Golden Horn: A historical survey of geotechnical investigations

La Corne d'Or – Une étude historique des investigations géotechniques

E.Togrol – *Istanbul Technical University, Turkey*

ABSTRACT: The Golden Horn is a 7.5 km. long natural inlet of Bosphorus Strait. The soft sediments and sloping bedrock formation create special geotechnical problems to the Golden Horn area. The object of the present lecture is to review the exiting data and describe some typical geotechnical problems encountered.

RESUME: La Corne d'Or est une prise naturelle de 7.5 km de longueur sur le Bosphore. Les sédiments mous et la formation du fond rocheux en pente créent des problèmes géotechniques spéciaux à la région de la Corne d'Or. L'objet de la conférence actuelle est de revoir les données existantes et de décrire quelques problèmes typiques rencontrées en géotechnique.

1 INTRODUCTION

Istanbul bestrides the confluence of the Bosphorus Strait and the Sea of Marmara, and the city's modern suburbs stretch along the both shores. The Golden Horn is a seven and a half kilometre long natural inlet of the Bosphorus. The maximum width of the Golden Horn is 700 m. at the mouth (Fig. 1). The minimum width is 180 m. at the outlets of Alibey and Kağıthane Creeks. For about two kilometres from the downstream end of the Golden Horn, there exists a depression with a maximum depth of 40 m., but preceding upstream, the depth of the water suddenly decreases to a few meters. Echo-soundings showed a transition slope of 2.25 p.c. (about 1.3^0) between the two levels of the sea bottom (Fig. 2). The western shores of the Golden Horn are gently sloping to heights of 40-60 m., whereas the eastern shores have higher slopes reaching to 80-140 m. (Fig. 3). Besides being subject of many geotechnical investigations, the Golden Horn has also a place in the history of soil mechanics.

Terzaghi spent six productive years in Istanbul between 1916 and 1922. During his stay in Istanbul, he had the opportunity to re-evaluate and reconsider his engineering experiences of the past from the perspective of the present (Soydemir, 1973). It was a concentration of enormous intensity. Then came the day of realisation: one pleasant morning in March, 1919 – as he many years later told the incident to Dr. Bjerrum, "... *I was sitting in a mood of depression at an old, rustic coffee house overlooking the Golden Horn* (Pierre Lotti Coffee House). *I suddenly visualised what was needed to obtain a rational approach to the problem involved in earthwork and foundation engineering. I realised that progress depended entirely on the development of testing equipment, and methods which could give a quantitative measure of the mechanical properties of the soils involved. On two sheets of paper, I listed a number of possible ways of testing soils and made sketches of the equipment needed.*" Regarding the same incident, a year later Terzaghi wrote to Wittenbauer, "... *at the beginning of March, 1919, I listed on a single sheet of paper everything we needed to know about the physical properties of clay in order to be in a position to treat the fundamentals of earthwork engineering on a scientific basis. My demand seemed excessive even to myself, and I doubted that I would live to see that all the questions answered.*"

Along with his teaching and research in Istanbul, in 1921, Terzaghi had the golden opportunity to be involved in an ideal project as a consulting foundation engineer. He wrote to Professor H. Peynircioğlu in 1950 about that project, "...*In 1921, it was in Istanbul, at the site of the steam power plant in Silahtar* (situated at the estuary of the Golden Horn), *where I had first the opportunity for a practical application of the fundamental principles set forth later in my writings. For this reason, I always considered Istanbul as the birthplace of what I was able to contribute to the scientific development of earthwork engineering*" (Peynircioğlu, 1973).

It should thus be rewarding to review the studies focused on disclosing the geotechnical secrets of the Golden Horn.

2 GEOLOGY OF THE ISTANBUL AREA

2.1 General

The geology of the Istanbul area has been studied by many investigators (e.g. Penck, 1919; Paeckelmann, 1925, 1938; Chaput, 1936; Sayar, 1951; Sayar and Sayar, 1962; Yalçınlar, 1976; Sayar, 1976). Penck was first to recognize the shales and graywackes as the oldest of the formations encountered in the area. He named them as the Thrace series, belonging to the Early Devonian to upper Paleozoic Era. Later Packelmann changed this dating to Late Devonian. However, subsequent investigations indicated the existence of various litological and paleontological zones in Thrace series, and it is concluded that they belonged to the Early Carboniferous Period of the same era.

Another important geological feature of the Istanbul area is the Middle and Upper Miocene formations of mactra limestones, clays, marls, sands, and gravels of the Tertiary Period. Miocene (Tortonian) marine deposits are encountered in much smaller areas in comparison with the lacustrine and fluviatile originated Upper Miocene (Sarmacien) deposits. The Tertiary formations nearest to the Golden Horn are found within the walled part of the old city.

The first geological map of the old city and the Golden Horn area was prepared by Chaput (1936). The area later studied in detail by Sayar and Sayar (1962) (Fig. 4). They have found that the area consists of Paleozoic (Upper Devonian) greywacks, fine micaceous sandstones, and shales which were overlain unconformably by Sarmatian sand, clay, marl, and limestones deposits.

The Sea of Marmara, connected to the Black Sea and the Aegean Sea by straits (the Bosphorus and the Dardanelles). The Sea of Marmara has a shelf on the northern shore deepening steeply towards the south.

Figure 1. Entrance of the Golden Horn to the left of the picture.

