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Influence of Bentonite Content on the Compressibility Parameters of Processed Sand-Bentonite Mixtures

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Abstract

Bentonite has employed by industry to exercise various structural applications due to its unique properties especially when the material is transferred to a liquid state under water. Swelling property of bentonite to produce various water suspensions, this depends upon the relative constituents of clay and water. These mixtures are employed as bonding and plasticizing agents. Bentonite provides a large surface area per unit weight of clay, due to its large surface area in stabilizing the medium to carry other chemicals. Bentonite reacts chemically with many organic materials to form compounds which are used as a gelling agent in a variety of organic liquids. One-dimensional consolidation tests are performed on four sand-bentonite mixtures containing 10, 20, 30 and 40 % by dry weight bentonite to study the 1-D compressibility behavior of compacted sand-bentonite mixtures. These specimens are mixed at wet of optimum water content. To overcome the problem of the high tendency of bentonite to swell, two techniques are used. The first one is following the consolidation-swell test procedure by Nelson and Miller and the other one is mixing the soil at water content equivalent to liquid limit. The water contents for these tests are chosen in an attempt to achieve the same initial void ratio of 0.71 for all bentonite contents. Finally, final conclusion is mentioned for the effect of bentonite content on the compressibility parameters of sand-bentonite mixtures. This research arrived to that the initial water content has no effect on the mixture, which contains 10 percent bentonite, whereas a significant effect is noticed for 20 and 30 % bentonite mixtures. It was found that for mixtures containing 20 and 30 % bentonite, the compressibility parameters, Cc, Cs, av, and m_v for the specimens mixed at liquid limit are higher than those for specimens mixed wet of w_{opt}.

Keywords: *Bentonite, Sand-Bentonite mixtures*, *One-dimensional consolidation*, *Compressibility.*

1. Introduction

The bentonite industry was established over seventy years old, the name of bentonite was applied as early as 1848 by Knight to a highly plastic clay material occurring near Fort Benton, Wyoming (GRIM, 1953, P.361). According to Chisholm (1960. P. 30) the first commercial bentonite was shipped in 1888 under the name "Taylorite". From this modest beginning, in which production amounted to only a few tons per year. Bentonite production now exceeds a million tons per year. The origin of bentonite could be attributed to the alternation of volcanic ash, or glass, but common use of the term is often extended to include material of primarily composition which may have formed in another manner [1].

Industry uses bentonite for its inherent physical properties or for the physical properties or for the physical properties it can develop in another material or product. Through understanding of the chemistry and structure of bentonite, more appropriately, is helpful when discussing bentonite applications because its physical properties are so closely related to these parameters. The greatest applications of bentonite are those that involve mixture with water. By adjusting the water content in combination with a given quantity of clay, properties of the mixture can be developed, which are utilized by industry for bonding, plasticizing, and suspending applications [2].

When the water-to-clay ratio is low, this combination is used combination is used as bonding agent for a variety of materials because the consistency of the mixture is more rigid than plastic, and it possesses adhesive properties. Accordingly, bentonites are used to bond foundry molding sands, animal feeds and insulation materials.

When the water-to-clay ratio is increased, plasticity develops in the mixture as the water adsorption capacity of the bentonite is just exceeded. This clay-water combination is used as a plasticizing agent in certain ceramic wares and concrete.

Very high water-to-clay ratios ultimately from suspensions which have a multitude of industrial applications, the largest of which is as drilling muds of fluids for the rotary drilling industry. The large surface area of bentonite is utilized by applications as a chemical, or in particular, insecticide carrier. Surface area is also of primary importance to bentonite applications as an emulsifier and emulsion stabilizer [3].

The major variable in the research work of Akbar J. *et al.*, 2013 [4] is Bentonite as partial replacements by weight of cement. The experimental program explained by this explosion contains two parts. The first part was to investigate the potential use of Bentonite to evaluate its impact on Compressive strength of High Performance Concrete (HPC). An HPC batch, properly mix designed was primed, aiming at strength of 6000psi. Super plasticizer was also introduced to attain high workability. Some part of the batch was treated for a Compressive Strength test. The second part of research work addresses its effect on Durability of concrete. For this purpose the rest of the batch was exposed to a cycle of wetting and drying in sulfate ironic atmosphere, the solution containing 50 g/l of Na_2SO_4. The durability was measured in terms of resistance offered to the penetration of sulfate ions into the concrete.

Performing 1-D consolidation test on soils have a tendency to swell or expand when water is added requires special procedures. Nelson and Miller (1992) introduce consolidation-swell test as a special procedure for 1-D consolidation of fine grained soil that have the tendency to swell [5-6]. The test procedure contains initial loading of unsaturated test specimen to a prescribed stress. The test specimen is then allowed to swell under loading when water is added. After swelling the sample further loading and unloading were performed under standard manner [7]. There is another way to overcome the problem of swelling in the 1-D consolidation process is mixing the soil initially at water content equivalent to the liquid limit of the soil. In this research, the two test procedures are applied on sand bentonite mixtures of 10, 20, 30, and 40%. The results of each procedure are presented and comparison between the two obtained results is discussed.

2. Materials

2.1. Chemical and Physical Properties of Soil Constituents

The constituent materials used in this study are 40-140 silica sand and a powdery bentonite. Sand-bentonite mixtures containing 10, 20, 30, and 40 percent bentonite are tested using one dimensional consolidation tests to evaluate the effect of bentonite content on the compressibility of the mixture. Two additional sand-bentonite mixtures containing 60 and 80 percent bentonite are tested to determine the effect of the bentonite content on the index and compaction properties.

