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RELATIONSHIPS BETWEEN GEOTECHNICAL PROPERTIES OF THE ANTALYA TRAVERTINE (TURKEY)

RELATIONS ENTRE LES CARACTÉRISTIQUES GÉOTECHNIQUES DES TRAVERTINS D'ANTALYA (TURQUIE)

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Abstract

The Plio-Quaternary travertines are exposed in the vast area around the Antalya region. Travertine is the major subgrade formation in this area. For geological and geotechnical purposes the Antalya travertine can be divided into three different groups and these are spongy, weak, and massive travertine. Geomorphogically the travertine is dissected into four major plateau, namely Döşemealtı, Varsak, Düden, and Arapsuyu.
The study is specially based on the geological and geotechnical properties of the Lara travertine included in the Düden plateau. The upper most spongy travertines locally can be mixed with underlying weak travertines. The massive travertines are dominantly micritic and brownish and beige in colour. The weak travertine comprises block, gravel, sand, and silt-grade materials coming from massive travertines.
Rock Quality Disignation for spongy is "poor", weak and massive is "fair". Unit weight in order is 13.2, 15.6 and 19.9 kN/m^3. Mean porosity is between 52.47 % and 25.23 %, and all of the travertines are "extremely porous". Mean permeability in order is 78.4, 42.2, and 8.2 litre/minute. Schmidt hardness of spongy is "very soft", weak is "soft", and massive is "moderate". The uniaxial test results range between 2.37 and 19.0 MPA. The massive travertine is classified as "middle modulus ratio" and "very low strength".

Résumé

Des travertines d'âge Plio-Quaternaire affleurent en large superficie à Antalya et dans ses environs, où ils constituent la fondation des constructions. Du point de vue de constitution les trois sortes de travertins sont le travertin spongieux, le travertin tendre et le travertin massif. Les travertins se distinguent géomorphologiquement en quatre plateaux principaux, comme ceux de Döşemealtı, Varsak, Düden et Arapsuyu.
Dans cette recherche, on a étudié les caractéristiques géologiques et géotechniques des travertins dans la région de Lara qui se situe sur le plateau de Düden. Le travertin spongieux qui se trouve au plus haut niveau, est mélangé localement avec le travertin tendre qui se situe au dessous du précédent. Le travertin massif dont la couleur est beige et de divers tons de marron présente une structure micritique. Le travertin tendre contient des éléments de la taille de blocs, de cailloux, de sables et de silts, qui appartiennent au travertin massif.
Si on se réfère au coefficient de qualité des roches, le travertin spongieux est de « mauvaise qualité » et les travertins tendre et massif sont de « moyenne qualité ». Le poids de l'unité de volume est en ordre de 13,2, 15,6 et 19,9 kN/m^3. La porosité moyenne se situe entre 52 % et 25 % et tous les travertins sont extrêmement poreux. La perméabilité moyenne est de l'ordre de 78,4, 42,4 et 8,2 l/min. D'après la dureté Schmidt, la classification du travertin spongieux est « très mou », du travertin tendre « mou » et du travertin massif « moyen ». Les résultats des essais de compression simple situent les travertins entre 2,37 MPa et 19,0 MPa.

Introduction

In the determination of new residential areas, it is necessary to carry out geological and geotechnical investigations on the foundation rocks, and prepare land usage maps. Due to the mode of occurrence, travertine exhibits some geotechnical problems. Foundation rock in Antalya, which is a rapidly developing tourism centre of Türkey on the Mediterranean coast, is travertine (Fig. 1). Travertine formation around Antalya is related to the Kırkgöz springs in the north of the city, and has continued since the Pliocene. Geological and geotechnical properties of the travertine also vary, depending on different locations.

The aim of this investigation was to outline the geological and geotechnical properties of travertine around Antalya, especially at the Lara area. For this purpose, lateral and vertical distribution of travertine was investigated using existing borehole records; trial pits and natural trenches in the area. Discontinuities within this unit, such as dissolution cavities, caves, fissures, joints have been examined. Physical and petrographic properties of samples, representing different travertine types have been investigated to outline the relation between the grain sorting in the formation and the shear strength.

