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Experimental Studies of Shearing Properties on Compacted Nakdong River Silty Sands under Unconsolidated Undrained Condition

비압밀비배수조건에서 다져진 낙동강 실트질 모래의 전단거동에 대한 실험적 연구

Khin Swe Tint[1] · Kim, Young-Su[†]
킨스웨틴 · 김 영 수

ABSTRACT : In this study, the effect of different silt contents on the shear characteristics of silty sands was evaluated. Two series of triaxial compression tests were performed on the cylindrical specimens of compacted Nakdong river sand with 10% and 30% silt contents under unconsolidated undrained condition. All identical specimens were prepared to compact with same initial water content for five layers and saturated using control panel and then sheared under initial effective confining pressure, 100 to 400kPa. All specimens exhibited a strain softening tendency after failure in stress-strain curves and deviator stresses of specimens with 10% silt content were greater than those of specimens with 30% silt content. Pore water pressures of specimens with 10% silt content were observed negative(i.e. swelling) due to increasing void ratio after failure but those of specimens with 30% silt content were shown only positive. The behavior of compacted cylindrical specimens with low silt content was more dilative than that of high silt content. Peak deviator stresses decreased as increasing silt content and peak pore water pressures increased as increasing silt content.

Keywords : Stress-strain, Pore water pressure, Silty sands, Dilatancy, Triaxial test, Mohr circle

요 지 : 본연구에서는 실트함유량에 따른 다양한 실트질모래의 전단특성에 관한 효과를 평가했다. 두 종류의 삼축 압축시험은 다져진 낙동강 모래속에 실트 함유율 10%와 30%를 혼합한 조건에서 원형공시체를 성형하고 비압밀 비배수 상태로 실험을 수행하였다. 모든 동일한 공시체는 같은 초기함수비로 5층으로 나누어 준비하여 포화시킨 다음 초기 유효 구속압을 100~400kPa까지 증가시킨 후 전단한다. 모든 공시체는 파괴 후 변형이 감소하는 경향을 보이며 응력변형률 곡선과 축차응력은 실트함유율이 10%일 때가 30%일 때 보다 크게 나타났다. 간극수압은 실트함유율 10%인 공시체가 파괴 후의 간극비 증가로 인해 부의 영향이 나타났지만 반면에 실트함유율 30%인 공시체는 양의 경향을 나타났다. 실트함유량이 낮은 다져진 공시체의 거동은 실트함유량이 높은 경우보다 더 심한 다이러턴시 경향을 나타났고 최대축차응력은 실트함유량이 증가함에 따라 감소하였고 최대간극수압은 증가하였다.

주요어 : 응력변형률, 간극수압, 실트질모래, 팽창현상, 삼축시험, 응력곡선

1. Introduction

A quick or unconsolidated undrained test is usually performed to obtain the shear strength parameters of both fine and coarse grained soils either in undisturbed or remolded. In this research, the identical soil specimens are compacted for setting due to cohesionless under undrained loading. The unconsolidated undrained triaxial strength is applicable to situations where the loads are assumed to take place so rapidly. Yamamuro et al., 2001, Brandon et al., 2006, Lade et at., 1997 and 1998 used c_u and ϕ_u for analysing undrained situations (e.g., short term stability, quick loading and quick results). When conducting site investigations for buildings, in most circumstances short term stability will be the most critical. The UU test is not applicable when the rate of construction is slow allowing consolidation of soil. Hence the test is representative of soils in construction sites where the rate of construction is very fast and the pore waters do not have enough time to dissipate. The designs using UU parameters are mostly conservative. The stress-strain curves are significant for the development of soil failure, which depends on the range of stress-strain response obtained from triaxial compression tests (Tint et al., 2009). The undrained shear strength is a measured response of soil during undrained

1) Lecturer, Ph.D, Dept. of Civil & Environmental Engrg, Gyeongsan University College, Korea (E-mail : khinswetint@yahoo.com)
† Member, Prof., Ph.D, Dept. of Civil & Environmental Engrg, Kyungpook National Univ., Korea (E-mail : kimysu@knu.ac.kr)

loading with an assumption of zero volume change, but it is not a fundamental soil property (Chen et al., 1993). In general, this phenomenon for sandy and silty soils is encountered mainly in saturated soil deposits. There is no doubt that triaxial compression test is presently the most widely used procedure for determining strength and stress-strain responses of soils (Sheng et al., 1997). Sandy silt and silty sand are more difficult to characterize than the behavior of clay or sand because of their tendency to dilate during shear and establishing a consistent and practically useful failure criterion (Yamamuro et al., 2001). Silty sand can be deposited into dense configurations that result in more dilatant behavior than clean sand (Kuerbis, 1989).