The Atterberg limits of the soil mixtures are plotted as a function of the bentonite content. The liquid limit increases linearly as the bentonite content increases for all the soil mixtures. The plastic limit decreases as the bentonite content increases until a bentonite content of 40 percent, and then the plastic limit increases with an increase in the bentonite content. As a result, a bentonite content of 40 percent represents the critical bentonite content before which the sand governs the behavior causing the plastic limit to decrease, and after which the clay governs the behavior causing the plastic limit to increase.

2.2. Chemical Analysis of Bentonite

Bentonite from Kasr ElSagha near Fayoum (about 6000 years). Sinai Manganese Company has supported a number of research projects to upgrade bentonite by Alkaline and Acidic activation, to be used in deep water and petroleum wells. Table 1 presents the chemical analysis of bentonite.

Table1. Chemical Analysis of Bentonite

Compound	PCT
SiO_2	49 - 55
Al_2O_3	20 - 24
Fe_2O_3	2.5 - 6
CaO	2 - 6
MgO	0.5 - 2
K_2O	1.4
Na_2O	1.1 – 2.4
L.O.I	9 – 10

2.3. Preparation of Test Specimens

The dry sand and the bentonite (with natural water content 6.5%) are mixed until the color of the dry mixture is homogenous, and then the required amount of additional water is added to the mixture before remixing. The mixture is kept in sealed, double plastic bags for 24 hours before it is compacted.

Two initial water contents are used for the one-dimensional consolidation tests, i.e., specimens mixed at < 9 percentage points wet of optimum, and specimens mixed at the liquid limit. For the first case, the standard compaction procedure (ASTM D698) is used to compact the specimens. After compaction, the specimen is extruded from the mold, and 3cm of each end are removed using a sharp knife. The 7.1 cm (2.8-in) consolidation ring is then pushed into the remaining portion of the compacted soil and the ends of the specimens are trimmed flush with the ring. For the specimens mixed at the liquid limit, the oedometer is assembled and then the wet soil (soil paste) is transferred into the ring and compacted using a putty knife being careful to prevent the existence of any air voids within the soil in the ring.

3. Experimental program

One-dimensional consolidation tests are performed using the conventional oedometer. The compressibility parameters (C_v, a_v, m_v, C_c), are determined by performing one-dimensional consolidation tests on different sand-bentonite mixtures. These tests are performed to evaluate the compressibility behavior of the sand-bentonite mixtures.

The consolidation-swell test procedure described by Nelson and Miller (1992) is followed for specimens mixed wet of optimum water content. The specimens are loaded initially under a 34.5 kPa (5 psi) pressure. Then, water is added until the swelling stops.

Swelling was observed by plotting the change in the void ratio versus the elapsed lime. The applied pressure is doubled in the conventional way to 69, 138, 276, 552 kPa in 24-hour increments or until primary consolidation stops.

4. Analysis of Test Results

The effect of the bentonite content on the compression, C_c, and swelling indexes, C_s, is shown in Figures 1 and 2, and the values are summarized in Table 2. In general, C_c and C_s increase as the bentonite content increases for specimens mixed either wet of w_{opt} (Figure 1a) or at the liquid limit (Figure 1b) illustrating the expected effect of increased clay (bentonite) content on the compressibility of the mixture. In addition, C_c is higher than C_s for a given bentonite content and given mixing water content, w_c.

As shown in Figure 2**a**, the values for C_c for specimens mixed at the liquid limit tend to be slightly higher than the corresponding values for the specimens mixed wet of w_{opt}. However, no Consistent difference between the C_s values for specimens mixed at the liquid limit relative to specimens mixed wet of w_{opt} is apparent from the data plotted in Figure 2b.

The values for the coefficient of compressibility, a_v, and the coefficient of volume compressibility, m_v, for specimens mixed wet of w_{opt} and at the liquid limit are listed in Tables 3 and 4, respectively. As indicated in Figures 3 through 5, the values for a_v and m_v for a given σ' tend to increase as the bentonite content increases regardless of whether the specimens are mixed wet of w_{opt} or at the liquid limit, the values are summarized in Tables 5 and 6.

The coefficient of consolidation, c_v, was calculated for each applied stress increment using the following equation:

$$c_v = \frac{0.197 H_d^2}{t_{50}} \quad (1)$$

Where H_d is the drainage distance corresponding to 50 percent consolidation under the given load increment (m), and t_{50} is the time required to reach 50 percent consolidation under the given load increment (s). The c_v values are plotted as a function of the average effective stress in Figures 6 and 7. As shown in Figure 6 for specimens compacted wet of w_{opt}, c_v increases slightly with an increase in average effective stress for the specimen containing 10 percent bentonite, whereas c_v decreases slightly with increase in average effective stress for the specimens containing 20, 30, and 40 percent bentonite mixtures.

As shown in Figure 7 for specimens compacted at the liquid limit, a slightly increasing trend in c_v with increasing average effective stress is shown for the specimens containing either 10 or 20 percent bentonite, whereas a slightly decreasing trend in c_v with increasing average effective stress is shown for the 30 percent bentonite mixture. Based on the plots in Figures 6 and 7, there apparently is a critical bentonite content that affects the trend in c_v with average effective stress. In the case of the specimens mixed wet of w_{opt}, this critical bentonite content apparently is between 10 and 20 percent. In the case of the specimens mixed at the liquid limit, this critical bentonite content apparently is between 20 and 30 percent.

Table 2. Compressibility parameters of four sand-bentonite mixtures.

