academicJournals

Vol. 4(7), pp. 232-238, Julyl, 2013
DOI 10.5897/JCECT12.025
ISSN 1996-0816 © 2013 Academic Journals
http://www.academicjournals.org/JCECT

Journal of Civil Engineering and Construction Technology

Full Length Research Paper

Effect of fines mineralogy on the oedometric compressional behavior of sandy soils

K. Lupogo

Department of Geology, College of Natural and Applied Sciences, University of Dar es Salaam, P. O. Box 35052, Dar es Salaam Tanzania.

Accepted 12 December, 2012

Oedometer tests have been performed on reconstituted samples prepared to study the consolidation behavior of sandy soils. The influence of fines content and type can be determined with oedometer test by utilizing intergranular void ratio. Result shows that, up to transition fines content, compression behavior of the mixtures is mainly controlled by the sand grains. When concentration of fines exceeds transition fines content, fines controls the compression. The transition fines content varies between 15 and 35% regardless of fines mineralogy. This range of fines content is also consistent with various values reported in literature regarding the strength alteration. It can be conclude that the presence of fines on sand does not increase the compression of the sand but it is improving it. Therefore for mixtures with fines content above 10% between 15 to 35% are useful for reclamation activities because of their low oedometer compression.

Key words: Silty sand, fines, fines content, oedometer, compression.

INTRODUCTION

Fines are often encountered in dredging reclamation works. The presence of fines in sandy soil is generally recognized as a problem in geotechnical engineering as it is believed in dredging practice and tendering that soil containing fines is more compressible and increases tendency to creep.

The occurrence of fines in sandy soil may be due to degradation of material during dredging processes and due to an increase shortage of clean sandy soils near the project locations the use of mixed sand, which includes silty sand, clayey sand, sandy clay and sandy silt in reclamations works will be a viable option.

It has been pointed out by Mitchell (1993) that the fines content in sandy soils have a major influence on engineering properties such as strength and stiffness, resistance to liquefaction, volume change behavior and hydraulic conductivity.

In dredging reclamation works, sandy soils with different fines contents are often encountered. The amount of fines in the fill material depend on dredged material, applied loading method, transport method and placement method. Therefore, the fines contents of the fill material can vary widely from a project to project and even within a single reclamation work. The influence of the variation of amount fines content on the engineering properties of sandy soil is not well understood. As practice in dredging and reclamation works, mostly the fills are constructed with material, which differ fundamentally from clean sand. The presence of fines in sandy soil is assumed to increase the compressibility of fill material.

It has been noticed that volume change behavior of these types of materials, especially compressibility problems have not been studied systematically in the laboratory level (Monkul et al., 2007). This study will focus more on compressibility of sandy soil as

E-mail: kennlupogo@udsm.ac.tz.

influenced by type of fines and variation of fines contents.

The parameters influencing the mechanical behaviour of sandy soils under stress conditions have been extensively studied by Amini and Qi (2000), Naeini and Baziar (2004), Della et al. (2009), Sharafi and Baziar (2010) and Belkhatir et al. (2012). The influence of laboratory initial conditions such as the relative density, the degree of saturation, the sample preparation method, the overconsolidation ratio and the stress ratio are well understood. However, the influence of other parameters such as the minarealogy of fines, the structure, size and shape of the grains are incomplete and requires further investigation.

Martins et al. (2001) noted that the presence of fines avoids obtaining a unique compression line for a particular coarse grained soil. Moreover, they stated that a new framework is needed for sandy soil which do not behave in accordance with the general compression behavior describe for other soils in literature. Fukue et al. (1986) studied the consolidation behaviour of mixture of sand and clay. They described that the compressibility decreases strongly if the void ratio of sand reaches a given value, defined as the threshold sand void ratio. During consolidation, the clayey part dominates the consolidation properties of the mixture until the sand content reaches the point where sand grains come into contact with each other. If the mixtures are compacted beyond the threshold void ratio, the soil has very low compressibility. The void ratio of the sand skeleton in this state was mentioned to vary between 1.25 and 1.4. The mixtures will have low compressibility and high strength because the friction resistance and cohesion are expected to increase during consolidation or shearing in this range of void ratios. Generally, mixtures or soils behave like sand with properties of fines in this range of void ratio.

