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Determination of Dynamic Parameters of Clay

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ABSTRACT:In general, besides being static case of studies at soils and construction, with dynamic effects, which are the one of the most influential elements of soils and constructions, the effects of cyclic stresses on the soil are investigated. Preliminary knowledge of the behavior of the soils during cyclic loading, ensures that the necessary precautions are taken and the damage to structures on these soils can be reduced. In the past, it was thought that the damaging effect of earthquakes was due to the inadequate selection of building materials and building elements but with recent earthquakes it is found that soils are very effective for the earthquake's damage and magnitude. Also, large shear strains occur in strong earthquakes. The behavior of the soils under a certain load, such as strain, compression and resistance to shear stresses control with effective stresses. During the earthquake, the behavior of the soil is affected by the water pressure of the pore as well as the physical characteristics of the soil. Therefore, for the analysis of dynamic parameters under low stresses, resonant column test was carried out in clay soil sample, at different cell pressures and after that cyclic loading was applied to sample in the torsional shear test until the failure. As a result of the tests, with increasing cell pressure, the maximum shear modulus of the clay soil was increased while the damping ratio decreased in the resonant column test. In the torsional shear test, the pore water pressure increased with increasing the cycles.

KEYWORDS: Resonant column test, Torsional shear test, Earthquake, Soil dynamic.

I. INTRODUCTION

In order to take precautions against the problems that dynamic effects can cause to the soil, both the dynamic effects and the properties of the soil must be well known. Knowing in advance the behaviour of the soil layers during cyclic loading, provides to taking necessary precautions and reducing the damage that may occur due to structures on these layers. Cyclic loading can be high amplitude and short-term such as earthquake or it can be low amplitude and longterm such as wave, traffic load, machine fundamental vibration. Behaviour of clay soils under cyclic loads is a complex problem. A basic method for calculating both soil bearing capacity and deformations under cyclic loading, is not developed yet [1]. The reason of this, many factors that affecting dynamic behaviour such as, time-dependent damping, pre-consolidation period, cyclic load's characteristics, ground parameters and groundwater. The studies examined carried out the damage that will occur on the soils because of dynamic load are generally focused on the problem of liquefaction on the sands. During an earthquake, clay was considered more resistant to earthquake vibrations when compared to sand [2]. Nevertheless, it was observed that serious structural damages occurred in thick clay layers during the earthquake [3,4]. As a result of the investigations, it was realized that large deformation caused by seismic motion during the earthquake is a feature of clay soils. The increasing of the earthquake waves amplitude when it passes through the soft soil layers near the surface, cause significant effects on structural damage. Also it was observed that in Japan, Niigata earthquake at 1964 and Miyagiken-oki earthquake at 1978, caused many collapses in clay soils [5] Such situations bring to mind the question that whether the clay indeed more resistant from sand to cyclic loads or not. Although this is partially true for short-term cyclic loading, the situation in the case of long-term cyclic loading is different [6]. Furthermore, even if the cyclic shear strength of the horizontal layered clay soils does not cause a serious stability problem, the increase of the pore pressure during the earthquake can cause severe settlements. For this reason, it is important to investigate behaviour of consolidation and pore water pressure under the cyclic loading of clay. In this study, the clay specimen was prepared under the 100kPa compaction energy and it was consolidated at 100kPa, 150kPa



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and 200kPa cell pressure. After each consolidation phase, strain controlled resonant column test was experimented on the same sample. After the last resonant column test, the torsional shear test was applied to the sample until the failure. Thus, the dynamic behaviour of the clay soil was investigated.

II. RELATED WORK

Cyclic stresses cause the reduction of effective stress on the soils, thus reducing undrained shear strength and stiffness. Cyclic stresses lead to a decrease in undrained shear strength in clay soils. In clays, as result of cyclic stresses settlements can occur immediately after the earthquake and also it can be after a long period of time due to the properties of the soil [7]. These settlements usually occur as a consolidation stage and it appears when the pore pressure that occurred by cyclic loads during an earthquake, is dissipated.