However, silty sand also has been shown to have a greater potential for exhibiting much more volumetrically contractive behavior when deposited in very loose states (Lade and Yamamuro 1997). The limiting void ratios varied with silt content, and were determined by methods discussed by Lade et al. (1998). Specimens do not perform the change of volume at critical state during shearing under loading. From these results, cohesionless compacted silty sands were found dilative manner among the soil particles. Deviator stresses of specimens with 10% silt content were larger than those of specimens with 30% silt content. The shear strength of specimens with 10% silt content was greater than that of high silt content. Moreover, although negative pore water pressures of specimens with 10% silt content were observed as increasing void ratio (i.e. swelling), the specimens with 30% silt content showed only positive pore water pressure due to increasing pore water pressure during shearing. There is no exact undrained shear strength and frictional angle is not equal to zero value in this research that is a similar result of consolidated undrained test because of compacted specimens and dilative behavior among the soil particles.

2. Experimental Procedures

The soil materials were selected from around the middle part of Nakdong River in Gumi and brought to soil testing laboratory. The silty sand soils were mixed with 10% and 30% silt content by dry weight of the sand in the laboratory. Laboratory tests included physical properties and unconsolidated undrained triaxial compression tests. Fig. 1 shows grain size distribution curves of compacted Nakdong River silty sands. Any material passing No. 200 sieve was identified as silt (Yamamuro and Wood, 2004). Physical properties of 10% silt content and 30% silt content of compacted Nakdong River silty sands and silt are presented as shown in Table 1 and 3. At first, the weights of silt and sand for each layer were 5.9 and 53.4g of specimens with 10% silt content and 17.9 and 41.9g of specimens with 30% silt content. They mixed together with same water content for five equal layers. The initial same water content for all specimens was 5.93%. The cylindrical triaxial specimens were compacted in five equal layers step by step for diameter in 5cm and height in 10cm.

After setting the specimens, the saturation of samples was performed until B-value is at least 0.98. The compacted specimens were sheared under a constant strain rate is 0.1 mm/min. To obtain the undrained shear strength of the silt-sand mixture at each percentage, four identical specimens were prepared and initially subjected to shear with initial effective confining stresses, σ'_c = 100, 200, 300 and 400kPa respectively and then loaded axially to failure under uncon-

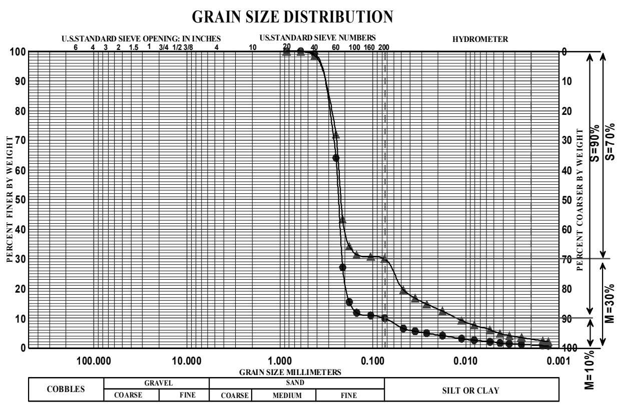


Fig. 1. Grain size distribution curves of compacted Nakdong river silty sands

Table 1. Physical properties of 10% silt content and 30% silt content of compacted Nakdong River silty sands

Silt (%)	Sand (%)	G_s	D_{60} mm	D_{30} mm	D_{10} mm	C_u	C_z	e	$e_{(max)}$	$e_{(min)}$	D_r (%)	γ_d (t/m^3)	USCS
10	90	2.655	0.25	0.22	0.08	3.125	2.42	0.758	1.226	0.642	80	1.51	SP-SM
30	70	2.653	0.24	0.20	0.027	8.89	6.173	0.743	1.295	0.606	80	1.523	SP-SM

Table 2. Final void ratios and water contents of compacted Nakdong River silty sands

Test	σ'_3 (kPa)	Silt 10%	Silt 30%	Silt 10%	Silt 30%
		Water content(%)		Void ratio, e	
UU	100	31.93	26.67	0.848	0.693
	200	30.89	25.40	0.820	0.674
	300	29.78	23.71	0.791	0.629
	400	27.93	21.10	0.742	0.560

solidated undrained condition in triaxial compression test beyond a saturation stage. As effective shear strength parameters are required, axial load (deviator load) is applied in a strain controlled manner. In the case of a strain controlled test, this may be attached to the bottom plate of the machine which is moving up at the constant rate. In all stages of the test undrained conditions are maintained without allowing for any pore water pressure dissipation. Table 2 exhibits void ratios and water content of compacted Nakdong River silty sands after shearing at the end of the tests.

