Comparison of Menard pressuremeter test results around the DSI buildings before and after Kahramanmaraş earthquakes on 6th February 2023

Comparaison des résultats du test du pressiomètre de Menard autour des bâtiments de la DSİ avant et après les tremblements de terre de Kahramanmaraş du 6 février 2023

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ABSTRACT

Türkiye is a geographically active region known for its high seismicity, hosting some of the most active faults in the world. On February 6, 2023, two consecutive earthquakes of Mw 7.7 and Mw 7.6 occurred in the province of Kahramanmaraş within a 9-hour span. This rare and unprecedented tectonic event stands out in terms of seismic activity over the past century. This study aims to compare Menard pressuremeter test results before and after the earthquakes around the DSI (State Hydraulic Works) buildings in Kahramanmaraş, focusing on changes in the Menard Deformation Modulus (Em) and Limit Pressure (Pl) values. The Pressuremeter tests were conducted before the earthquake at boreholes in the planned construction area, and similar tests were repeated in similar locations after the earthquake to observe the changes in deformation modulus and limit pressure. The variability of the Em/ Pl values was statistically interpreted. This study also highlights the importance and need of detailed post-seismic evaluations of soil properties to ensure the safety requirements of building foundations. Additionally, the findings offer valuable insights for the future studies on earthquake-resistant constructions located particularly on vulnerable seismicity areas.

RESUME

La Turquie est une région géographiquement active, connue pour sa forte sismicité, abritant certaines des failles les plus actives au monde. Le 6 février 2023, deux séismes successifs de magnitude Mw 7,7 et Mw 7,6 se sont produits dans la province de Kahramanmaraş, sur une période de 9 heures. Cet événement tectonique rare et sans précédent se distingue par son activité sismique au cours du siècle passé. Cette étude a pour objectif de comparer les résultats des tests de pressiomètre Menard avant et après les séismes autour des bâtiments de la DSI (Direction Générale des Affaires Hydrauliques) à Kahramanmaraş, en mettant l'accent sur les changements des valeurs du module de déformation Menard (Em) et de la pression limite (Pl). Les tests pressiométriques ont été réalisés avant le tremblement de terre dans des forages situés dans la zone de construction prévue, et des tests similaires ont été répétés dans des endroits similaires après les tremblements de terre afin d'observer les changements dans le module de déformation et la pression limite. La variabilité des valeurs de Em/Pl a été interprétée statistiquement. Cette étude met également en évidence l'importance et la nécessité d'évaluations détaillées des propriétés du sol après un séisme afin de garantir les exigences de sécurité des fondations des bâtiments. De plus, les résultats offrent des perspectives précieuses pour les futures études sur les constructions résistantes aux séismes, en particulier dans les zones sismiques vulnérables.

Keywords: Menard pressuremeter test; post-earthquake soil evaluation; seismic performance of foundations.

1. Introduction

On February 6, 2023, two earthquakes with magnitudes of 7.7 and 7.6 struck 11 cities in southeastern Türkiye, causing widespread destruction and significant loss of life. Kahramanmaraş was among the affected cities, with over 50,000 fatalities, 40,000 collapsed buildings, and more than half a million structures sustaining damage (Presidency of The Republic of Turkey Strategy and Budget Department, 2023).

The epicentres of the two major earthquakes were located in the Pazarcık and Elbistan districts of Kahramanmaraş. Both seismic events occurred along the East Anatolian Fault Zone, one of Türkiye's primary active fault systems. In the aftermath of these two significant earthquakes, a powerful aftershock with a moment magnitude of 6.6 occurred, its epicentre situated in the Nurdağı District of Gaziantep. Additionally, on February 20, 2023, another aftershock with a magnitude of Mw = 6.4 struck the Yayladağı district of Hatay (AFAD, 2023).

