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Araştırma Makalesi / *Research Article*

Improvement of Clay Soil Using a Plaster Mortar Additive

Killi Bir Zeminin Sıva Harcı Katkısı Kullanılarak İyileştirilmesi

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ABSTRACT

The engineering properties of a clay soil and its mixtures (5, 10 and 15% by weight) with a plaster mortar additive (PMA) were studied through a series of soil mechanical tests to investigate possibilities to improve its undesired/problematic plasticity, strength, compaction and consolidation characteristics. The tests included the Atterberg limits, shear box, compaction, consolidation, and unconfined compressive strength tests. The results demonstrated that using PMA can significantly enhance the soil properties and serve as a soil stabilizer. Adding PMA led to a decrease in the plasticity values of the soils. Moreover, it was observed that the highest maximum dry unit weight and the lowest optimum moisture content were achieved when 15% PMA was added. The soil strength properties reached maximum values when the mixtures contained 15% PMA. Additionally, an optimal coefficient of volume compressibility (m_v) was obtained when the PMA ratio in the mixtures was 10%. It was concluded that the plaster mortar additive used in this study could significantly improve the geotechnical parameters of the soil.

Keywords: Handere clay, soil stabilization, plaster mortar additive, compaction

ÖZ

Killi bir zeminin ve sıva harcı katkısı (PMA) ile oluşturulan karışımlar ile (ağırlıkça %5, % 10 ve %15) plastisite, dayanım, kompaksiyon ve konsolidasyon karakteristikleri gibi jeoteknik özelliklerinin iyileştirebilme olanakları bir dizi zemin mekaniği deneyi ile incelenmiştir. Örnekler üzerinde Atterberg limitleri, hidrometre, özgül ağırlık, kesme kutusu, kompaksiyon, konsolidasyon, serbest basınç dayanım testleri yapılmıştır. Zeminin plastisite değerlerinin sıva harcı katkısı ilavesi ile azaldığı görülmüştür. Karışımlarda en yüksek maksimum kuru birim hacim ağırlık ve en düşük optimum su içeriği değerlerinin %15 sıva harcı katkısı ilavesi ile elde edildiği bulunmuştur. Zeminin dayanım özeliklerinin %15 sıva harcı katkısı ilave edildiğinde maksimum değerlere ulaştığı belirlenmiştir. Zeminin sıkışma katsayısı (m_v) değerlerinin %10 sıva harcı katkısı ilavesi ile en ideal değerlere ulaştığı belirlemiştir. Bu çalışmada kullanılan sıva harcı katkısının zeminin jeoteknik parametrelerini önemli ölçüde iyileştiebildiği sonucuna varılmıştır.

Anahtar kelimeler: *Handere kili, zemin iyileştirme, sıva harcı katkısı, kompaksiyon*

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INTRODUCTION

Cement-based soil stabilization has been a widely employed method in geotechnical engineering for many years. Soil, which serves as the foundation for buildings and human settlements, is an awe-inspiring natural phenomenon. In numerous civil engineering projects, problematic soils are characterized by low bearing capacity that require stabilization. Chemical stabilization is one of several engineering techniques used to enhance the mechanical and durability properties of soils. Naturally, soils exhibit various types, including soft and weak soils with low bearing capacity, moderately stiff soils with satisfactory bearing capacity, and highly stiff soils with high bearing capacity.

During the building of structures, tunnels, and bridges, it is essential to assess the soil quality and its cohesive properties thoroughly. Certain soils possess weak characteristics that render them unable to withstand imposed loads, necessitating the enhancement of their properties to provide adequate support for the structures built upon them. Various materials are employed to improve soils, including lime, cement, tire chips, natural fibers, bitumen, biopolymer, fly ash, waste glass powder, natural rubber latex and chemical substances such as magnesium chloride (Yang et al., 2002; Youwai and Bergado, 2004; Cetin et al., 2006; Tran et al., 2022; Sheob et al., 2023; Agarwal et al., 2023; Aswad et al., 2023; Akbarimehr et al., 2023; Zhou et al., 2023).

Soil stabilization is a geotechnical process to enhance soil quality and improve its engineering properties. It involves various methods such as mechanical interventions, chemical treatments, and other techniques aiming to maintain soil stability, improve engineering characteristics, limit water absorption capacity, and reduce compressibility (Zada et al., 2023; Sharma et al., 2018; Suresh and Murugaiyan, 2021). In the past several decades, precast concrete with high strength and fast installation has been extensively used for soft-ground improvement (Chen et al., 2019; Ding et al., 2020; Li et al., 2018; Pengjiao et al., 2020; Tong et al., 2022; Wang et al., 2018a; Wang et al., 2018b; Zhuang et al., 2020).

Not all soils in their natural state possess the required properties to support foundations and structures adequately. Soil improvement techniques are frequently employed in countries prone to earthquakes or land scarcity. These countries actively seek to enhance their soils, aiming to reduce risks and improve weak soil conditions. Over the years, soil improvement techniques have evolved through successful and unsuccessful attempts. Cost, technical feasibility, and environmental impacts must be carefully considered when selecting soil improvement methods. Once the area where soil improvement is needed has been identified, one or more techniques are applied to achieve the following objectives: Reduce settlement, reduce swelling and shrinkage, increase shear strength, reduce permeability, reduce compressibility, increase bearing capacity increase safety factor against possible slide, reduce liquefaction risk (seismic areas).

The aim of this study is to investigate possibilities to improve the undesired/problematic plasticity, strength, compaction and consolidation characteristics of a clayey soil known as the Handere Formation of the late Miocene to Pliocene age (Schmidt, 1961), which outcrops throughout the northern parts of Adana city (the fifth largest city in Türkiye), where extensive settlement projects are now underway especially after the devastating Pazarcık Mw=7.8 (USGS) and Elbistan (Kahramanmaraş) Mw

= 7.5 (USGS) so-called twin earthquakes on February 6th, 2023 killed more than 60,000 people both in Türkiye and Syria. Grain size (both sieve and hydrometer) and Atterberg limits analysis, direct shear, compaction and consolidation tests were performed on the clayey soil alone and its mixtures (5, 10 and 15% by weight) with plaster mortar additive (PMA). The PMAs are an easily/commercially available, high-performance micro air-entraining mortar admixture originally designed to improve the permeability, workability, and freeze-thaw resistance of plaster mortars. Using the PMA in civil engineering applications such as foundations, embankments and backfills behind retaining structures over weak or high-compressibility soils is advantageous because of its easy application, fast curing and relatively low cost compared to some other soil improvement materials such as fibers and chemical substances.