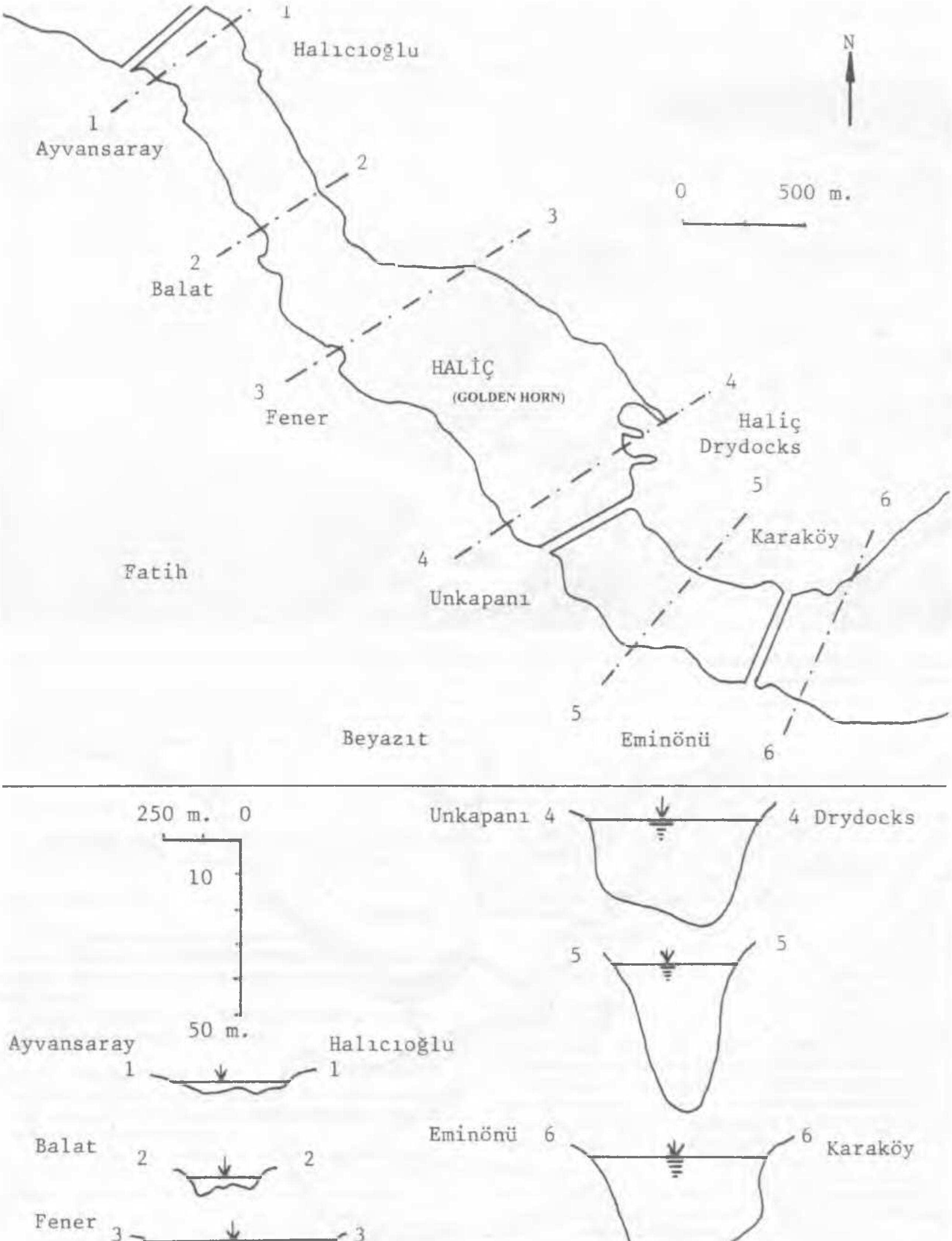

Figure 2. Sections of the Golden Horn (Sayar, 1976).

Figure 3. Atatürk Bridge in the fore ground and the New Golden Horn Bridge in the background. Also, Alibey and Kağıthane Creeks are seen in the far end of the Golden Horn.

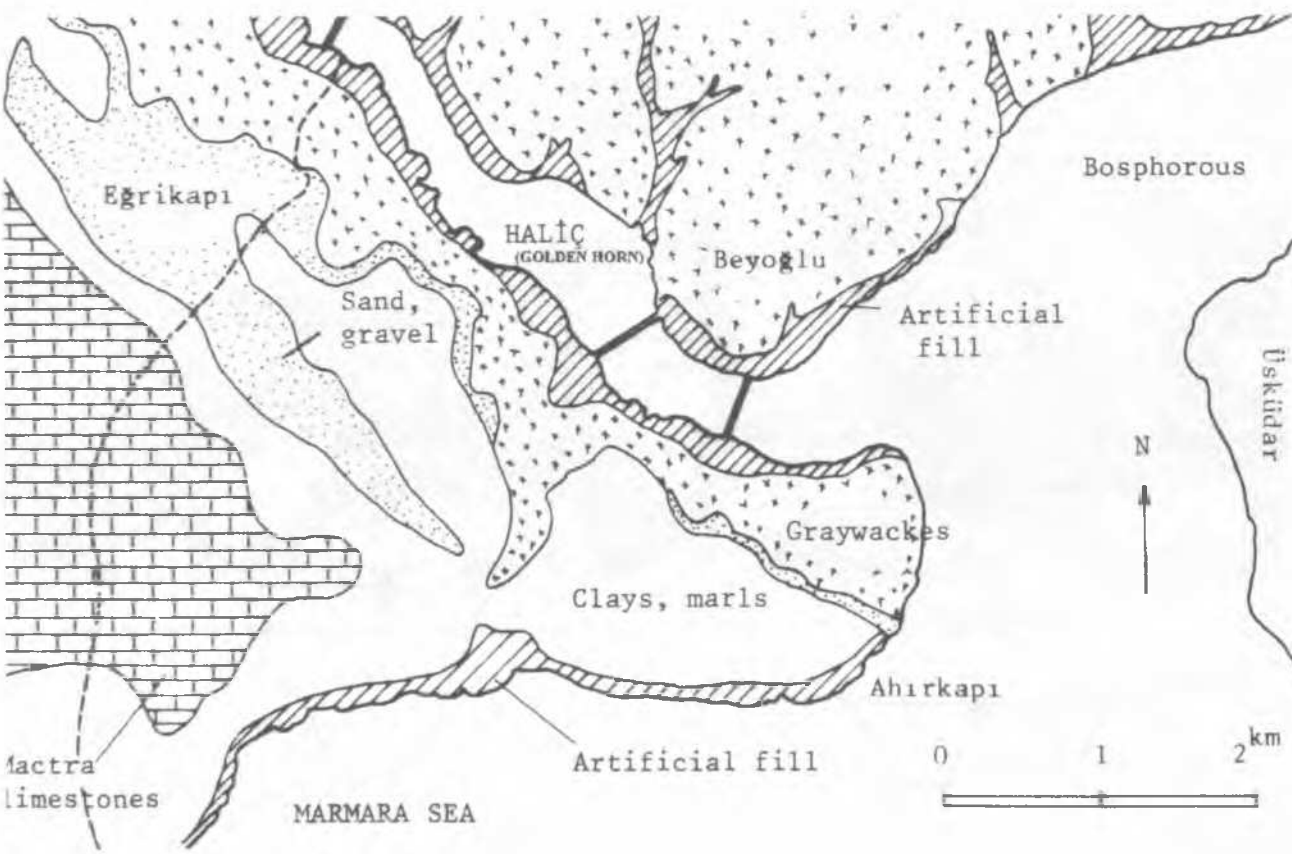

Figure 4. Geological map of Istanbul (Sayar, 1976).

The Bosphorus is 28.5 km. long, 550 m. to 3000 m. wide, and in medial sections, 33 m. to 118 m. deep. The Bosphorus seems, morphologically, to be an fault-controlled valley considering its parallel and indented shorelines.

Istanbul Peninsula comprises the area between the Istranca Mountains and the Bosphorus. This area is the extension of the Kocaeli peneplain with a gently ondulating topography with elevations not exceeding 200 m. It differs, morphologically, from the Asian side of the Bosphorus, the Kocaeli Peninsula, by a lack of high peaks. The water divide in the Istanbul Peninsula is very close to the Black Sea coast at the Belgrade Forest. Kağıthane and Alibeyköy creeks flow into the Golden Horn. Delice and Karasu creeks flow into Büyükçekmece Lake, and Sarıdere into Küçükçekmece Lake.

The eastern Marmara is bounded by the Izmit and Gemlik Gulfs between which Kapıdağı Peninsula is located. Sapanca Lake and Adapazarı Plain are collapsed structures in addition to Orhangazi and Mekece Plains and Iznik Lake. The shoreline range south of Marmara separates it from the collapsed structures, namely Manyas-Apolyon Lakes and plains such as Bursa, Yenişehir, and Inegöl.

The greater Istanbul area comprises Istanbul and Kocaeli Peninsulas. The European and Asiatic parts of the city are separated by the Istanbul strait (The Bosphorus). The Sea of Marmara constitutes the southern boundary of the region. It has three depressions over 1100 meters in depth. From west to east they are Tekirdağ, Central Marmara, and Çınarcık Basins. Submarine ridges rising several hundred meters above the floors of the neighbouring basins separate these depressions. The Çınarcık Basin is located south of Istanbul, bordered in the north by a narrow shelf, and in the south by a wide and deep shelf area.

The coastal region between Çatalca and the Bosphorous consists of Miocene continental to lagoonal sedimentary rocks, less than 150 m. thick. This stratum lies unconformably over the Eocene limestones and Paleozoic sedimentary rocks. The Paleozoic rocks extend to the Princess Islands, which lie on the northern shelf. These rocks consist mainly Ordovician quartzites (Ketin, 1953).

2.2 Stratigraphy

The fundamental time-stratigraphic units of the Istanbul area belong to the Paleozoic, Mesozoic, and Cenezoic Eras.

2.2.1 Paleozoic Era

2.2.1.1 Ordovician Period (Kocaeli series)

Lower Ordovician (O_1) (Kurtköy Formation) consists of pink coloured arkose series: conglomerates, sandstones, mudstones, and shales.

