Oedometer and direct shear tests to the study of sands with various viscosity pore fluids

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ABSTRACT: This study presents a brief review of tests of sands with different viscosity pore fluids in the soil mechanics, and a series of experimental study to identify some characteristics of the behavior of geomaterials with different viscosity pore fluids. Pore fluid viscosity likely to affect the engineering behaviour of sands, such as compressibility, stress- strain properties, stiffness, damping, and liquefaction characteristics. Chemical composition of groundwater may be changed by products of chemical processes because of either the structure or the dissolution harmful substances. For this reason, influences of the pore fluid viscosity on the behaviour of sands have received attention in this study. During the investigation, water, gasoline and petrol saturated angular and rounded sands having the diameter of 0.3- 0.6 mm and 2- 1 mm were tested in oedometer and direct shear testing machines. The experimental results show that the size of particles and the type of pore fluids significantly affect the stress- strain relations and consolidation behavior of the materials. Here in this investigation, some changes in the maximum shear strength, void ratio, internal friction angle values and compressibility characteristics are described for further use by researchers.

1 INTRODUCTION

Viscosity is one of the important physical properties of many fluid products, and can be described as a fluid's resistance to flow. Fluids resist the relative motion of immersed objects in them as well as to the layers motion with different velocities within them. A brief review of the literature enables one to identify some important characteristics of the behavior of geomaterials with different viscosity pore fluids. The authors therefore consider it is to be further noted that the studies from various approaches such as centrifuge tests (Zeng et al, 1998) and soil dynamics (Ellis et al, 2000) as well as fundamental soil behaviour (Ratnaweera & Meegoda, 2006).

In centrifuge model tests, it is common to use pore fluids having high viscosity to unify time-scaling factors for dynamic and consolidation events. The use of a pore fluid with higher viscosity reduces the permeability of a geomaterial, making it possible to achieve similar time scale. Zeng et al. (1998) presented a series of permeability test results on two types of sands. They found that using a glycerine-water mixture as the pore fluid has no significant effect on the strength and stress-strain relationship of Ottawa sand No. 40. Coefficients of permeability are inversely proportional to the viscosity. On the other hand, at small hydraulic gradients, it was observed that the highly viscous fluids can lead the clogging of flow through the pores. Pore fluid viscosity is possibly to make some contribution to the dynamic behaviour of sands, such as stiffness, damping, and liquefaction characteristics. As particles move with respect to each other, local viscous loss is likely to occur mainly close to the particle contacts (Ellis et al., 2000). Wilson (1988) studied the effect of pore fluid viscosity on damping in sand, and showed that the change in damping between oil and water-saturated samples increased with applied shear strain. It was interpreted that pore fluid would be forced to flow around the moving soil particles by shear deformation. Actually, soils could be contaminated due to viscous fluids through a different sources (e.g., leakage of oil from pipelines). Ratnaweera & Meegoda (2006) published a study presenting a series of unconfined compression tests on fine-grained soils contaminated with varying amounts of chemicals. Their observations, which showed a decrease in shear strength and stress-strain behaviour due to the presence of the additives, were attributed to changes in dielectric constant and pore fluid viscosity caused by the additives. Consolidated drained triaxial test results on a granular soil showed a similar behaviour. This is attributed to mechanical interactions at particle contacts, caused by the enhanced lubrication offered by the more viscous, compared to water, pore fluid. For fine-grained soils, the reduction in shear strength is attributed to physicochemical effects caused by a reduction in dielectric constant, and mechanical interactions caused by higher pore fluid viscosity. Evgin & Das (1992) carried out triaxial tests on clean and oil contaminated quartz sand. They found that for both loose and dense sands, full saturation with motor oil causes a significant decrease in the friction angle and also drastic increase in volumetric strain. They also showed by finite element analysis that settlement of footing increased due to oil- contamination. Shine & Das (2001) studied the bearing capacity of unsaturated oil- contaminated sand. They observed that oil contamination drastically reduces the bearing capacity. Cabalar & Clayton (2010) carried out a series of triaxial tests on Leighton Buzzard quartz sand. They used a silicon oil, syrup which prepared from the solubility of sugar in water resulting different viscosity syrup. The results shows a sharp decrease followed by a gradual increase in the deviatoric stress, stiffness, and a sharp increase followed by a gradual decrease in corresponding pore pressure.