Elgohary (1973) stated that the uniaxial consolidation theory of Terzaghi does not cover the cyclic loads and in most applications the equation of this theorem is used. In that study, kaolin sheath with Gs = 2.60, LL = 71%, PL = 40% and PI = 31 is used. Slurry method is used when preparing the samples. Using kaolin clay, the three-axis consolidation and consolidation under cyclic loading is compared. Also it is declared that, when a floor layer is subjected to cyclic loading, when the layer is loading, the positive pore water pressure increases, and the negative pore water pressure increases when the layer is unloading. As the cyclic loading and unloading conditions continue, positive pore water will decrease, negative pore water will increase, and finally a steady state will occur. Finally, the positive and negative pore water pressure will have the ultimate equilibrium value. The equilibrium in steady-state conditions implies that the consolidation ratio will be a function of the cyclic loading model. This means that the part of the pressure applied at this point is transferred to the ground level, and the rest of the pressure affects the pressure of the water, and in this case the floor is completely elastic and the shape change reaches its maximum values. As a result of the study, it is seen that the consolidation that occurs as a result of continuous load is progressing faster than cyclic loading. Due to this reason, while continuous consolidation continues to its progress, the consolidation in the cyclic load only occurs during loading and when the load is lifted, the swell slow down the consolidation is announced [8].

Ansal and Tuncan (1989) obtained samples with over-consolidation ratios of 1, 3 and 5 using the CH class clay under the Golden Horn and the CL-OL class silt clay from Baltalimani. In their experiments, the consolidation ratio due to cyclic stresses that occurred during the damping of the water pressure is inspected. Dynamic simple three axis and dynamic simple cutting devices without drainage is used in their studies. Cyclic loading was applied to sample at 0.1 Hz frequency and as 50 cycles. As a result of their experimentation, a little amount of pore water pressure appeared because of the cyclic loading in the over consolidated clays. Also settlement is at negligible levels. However, in the case of normally consolidated clays, a large amount of pore water pressure is appeared. This situation caused a serious amount of settlement. In the second part of their work, researchers examined of the number of cycles causing the settlement and the magnitude of dynamic shear stress causing consolidation in the normal consolidated clays. The increase at the number of cycles has led to an increase of the pore water in the sample. In the same way, it is observed that, as the dynamic shear stress applied to the sample increases, the pressure in the pore water increases [9].

Yıldırım and Ersan (2007) examined the consolidation settlements in soft clay soils resulting from cyclic tensioning with simple shear tests. Using different stress magnitudes and different number of cycles, they used a high plastic clay soil with a liquid limit of 73%, a plastic limit of 25%, a plasticity index of 48 and a grain specific weight of 26.4kN / m3 is used in their studies. The clay they used in their studies were obtained from the Zeytinburnu region of Istanbul and there are 48.5% clay in the clay ground. They used the slurry method in their experiments. In the study, successive cyclic stresses were applied on normal consolidated clay samples with 50 cycles each series. The sample was allowed to drain for 60 minutes between the series. In the experiment, two-way sinusoidal cyclic load with 0.1 Hz frequency stretching control was used in drainage-free conditions, and samples were loaded at different strain amplitudes at different cycles. In the experiment, it was observed that during the initial loading stage, the drainage pressure increased in the drainage-free conditions. However, due to the reduction in the ratio of voids with allowed drainage after each cyclic loading series, the void space that occurs in consecutive loading stages has gradually decreased. In addition, the increase in the cyclic stress ratio and the number of cycles affected the shape changes in the soil. As the strain rate and the number of cycles increased too. The volumetric deformation between each cyclic



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series in the study decreased as the number of series increased. At the initial stretching ratio of 7%, the volumetric strain ratio was 2% at 100 cycles, while at the end of 5 batches, this ratio decreased to 0.4% [10].

