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Physical Modelling in Geotechnics

Consolidation behavior of diatomite and characterization methodology

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ABSTRACT: This paper presents the results of an experimental program in order to study about the compressibility behavior of diatomite and to determine when the primary consolidation of diatomite ends. Standard one-dimensional consolidation test was performed on endmember soils such as silica silt, kaolinite, and diatomite. In this experiment, time-dependent consolidation curve of diatomite was evaluated using various methodology analysis. The tests that were conducted on kaolinite shows curve that can distinguish between primary and secondary consolidation clearly on semi-log time scale graph. On the other hand, consolidation experiments on diatomite show a not well-defined trend, hence, the end of primary consolidation was not obvious. Immediate elastic settlement of diatomite at low pressure is approximately 15% in the total settlement while silica silt, which has similar chemical compositions but different particle morphology, shows approximately 60% immediate settlement in the total settlement.

Keywords: Compressibility, Consolidation, Diatomite, Time-rate behavior

1 INTRODUCTION

Diatomite is fine-porous rocks which is made from fossilized diatoms. It mainly consists of extremely small frustules (Ivanov and Belyakov, 2008). The frustules are generally symmetrical and have void that can store water (Zhang et al., 2003). While there are various diatom species, thus, the number of their frustules and their large fragments vary greatly, diatoms are generally divided into two categories based on their frustule shape: centric diatom which has discoid frustule shape, and pennate diatom with elongated symmetry frustule shape (Round et al., 1990; Subhash et al., 2005; Ivanov and Belyakov, 2008). Large diatomite deposit can be found mostly in marine sediments. Also, due to volcanic activity, diatomite can be found in lake or coastal areas where silica content is high.

The diatoms-dominated marine soil displayed unusual behaviour compared to the other inorganic mineral soils (Shiwakoti et al., 2002). In design considerations, soil compressibility characteristics is one of the important parameters. Soil compressibility is affected by many factors such as water content, dry density, strain rate, sample disturbance, mineralogy of soil, duration of loading increment, and stress history (Sridharan et al.,1994). Previous studies of consolidation tests were conducted based on either ASTM D2435 (2004) or BS 1377 – part 5 (1990) which load increment is applied to the soil sample be held constant for a particular duration until the completion of excess pore water dissipation is completed. However, the completion time of primary consolidation is unique for every soil type.

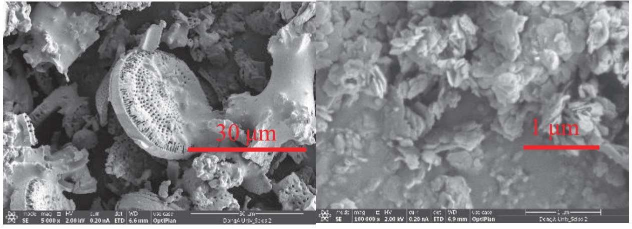
On the compressibility of diatomite, Shiwakoti (2002) mentioned that consolidation mechanism of diatomite is complex. Unlike other soils, diatomite, which each particle is a skeleton with huge void space, when loading is applied, the breaking mechanism of diatomite contributes greatly on the soil deformation, adding another significance on the role of mineralogy on soil compressibility. Thus, special attention is needed on design where the diatomite content is found.

Due to the unique characteristics and the abundance of diatomite in marine sediment, we study the compressibility behavior of diatomite-dominated soils to provide proper design parameters for offshore structure construction. In order to understand the compressibility behaviour of diatomite, one-dimensional consolidation test was conducted on diatomite, silica silt, and kaolinite and compare the behavior between each other.

2 METHODOLOGIES

2.1 Material Properties

The tests were conducted on silica silt, diatomite, and kaolinite powder that commercially available.



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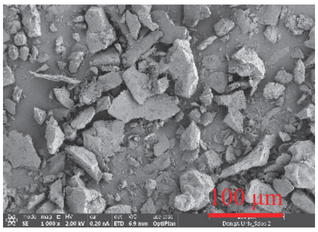

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Fig. 1. Scanning electron microscope: a. Diatomite, b. Kaolinite, and c. Silica silt.