Fukue et al. (1986) mentioned the advantages of using sand–clay mixtures for reclamation of embankments if the proper mixture can be found. These advantages are: 1) a cohesion can be expected and may reduce the liquefaction potential, 2) in terms of settlements, compressibility may be as low as that of sand or gravel, 3) most of the displaced soft sediments can be used in mixtures, 4) soil containing certain amounts of clay can also be used for reclamation if they satisfy the new standard for materials.

Monkul et al. (2006) studied the compression behavior of clayey sand and transitional fines contents. He concluded that the compressional behavior of clayey sand can be determined by oedometer test and by utilizing the intergranular void ratio rather than the global void ratio. For a given initial condition and predetermined stress, one dimensional compression of clayey sand is controlled by the coarse grain matrix up to the transitional fines content. For soils containing fines greater than transitional fines content, the compression is controlled by fine grain matrix. He described that the transition fines content is independent of the minimum void ratio.

Transition fines content can be defined to be between 19 to 34% .These studies can be considered as pioneering studies for the consolidation behaviour of sand–clay mixtures and for classification of such materials.

The objective of the present study is to systematically investigate the compressional behavior of sandy soil under the influence of different clay types from the perspective of Equivalent grain void ratio concept by defining the transition fines content and granular compressional index parameters. Influence of fine content and stress condition has been studied by means of oedometer test on reconstituted fines-sand mixtures.

Void ratio and sandy soils texture

The evaluation of the initial soil state is very important for studying the mechanical behavior of granular soils. There are several possibilities to define the initial state of granular soils, the most common parameters are the intergranular void ratio (), the interfine void ratio (), the global void ratio () and the relative density ().Void ratio and relative density are common but others are specific for sand with fines.

Mitchell (1993) introduced the use of the skeleton void ratio or granular void ratio, whereas Thevanayagam et al. (2000) introduced the use of the intergranular void ratio to study the behavior of soil that contains coarse and fine particles. The parameters intergranular void ratio, granular void ratio, or skeleton void ratios are based on the same concepts (Yang, 2004; Monkul et al. 2007; Rahman et al., 2008). These parameters are calculated by considering the fines as voids.

The intergranular void ratio is a more representative packing index to correlate sand-like properties. A formulation of intergranular void ratio by Thevanayagam (2000) can be represented as:

$$e_s = \frac{e + fc}{1 - fc} \quad (1)$$

Where *e* is global void ratio, - fine content. The use of the intergranular void ratio is limited to soils with fines content below the threshold fines content (TFC) which is between 20 to 30% as pointed out by different authors (Thevanayagam, 1998; Ni et al., 2004; Yang, 2004; Rahman et al., 2011). At higher fines content (relative to the void space), the fines begin to participate in the force structure. Therefore, Thevanayagam et al. (2002) proposed the use of equivalent granular state parameter, e_s defined by Equation (2) below as a better alternative state to *e*:

$$D_r = \frac{e_{\max} - e}{e_{\max} - e_{\min}} \quad (2)$$

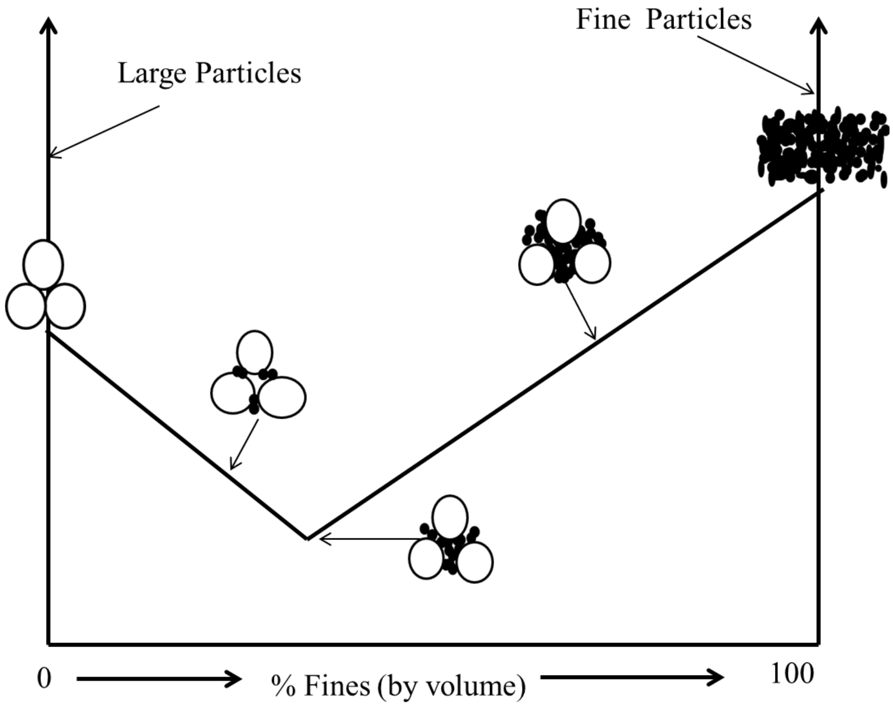

Figure 1. Schematic explanation of silt sand mixture (Lade and Yamamuro, 1998).

where, b represents the fraction of fines that are active in force structure. The basic assumption of behind Equation (2) requires. The e_s was also being referred to as, equivalent inter-granular contact void ratio (Thevanayagam et al., 2002), corrected intergranular void ratio (Yang et al., 2006b), equivalent inter-granular contact index void ratio (Thevanayagam, 2007), equivalent granular void ratio (Rahman and Lo, 2008b; Rahman et al., 2008, 2011).

In Figure 1, the evolution of the void ratio is shown for different fines contents. There are three zones between the two extremes for sand silt mixtures. When the silt content is about 10 to 20% the sand behavior is dominant. The second zone applies for approximately 25 to 45% of silt for which the silt skeleton is replacing the sand skeleton. In this case the silt particles fill the sand voids, which leads to a considerable decrease of the void ratio and neither the sand nor the silt can play its own role as they do alone. The third zone applies for a higher percentage of silt content for which the silt behavior dominates (Bahadori, 2008). Thevanayagam and Mohan (2000) worked on quartz sand with different contents of plastic fines, and they concluded that a fines content between 20 and 30% in a coarse grain matrix defines the transition between the two types of behavior. For a fines content of 10% or lower, the coarse–grained matrix dominates the compressibility and for fines contents of 40% or higher the fines dominate the behavior. It can be concluded that, the transition behavior of the mixed sand-fines mixture is somewhere between 25 and 45%. It is expected that at this range of fines contents the mixture will have a low void ratio and a low compressibility.

MATERIALS AND METHODS

To get undisturbed mixed samples from field for laboratory testing is difficult. An alternative approach is to test reconstituted samples obtained by mixing sand with various quantities of fines. Four types of materials were used. The host sand consists of a blend of two types of sand. Coarse quartzic sand from the river Maas was mixed with artificially (crushed) quartz sand produced by Sibelco LM25 in a proportion of 2 to 1. In the first series of tests (series A), the filler material was a quartz flour also produced by Sibelco by iron-free grinding of selected quartz sand with a high silica-content in ball- or vibration mills and control of particle size. The flour is commercialized under the name of M10. In the second series of tests, fines were sampled above a sand quarry in Bierbeek nearby Leuven, Belgium. The Belgium silt belongs to an Eocene loess deposit that lies above the sand of Brussels formation.

The index parameters of sand and fines mixtures shown in Table 1 were determined by means of sieve, hydrometer, specific gravity and consistency limit tests. These tests were performed in accordance with British standards (BS-1377, 1990). Maximum void ratio (e max) of sand was obtained by pluviation of sand grains into a mold of known volume filled with water.

Sand – fines mixtures were prepared on dry weight basis using oven dried sand and fines which were thoroughly mixed. Therefore, the fines content (FC) refers to the percentage of fine grains in total weight of solids. The sand – fines mixtures were mixed manually in dry state. The mixing process continued for 10 to 15 min, until the mixtures are observed to be visually homogeneous. Then the mixtures were inundated to desired water content soaking period of 24 h. After soaking period, wet mixing was performed for 15 min in such a manner that sand grains were dispersed in mixture

Table 1. Characteristics of the mixtures of artificial silt and Belgium silt.

