UNIVERSIDAD SAN FRANCISCO DE QUITO USFQ

Colegio de Ciencias e Ingenierías

Oedometric Behavior of Soil-Diatom (*Aulacoseira Alpigena*) Mixtures Before Frustule Cracking

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Ingeniería Civil

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HOJA DE CALIFICACIÓN
DE TRABAJO DE FIN DE CARRERA

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RESUMEN

Este estudio presenta un estudio de laboratorio físico y mecánico sobre el limite líquido, limite plástico y la consolidación primaria uniaxial de diferentes mezclas de caolín (suelo fino) y diatomeas (fósiles de algas unicelulares). Los ensayos de laboratorio utilizados para para analizar las propiedades de la diatomea de tipo *Aulacoseira Alpigena* fueron; ensayo de copa Casagrande, ensayo de hidrómetro para la distribución de tamaño de partículas y el ensayo de consolidación con edómetro unidimensional para descubrir las características de compresibilidad. Adicionalmente, se añadieron índices de caracterización de suelo con el coeficiente de consolidación, índice de compresibilidad e índice de hinchamiento los cuales variaron con la concentración de diatomeas en el suelo. Esto indica que a mayor cantidad de concentración de diatomeas se tiene mayor porosidad y vacíos por donde el agua puede liberarse y empieza a tener comportamiento arenoso. Una característica interesante de este tipo de mezclas saturadas es que si es manipulado suavemente se comporta como un suelo fino mientras que, si se manipula mas abruptamente y se coloca carga concentrada, como en el ensayo de Casagrande, la muestra parece seca y dura como si el agua se hubiera evaporado.

Palabras Clave: Consolidación, concentración de diatomeas, limites, esfuerzo.

ABSTRACT

This article presents a mechanical laboratory study about the liquid limits, plastic limits, and the uniaxial primary consolidation of different diatom-kaolinite concentrated soils. Laboratory tests used to analyze physical and mechanical properties of *Aulacoseira Alpigena* type diatom concentration in fine grained soils are Casagrande test, Hydrometer test for grain sized distribution and one-dimension oedometer test to discover compressibility characteristics. Additionally, further characterization was achieved with coefficient of consolidation which resulted in higher coefficients proportionally with higher diatom concentration. This means that with more diatom presence there is more space where water can escape and begins to have sand like properties. One curious characteristic of this type of diatom is that when manipulated softly it behaves like a normal fine grain soil, but when sudden stress is applied, as in Casagrande test, the sample appears dry and hard like if all the water has been evaporated.

Keywords: Consolidation, diatom concentration, limits, stress.

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INTRODUCTION

Soils are exceedingly difficult to characterize because of the variability of mixtures, concentrations and, also, the sudden change of content within a specific area of interest. However, this characterization and classification is important to achieve a satisfactory performance of mechanical support when a structure is being constructed above. There must be specific information of the soil to design and place the structure´s foundation.

Diatom soils become critic in these cases because when construction takes place above diatom deposits it can have low bearing capacity characteristics that lead to significative settlements that most certainty can be dangerous for the structure and people inside it.

Deposits containing a high concentration of diatoms can be found in marine and lacustrine areas with high number of phytoplankton, being natural source of food for marine organisms. Also, volcanic activity promotes the production of silica which is the base material of the diatom frustule.

Where all this ingredients meet is where more probability of this deposits is to be found, mainly where there is a high number of active volcanoes, countries like Mexico, Ecuador, Chile, and areas in the United States have been found to have significant deposits of this type of soils.

Under a microscope we can see that diatoms are fossilized frustules of different shape and size that are made of silica. The important part of these frustules is that is highly porous, for instance it can absorb a great amount water, this characteristic can change drastically the classification of the overall soil such as atterberg limits, void ratios, compressibility, strength, even shear strength.

One clear example of the phenomenon is in part what is happening in the Metropolitan Cathedral in Mexico DF. Before Spaniard colonization, aztaztecas lived in an island on lake

Texcoco, this area had fine grained soil and all the characteristics that met to have diatom deposits. After the colonization, the cathedral was built above of the dried lake and the settlement problems began. Nowadays the cathedral settles 40cm every year because of water escaping, causing rapid consolidation. (Meli, 2011)

TOPIC DEVELOPMENT

RESEARCH SIGNIFICANCE

Samples of the tested materials were selected over the amount of diatom material mixed into kaolinite which is classified as a fine grain soil. Throughout this laboratory tests there is going to be a discussion about the results of the mechanical behavior of the different samples.