Abbaspout et al. (2015) examined the increase in consolidation and pore water pressures in samples they prepared with slurry mud. Samples are placed them in a water tank in order to create cyclic stress. Due to the change in water level between the upper and lower surface of the sample have been placed, the cyclic loading by means of different lifting forces have formed. Ground samples from the Meybod region of Iran, which had a liquid limit of 28, a plastic limit of 20 and a specific gravity of 2.57 in their CL class is used in their studies. A new method has been presented for determining the consolidation coefficient by making use of the results obtained. Then this compared with the logarithm time method and the square root time method. The method of they represented gives approximately equal results with these two methods. Researchers have said that using logarithmic time and graphs in square root time method can lead to erroneous results, but this error can be removed from the way by the method they represented. Moreover, according to the results obtained, the theoretical method revealed significant differences with the experimental results. It is indicated that, due to fact that at the beginning of cyclic loading the damping of pore water is faster [11].

III. METHODOLOGY

Resonant column test has been used since the late 1930s to determine the ground slip parameters at low deformation amplitudes [12,13]. Nowadays, the resonant column test can calculate the shear modulus and damping ratio at the deformation amplitudes between 10^{-5} % and 1%. Hardin and Drnevich (1972a) reported that, in the absence of consolidation, it was a very suitable test method for determining cyclic shear behaviour at the time of the resonant column experiment [14]. Resonant column test can be used for analysis and design related to earthquake effects, traffic vibrations, machine foundation and static loading situations where consolidation has not occurred [15]. The resonant column experiment was first described in 1981 by Drnevich et al. (1978) have been standardized by ASTM based on their large scale work [15]. Since the 1980s, many researchers have contributed to the development of the resonant colon experiment [16,17]. Werden et al. (2013) presented a new approach to the resonant colon experiment [18]. In this approach, a new torsional sheer and resonant column device with semi-fixed base and free head is introduced. In this device, a relatively rigid torque transducer head is positioned between the base and the stationary chamber base (Figure 1).



Figure 1. Resonant column device [11]

Drnevich et al. (2015) presented an overview of the updates you have made to the introduced device by Werden et al. (2013) [19]. They have described new solutions for determining shear modulus, damping and shear deformation from the data obtained by the resonant column experiment with the new approach and how these solutions can help to



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calibrate the device. In addition, the characteristics of this new type of device, which is found in the Standard Test Methods for Substrate Module and Damping with Fixed Base Resonant Column Device (ASTM D4015, 2015), have been examined [20]. In this study, the dynamic behaviour of clay soils, Werden et al. (2013) the resonant column test is used.

A. Sample Preparation

Laboratory experiments on the soils are an important part of geotechnical engineering for both research and design purposes. The sample preparation method has a critical pre-requisite for correct modelling of the experiments to be carried out. Many studies have shown that soil behaviour is highly dependent on laboratory specimen preparation techniques [21,22]. There are various sample preparation methods in the literature. The most commonly used methods are dry pluviation, moist tamping, water sedimentation, slurry deposition, dry deposition and moist vibration [23,24,25]. For sample preparation of cohesive soils in the laboratory test, the most commonly used methods are slurry deposition and compaction [26]. ASTM D 4015 - 92 standard is used for compacting the specimen in the study. It is stated in this standard that the diameter of the samples should be at least 33 mm and the aspect ratio should be at least 2. The samples were prepared by moist tamping method to have a diameter of 70 mm and a length of 140 mm. It is desirable that the sample has a pre-consolidation pressure of 100kPa. Therefore, when the sample was prepared, the compaction energy was used. Compaction energy can be adjusted with the number of cycles and the falling height of the steel hammer [27, 28].

In this study, pre-consolidation pressure was determined by performing a consolidation test on the sample which was prepared equivalent to 100kPa compaction energy. In this way, compaction energy was controlled. As a result of the consolidation test, the pre-consolidation pressure was found 100kPa. (Figure 2).



B. Materials

In this study, the variation in the dynamic behaviour of the clay soil was investigated by resonant column test and torsional shear test. The geotechnical properties of the clay soil used in the tests are given in Table 1.