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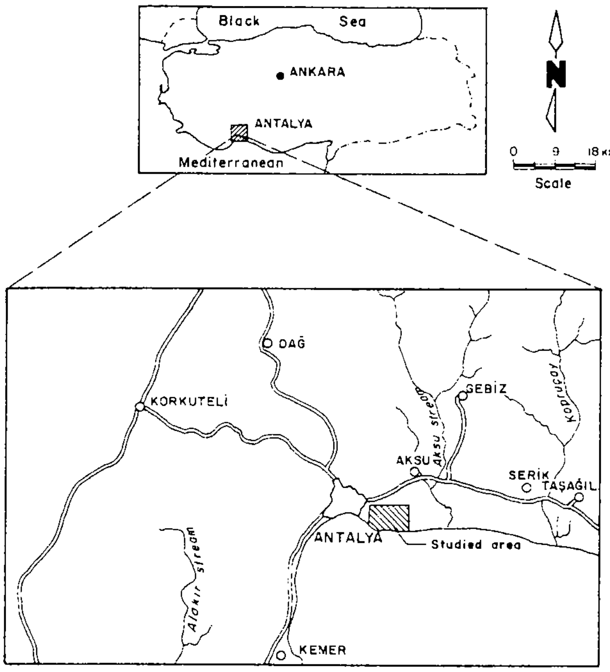

Fig. 1 : Location map of the study area.

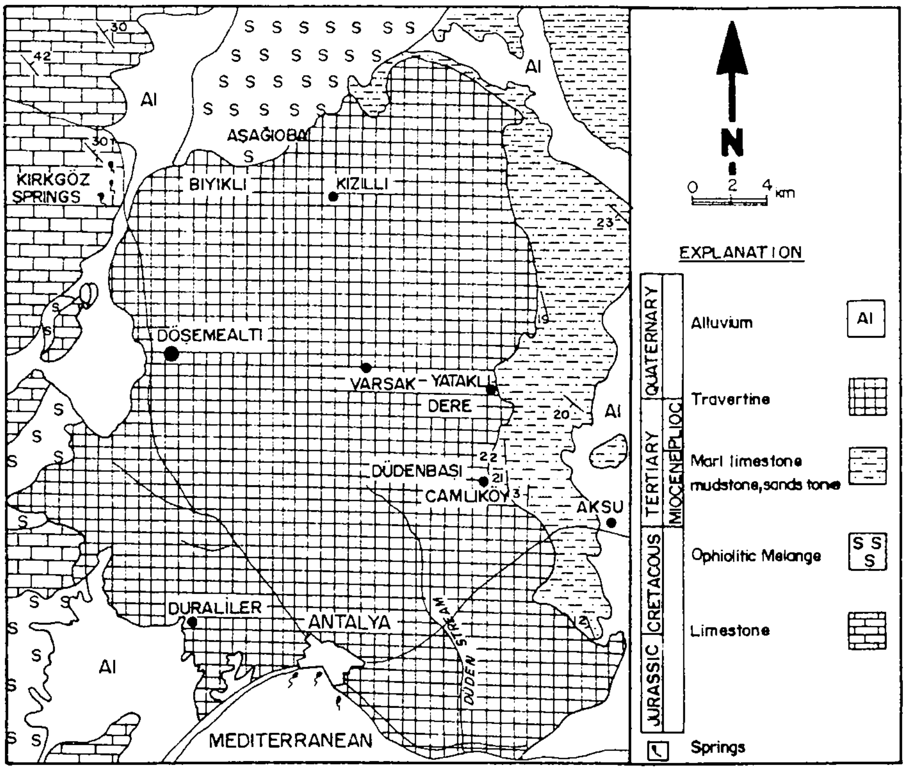

Fig. 2 : Geological map of the Antalya region (after DSI, 1985).