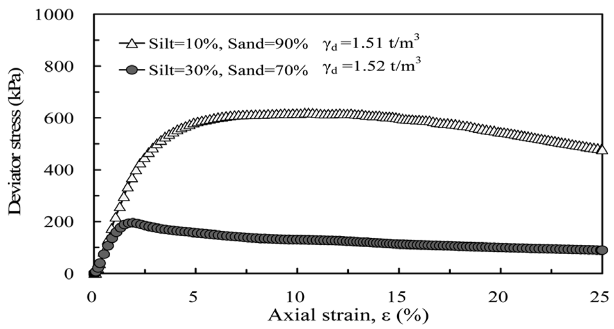
3. Discussion of Comparison Between Experimental Results of Compacted Silty Sands

If the test specimens are 100% saturated, consolidation cannot occur when the confining pressure is applied nor during the shear portion of the test since drainage is not permitted. Therefore, if several specimens of the same material are tested, and if they are all at approximately the same water content and void ratio when they are tested, they will have approximately the same undrained shear strength. If the test specimens are partially saturated or compacted specimens, where the degree of saturation is less than 100%, consolidation may occur when the confining pressure is applied and during shear, even though drainage is not permitted. Therefore, if several partially saturated specimens of the same material are tested at different confining stresses, they will not have the same undrained shear strength. Mohr failure envelope for unconsolidated undrained triaxial tests on partially saturated and compacted soils is usually curved. Therefore, cohesionless silty sands of different silt contents with various sand contents from this research could not obtain the same undrained shear strength in practical. Moreover, Mohr failure envelope for remolded and undistributed specimens will usually be a horizontal straight line over the entire range of confining stresses applied to the specimens if the specimens are fully saturated in theory. According to actual experimental results, there was no a horizontal straight line (i.e. $\phi \neq 0$) and could not obtain accuracy value for undrained shear strength because all specimens of silty sands were subjected that it first exhibited positive pore water pressure, and dilation occurred and then pore water pressure became negative under undrained loading among the soil grains during shearing (Terzaghi et al. 1963). The low silt content is practically higher dilatancy effect than high silt content of silty sand. There was a same result between theory and practical in cohesionless compacted silty sand soils even saturation.

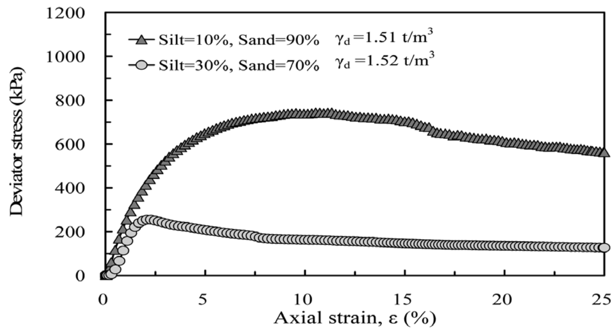
The deviator stress-strains of specimens with 10% silt content were greater than those of specimens with 30% silt content due to swelling (i.e. increasing negative pore water pressure) and displayed softening tendency after failure as shown in Fig. 2. The pore water pressures of specimens with 10% silt content were lower than those of specimens with 30% silt content because of increasing void ratio and broken interlocking among the soil particles of specimens (Terzaghi et al. 1963) with 10% silt content so they showed only negative pore water pressure values after failure as shown in Fig. 3. As increasing initial effective confining pressures, each of peak negative pore water pressures can be found such as -150kPa at σ'_3 = 100kPa, -125kPa at σ'_3 = 200kPa, -100kPa at σ'_3 = 300kPa and -50kPa at σ'_3 = 400kPa under decreasing void ratio with reducing peak negative pore water pressure of specimens with 10% silt content in each of UU tests. Thus, the specimens of low silt content displayed more dilative manner than those of high silt content as increasing negative pore water pressures and reducing final water content and void ratios as shown in Table 2.

