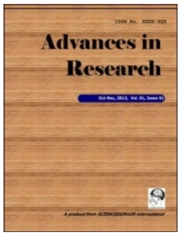

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Shear Behaviour of Sand with Fines

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

The aim in this paper is to present the comparison of results from the present study and published results for sand with fines (clay or silt) contents. The stress ratio and normalized peak deviator stress for sand-clay specimens are discussed, while the stress path and stress ratio of sand-silt specimens are presented, along with the data available for other types of sand with fines contents. It is found that the results from the present study are generally in agreement with the published results. The conditions of the tests undertaken for the soil specimens used for comparison purposes are similar.

Keywords: Mining sand; silt content; clay content.

1. INTRODUCTION

Active tin mining in Malaysia started since 19th century after the British colonization of the Malay Peninsula. These mining activities resulted in about 113,700 hectares of tin tailings in the western side of Peninsula, beginning in the north of Ipoh and stretching southward to

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Malacca [1,2,3]. The largest tin mining area is located at the State of Perak and Kuala Lumpur [1,3,4]. Tin tailings are waste lands with products of mining, which can be categorized in two fractions, namely sand tailing and slime tailing [2,4,5]. Sand tailing has very coarse textures, while slime tailing consists of very fine soils and minerals (silt and clay) with very compact structure [4,5]. The tin tailing areas are used for agricultural purposes, housing estates, aquaculture (ponds) and recreational parks [2,5]. The sand resources from these mining areas could be utilized for construction purposes. Therefore, mining sand is chosen as the host sand in the present study.

The understanding on the mechanical properties of clean mining sand with silt or clay content is essential to do realistic analyses on geotechnical problems involving these materials, especially in the ex-mining areas. The fines in natural soils could change the behaviour of host sand significantly [6,7,8,9,10,11]. It has been recognized that the existence of clay content affects the shear strength and compression response of sands [9,12]. On the other hand, silty sand has the tendency to dilate during shearing [13,14]. Sandy silt tends to decrease in pore water pressure and dilate due to increasing strains as the soil specimens are sheared [15]. Salgado [16] and Yang [17] discover that the presence of silt will enhance the strength of silty sands. Hence, the research on mining sand in Malaysia as host sand with different fines content is carried out in the present study. Mining sand is used as there is limited research done regarding this type of sand.

Several journals [18,19,20,21,22,23] have been published regarding the behaviour of sand with different fines (clay and silt), and thus, this paper aims to present the comparisons of experimental results with published results.

2. SOIL MATERIALS

The mining activities in Ipoh stretching towards Malacca in Malaysia resulted in tin tailings which consist of sand tailing and slime tailing. The sand tailing, termed as mining sand, is selected as the coarser grain matrix (host sand) in the present study and it consists of mostly silica.

The finer grain matrix used to mix with mining sand is either kaolin clay or silt. Kaolin clay has been processed to remove natural existing materials such as quartz, iron oxides and other clay minerals. Kaolin is white in colour, soft and mainly composed of fine-grained and plate-like particles. Kaolin clay is chemically hydrated aluminium silicate and structurally unmodified and it consists of mainly kaolinite minerals. The silt used in the present study is defined as high purity crystalline quartz filler with pH ranges from 5.6 to 7.5. It is a type of nonplastic silt that is composed of 99.8% silica (SiO_2), with 0.05% Aluminium Oxide (Al_2O_3) and 0.01% Iron Oxide (Fe_2O_3) as secondary components.

Fig. 1 shows the grain-size distributions of mining sand, silt and kaolin clay used in the present study. The mining sand used is angular. Its uniformity coefficient, C_u, and curvature coefficient, C_z, are 2.08 and 1.27, respectively. Mining sand is classified as well-graded soil. The median particle sizes, D_{50}, of mining sand and silt are 0.25 mm and 0.025 mm respectively.

Mining sand, silt and kaolin clay have specific gravities of solid particle of about 2.63, 2.65 and 2.69, respectively. The kaolin clay has a liquid limit of 61%, plastic limit of 34% and plastic index of 27%. Since both mining sand and silt are nonplastic, the liquid limit and plastic limit tests were not conducted on these nonplastic soil specimens.