Geology of the Adana Basin

The Adana Basin, where the study area is located, comprises marine and terrestrial sediments and limestones spanning from the Oligocene to the recent era. The basin's stratigraphy from bottom to top, consists of the Gildirli formation from the Oligocene age at the very bottom and Quaternary age alluviums of the Seyhan and Ceyhan rivers at the top. Overlying the Gildirli Formation is the Karaisalı Formation, dating back to the Early Miocene, which was deposited in a shelf setting. A detailed geological map is given in Figure 1 and discussed further by Yetiş and Dermikol (1986), Ünlügenç (1993), Yetiş et al. (1995).

The Handere Formation is conventionally known to rest on the marine deposits of the Kuzgun Formation (Gürbüz & Kelling, 1993; Yetiş et al., 1995; Nazik, 2004; Darbaş ve Nazik, 2010. Recent studies show that the Handere formation has an unconformable contact with the Kuzgun formation (Cosentino et al., 2010a, b; Cipollari et al., 2012). The conventionally accepted stratigraphy of the unit refers to the gypsum member of the Handere formation being located at the top of the formation; recent studies indicate that these gypsum levels are located at the bottom of the unit and have contact with the Kuzgun formation (Cosentino et al., 2010a, b; Cipollari et al., 2012).

The Handere formation is exposed in a large area in the northern part of Adana city, a promising candidate for new settlements, especially after the recent devastating earthquakes. Therefore, the engineering properties of the unit have been investigated in detail. The clayey soils and the gypsum levels within the Handere Formation are not eligible for building structures; because the clayey soils in the Handere Formation have high shrink-swell capacity and collapsing potential due to their gypsum content. However, many buildings and a lot of infrastructure have already been built. The current structures and the following generation buildings and infrastructure were under different types of risk if these clayey soils and gypsum levels would be not treated.

MATERIALS AND METHODS

Materials

The clayey soil used in this study was obtained from the Handere formation of the late Miocene to Pliocene age (Schmidt, 1961). This unit is exposed in a large area in the northern part of Adana city, where extensive settlement projects are presently underway. Though it predominantly comprises clay levels, various other sedimentary rock types such as sandstone, gravelly sandstone, siltstone, mudstone and marl are also included especially in the upper levels of this regressive unit. Additionally, problematic gypsum lenses of varying thicknesses can be found in certain levels of the unit. Conglomerates exhibit large-scale trough cross-bedding, while fine-grained materials show parallel lamination. The thickness of the formation falls within the range of 120 to 700 meters, as reported by Yetiş and Demirkol (1986).

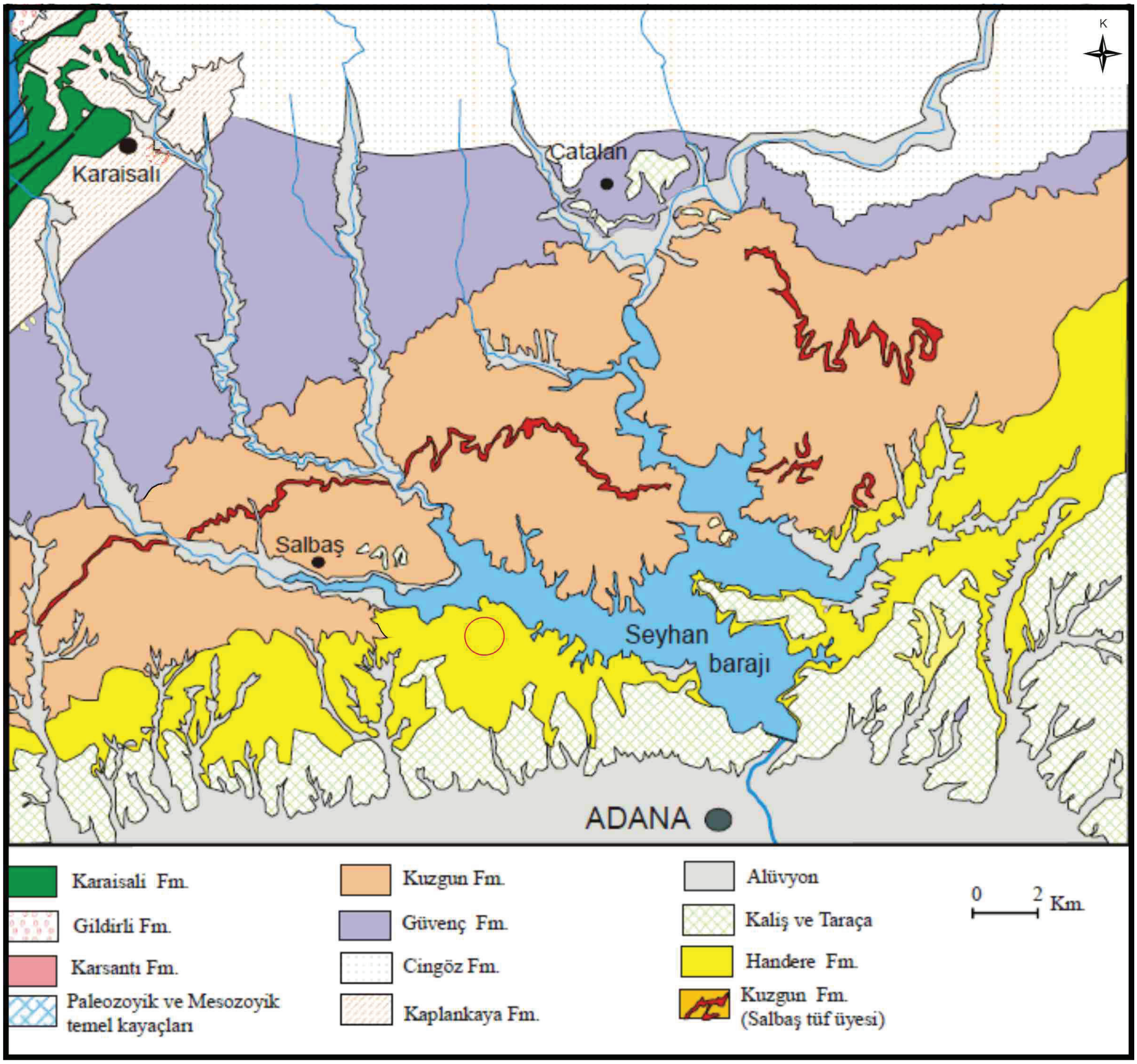

Figure 1. Geological map of the study area [modified from Yetiş and Dermikol (1986), *Ünlügenç* (1993), and Yetiş et al. (1995), the red circle shows sampling location].

