and scalping of the material used in testing disturbed materials.

7. CURRENT CONCLUSION OF THE COMPONENT

Direct shear tests were conducted by Golder Associates and NMT on samples collected from the rock piles and analogs at the Questa mine. It appears that there is evidence to support the moisture softening of Questa Mine material. The peak friction angle of the materials from Questa rock piles and analogs reduces as the water content increases. These results suggest that indeed the Questa rock-pile material shows size effect; scalping the material causes reduction in the measured friction angle. The effect of scalping on cohesion except for samples MIN-SAN-0002 and SSW-SAN-0002, indicates that larger air-dried samples show lower cohesion values (Fig. 5). This could be the result of having less fine-size material in the larger samples. The 12-inch dry samples have higher resistance corresponding to higher friction angle compared to the 2.4-inch 2-inch dry sample (Fig. 4). The size effect observed in this study is consistent with those reported by Kirkpatrick (1965), Koerner (1970) and Marsal (1965a).

TABLE 1. Golder (2.4-inch samples) and NMT (2-inch samples) shear test results for air-dried samples.

SAMPLE ID (GOLDER)	**SAMPLE ID (NMT)**	**DESCRIPTION**	**2.4 inch DRY, GOLDER RESULTS**		**2 inch DRY, NMT RESULTS**	
			Normal Stress (50-700kPa)		**Normal Stress (50-700kPa)**	
			c (kPa)	φ(degrees)	c (kPa)	φ(degrees)
MIN-SAN-0002	MIN-SAN-0001	Debris Flow	32.2	39.3	26.1	39.7
QPS-SAN-0002	QPS-SAN-0001	Alteration Scar	54.4	38.5	33.4	38.4
SSW-SAN-0006	SSW-SAN-0005	Sugar Shack West	30.3	39.2	28.9	35.3
SPR-SAN-0002	SPR-SAN-0001	Spring Gulch	33.9	38.4	26.6	38.1
SSW-SAN-0002	SSW-SAN-0001	Sugar Shack West	64.4	35.8	17.7	41.6

TABLE 2. Shear strength parameters from direct shear tests by Golder Associates using the 12-inch shear box. Note A and b are shear strength parameters in equation 1.

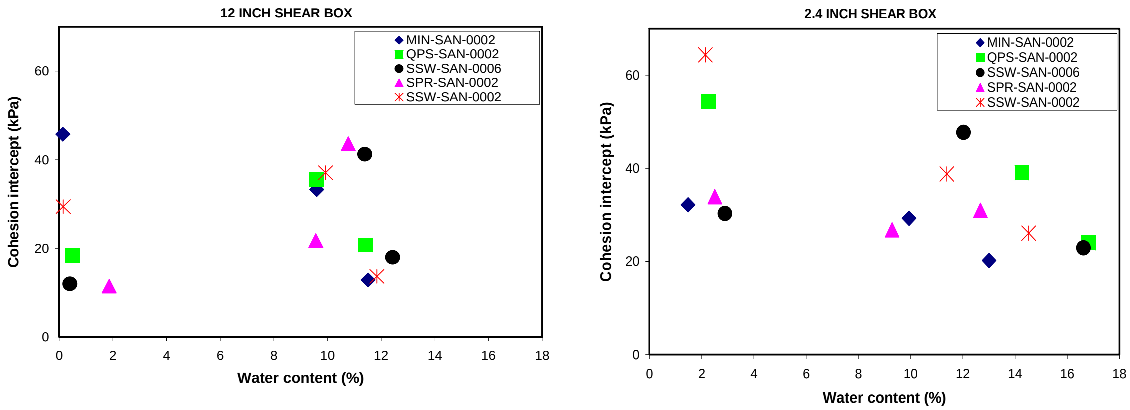
Sample ID	Description	Condition	Water Content (%)	c (kPa)	φ (degrees)	A (kPa**(1-b))	b
MIN-SAN-0002	Debris Flow	Dry	0.1	45.8	45.7	3.98	0.79
QPS-SAN-0002	Alteration Scar		0.5	18.4	48.3	1.98	0.91
SSW-SAN-0006	Sugar Shack West		0.4	12.0	48.1	2.40	0.87
SPR-SAN-0002	Spring Gulch		1.9	11.5	52.1	2.24	0.91
SSW-SAN-0002	Sugar Shack West		0.2	29.4	47.0	3.48	0.81
MIN-SAN-0002	Debris Flow	Moist	9.6	33.3	45.6	2.57	0.86
QPS-SAN-0002	Alteration Scar		9.6	35.5	44.9	3.36	0.81
SSW-SAN-0006	Sugar Shack West		11.4	41.3	36.8	3.54	0.76
SPR-SAN-0002	Spring Gulch		9.6	21.8	48.4	2.03	0.91
SSW-SAN-0002	Sugar Shack West		9.9	37.1	43.5	4.40	0.75
MIN-SAN-0002	Debris Flow	Wet	11.5	12.9	40.2	1.95	0.86
QPS-SAN-0002	Alteration Scar		11.4	20.8	41.7	1.67	0.91
SSW-SAN-0006	Sugar Shack West		12.4	18.0	34.2	1.25	0.91
SPR-SAN-0002	Spring Gulch		10.8	43.6	41.3	3.43	0.79
SSW-SAN-0002	Sugar Shack West		11.8	13.7	42.6	2.36	0.84

TABLE 3. Shear strength parameters from direct shear tests by Golder Associates using the 2.4-inch diameter shear box. Note A and b are shear strength parameters in equation 1.

Sample ID	Description	Condition	Water Content (%)	c (kPa)	φ (degrees)	A (kPa**(1-b))	b
MIN-SAN-0002	Debris Flow	Dry	1.5	32.2	39.3	2.85	0.81
QPS-SAN-0002	Alteration Scar		2.3	54.4	38.5	6.14	0.69
SSW-SAN-0006	Sugar Shack West		2.9	30.3	39.2	2.32	0.84
SPR-SAN-0002	Spring Gulch		2.5	33.9	38.4	2.96	0.80
SSW-SAN-0002	Sugar Shack West		2.1	64.4	35.8	4.75	0.73
MIN-SAN-0002	Debris Flow	Moist	9.9	29.3	38.4	1.70	0.89
QPS-SAN-0002	Alteration Scar		14.3	39.1	35.3	3.54	0.76
SSW-SAN-0006	Sugar Shack West		12.0	47.7	34.0	3.68	0.75
SPR-SAN-0002	Spring Gulch		9.3	26.8	38.9	1.80	0.88
SSW-SAN-0002	Sugar Shack West		11.4	38.8	35.8	2.47	0.82
MIN-SAN-0002	Debris Flow	Wet	13.0	20.2	35.9	1.66	0.88
QPS-SAN-0002	Alteration Scar		16.8	24.0	34.4	1.65	0.87
SSW-SAN-0006	Sugar Shack West		16.6	22.9	30.7	1.32	0.89
SPR-SAN-0002	Spring Gulch		12.7	31.0	33.2	1.57	0.88
SSW-SAN-0002	Sugar Shack West		14.5	26.1	35.6	1.68	0.88

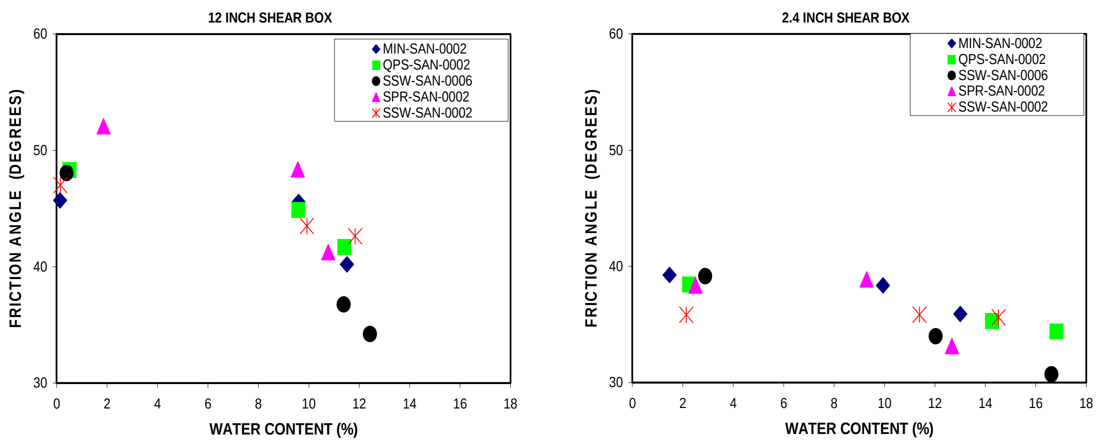
TABLE 4. Shear strength parameters from direct shear tests by Golder Associates using the 2.4-inch square shear box. Note A and b are shear strength parameters in equation 1.

Sample ID	Description	Condition	Water Content (%)	c (kPa)	φ (degrees)	A (kPa**(1-b))	b
MIN-SAN-0002	Debris Flow	Dry	1.4	53.4	38.6	3.94	0.77
MIN-SAN-0002	Debris Flow	Moist	9.8	38.2	36.1	3.17	0.78
MIN-SAN-0002	Debris Flow	Wet	10.9	29.7	32.7	1.64	0.87



(a) (b)

FIGURE 2. Cohesion intercept versus water content for a) 12-inch samples, b) 2.4-inch samples.



(a) (b)

FIGURE 3. Friction angle versus water content for a) 12-inch samples, b) 2.4-inch samples.