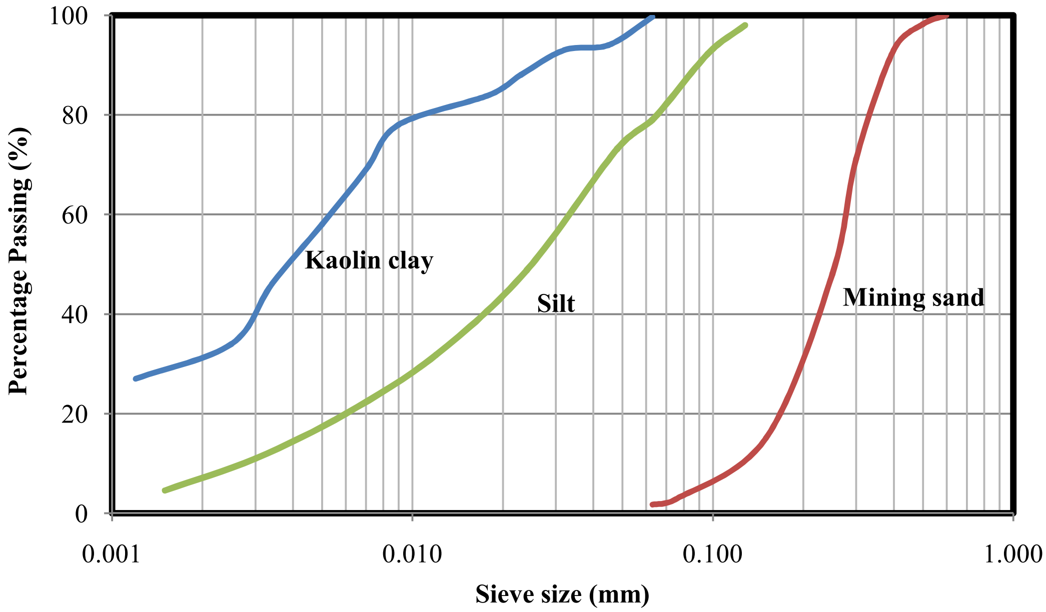


Fig. 1. Sieve analysis for mining sand, silt and kaolin clay

3. EXPERIMENTAL PROGRAMME

Soil specimens were prepared by first estimating the weights of desired sand and fines (clay or silt) contents. Then, the oven dried sand and different additives were manually mixed in dry state. The dry mixing process for the soil specimens were carried out until the mixtures were observed to be visually homogeneous. The soil specimens were prepared using dry-tamping method, which was performed by compacting the mixture in three equal layers to a required relative density (D_r) of 65% (medium dense) in the mold. The diameter and height of every soil specimen were measured to be 50 mm and 100 mm, respectively.

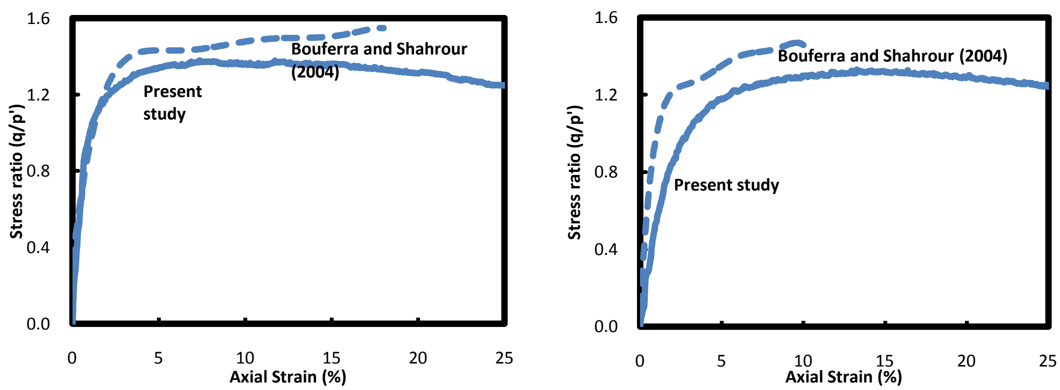
Isotropically consolidated undrained (CIU) tests were conducted on soil specimens using GDS VIS (Virtual Infinite Stiffness) triaxial equipment. Saturation was achieved by applying cell and back pressures. Full saturation of soil specimens was assumed to have taken place when Skempton's B-parameter was greater than 0.95. Soil specimens were isotropically consolidated to different confining pressures which were 100 kPa, 200 kPa and 300 kPa. The testing apparatus was computer-controlled, and the stress-strain data were recorded automatically. Undrained triaxial tests on soil specimens were carried out at axial strain rate of 0.4 mm/min. The shearing tests were discontinued at an axial strain (ε) of approximately 25%.