Bentonite content (%)	Optimum water content, wopt	Liquid limit	Mixture water content, w (%)	Swelling time (days)	Compression Index, Cc	Swelling Index, Cs
10	14.1	39.3	24.6	0	0.0764	0.0153
			39.8	0	0.199	0.0111
20	15.2	75.1	23.2	17.0	0.365	0.122
			75.7	0	0.578	0.266
30	15.9	105	22.1	42.0	0.625	0.365
			105	0	0.671	0.265
40	17.3	135	21.3	61.0	0.711	0.498

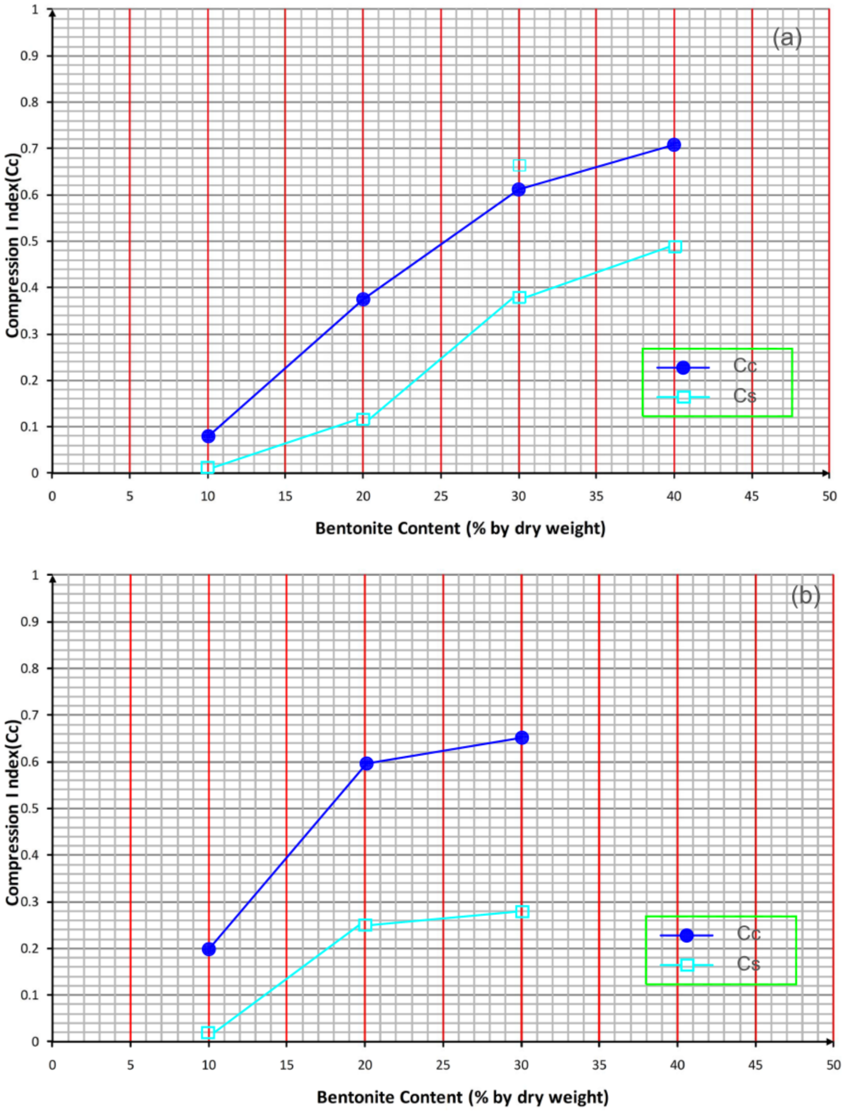

Figure 1: Effect of bentonite content on the 1-D compression and swelling indexes for sand-bentonite specimens: (a) specimens mixed wet of optimum water content; (b) Specimens mixed at liquid limit.

Table 3. Effect of the bentonite content on the coefficient of compressibility and volume compressibility for specimens mixed wet of optimum water content.

Bentonite content (%)	Average Induced Effective Stress,$\sigma^{/}$ (kPa)	Coefficient of Compressibility, a_v (kPa^{-1})	Coefficient of Volume Compressibility, m_v(kPa^{-1})
10	51.8	$5.79x10^{-4}$	$3.55x10^{-4}$
	104	$4.35x10^{-4}$	$2.67x10^{-4}$
	207	1.45x10-4	$8.90x10^{-5}$
	414	$1.44x10^{-4}$	$8.89x10^{-5}$
20	51.8	$7.83x10^{-4}$	$4.06x10^{-4}$
	104	$1.30x10^{-3}$	$6.75x10^{-4}$
	207	$7.97x10^{-4}$	$4.14x10^{-4}$
	414	$4.71x10^{-4}$	$2.44x10^{-4}$
30	51.8	$1.16x10^{-3}$	$5.52x10^{-4}$
	104	$1.74x10^{-3}$	$8.29x10^{-4}$
	207	$1.45x10^{-3}$	$6.9x10^{-4}$
	414	$8.69x10^{-4}$	$4.14x10^{-4}$
40	51.8	$1.74x10^{-3}$	$5.23x10^{-4}$
	104	$2.03x10^{-3}$	$9.14x10^{-4}$
	207	$1.59x10^{-3}$	$7.16x10^{-4}$
	414	$1.01x10^{-3}$	$4.55x10^{-4}$

Table 4.Effect of the bentonite content on the coefficient of compressibility and volume compressibility for specimens mixed at the liquid limit.