Due to its proximity to the earthquake epicenters, the central area of Kahramanmaraş was significantly affected, and the structures within the campus of the DSI (State Hydraulic Works) 20th Regional Directorate sustained extensive damage (Figure 1). As a result, the need for new building sites within the campus area, led to the conduction of geotechnical investigations in the region. Prior to the earthquake, the campus was planned for redevelopment, and geotechnical studies had already been conducted. However, following the earthquake, all geotechnical investigations were repeated, and data from both pre- and post-earthquake conditions were collected for the same area.

Figure 1. DSI 20th Regional Directorate building after earthquake

This study seeks to compare the results of Menard pressuremeter tests conducted before and after the earthquakes around the DSI buildings in Kahramanmaraş, specifically examining changes in the Menard Deformation Modulus (Em) and Limit Pressure (Pl) values. Pressuremeter tests were initially carried out at boreholes within the planned construction area before the earthquake, and similar tests were repeated at corresponding locations afterward to assess variations in bearing capacity and settlement. For this reason, the experiments were conducted at the planned building sites, including the regional headquarters building, training facility, warehouses, machinery maintenance building, workshop and auxiliary workshop buildings, drilling department building, and warehouses, within the Regional Directorate campus.

2. Background

The 2023 Kahramanmaraş Earthquakes rank among the most devastating seismic events of the past century, resulting in extensive damage across 11 cities, in contrast to prior earthquakes that were typically confined to specific regions. Following these seismic events, significant surface degradation was observed in several settlements. This deterioration was particularly evident in areas with soft soils, where it manifested as large-scale cracking.

Since the accelerations acting on the structures are higher in soils with basin effect than in rock soils, the structures are strained with much more impact than expected and may cause severe damages. In some soils, it was observed that liquefaction caused settlements in the buildings, and in some places, surface deformations passed directly under the structures and caused major damages. In addition to damages on the buildings and the infrastructures, liquefactions, landslides, rockfalls, and rock avalanches were also observed during the earthquake sequence (Gokceoglu, 2023).

The extent of earthquake-induced damage can be influenced by various characteristics of the soils in the affected area. In cases where the damage is associated with significant soil instability, leading to substantial permanent ground movements, the connection between the damage and local soil conditions becomes evident. For instance, loose granular soil deposits may experience compaction due to the seismic vibrations, resulting in substantial and uneven ground settlements.

3. Study Area

3.1. Geology of the Study Area

The southern part of the Kahramanmaraş city center is generally located within the Maras Plain and consists of quaternary-aged ancient alluvial deposits. Toward the northern side, the slopes of Ahır Mountain contain middle miocene-aged conglomerate units from the Yenicekale formation and quaternary-aged slope debris. Higher topographical areas are characterized by eocene-aged clayey limestone units from the Midyat formation, which also serve as the source of many streams in the region.

The area surrounding the project site primarily consists of quaternary-aged alluvial deposits beneath the vegetal soil. Geophysical, geological, and geotechnical investigations conducted in the field revealed that, below the approximately 0.50 m thick gravel fill, concrete, and organic soil layer, the sub-levels consist of alluvial deposits with varying characteristics, including sandy-gravelly, fine-grained, high to very high plasticity silty clays and clay units of medium to high strength. In the current study, geology of the area will be evaluated in two main groups regarding their dominant characteristics, as sand and gravel, and clay.

3.2. Boreholes

The geotechnical studies in the field involved a total of 27 boreholes with the drilling of 16 boreholes before the earthquake and 11 boreholes after the earthquake. The data used in this study were obtained from a total of 17 boreholes, with 8 boreholes drilled before the earthquake and 9 boreholes drilled after the earthquake since the pressuremeter tests were conducted in these boreholes. Figure 2 presents the locations of boreholes. The depths of the borings ranged between 20-30 metres. The groundwater level is more than 24 m below the ground surface in two of the boreholes while others does not have any evidence of groundwater.

Figure 2. Borehole locations before and after earthquake.