The objective of this study is to conduct a laboratory testing program to investigate the effects of various viscosity pore fluids (water, gasoline, petrol) to the behaviour of two different particle sizes (0.3 mm- 0.6 mm, and 1.0 mm- 2.0 mm) sands having distinct shapes (rounded and angular) tested in oedometer and direct shear testing equipments.

2 MATERIALS AND METHOD

The materials used in the tests described in this paper were Trakya Sand obtained from Thrace Region in North-west of Turkey, and a commercially produced crushed stone sand obtained from Gaziantep City in Southern-central of Turkey. Trakya Sand, which is commonly used in the experimental works, was supplied by Set/Italcementi Group, Turkey, confirming to TS EN 196-1. Crushed stone sand used in this investigation is widely consumed in civil engineering works, in particularly in earthworks, in Gaziantep City and its vicinity. As it can be seen from the Figure 1, Trakya Sand particles have relatively rounded shape, whereas the Crushed stone sand particles have angular shape. Particle sizes, specific gravities and minimum and maximum dry densities of the sands used during the experimental study are presented in Table 1.

Table 1. Some properties of teh sands used in the experimental study

Type of sand	Particle size (mm)	Specific gravity (G_s)	$\gamma_{d\,(max)}$ (g/cm^3)	$\gamma_{d\,(min)}$ (g/cm^3)
Crushed stone sand (AS: Angular Sand)	1.0- 2.0	2.68	1.69	1.29
	0.3- 0.6	2.68	1.67	1.33
Trakya Sand (RS: Rounded Sand)	1.0- 2.0	2.65	1.61	1.37
	0.3- 0.6	2.65	1.52	1.31

Figure 1. Picture of (a) crushed stone (Angular Sand: AS), and (b) Trakya (Rounded Sand: RS) sands used during the experimental study.

'Direct shear' (TS 1900- 22) and 'oedometer' (ASTM D3080) testing apparatuses were employed during the investigation. In the tests performed in direct shear machine, dry sands were gently spooned in thin layers into box, and the box was assembled with instruments (i.e., screws, top porous stone). Specimen height inside the box was measured, area correction was made, and the two vertical screws were removed after loading frame employed. Then, the shear box mould was completely filled with the required fluid and kept for a period of time for saturation. Applying the vertical load, shearing was commenced with a 0.1 mm/min rate of loading. Shear force, horizontal and vertical displacements were recorded at every 50 seconds, until the specimen fails. Similarly, the sandy soils were gently spooned in an oedometer cell to have loose specimens. After assembling the instruments (e.g., screws, porous stone, loading frame), and making the measurements of dimensions, specimens were left for a while for saturation. Then, loadings were commenced with the effective stress increments of 22.195, 44.354, 88.78, 177.56, 355.12, and 710.24 kPa.

3 RESULTS AND DISCUSSIONS

Tables 2 and 3 give summaries of the specimens sheared under different loads (27.24, 54.48 and 108.96 kPa) in the direct shear tests reported here. Specimens with water had the highest angle of internal friction (ϕ) values, as the specimens with gasoline had the ϕ lowest value in all shape and size of the sands. It is seen that the Angular Sand (AS) specimens (i.e., Crushed stone sand) tested in direct shear apparatus have higher ϕ values than the Rounded Sand (RS) specimens (i.e., Trakya Sand) tested in direct shear apparatus have. It was also noted that the initial relative density of all specimens fell between 20 and 35%, with most specimens having a relative density in the region of 25–30%. The specimens were loose.