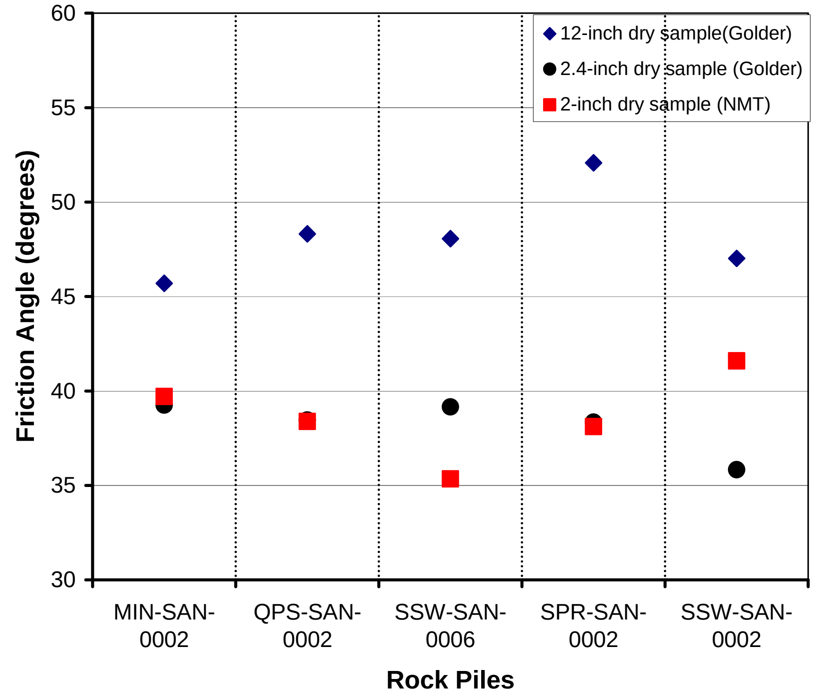


FIGURE 4. Size effect on friction angle for all rock piles (normal stress of 50 to 702kPa).

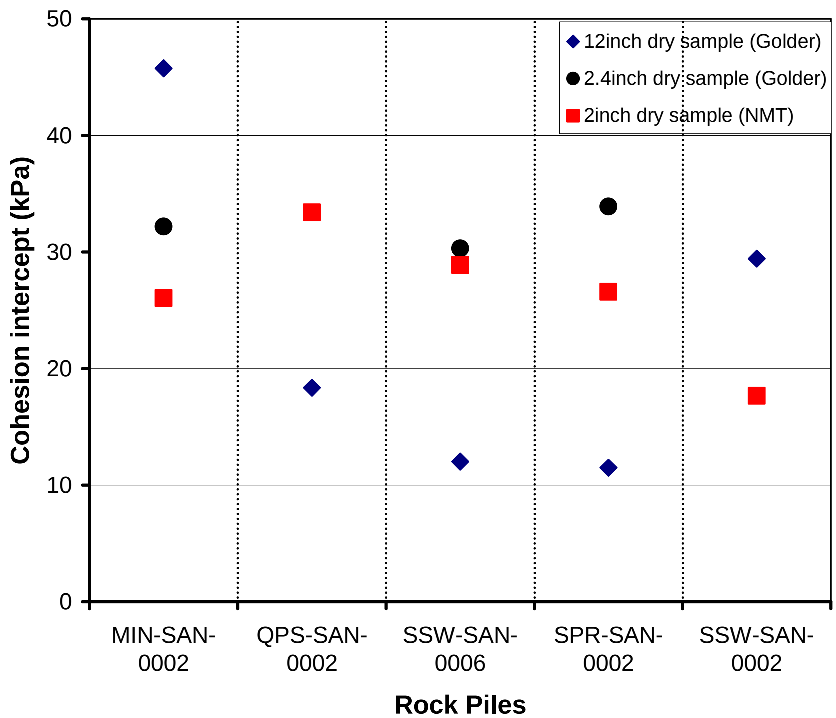


FIGURE 5. Size effect on cohesion for all rock piles (normal stress of 50 to 702kPa).

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9. TECHNICAL APPENDICES

McLemore, V.T., Fakhimi, A., Boakye, K., Ayakwah, G.F., Anim, A., Donahue, K., Ennin, F., Felli, P., Nunoo, S., Tachie-Menson, S., Gutierrez, L., and Viterbo, V.C., 2008, Geotechnical investigations of the Questa rock piles, Taos County, New Mexico: New Mexico Bureau of Geology and Mineral Resources, Open-file report, in preparation.

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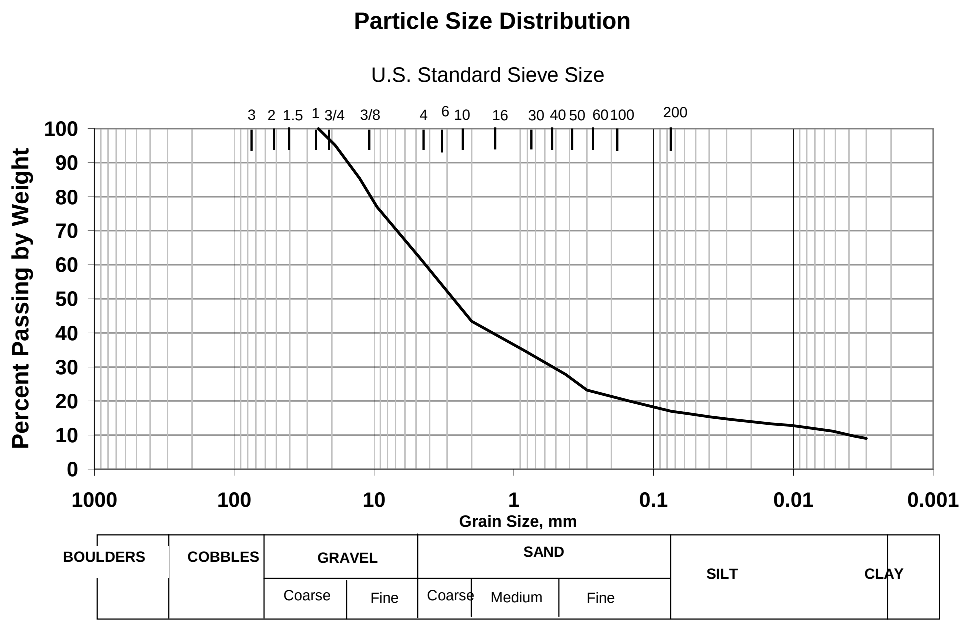
APPENDIX 1. Description of samples. QSP—quartz-sericite-pyrite hydrothermal alteration, SWI—Simple Weathering Index. Refer to DRA-27 for description of SWI.

	Sample	MIN-SAN-0001	SPR-SAN-0001	SSW-SAN-0001	SSW-SAN-0005	QPS-SAN-0001
	Description	debris flow	rock pile	rock pile	Rock pile	alteration scar
Composition of rock fragments (%)	rhyolite (Amalia Tuff)	5			95	
	andesite		100	100	3	95
	Intrusive aplite	95			2	5
Amount of hydrothermal alteration (%)	QSP	30	35	25	50	30
	propylitic		7	5		7
	argillic	3			1	
	SWI	3	2	4	4	4
Mineral composition (%)	quartz	45	25	32	37	42
	K-feldspar/ orthoclase	13	21	8	22	4
	plagioclase	2	18	18	2	10
	biotite			0.01		
	illite	28	14	23	23	31
	chlorite	2	8	5	3	3
	smectite	1	3	4	1	3
	kaolinite	3	1	1	1	1
	epidote		2	0.01	3	
	Fe oxides	1	4	2	0.6	0.8
	rutile	0.4	0.6	0.5	0.4	0.4
	apatite	0.2	0.9	0.3	0.3	0.2
	pyrite	0.01	0.3	0.3	0.1	
	calcite	0.1	0.5	0.1	0.3	0.2
	gypsum	0.2	2	2	1	1
	zircon	0.04	0.03	0.03	0.04	0.04
	sphalerite					
	fluorite					
	jarosite	3		4	5	4
	copiapite					
	organic carbon	1				
	SUM MINERALS	99.95	100.33	100.25	99.74	100.64

APPENDIX 2. Wet sieving analysis results from Golder Laboratory.



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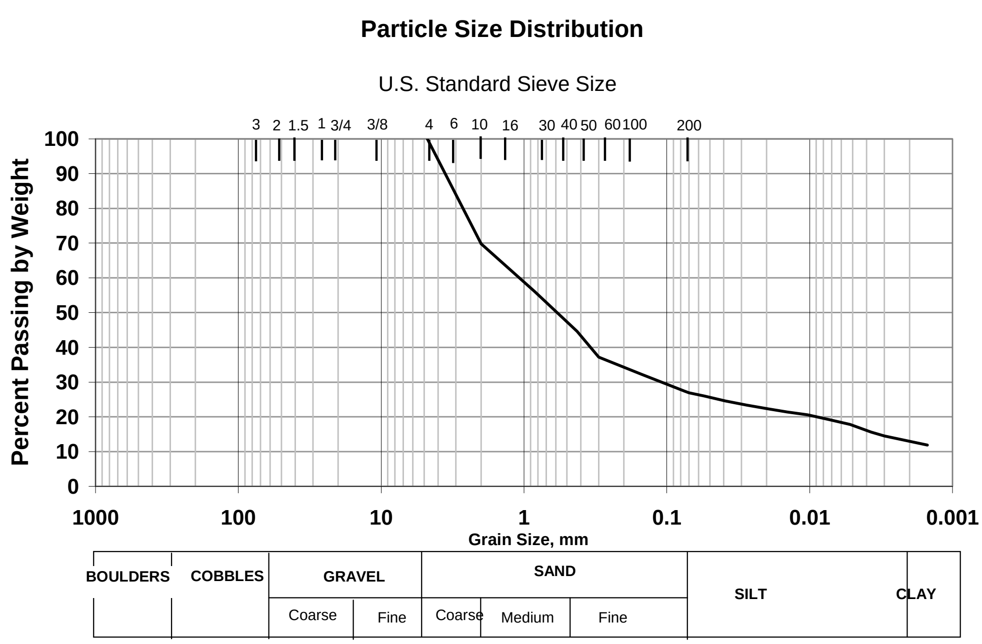