Şekil 1. Adana Baseninin jeolojik haritası [Yetiş ve Dermikol (1986), Ünlügenç (1993), ve Yetiş ve ark.(1995)'den değiştirilerek, kırmızı daire örnek alınan lokasyonu göstermektedir].

Plaster Mortar Additive (PMA)

This study employed MasterCast 301 high performance plasticizer admixture for plaster mortars as a soil stabilizing agent. MasterCast 301 is a high-performance micro air-entraining mortar admixture designed to improve plaster mortars' permeability, workability, and freeze-thaw resistance. It is composed of a dilute solution of surface-active substances combined with an organic acid with a specific gravity of 1.0-1.1 kg/lt. It has a homogenous air entraining feature, reduces segregation and efflorescence effects on mortars without admixture, enhances neatness and workability features in mortars, enhances strength to freeze-thaw cycle and lowers costs.

The material finds application in various contexts, including indoor and outdoor spaces for vertical applications, in plaster mortars to improve impermeability, and in brick and stone coating mortars to improve workability (https://mbcc.sika.com/en-tr/products/mastercast/mastercast-301)

Methods

After collecting soil samples from the field and transporting them to the laboratory, four different sample cases were prepared: 0% PMA (pure soil) and soil mixed with PMA at 5%, 10%, and 15% by dry weight. Soil mechanical tests were conducted in the laboratory using appropriate equipment to analyze the soil properties and assess the impact of PMA on the soil properties and their potential for improvement. The soil mixtures' optimum water contents (ω_{opt}) and maximum dry unit weights (γ_{dmax}) were determined through the standard proctor tests. The mixtures were compacted within the proctor mold at the determined optimum water contents. The direct shear and consolidation tests were subsequently conducted on subsamples obtained from the compacted samples. The soil mechanical tests adhered to the following standards set by the ASTM (American Society for Testing and Materials).

- Standard Proctor test (ASTM D 698, 2009)
- Unconfined compressive strength test (ASTM D 2166, 2009)
- Shear box test (ASTM D 3080, 2003)
- Consolidation test (ASTM D 2435, 2009)

Standard Proctor Test

In 1933, Proctor developed a laboratory compaction test procedure for calculating the maximum dry unit weight achievable through soil compaction. This value can be utilized as a specification for field compaction activities. The test is conducted following the guidelines outlined in ASTM D698 (2009). This particular test is utilized to determine the optimum moisture content at which the maximum dry density of the soil is achieved. When constructing infrastructure such as airports, highway bridges, and other structures, it is often necessary to compact the soil to improve its strength.

Unconfined Compressive Strength Test

The test was conducted following the American Society for Testing Materials (ASTM) standard D2166 (2009). This particular test is designed to determine the compressive strength of cohesive soil when subjected to axial load application under strain-controlled conditions. The test can be performed on the soil in its intact, remolded, or reconstituted state. It provides an approximation of the cohesive soil's strength in terms of total stresses.

Direct Shear Test

The test is conducted according to ASTM D 3080 (2003). The objective of this test is twofold: to quantify the soil's cohesion (c) and internal friction angle (φ) and to analyze the shear behavior of the soil sample.

Consolidation Test

The consolidation test is carried out following the specifications outlined in ASTM D 2435 (2009). The purpose of the consolidation test is to assess the extent and rate at which a laterally confined soil specimen experiences volumetric contraction under different vertical pressures. By subjecting the soil specimen to varying vertical pressures, valuable information regarding the magnitude and rate of volume decrease can be obtained to understand the consolidation characteristics of the soil.

RESULTS AND DISCUSSION

Standard Proctor Test

This test aims to determine the optimum moisture content (ω_{opt}) and maximum dry density (γ_{dmax}) values before and after adding the PMA. The results obtained from the Standard Proctor tests, as illustrated in Figure 2, depict the variations in optimum water content and maximum dry density observed when different percentages of PMA were added (5%, 10%, and 15%, respectively).

According to the results, the ω_{opt} for the 0% PMA was 24.2%, while the dry density was 1.455 g/cm^3. For the PMA-treated soil, the compaction tests revealed an ω_{opt} of 22.5% for soil mixed with 5% PMA, resulting in a γ_{dmax} of 1.465 g/cm^3. Similarly, a ω_{opt} of 21.5% was determined for soil mixed with 10% PMA, resulting in a dry density of 1.5 g/cm^3. With an increase in the PMA ratio to 15%, the ω_{opt} decreased to 21.4%, and the γ_{dmax} increased to 1.56 g/cm^3.

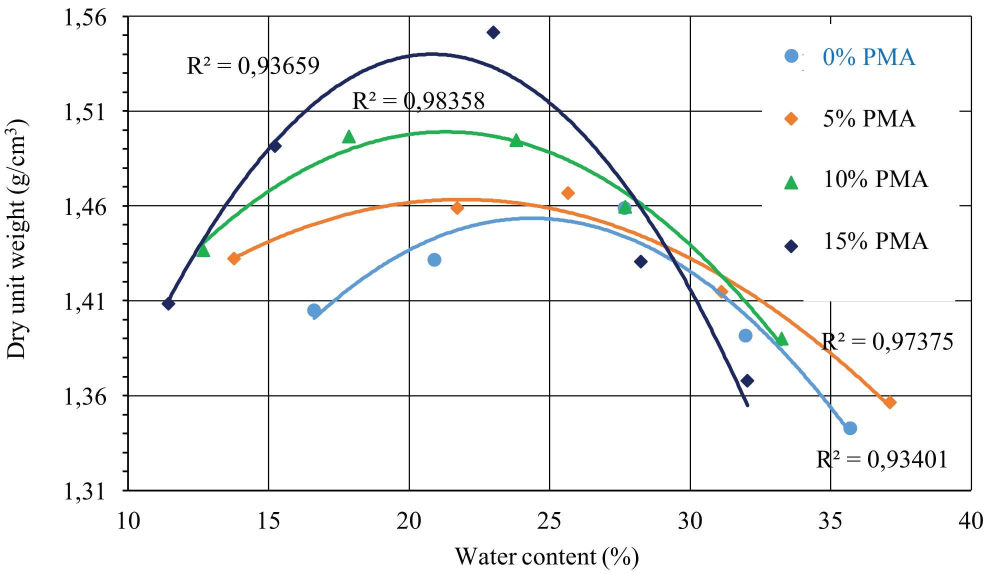

Figure 2. Standard Proctor test results.