Material fines content (%)	Specific gravity (g/cm^3)	Coefficient of uniformity	D10 (mm)	D30 (mm)	D50 (mm)
		Artificial silt			
Host sand	2.65	1.21	0.75	0.85	0.9
7	2.67	100.00	0.018	0.7	1.23
10	2.67	175.00	0.01	0.5	1.22
15	2.67	269.23	0.0065	0.25	1.21
20	2.67	309.09	0.0055	0.08	1.2
25	2.67	340.00	0.005	0.025	1.2
30	2.67	326.53	0.0049	0.01	0.9
50	2.67	111.11	0.0045	0.005	0.01
Host silt	2.67	10.00	0.002	0.006	0.0105
		Belgium silt			
Host sand	2.65	1.21	0.75	0.85	0.9
7	2.67	16.67	0.108	1	1.23
10	2.67	17.50	0.1	0.8	1.22
15	2.67	116.67	0.015	0.6	1.21
20	2.67	154.55	0.011	0.35	1.2
25	2.67	157.41	0.0108	0.2	1.2
30	2.67	158.42	0.0101	0.1	0.9
50	2.67	71.43	0.007	0.025	0.1
Host silt	2.67	6.67	0.006	0.02	0.032

uniformly and segregation was prevented.

Oedometer samples were tested in 7.5 cm diameter rings. Care was taken in order to avoid air entrapment during placing sample into rings. For all samples the degree of saturation is 0.95. Loadings were initiated from 3.5 KPa and terminated at 1108.3 kPa. It was found in preliminary tests that primary consolidation had been already completed in 2 h. Therefore, loading duration was set at 2 h in accordance with ASTM standard D 2435-96 method.

The initial water content, initial global void ratio and initial intergranular void ratio of the samples for both sets are given in Table 2.

RESULTS

Relationship between effective stress and vertical strains

The relationship between effective stress and vertical strains for the different materials tested at different relative densities and fines contents is shown in Figure 2. The artificial silt mixtures were tested at an assumed relative density of 50% the slope of their virgin compression curves do not show any trend as function of fines content. The Belgium silt mixtures were tested at an assumed relative density of 50%; the compression line steepness increases with an increase in fines content. Figure 3 shows the relationship between void ratio and vertical effective stress. The initial void ratios are as expected, considering the targeted void ratios.

DISCUSSION

The main objective of this study was to understand the effect of fines mineralogy and fines content on the compressibility of sandy soil and including the change on the void ratio and compressive index.

Equivalent grain void ratio concepts

Intergranular void ratio concept employ the concept of using the void ratio created by the granular material and considers the fines as voids. Based on this concept the influence of fines on the compressibility of sand silt mixture can be depicted.

Figure 4 shows variation of Equivalent grain void ratio with vertical effective stress. These curve have similar features as those plotted for vertical effective stress as function of void ratio. However, using intergranular void ratio the curves are shifted in position but the nature of deformation of the sample remain the same.

Monkul and Ozden (2005) introduced the concept of transition fines content as fines content at which contact between grains occurs. In this concept, it is assumed that direct grains contacts of coarse grains can be initiated when intergranular void ratio of the mixture become equal to the maximum void ratio of the host granular material. Transition fines content is determined by intersection of

Table 2. The initial water content, initial global void ratio and initial intergranular void ratio of artificial silt and Belgium silt.

Sample	Silt (%)	Minimum void ratio	Maximum void ratio	water content	Initial density (kg/m^3)	Dry density (kg/m^3)	Initial void ratio	Relative density (%)
Artificial silt								
A10	10	0.318	1.046	0.20	1932.9	1610.8	0.651	54
A11	10	0.318	1.046	0.20	1752.2	1642.7	0.619	59
A12	15	0.276	0.867	0.21	2065.6	1700.4	0.564	51
A13	20	0.201	0.734	0.18	2175.0	1843.2	0.443	55
A31	20	0.201	0.734	0.17	2120.7	1812.6	0.468	50
A14	25	0.171	0.781	0.20	2147.8	1789.8	0.486	48
A32	25	0.171	0.781	0.18	2126.4	1802.1	0.476	50
A15	30	0.16	0.783	0.17	2143.5	1786.2	0.489	47
A16	30	0.16	0.783	0.17	2143.5	1786.2	0.489	47
A33	30	0.16	0.783	0.18	2115.2	1792.6	0.484	50
A17	50	0.233	1.323	0.20	1901.5	1584.6	0.679	59
A18	50	0.233	1.323	0.20	1901.5	1584.6	0.679	59
A34	50	0.233	1.323	0.29	1929.6	1495.8	0.778	50
Belgium silt								
B1	7	0.318	1.046	0.20	1932.9	1610.8	0.651	54
B2	10	0.318	1.046	0.20	1752.2	1642.7	0.619	59
B3	15	0.276	0.867	0.21	2065.6	1700.4	0.564	51
B4	20	0.201	0.734	0.17	2120.7	1812.6	0.468	50
B5	25	0.171	0.781	0.18	2126.4	1802.1	0.476	50
B6	30	0.16	0.783	0.18	2115.2	1792.6	0.484	50
B7	50	0.233	1.323	0.29	1929.6	1495.8	0.778	50