Upper Ordovician (O_2) (Aydos Formation) consists of quartzite series including quartzarenite.

2.2.1.2 Silurian Period

The shale, sandstone, greywacke unit is the Ordovician/Silurian transition zone (OS_1) (Gözdağ Formation). The unit is compact, laminated, and nonfossilliferous.

Lower Silurian (S_2) consists of coloured shale, siltstone, and red conglomerate of arkosic composition. Cross-bedding is frequently observed. No fossils have been encountered. Lower Silurian does not outcrop on the west of the Bosphorous.

Upper Silurian (S_1) (Dolayoba Formation) consists of blue, dark coloured crinoidal sandy limestone and marl.

2.2.1.3 Devonian Period

The dark blue limestones and coral limestones of the Istanbul region are dated either Late Silurian / Early Devonian (Sd_1) (Istinye Formation). The Lower Devonian units of Istinye region unconformably overlie Dolayoba limestones of Silurian (S_1).

Besides Sd_1 three units of Devonian period are identified.

Intercalated fossiliferous shales and limestones constitute the Early Devonian (d_2) units (Kartal Formation).

Middle Devonian (d_3) consists of sandy limestones, shales, and sandstones.

Upper Devonian (d_4) (Büyükada Formation) consists of nodular limestones and shales. On both shores of the Golden Horn, Upper Devonian (d_4) units dominate the soil profile. There nodular limestones are intercalated with carbonated shales and shales with high silicium content.

2.2.1.4 Carboniferous

Carboniferous units are first detected by Yalçınlar (1951, 1952) in the vicinity of Cebeciköy in a series consisting of blue limestone, slate, and sandstone. Carboniferous units outcrop on the European side of the Bosphorous. The shales and graywackes of the Carboniferous are occasionally interbedded by fine particled claystone and conglomerate levels. Three units of Carboniferous have been so far identified.

Radiolarite Formation (k_1) (Baltalimanı Formation) : Chert containing phosphate nodules; occasionally intersected by andesite and diabase dykes.

Alternating sandstones, shales, and argillaceous graywackes (k_2) (Trakya Formation);

Recrystalized bioclastic dark blue limestones (k_3) (Cebeci Formation).

2.2.2 Mesozoic Era

2.2.2.1 Triassic Period

In the Istanbul area Triassic is represented by four units:

The Scythian unit (t_1) consists of red beds of basal conglomerate and nonfossilliferous sandstones;

The Anisian unit (t_2) consists of dolomitized limestones;

The Ladinian unit (t_3) consists of reddish-grey nodular limestone intercalated with thin marl layers; and

The Carnian unit (t_4) of grey-green shale and siltstone containing Halobia.

2.2.2.2 Cretaceous Period

Units of Lower Cretaceous (kra) consist mainly of radiolarian limestone, conglomerate, shale and raidolarite.

The Upper Cretaceous (krü) consists of limestone and shale.

The Upper Cretaceous units are overlain by two other units of Cretaceous: (1) Flysch with alternating sandstone, mudstone, and limestone (krf), (2) andezitic lava, volcanic tuff, and volcanic breccia interbedded with limestone (krv).

2.2.3 Cenozoic Era

2.2.3.1 Tertiary Period

2.2.3.1.1 Paleogene

a. Eocene Epoch

Eocene units consist of marls intercalated with bedded limestones and sandstones (e) (Soğucak Formation).

Another unit, (el) (Kırklareli Formation) which belongs to Lutetian-Priabonian, consists of reefal limestones and partly dolomitized and detrital limestones. It shows lateral transition into sandy marls and has a rich fauna.

b. Oligocene Epoch

Marine Oligocene (old) extending from Çekmece to about 20-25 km west of Keşan is differentiated into two units. The lower one consists of marls and shales and the upper unit of lignite bearing sandstones. The lignite beds are dated as of Lower Oligocene.

Continental Oligocene (ol) (Gürpınar Formation) consists of lagoonal limestone with clay interbeds. It is vesicular, compact, and occasionally well bedded. It sits unconformably on the Eocene limestones. Conglomerates, claystones, and sandstones are also encountered in this unit.

2.2.3.1.2 Neogene

a. Miocene Epoch

Neogene in the Istanbul area is represented by extremely varying lithologies. The lower units of Miocene are marine sediments and continental sediments.

Marine sediments of Miocene (md) consist of sandstones, claystones, and limestones. Fairly continuous outcrops of the unit are observed on both sides of the Dardanelles. It can be seen as small isolated outcrops between Silivri and Tekirdağ.

Continental sediments of Miocene (mk) consists of sandstones, claystones, and conglomerates. The unit, widespread in Ergene basin, lies unconformably on marine sediments of Miocene at some localities and on the Marine Oligocene with lignites elsewhere.

Upper Miocene (or Sarmatian including Pliocene) units are widespread in Thrace. The Sarmatian between the Golden Horn and Büyükçekmece is differentiated, from base to top, as (1) gravel, sands, silts (ms_1) (Çukurçeşme Formation); (2) claystones and marls (ms_2) (Güngören Formation); and (3) limestones with Mactra (ms_3) (Bakırköy Formation). Marl and green clay beds of Güngören Formation are generally found on top of the sand and gravel deposits. These beds are encountered more commonly to the west of the Golden Horn. At the western part of the walled city, marl and clay beds are overlain by limestone beds. Güngören Formation contains vertebrate and mollusc fossils. Bakırköy Formation may easily be recognized by the variety of the mactra species they contain. Thick beds of limestone exist in the Bakırköy area.

In an investigation carried out in the vicinity of Küçükçekmece, the following units from base upward are identified for Neogene: (1) green plastic clays, (2) quartz sands with minor gravels, (3) fine grained silty sands with mica flakes, (4) marls with white shells of Mollusca and Mactra, and (5) limestone bands with Melanopsis and Mactra.

Sarmatian units uncomformably overlie those of Oligocene.

b. Pliocene Epoch

Continental Pliocene (Pl) is fairly widespread in the Istanbul region. It consists of gravel, sand, clay, peat, and lignite. The continental Pliocene in the Ergene basin of Thrace consists of gravel, sand and marls outcropping at hills, and slopes and depressions with a thickness locally exceeding 100 m.

Plio-Quaternary (PlK) deposits consist of lagoonal and fluviatile sediments covering large areas in northern parts of the Kocaeli Peninsula. These deposits may be seen in the Ergene basin and the Gelibolu Peninsula. It is represented by indurated sand, clay, and gravels.

2.2.3.2 Quaternary

Marine Quaternary (Kd) consists of overconsolidated clay, sand, and mud. It is seen south of the Izmit Gulf , at the southern shores of the Dardenelles. The Marine Quaternary between Yalova and Karamürsel consists of yellowish, badly cemented fossilliferous sand overlain by a conglomeratic sandstone containing fragmented shells of fossils.

Old Alluvium (Ke) forms a terrace made up by soil in the Ergene basin seen in the slope of large valleys of Pliocene Age. It consists of terraces and dunes.

Recent Alluvium deposits (al) represented by stream sediments consisting of gravel, sand, and clay. There are large depressional areas in the region covered by recent alluvium. Those deposits cover large areas along the shores of the Golden Horn.

Alibey and Kağıthane rivers transported large amounts of eroded material into the Golden Horn. The bedrock at Karaköy and between Eminönü-Unkapanı is found at a depth of 70 m., whereas the bedrock was found at a depth of 59.50 m. at Eyüp (Sayar and Sayar, 1962).

Flood-plain deposits occupy the bottom of the valleys of Alibey and Kağıthane Creeks. These deposits commonly consist of continuous layers of sand and clay laid down during the high-water season. The maximum thickness of the deposit is 40 meters in the vicinity of the Alibey Dam.