Şekil 2. Standart Proctor deney sonuçları.

Unconfined Compressive Strength

At the outset, the test was conducted on three specimens in the soil's natural state. Subsequently, the test was repeated after the introduction of varying proportions of PMA (5%, 10%, and 15%, respectively). The impact of PMA is presented in Figure 3 for each percent mixture, as well as the pure soil. Adding PMA to the soil yielded discernible variations in the test results. The average unconfined compressive strength exhibited an increase, rising from 1.22 kg/cm^2 for the 0% PMA to 1.64 kg/cm^2 for soil with 5% PMA, 2.43 kg/cm^2 for soil with 10% PMA, and 2.77 kg/cm^2 for soil with 15% PMA.

Direct Shear Test

The shear strength of the soil was assessed in the laboratory using a shear box test. The test was conducted in two stages. In the first stage, the clay soil was sheared at varying normal stresses (1.94 kg/cm^2, 2.78 kg/cm^2, 3.61 kg/cm^2, and 4.44 kg/cm^2), simulating possible various overburden or field conditions. In the second stage, the mixture samples were tested under the same loading conditions following the ASTM D3080 (2009) standard. The resulting shear strength-deformation curves are presented in Figure 4.

The shear strength parameters (c and φ) increased proportionately to the quantity of PMA introduced. The failure envelopes for the soils with different percentages of PMA are depicted in Figure 5.

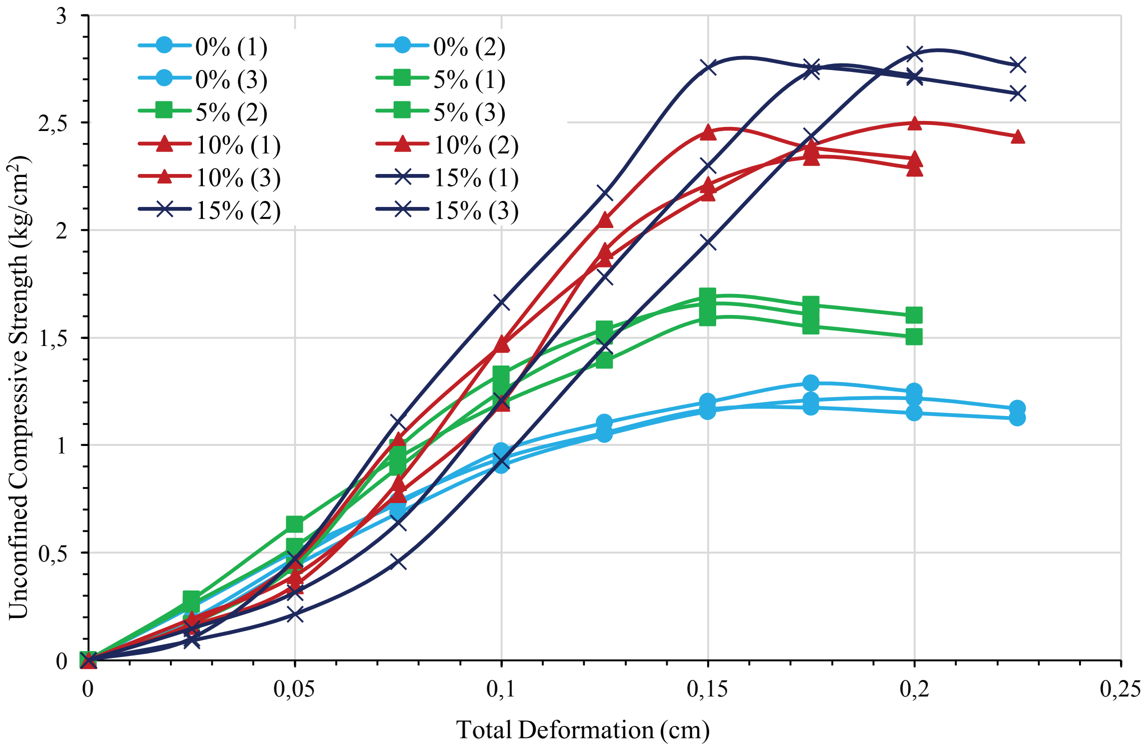

Figure 3. The unconfined compressive strength test results.
Şekil 3. Serbest basınç dayanımı deney sonuçları.