Something important to note about is that the tests are evaluated before the breakage of the frustules, therefore, elastic soil behavior is forecasted.

METHODS AND MATERIALS

For these experiments, tests were based on the ASTM specifications. The first test that was computed was the specific gravity by water pycnometer associated with method A of ASTM D854-02. Liquid Limit and Plastic Limit were computed based on the method A of ASTM D4318-00. Water content was based on ASTM D422-63. For the primary consolidation test using the oedometer specifications of ASTM D2435-03 were used to complete the test.

For the consolidation curves the method used was “Taylor square root of time,” the reason for this was that reaching 100% of primary consolidation can result excessive periods of time between readings. What this method estimates is the time in which 90% of primary consolidation is completed and can be used to calculate the coefficient of consolidation (Cv) (ASTM, 2003). After the consolidation curves, deformation (mm) vs square root of time, were completed, other properties had to be calculated to achieve the final graphs. With initial and final measurements such as height, moist weight, dry weight, and water content it was able to obtain the changes in void ratios before and after the test to obtain the void vs stress curves and analyze how different diatom content changes the physical and mechanical properties of the sample. With these curves also two other indexes were calculated, compression index (Cc) and swell index (Cs)

Square root of time graphical method was used to find the tome in which 90% of consolidation is completed (t90). This value was found for every load increment and related to this time was a difference in the relative height for each specimen. To calculate Cv equation (1) was used.

$$Cv = \frac{Tv * HDr^2}{t90} \qquad (1)$$

The elements in this equation were found in the norm. The time factor (Tv) is the flow of velocity in the height dimension in the one-dimensional consolidation test. This factor includes a constant initial pore water content to be found in small samples that has a value of 0.848. The value HDr is the average longest drainage path for the 90% of the primary consolidation (ASTM, 2003). And finally, t90, as explained before, is the abscissa of time in which 90% of the primary consolidation is finished that was calculated graphically in the deformation vs square root of time curves for each load increment.

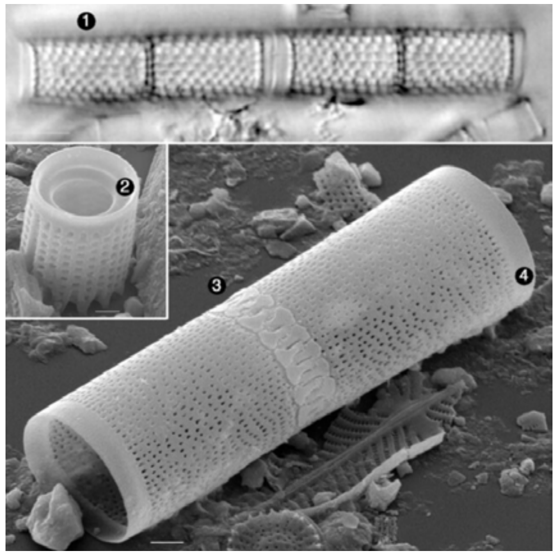

Figure 1 Scanning electron microscopy (SEM) image of Aulacoseira type diatoms

The type of diatom evaluated in this investigation is part of the *Aulacoseira* family found in Utah, United states which is a mountainous state that has volcanic residues and lakes. The shape of this frustule is a symmetric cylinder which has porous center and sides. For this tests, unbroken frustules were used so that the range of consolidation is maintained in the elastic behavior.