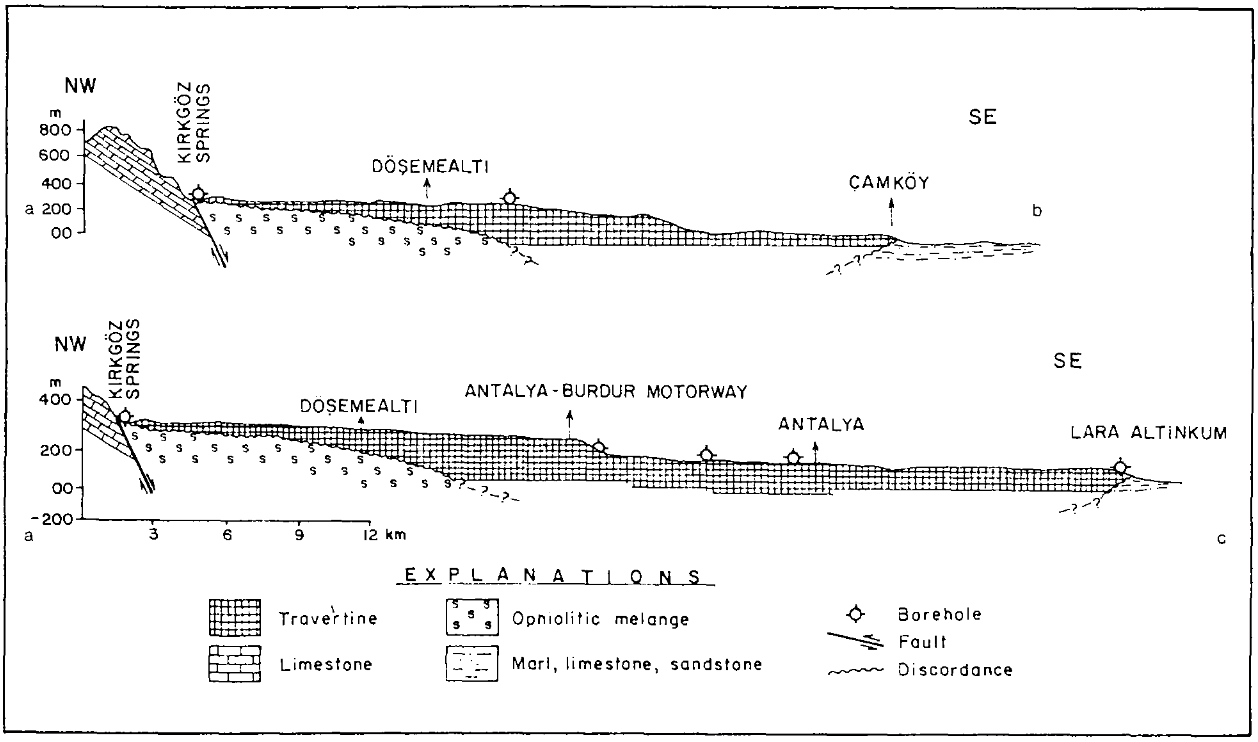

Fig. 3 : Geological section of the Antalya region.

Stratigraphy and lithological characteristics

Jurassic-Cretaceous limestones, a cretaceous ophiolitic complex, Miocene detritals and Plio-Quaternary travertine are exposed in the investigated area and its vicinity, in chronological order (Fig. 2 and 3).

Mesozoic limestones, which form the basement in the area are dark gray to black colored, and in microcrystalline structure. They are thick bedded and contain calcite veins. They have acquired an undulated appearance by the effect of rain water. They contain 98,83 $CaCO_3$, and the composition provides ease in karstification. Chasm, depression, sinkhole karst, polygonal karst, cavern and polje structures are observed.

The Upper Cretaceous ophiolite complex comprises serpentinite, radiolarite, sandstone and limestone units. They exhibit a complex structure both lithologically and tectonically. Marine Miocene, cropping out in the east of the investigated area is characterized by limestone, pebblestone, sandstone and marl. Whitish, yellow and light brown limestone occurs in layers with variable thickness.

Area of the Plio-Quaternary travertine plateau is approximately 630 sq km. It covers the Döşemealtı, Varsak, Düden and Arapsuyu plateaus. An additional one continues south beneath them, according to sea floor maps. Elevation of the Döşemealtı plateau from sea level ranges between 150-350 m, while those of Varsak, Düden and Arapsuyu between 60-150 m, 30-60 m and 0-30 m, respectively. The plateau beneath the sea level

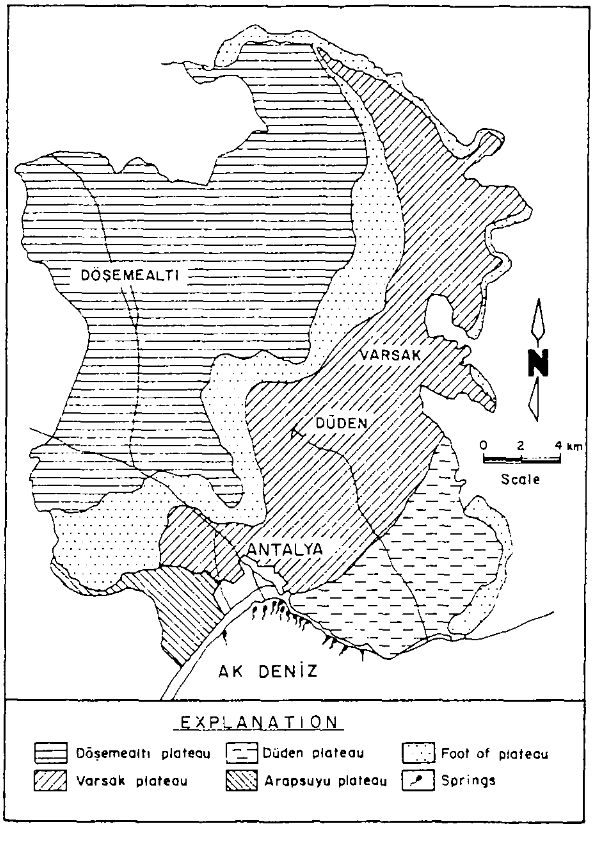

Fig. 4 : Geomorphological units of the Antalya region (after Nossin, 1989).

extends 2.5 km away from the shoreline. Then it sinks rapidly with a step to 50 m deep (Nossin, 1989) (Fig. 4).

