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Investigation of the Sample Disturbance Effects on Consolidation Parameters Obtained from Conventional Oedometer Tests

Numune Örselenmesinin Geleneksel Ödometre Deneyleri ile Belirlenen Konsolidasyon Parametrelerine Olan Etkilerinin İncelenmesi

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ABSTRACT

This study explores the effects of sample disturbance on the compression curves obtained from oedometer tests and the inferred effective preconsolidation stress (σ_p'). The samples were systematically disturbed by removing different fractions of the soil ranging from 10%, 20%, 30%, 40%, and 50% and remolding them back into place to reach the same initial void ratio. It was found that when the rate of disturbance was increased, it became more difficult to determine the σ_p' values on the compression curve; the typical bending point on the compression curve became increasingly indistinct, and negligible changes occurred in the σ_p' values of the disturbed soil samples up to a disturbance rate of 40%. If the soil samples whose consolidation parameters, such as preconsolidation stress, can't be determined are subjected to disturbances greater than 40%, it is recommended that no consolidation parameter for such samples be specified.

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ÖZET

Bu çalışmada, numune örselenmesinin geleneksel konsolidasyon deneyleriyle elde edilen sıkışma eğrileri ve ön konsolidasyon gerilmesine (σ_p') olan etkileri incelenmiştir. Laboratuvara getirilen numuneler sistematik olarak %10, %20, %30, %40 ve %50 oranında içleri boşaltılıp geri doldurularak örselenmiştir. Örselenme oranının artmasıyla, sıkışma eğrisi üzerinde σ_p' değerlerinin belirlenmesinin giderek zorlaştığı, sıkışma eğrisindeki tipik büküm noktasının giderek belirsiz bir hale geldiği ve %40 örselenme oranına kadar örselenen zemin numunelerinin σ_p' değerlerinde önemsenmeyecek miktarda değişimlerin olduğu tespit edilmiştir. Ön konsolidasyon gerilmesi gibi konsolidasyon parametrelerinin belirlenemediği zemin numunelerinin %40'dan daha fazla örselenmeye maruz kaldığı ve bu tür örnekler üzerinde konsolidasyon parametrelerinin belirlenmemesi gerektiği önerilmektedir.

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1. INTRODUCTION

To demonstrate the effects of mechanical and textural properties of soils on engineering parameters, the stresses that they have been exposed to since their formation and the effects of those stresses on the soil structure should be determined. The calculation of long-term settlement due to forces directly transmitted to the soil through the foundation, particularly in clayey soil, is of great importance for the engineering branches dealing with soil mechanics. The parameters obtained from the oedometer test are taken into account when calculating the amount of consolidation settlement. Casagrande (1932) suggested that soil has memory, and trapped in its texture is the maximum effective stress it has been exposed to since its formation. He defined the maximum effective stresses recorded in the texture of the soils as the effective preconsolidation stress σ_p', and developed the method named after him for determination of this value. The determination of consolidation parameters in soil mechanics through various calculations and analyses of graphical relationships has contributed greatly to investigations of grain size distribution, coefficient of permeability, preloading times, preconsolidation stresses, and the effects of such stresses on soil memory.

Stresses in soils can occur in any direction as a result of preconsolidation stress on the soil, the construction of engineering structures on the soils, or geological events such as folding, faulting, and creep [1]. If the loadings that apply stress to the soil have a long-term effect on the soil, all of the total stresses are recorded in the soil memory as effective stress [2]. Many researchers have developed different methods for the determination of the preconsolidation stresses that soils were subjected to in the past [3-9]. The reviews performed by these researchers are all based on Casagrande's method. Among the methods employed to determine the σ_p' value, the most reliable and frequently used is the one devised by the Casagrande (1936) method. Examples of numerous studies exploring the effects of sample disturbance on the mechanical properties of soils can be summarized as follows.