Table 1 Soil-diatom mixtures

Mixture	Fine-grained Soil Content (%)	Diatomite Content (%)
1	100	0
2	80	20
3	60	40
4	40	60
5	0	100

Table 2 Specific gravity, Liquid Limit, and Plastic Limit of soil-diatom mixtures

Mixture	Specific Gravity	Liquid Limit (%)	Plastic Limit (%)
1	2,65	36,15	23
2	2,55	49,6	37
3	2,45	64,6	43
4	2,35	83,2	49
5	2,15	-	-

Table 3 Liquid limit, swell index, and compression index of soil-diatom mixtures

Mixture	Liquid Limit (%)	Cs	Cc
1	36,15	0,0069	0,28
2	49,60	0,0122	0,212
3	64,60	0,0272	0,112
4	83,20	0,0279	0,095
5	-	-	-

Specimens for testing in this investigation were mixed in 5 different samples summarized in Table 1. Mixtures were distributed in diatom contents of 0%, 20%, 40%, 60% and 100%. In table 2 the Specific Gravity (Gs), Liquid Limit (LL) and Plastic Limit (PL) is represented related to its mixture. Plastic's limit variability in higher contents of diatom is considered because of the consistency that the sample acquires. When applied concentrated stress with the cradle key in the Casagrande cup, the sample appears to dry and has a more plastic behavior making the wedge process difficult.

In table 3 Liquid Limit is related to the compression and swell index for each mixture that were computed graphically with the consolidation curves.

ASTM D422-63 specifications were used to compute the particle analysis of soils with the hydrometer methods because the samples pass sieve N° 200, for instance, sieve analysis cannot be applied.

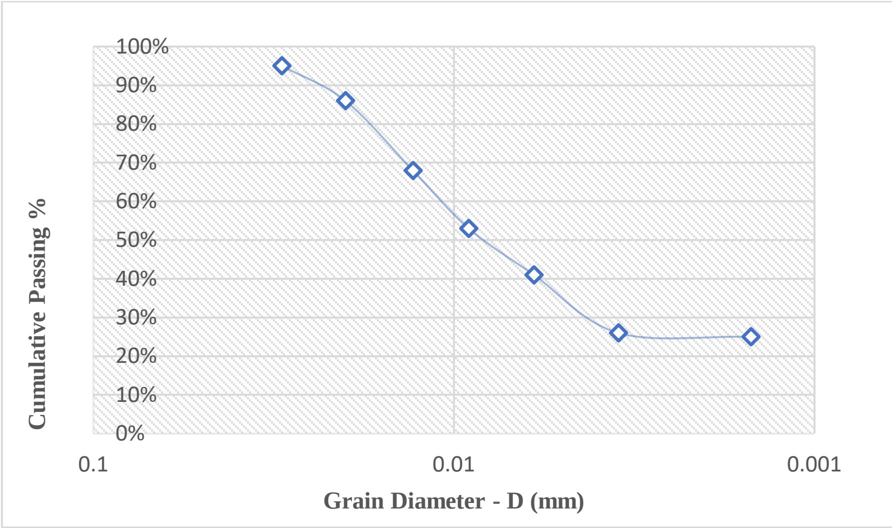

Figure 2 Fine-grained soil particle size distribution

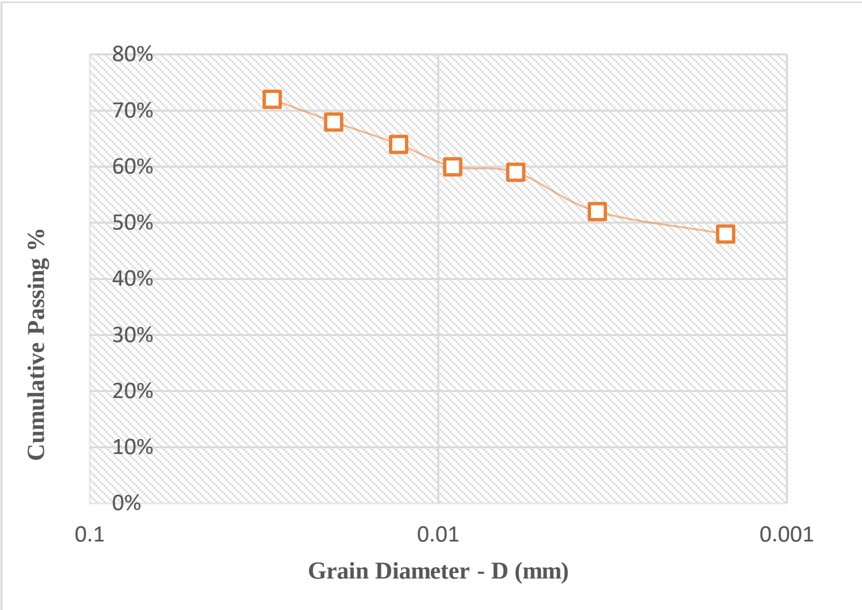

Figure 3 Diatom particle size distribution

Figure 2 shows distribution of the kaolinite (fine grained) soil and shows a fine distribution curve because it was bought, commercially they always try to give a nice distribution in diameter. On the other hand, in figure 3 particle distribution in the diatom shows variability because of the frustule sizes and also the porosity which can cause changes in the path of the particles in the pycnometer which changes the marks in their specific time.