Table 3. Physical properties of silt

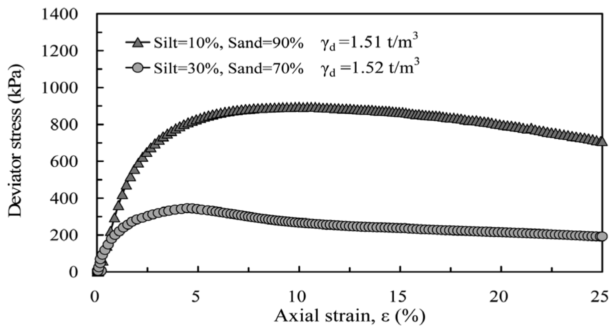
Specific gravity, G_s	Liquid Limit(%)	Plastic Limit(%)	Plastic Index(%)	Pass #4, (%)	Pass #200, (%)	USCS
2.640	34	26	8	100	100	ML



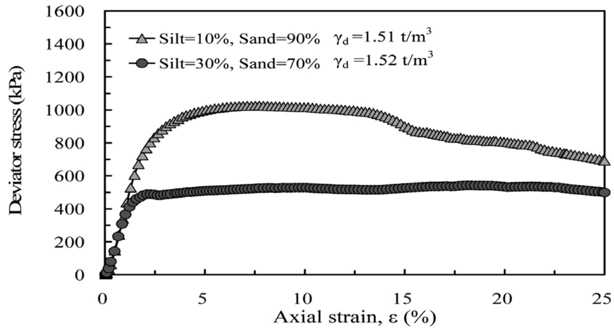
(a) σ′$_3$ = 100kPa, e (silt 10%) = 0.848, e (silt 30%) = 0.693



(b) σ′$_3$ = 200kPa, e (silt 10%) = 0.820, e (silt 30%) = 0.674

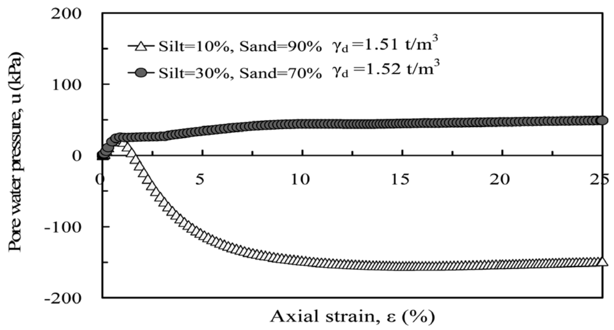


(c) σ′$_3$ = 300kPa, e (silt 10%) = 0.791, e (silt 30%) = 0.629



(d) σ′$_3$ = 400kPa, e (silt 10%) = 0.742, e (silt 30%) = 0.560

Fig. 2. Results of comparison between deviator stresses versus axial strain for compacted silty sands in UU tests



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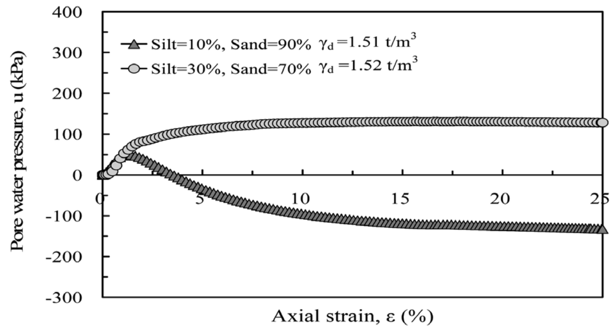
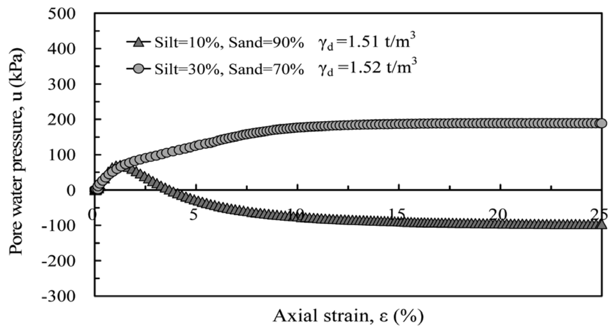
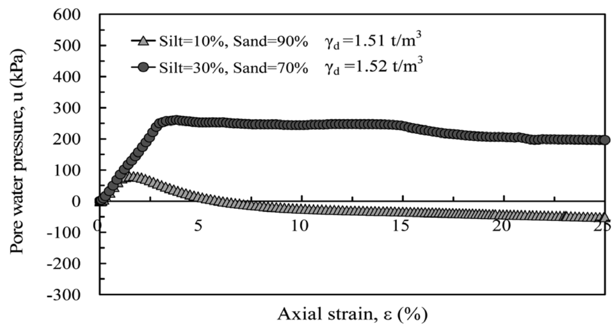