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Table 1. Index properties of clay

Soil	Liquid Limit (LL)	Plastic Limit (PL)	Specific Gravity (Gs)	Classification
Clay	57	28	2.64	СН

Specific gravity of clay was determined with pycnometer test and Atterberg limits of clay was determined with Casagrande test. In order to determine of the soil class according to the ASTM D4221-99 standard [29], hydrometer test was performed (Figure 3). The result of the classification, clay soil was determined as CH.





In this study, a clay soil sample was prepared at 100kPa compaction energy with moist tamping method and then subjected to saturation. The saturation of the sample is controlled by the B parameter of Bishop and the sample is considered saturated if B > 0.95. After the saturation phase sample was consolidated under 100kPa, 150kPa and 200kPa. After each consolidation phase, resonant column test performed on the same sample. Namely, after the saturation phase, fully saturated sample was consolidated under 100kPa pressure and after that resonant column test performed on that sample. When the first resonant column test finished, same sample was consolidated under 150kPa pressure and after the consolidation phase another resonant column test performed. After that second resonant column test, the sample was consolidated under 200kPa pressure and after this phase resonant column test performed one again. Finally, after the last resonant column test torsional shear test was performed on the same sample. Cyclic loading was applied under strain-controlled conditions. Shear strain was %1 in the resonant column test and %5 in the torsional shear test. Torsional shear test was performed conditions. The changes in damping ratio and maximum shear modulus were found for the clay sample that subjected to cyclic stresses after the different loading conditions with the resonant column tests. As a result of the experiments carried out, the maximum shear modulus (G_{max}) of the clay soils under the higher pressure was increased while the damping ratio (D) decreased (Figure 4). The results obtained were consistent with the results in the literature [30].



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Figure 4. Shear modulus in resonant column test

The torsional shear test was performed as 0.5 Hz frequency on the sample, the maximum shear strain would be 5%. As a result of the experiment, the sample was failure at the end of the cycle 29. During each cycle, 100 readings were made to find average peak shear stresses and peak shear strains.

Shear strain-damping ratio and shear strain-shear modulus curves also determined in torsional shear test. When the shear strain reached 5 percent during the test, the damping rate of the sample increased to 40.5% and the shear modulus decreased to 100kPa. At that time, 14.912kPa of excess water pressure was occurred in the sample. As the shear strain increased, the damping ratio increased and the shear modulus decreased (Figure 6 and 7).







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In the experiment conducted under undrained conditions, the pore pressure increased with the increasing number of cycles (Table 2).

Cycle	Excess Pressure		
1	1.7619		
2	3.0123		
3	4.149		
4	5.1152		
5	5.9677		
6	6.7634		
7	7.5591		
8	8.1843		
9	8.8663		
10	9.3778		
11	9.9462		
12	10.401		
13	10.799		
14	11.197		
15	11.538		
16	11.879		
17	12.163		
18	12.39		
19	12.504		
20	12.561		
21	12.617		
22	12.747		
23	12.89		
24	13.026		
25	13.049		
26	13.594		
27	14.026		
28	14.771		
29	14.912		

Table 2. Excess pore water pressure from torsional shear test

V. CONCLUSION

In this study, a clay soil sample was prepared at 100kPa compaction energy with moist tamping method then resonant column and torsional shear test was performed. After the sample get fully saturated, a consolidation test performed on the sample under 100kPa pressure. Subsequently, resonant column test performed on that sample. When the first resonant column test finished, same sample was consolidated under 150kPa pressure and after the consolidated under 200kPa pressure and after this phase resonant column test performed one again. Finally, after the last resonant column test torsional shear test was performed on the same sample. Thus, earthquakes occurring at different times on the same soils were modelled and the changes of the dynamic behaviour of the clay soil in this case



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is investigated. As a result of the resonant column test, the maximum shear modulus (G_{max}) of the clay soils under the higher pressure was increased while the damping ratio (D) decreased. In the torsional shear test the sample was failure at the end of the cycle 29. In the experiment conducted under undrained conditions, the pore pressure increased with the increasing number of cycles.

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