4. RESULTS AND DISCUSSION

4.1 Clayey Sand Samples (Houston-RF Sand)

In the undrained triaxial compression tests performed by Bouferra and Shahrour [24], the clayey sand specimens were reconstituted in laboratory by mixing various amounts of commercial kaolin clay (0%, 5%, 10%, 15% and 20%) with Houstun-RF sand. The kaolin clay contained 67% of silicates and 23% of aluminium hydroxide, and the Houston-RF (fine sand) with D_{50} of 0.47 mm was used commonly in France for academic research. The D_{50} of mining sand used in the present study is 0.25mm.

Fig. 2 illustrates the stress ratio (*q/p'*) comparison of sand-clay specimens with 0%, 10% and 20% clay content for the results of the present study and those performed by Bouferra and Shahrour [24]. The stress ratios of sand-clay specimens in the study used by Bouferra and Shahrour [24] are slightly higher than those in the present study, which could be due to the bigger sand particle size of Houston sand. However, in general, both the Houston-RF sand and mining sand specimens exhibit similar stress strain behaviour.



(a) Sand-clay with 10% clay content (b) Sand-clay with 20% clay content

Fig. 2. Comparison of stress ratio for sand-clay specimens

4.2 Sand-Clay Specimens (Standard 161 Sand)

In the experimental program performed by Abedi and Yasrobi [9], Standard 161 sand and a mixture of natural fines with bentonite in ratio of 3:1 were used as host sand and clay fines, respectively. The individual sand particle was angular with major minerals of silica, and categorized as poorly graded sand according to USCS. It had a uniformity coefficient, C_u, of 1.8. The clay fines mixture had liquid limit of 51, plastic limit of 21% and plasticity index of 30%. The host sand and mixture of clay fines had specific gravity of 2.67 and 2.7, respectively. Undrained monotonic triaxial compression tests were conducted on the host sand with mixture of clay fines content ranging from 0% to 30%, with a constant strain rate of 0.5 mm/min. The sand-clay specimens were prepared in initial dry density of 1.5 g/cm^3, with water content of 8% by weight. Saturation and consolidation of sand-clay specimens before triaxial loading were performed.

Fig. 3 displays the experimental results of normalized peak deviator stress ($q_{max}/q_{max(sd)}$) for sand-clay specimens subjected to initial confining pressure of 100 kPa, in comparison with published results presented by Abedi and Yasrobi [9]. The normalized peak deviator stress for both sand-clay specimens decreases as the clay content increases because the clay fines can break the load bearing chain (disperse the coarse grain further away) of sand-clay specimens which results in a decrease in peak strength [8]. Excess pore pressure generated during compression in sand-clay specimens also leads to a decrease in peak strength [7,9].