Extension of the continental travertine about 90 m from the shoreline beneath the sea points to the depression of the land area. Maximum travertine thickness of 260 m was found in drillholes around the Kızıllı district. According to its relationship with the underlying formations, and the determination of "Candona sp" fossil, which is a fresh water species, in a specimen taken from 42-44 m depth in the drill hole, the unit is assigned to the Plio-Quaternary. Quaternary alluvium is observed along the stream beds.

Mesozoic limestones are extremely fractured, jointed and faulted. By the epirogenic movements, dominantly N-S trending, and also NE-SW and NW-SE trending joint systems have developed on the travertine. Many karstic springs are present on the travertine plateau. Total discharge rate is 14,350 l/sec. These discharge from karstic cavities at sea level. Most prominent are the Duraliler (2,500 l/sec), Kemerağzı (1,580 l/sec), Arapsuyu (1,200 l/sec) and Uncalı (1,000 l/sec) springs. Water table lies 35-40 m deep and is close to sea level.

Formation and types of travertine

Discharger water from the Kırkgöz springs, which gives rise to the formation of travertine contains 160 gr/l Ca (DSI*, 1985). Calcium bicarbonate is obtained from the limestone unit, in which water percolates. Dissolution of calcium carbonate is possible only provided that the water contains free H^+. On the other hand, H^+ is liberated by the aid of CO_2.

$$H_2O + CO_2 = H^+ + HCO_3$$
$$CaCO_3 + H^+ = Ca^{++} + HCO_3$$

Free CO_2 in Kırkgöz springs is 105 mg/l. This amount shows that CO_2 is not only provided by rain water, but is also taken from soil by the decay of plants. Abundant rain fall causes chemical erosion in limestones. By solution, chasm, sink hole karst, cavern, polygonal karst, and polje structures are formed. The most outstanding are the Bıyıklı, Varsak, Taşkuyu, Ciğlik, Nebiler, Kovanlık chasms, and Karain, Selalan, Deniz, Yağca chasm caves.

In the percolation conduits, by the extraction of CO_2 by pressure effect, $CaCO_3$ precipitates according to the following equation :

$$Ca(HCO_3)_2 + CO_2 = CaCO_3 + H_2O + 2CO_2$$

Precipitation is less around the spring due to the availability of CO_2, but increases going far from it.

Investigation of the samples from the area studied have been made at the Geological Engineering Department, Sciences Faculty of Ankara University. Three types of travertine have been identified, related to precipitation.

1. Massive travertine

This type of travertine is creamy white coloured, with the surface red stained due to oxidation. It has precipitated in the deep sections of the lake, where precipitation rate has decreased. Cavities in the complex internal structure have been filled with sparry calcite. Root marks occur as tubular sections. Some of them are of dissolution cavity character. Poorly preserved gastropoda and ostracoda shell fragments may be observed. The parts with dissolution cavities and nodules exhibit a typical "planty tuff" appearance.

2. Weak travertine

Plants and algae present in the sedimentary environment assimilate CO_2 and help in precipitation. Calcium carbonate envelops the plant roots and stems. By the decay of the organic parts, they pile up irregularly upon each other, and become calcified. In the parts where the water flow and recharge are fast, previously precipitated travertine fragments are observed as marial cavity fillings in sand and silt size. Thickness varies between 2 and 12 m and form the base of the constructions. Compared to the massive type, it is more vacuolated. It is calcite in composition. There is a thin film of cement around some of the cavities. It is partially in tooth structure. This structure reflects the fresh water phreatic environment. Root casts and marks are less compared to the former. Mostly, algal structures (Cyanoficeal algal) are outstanding. In addition, it contains abundant Charocea and Gastropoda shell fragments. It is occasionally in fine crystalline micritic structure.

3. Spongy travertine

It dorms in shallow water, in environments where heating, evaporation and CO_2 loss are high. Colour is brown. It is widely distributed. The cavities included have been filled with sand, silt and clay size material, which are the products of previously precipitated travertine, as bands. It is made up of extremely irregular shaped, completely fine plant roots and balls, with dissolution cavities. Roots are enveloped by a thin film of acicular sparry calcite cement. It has formed by algal activity. Some vacuoles have been partially or completely filled with calcite cement. Fringed structures are formed in vertical flow. Massive, weak and spongy travertine are gradational laterally and vertically. Thickness is variable. Mineralogical composition of the travertine, is investigated by X-ray diffraction (XRD) technique, is entirely calcite.

Geotechnical investigations

In order to determine the geotechnical characteristics of the Antalya travertines, the Lara area in the east of Antalya has been investigated (Fig. 5). Field investigations in order to determine the lateral and vertical distribution of travertine, and to collect representative samples, 126 m of borehole drilling (S) has been performed in 7 locations, whose depths range between 10 to 17 m.