(b) σ′$_3$ = 200kPa, e (silt 10%) = 0.820, e (silt 30%) = 0.674



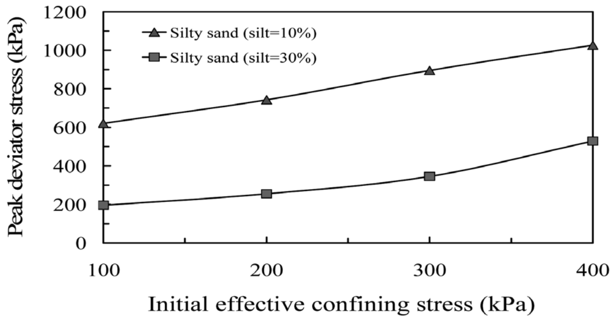
(c) σ′$_3$ = 300kPa, e (silt 10%) = 0.791, e (silt 30%) = 0.629



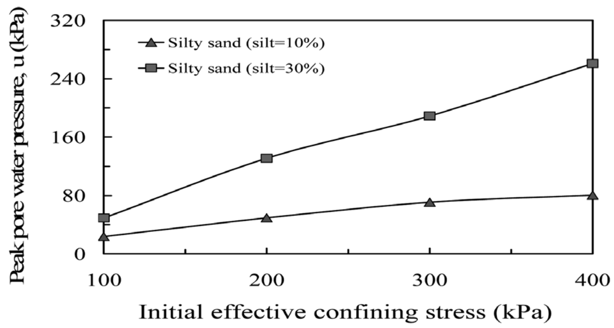
(d) σ′$_3$ = 400kPa, e (silt 10%) = 0.742, e (silt 30%) = 0.560

Fig. 3. Results of comparison between pore water pressures versus axial strain for compacted silty sands in UU tests

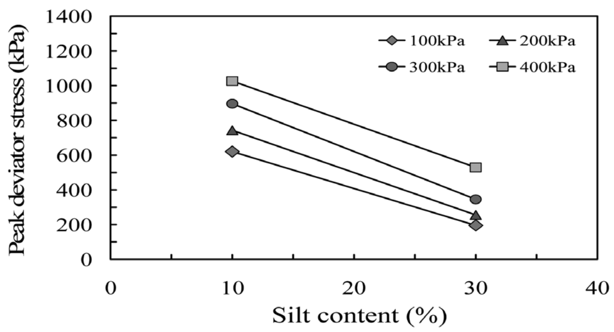
The peak deviator stresses of specimens with 10% silt content is greater than those of specimens with 30% silt content under increasing initial effective stress from 100kPa to 400kPa as shown in Fig. 4 (a). The peak pore water pressures developed as increasing initial effective confining stresses and peak pore water pressures of specimens with 30% silt content increased steeply but those of specimens with 10% silt content increased smoothly. Moreover, the



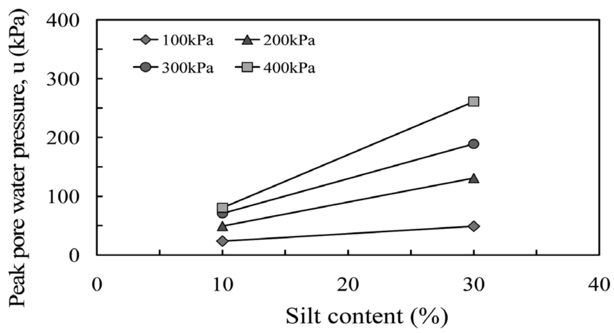
(a) Peak deviator stress versus initial effective confining stress