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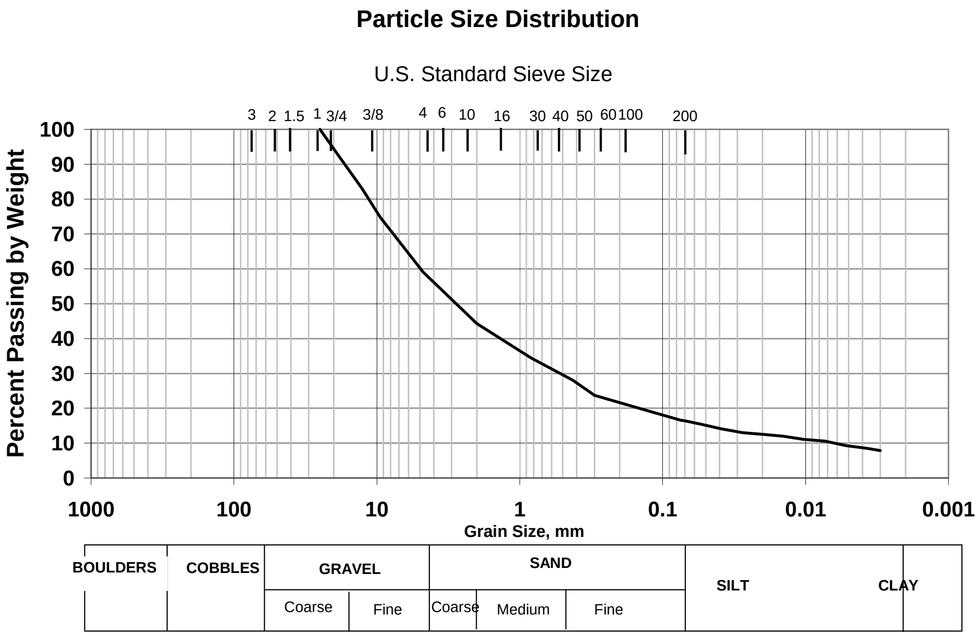
FIGURE 2-1. Wet sieving analysis results of the samples collected from Debris Flow (MIN-SAN-0002), a) -1-inch field material, b) minus No. 4 sieve material.



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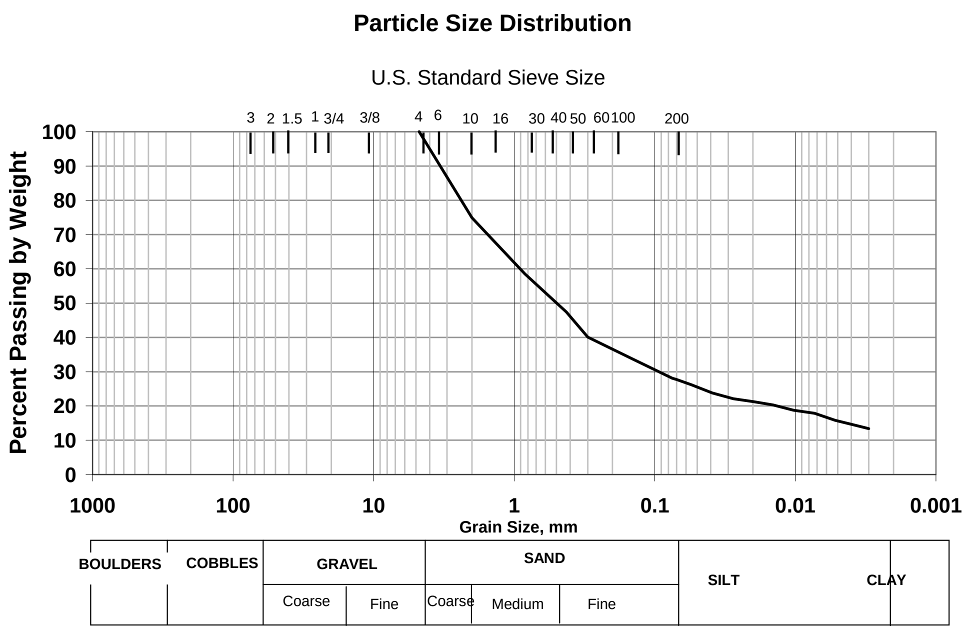
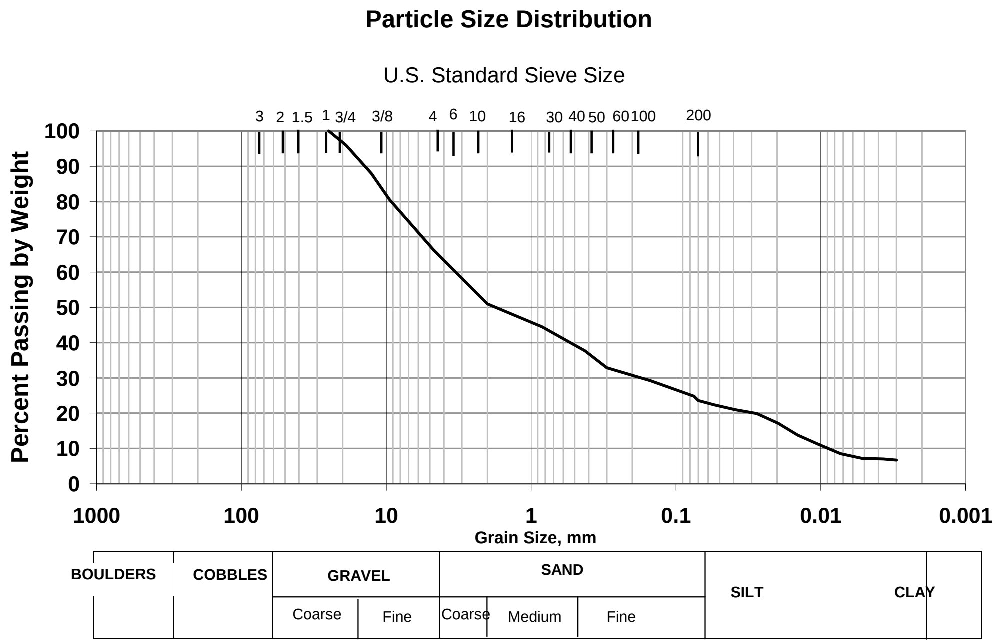


(b)

FIGURE 2-2. Wet sieving analysis results of the samples collected from Questa Pit Alteration Scar (QPS-SAN-0002), a) -1-inch field material, b) minus No. 4 sieve material.



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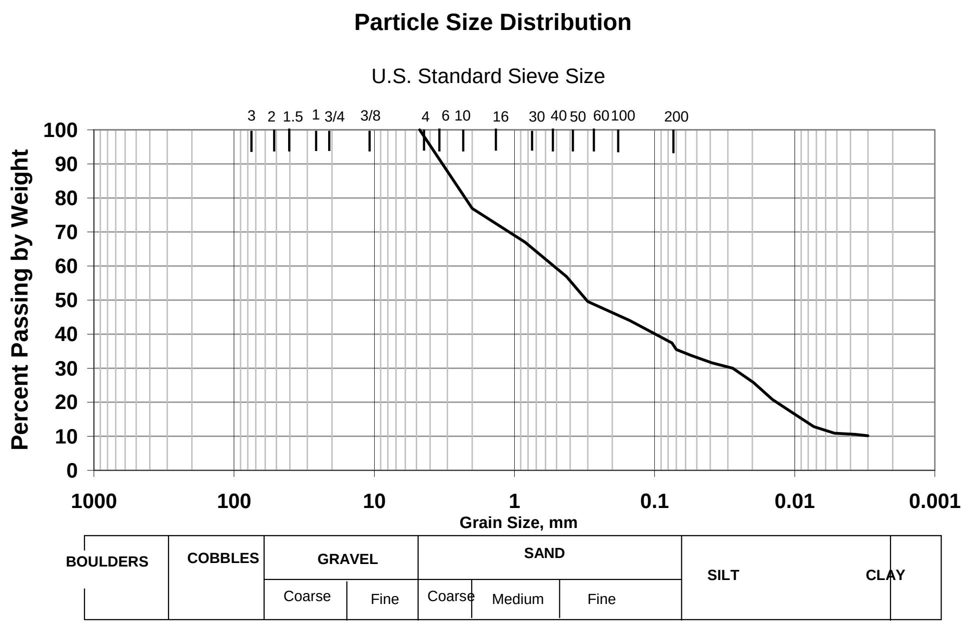