The extent of the marine deposits might be overlooked since the coast line has been greatly changed over the years. In this respect, borings made well inside the shoreline have provided valuable information. Marine deposits have been found between the depths of 14.40 m. and 18.00 m,. at a boring drilled 250 m. inside the shore, near Eminönü. In another boring on Atatürk Bulvarı, 750 m. inside the shore, marine deposits are recognized by the presence of shells.

An investigation originally aimed to investigate the time of the Mediterranean-Black Sea connection after glaciation also provided valuable information concerning the properties of the alluvium (Meriç, 1990). Samples obtained from underground railway and New Galata Bridge borings have been examined for their sedimentary, paleontologic and physical properties. Various micro- and macroorganisms have been detected. Of these, Foraminifera, represented by 23 families, 42 genera, 88 species, and 2 subspecies, are the most abundant group of microorganisms. Most of the genera and species belonging this group are found in the Golden Horn sediments. However, paleontological data were not considered sufficient to determine the date of the sediments. The electro-spino-resonance method used to date the sediments from both the Golden Horn and the Bosphorus yielded 7400 +/- 1300 years of absolute age. According to this result, the first marine influence probably began at this time, and marine conditions were established at around 5700 +/- 1800 years ago, as indicated by the character of the fossil groups, together with dated mollusc shells. Meriç (1990) concludes that a continental environment prevailed in the Istanbul area prior to opening of the Bosphorus. The Bosphorus area then was largely occupied by meandering river valleys draining the region to the north. The faults that previously affected the Paleozoic basement appear to have defined the course of those river valleys. Since the Black Sea was a closed lake before the last sea level rise, fresh Black Sea water and salty Mediterranean water admixed around Istanbul, creating a brackish water environment. The oldest human activities in the area were known at Fikirtepe (5000 B.C.) on the Asian side, and Yarımburgaz Cave (4800 B.C.) on the European side. They belong to Chalcolithique Age, and they are not the oldest archaeological sites in Anatolia. All the other earlier archaeological findings in Anatolia were from areas quite apart from the Marmara region.

Artificial fills overlie marine deposits along the shores of the Golden Horn. They contain boulders, gravel, sand , silt, shells, wood, pieces of concrete and mortar, and all kinds of city debris. In fact, most of the valleys of the old city were filled with every sort of material especially during Roman times. In addition, large areas have been reclaimed at various times in the history of the city. It is thus difficult to determine the engineering characteristics of such fills. Furthermore, in many locations, the sedimentary layers which are found under the artificial fill consist of large amounts of organic matter and shells. A boring made at the Silahtarağa Power House area revealed the existence of organic matter at a depth of 45 m. Organic matter had decomposed and methane gas was formed which had burned for weeks (Peynircioğlu, 1961).

3 TECTONICS

3.1 *Unconformities*

The basement of the Istanbul sheet suffered Hercynian and Alpine folding overprinted on Caledonian one.

The detritics of Eocene in the Çatalca region are believed to have been deformed by the Hercynian orogeny.

The units that have been subjected to Caledonian and Hercynian orogenies have generally been redeformed by the

Alpine orogeny. The effects of the older orogenies are partly erased, and directions of fold axes were occasionally rotated.

Units of Late Cretaceous and Eocene age were folded by the Pyrenean phase of the Alpine orogeny. The flysch of Eocene or Eocene-Oligocene age was folded by Savian or Styrian phases. Pliocene units were affected by epeirogenic movements with extremely open folds generated through the Wallachian phase. The unconformity between Sarmatian and Upper Pliocene units corresponds to the Attican or Rhodonian phase.

3.2 *Folds*

Caledonian folds are mostly tight with fold axes generally trending N-S. The folds are not always symmetrical. The Hercynian trends are also N-S with deviations to NNE-SSW. The deviation is attributed to the Alpine orogeny which generally trends E-W.

In the Golden Horn area, the Paleozoic substratum has a structure which is folded, faulted, and jointed under the influence of Hercynian and Alpine orogenies. The strikes and dips of the beds are often variable, but the general direction of folding is from N-S.

3.3 *Faults*

The Marmara Sea lies across the western extremity of the North Anatolian Fault System (Ketin, 1966; McKenzie, 1972). Hence a large number of faults are encountered at the Marmara Basin. The present fault geometry in the region was achieved during the Pliocene Age (Barka, 1992). The region is under the influence of the North Anatolian Fault. It is a transform fault forming part of the boundary between the Eurasian and Arabian plates. The North Anatolian Fault is seismically active, and has been the site, in recent years, of several large destructive earthquakes of great magnitude.

The North Anatolian Fault enters the Marmara Sea through Izmit Bay and reaches Thrace on the other side near Gaziköy. GPS measurement indicates that the Anatolian Plate south of the Marmara Sea is moving westward at a rate of 2 cm/year (Straub and Kahle, 1995; Strub et al., 1997). The Anatolian Plate has been travelling essentially as one unit attached to Africa since Cretaceous (Crampin & Üçer, 1975).

Various authors have pointed out that the North Anatolian Fault initiated in eastern Anatolia during the Late Miocene and propagated westwards reaching the Marmara Sea region during the Pliocene (Şengör, 1979; Suzanne et al., 1990; Barka, 1992).

One of the three deepest depressions of the Marmara Sea is the Çınarcık Basin which is situated south of Istanbul. Okay et al. (2000) describe the basin as wedge shaped, about 50 km. long and 20 km. wide at its widest extent in the west and with a surface area of 545 km^2. The basin floor is remarkably flat and featureless. It would be interesting to note that most of the basin floor lies at a depth of 1270 m. to 1150 m., and the maximum depth is 1289 m. in the eastern part of the basin. The northern slope of the Çınarcık Basin is about 3 km. wide with an average dip of 17^0. Okay et al. (2000) evaluated the recent seismic reflection data and pointed out that North and Inner Boundary Faults of the Çınarcık Basin are two arms of the North Anatolian Fault and corresponding bathymetrically to the northern and inner submarine slopes of the basin.

3.4 *Seismicity of the Golden Horn*

There is a wealth of historical earthquake data for the Marmara region. Inspection of the data shows no epicentres in the Golden Horn area. However, there are records of the damage from strong earthquakes which took place in the past. Earthquakes of 1488, 1509, and 1659 caused the destruction of a large number of buildings in the Golden Horn area. In 1509, Tsunami, earthquake sea waves overtopped the sea walls of Istanbul and Galata.

Burton et al. (1984) estimated the seismic risk in Turkey. They have determined strain energy release from cells of seismicity of 4^0 side and from this, the magnitudes are analogous to the maximum strain energy conceived throughout Turkey and its neighbouring areas. The seismic risk parameters from the cellular analysis of seismicity are interpreted as contoured seismic risk maps. They have also determined the most perceptible earthquake magnitude distribution for the same areas. The features of the contoured perceptibility map are found compatible with the existing Earthquake Zoning Map of Turkey which is entirely based on observed felt effects in Turkey. In both of those maps, the Golden Horn area falls into the zone where the largest magnitude expected over an interval of 75 years is 6.5.

4 WEATHER

From its geographical location Istanbul is pre-eminently a meeting place of winds. There are four main winds. The Poyraz is clean bracing wind from NE. The Lodos, or hot SW wind is utterly different. It constricts one's veins and dries up the lymphatic ducts. So hard is the Lodos on the temper, that in Ottoman times, it was said that judges refused to give judgement when it was blowing! The Meltem is a pleasant summer wind from the Black Sea. The Karayel is a cold wind from NW, which brings snow in winter.