Bentonite content (%)	Average Induced Effective Stress, $\boldsymbol{\sigma}^{/}$ (kPa)	Coefficient of Compressibility, a_v (kPa^{-1})	Coefficient of Volume Compressibility, m_v (kPa^{-1})
10	51.8	1.45x10-3	8.06x10-4
	104	1.01x10-3	5.61x10-4
	207	4.35x10-4	2.42x10-4
	414	1.81x10-4	1.01x10-4
20	51.8	2.61x10-3	1.19x10-3
	104	2.61x10-3	1.19x10-3
	207	1.31x10-3	6.01x10-4
	414	4.71x10-4	2.16x10-4
30	51.8	4.35x10-3	2.29x10-3
	104	2.75x10-3	1.45x10-3
	207	1.59x10-3	8.37x10-4
	414	6.88x10-4	3.62x10-4

Table 5. Effect of the bentonite content on the measured hydraulic conductivity and volume compressibility for specimens mixed wet of optimum water content.

Bentonite content (%)	Average Effective Stress, $\sigma^{/}$ (kPa)	Coefficient of volume Compressibility, m_v (kPa^{-1})	$k_{measured}$ (m/s)	$K_{measured}/m_v$ (kg/s^3)
10	51.8	3.55x10-4	3.09x10-11	8.70x10-11
	104	2.67x10-4	2.03x10-11	7.60x10-11
	207	8.90x10-5	2.16x10-11	2.43x10-10
	414	8.89x10-5	2.56x10-11	2.88x10-10
20	51.8	4.06x10-4	2.53x10-11	6.23x10-11
	104	6.75x10-4	3.08x10-11	4.56x10-11
	207	4.14x10-4	2.00x10-11	4.83x10-11
	414	2.44x10-4	1.36x10-11	5.57x10-11
30	51.8	5.52x10^{-4}	4.84x10^{-11}	8.77x10^{-11}
	104	8.29x10^{-4}	1.35x10^{-11}	1.62x10^{-11}
	207	6.9x10^{-4}	4.15x10^{-11}	6.01x10^{-11}
	414	4.14x10^{-4}	1.03x10^{-11}	2.49x10^{-11}
40	51.8	5.23x10^{-4}	1.51x10^{-11}	2.89x10^{-11}
	104	9.14x10^{-4}	7.08x10^{-11}	7.75x10^{-11}
	207	7.16x10^{-4}	1.39x10^{-11}	1.94x10^{-11}
	414	4.55x10^{-4}	1.81x10^{-11}	3.98x10^{-11}

Table 6 Effect of the bentonite content on the coefficient of volume compressibility and measured hydraulic conductivity for specimens mixed at liquid limit.

Bentonite content (%)	Average Effective Stress, $\sigma^{/}$ (kPa)	Coefficient of volume Compressibility, m_v (kPa^{-1})	$k_{measured}$ (m/s)	$K_{measured}/m_v$ (kg/s^3)
10	51.8	8.06x10-4	2.34x10-11	2.90x10-11
	104	5.61x10-4	3.12x10-11	5.56x10-11
	207	2.42x10-4	1.26x10-11	5.21x10-11
	414	1.01x10-4	1.25x10-11	1.24x10-10
20	51.8	1.19x10-3	2.86x10-11	2.40x10-11
	104	1.19x10-3	2.07x10-11	1.74x10-11
	207	6.01x10-4	8.45x10-12	1.41x10-11
	414	2.16x10-4	1.13x10-11	5.23x10-11
30	51.8	2.29x10^{-3}	2.03x10^{-11}	8.86x10^{-12}
	104	1.45x10^{-3}	1.83x10^{-11}	1.26x10^{-11}
	207	8.37x10^{-4}	1.54x10^{-11}	1.84x10^{-11}
	414	3.62x10^{-4}	8.52x10^{-11}	2.35x10^{-11}