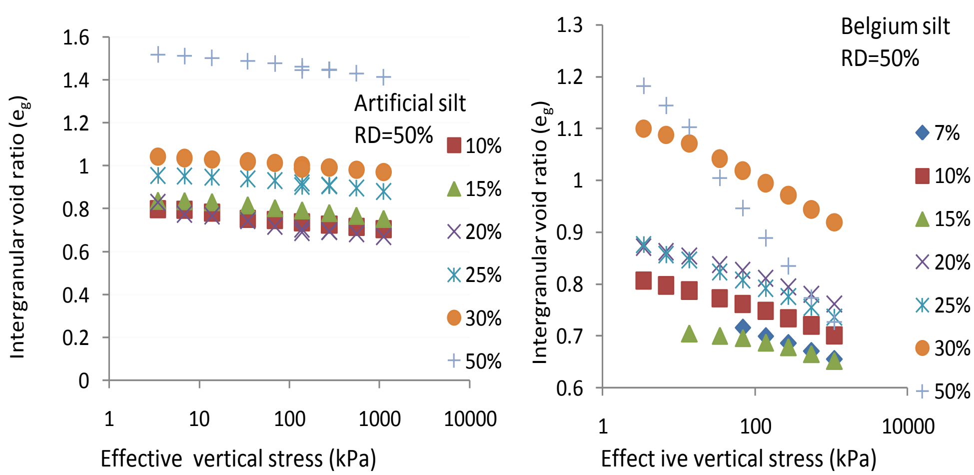

Figure 2. Relationship between vertical strain and effective vertical stress.

maximum void ratio line with intergranular void ratio against effective vertical stress curves.

Granular compression index ($C_{c\text{-}s}$)

The granular compression index ($C_{c\text{-}s}$) was introduced by Monkul and Odzen (2005). The importance of this parameter is on depicting the compressional characteristics of the silt sand mixture. The definition of $C_{c\text{-}s}$ is similar to the definition of compression index Cc and is expressed based on the decrease of Equivalent grain void ratio with effective stress increment as in Equation 3.

$$C_{c-s} = \frac{\Delta e}{\Delta \log \sigma'} \quad (3)$$

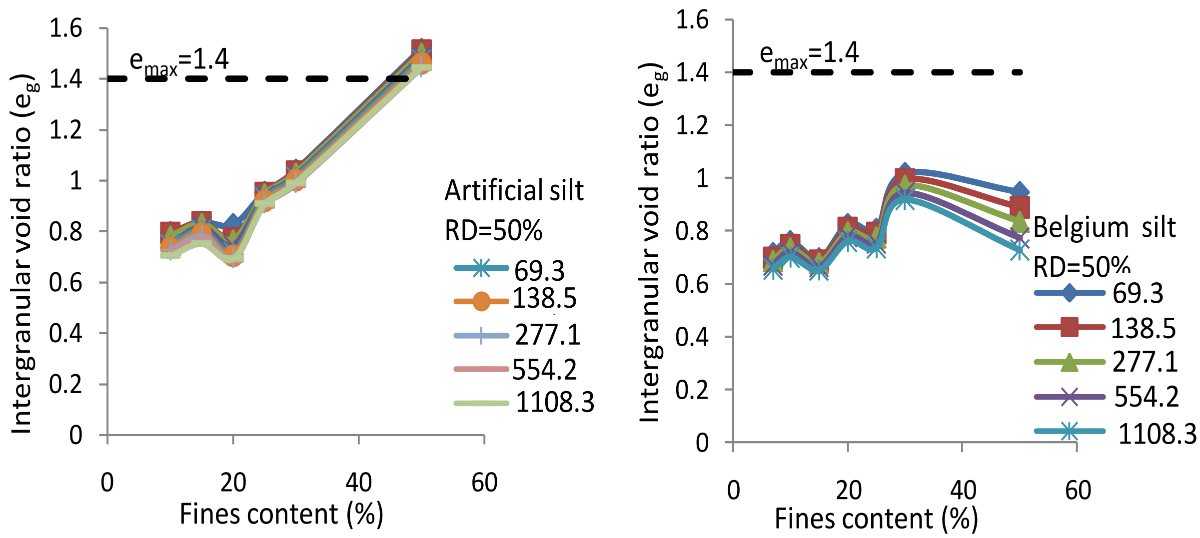

Figure 3. Relationship between void ratio and effective vertical stress.

