Influence of diatom microfossils on soil compressibility

Influence des microfossiles de diatomées sur la compressibilité des sols

Díaz-Rodríguez J.A., González-Rodríguez R.
Department of Civil Engineering, National University of Mexico, MEXICO

ABSTRACT: There are several sites in the world where diatom microfossils have been detected in the soil deposits (e.g., Mexico City, Mexico and Osaka Bay, Japan). These soil deposits are characterized to have singular physical and mechanical properties that do not follow the well established empirical equations relating index properties with strength and deformation parameters. To evaluate the influence of diatom microfossils on the soil compressibility, this paper presents the experimental results of a series of odometer tests using artificially prepared mixtures of diatom microfossils and kaolin (D+K). Test results indicate that the presence of diatom microfossils substantially alters the index properties as well as compressibility.

RÉSUMÉ : Il ya plusieurs endroits dans le monde où les diatomées microfossiles ont été détectées dans les dépôts de sol (par exemple, la ville de Mexico, le Mexique et la baie d'Osaka, Japon). Ces dépôts de sols se caractérisent par des propriétés physiques et mécaniques singulières, qui ne suivent pas les équations empiriques bien établies reliant les propriétés d'index avec les paramètres de résistance et de déformation. Pour évaluer l'influence des microfossiles de diatomées sur la compressibilité du sol, cet article présente les résultats expérimentaux d'une série de tests d'œdomètre utilisant des mélanges préparés artificiellement de microfossiles de diatomées et de kaolin (D + K). Les résultats des tests indiquent que la présence de diatomées microfossiles modifie considérablement les propriétés de l'index ainsi que de compressibilité.

KEYWORDS: laboratory tests; compressibility; diatomite; kaolinite; mixtures

1 INTRODUCTION

There are several sites in the world where diatom microfossils have been detected in natural marine and lacustrine soil deposits (Shiwakoti et al., 2002; Díaz Rodríguez, 2003; Díaz-Rodríguez, et al.,1998; Terzaghi, et al., 1996).

Natural soils are mixtures of clay particles and coarse-grained soil constituents, therefore the engineering behavior of a particulate material, consisting of individuals of a number of different components (including pores or voids), is in general, not simply given by the sum of reactions of the single individuals. Much more important for the whole system is usually the mutual interactions and interference between these individuals (particles or grains), which will be influenced by their spatial arrangement (*i.e.* fabric). The soil fabric and its close relationship to soil behavior have been studied intensively by several researchers since many years ago. The level of participation by different types and sizes of particles within the soil matrix in the transfer of interparticle contact stresses dictates the stress-strain behavior.

Soil microstructure is one of the governing factors that are responsible for the mechanical behaviour of clays. The microstructure of soils implies the combined effects of fabric, chemical composition, mineralogical constitution, and interparticle forces. It is required a greater understanding of soil microstructure and the contribution of soil particles of different size to its mechanical response.

This paper addresses the analysis of soil compressibility of soil mixtures ranging from pure kaolinite to 60% diatomite and 40% kaolinite.

2 DIATOM MICROFOSSILS

Diatomite or diatomaceous earth is a porous and lightweight sedimentary rock resulting from accumulation and compaction of diatom remains over a geological time scale. It is a chalk-like sedimentary rock that is easily crumbled into a fine white to off-white powder. Diatomite is relatively inert. The typical chemical composition of diatomite is approximately 90 percent silica, and the remainder consists of compounds such as aluminum and iron oxides. It has a high absorptive capacity, large surface area, low bulk and density. This powder has an abrasive feel, similar to pumice powder.

Diatoms skeletons or frustules are symmetric in shape and contain a large proportion of voids. Losic et al. (2007) indicate that a large percentage (≈ 60 - 70%) of the diatom´s frustules is essentially void space. Then the intraskeletal pore space of diatoms provides a chamber which can store water. Although the intricate frustules of diatoms have been well described, at the micro- and nano-scales of single cells and their interactions, interpretations based solely on physical principles have often been enlightening (Purcell, 1977; Vogel, 1983). Particle-surface interactions remain poorly understood and can produce unpredictable or inexplicable results (Feitosa and Mesquita, 1991).