* State Hydraulic Work.

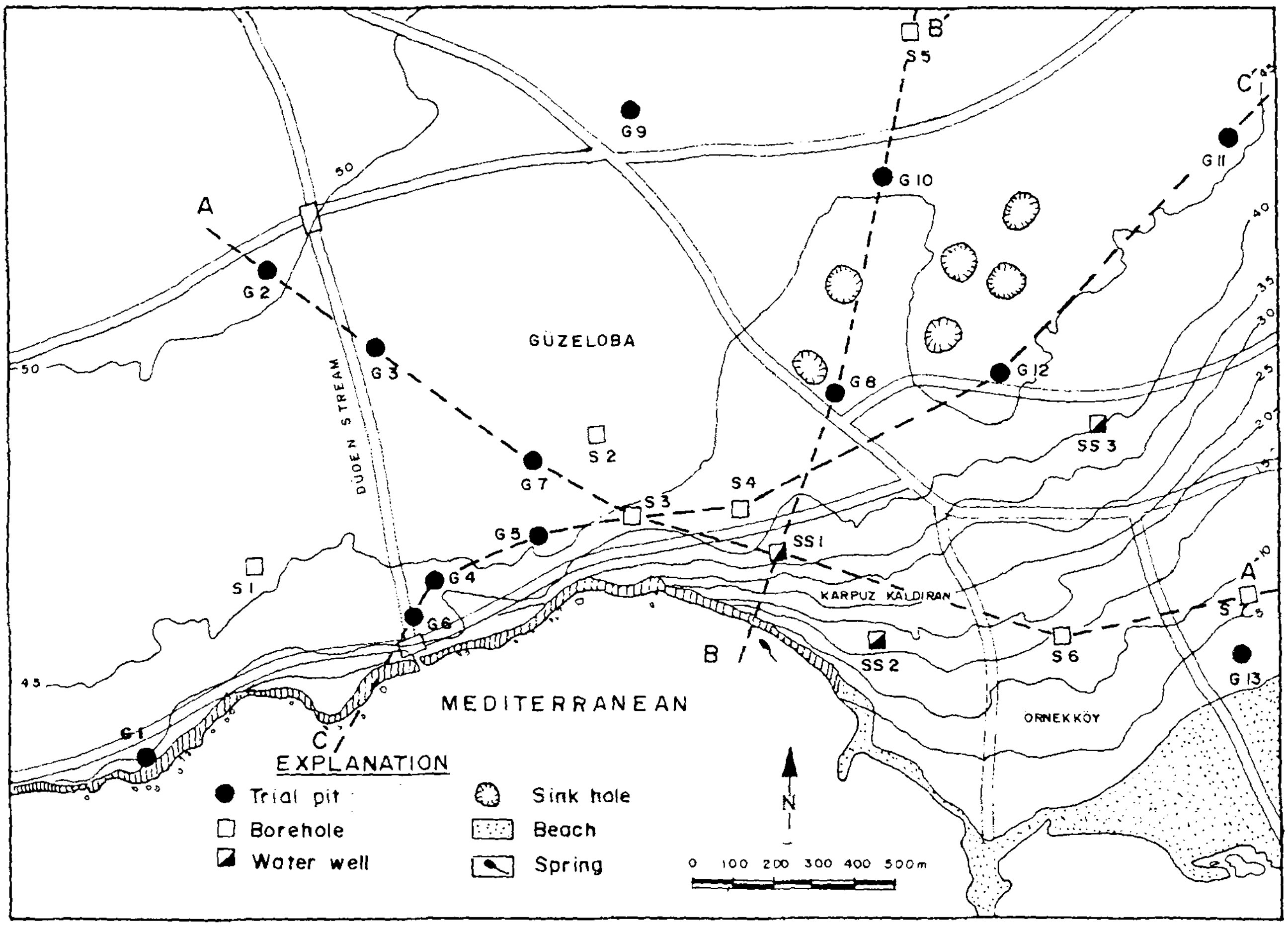

Fig. 5 : Map of the borehole, water well, and trial pit of the study area.