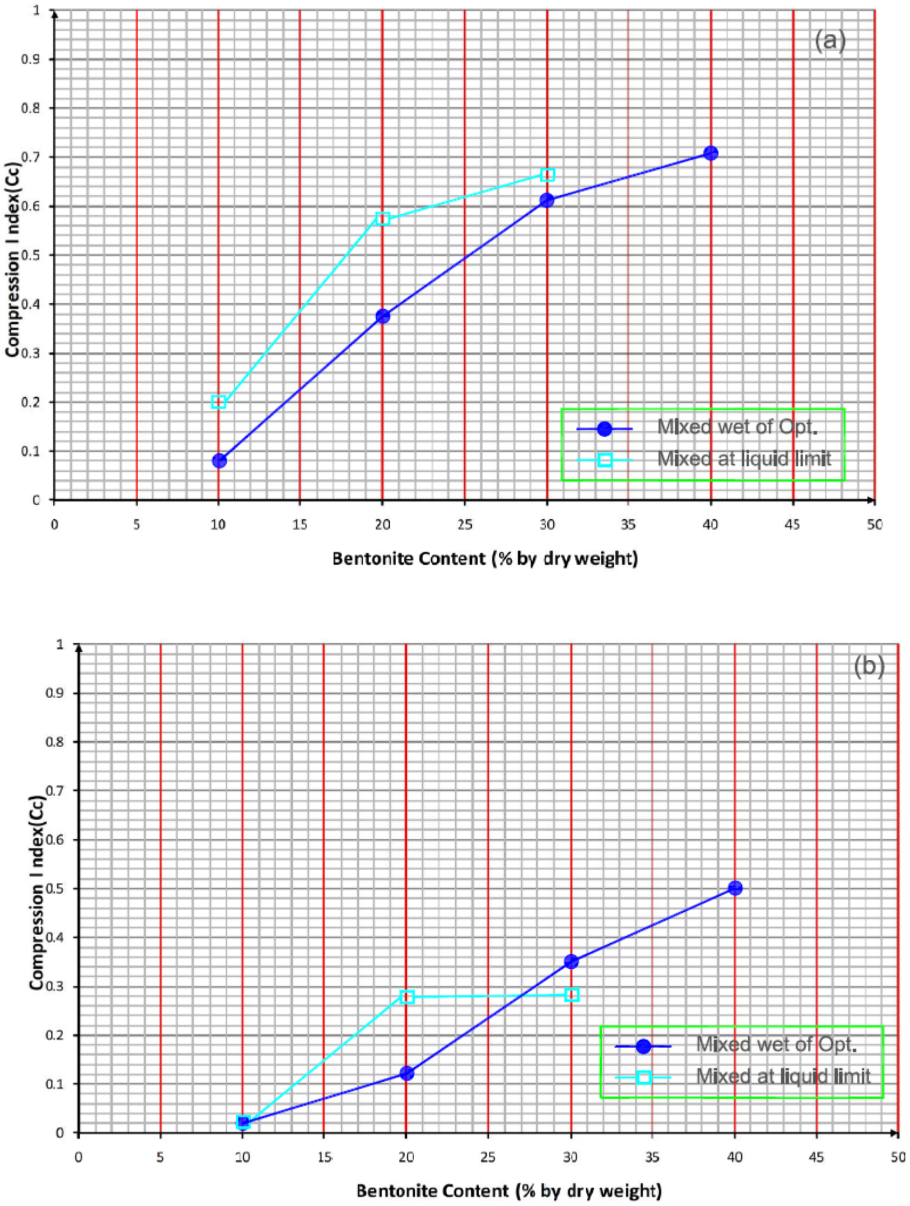

Figure 2. Effect of initial water content on the 1-D compressibility parameters of Sand-bentonite mixtures: (a) compression index; (b) swelling index.

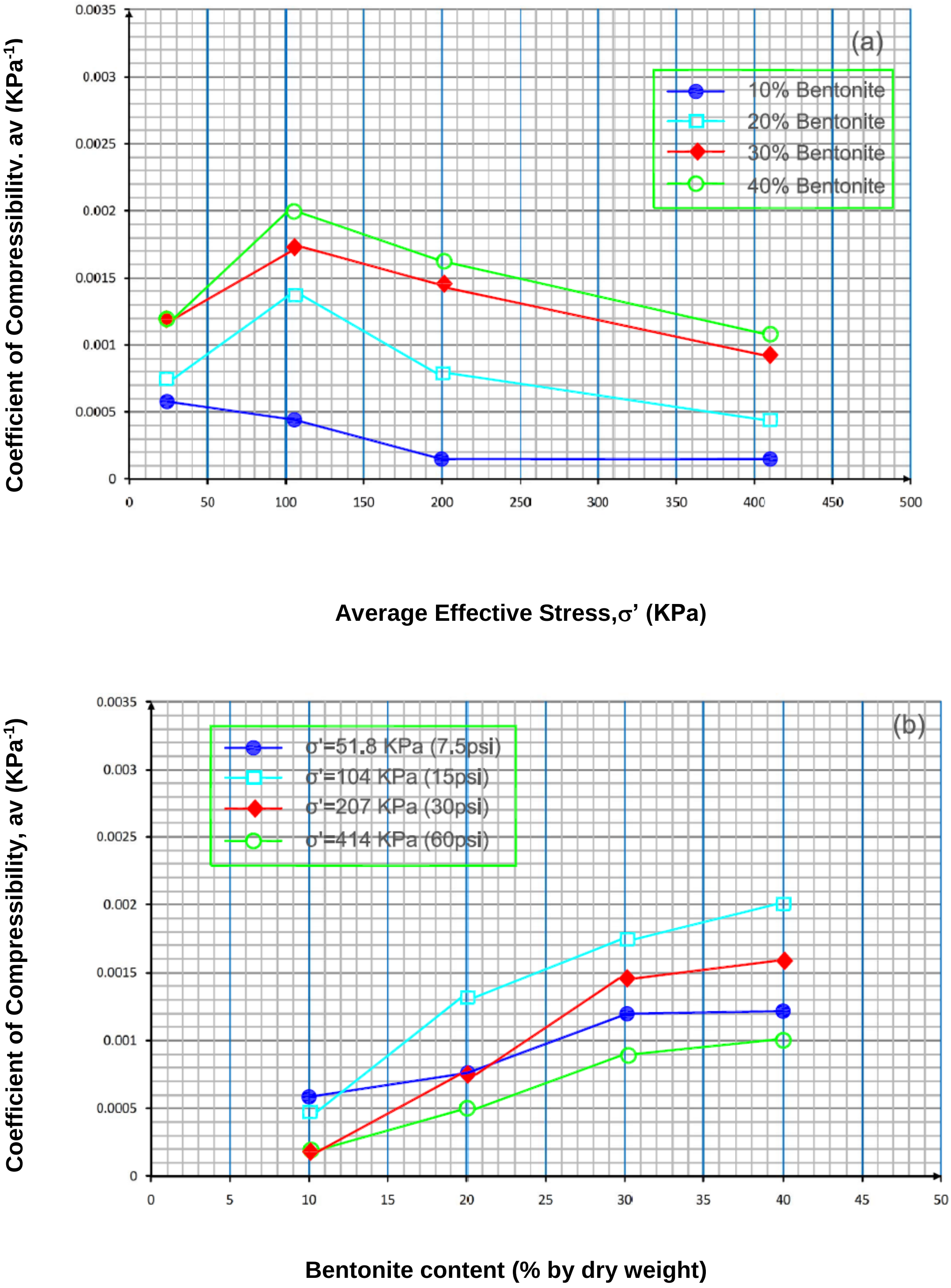

Figure 3. Effect of (a) average induced effective stress and (b) bentonite content on the coefficient of compressibility, a_v for sand- bentonite mixtures mixed wet of optimum water content.