3 ARTIFICIAL MIXTURES OF DIATOMITE AND KAOLIN

The experimental program followed in this investigation consisted in the elaboration of six mixtures: diatomite (D) was mixed with kaolin (K) in proportions of 0% diatomite (100K), 20% diatomite (20D + 80K), 30% diatomite (30D+ 70K), 40% diatomite (40D+60K), 50% diatomite (50D + 50K), 60% diatomite (60D + 40K). All mixtures were performed based on dry weight proportions.

3.1 Material used in mixtures

The kaolin and diatomite used in this investigation are products commercially available in Mexico. Kaolin is mainly composed of clay sized particles and soil particles smaller than

2 micrometers account for about 60%. The value of specific gravity of solid particles is 2.6. Diatomite is mainly silt sized; its silt sized particle account for more than 88% while clay size particles are about 3%.

3.2 Preparation of sample mixtures

Dry kaolinite powder and dry diatomite were thoroughly mixed in required proportion by weight. The homogenized mixtures were placed in the bowl of a blender and the necessary distilled water was added so that the mixture had the water content corresponding to its liquid limit. There was no any particle segregation when two different materials were mixed. The wet mixture was placed by spooning, in a cylindrical mold of 12.9 cm in diameter and 16 cm in height. The cylindrical mold served as consolidation cell, for that, two porous stones were introduced, one in the superior part and the other in the inferior one, both protected with filter paper, to avoid occluding the porous stones. The cylindrical mold with the mixture was placed in a consolidometer frame and a vertical stress of 130 kPa was applied during 28 days. Once the time of consolidation has elapsed, we extracted the soil sample, using a wire between separate the mold from the soil.

3.3 Index Tests

ASTM standards were followed in determining index properties, summarized in Table 1.

Atterberg limits increase with the increase in diatomite content, however, I_P decreased. Activity (i.e., the ratio between the plasticity index and clay size particles percentages) of the diatomite-kaolin mixtures increased with the increase in diatomite content (Table 1), this apparent increase is quite contradictory to the conventional perception, as mentioned by Shiwakoti et al. (2002). This fact suggests that the diatoms do not behave as silt size inert particles; on the contrary, they behave as very active clay particles.

Table 1. Index properties and physical properties of soil mixtures

Mixture D + K	w (%)	w_L (%)	w_P (%)	I_P (%)	γ_d (kN/m^3)	Activity
100K	43.00	56.40	28.90	27.50	11.06	0.42
20D + 80K	45.60	58.90	33.70	25.20	10.98	0.48
30D + 70K	49.00	63.75	40.25	23.50	10.70	0.51
40D + 60K	52.40	68.60	46.80	21.80	10.43	0.53
50D + 50K	55.15	72.05	51.75	20.30	9.95	0.59
60D + 40K	57.90	75.50	56.70	18.80	9.48	0.65

4. COMPRESSIBILITY OF SOIL MIXTURES

ASTM standards were followed in determining compressibility properties of the soil mixtures, and strain data are given in Table 2.

Table 2 Results of compression tests on diatomite-kaolin mixtures

Mixture D + K	Stress						
	25 Kpa	50 Kpa	100 Kpa	200 Kpa	400 Kpa	800 Kpa	1600 Kpa
100K	6.992	7.949	9.630	11.843	14.248	16.996	20.374
20D + 80K	1.047	1.492	2.142	3.205	4.634	7.441	11.189
30D + 70K	1.134	1.445	1.941	2.913	4.453	7.693	12.724
40D + 60K	1.354	1.752	2.398	3.449	5.264	9.114	15.602
50D + 50K	1.083	1.492	2.142	3.362	5.413	9.732	16.449
60D + 40K	1.268	1.654	2.268	3.425	5.402	9.689	16.823

A series of six tests was carried out on 63.3 mm diameter and 25.4 mm high specimens through the incremental load (IL). The equipment used was similar to that described by Head (1982). The specimens were separated from the porous stones with a single thickness of Whatman No. 50 filter paper. The applied pressures ranged from 25 kPa to 1,600 kPa. Each test involved 7 load increments that were applied daily. The effect of the stress increment ratio on the compression curve is not considered herein. Calibrations were made of each apparatus to reduce the effects of compliance in the measurement of sample displacement.