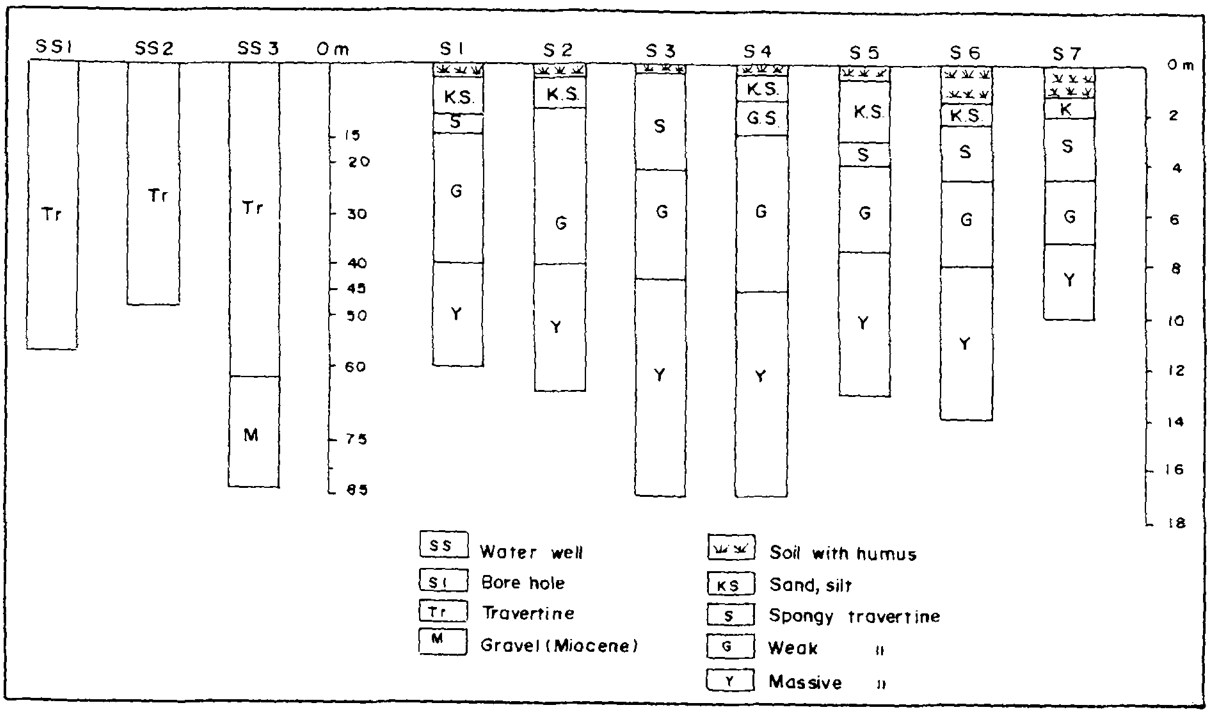

Fig. 6 : Deep of the borehole and water well, and lithological units.

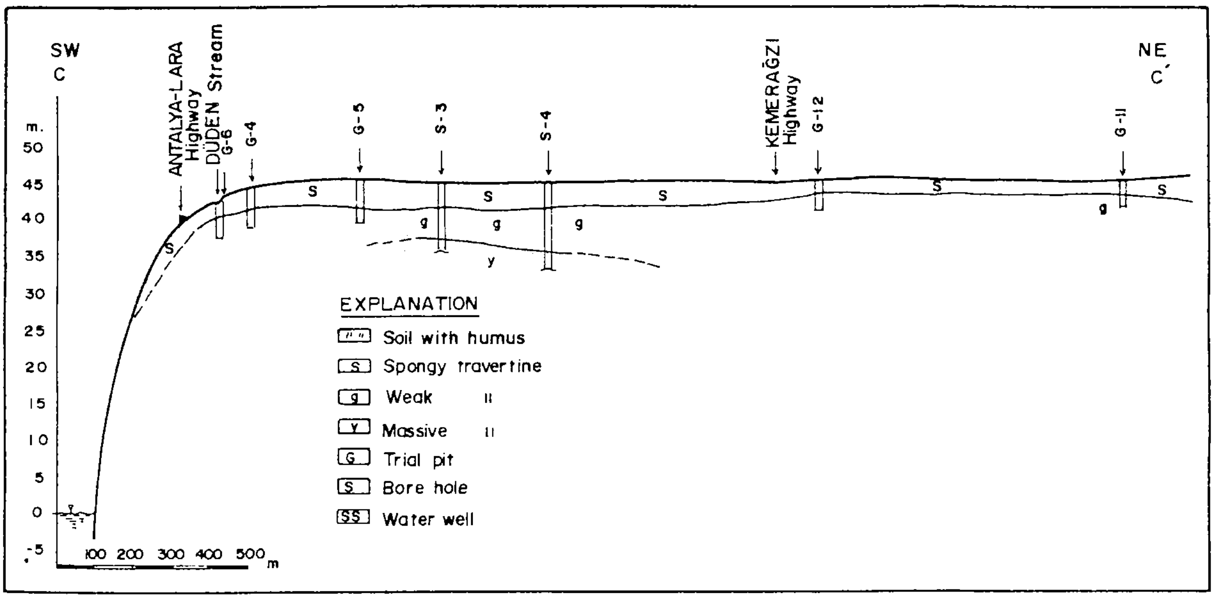

Fig. 7 : Geological section (C-C') of the study are.