Ward et al. (1959) even identified the maximum horizontal effective stresses that the soil had been subjected to in the past using Casagrande's (1936) method [10]. On the other hand, Cetin (1997; 2000) determined the movement pattern of the fault 1100 years ago (seismic/aseismic) by finding the preconsolidation stresses recorded in the soil memory along the Meers fault in the USA [11-12]. Gunaydin and Cetin (2020) also used the same method on the East Anatolian Fault [13]. Yang et al. (2020) studied the effects of sample disturbance on the cyclic shear strength of clays [14]. Lim et al. (2019) assessed the geotechnical parameters of soils during design, which were obtained by different types of samplers depending on the disturbance in the soil caused by the samplers [15]. Tommasi et al. (2019) evaluated the disturbance of open sea sediments using two types of gravity piston coring techniques [16]. Lukas et al. (2019) explored the effects of soil disturbance caused by samplers used in low-plasticity soils on undrained shear strength [17]. D'Ignazio et al. (2017) reported the disturbance that occurs during the preparation, handling, and storage of soil samples taken from quick clay using the finite elements method [18]. Carroll and Long (2017) assessed the effects of disturbance on the results of cone penetration tests with pore water pressure and shear wave velocity tests using different types of samplers in silt soils [19]. Karlsson et al. (2016) commentated on the effects of sample disturbance on estimations of the amount of settlement in soft clay [20]. Zapata-Medina et al. (2014) questioned the effects of stress history and sample disturbance on over-consolidated clays in the laboratory [21]. Horng et al. (2011) studied the change in the undrained shear strength of disturbed samples [22]. Ingles and Lafeber (1966) explored whether or not the pore distribution and grain orientation of soils can change due to the alteration of stresses caused by disturbance, etc., on the soil [23]. The mentioned studies, however, deal mainly with the effects of the type of sampler on disturbance and the effects of disturbance on the mechanical parameters of the soil.

While there has been no study to date directly addressing the effects of systematic sample disturbance on σ_p' values determined through conventional oedometer consolidation tests, the studies that most closely resemble the present study are those conducted by Lunne et al. [24-25]. Lunne et al. (2008) over-consolidated natural soil samples by preloading in the laboratory. They conducted drained constant rate of strain (CRS) consolidation tests and undrained triaxial tests on natural soil samples and soil samples that they had disturbed through different loading techniques to explore the stress-strain relationship in both types of soil samples. They determined the effects of the applied disturbance method on this relationship [26].

In the present study, a systematic disturbance method was employed, and the effects of sample disturbance on σ_p' were addressed, for which identical soil samples were taken from the field and brought to the laboratory. The samples were systematically disturbed at a rate of 10%, 20%, 30, 40%, and 50% in the laboratory. The purpose of systematically disturbing the samples was to create further stresses on the soil structure and texture, in addition to the stresses they had been subjected to in their natural formation environments, with the aim of investigation of the effects of these stresses on the typical compression curves and σ_p' of the soils. Oedometer tests were conducted on the systematically disturbed soil samples and those with a disturbance rate of 0% (intact: not subject to any disturbance). Parameters such as σ_p', compression index (C_c), recompression index (C_r), void ratio (e), and curvature angle (C_a) values were determined by the oedometer tests on the soil samples with a disturbance rate of 0% and the systematically disturbed soil samples. In this study, a specific method was employed to determine the change of curvature in the void ratio (e)-effective stress (σ') graph. This method involves the intersection of the straight-line portion of the virgin compression curve and the linear extension line up to the σ_p' to determine the angle between them in degrees. This angle is defined as the “curvature angle” (C_a) and is shown in Figure 1. The consolidation parameters such as C_c, C_r, σ_p', and C_a values of each sample were compared using the e-σ' graphs.