The information about the boreholes where pressuremeter tests were conducted before and after the earthquake is presented in Table 1. The boreholes date back to 2022 and 2023 with similar seasonal conditions during the spring periods.

Table 1. Borehole information

	Boreholes Before Earthquake		Boreholes After Earthquake	
Location	**Name**	**Depth**	**Name**	**Depth**
Headquarter Building	SK-2	25	SK-1	30
			SK-2	30
Training Facility	SK-5	25	SK-3	30
			SK-4	30
Warehouses	SK-7	25	SK-5	30
Maintenance Department	SK-12	25	SK-6	30
Workshops	SK-10	25	SK-8	30
Auxiliary Workshops	SK-14	25	SK-9	30
Drilling Department	SK-15	25	SK-11	20
	SK-16	25		

3.3. Pressuremeter Tests

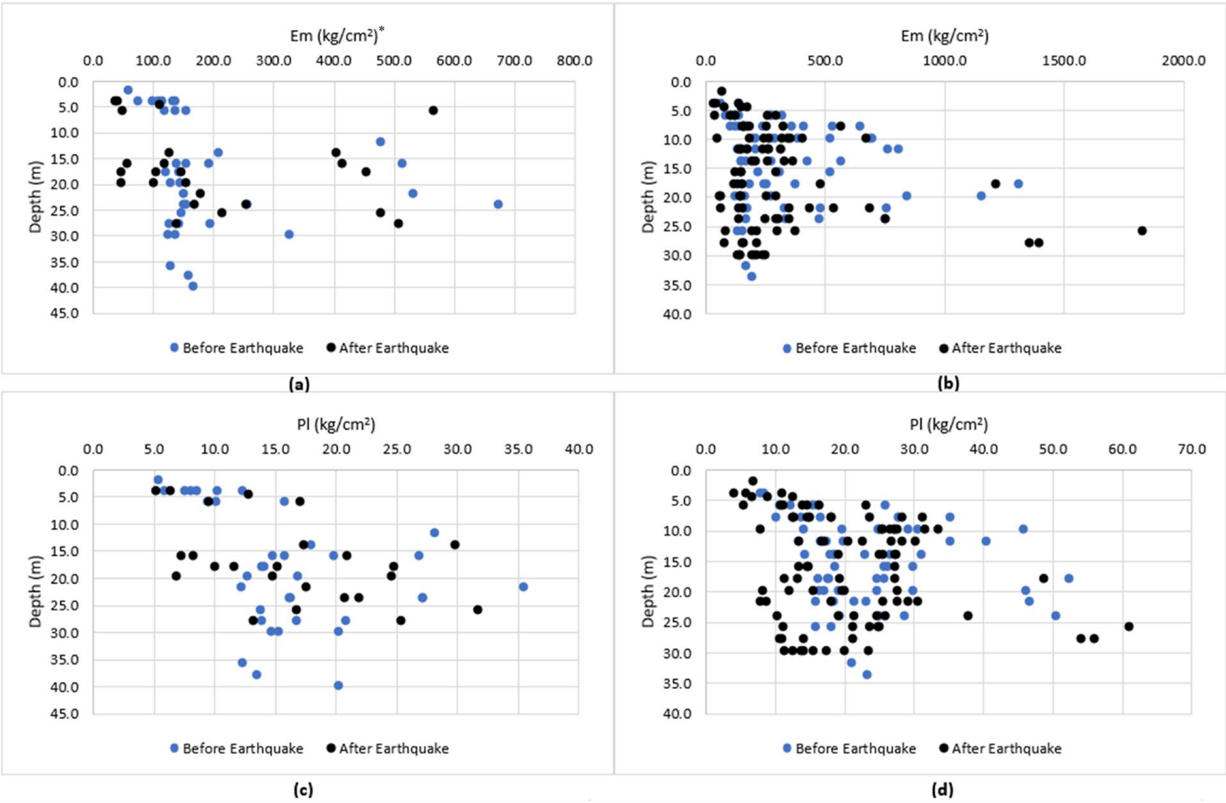
The pressuremeter test is an in-situ method used to assess the lateral deformation properties of the soil at a specific depth. This equipment was developed by Menard (1957) and introduced as the "Menard Pressuremeter." The device comprises two main components: the measuring unit and the probe unit. The measuring unit, located on the ground surface, includes several gauges that record pressure and volume, while the probe unit, inserted into a borehole, contains three independent cells: one measuring cell and two guard cells. Once the probe is positioned at the desired depth, an increase in pressure within the measuring cell causes deformation of the borehole walls.