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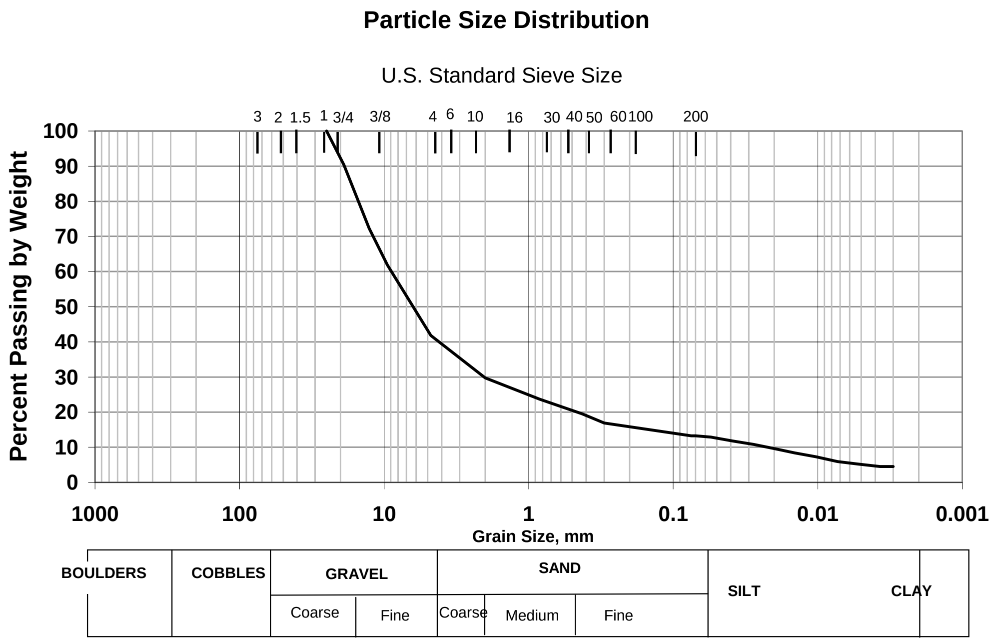
FIGURE 2-3. Wet sieving analysis results of the samples from Sugar Shack West rock pile (SSW-SAN-0006), a) -1-inch field material, b) minus No. 4 sieve material.



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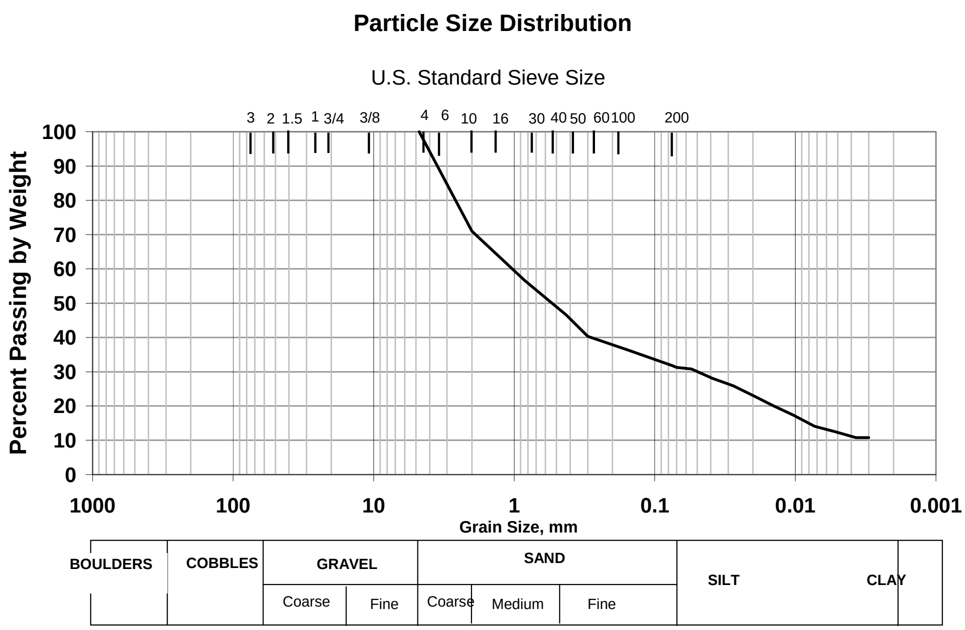
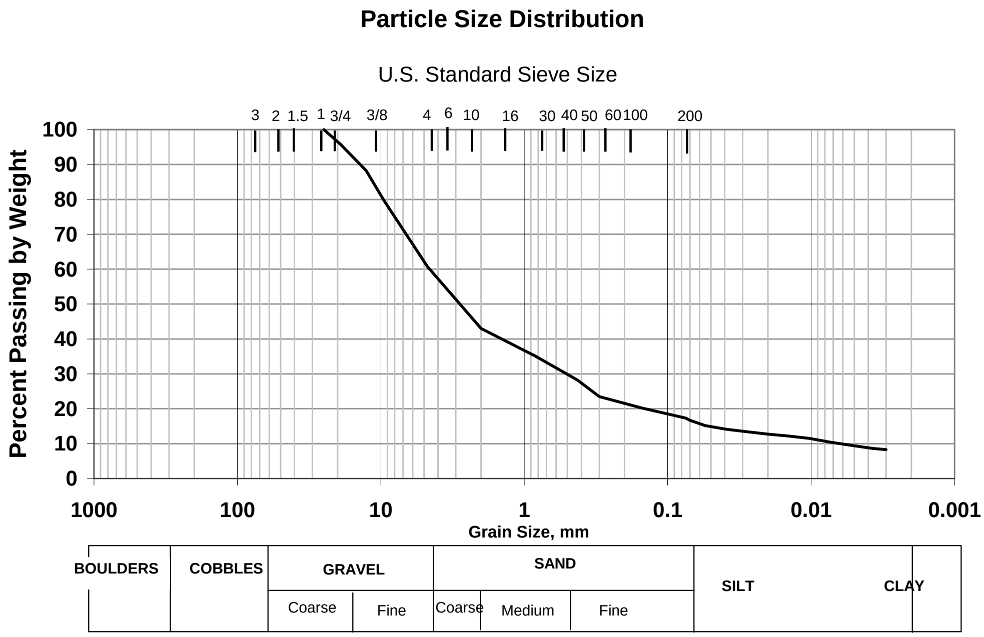


(b)

FIGURE 2-4. Wet sieving analysis results of the samples from Spring Gulch rock pile (SPR-SAN-0002), a) -1-inch field material, b) minus No. 4 sieve material.



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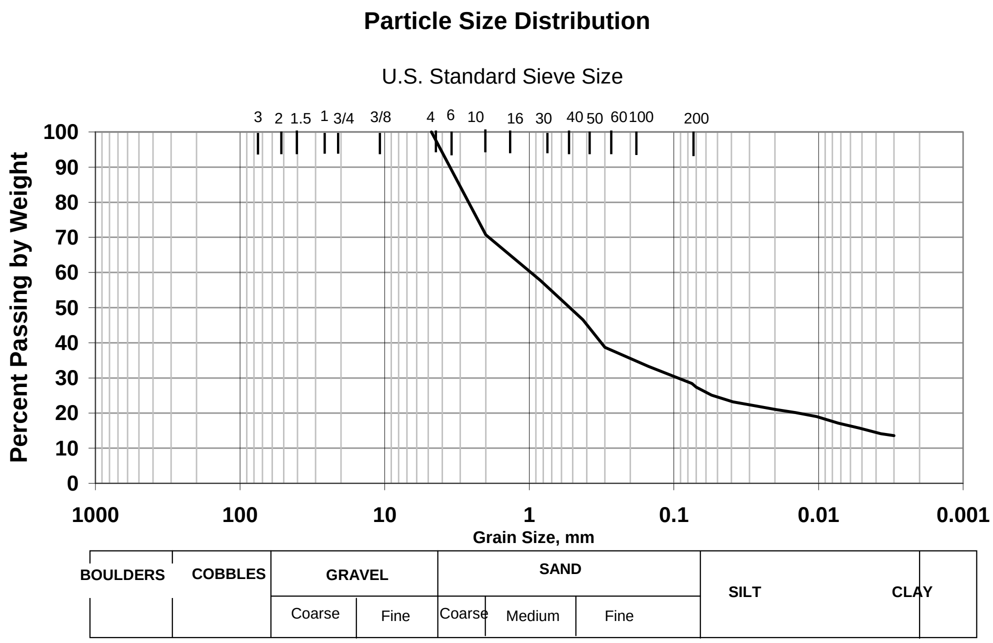


(b)

FIGURE 2-5. Wet sieving analysis results of the samples from Sugar Shack West rock pile (SSW-SAN-0002), a) -1-inch field material, b) minus No. 4 sieve material.

APPENDIX 3. Shear stress versus shear displacement and normal displacement versus shear displacement graphs for both 12-inch and 2.4-inch shear boxes under dry, moist, and wet conditions.