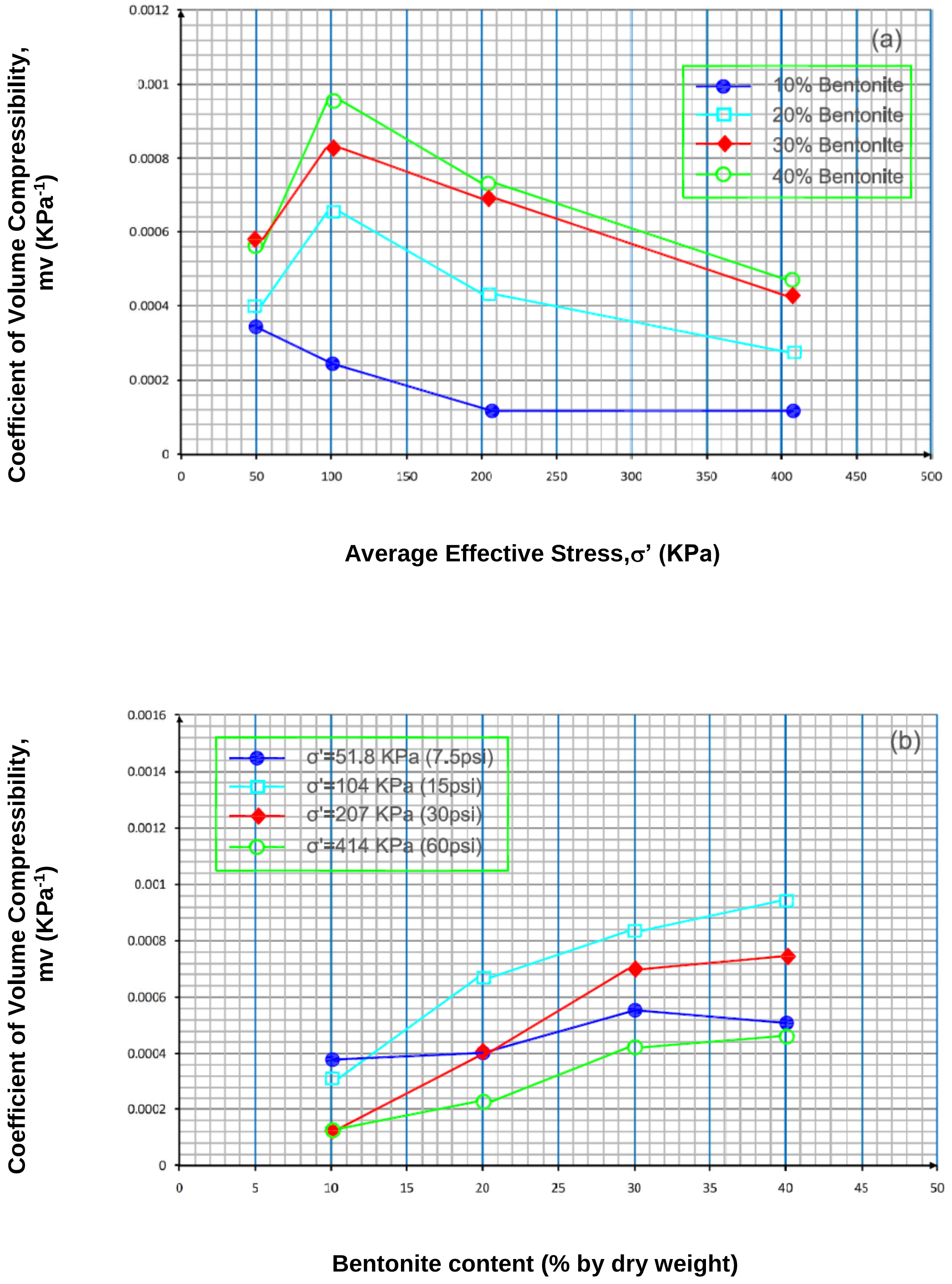

Figure 4. Effect of (a) average induced\ effective stress and (b) bentonite content on the coefficient of volume compressibility, m_v for sand- bentonite mixtures mixed wet of optimum water content.