Table 2. Summary of RS specimen data

Pore fluid	Maximum shear strength (kN/m2)			Internal friction angle (ϕ)		
	particle size 2- 1 mm	particle size 1- 0.6 mm	particle size 0.6- 0.3 mm	particle size 2- 1mm	particle size 1- 0.6 mm	particle size 0.6- 0.3 mm
Water	21.16 48.65 86.88	19.51 41.22 78.46	16.9 35.75 75.35	39.79^{o}	36^{o}	34.27^{o}
Petrol	19.15 41.45 73.64	16.64 34.85 66.57	16.01 37.03 54.67	34.73^{o}	31.64^{o}	28.2^{o}
Gasoline	17.05 33.19 67.6	15.78 31.56 62.21	10.58 28.78 58.30	31.73^{o}	29.8^{o}	27.4^{o}

Table 3. Summary of AS specimen data

Pore fluid	Maximum shear strength (kN/m2)			Friction (ϕ)		
	Particle size 2- 1 mm	Particle size 1- 0.6 mm	Particle size 0.6- 0.3 mm	Particle size 2- 1mm	Particle size 1- 0.6 mm	Particle size 0.6- 0.3 mm
Water	27.54 49.95 104.89	23.22 48.05 98.61	21.63 42.11 86.79	43.71^o	41.9^o	38.37^o
Petrol	24.27 54.58 103.8	22.3 46.12 94.21	18.29 41.73 83.16	43.8^o	40.66^o	37.2^o
Gasoline	21.82 47.95 96.14	15.78 31.56 62.21	16.44 35.97 82.69	41.2^o	37.07^o	36.2^o

Figure 2 shows the variation of shear stress and horizontal displacement size of sand and type of pore fluids in AS specimens under a vertically applied load of 27.24 kN/m^2. It can be seen that the shear stress values decrease as the viscosity of pore fluid increases for all sizes of both AS and RS specimens tested. Amount of decrease in shear stress values in AS specimens seems to be higher than those in RS specimens. It is interpreted that the difference in behaviour between the AS and RS specimens may be attributed to the slipping of the rounded particles over each others, and interlocking of the angular particles. Figure 3 presents the relationships between the stress and horizontal displacement for different particle size of RS specimens with different pore fluids.

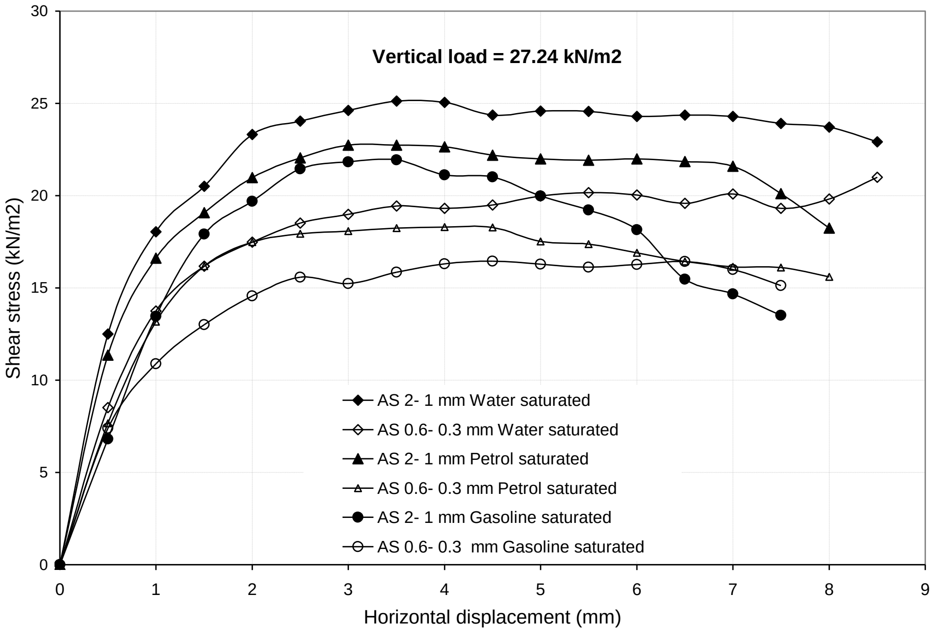

Figure 2. Stress- displacement for different particle size of AS specimens with different pore fluids