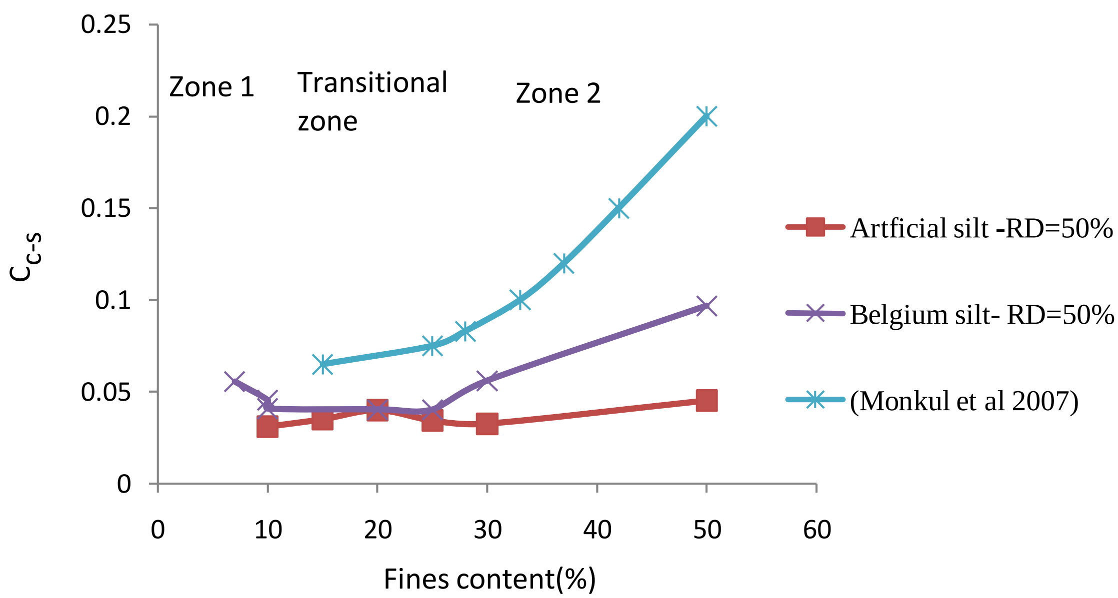

Figure 4. Relationship between equivalent grain void ratio and effective vertical stress.

Figure 4, shows relationship between C_{c-s} and fines content.The trend observed in these curve is the same as those shown in the figure showing relationship between Cc and fines content. Relationship between C_{c-s} and fines contents it shows clear the influnce of fines n compressibility as one can see from Figure 4. Mixtures with fines content below 10% Cc-s decrease with increase fines content while for mixture between 10 and 25% have low C_{c-s} values while for mixture above 25% C_{c-s} values increases with and increase in fines content. Tested material show to have low Cc-s compared to material tested by Monkul et al. (2007) as it can be observed in the Figure 4. This can be due to the difference in mineralogy and grain sizes in the mixtures.Relationship between Cc-s and fines contents does shows clear differences at higher fines content for Artifical silt and belgium silt.

There are three zones can be observed in Figure 4 (that is, zone 1, transitional zone and zone 2). In zone 1, the coarse grain matrix can be assumed to have almost a continuous framework with grain to grain contacts and fines are mostly located in the intergranular voids and in the contacts between the grains, as load applied the fines at the contacts tends to move and fill the intergranular voids, hence compressive behavior decrease with increase in fines contents in this zone. In transition zone, all fines available fill the intergranular voids and hence forming the continuous framework with grains to grain contact. In zone 2, as fines increases, sand grains become more dispersed so that there exist almost no grain contact and therefore the compressibility of the soil continues to increase and it is controlled by the finer grain matrix.

Conclusion

Oedometer tests have been performed on reconstituted samples prepared in laboratory to study the consolidation behavior of sandy soils. The influence of fines content and type can be determined with oedometer test by utilizing intergranular void ratio.