NX core samples have been collected from the bore holes. Block samples were also collected from 13 observation pits (G), whose depths vary from 3 to 9 m, and from a large number of natural trenches. Data obtained from three wells drilled for water supply (SS), at depths ranging between 84 and 48 m, showed that the thickness of travertine was 62 m. The lithological units cut in the drills are shown in Fig. 6, and the geological section is presented in Fig. 7.

Geotechnical characteristics, core recovery, rock quality designation (RQD) and Schmidt hardness of travertine have been determined in situ, and results are presented in Table 1. Physical and mechanical properties are given in Table 2. Relevant ASTM and Turkish Standards have been referred to in determining the characteristics.

Table 1 : Core yield (%) and RQD values for travertines.

Characteristic	Spongy	Weak	Massive
Core recovery (%)	58	67	89
RQD (%)	36	53	68

According to the RQD values, spongy travertine is "poor", weak and massive travertines are "fair". According to porosity (n) value, all are over 20 %, and "highly porous" in the MOOS-Quervain classification. Schmidt hardnesses have been taken as the average of 500 measurements. Massive travertine hardness is "moderate", weak travertine hardness is "soft", and spongy travertine hardness is "very soft" (Hunt, 1986).

Uniaxial compressive strength of masive travertine has been determined to be "very low strength", and according to static elasticity module, in the "intermediate modulus ratio and very low strength" category (Deere and Miller, 1966). Weak and spongy travertines have so low strength not to be considered within this classification. Free filtration experiments carried out in more than 400 filtration wells around Antalya yielded values of 8.2 l/min for massive travertine; 42.4 l/min for weak travertine and 78.4 l/min for spongy travertine.

Table 2 : Geotechnical properties of the travertine types.

Properties	Massive			Weak			Spongy		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Dry unit weight (γd, kN/m^3)	18.2	23.2	19.9	11.1	18.4	15.6	8.8	16.1	13.2
Specific gravity (Gs)	2.57	2.71	2.67	2.58	2.70	2.64	2.51	2.73	2.65
Porosity (n, %)	14.71	32.09	25.23	27.50	51.51	38.09	39.70	67.88	52.47
Schmidt hardness (MN/m^2)	22.0	54.0	41.4	10	24	15.9	< 10	11.0	< 10
Unconfined compression strength (σc, MN/m^2)	13.10	26.40	19.00	4.63	11.00	6.28	0.72	4.85	2.37
Static Elasticity Modülüs (E, MN/m^2 × 10^3)	4.90	5.10	5.00	3.10	3.17	3.15	2.36	2.52	2.40
Permeability (K, l/min)	1.4	18.6	8.2	38.6	53.2	42.4	60.0	107.0	78.4

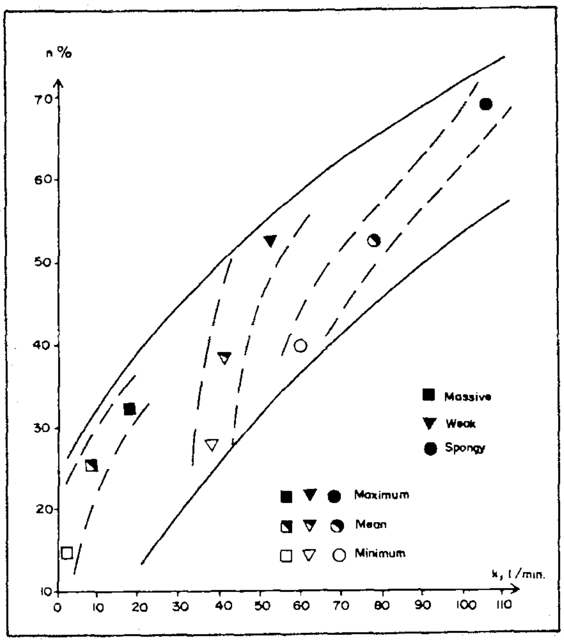

Fig. 8 : Relationship between porosity (n) and permeability (k) of the travertine types.

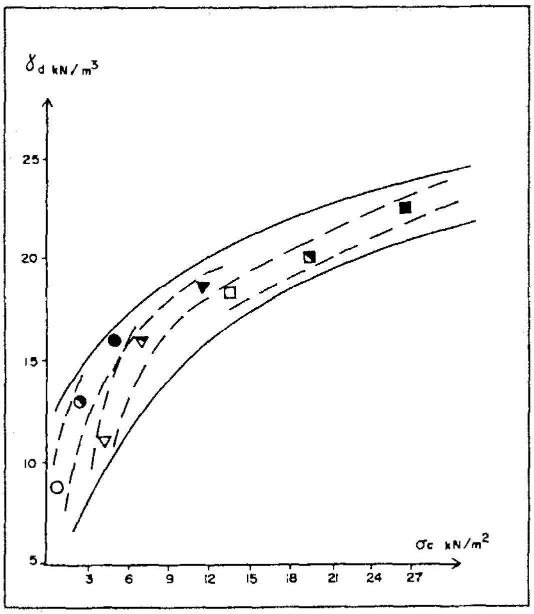

Fig. 9 : Relationship between dry unit (γd) and uniaxial compressive strength σc) of the travertine types.