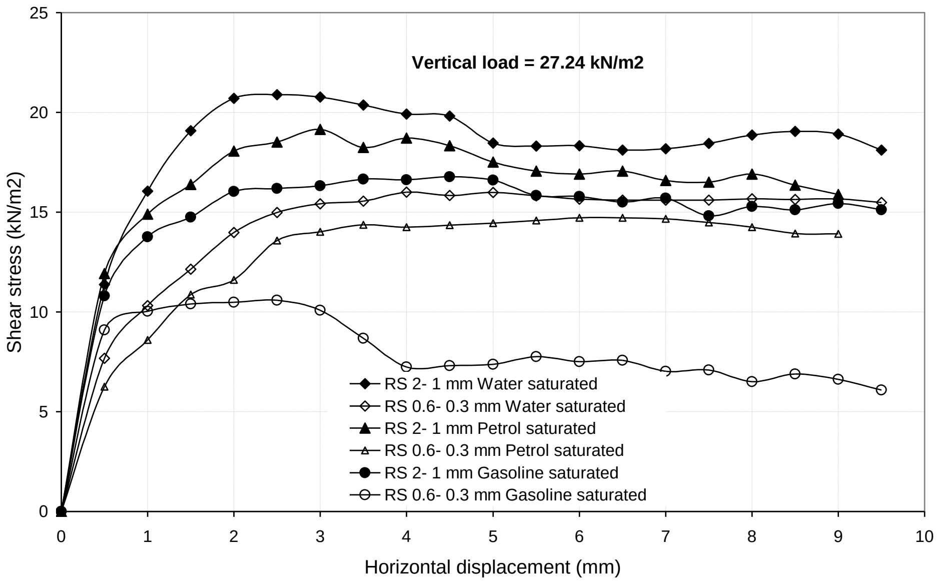

Figure 3. Stress- displacement for different particle size of RS specimens with different pore fluids

Figures 4 and 5 give the one dimensional consolidation testing results that were used to study of the change in void ratio of the various specimens with different pore fluids under the vertical stresses from 22,195 kPa to 710,24 kPa. There is significant effects of the pore fluid viscisity on the compressibility of the specimens tested. As can be seen from the Figure 4, initial void ratio (e_o) value of the different particle sizes (0.3 mm- 0.6 mm, 1.0 mm- 2.0 mm) of AS specimens saturated with gasoline is the highest, as those saturated with petrol is the lowest one. It is also seen that the particles having a larger size have less void ratio values than those having smaller size. Comparing the results given in the Figures 4 and 5, it is noted that e values in AS specimens are more than the e values determined in RS specimens. That could be because of an more open arrangement taken place in matrix of the angular particles.

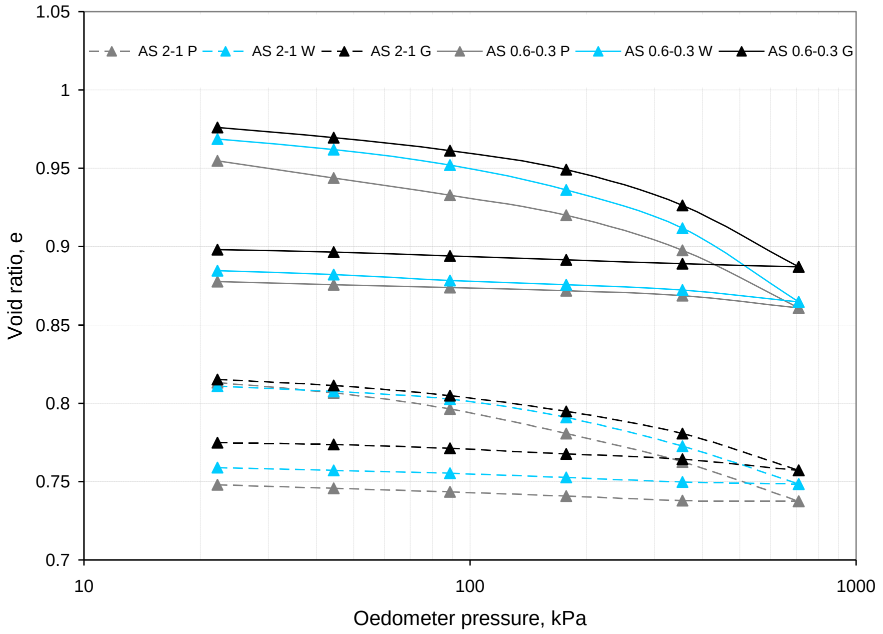

Figure 4. One-dimensional consolidation characteristics for different particle size of AS specimens saturated with different viscosity pore fluids (G: Gasoline, P: Petrol, W: Water).