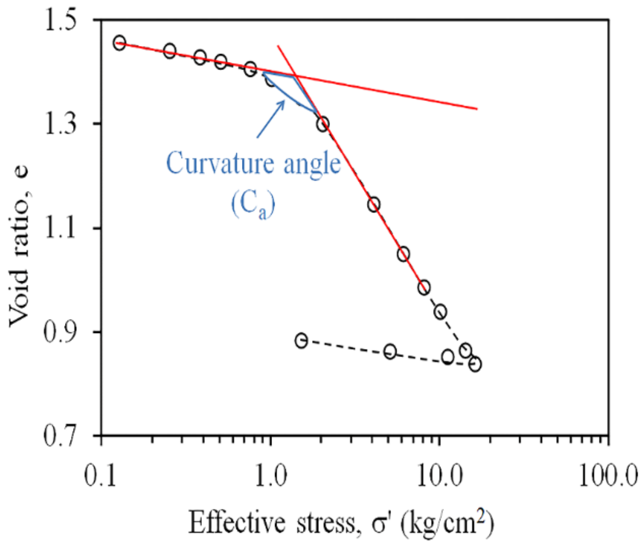

Figure 1. Approach to determine the curvature angle (C_a).

2. MATERIAL

2.1. Soil samples

The disturbed and undisturbed soil samples used in the study were taken from the Quaternary sediments of the Nigde stocks in the southeast of the Central Anatolian Region, Turkey, where clayey silt is densely located. The index properties of the soil samples were determined and presented in Table 1.

Table 1. Index properties of soil samples used in this study.

Symbol	Definition	Unit	Value (Average)
γ_n	Unit weight	g/cm^3	1.74
γ_d	Dry unit weight	g/cm^3	1.21
γ_{sat}	Saturated unit weight	g/cm^3	1.76
γ_s	Solid unit weight	g/cm^3	2.65
e	Void ratio	%	118.41
n	Porosity	%	54.38
w	Water content	%	43.02
S_r	Saturation	%	96.35
LL	Liquid limit	%	52
PL	Plastic limit	%	38
USCS	Unified Soil Classification System	-	MH

MH: Inorganic silt of high plasticity.

3. METHODS

3.1. Sampling

The samples were taken in two groups, namely, disturbed and undisturbed, from a foundation, where the disturbance was minimum and where the water content was maximum. The disturbed samples were collected from the sidewall of the foundation excavation using the grooving method such that they weighed 20 kg. The samples were then reduced to 5 kg using the quartering method. The undisturbed samples were taken using two different methods, namely, consolidation rings and tubes.

Usually, block samples are brought to the laboratory for consolidation tests, and the process of inserting them into the consolidation ring (50 mm in diameter and 20 mm in height) is carried out in the laboratory. In this study, this process was carried out in the field as the sample disturbance was significant. For the insertion of undisturbed samples into the consolidation rings, the inner surfaces of the rings were lubricated, after which the rings were seated on the soil surface and pressed into the soil with the help of the mold placed on them. To keep sample disturbance to a minimum, the consolidation rings were not hit with a hammer or any other tool, with only pressure applied to take the samples. A total of 18 intact samples were taken using this method. Each oedometer test was performed for 3 soil samples, and their average values were given in the study. In the sampling process with the sample tube, the weight of the standard sampling device was dropped from a certain height so that the soil sample penetrated the tube. This method was applied to fill 5 sample tubes. Index properties of soils were determined using tube samples. The different stages of the sampling process are shown in Figure 2. Oedometer tests were performed according to the American Society of Testing Materials (ASTM) D2435 standard (ASTM, 2003) on the systematically disturbed and undisturbed soil samples by applying 24-h incremental loading [27]. When the preconsolidation stress is being approached, the load increments placed on the soil samples are reduced to more precisely define the transition between the reloading curve and the virgin compression curve.

Figure 2. a) Tube sampling with sampling device, b) cleaning the outer side walls of the tube samples, c) waxing of the upper and lower parts of the tube samples, d) undisturbed soil sample image was taken into the consolidation ring.