After the classification of the diameters according with the ASTM D2487-17 specifications it was concluded that kaolinite fine grained soil is classified as low plasticity clay (CL) and the diatomite is classified as a silt of low plasticity. It is important to mention that diatomite classification and particle size distribution varies highly depending on the sampling and if the frustules are broken or complete.

PROCEDURE

The focus of this investigation is to compute and analyze the physical and mechanical properties of diatomite mixtures with fine grained soil, for instance, a chain of tests was implemented and had a connection with the previous one. The selected mixtures for diatom-kaolinite mixtures for every test was based on diatomite content; 0%, 20%, 40% 60% and 100%. First the physical tests were made; water content, liquid limit, plastic limit, specific gravity by water pycnometer, and the particle size distribution with the hydrometer, all of them with ASTM normative.

Then the mechanical test was implemented with the oedometer using ASTM D2435-03 specifications for the one-dimension consolidation properties. Kaolinite and diatom mixtures were kept the same as the physical tests, but water content was calculated as 1.5 times each mixture’s Liquid Limit to make the saturated samples.

In the pre-loading step of the test, low loadings were selected in order to avoid swelling and the unevenness of the sample with the abrupt change of load. The pre-loading loads selected were 30g, 60g and 120g that was the weight of the consolidation cap. In the loading steps the weights that were selected had an approximated increment of 2 times the previous one: 500g, 1000g, 2000g, 3500g, 7000g, and 14000g which resulted in stresses of 4kPa, 8kPa, 16kPa, 32kPa 64kPa and 120kPa. It is important to acknowledge that these stresses don't reach the yielding stress of the frustules to maintain the results in the elastic range.

Table 4 : Loading increments for each tested sample.

Load step	Pre-Loading (g)	Loading (g)
1	30	500
2	60	1000
3	120	2000
4	-	3500
5	-	7000
6	-	14000

Each loading step was changed when the time passed the mark of the t90 and the slope of the deformation vs time graph became constant.

RESULTS

First, the liquid limits of the mixtures are represented in Figure 4. The percentage presents a proporional increase with the diatom content in the mixture. This physical behavior can be explained bye the increment of porosities and voids in the frustules of the diatom that increase the capacity of the soil to retain water.

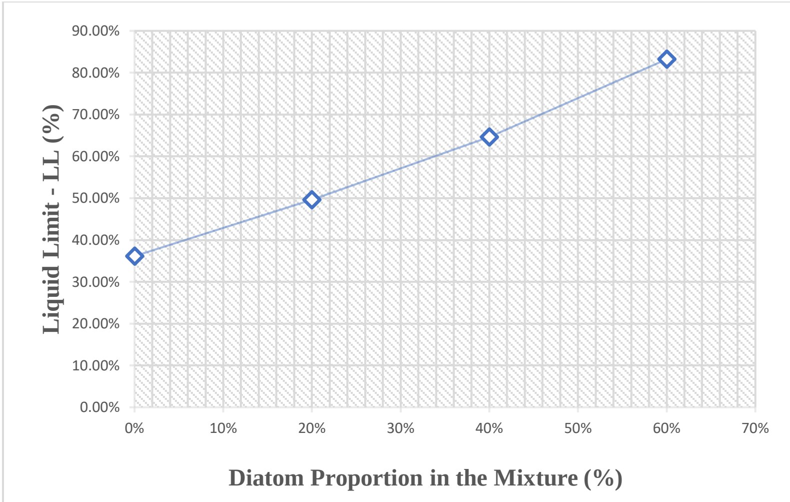

Figure 4 Liquid limits of the tested samples

Plastic Limit results also became higher proportionally to diatom content, even though in the practice it was complicated to manipulate because of the counterintuitive characteristics of the diatom. Increase in diatom content made retain more water and when making the cylindrical test the sample appeared dryer.