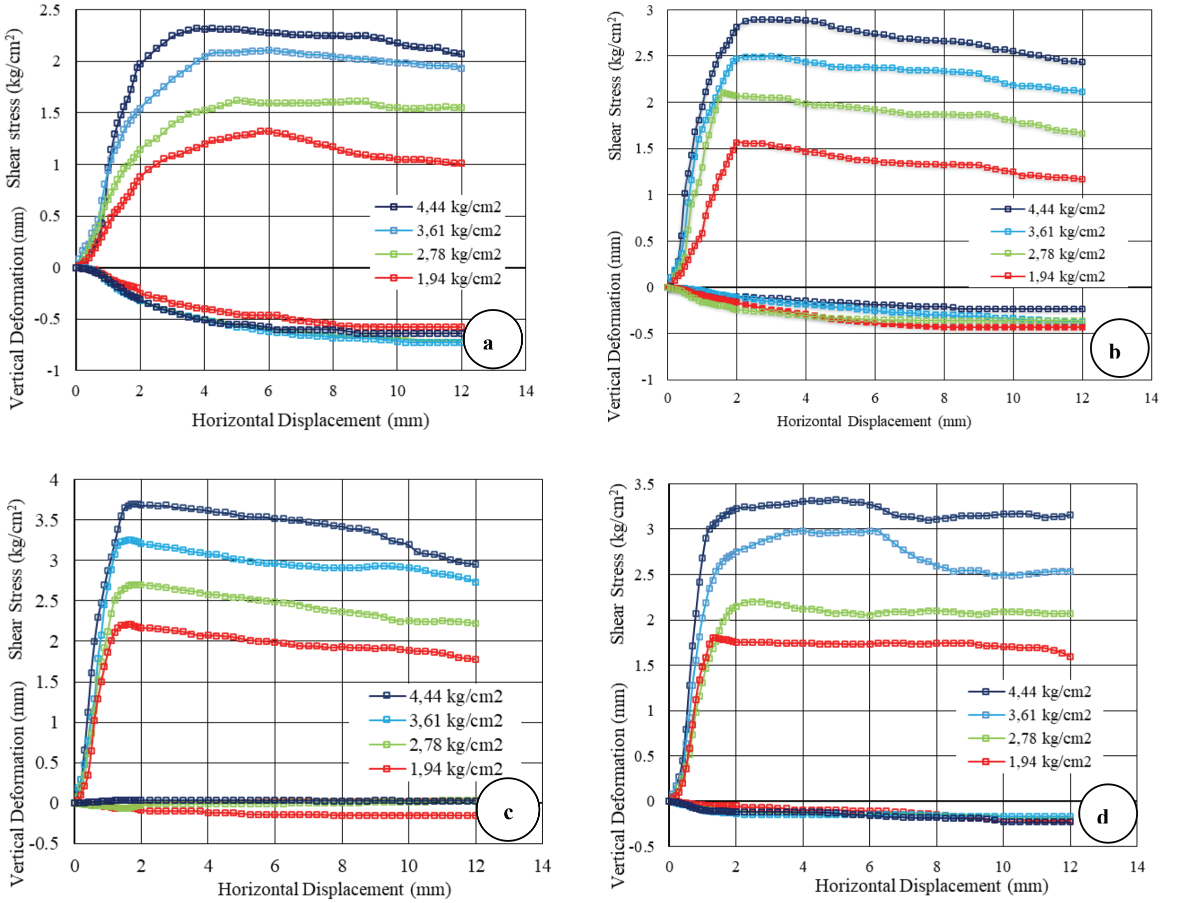

Figure 4. Stress-strain curves for the a) 0% PMA, b) 5% PMA added soil, c) 10% PMA added soil, and d) 15% PMA added soil under different normal stresses.

Şekil 4.a) %0 PMA eklenmiş zeminin, b) % 5 PMA eklenmiş zeminin, c) % 10 PMA eklenmiş zeminin, d) % 15 PMA eklenmiş zeminin farklı normal gerilmeler altında gerilme-deformasyon eğrileri.

Based on the findings from the test results, it was observed that the soil cohesion exhibited a gradual increase as the percentage of PMA increased. This suggests a positive effect of PMA. The internal friction angle similarly increased in direct proportion to the addition of PMA, culminating at approximately 15%. This observation reaffirms the positive influence of PMA on the soil, as depicted in Figure 6.

Consolidation Test

The standard consolidation tests were conducted both on the clay soil alone and the subsamples obtained from the 5%, 10%, and 15% PMA mixture samples compacted under the determined optimum moisture contents in order to study their compressibility characteristics.

The loading program was chosen as 0.25, 0.50, 0.75, 1.0, 1.5, 2.0, 3.0, 4.0, 5.0, 6.0, 8.0, and 10.0 kg to obtain a more detailed curve with a distinct break.

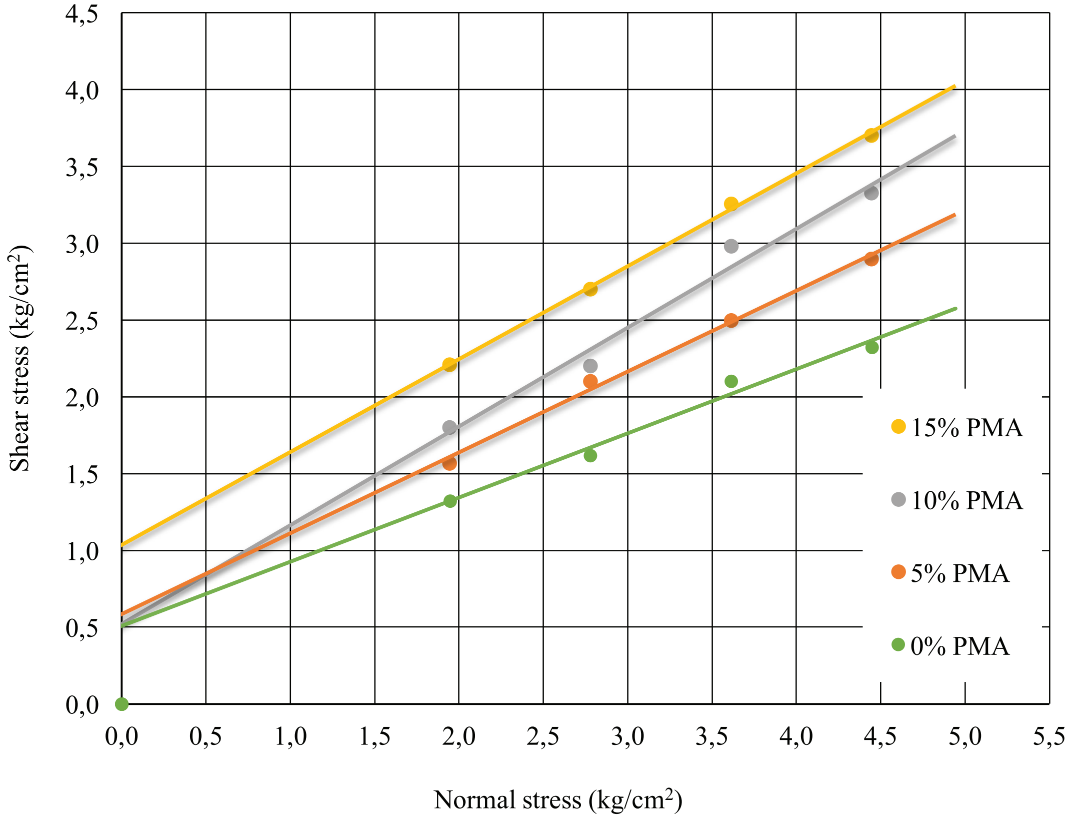

Figure 5. Failure envelopes for the soils before and after adding PMA.
Şekil 5. PMA eklenmiş ve eklenmemiş zeminlerin kırılma zarfı.