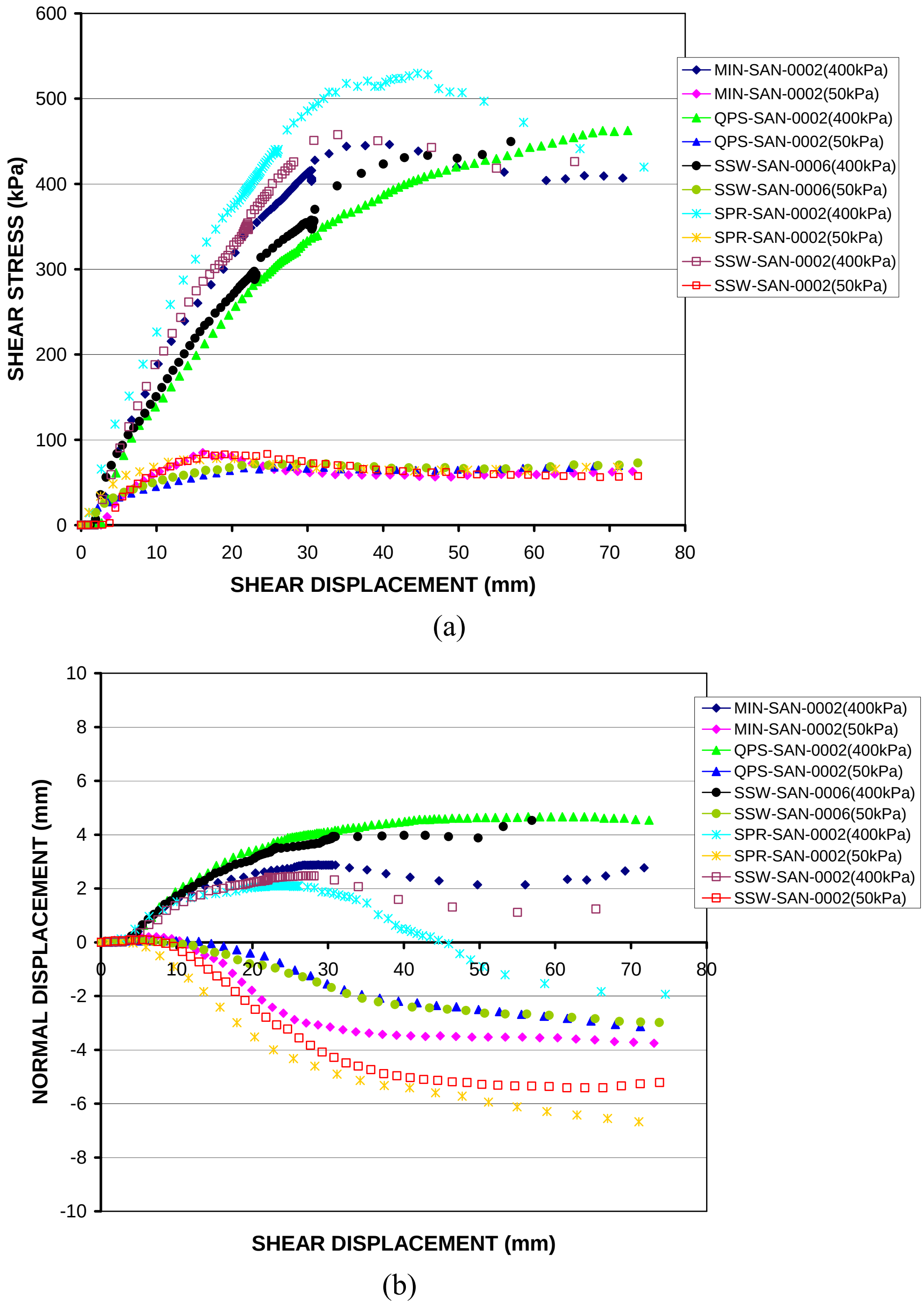
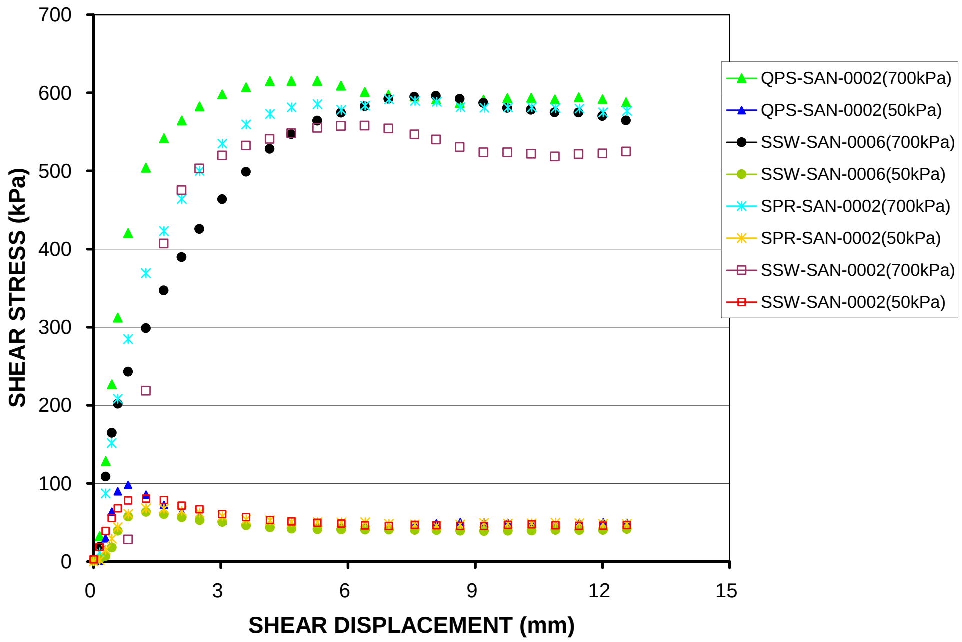
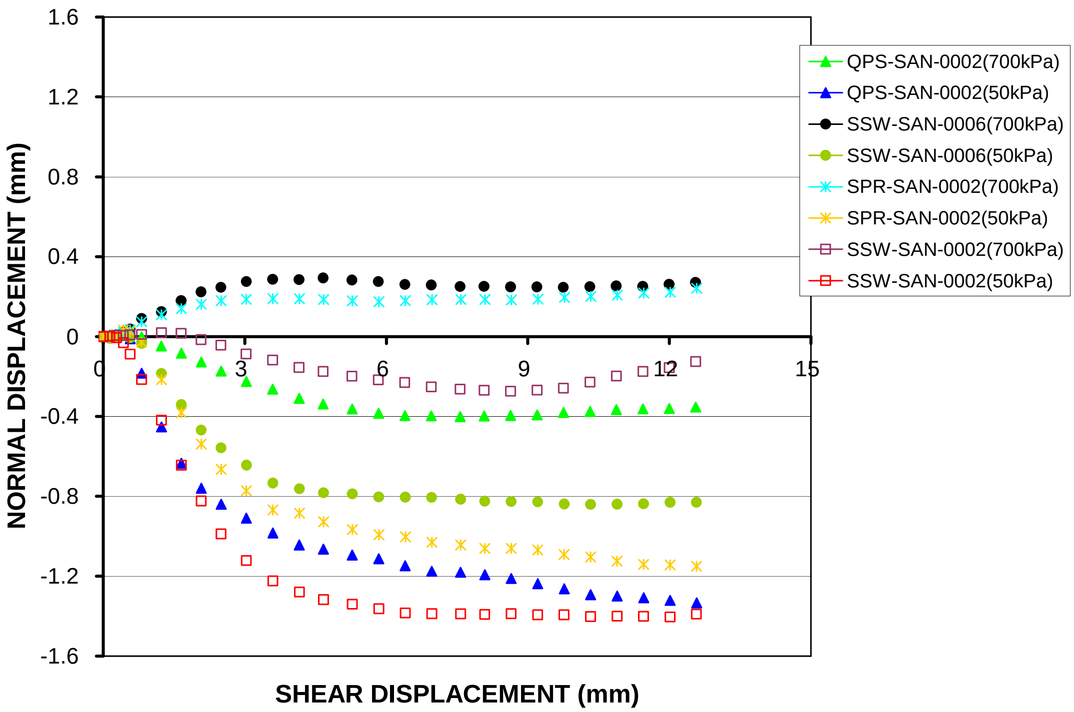


FIGURE 3-1. a) Shear stress vs. shear displacement, b) normal displacement vs. shear displacement, for 12-inch dry samples. Positive normal displacement shows contraction of the sample.

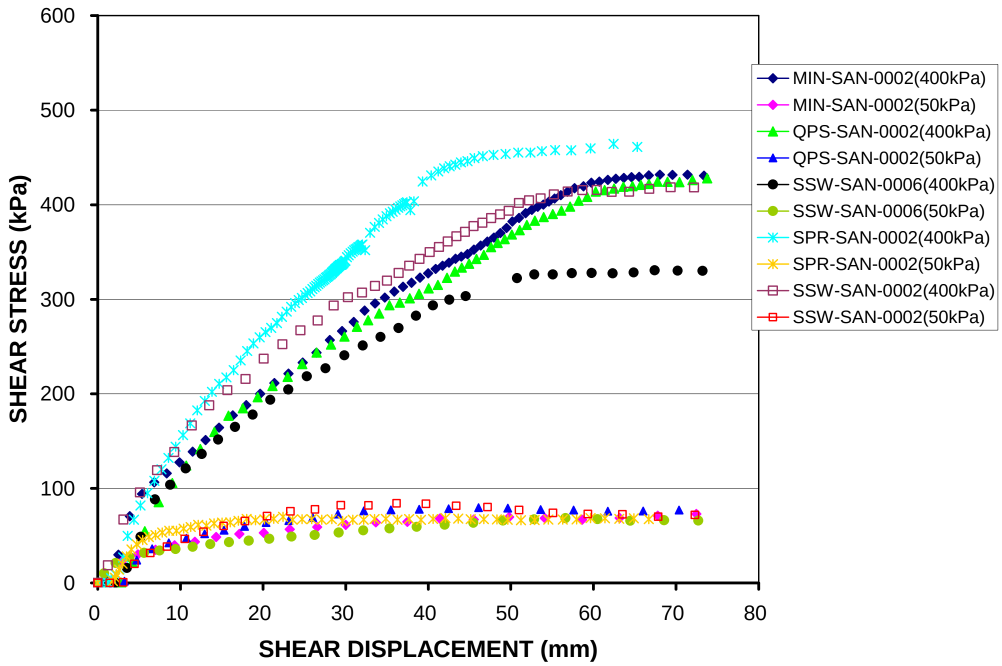


(a)