The stress-strain relationship (ε_v – σ'_v plots) from incremental one-dimensional consolidation tests, are presented in Figure 1. It can be seen from the figure that the stress-strain curves show different characteristic that depend on the diatomite content.

- The compression curve for 100% kaolinite is shown as reference curve
- The mixture 20D+80K shows a marked decrease of deformation.
- The mixtures of diatomite content of 30, 40, 50, and 60% show different behavior. As diatomite content increase the vertical strain begins to increase.

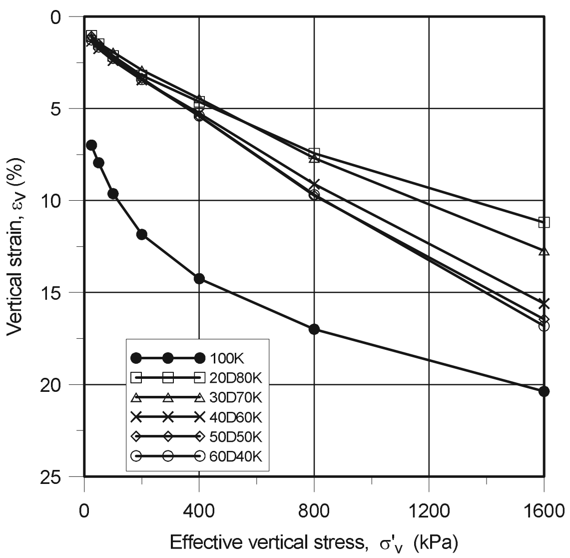

Figure 1 Stress-strain behavior on diatomite-kaolin mixtures

The variation of strain in diatomite content is shown in Figure 2, each curve is identified with the vertical stress applied. It can be seen from the figure that each curve shows different characteristic that depend on the vertical stress.

- For small values of the vertical stress (25 to 100 KPa) there is a plateau between 20 to 60% of diatomite content.
- From a vertical stress of 200 KPa the plateau tends to disappear and the shape of the strain pattern denotes a change in the behavior for high stress levels.

The stress-strain relationship (ε_v – log σ'_v plots) for different mixtures, are presented in Figure 3. It can be seen from the figure that there is a sudden change in the pattern when diatomite is added to the mixture. Curve 100K represents the general ε_v – log σ'_v relationship for random type of structure typical of a remolded clay. Other compression curves represent incipient structured soils.

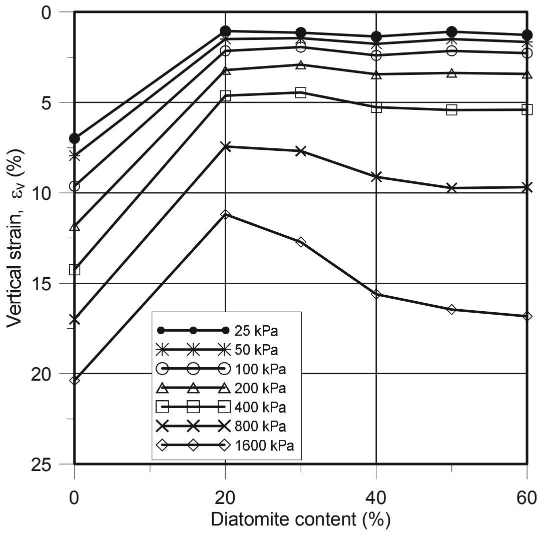

Figure 2 Variation on strain with diatomite content

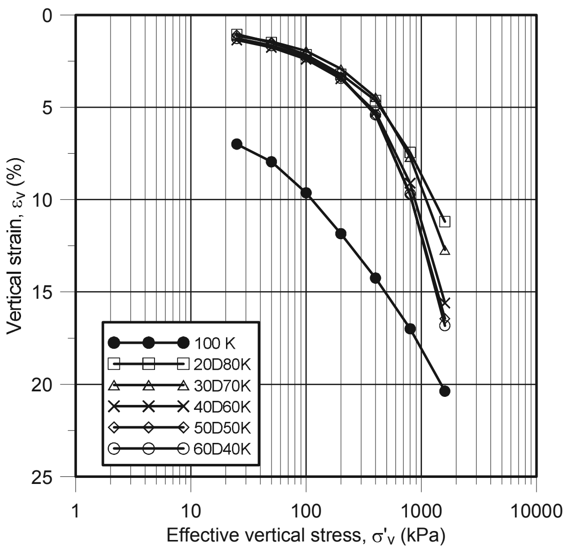

Figura 3 Comparion between stress-strain curves obtained with different diatomite content

5. DISCUSSION

The compressibility of fine-grained soils containing a high percentage of clay minerals depends not only on the mechanical properties of its constituents, but also on physico-chemical factors.