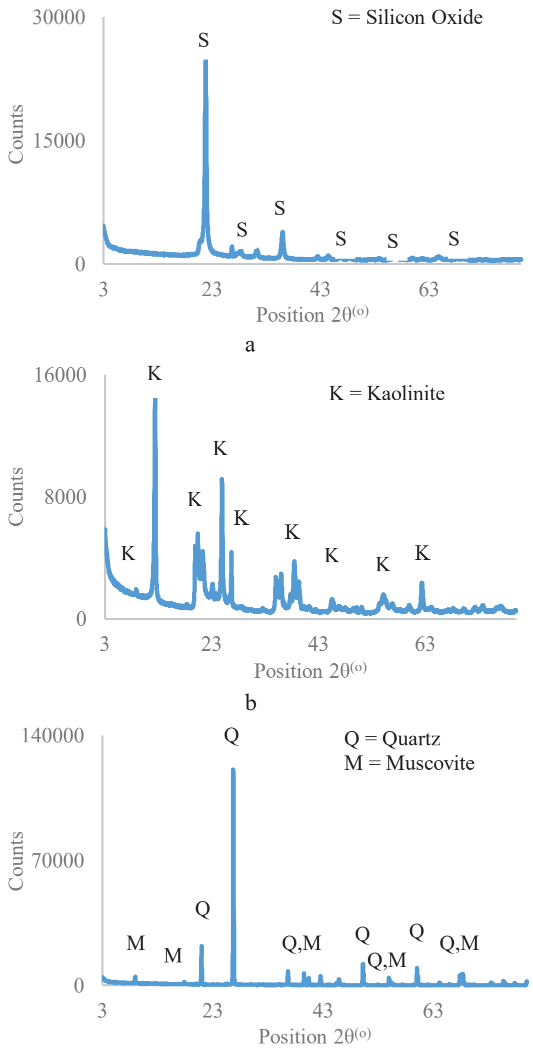

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Fig. 2. X-ray diffraction graphics of: a. Diatomite, b. Kaolinite, c. Silica silt.

Table 1. Material properties

Parameter	Unit	Diatomite	Kaolinite	Silica Silt
Specific Gravity (G_s)		2.26	2.6	2.58
Average Particle Size (D_{50})	µm	21	19	50
Liquid Limit (*LL*)	%	153.7	62.4	33.1

Diatomite is microfossil algae that inhabit both marine and fresh water (Subhash et al., 2005). The shape of diatom frustule is disk-like shape with huge void space which is shown by the result from scanning electron microscope (SEM) (Fig.1a). X-ray diffraction test (XRD) shows that diatomite is mostly consist of silica oxide that indicates the content of diatom frustule (Fig.2a). In case of kaolinite, the SEM picture shows a relatively small size of the material (Fig.1b). XRD test (Fig.2b) gives the material mineralogy content information that kaolinite mostly consists of aluminum silicate hydroxide $(Al_4(OH)_8(Si_4O_{10}))$ which is typical kaolinite chemical formula (Varga, 2007). Silica silt, which made of mainly quartz and portion of muscovite (Fig.2c), has relatively larger size and edgy point (Fig.1c)

Several tests were conducted in order to identify the properties of the materials. Specific gravity (G_s) tests were conducted based on water pycnometer method (ASTM D854, 2002). Microtac MRB Particle Analyzer was used to measure particle size distribution test. As for liquid limit (*LL*), the test was conducted using fall-cone penetrometer test (BS 1377 part 2, 1990) since it resulted in more objective determination due to less operator-dependent factor involved. The result can be seen on Table 1.

2.2 Consolidation Test

The experiment procedure was conducted based on ASTM D2435 (2004). On default, the duration between each loading increment is 24 hours. In these tests, the duration was prolonged as much as necessary so that the water dissipation process is complete. The next loading was added when flat plateau was observed on the time-dependent curve. Deionized water was used to make reconstituted soil mixture.

Since the material was in the form of powder, reconstituted sample was made by mixing material with deionized water as much as between 100% to 150% water content at liquid limit (LL_{DW}) (Burland, 1990). It was observed that the water content for diatomite mixture was approximately 1.26 times the LL_{DW} while kaolinite mixture was 127% LL_{DW} and for silica silt is 125% LL_{DW}.