3.2. Systematic sample disturbance

For the purpose of the study, the soil samples brought to the laboratory for oedometer tests were artificially disturbed at the rates of 10%, 20%, 30%, 40%, and 50%. Details of systematic disturbance of the soil samples are as follows: First, molds were formed on transparent paper, having the same diameter as the consolidation rings. Disturbance rates were selected for each mold. Boundary lines were drawn on the edges of the molds, and the boundaries of the sections to be disturbed were determined with a ruler. The marked areas were emptied using a pointed tool (Figure 3). The emptied sections were filled back with the soil removed from the voids. The same procedure was carried out for the remaining samples and for all selected percentiles.

Figure 3. a) Percentage slices determined on transparent paper, b) marking the boundaries, c) marking the determined percentile on the soil sample and d) views of the slices to be emptied on the soil sample.

This process involves the selection of slices in different directions so that the disturbance is spread across the soil sample. Precautions were taken to protect the water content of the soil sample by carrying out the process as quickly as possible. The tests were started by placing the prepared samples immediately into the oedometer cell. It was avoided going beyond the determined boundaries of disturbance. Figure 4 shows the amount of systematic disturbance in the soil samples.

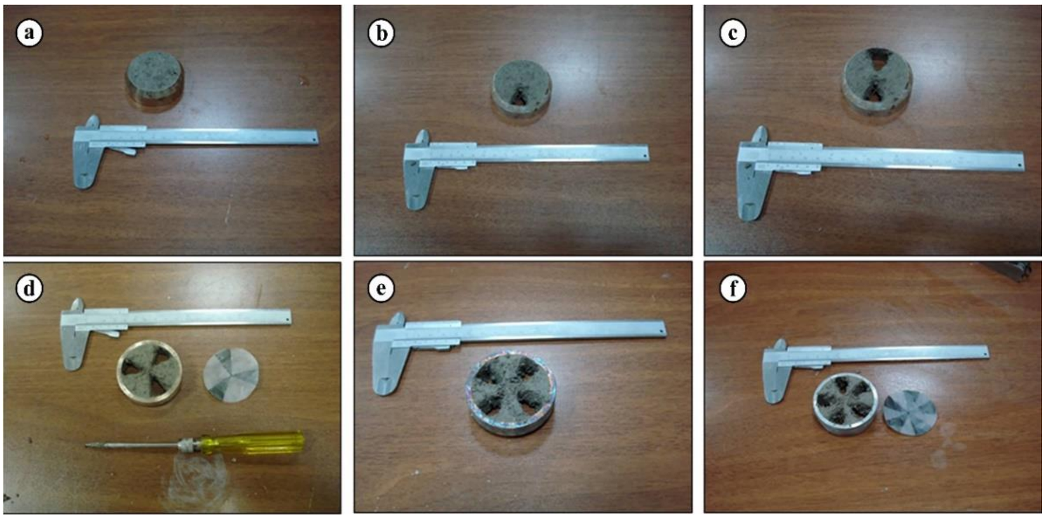

Figure 4. a) Intact soil sample (0% disturbance), b) 10% disturbed soil sample, c) 20% disturbed soil sample, d) 30% disturbed soil sample, e) 40% disturbed soil sample and f) 50% disturbed soil sample.

4. EXPERIMENTAL RESULTS

Data for the oedometer test of the intact soil samples that had a disturbance rate of 0%, and the other soil samples that were systematically disturbed, are presented in Table 2. The results of the consolidation tests indicate that the σ_p' values of all systematically disturbed soil samples, excluding the sample with a disturbance rate of 50% (i.e., those with a disturbance rate of 10%, 20%, 30%, and 40%), and the undisturbed soil samples (a disturbance rate of 0%), were approximately 1.85 kg/cm^2. Figure 5 shows the σ_p' values of all soil samples. As can be concluded from the data, it is seen that there is a significant change in the preconsolidation stress of up to 20% disturbance. From this ratio (20% disturbance), it is possible to say that there is no significant change in the pre-consolidation stress.