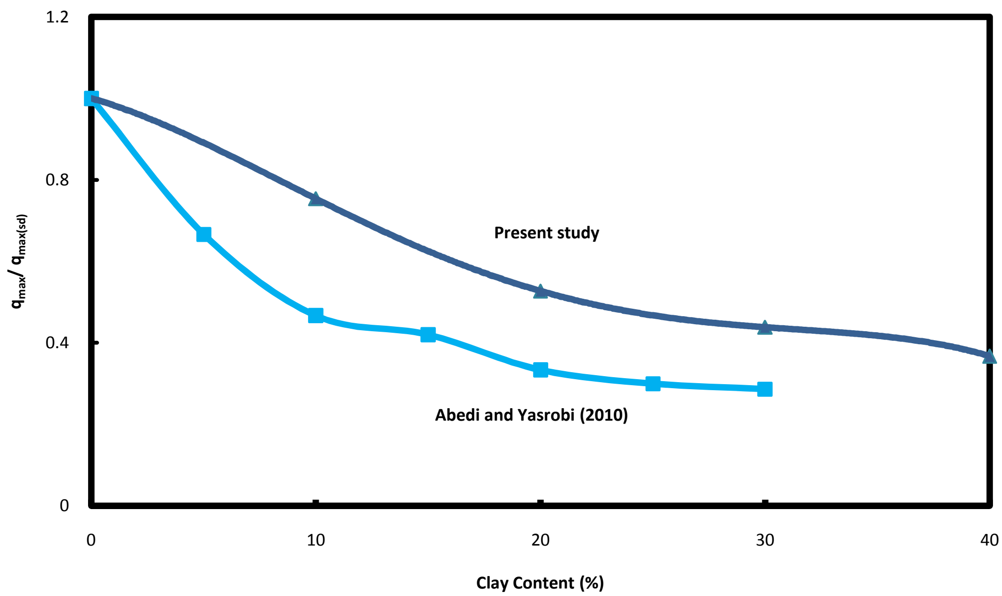


Fig. 3. Comparison of normalized peak deviator stress for sand-clay specimens

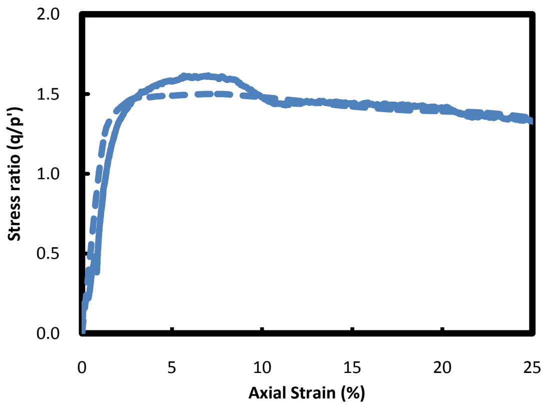
4.3 India Silty Sand Samples

Sitharam [25] used two types of sand-silt specimens (termed as Soil Sample-1 and Soil Sample-2) which were collected from two locations close to Kutch area, Gujarat State in India. Strain-controlled, monotonic undrained triaxial tests were performed on isotropically consolidated soil specimens with an axial strain rate of 0.6 mm/min. The sand-silt specimens were medium dense and contained 20% silt at confining pressures of 100 kPa, 200 kPa and 300 kPa.

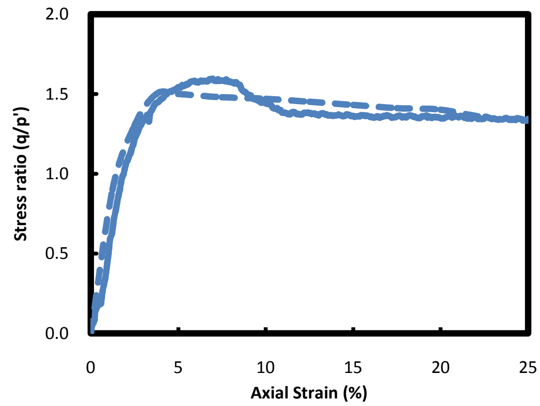
The comparisons of results for sand-silt specimens (20% silt content) subjected to different confining pressures are presented in Fig. 4. The magnitudes of stress ratio (*q/p'*) for both types of sand-silt specimens are almost similar. However, in the present study, the sand-silt specimens show strain softening behaviour, because the mining sand used in the present study is dilative and dominant over the behaviour of specimens. Fig. 5 shows the stress paths for both sand-silt specimens. The stress paths of sand-silt specimens indicate tendency of the specimens to dilate. The silt content in the sand-silt specimens enhances the strength of sand-silt specimens.

4.4 New Zealand Sand-Silt Mixtures

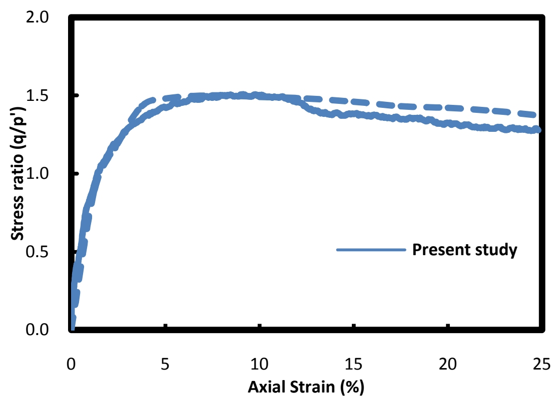
The sand-silt specimens used in the study of Rees [26] was obtained from Fitzgerald Bridge, New Zealand. These original sand-silt specimens were classified as clean to silty sands, with fines contents of 1 – 12%. In order to perform tests on clean sand, sandy soil was separated into clean sand and fines components using dry sieving. The plasticity test in accordance to Standards Association of New Zealand (1986) revealed that the silt fines were nonplastic. Monotonic undrained triaxial compression tests were performed on clean sand with 0%, 10%, 20% and 30% silt contents.