The focus of this experimental study is on the time-dependent behavior of diatomite. Therefore, the time-deformation reading will be interpreted by various methods. Casagrande and Fadum (1940) proposed *log-t*

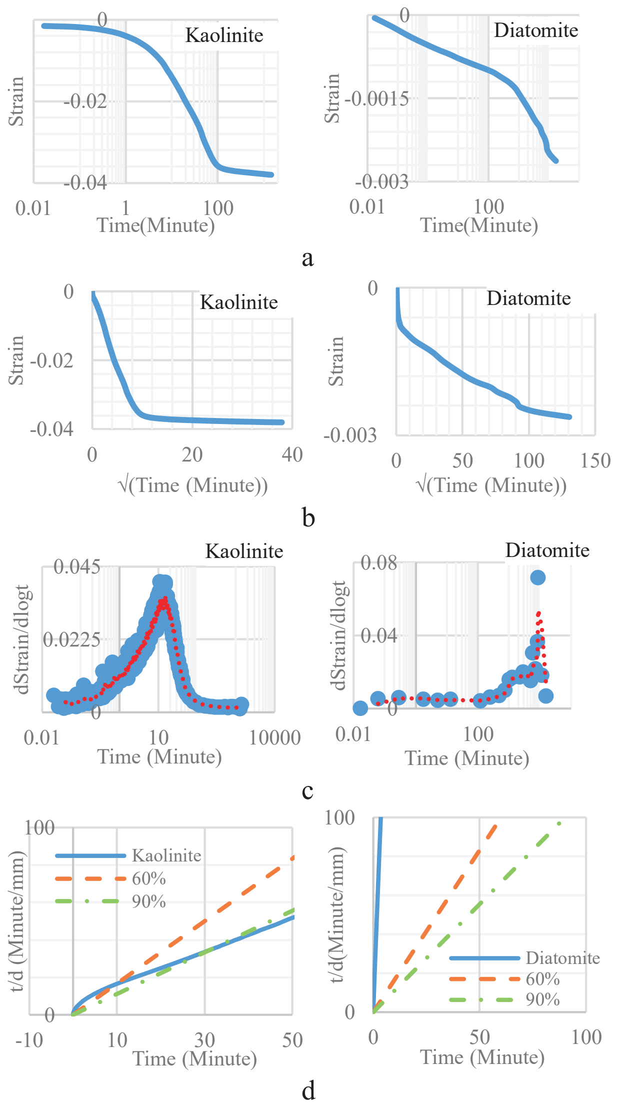

Fig. 3. Time-dependent consolidation analysis of kaolinite and diatomite at 10 kPa loading: a. Logarithmic time scale (Casagrande and Fadum, 1940), b. Square root of time (Taylor, 1948), c. Inflection point method (Mesri et al., 1999), d. Rectangular hyperbola fitting method (Sridharan and Sreepada Rao, 1981).

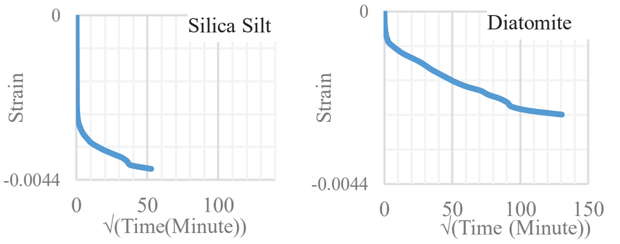

Fig. 4. Comparison on square root of time curve between silica silt and diatomite

method on which the time axis is in logarithmic scale. Square root of time method (Taylor, 1948) interprets the time axis in square root scale. Inflection point method (Mesri et al., 1999) plot the gradient of *log-t* method in y-axis and time in x-axis in logarithmic scale. On rectangular hyperbola fitting method (Sridharan and Sreepada Rao, 1981) the ratio of time over deformation with time. The time-dependent consolidation behavior of both diatomite and kaolinite was analyzed by these methods in order to compare the behavior between them since kaolinite has a clear distinction between primary consolidation and secondary consolidation. Silica silt time-rate consolidation behavior was also compared with diatomite considering both have granular particle.