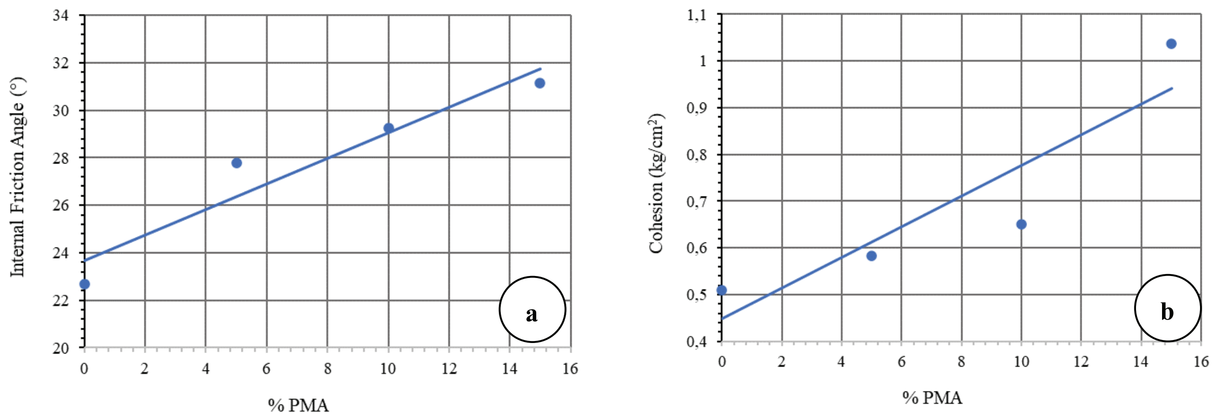

Figure 6. PMA % - a) internal friction angle and b) cohesion relationships.
Figure 6. % PMA ile a) içsel sürtünme açısı ve b) kohezyon arasındaki ilişki.

The void ratio vs. log of effective stress curves for the tests are shown in Figure 7.

The initial void ratios decreased from 0.8723 in 0% PMA to 0.7695 at 15% PMA.

As can be seen, the coefficient of the volume of compressibility (m_v) decreases as shown but with the increase to 10% of PMA (Fig. 8). It gradually decreases in the soil by 5%, m_v decreases sharply.

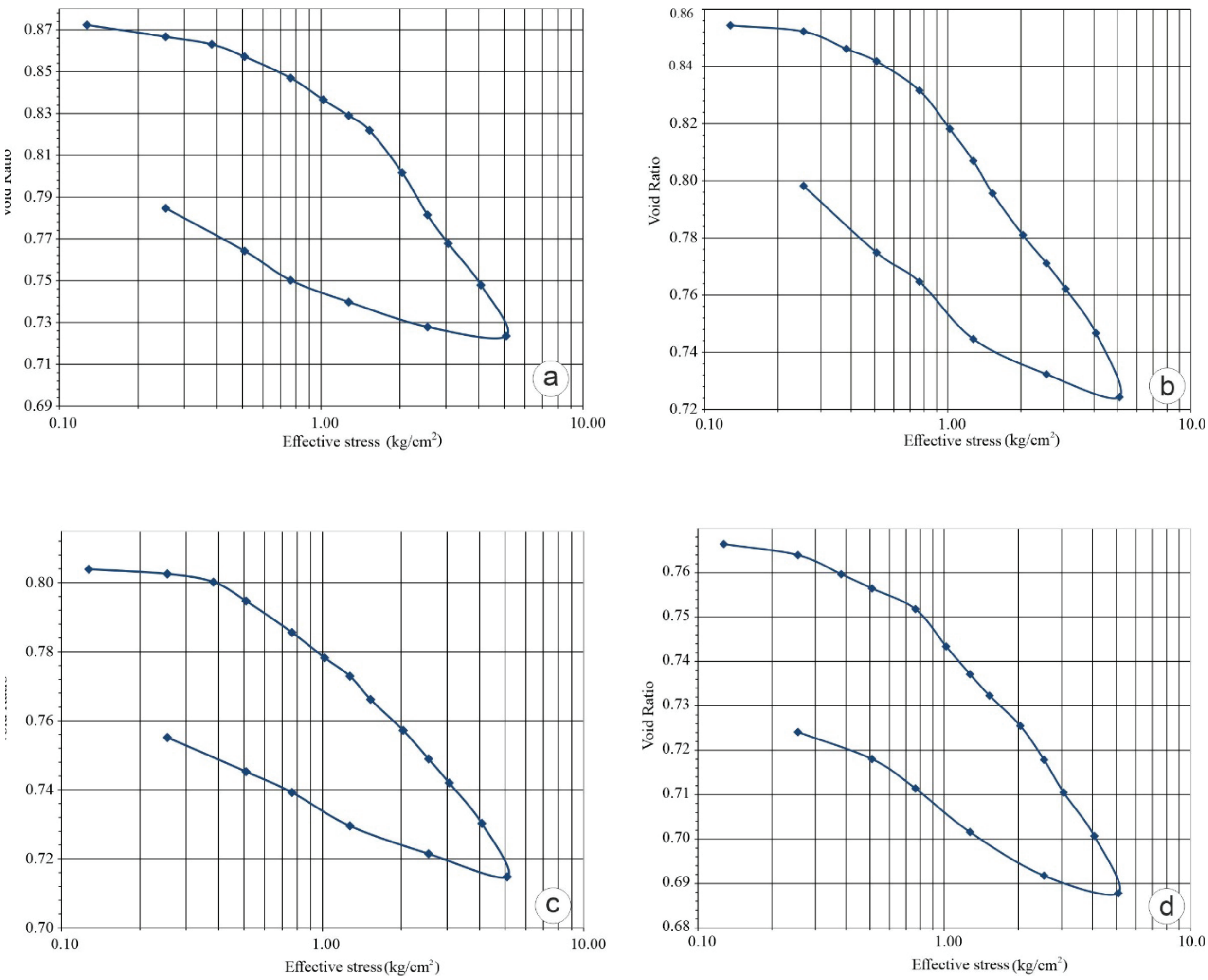

Figure 7. Void ratio versus effective stress curve for the a) 0 % PMA, b) 5% PMA added soil, c) 10% PMA added soil and d) 15% PMA added soil.