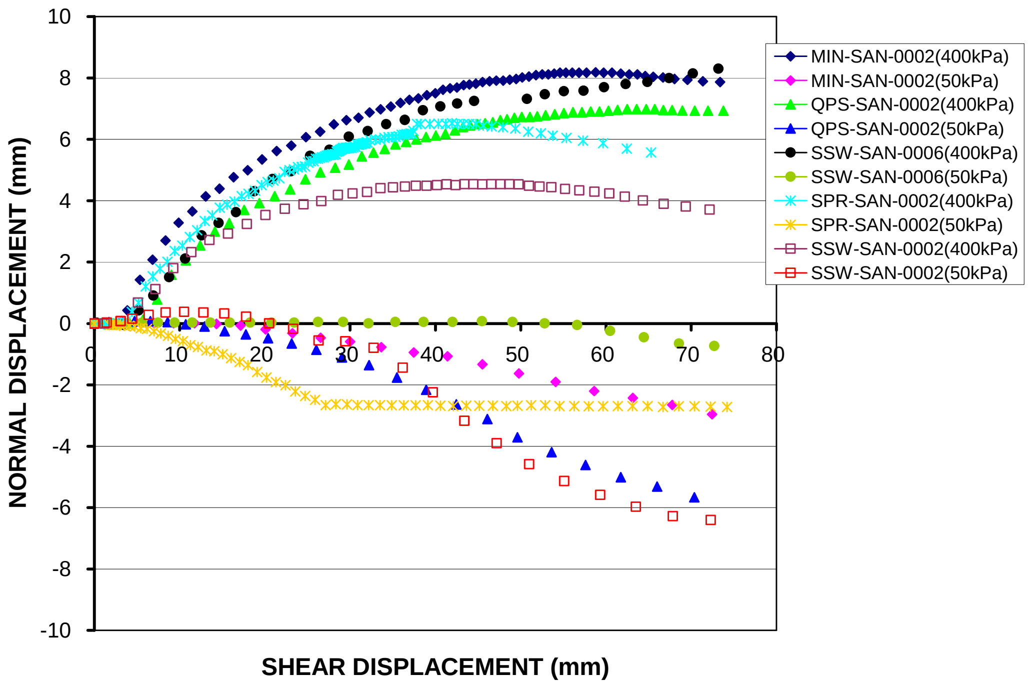


(b)

FIGURE 3-2. a) Shear stress vs. shear displacement, b) normal displacement vs. shear displacement, for 2.4-inch dry samples. Positive normal displacement shows contraction of the sample.

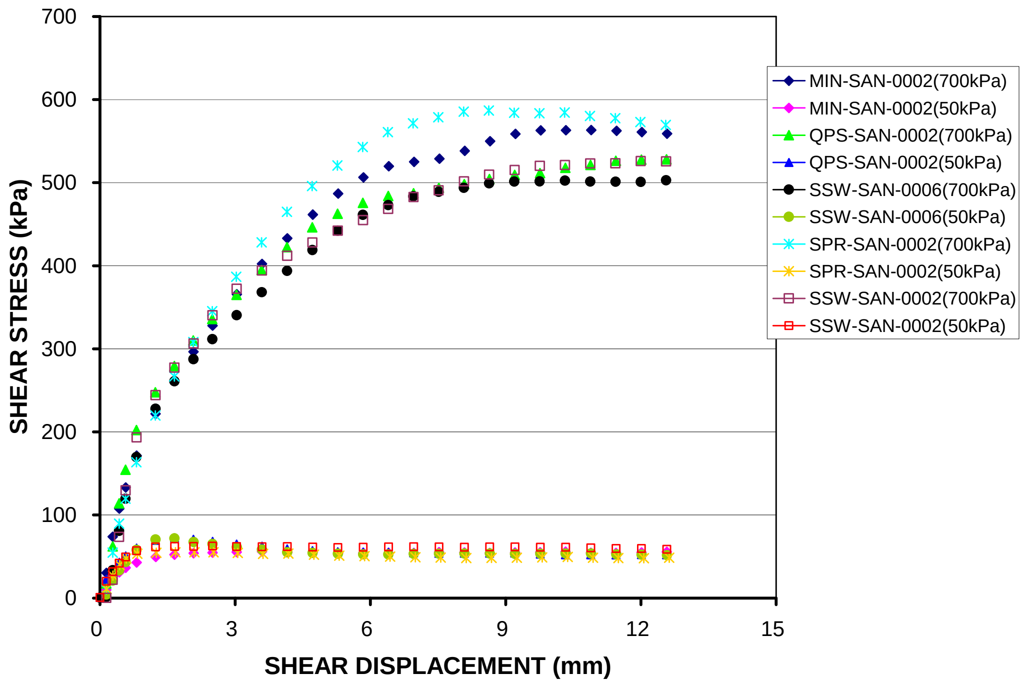


(a)

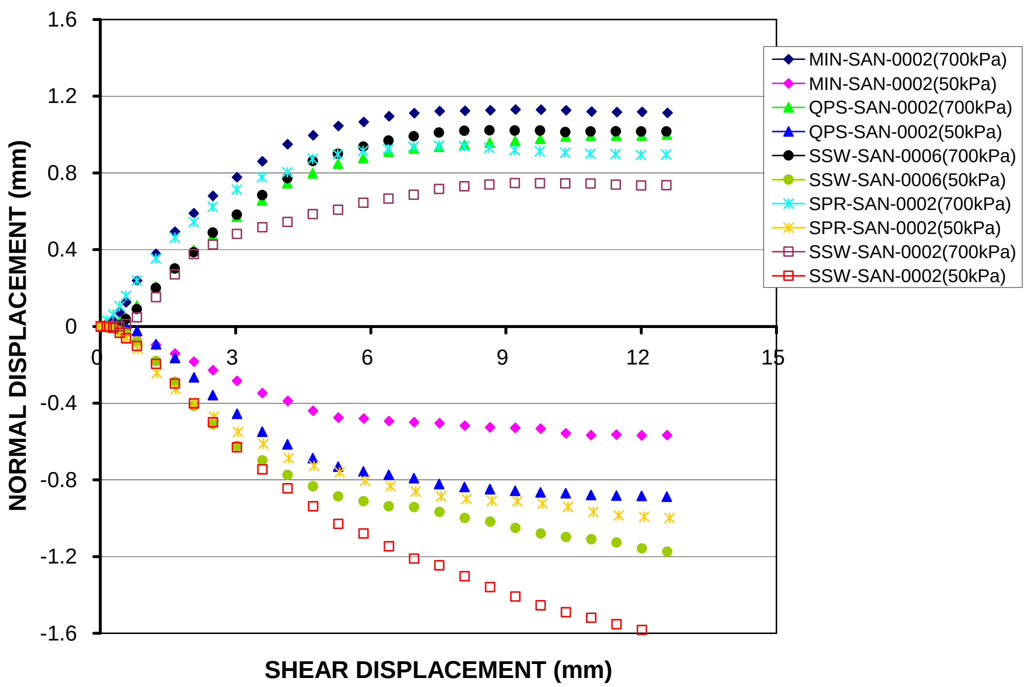


(b)

FIGURE 3-3. a) Shear stress vs. shear displacement, b) normal displacement vs. shear displacement, for 12-inch moist samples. Positive normal displacement shows contraction of the sample.

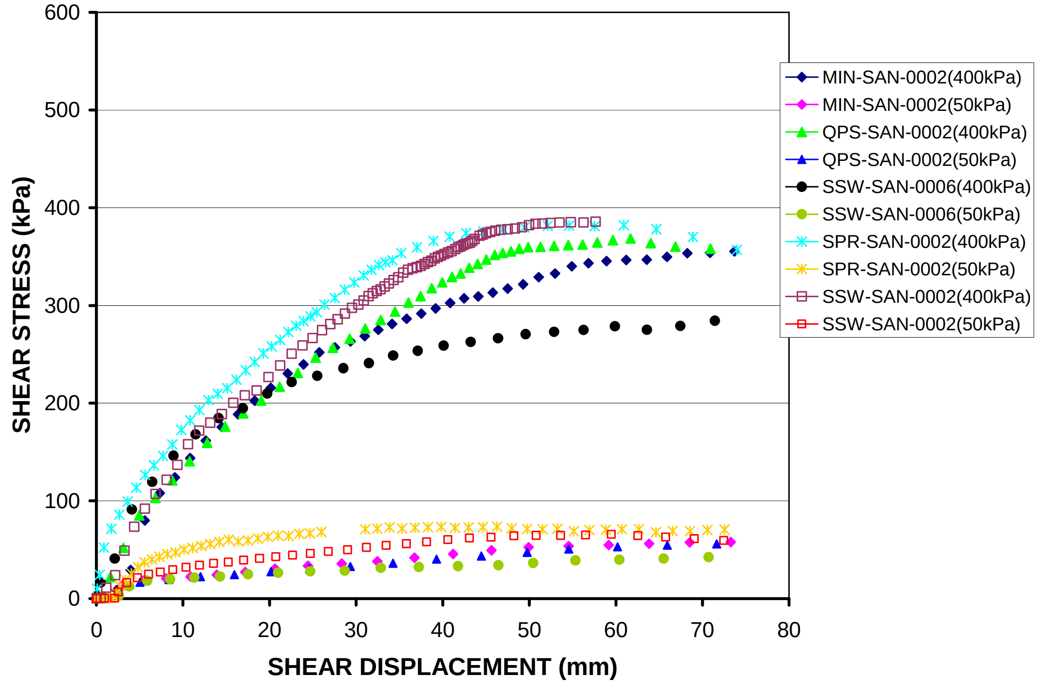


(a)