Relationships between the geotechnical characteristics

The relationship between the porosity and permeability (n-k) of travertine types is shown in Fig. 8. Permeability increases proportional to the increase in porosity. Relationship of dry unit weight to unconfined compressive strength (γd-σc) is shown in Fig. 9. Unconfined compressive strength is the highest for the travertine

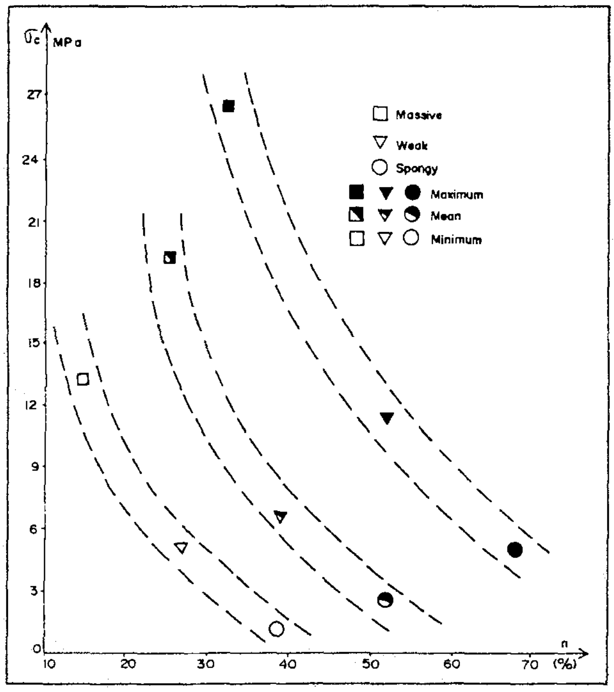

Fig. 10 : Relationship between uniaxial compressive strength (σc) and porosity (n).

with highest dry unit weight. Spongy travertine has the lowest dry unit weight and compressive strength. Unconfined compressive strength decreases as the porosity increases. the decreases, which is not linear is shown for massive, weak and spongy travertines, in Fig. 10.

Results and discussion

The area studied is located in the Düden Plateau. Field and laboratory investigations on the travertines have yielded the following results : Soil with plant remnants is underlain by 2.00-10.00 m thick spongy travertine, which occasionally carries traces of alteration. Average thickness of the weak travertine, intercalated with spongy travertine, is 6.50 m. Underlying these two is the massive travertine, down to depth of 62 m.

Spongy, weak and massive travertine, the occurrence of which is related to sedimentary processes and environmental conditions, available flora and fauna, carbonate concentration, temperature and depth, are completely made up of calcite.

Massive travertine has formed in environments with a lower sedimentation rate and in the deeper parts of the lake; thus the porosity and permeability are lower compared to the other types. Tubular cross-sectioned root marks, dissolution vacuoles and circular conchoidal particles are observable in thin sections. This travertine, with micritic texture, yields higher dry unit weight, uniaxial compressive strength and static elasticity module than the others. On the other hand, porosity and permeability are lower than the weak and spongy travertine.

Weak travertine has mostly precipitated in fresh water environments, and contain more vacuoles, algal structures, Charocea and Gastropoda shell fragments. Considering the geotechnical characteristics, they yield lower values than the massive travertine. Spongy travertine is extremely irregularly shaped, contains dissolution cavities and has completely formed thin root marks and balls. Thus, it is the travertine type with the lowest dry unit weight and strength. On the otherhand, it contains the maximum amount of pores and has a high permeability.

As seen in Fig. 9, uniaxial compressive strength value increases proportionally to the bulk density. Massive travertine with the lowest cavities and pores has the maximum strength. As the porosity increases permeability coefficient also increases. The highest porosity belongs to spongy travertine (Fig. 8).

As the porosity decreases unconfined compressive strength increases. For the massive travertine, mean strength is 19.00 MN/m^2 with porosity 25.23 %. However, in spongy travertine, while the mean strength is 2.37 MN/m^2, mean porosity increases to 52.47 %.

Spongy and weak travertines show an average thickness of 9 m in the Lara area, and form the foundation unit for construction. The karstic cavities are vertical. No serious problem is expected considered the bearing capacity, but the karstic cavities beneath may cause some stability problems. For this reason, drill holes must be made on the points where the columns will be located, and it must be determined whether karstic cavities are present.

Acknowledgement

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