Şekil 7. a) %0 PMA eklenmiş zeminin b) %5 PMA eklenmiş zemin c) %10 PMA eklenmiş zemin d) %15 PMA eklenmiş zemin için boşluk-oranı-efektif gerilme eğrileri.

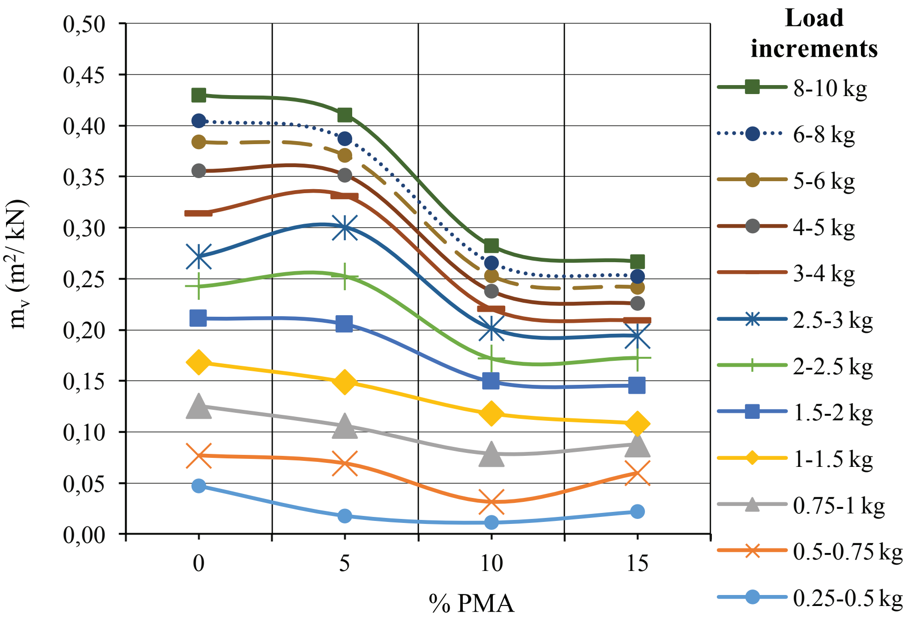

Figure 8. The coefficient of volume of compressibility (m_v) changes under different loads with respect to % PMA.
Şekil *8. PMA yüzdelerine göre farklı yük kademelerinde hacimsel sıkışma katsayılarının değişim grafiği.*

Then, while it stays about the same for higher loading increments (1.5-10 kg, for example), it slightly decreases for the load increment of 1-15 kg and it slightly increases for the load increment of 0.25-1.0 kg. Notably, the m_v exhibited a decreasing trend. The decrease was gradual for soils with a 5% PMA content but became more pronounced with a 10% PMA content. Subsequently, the m_v remained relatively constant for higher loading increments (1.5-10 kg), experienced slight decreases for load increments of 1-15 kg, and displayed slight increases for load increments of 0.25-1.0 kg.

CONCLUSIONS

According to the compaction test results, the optimum water content for the 0% PMA was 24.2% and the dry density was 1.455 g/cm^3. After 15% PMA treatment, the optimum water content and the maximum dry density became 21.4% and 1.54 g/cm^3 respectively. The optimum moisture content decreased from 24.2% in 0% PMA to 21.4% at 15% added PMA. The dry soil density increased from 1.46 g/cm^3 in 0% PMA to 1.54 g/cm^3 at 15% added PMA.

According to the consolidation test, the void ratios decreased from 0.8723 in 0% PMA to 0.7695 at 15% PMA added soil. The coefficient of volume of compressibility (m_v) decreases as % PMA increases. The decrease is higher in higher load increments than the lower ones. The plasticity values of the soils were reduced by the addition of PMA. Furthermore, it was determined that the highest maximum dry unit weight and the lowest optimum moisture content were obtained by 15% PMA addition. The soil strength properties reached the maximum values for the 15% PMA added mixtures. Likewise, it is determined that the coefficient of volume compressibility (m_v) is ideal when the PMA ratios in the mixtures are 10% and 5%, respectively. The unconfined compressive strength increased from 1.27 kg/cm^2 in 0% PMA to 2.77 kg/cm^2 with 15% PMA addition. The shear strength of 0% PMA increased from 1.09 kg/cm^2 to 3.35 kg/cm^2 (more than 200%) for the 15% PMA added soil. In conclusion, the PMA significantly enhanced the soil properties and can be used as a soil stabilizer.

REFERENCES

Akbarimehr, D., & Fakharian, D. (2021). Dynamic shear modulus and damping ratio of clay mixed with waste rubber using cyclic triaxial apparatus. Soil Dynamics and Earthquake Engineering. 106435.

Agarwal, B. K., Shah, J. & Sachan, A. (2023). Determination of optimum content of additive for stabilization of expansive soil considering its shrinkage, swelling, desiccation cracking, and shear strength response. Transportation Infrastructure Geotechnology.

Ahmed, H. (2023). Two-dimensional study of the inclusions of skirt sand and deep cement piles to improve the load-displacement behavior of circular foundations on soft clay soil. Heliyon. e13627.

ASTM D 2166, (2009). Standard Test Method for Unconfined Compressive Strength of Cohesive Soil, In: Annual Book ASTM Standards, Volume 04.08, West Conshohocken, p 201–206.

ASTM, D 2435, (2009). Standard Test Method for One-Dimensional Consolidation Properties of Soils, In: Annual Book of ASTM Standards, Volume 04.08, West Conshohocken, p 238–247.

ASTM, D 3080-98, (2003). Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions. Annual Book of ASTM Standards, pp.347–352. West Conshohocken, PA, 4.08.

ASTM, D 698-00, (2009). Standard Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort. Annual Book of ASTM Standards. American Society for Testing and Materials, 04.08, West Conshohocken, pp. 78–87.

Aswad M. F., Al-Gharbawi, A. S. A, Fattah, M. Y., Mustfa, R. H. & Hameed, H. R. (2023). Improvement of Clayey Soil Characteristics Using Poly Acrylamide Geopolymer, Transportation Infrastructure Geotechnology.

Cetin, H., Fener, M. & Günaydın, O., 2006. Geotechnical properties of tire-cohesive clayey soil mixtures as a fill material. Engineering Geology, Elsevier, Vol. 88, pp. 110-120.