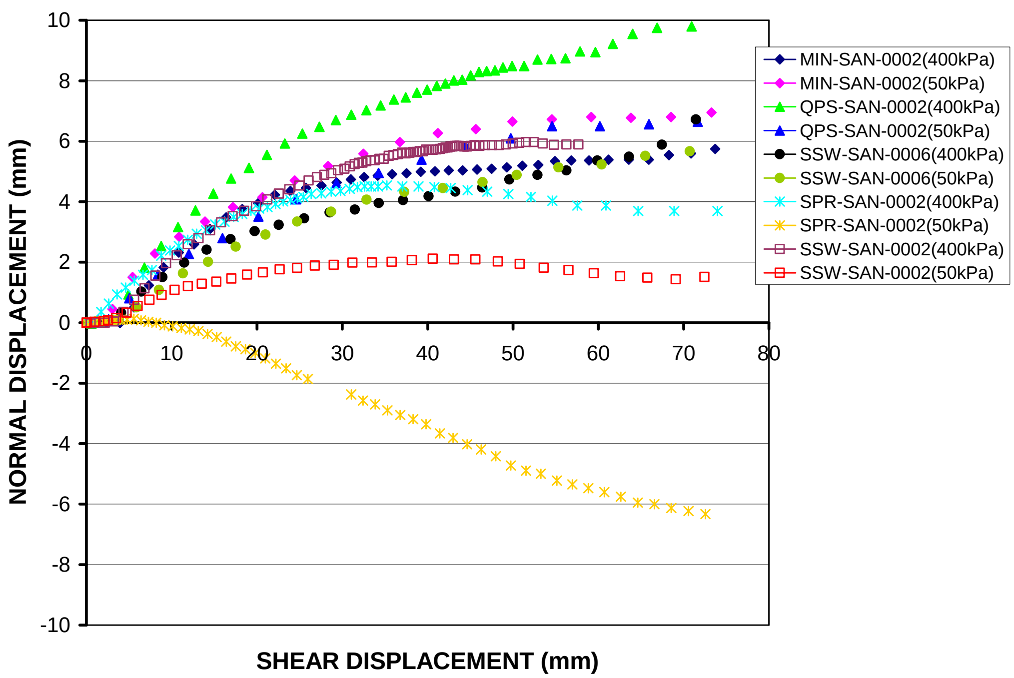


(b)

FIGURE 3-4. a) Shear stress vs. shear displacement, b) normal displacement vs. shear displacement, for 2.4-inch moist samples. Positive normal displacement shows contraction of the sample.

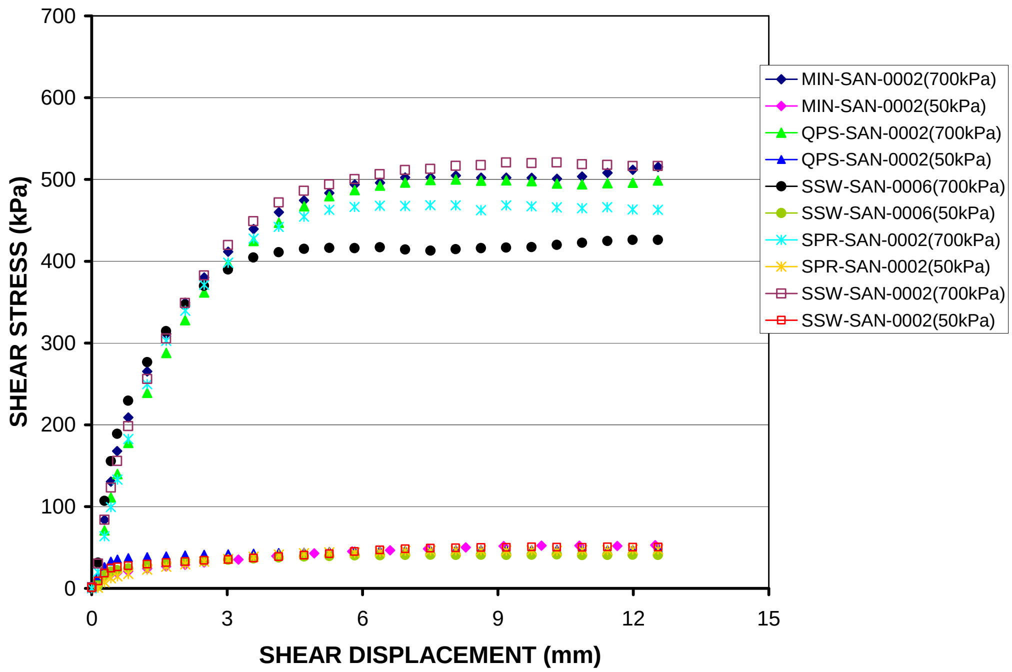


(a)

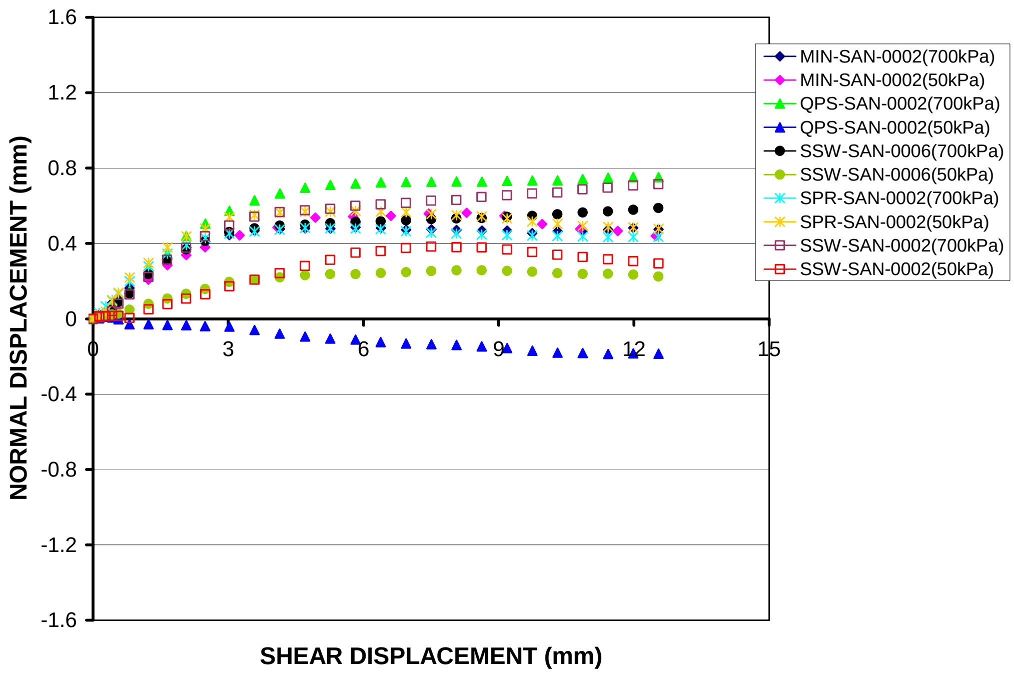


(b)

FIGURE 3-5. a) Shear stress vs. shear displacement, b) normal displacement vs. shear displacement, for 12-inch wet samples. Positive normal displacement shows contraction of the sample.



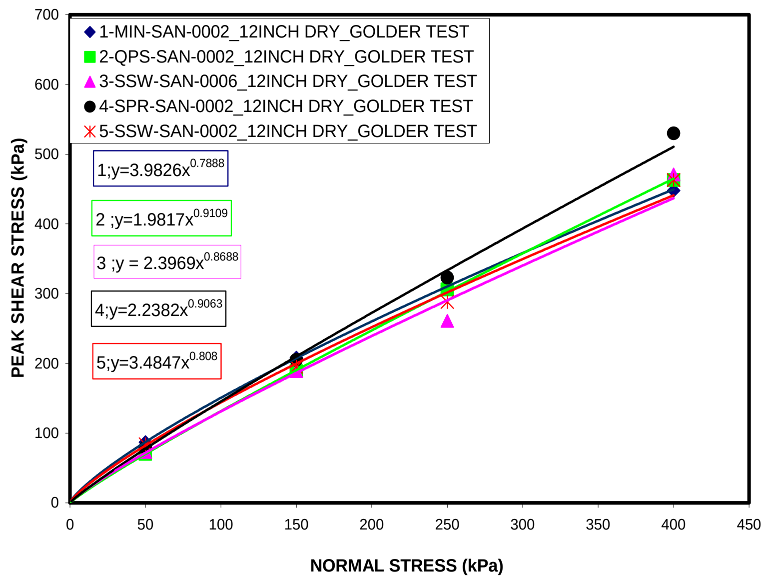
(a)



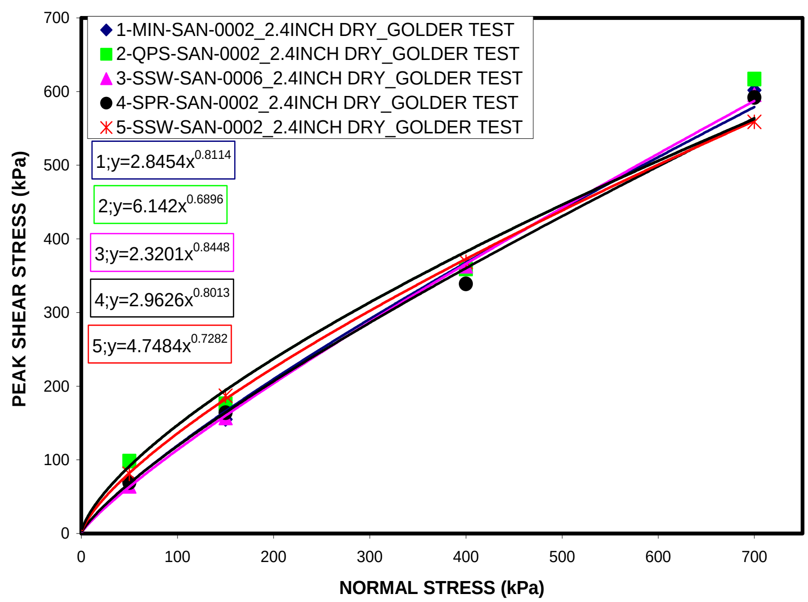
(b)

FIGURE 3-6. a) Shear stress vs. shear displacement, b) normal displacement vs. shear displacement, for 2.4-inch wet samples. Positive normal displacement shows contraction of the sample.