5 SOIL CONDITIONS

5.1 *General*

Over the centuries, the detritus brought by Alibey, Kağıthane, and other creeks, heavy industrial and domestic wastes, and uncontrolled fills have changed drastically almost the entire cross section of the Golden Horn. Along the shores, many valleys have been levelled off by generally uncontrolled fills, and comparatively large areas have been reclaimed.

The typical soil profile of the area consists of loose artificial fills and soft clay deposits which are underlain by a sloping bedrock. Such a profile brings out the need for a careful reconnaissance for any construction, large or small. However, the geotechnical problems involved when building along the shores of the Golden Horn have only occasionally been appreciated in the past. Subsidence, lateral movements, and large scale slides have been common features of the Golden Horn shore for centuries now. Twenty years ago it was possible to observe the examples of damage charged by excessive total and differential settlements and slides. However, a few but reliable records of such settlements are given by various authors (i.e. Peynircioğlu, 1961, 1962, 1975; Durgunoğlu & Akşit, 1978; Aksoy, 1982). The two-storied Hilal Han, which was built along the shore between Galata and Atatürk Bridges at Yemiş, tumbled into the sea one night in 1952 (Peynircioğlu, 1961, 1962). Peynircioğlu (1962) reports settlements of 150 – 200 cm., lateral movements of 25 - 30 cm., and tilts of about 10 p.c. In the eighties, all such buildings, with the exception of those having historical significance, were demolished by the Municipality to establish a green belt (Fig. 5).

5.2 *Soil profile*

The variation of the soil profile along the shoreline of the Golden Horn has been determined through a large number of exploratory borings and soil testing.

The thickness of the man-made fill is over 40 m. along the south shore and over 30 m. along the north shore on the axis of the New Galata Bridge. The thickness of the fill decreases with increasing distance from the shore. Man-made fill layer is

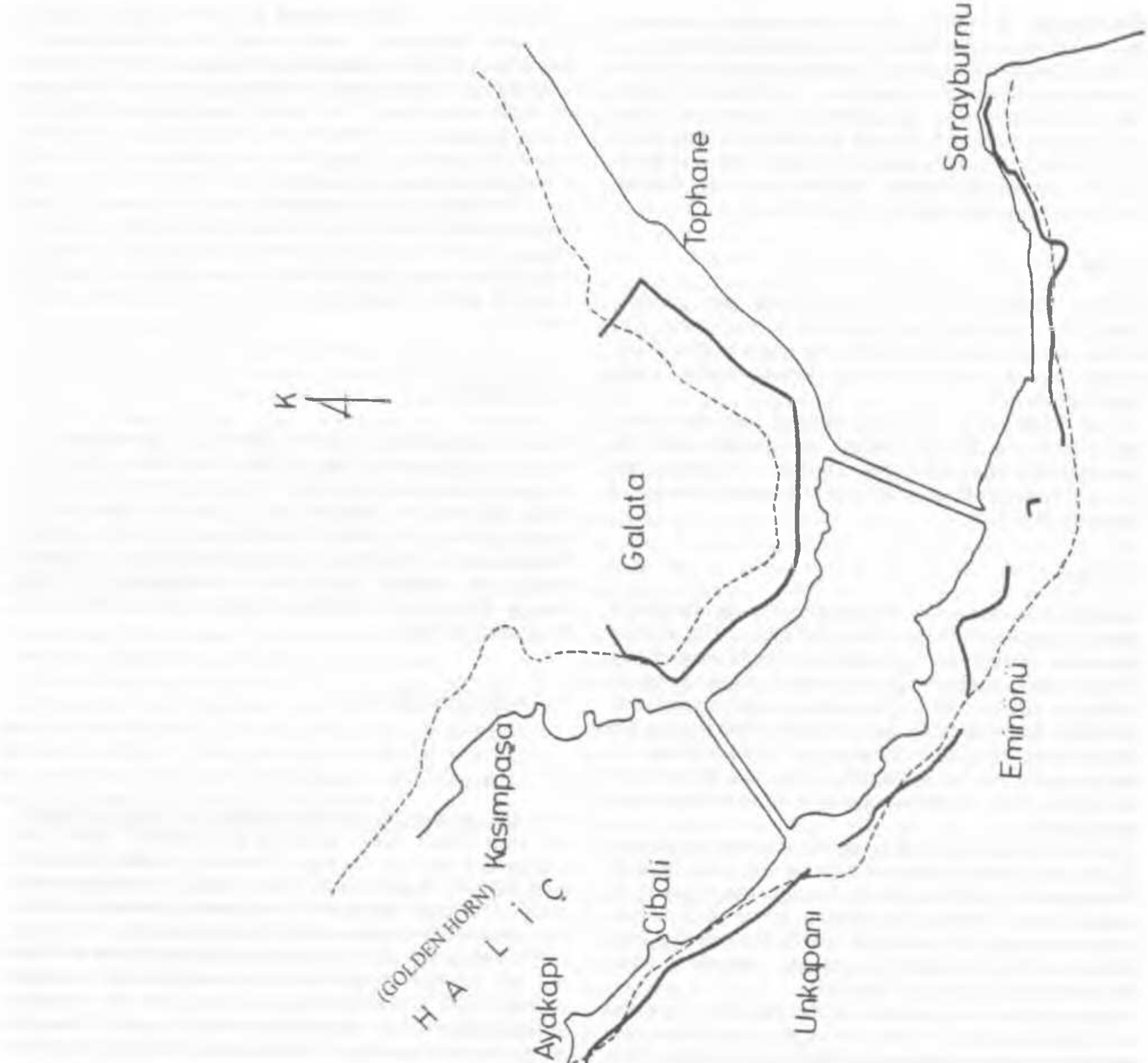

Figure 5. The extend of the reclaimed ground along the Golden Horn. ---- Old shore line ——Walls of the Old City and Galata

underlain by sedimentary layers which are described as light gray to dark-gray fat organic silty clay of marine origin. Occasionally this formation is referred to as alluvium. It should also be noted that the silt content of the alluvium increases over the depths from 60 to 80 meters below the sea level (Togrol et al. 1991). Therefore a more accurate definition of the alluvium between those depths should be slightly sandy clayey silt. The lower parts of the alluvium are very probably underconsolidated.

The alluvium is generally underlain by a few meters of weathered shale and partly by cobbly gravel. The greywacke bedrock belongs to Paleozoic (Upper Devonian). A detailed study of the samples obtained from depths of 33.00 m. to 92.00 m. at the New Galata Bridge site show that the bedrock is mainly weathered greywacke. Its colour is dark gray, at places brown. In two borings greywacke is replaced by limestone and in two borings by shale. However, greywack is the deepest layer in all borings.

The Eminönü Trade Center building is located on 14.00 to 16.00 m. thick uncontrolled fill (Peynircioğlu, 1961). The depth of the man-made fill layer and the bedrock are given in Table 1. Soil profile and the depths of the bedrock are shown in Figure 6.

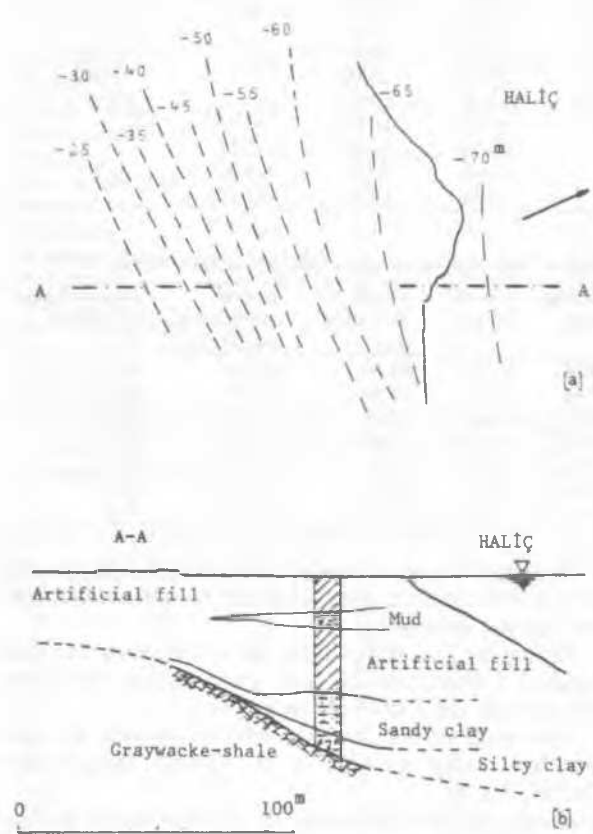

Figure 6. Trade Center borings (Peynircioğlu, 1962).