The difficulty in dealing with soil mixtures is manifested not only by the complexity of their behavior, but also in the absence of index parameters to characterize and compare soil mixtures. Consequently, a soil with a different composition (e.g., diatomite-kaolin with varying diatomite content) must be treated as a different material every time there is a change in the soil composition, and laboratory tests must be performed wherever there is a significant variation in the soil composition.

Therefore part of their compressibility is determined by the mechanical properties of the soil particles and the balance by the physico-chemical interaction of their constituents.

5.1 Index properties

According to Tanaka and Locat (1999) the increase in activity is believed to be an example of the influence of diatom microstructure on the test results.

5.2 Compressibility

The influence of diatom microfossils on soil compressibility is complex and depends on several factors (*e.g.*, diatomite content and stress level). The results of this experimental program show that the influence of diatoms microfossils in the engineering behavior of soils cannot be ignored.

There are several very interesting phenomena associated with the flow over cavities, like that presented by the frustules of diatoms. Models developed to examine shear flow over pores of different shapes, radii, and depths have shown that pores morphology is important in determining the streamlines of flow (Pozrikidis, 1994). The kinematics structure of the flow is discussed with reference to eddy formation and three-dimensional flow reversal. This associate phenomenon suggests that water inside diatom frustules could not be mechanically inert and affect the pore water pressure generated in the interstices between diatoms and clay particles. It therefore, influences the effective stress and the change the stiffness.

Relationship between diatomite content and C_c are shown in Figure 4 for the six mixtures. The results show that the compressibility of kaolin increases sharply with the addition of diatomite. Therefore, the C_c value for mixtures with diatomite is larger than pure kaolinite.

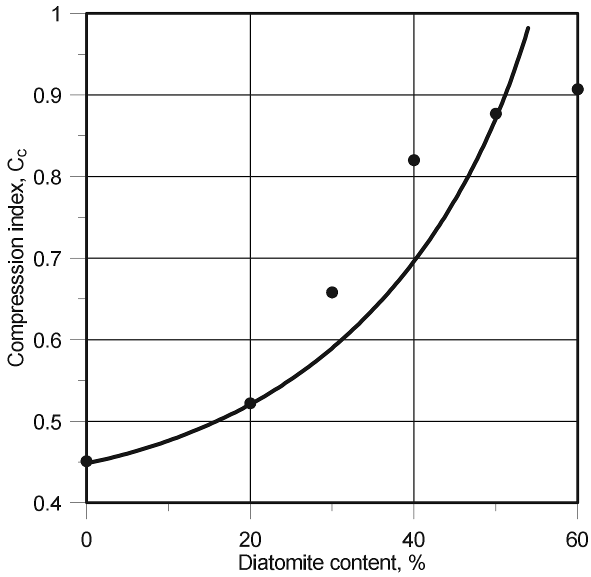

Figure 4 Relationship between diatomite content and C_c

6. CONCLUSIONS

Diatoms are outstanding examples of natural micro- and nano-structured materials that control the mechanical, hydraulic, and physico-chemical properties of soils. It is concluded that diatomaceous soils exhibit the following characteristics:

1. Activity increase with the increase in diatomite content.
2. The stress-strain curves show different characteristics depending on the diatomite content.
3. The strain-diatomite content curves show different characteristics depending on the stress level.
4. The presence of a significant amount of microfossils can significantly influence the mechanical behavior of soils, particularly the compressibility.

5. The compressibility for mixtures with diatomite is larger than pure kaolin
6. The compressibility of fine-grained soils containing a high percentage of clay minerals depends not only on the mechanical properties of its constituents, but also on physico-chemical factors.
7. However, our knowledge about the interaction between diatoms, clay particles, and water is in its infancy. Hence, it is necessary to pursue in greater detail the study of topics such as hydrodynamic effects and chemical reactions of diatom frustules.

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