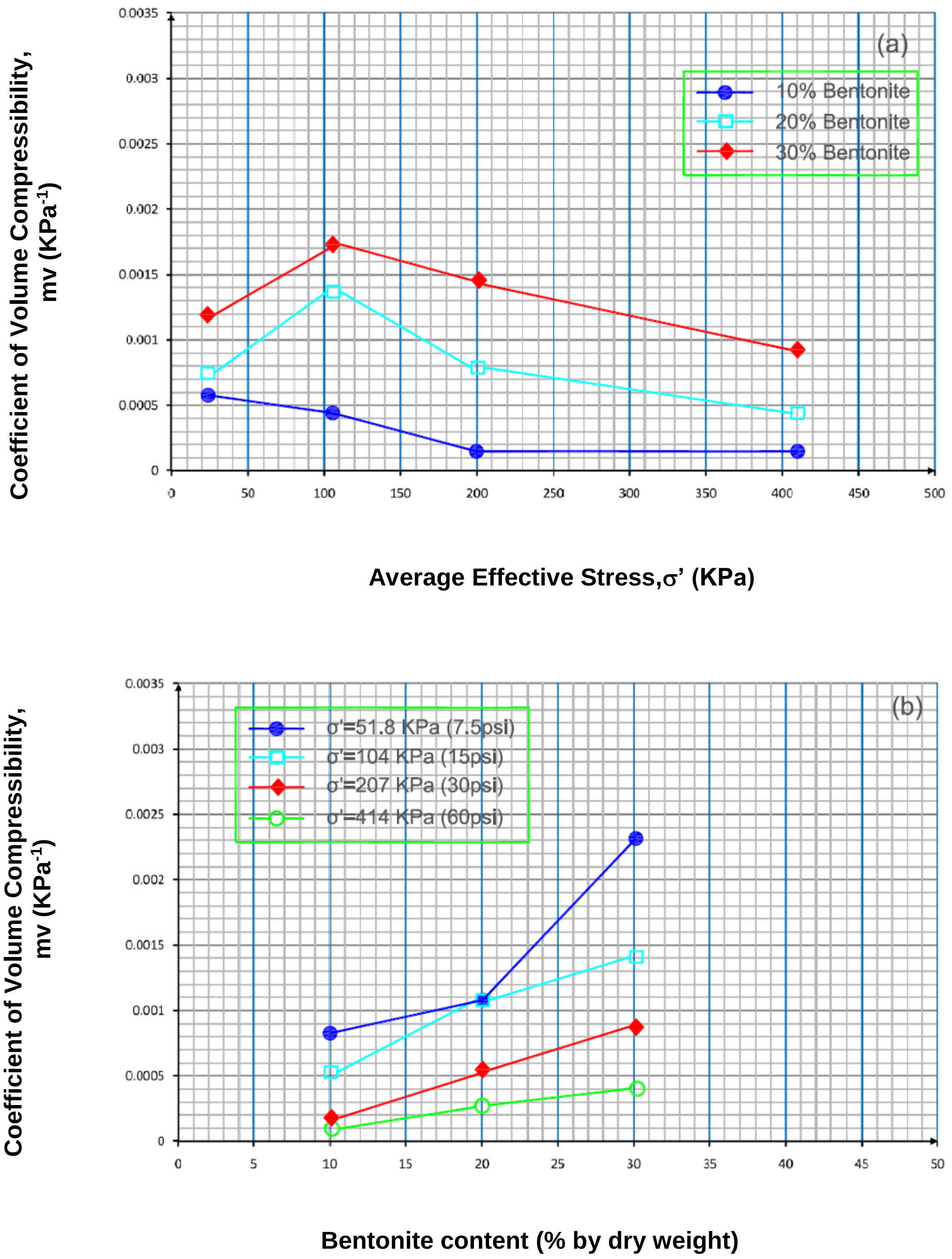

Figure 5. Effect of (a) average effective stress and (b) bentonite content on the coefficient of compressibility, m_v for sand- bentonite mixtures mixed at the liquid limit.

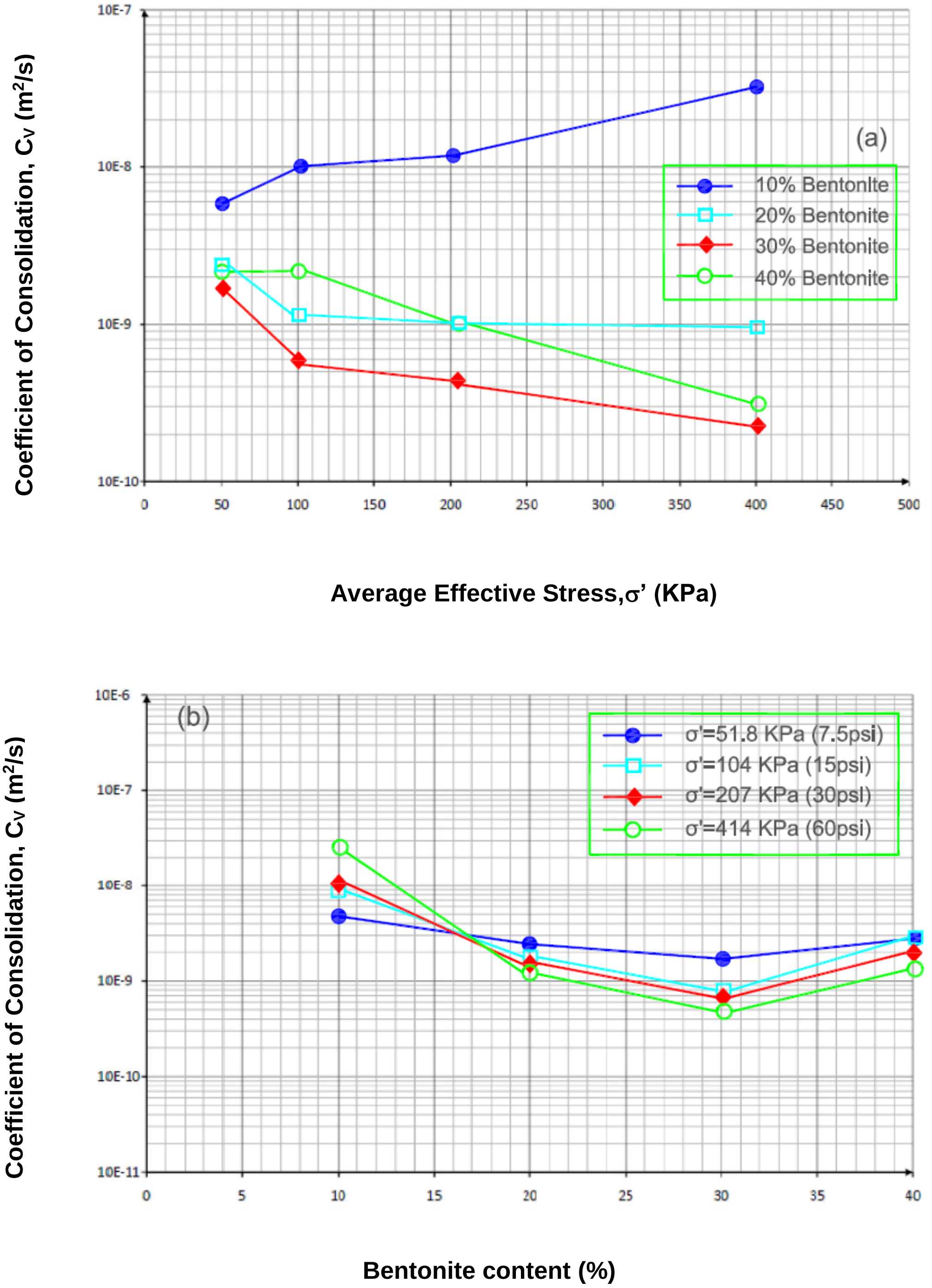

Figure 6. Effect of (a) effective stress and (b) bentonite content on the coefficient of consolidation, c_v for sand- bentonite mixtures mixed wet of optimum water content.