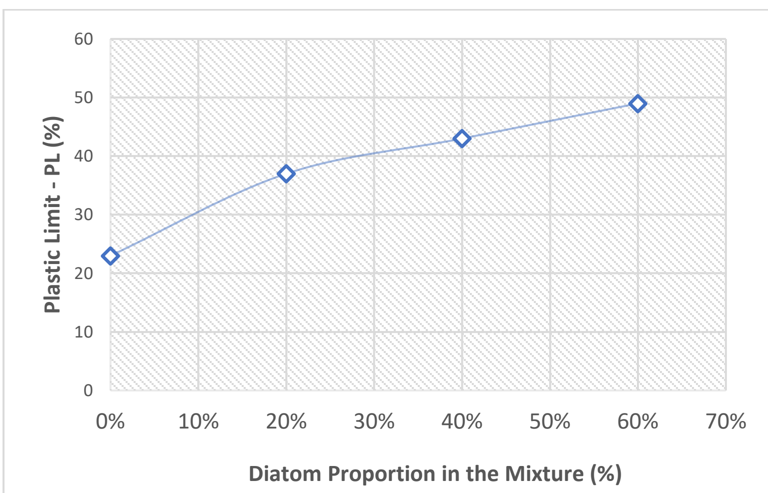

Figure 5 : Plastic limits of the tested samples

For the oedometer test, after the initial graphics of deformation vs time, results were computed and aditional values were calculated in relation to voids in mixture. One thing to take into account is that the geologial pressure history of the epecimens was erased to obtain the normal consolidation with the help of water.

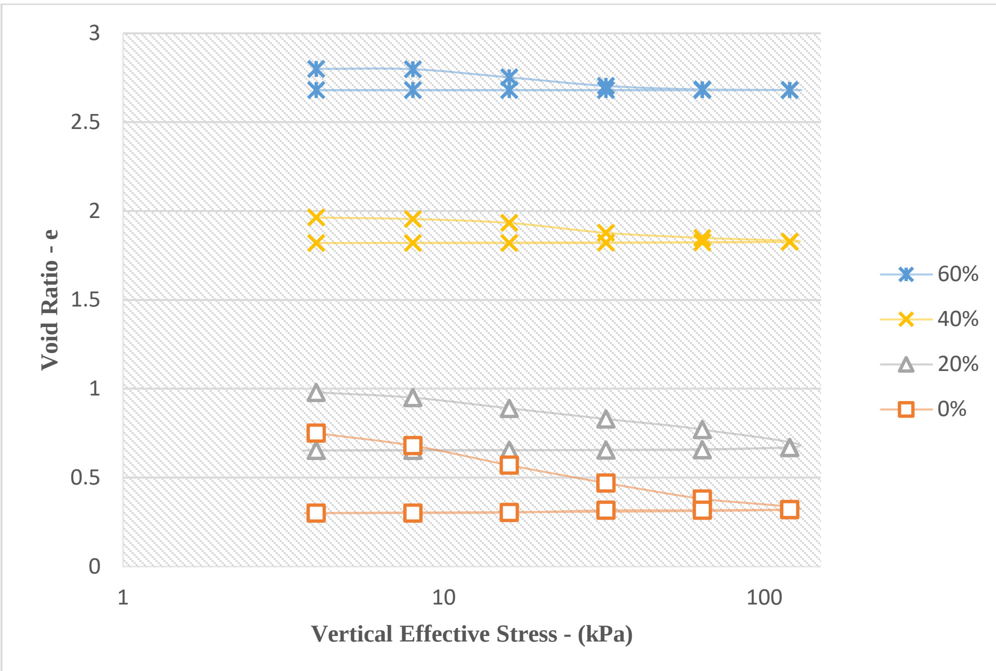

Figure 6 Consolidation curves of tested samples

The increment of voids in the consolidation curves is explained by the increment of diatom content and it is proportional because of the porosity of the frustules. It can also be noted the relationchip between the loading and unloading curves, the higher the diatom content in the mixture the lower the compressibility, that's why in Figure 7 we can see that those curves appear closer to each other.