The pressuremeter tests conducted in the study area is presented in Figure 3.

Figure 3. Pressuremeter test being conducted in study area

In this study, the pressuremeter tests were performed in accordance with ASTM 4719-20. Figure 4 shows the variation of Em values for sand and gravel, and silty clay soils. For sand and gravel, measured Em values range between 57.8 and 672 kg/cm^2, with an average of 191.4 kg/cm^2 before earthquake while Em values range between 36.6 and 563.8 kg/cm^2 with an average of 204.1 kg/cm^2 after earthquake. For silty clay soils, measured Em values range between 64 and 1304.9 kg/cm^2, with an average of 337.6 kg/cm^2 before earthquake and Em values range between 30.3 and 1829.2 kg/cm^2, with an average of 274.9 kg/cm^2 after earthquake. Although the results show an increase in the measured Em values with depth, the rate of increase could not be clearly defined due to other factors such as grain size distributions, mineralogy and geological conditions, which are influential as well, only lower and upper bounds could be drawn for them. A comparison of the average Em values before and after the earthquake reveals an increase in sand and gravel, whereas a decrease is noted in silty clay.

Figure 4 also shows the variation and histogram of Pl values for sand and gravel, and silty clay soils. For sand and gravel, values range between 5.4 and 35.4 kg/cm^2, with an average of 15.8 kg/cm^2 before earthquake and values range between 5.1 and 31.7 kg/cm^2, with an average of 16.2 kg/cm^2 after earthquake. For silty clay soils measured Pl values range between 7.9 and 52.2 kg/cm^2, with an average of 22.9 kg/cm^2 before earthquake while values range between 4 and 61 kg/cm^2, with an average of 20.3 kg/cm^2 after earthquake. There was an increase in Pl values with depth, and although a unique trend could not be determined, a lower bound line could be obtained. A comparison of the average Pl values before and after the earthquake reveals an increase in sand and gravel, whereas a decrease is noted in silty clay, similar to the Em values.



*1 kg/cm^2 = 98.0665 kPa

Figure 4. Em values in sand and gravel (a), Em values in clay (b), Pl values in sand and gravel (c), Pl values in clay soils (d)

4. Analyses and Discussion

Prior to analysing the probability density functions of the Em/Pl values from pressuremeter tests conducted on sand-gravel and clay formations, both pre- and post-earthquake, four sample datasets were first evaluated to detect potential outliers. Outliers are extreme values, either much lower or higher than the typical data points, which can distort the overall behaviour of data within similar data groups. To identify these outliers, the Box and Whiskers method was employed, a non-parametric technique that constructs a box using the first quartile (Q1, representing the 25th percentile) and the third quartile (Q3, representing the 75th percentile). The whiskers extend to Q1 - 1.5 * IQR and Q3 + 1.5 * IQR, where IQR refers to the interquartile range (Q3 - Q1). The data values out of the whisker extensions are assumed to be outlier candidates. Showing the star symbols as outliers, cross marks as mean points, and mid-lines of boxes as median lines, the dataset behaviours before and after eliminating outliers are shown in Figure 5.