(a) σ'_c = 100 kPa



(b) σ'_c = 200 kPa



(c) σ'_c = 300 kPa

Fig. 4. Comparison of stress ratio for sand-silt specimens with 20% silt content at different confining pressures

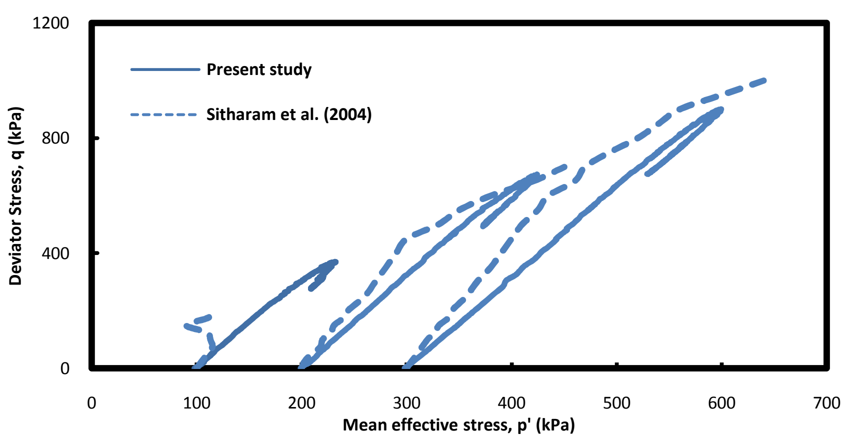
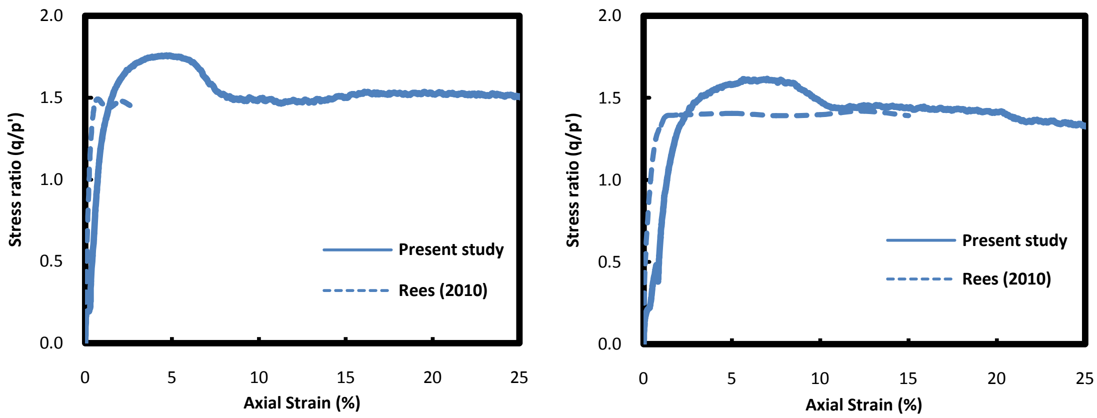


Fig. 5. Comparison of stress paths for sand-silt specimens with 20% silt content at σ'_c = 100 kPa, 200 kPa and 300 kPa

Fig. 6 shows the present and Rees [26] results on stress ratio (*q/p'*) versus axial strain relationship for sand-silt specimens with 10% and 20% silt contents at confining pressure of 100 kPa. The experimental results of Rees [26] reach the peak of stress ratio at lower axial strain. The sand-silt specimens in the present study yield almost similar residual strength as compared to those by Rees [26]. The sand-silt specimens in the present study show strain softening behaviour. However, the published results by Rees [26] did not exhibit significant strain softening as shown in Fig. 6(b).



(a) Sand-silt with 10% silt content (b) Sand-silt with 20% silt content

Fig. 6. Comparison of stress ratio for sand-silt specimens with different silt contents (σ'_c = 100 kPa)

5. CONCLUSION

The results of the present study for sand-clay and sand-silt specimens are compared with some available published data in literature. In general, the stress ratios of sand-clay and sand-silt specimens in the present study are consistent with those shown in published results. The normalized peak deviator stress ($q_{max}/q_{max(sd)}$) of sand-clay specimens decreases with clay content as clay fines break the load bearing chain of sand-clay specimens. The development of positive excess pore pressure during compression in sand-clay specimens also decreases their peak strength. On the other hand, the stress paths of sand-silt specimens indicate the dilatancy of the specimens. The silt content enhances the strength of sand-silt specimens.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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