Chen, Y., Zhao, W., Han, J., & Jia, P. (2019). A cel study of bearing capacity and failure mechanism of strip footing resting on c-φ soils. Comput. Geotech. 111, 126–136.

Cosentino, D., Darbaş, G., Gliozzi, E., Grossi, F., Gürbüz, K. & Nazik, A. (2010a). How did the Messinian salinity crisis impact the Adana Basin? 7th International Symposium on Eastern Mediterranean Geology, Adana, Turkey, 18–22 October 2010. Abstract Book, 145.

Cosentino, D., Darbaş, G., & Gürbüz, K. (2010b). The Messinian salinity crisis in the marginal basins of the peri-Mediterranean orogenic systems: examples from the central Apennines (Italy) and the Adana Basin (Turkey). EGU General Assembly 2010. 2-7 May, 2010 in Vienna, Austria, p.2462

Cipollari, P., Cosentino, D., Radeff, G., Schildgen, T. F., Faranda, C., Grossi, F., Gliozzi, E., Smedile, A., Gennari, R., Darbas, G., Dudas, Ö., Gürbüz, K., Nazik, A., & Echtler, H. (2012). Easternmost Mediterranean evidence of the Zanclean flooding event and subsequent surface uplift: Adana Basin, southern Turkey. Geological Society, London, Special Publications Volume 372 Pages 473 – 494.

Darbaş, G. & Nazik, A. (2010). Micropaleontology and paleoecology of the Neogene sediments in the Adana Basin (South of Turkey). Journal of Asian Earth Sciences 39, 136–147.

Ding, X., Qu, L., Yang, J., & Wang, C., (2020). Experimental study on the pile group-soil vibration induced by railway traffic under the inclined bedrock condition. Acta Geotech. 15 (12), 3613–3620.

Faranda, C., Cipollari, P., Cosentino, D., Gliozzi, E. & Pipponzi, G. (2008). Late Miocene ostracod assemblages from eastern Mediterranean coral-reef complexes (central Crete, Greece). Revue de Micropaléontologie 51, 287–308.

Gürbüz, K. & Kelling, G. (1993). The provenance of Miocene submarine fans in the northern Adana Basin, southern Turkey: a test of discriminant function analysis. Geological Journal 28, 277–293.

https://mbcc.sika.com/en-tr/products/mastercast/mastercast-301

Pengjiao, J., Wen, Z., Khoshghalb, A., Pengpeng, N., Baofeng, J., Yang, & C., Shengang, L., (2020). A new model to predict ground surface settlement induced by jacked pipes with flanges. Tunn. Undergr. Sp. Tech. 98, 103330.

Proctor, R. R., (1933). Fundamental principles of soil compaction. Engineering News-Record, Vol. 111, Nos. 9, 10, 12, and 13.

Schmidt, G. C., (1961). Stratigraphic nomenculature for Adana region, Petroleum District VII: Petroleum Administration Bulletin, Ankara, 6. 47- 63.

Sharma, L., Sirdesai N. N., Sharma K. M, & Singh T. N. (2018). Experimental study to examine the independent roles of lime and cement on the stabilization of a mountain soil: a comparative study, Appl. Clay Sci. 152 183–195.

Sheob. M., Sajid, M., Ansari, A., M., Rais, I., Sadique, M.R., & Ahmad, S. (2023). Using a blend of cement and waste glass powder to improve the properties of clayey soil. Materials Today: Proceedings.

Suresh, R. & Murugaiyan, V. (2021). Influence of chemical admixtures on geotechnical properties of expansive soil, Int. J. Eng., Trans. A: Basics 34 (1). 19–25.

Tong, L., Li, H., Ha, S.I. & Liu, S., (2022). Lateral bearing performance and mechanism of piles in the transition zone due to pit-in-pit excavation. Acta Geotech 17 (5), 1935–1948.

Tran, Q, N., Hoy, M., Suddeepong, A., Horpibulsuk, S., K., K. & Arulrajah, A. (2022). Improved mechanical and microstructure of cement-stabilized lateritic soil using recycled materials replacement and natural rubber latex for pavement applications. Construction and Building Materials, 347, 128547.

Ünlügenç, U. C. (1993). Controls on Cenozoic sedimentation, Adana Basin, Southern Turkey. PhD thesis, University of Keele.

Wang, A., Zhang, D., & Deng, Y., (2018a). Lateral response of single piles in cement-improved soil: numerical and theoretical investigation. Comput. Geotech. 102, 164–178.

Wang, A., Zhang, D., & Deng, Y., (2018b). A simplified approach for axial response of single precast concrete piles in cement-treated soil. International Journal of Civil Engineering. 16 (10), 1491–1501.

Yang, S., Lohnes, R.A., & Kjartanson, B.H. (2002). Mechanical properties of shredded tires. Geotechnical Testing Journal 25, 44–52.

Yetiş, C. & Demirkol, C., (1986). Adana Baseni Batı kesiminin detay etüdü. MTA Rapor No: 8037, 187s. (unreleased, in Turkish).

Yetiş, C., Kelling, G., Gökçen, S.L. & Baroz, F. (1995). A revised stratigraphic framework for Later Cenozoic sequences in the northeastern Mediterranean region. Geol. Rundsch. 84, 794–812.

Yi, Y. L. Liu, & Gu, S. (2015). Microstructural and mechanical properties of marine soft clay stabilized by lime-activated ground granulated blast furnace slag, Appl Clay Sci 103 71–76.

Youwai, S., & Bergado, D.T., (2004). Numerical analysis of reinforced wall using rubber tire chips-sand mixtures as backfill material. Computers and Geotechnics 31, 103–114.

Zada, U., Jamal, A., Iqbal, M., Eldin, S. M, Almoshaogeh, M., Bekkouche, S. R., & Almuaythir, S., (2023). Recent advances in expansive soil stabilization using admixtures: current challenges and opportunities. Case Studies in Construction Materials. e01985.

Zhuang, Y., Cui, X., Zhang, S., Dai, G., & Zhao, X. (2020). The load transfer mechanism in reinforced piled embankment under cyclic loading and unloading. Eur. J. Environ. Civ. En. 1–15.

Zhou, EQ., Yao, Y., Cui, L. & Wang, L. (2023). Shear strength characteristics of unsaturated rubber silt mixtures. Rock and Soil Mechanics, 44 (7): 1949-1958.