The behavior of the loading confirms the constant of the elastic range, as it was stipulated before, the loadings are significantly lower than those of the yielding stress of the frustules.[8]

After the test there was a slight increase of height between the last consolidation part and the last measurement before the sample was put in the oven.

As mentioned before particles don't crack, but they rearrange, and that caused some variability in the final results of the testing.

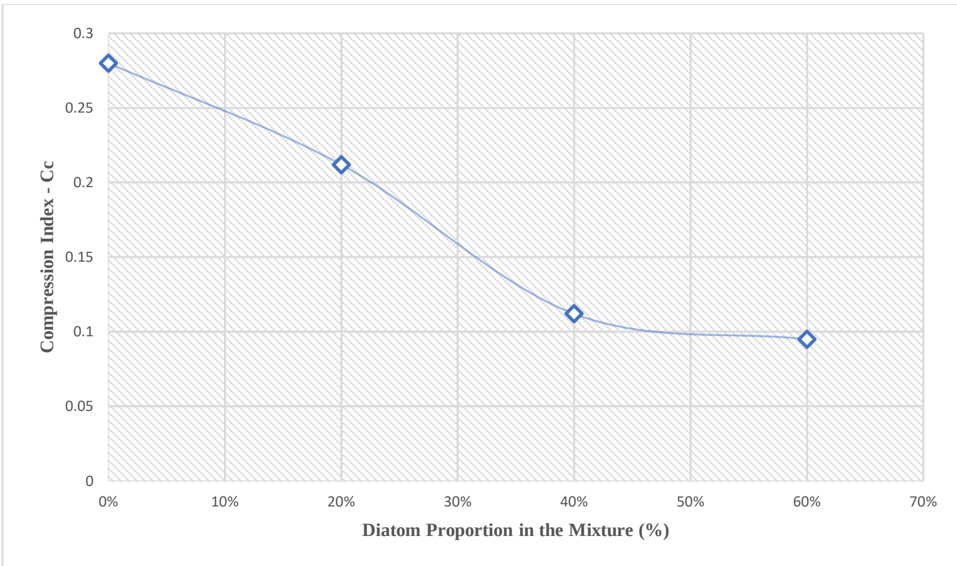

Figure 7 Compression index of the tested samples

Data and results in Figure 7 were used to calculate compression index (Cc) of the samples which are graphed in Figure 8 and the swell index (Cs) that is graphed in Figure 9.

Values of Cc were calculated for every mixture and for the curve shape it can be analyzed that there is a loss of compressibility as the diatom concentration increases, mentioned previously in the consolidation curve, and can be explained by the elastic behavior in which frustules do not break but rearrange.(Nevarez, 2019) As the microstructure of the soil is not affected, compressibility gets lower values.

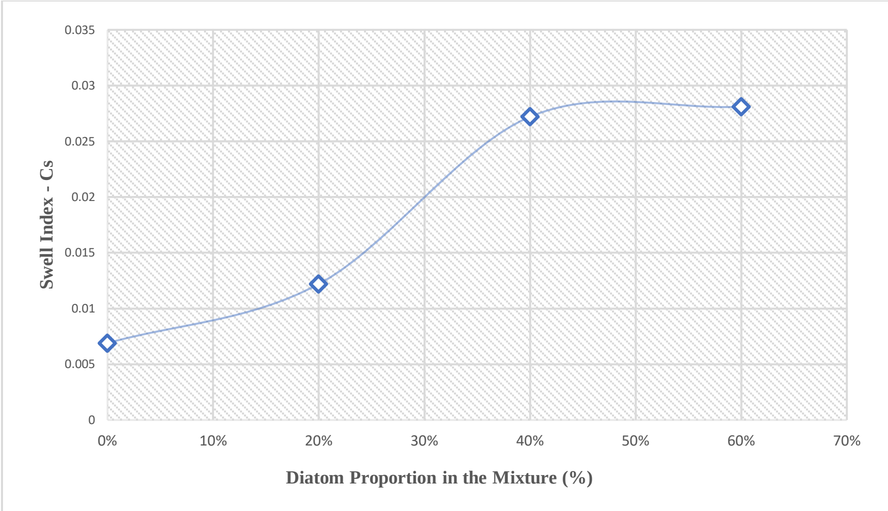

Figure 8 Swell index of tested samples

On the other hand, Cs increases proportionally with the diatom content in the mixture. This behavior can also be explained by the elastic range of the unbroken frustules, swelling increases because of the recovery of shape and position of the frustules, when there is more content of diatom the sample can recover and swell in the unloading jumps of the tests. (Arenaldi, 2019)