Figure 5 presents the change in e values of the different particle sizes (0.3 mm- 0.6 mm, 1.0 mm- 2.0 mm) of RS specimens saturated with gasoline, petrol and water. As distinct from the previous Figure, higher e values were obtained in the RS specimens with water, and lower e values were obtained in gasoline as pore fluid. It is interpreted that it could be because of the presence of some AS grains having carbonate that could cause chemical reactions. Actually, it points out the importance of the mineralogy of geomaterials tested in various pore fluids.

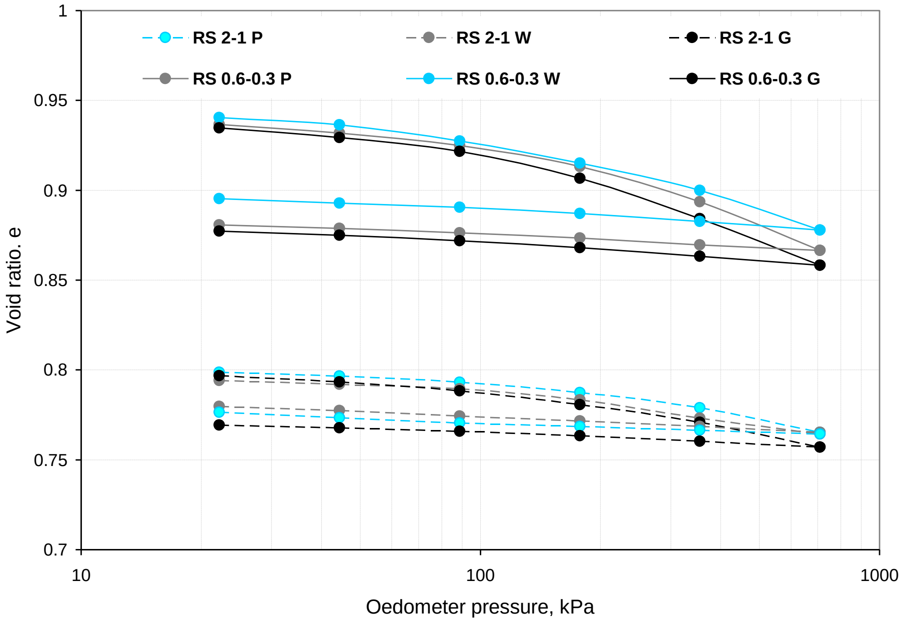

Figure 5. One-dimensional consolidation characteristics for different particle size of RS specimens saturated with different viscosity pore fluids (G: Gasoline, P: Petrol, W: Water).

4 CONCLUSIONS

The tests reported in this paper show the effects of various viscosity pore fluids (water, gasoline, petrol) to the behaviour of two different particle sizes (0.3 mm- 0.6 mm, and 1.0 mm- 2.0 mm) sands having distinct shapes (rounded and angular) tested in oedometer and direct shear testing equipments.

1. Internal friction angle (ϕ) of the sands tested here decrease as the pore fluid viscosity increases. A more decrease in the internal friction angle was observed in rounded shaped sand in all pore fluids types used (i.e., water, petrol, gasoline).
2. A significant difference in shear stress of both sands used was noted for different particle sizes of the sands.
3. Compression characteristics of the sands used were affected by the viscosity of pore fluids. Compressibility of the sands increases with increase in pore fluid viscosity, however in some cases, particularly in more viscous environment, the compressibility of the sands could decrease. This may be due to the mineralogy or arrangements of sand grains.

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