Table 1. Eminönü Trade Center borings.

Boring No.	Length of borehole (m.)	Bottom elevation of the fill (m.)	Top elevation of the bedrock (m.)
B1	34.50	-18.00	-32.50
B3	37.50	-31.90	-34.10
B4	52.50	-41.00	-45.80
B5	67.50	-42.70	-64.50

A large number of borings were made during 1974 for the waste water collector tunnels on both sides of the Golden Horn (Fig. 7). The depth of the fill layer and the depth of the bedrock are given in Tables 2 and 3.

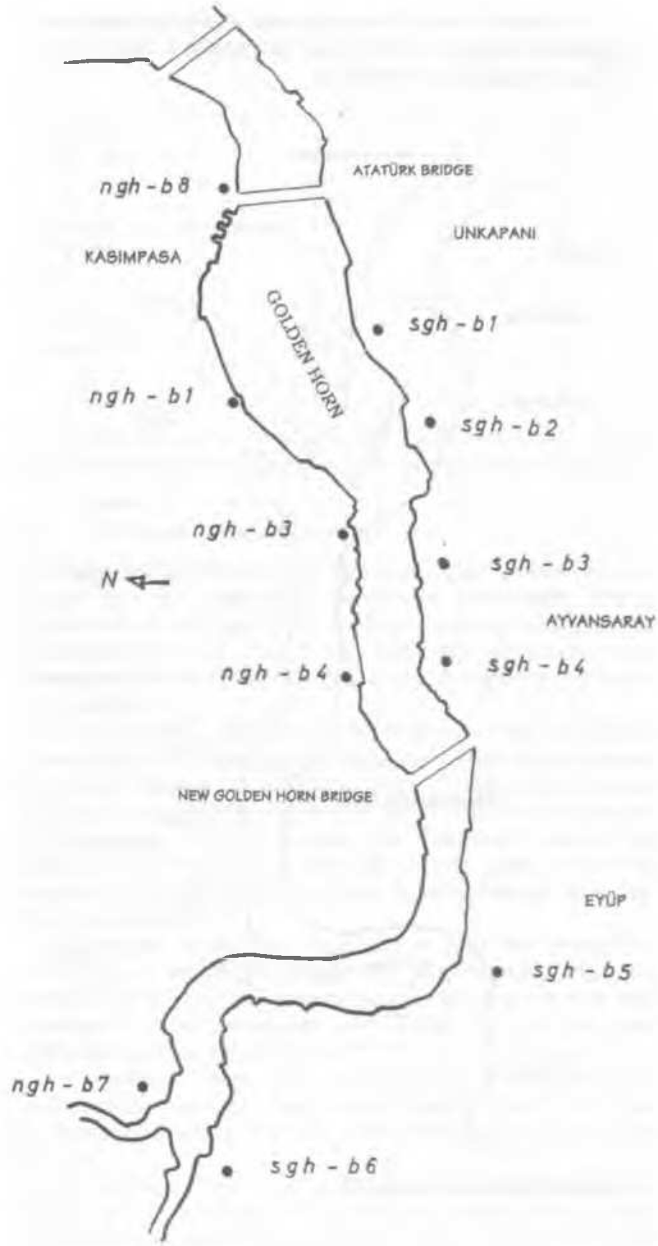

Figure 7. Waste water collector borings (1974).

Table 2. Southern Golden Horn waste water collector borings (1974).

Boring No.	Elevation (m.)	Length of boring (m.)	Bottom elevation of fill (m.)	Top elevation of bedrock (m.)
Sgh-b1	+3.25	15.50	-	+0.25
Sgh-b2	+2.50	21.00	-	-8.50
Sgh-b3	+2.50	28.50	-	-15.80
Sgh-b4	+2.25	33.00	-2.80	-22.75
Sgh-b5	+5.00	41.50	-	-29.00
Sgh-b6	+5.50	20.00	-	-7.50
Sgh-b7	+4.50	20.00	-1.50	-10.50

Table 3. Northern Golden Horn waste water collector borings (1974).

Boring No.	Elevation (m.)	Length of boring (m.)	Bottom elevation of fill (m.)	Top elevation of bedrock (m.)
Ngh-b8	+3.50	18.00	+0.50	-9.50
Ngh-b1	+2.50	21.70	-4.00	-7.50
Ngh-b3	+3.25	11.90	-2.95	-5.50
Ngh-b4	+1.00	28.65	-8.00	-27.50
Ngh-b7	+3.50	12.50	+1.00	-4.00

A further series of borings were made for waste water collector tunnels in 1982 along the southern shores of the Golden Horn (Figs. 8) (Table 4).

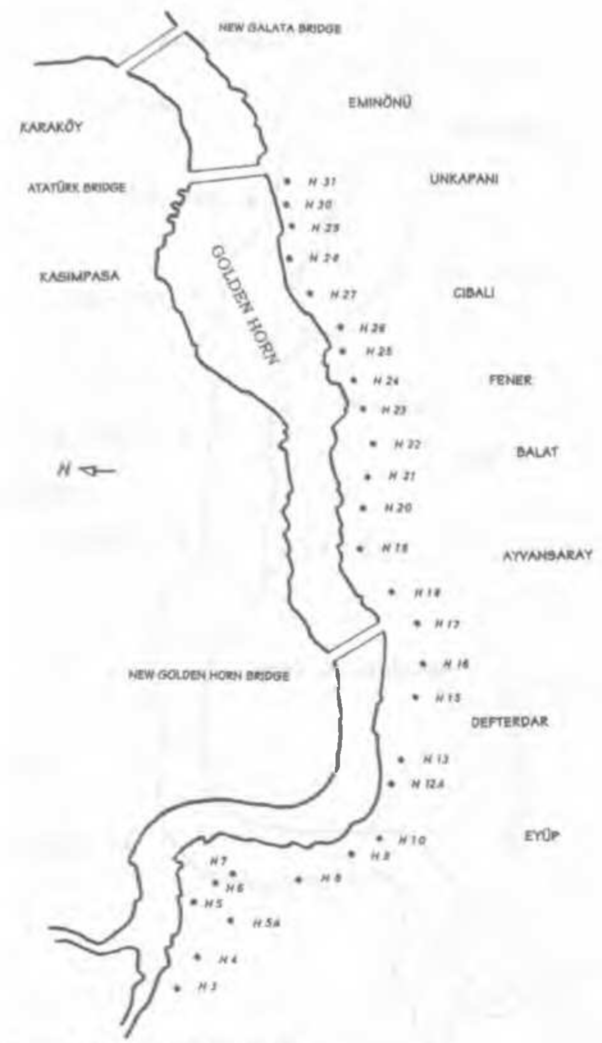

Figure 8. Collector borings (1982).

Borings Nos. 31, 30, 29, and 28 are made between Unkapanı and Cibali and possess similarities. The soil profile consists of about 8 m. thick fill layer which is underlain by a 4.50 m. thick shell layer. Below that elevation medium, dense sand is encountered in boring No.31 whereas in other three borings, boreholes went into stiff clay.