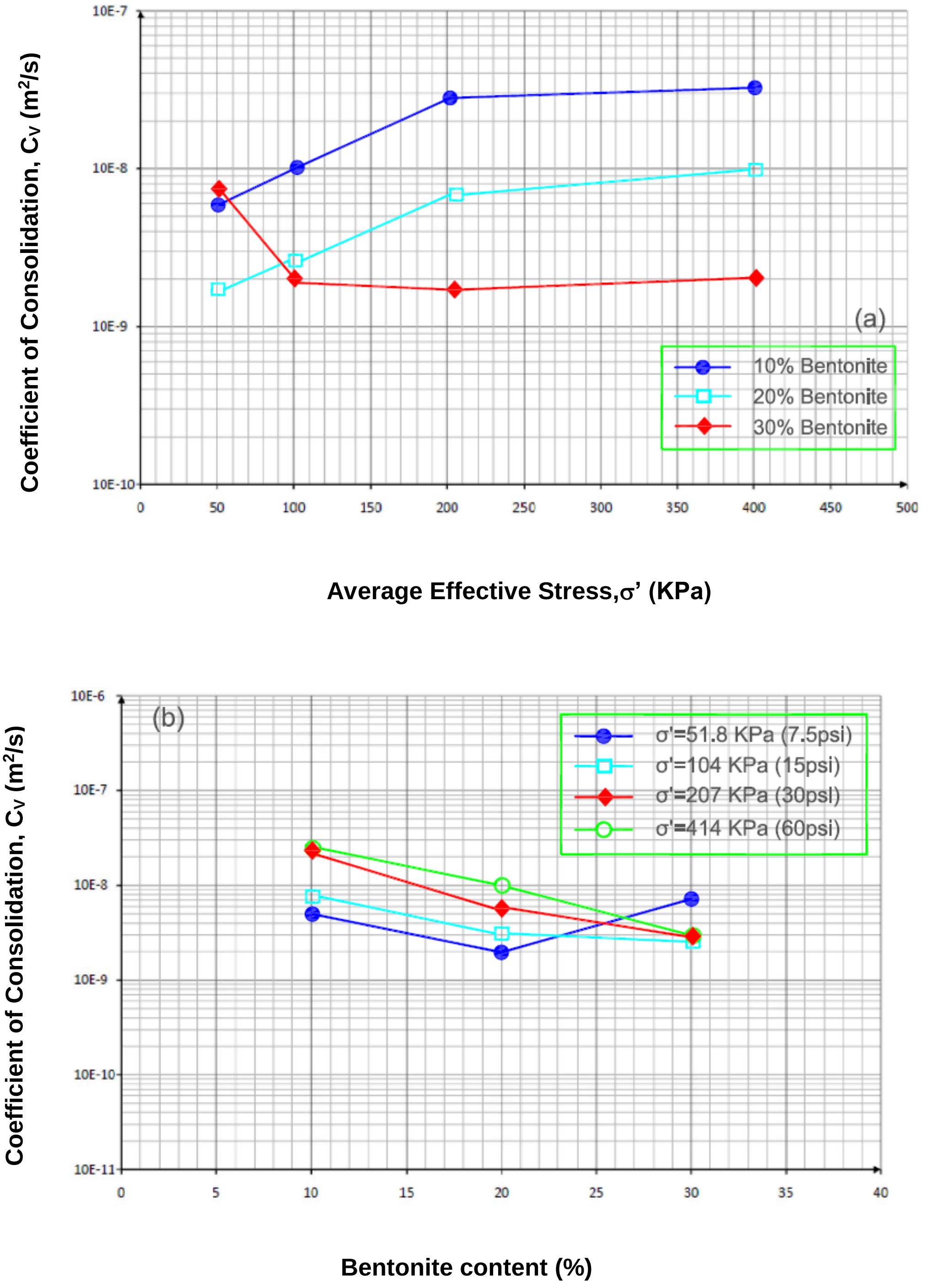

Figure 7. Effect of (a) effective stress and (b) bentonite content on the coefficient of consolidation, **c_v** for sand- bentonite mixtures mixed at the liquid limit.

5. CONCLUSIONS

- The initial water content has no effect on the mixture containing 10 percent bentonite, whereas a significant effect is noticed for 20 and 30 percent bentonite mixtures.
- For mixtures containing 20 and 30 percent bentonite, the compressibility parameters, C_c, C_s, a_v, and m_v for the specimens mixed at liquid limit are higher than those for specimens mixed wet of w_{opt}.
- As expected, the compressibility parameters C_c, C_s, a_v, and m_v increased as the bentonite (clay particle)-content increases.
- The coefficient of consolidation, C_v slightly increase or decrease on the normally consolidated part of the curve (C_v versus σ').
- No significant difference among the measured compressibility parameters C_c , C_s , a_v, and m_v using the oedometer (one-dimensional)

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