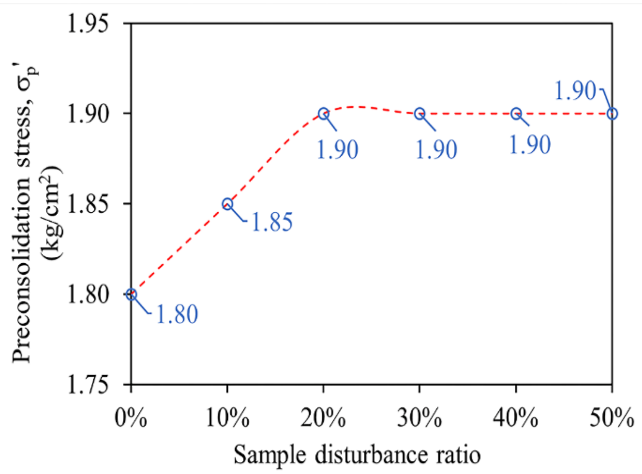

Figure 5. Preconsolidation stress values of soil samples obtained by Casagrande's method from oedometer tests.

The compression index values of the soil samples used in this study are given in Table 3. Recompression index (C_r) values of the soil samples increase with an increase in the amount of disturbance due to the change depending on the slope of the recompression curve. According to Table 3, it is possible to say that there are decreasing and increasing changes in the compression indexes.

Table 2. Odometer test data of disturbed soil samples.

Sample Disturbance Ratio:			0%		10%		20%	
Time (Hour)	Load (kg)	σ_v' (kg/cm^2)	D (cm)	e	D (cm)	e	D (cm)	e
24	0.25	0.127	0.010	1.456	0.010	1.456	0.015	1.449
48	0.50	0.255	0.021	1.440	0.025	1.435	0.033	1.423
72	0.75	0.382	0.029	1.429	0.034	1.422	0.047	1.403
96	1.0	0.509	0.036	1.419	0.042	1.410	0.056	1.391
120	1.50	0.764	0.045	1.406	0.056	1.391	0.069	1.372
144	2.0	1.019	0.059	1.386	0.069	1.372	0.081	1.355
168	3.0	1.528	0.085	1.349	0.090	1.342	0.101	1.327
192	4.0	2.037	0.120	1.300	0.120	1.300	0.125	1.293
216	8.0	4.074	0.229	1.145	0.229	1.145	0.210	1.172
240	12.0	6.112	0.296	1.050	0.296	1.050	0.270	1.087
264	16.0	8.149	0.342	0.985	0.342	0.985	0.312	1.027
288	20.0	10.186	0.375	0.938	0.375	0.938	0.349	0.975
312	28.0	14.260	0.427	0.864	0.427	0.864	0.405	0.895
336	32.0	16.297	0.446	0.837	0.446	0.837	0.437	0.850
336	22.0	11.205	0.436	0.852	0.436	0.852	0.413	0.884
360	10.0	5.093	0.429	0.862	0.429	0.862	0.386	0.923
386	3.0	1.527	0.414	0.883	0.414	0.883	0.346	0.978
Sample Disturbance Ratio:			**30%**		**40%**		**50%**	
Time (Hour)	**Load (kg)**	**σ_{vc}' (kg/cm^2)**	**D (cm)**	**e**	**D (cm)**	**e**	**D (cm)**	**e**
24	0.25	0.127	0.002	1.449	0.010	1.456	0.000	1.470
48	0.50	0.255	0.032	1.423	0.046	1.405	0.016	1.447
72	0.75	0.382	0.050	1.403	0.067	1.375	0.028	1.430
96	1.0	0.509	0.063	1.391	0.083	1.353	0.038	1.416
120	1.50	0.764	0.085	1.372	0.108	1.317	0.055	1.392
144	2.0	1.019	0.104	1.355	0.128	1.289	0.069	1.372
168	3.0	1.528	0.131	1.327	0.154	1.252	0.093	1.338
192	4.0	2.037	0.159	1.293	0.181	1.213	0.115	1.307
216	8.0	4.074	0.248	1.172	0.255	1.108	0.175	1.222
240	12.0	6.112	0.305	1.087	0.301	1.044	0.224	1.152
264	16.0	8.149	0.346	1.027	0.336	0.993	0.261	1.100
288	20.0	10.186	0.379	0.975	0.360	0.959	0.289	1.060
312	28.0	14.260	0.421	0.895	0.403	0.899	0.336	0.993
336	32.0	16.297	0.441	0.850	0.423	0.871	0.355	0.967
336	22.0	11.205	0.430	0.884	0.401	0.902	0.353	0.969
360	10.0	5.093	0.398	0.923	0.379	0.932	0.345	0.981
386	3.0	1.527	0.361	0.980	0.353	0.970	0.330	1.000