(b) Peak pore water pressure versus initial effective confining stress

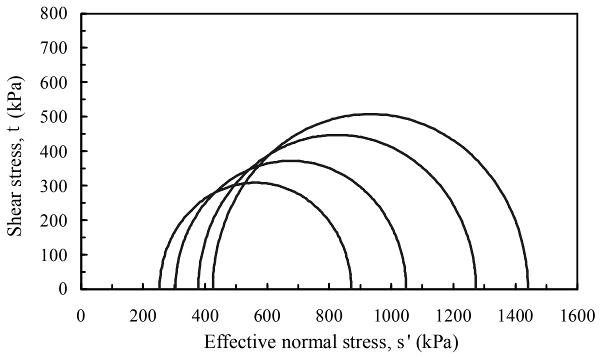


(c) Peak deviator stress versus silt content curves

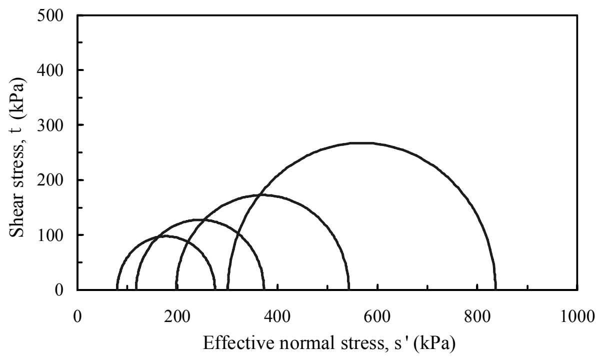


(d) Peak pore water pressure versus silt content curves

Fig. 4. Results of comparison between 10% and 30% silt contents of Nakdong river compacted silty sands in UU tests



(a) 10% silt content of silty sand



(b) 30% silt content of silty sand

Fig. 5. Mohr's circles of compacted silty sands for UU tests

peak pore water pressures of specimens with 30% silt content were greater than those of specimens with 10% silt content as shown in Fig. 4 (b). According to test results, the peak deviator stresses decreased with increasing silt content as shown in Figs. 4 (c). The peak pore water pressures increased with high silt content under increasing initial effective confining stresses as shown in Fig. 4 (d). Even though both compacted silty sands could be observed the different behaviors in stress-strain and pore water pressures curves, there were same manner for Mohr failure envelopes which could show a curve line for each of compacted silty sands. The undrained shear strength could not obtain exactly as friction angle is not equal to zero (i.e. $\phi \neq 0$) even the soil specimens were saturated at B = 0.98. Each Mohr's circle is expended due to low-cohesion and dilatancy effect (Tint et al., 2007). Undrained shear strength could not be determined for the specimens with 10% and 30% silt content of compacted silty sand soils because the undraind frictional angle is greater than zero (i.e. $\phi > 0$) as shown in Fig. 5.

4. Conclusions

The experimental program to study the behavior of different silt contents for silty sands under unconsolidated undrained conditions were undertaken in which two series of triaxial tests were performed. The following primary conclusions were obtained as a result of this study:

(1) From experimental results, we can conduct the deviator stresses of the specimens with 10% and 30% silt contents showed strain softening tendency after failure. The deviator stresses of the specimens with 10% silt content were greater than those of the specimens with 30% silt content under increasing initial effective confining pressure during shearing.
(2) Pore water pressures of the specimens with 30% silt content exhibited only positive but those of the specimens with 10% silt content presented negative values due to increasing void ratio (i.e. dilation) after failure. Thus, pore water pressures of specimens with 30% silt content were greater than those of specimens with 10% silt content because the specimens with 10% silt content were more dilative manner than those with 30% silt content among the soil particles after failure.
(3) Peak deviator stress decreased as increasing silt content but peak pore water pressure increased as increasing silt content under higher initial effective confining pressures. Each of all specimens with 10% and 30% silt contents showed decreasing final water content and void ratios with increasing initial effective pressures. Final water content and void ratios of the specimens with 10% silt content are greater than those of the specimens with 30% silt content.
(4) Even though all samples were compacted for each of five equal layers with same initial water content and performed saturation condition before shearing, each Mohr failure envelope of both silty sands could not obtain a horizontal line. From these research studies, there is no accurate undrained shear strength and the friction angle is not equal to zero due to compaction and dilation behaviors among the soil grains.
(5) Mohr failure envelopes of compacted silty sands under unconsolidated undrained tests can be observed as a similar result of consolidated undrained tests because the frictional angle is greater than zero. This experimental research can be proved as a same result of theory for Mohr failure envelope of compacted soils in UU tests.

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