After pre-processing the Em/PI values for sand and gravel, and clay-dominant layers through the drillhole intervals, the data are fitted to probability density functions, yielding p-values of the Anderson–Darling test greater than 0.05 for a 95% confidence interval, as presented in Figure 6. The expected (mean) values of the datasets labeled 1, 2, 3, and 4 are 10.75, 10.46, 13.59, and 11.18, respectively. Labels 1 and 2 represent the Em/PI values for sand and gravel before and after the earthquake, while labels 3 and 4 represent those for clay before and after the earthquake.

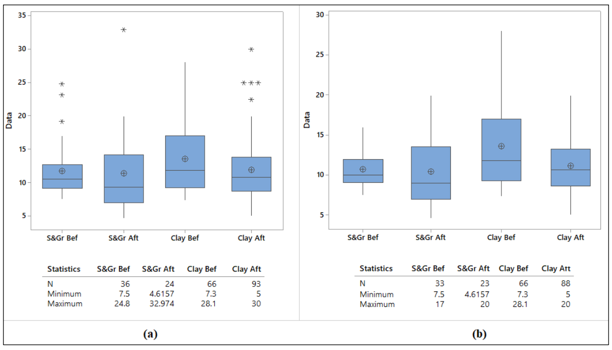


Figure 5. Box and whiskers plot of the datasets before (a) and after (b) eliminating the outliers

Datasets labelled 1 are compared with those labelled 2 using a two-sample t-test to determine whether there is a statistically significant deviation between the mean values of the datasets, aiming to assess whether the earthquake caused a measurable difference in the Em/PI values. A similar comparison is performed for datasets labelled 3 and 4. The two-sample t-test is a hypothesis testing method used to evaluate whether the mean values of two samples are significantly different. The null hypothesis (H0) accepts that there is no significant difference between the mean values of the two samples, while the alternative hypothesis (H1) accepts that a significant difference exists, considering the limit values of the mean values for a specific confidence interval. A p-value greater than 0.05 for a 95% confidence interval indicates that the null hypothesis (H0) is accepted. The test results can be observed in Figure 7.