σ_{vc}': Effective vertical consolidation stress, D: Displacement, e: Void ratio.

Table 3. Compression index values of soil samples obtained from oedometer tests.

Sample Disturbance Ratio	C_r	C_c
0%	0.056	0.51
10%	0.070	0.51
20%	0.090	0.51
30%	0.143	0.48
40%	0.169	0.38
50%	0.183	0.42

C_r: Recompression index, C_c: Compression index.

As for the curvature angle (C_a) values in all of the soil samples, the undisturbed sample had the lowest C_a value (140°) and the most disturbed sample had the highest C_a value (165°), meaning that as the rate of disturbance increases, so do the C_a values. Figure 6 gives the C_a values of the soil samples.

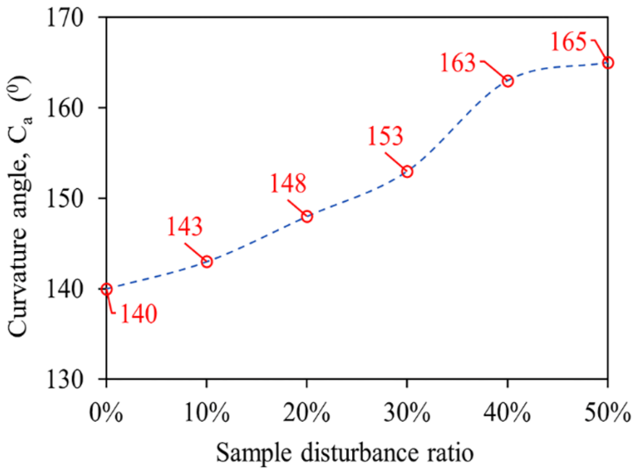

Figure 6. Curvature angle (C_a) values of soil samples.

All e-σ' graphs of the soil samples used in the study are presented in Figure 7. As can be seen in Figure 7, a comparison of the compression curves of the soil samples (except for the compression curve of the sample with a disturbance rate of 50%) suggests a relationship similar to that observed in the relevant literature. Because the structure and texture of the sample that was moved at a rate of 50% were moved at a rate higher than a certain rate, it behaves differently than the other samples.

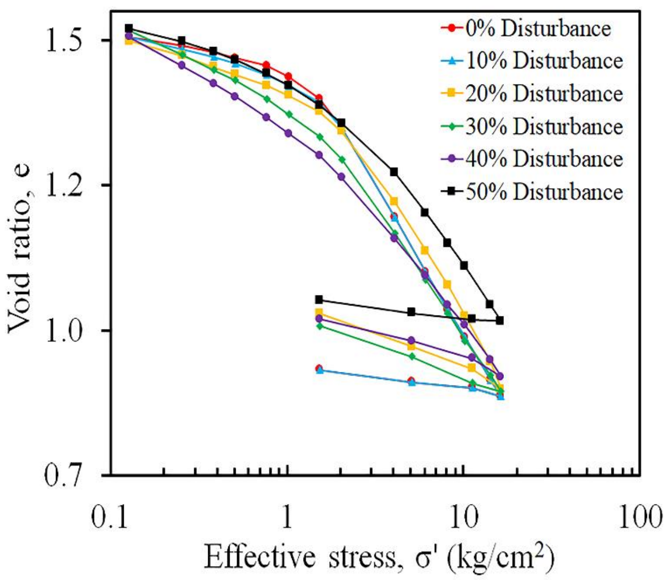

Figure 7. Void ratio (e) – effective stress (σ') graphs of the soil samples.