Similarities are also found in borings Nos. 23, 22, 21, 20, 19, and 18 which were drilled at location between Fener and the Golden Horn bridge. The thickness of the fill layer is about 7.50 m. The fill layer is underlain by silty clay, sand-gravel, shell, and a clayey shell series.

The thickness of the fill layer in boring No.17 is 8.00 m. which is underlain by a sandy shell layer.

Boring No.12A is made at Eyüp where that part of the Golden Horn is very shallow. The soil profile in the boring consists of 8.50 m. fill which is underlain by stiff silty clay.

Borings Nos.11 to 2 are made along the shore between Eyüp and Silahtar. In some of those borings, the depth of the bedrock was reached. Boring No.5A is made at a high ground where it was possible to locate the outcrop of the bedrock. TCR values vary between 0 and 70 and increase with depth. RQD values are between 0 and 17.

Table 4. Southern Golden Horn waste water collector borings (1982).

Boring No.	Elevation (m.)	Length of boring (m.)	Bottom elevation of fill (m.)	Top elevation of bedrock (m.)
31	+2.82	19.10	-4.18	-
30	+1.97	15.00	-5.03	-
29	+1.90	15.00	-8:10	-
28	+2.45	15.00	-6.55	-
27	+2.55	15.00	-1.35	-
26	+1.64	15.00	-4.36	-
25	+1.61	10.45	-4.89	-
24	+1.94	10.00	-1.06	-
23	+2.48	10.09	-4.59	-
22	+2.44	10.00	-6.06	-
21	+2.65	10.15	-5.35	-
20	+1.58	10.05	-4.42	-
19	+2.05	10.25	-5.95	-
18	+2.87	10.45	-5.19	-
17	+3.08	10.20	-4.92	-
16	+2.71	10.15	-0.79	-
15	+1.25	10.05	-5.75	-
12A	+1.99	20.05	-6.51	-
11	+0.91	20.00	-0.59	-
10	+2.92	14.30	-0.58	-
9	+15.00	15.00	-	+1.71
8	+6.36	15.00	-	+4.36
7	+4.44	12.00	-	+0.94
6	+12.26	16.00	-	+12.26
5A	+36.42	40.40	-	+35.67
5	+5.14	12.00	-	+3.39
4	+7.45	10.00	+3.45	-
3	+5.92	10.00	+2.42	-
2	+4.00	7.50	+1.00	-1.70
1	+4.00	10.10	+1.30	-

Table 5. Borings along the axis of the Golden Horn Bridge (1970).

Boring No.	Elevati on (m.)	Length of the boring (m.)	Bottom elevation of the fill (m.)	Top elevation of bedrock (m.)
P-6R	-1.10	64.60	-6.10	-62.00
P-6L	-1.30	65.80	-7.30	-63.50
8A	-0.80	76.80	-5.80	-64.50
P-7R	+1.33	37.50	-5.17	-30.17
P-7LA	+0.85	40.00	-5.95	-30.55
P-7L	+1.28	39.17	-5.72	-33.22
P-8	+5.67	17.00	-1.33	-7.73

Boring No.3 gives a slightly different soil profile: the fill layer is 4.00 m. thick, and is underlain by 4.50 m. thick soft silty clay and loose gravel.

Boring No.1 is drilled along the Alibey creek. In that boring a 2.70 m. thick fill layer is underlain by stiff silty clay, soft silty clay, and loose shell layers.

The depth of the fill layer and the bedrock are also determined along the axis of the Golden Horn Bridge (Table5) (Fig. 9).

During the soil exploration for the New Galata Bridge, weathered sandstone was encountered at an elevation of –9.85 m. at boring No.G9. The variations of the elevations of weathered and intact rock are given in Table 6.

5.1 *Index properties*

The average index properties of alluvium samples obtained from various locations along the Golden Horn area are given in Table 7.

The liquid limit of those soft layers at the Golden Horn is usually between w_L = 0.50 and 0.80, and the plastic limit between w_p = 0.25 and 0.45. The natural water content of those layers is very close to the liquid limit. Akgüner et al. (1996) report natural water contents greater than the liquid limit. Unconfined compressive strengths of samples taken from depths down to 60 m. vary between 0.00 and 120 kPa.

Table 6. Variation of the depth of bedrock at the New Galata Bridge site.

Boring No.	Soil elevation (m.)	Length of borehole (m.)	Bottom elevation of fill layer (m.)	Elevation of weathered/ intact rock (m.)
G9	3.60	21.10	-5.90	-9.85
G16	2.18	41.95	-25.82	-29.02/ -3.32
G15	1.80	50.05	-33.20	-37.70/-3.20
G17	0.95	45.50	-29.05	-/-35.25
G8	0.53	43.20	-32.97	-40.47
G10	0.63	43.09	-30.87	-34.42
G7	-28.80	78.55	-43.10	-75.90
G6	-39.00	79.70	-	-76.00/-9.50
G5	-35.00	79.30	-	-75.75/-7.00
G4	-28.90	78.80	-34.80	-/73.80
G3	1.16	65.50	-40.23	-/-60.33
G13	-1.47	68.75	-42.22	-/-62.97
G14	1.36	67.18	-42.14	-/-63.14
G11	2.00	26.00	-24.00	-
G12	2.50	26.00	-23.50	-
G1	3.33	65.25	-42.16	-58.66/-
G2	3.76	44.60	-31.34	-34.54/-

Table 7. Average properties of the alluvium.

Location	Depth (m.)	w_L (%)	w_p (%)	w_n (%)
Eyüp,Hasköy, Sütlüce (1)	0 - 60	60 – 80	30 - 40	50 - 75
Sütlüce, Istanbul Değirmencilik (2)	0 - 20	85 – 90	40 - 45	60
Unkapanı (3)	30 - 60	50 – 60	25	50
Third Golden Horn Bridge (2) (4)	0 - 60	60	25	60
Silahtarağa Extension (2)	8 - 28	67	31	67
Hasköy,Şark Değirmenleri (5)	13 - 33	63 - 77	32 -37	53 - 62
New Galata Bridge (6)	34 -54	64	28	49
Golden Horn Development (7)	0 - 25	30 – 73	11 – 49	20 - 110

(1) Peynircioğlu, 1962. (2) Togrol, 1975. (3) Peynircioğlu, 1961. (4) Maden, 1975. (5) Peynircioğlu, 1965. (6) Togrol et al., (1986) (7) Akgüner et al., 1996.

Table 8. Variation of index properties with depth at Hasköy.

Depth (m.)	w_L (%)	w_p (%)	I_p (%)	w_n (%)	q_u (kPa)
13	68	34	34	54	70
16	74	35	39	53	70
18	72	35	32	53	70
20	75	35	40	60	40
22	72	37	35	61	60
24	77	35	42	62	30
26	76	36	40	61	70
28	70	36	34	55	80
30	63	32	31	50	80
33	64	34	30	50	100

The typical variation of test results on samples obtained from Boring No.1 at Hasköy Şark Değirmenleri A.Ş. site is given in Table 8 (Togrol, 1967).

Tests conducted on the samples obtained from the borings made for the Third Golden Horn Bridge show that the undrained shear strength of the sedimentary layer is 10 kPa for clays with a liquid limit greater than 0.50. The shear strength of layers with a liquid limit less than 0.50 is greater than 10 kPa.

The sensitivity of the clay ranges between 3 and 6 which indicates that a large deformation of the clay can cause a decrease in the strength of the soil layer (Togrol, 1975).

It was possible to make a detailed study of the soil conditions during the soil investigation for the New Galata Bridge. There alluvium is considered as three sub-layers (Table 9).

Table 9. Sub-layers of the alluvium (1985).