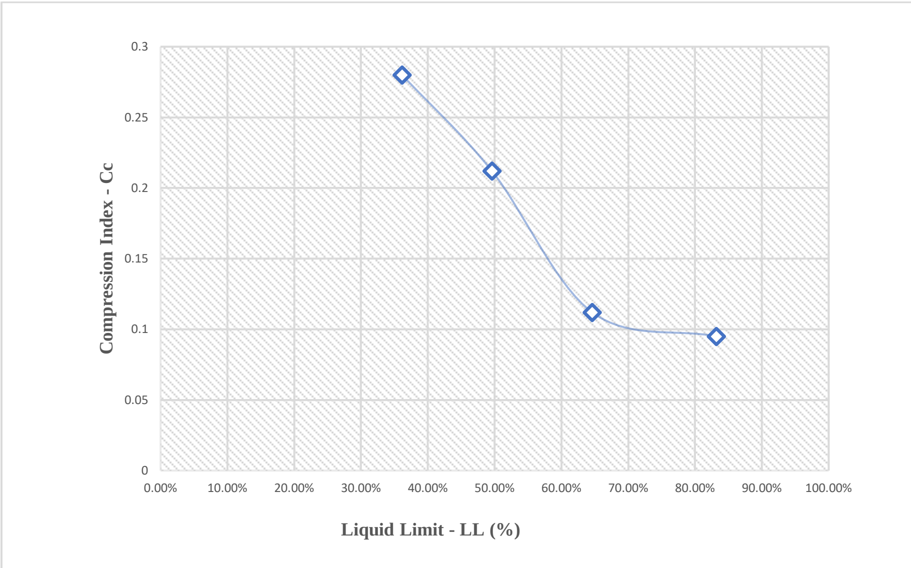

Figure 9 Relationship between the Compression Index and Liquid Limit of the tested samples

As shown on Figure 8 where Cc decreases with the diatom proportion and in Figure 5 where Liquid Limit increases with diatom proportion, Figure 10 was computed with the relationships between the two. It can be shown here that compressibility increases. Diatom proportions give a higher compressive strength due to its elasticity before cracked frustules in spite of the increase of void space. If the cracking is considered, water can be released and can cause an increment of the compression index proportionally to the Liquid Limit.

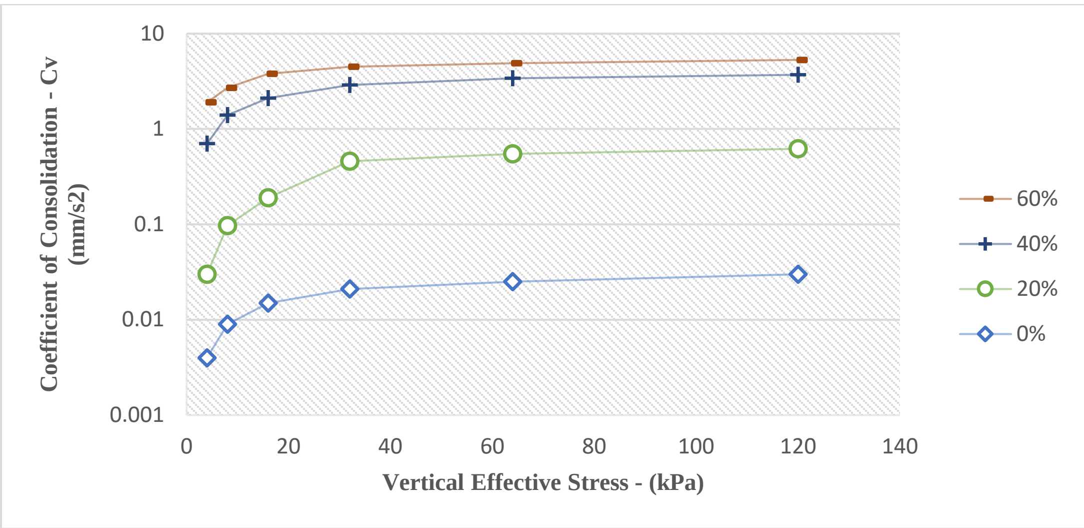

Figure 10 Coefficient of consolidation of tested samples

As it is shown in the graph, Coefficient of Consolidation (Cv) increases with diatom content and also with stress. As voids increase with diatom content, compressive strength increases and also the time for stability reduces. Samples reached faster the t90 as diatom content got higher and loads got higher in the experimentation. It is important to notice that this void increment results in energy that could be released abruptly if elastic behavior terminates, and cracking starts to take place. (Shukla, 2009)