The initial void ratios (e_0) and final void ratios (e_f) given in Figure 8 indicate that the e_0 values of all soil samples are close to each other, but the e_f values differ depending on the deformations. The e_f values were noted to increase as the amount of disturbance increased. The fact that the e_0 values are so close to each other indicates that the prepared samples were identical and that the systematic disturbance had been carried out for the purpose of the study.

With the increase in the amount of disturbance, the compression curves shift downward and leftward in the e-σ' graphs. This is thought to be since the soil samples converge with the σ_p' values with increasing disturbance, and that immediately afterward, their structures change rapidly and become over-consolidated. The fact that the e_0 values of the undisturbed soil samples (0% disturbance) and those disturbed at varying rates are almost equal is an indication that the disturbance process and the re-establishment of the samples have been carried out successfully.

There has been no research to date on the relationship between the level of proportional disturbance and σ_p' and e-σ_p' graphs, other than those investigating the e-σ_p' graph relationships of undisturbed samples and the same type of fully disturbed (remolded) samples.

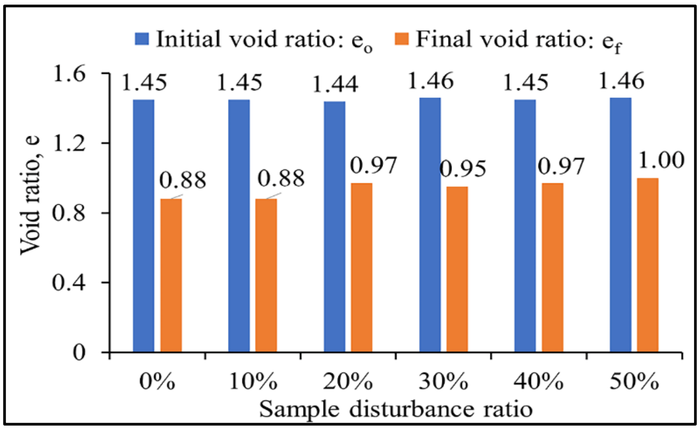

Figure 8. Initial void ratio (e_0) and final void ratio (e_f) values of soil samples.

As such, the significant results obtained from the systematically disturbed soil samples in this study can be considered the contributions of this study to the literature. Quigley and Thompson (1966) studied the compression curves of a sensitive marine clay called Laurentian or Leda clay [28]. From this point of view, fracture or sudden bending when the preconsolidation stress is reached is typical for highly sensitive clays. The curve slopes slightly up to this point; but as soon as the preconsolidation stress is reached, the structure of the soil collapses quickly and dramatically [29].

It has been observed that the void ratio - effective stress curves determined in this study behave as accepted in the literature. All of the results show that it would be helpful to have a wider range of samples to learn more about how systematic disturbance affects consolidation.

5. CONCLUSION

The results obtained in this study can be listed as follows:

It was found that negligible changes had occurred in the σ_p' values of the disturbed soil samples up to a certain disturbance rate 40%.

It was seen that the C_a values went up as the soil samples that were tested were moved around more.

It was found that as the level of disturbance of the soil samples was increased, the breaking and bending points in the typical compression curves became increasingly indistinct due to the rising stress in the soil samples with greater disturbance levels.

The breaking and bending points that cannot be clearly distinguished on the compression curves of e-σ_p' graphs in such experimental applications must be derived from soil samples with a disturbance rate of more than 40%. Such soil samples are not recommended for use in determining σ_p' values and other consolidation parameters.

It is thought that using a larger number of soil samples with different rates of disturbance will give results that back up this study even more.

Author's Contributions

Muharrem DUMANLILAR: Investigation, Resources, Validation, Formal analysis
Mustafa FENER: Supervision, Term, Methodology, Validation, Formal analysis
Mehmet Can BALCI: Investigation, Writing - Original Draft, Writing - Review & Editing

Statement of Conflict of Interest

The authors of the article declare that there is no conflict of interest between them.

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