APPENDIX 4. Non-linear coulomb failure envelopes for the 12-inch and 2.4-inch direct shear tests samples, under dry, moist and wet conditions.

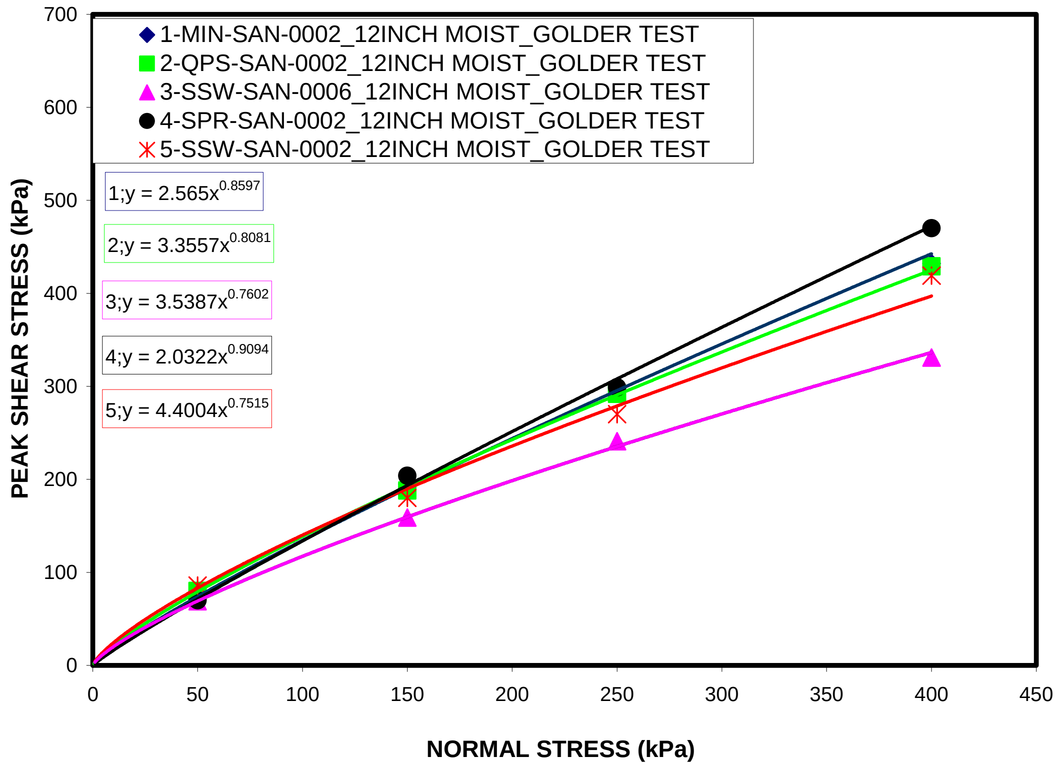


(a)

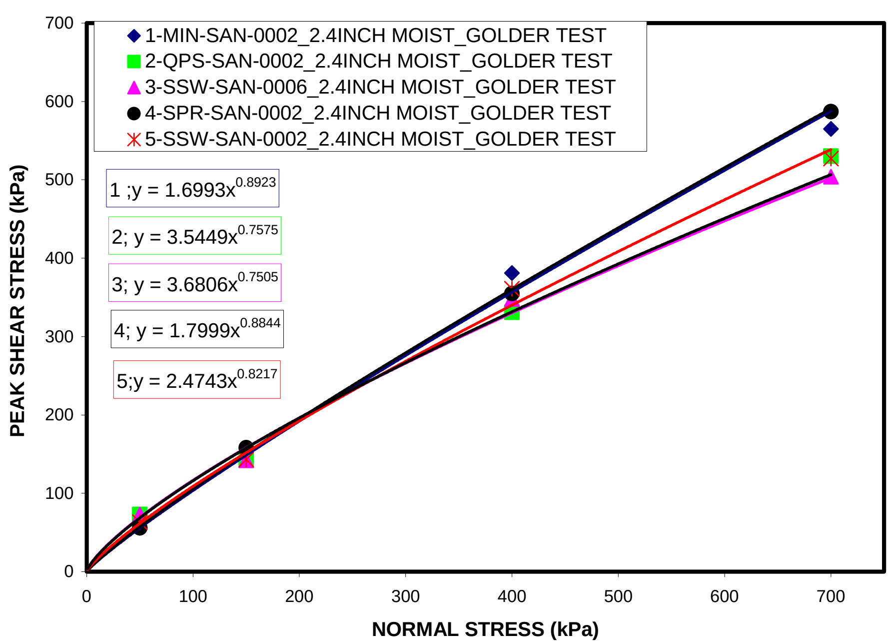


(b)

FIGURE 4-1. Curve failure envelope for a) 12-inch and b) 2.4-inch dry samples.

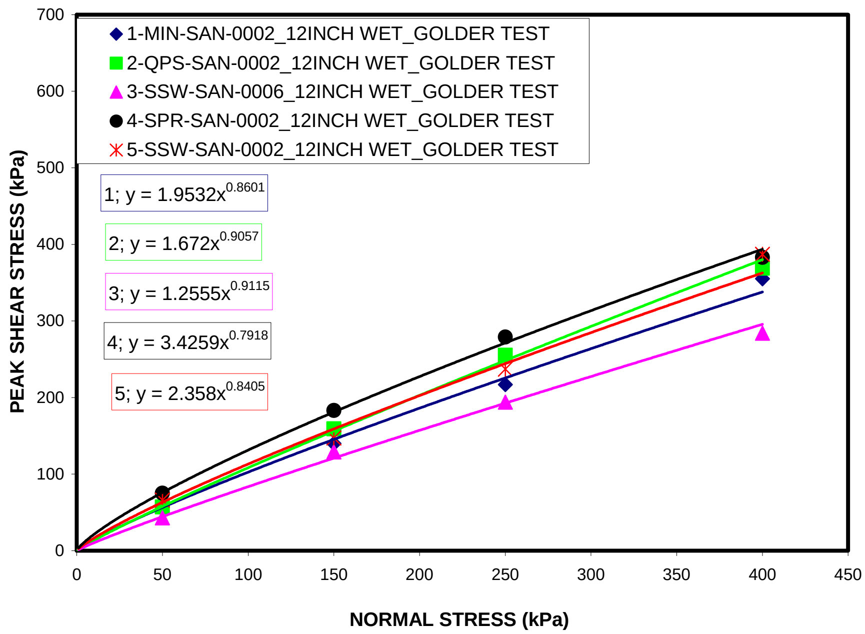


(a)

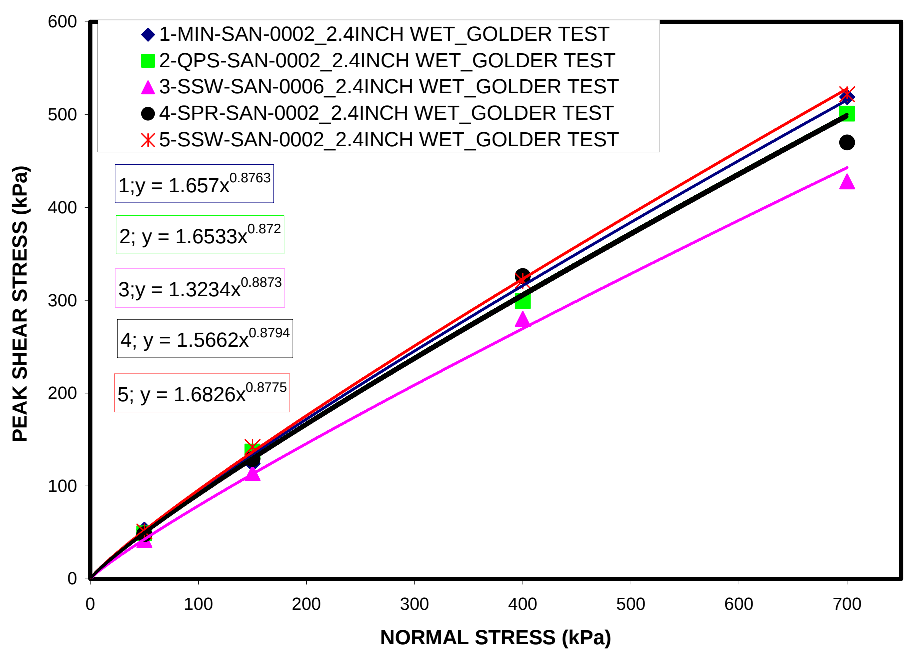


(b)

FIGURE 4-2. Curve failure envelope for a) 12-inch and b) 2.4-inch moist samples.



(a)



(b)

FIGURE 4-3. Curve failure envelope for a) 12-inch and b) 2.4-inch wet samples.

APPENDIX 5. Moisture softening and size effect of Questa mine materials. Larger (12-inch) dry specimens show higher friction angles.