CONCLUSIONS

After the results and analysis of the tests it can be concluded that the increment of diatom content can change the physical and mechanical behavior of the fine-grained soil.

First of all, talking about physical properties, diatom frustules are bigger than kaolinite, so it changed the overall particle size as well as its Specific Gravity.

The curious part is that, as the interparticle voids increase because of the difference in size, also the interparticle voids increase because of the high porosity of the diatoms. These void characteristics result in space for water to fill, as a result, liquid limit and plastic limits increase with the proportion of diatoms.

Compression indexes have lower values with the increase of diatom proportion because of its high compression strength in its elastic range of behavior. This results in high swell indexes due to the space and shape recovery in the unloading stage.

Coefficients of consolidation are affected by these indexes and, as a result, with more diatom content and more load, the compression stage is faster because of pressure dissipation, for instance, in the oedometric test, the samples reached t90 in less time.

As porosity increases in the sample, more drainage is available for faster consolidation process. (Arenaldi, 2019)

Finally, is important to mention that this oedometric tests for different diatom proportions were analyzed in the elastic behavior range of the frustules. Compared to other tests made with higher loads and passing the yielding stress of the diatoms it can be assumed that with breaking of the frustules the results of compressibility indexes could change due to the sudden dissipation of water and reducing voids in the sample. This could be dangerous if used as soil for construction as settlements could get bigger in time.

In future investigations other shapes and characteristics of diatoms can be put to test as well as an increment in stresses to pass yielding strength and also analyze these types of soils for shear strength.

BIBLIOGRAFIC REFERENCES

ASTM D2216-19 (2019) , A. S., *Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass.* ASTM International, West Conshohocken, PA, 2019, www.astm.org

ASTM D2435-03 (2003), A. S., *Standard Test Method for One-Dimensional Consolidation Properties of Soils. ASTM International,* West Conshohocken, PA, 2003, www.astm.org

ASTM D2487-17 (2017), A. S., *Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)*. ASTM International, West Conshohocken, PA, 2017, www.astm.org

ASTM D422-63 (2002), A. S., *Standard Test Method for Particle-Size Analysis of Soils*. ASTM International, West Conshohocken, PA, 2002, www.astm.org

ASTM D4318-00, A. S. (2000), *Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils.* ASTM International, West Conshohocken, PA, 2000, www.astm.org

ASTM D854-02 (2002), A. S., *Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer.* ASTM International, West Conshohocken, PA, 2002, www.astm.org

Arenaldi, G., Ovalle, C. y Barrios, A. (2019). *Compresibilidad y propiedades dinámicas de suelos diatomáceos de Mejillones*. 25, 6-14

Hernandez, Y. Lozada, C. (2019) *Efecto del porcentaje de diatomeas en la curva compresibilidad del suelo* (2019) Escuela colombiana de ingeniería Julio Garavito, Bogotá.

Nevarez, O. Diaz, J (2019) *Compresibilidad de mezclas diatomeas-bentonita mediante ensayos de velocidad de deformación constante* (2019) Universidad Nacional Autónoma de Mexico, CD. MX.

Shukla, S., Sivakugan, N., and Das, B. (2009), *Methods for determination of the coefficient of consolidation and field observations of time rate of settlement—an overview*. International Journal of Geotechnical Engineering, 3, 2009, pp. 89–108.

Sonyok, D. R., and Bandini, P. (2019), *Oedometric Behavior of Diatomite–Kaolin Mixtures*. Journal of Geotechnical and Geoenvironmental Engineering,145, 2019

Meli, R. Sanchez, A. (2011) *La rehabilitación de la catedral metropolitana de la ciudad de Mexico*. 2011 UNAM www.revista.unam.mx