3 RESULTS

3.1 Time-dependent Consolidation Analysis Comparison Between Diatomite and Kaolinite

Fig.3 gives information about the time-rate consolidation analysis comparison between kaolinite and diatomite at 10 kPa loading with various methods. Overall, the degree of consolidation determination method with each method can be easily observed on kaolinite curves. On the other hand, it is hard to analyze from diatomite curves.

On *log-t* scale analysis (Fig.3a), while kaolinite shows a typical reverse “s” shaped curve, diatomite curve has steeper line at the beginning, followed by increase on the deformation rate, and ends when a relatively flat curve was observed. Kaolinite acquired a small rate of deformation in one day duration while the diatomite was 11 days. The curves indicate that for kaolinite, the end of primary consolidation is around 90 minutes while diatomite is more than 10 days. In case of square root of time (Fig.3b) kaolinite curve analysis has consistent result with that of *log-t* method. However, diatomite curves imply the 90% consolidation is at an early stage, which has opposite interpretation with the *log-t* method. Inflection point method (Fig.3c) signify 68.68% degree of consolidation at the inflection point. Both kaolinite and diatomite curves have reasonable result with *log-t* method. Even so, further observation for diatomite is needed since the plot still does not have consistent trend after the inflection point. On Fig.3d, unlike kaolinite which have intersection between the curve and 60% and 90% degree of consolidation gradient line, the diatomite curve does not have any interception. Thus, it is impossible to determine the degree of consolidation based on hyperbola method on diatomite.

3.2 Time-dependent Consolidation Analysis Comparison Between Silica Silt and Diatomite

Fig.4 illustrates the square root of time method comparison between silica silt and diatomite at 10 kPa in order to compare diatomite behavior with the other granular material. Generally, diatomite and silica silt has slightly similar pattern. Starting with high initial deformation, the deformation rate become significantly smaller. At some point followed by minimal deformation rate.

While initial stage on deformation of silica silt was a major contributor on the overall deformation of the material, most of deformation that occurred on diatomite was greatly due to the linear downward trend after the initial drop. Also, silica silt has more stable trend compared to the diatomite. Since diatomite has a large water holding capacity due to its skeleton structure, the irreversible breakage of diatomite frustules causes most of the deformation on the diatomite. Shiwakoti (2002) reported that at pressure 10 kPa, diatomite lost more than 100% of its water content and the water holding capacity was reduced by 30%. In addition, diatomite has longer duration to reach the minimum deformation rate. It suggests that diatomite particle breakage progressed gradually. Therefore, particle breakage of diatomite has an important role on time-dependent consolidation of soil.

4 CONCLUSIONS

Diatomite time-dependent consolidation mechanism is complex. Unlike kaolinite, the time-rate consolidation analysis for diatomite is inconsistent, hence, hard to interpret. While *log-t* method indicates the end of primary consolidation is at the near end of loading increment duration, the square root of time shows that 90% consolidation is at the early stage. Also, further observation is needed in order to analyze using inflection point method since more data is needed in order to get more consistent trend. In case of hyperbola fitting method, the curve does not intercept with neither 60% and 90% degree of consolidation gradient line. Therefore, the time-dependent analysis for diatomite is still ambiguous.

The major factor on diatomite compressibility is the breakage of the diatomite frustules. In comparison with silica silt, which also granular material, diatomite shows similar pattern. However, while silica silt deformation is dominated by the initial stage, diatomite deformation is majorly contributed by the first linear downtrend of the curve. In addition, the duration to achieve the minimal deformation rate for diatomite is relatively long. Since diatomite is known by its huge void volume (Shiwakoti et al., 2002) while having a structure that breaks easily at low force (Subhash et al., 2005), the void volume greatly decreases when load is applied, thus results in deformation. It can be implied from the curve that breakage of diatomite frustules is not instantaneous. Moreover, the diatomite curve displays more fluctuated trend than silica silt curve. It suggests random portion of diatomite frustules breaks overtime.

The diatomite time-dependent results might highlight the particle breakage. However, the observation in this experimental study results in many assumptions. Therefore, further study in order to clarify the mechanism on the behavior is needed.

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