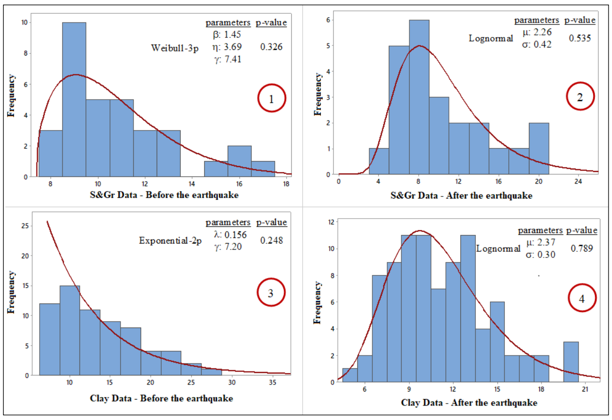


Figure 6. Best-fitted probability density functions of the datasets

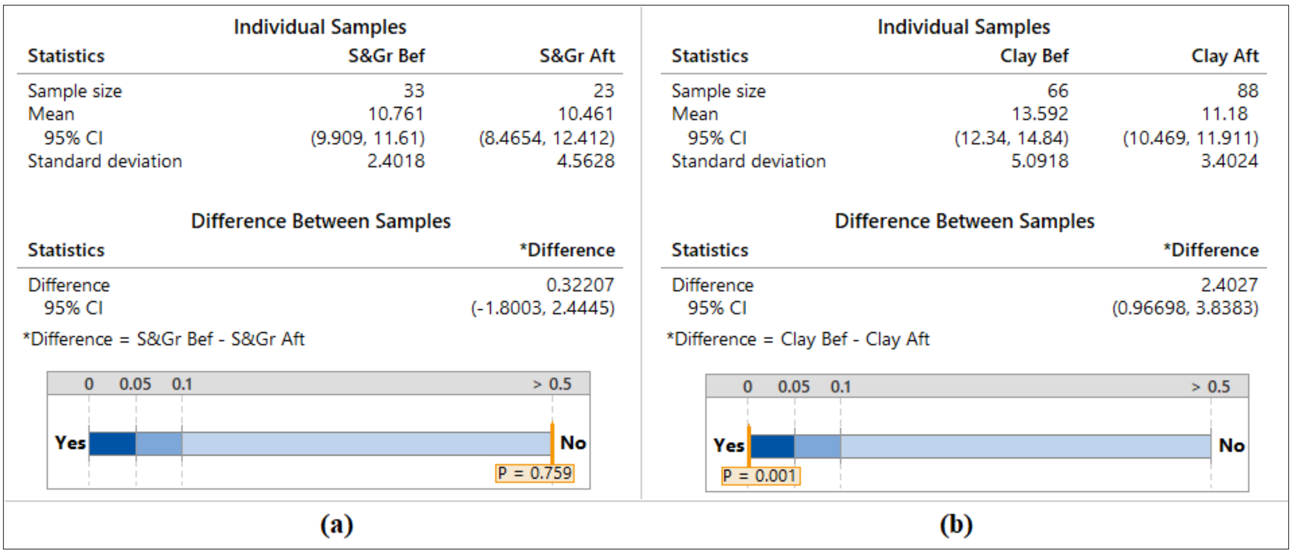


Figure 7. Two-sample t-test results of sand and gravel (a) and clay datasets (b)

The p-value of 0.759 for the sand and gravel datasets indicates that the differences between the mean values are not statistically significant, suggesting that the earthquake movements did not induce any measurable change in the Em/PI values. On the other hand, the p-value of 0.001, which is below the significance level of 0.05, proves that the mean values of the Em/PI values for the clay formation before and after the earthquake are significantly different. The mean Em/PI value for clay before the earthquake is 13.59, with a range of 12.34 to 14.84 at a 95% confidence interval. After the earthquake, the mean value decreases to 11.18, with a range of 10.47 to 11.91 at the same confidence interval. This suggests a measurable drop in the Em/PI value following the earthquake.

5. Conclusions

This study intends to observe the changes in deformation modulus and limit pressure values obtained from Pressuremeter tests in similar locations before and after the Kahramanmaraş earthquake, employing various statistical analysis. The study used the Em and Pl values as input parameters in multiple regression analyses to characterize the mechanical properties of sandy and clayey soils. For the sand and gravel datasets indicates that the differences between the mean values are not statistically significant, suggesting that the earthquake movements did not induce any measurable change in the Em/PI values. On the other hand, the Em/PI values for the clay formation before and after the earthquake are significantly different. A measurable drop in the Em/PI value is obtained after the earthquake.

The majority of existing literature has focused on homogeneous regions, as the higher heterogeneity of alluvial deposits leads to weaker correlations in these soils. In studies conducted in heterogeneous areas, it is recommended that further research thoroughly investigates the relationship between in-situ tests.

References

AFAD. (2023). *06 Şubat 2023 Pazarcık-Elbistan Kahramanmaraş (Mw:7.7-Mw:7.6) Depremleri Raporu.* Ankara: Afet ve Acil Durum Yönetimi Başkanlığı.

ASTM. (2000). *Standard test method for pre-bored pressuremeter test-ing in soils (D4719).* Thomson Reuters.

Gokceoglu, C. (2023). 6 February 2023 Kahramanmaraş-Türkiye Earthquakes: From Human needs to SDGs. *39th International Symposium on Remote Sensing of Environment (ISRSE-39)* (pp. 417-424). Antalya: International Center for Remote Sensing of the Environment, Inc. (ICRSE).

Menard, L. (1957). *An apparatus for measuring the strength of soils in place.* University of Illinois.

Presidency of The Republic of Turkey Strategy and Budget Department. (2023). *2023 Kahramanmaras ve Hatay Depremleri Raporu.* Presidency of The Republic of Turkey Strategy and Budget Department.