For a given initial condition and predetermined stress, one dimensional compression behavior of sandy soils is mainly controlled by coarser matrix up to transition fine content. This behavior does not depend on the type of fines and it is almost the same for both plastic fine and non-plastic fines. For both type of fines , at transitional fines, content (15 to 30%) the packing density is higher resulting to lower compression and for Belgium silt sand mixtures compression is relative high compared to artificial silt sand because its mineralogical contents. For soils containing fines greater than transition fines content, the compression behavior is controlled by finer grains matrix regardless of fines types.

Results show that mineralogy has influence on size and shape of fines which also accounts for differences in compressibility between these two materials. The difference in compressibility between mixtures of artificial silt and mixtures of Belgium is that due to mineralogical compositional of the silts. In mixtures of artificial, the silt used was pure crushed quartz while the mineralogical composition of Belgium silt contains quartz, kaolinite, mica and calcite. The presence of the mica in Belgium mixtures for higher fines contents act as lubricant because of its flexible sheet structure which deform easily under loading. As a result, Belgium silt is more compressible as fines content increases above transitional fines content.

ACKNOWLEDGEMENTS

The authors greatly appreciate the support of TUDelft and Boskalis Dredging Company for partially funding this study. Dr. Dominic Ngan–Tillard and Co. are acknowledged for their valuable suggestions, continuous concern and steady assistance. The author also acknowledges Mr. Wim Vaal for his assistance in the experimental program.

REFERENCES

Bahadori H, Abbas G, Towhata I (2008). Effect of non-plastic silt on the anisotropic behavior of sand. Soils Found. 48:531-545.

Belkhatir M, Arab A, Della N, Missoum H, Schanz T (2012). Experimental Study of Undrained Shear Strength of Silty Sand: Effect of Fines and Gradation. Geotechnical and Geological Engineering. Available at: http://rd.springer.com/article/10.1007/s10706-012-9526-1 [Accessed August 12, 2012]

Della N, Arab A, Belkhatir M, Missoum H (2009). Identification of the behavior of the Chlef sand to static liquefaction. J. Comp. Rendus Me´canique (CRAS) 337:282–290.

Fukue M, Okusa S, Nakamura T (1986). Consolidation of sand-clay mixtures. Consolidation of soils, ASTM Special technical Publication 892, R.N Yong and F.C Townsend, pp. 627-641.

Mitchell J (1993). Fundamentals of Soil Behavior. New York: John Wiley & Sons, Inc.

Monkul M, Ozden G (2007). Compressional behaviour of clayey sand and transition fines content. Eng. Geol. 89:195-205.

Naeini SA, Baziar MH (2004). Effect of fines content on steady state strength of mixed and layered samples of a sand. Soil Dyn. Earthq. Eng. 24:181-187.

Ni Q, Tan T, Dasari G, Hight D (2004). Contribution of fines to the compressive strength of mixed soils. Geotechnique 54:561-569.

Rahman M, Lo S, Gnanendran C (2008). On equivalent granular void ratio and steady state behaviour of loose sand with fines. Can. Geotechn. J. 45:1439-1456.

Rahman M, Robert LO (2011). Effects of fines and fines type on undrained behaviour of sandy soils under critical state soil mechanics framework. In World Scientific Publishing Co. Pte. Ltd., pp. 403-408. Available at: http://www.worldscientific.com/doi/abs/10.1142/9789814365161_0050 [Accessed August 5, 2012].

Rahman M, Lo SR (2008b). "The prediction of equivalent granular steady state line of loose sand with fines." Geomech. Geoeng. 3(3):179-190.

Sharafi H, Baziar MH (2010). A laboratory study on the liquefaction resistance of Firouzkooh silty sands using hollow torsional system. EJGE 15:973–982.

Thevanayagam S, Shenthan T, Mohan S, Liang J (2002). Undrained fragility of clean sands, silty sands and sandy silts. J. Geotechn. Geoenviron. Eng. 128:849-859.

Thevanayagam S (2007). “Intergrain contact density indices for granular mixes: Framework.” J. Earthq. Eng. Eng. Vib. June.

Thevanayagam S, Mohan S (2000). Intergranular state variables and stress-strain behaviour of silty sands. Geotechnique 50(1):1–23.

Yang S (2004). Characterization of properties of sand-silty mixture. PhD thesis.

Yang S, Sandven R, Grande L (2006). Steady-state lines of sand-silt mixture. Can. Geotech. J. 43:1213-1219.