Soil	Parameter	Mean value (%)	Standard deviation (%)	Number of samples
Dark gray shelly clay	w_n	72	2	3
	w_L	80	5	3
	w_p	38	3	3
	I_c	19	11	3
Dark gray silty clay	w_n	49	6	30
	w_L	64	8	30
	w_p	28	3	30
	I_c	44	14	30
Dark gray organic clay	w_n	43	4	5
	w_L	66	6	5
	w_p	32	2	5
	I_c	65	17	5

Liquid limit and plasticity index values of Upper Golden Horn investigations are shown on the plasticity chart (Fig. 10)

5.4 *Deformations and settlements*

The observed settlements of buildings along the Golden Horn are larger than the calculated consolidation settlements. This is explained by the fact that the shear stresses underneath the foundations are very close or even sometimes equal to the shear strength of the soil (Peynircioğlu, 1961). It could also be due to creep effects.

The foundation problems of the buildings along the Golden Horn caught the attention of geotechnical engineers, and the area served as an open air laboratory. Karl Terzaghi was probably the first geotechnical engineer to use it early in this century (Peynircioğlu, 1975). However, the 'laboratory' area of the Golden Horn was incorporated into a vast green belt in the eighties, and practically all the tilted or partly damaged buildings were demolished.

Silahtarağa Power Plant was built in 1915 and enlarged in 1955. This Plant had the longest and most reliable settlement record in the area. The foundation pressure was 50 kPa, and measured total settlements were 8 cm. to 100 cm., and differential settlements 50 cm.

A fountain which was built in 1810 at Unkapanı on sedimentary deposits had settled more than 180 cm. (Peynircioğlu, 1961). The tilt of the fountain was measured as 6.5 p.c.

Peynircioğlu (1962) also reports the deformation and settlement of a number of buildings at Kantarcı Ocağı Street. The lateral movements of the 105 year old buildings, at the time of the study, reached 30 cm. All buildings at that street were built on man-made fill. The shear strength of the fill was estimated as between 60 – 140 kPa.

Settlements of a flour mill at the upper Golden Horn area (Sütlüce) were measured as 45 cm. and 86 cm. The tilt of the building was 0.05 to 0.07.

It should be interesting to note that most of the buildings mentioned in these paragraphs were still in use at the time of the studies.

5.5 *Consolidation*

Coefficient of volume compressibility and coefficient of consolidation of alluvium samples obtained at the New Galata Bridge site are determined through laboratory oedometer tests (Table 10, 11).

Table 10. Coefficient of compressibility, m_v of alluvium (m^2/kN).

Depth (m.)	Pressure interval (kN/m^2 x 10^{-5}) 0 - 25	25 -50	50 - 100	100 - 200	200 - 400
42.93	51	66	34	28	23
45.93	109	52	24	19	13
53.13	28	59	33	29	21
45.98	77	51	38	29	21
50.59	68	45	39	23	15
Mean	67	55	34	26	19

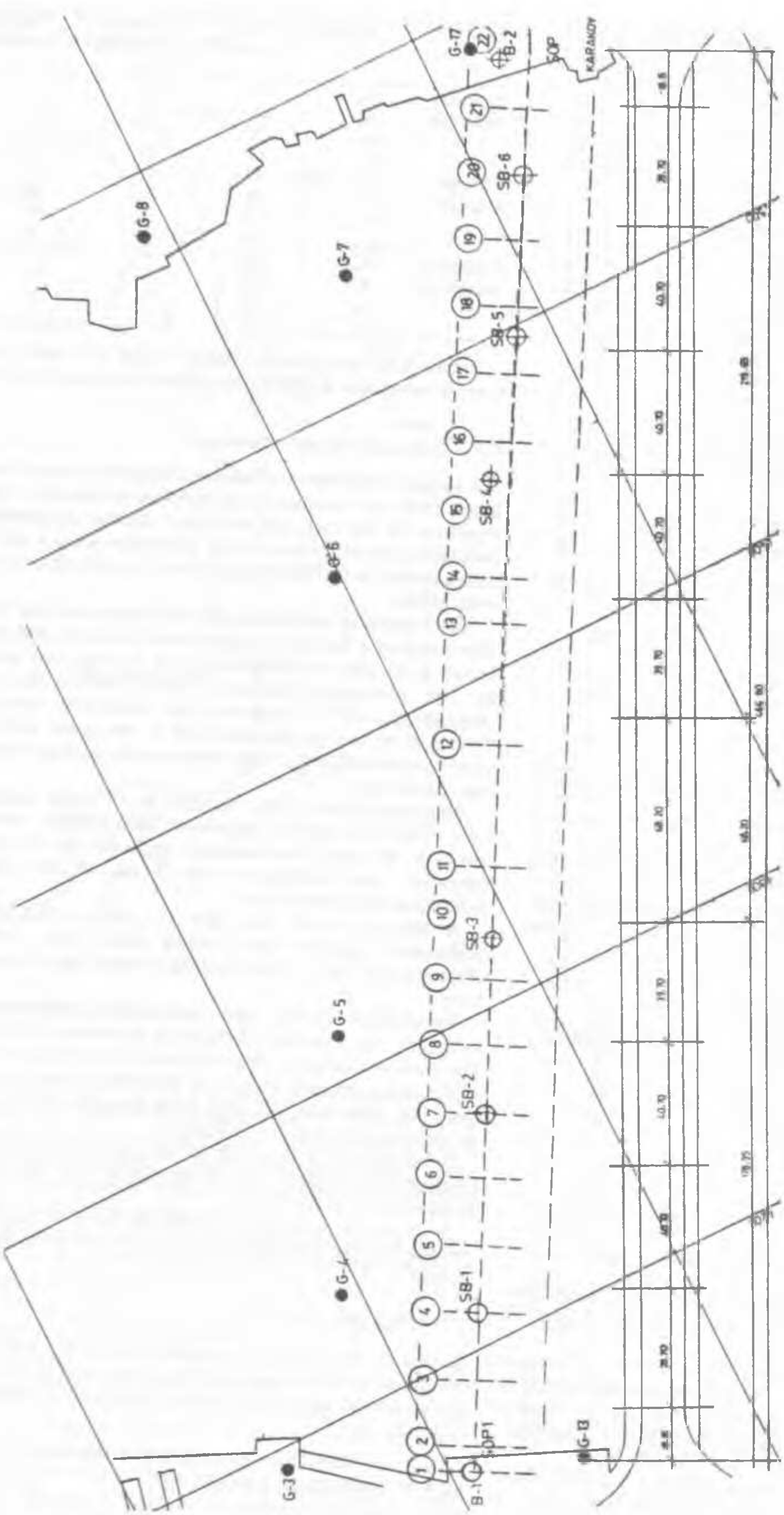

Figure 9. Borings for the New Galata Bridge (1985).

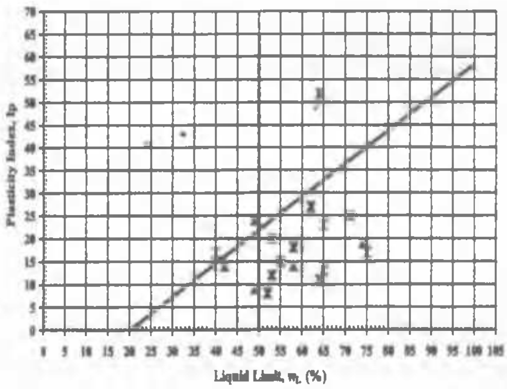

Figure 10. The cluster of soft sediments on the Plasticity Chart.

Table 11. Coefficient of consolidation of alluvium, c_v ($cm^2/sec \times 10^{-7}$).

Depth (m.)	Pressure interval (kN/m^2) 0 - 25	25 - 50	50 - 100	100 - 200	200 - 400
42.93	31	50	37	37	33
45.93	88	95	119	185	177
53.13	314	317	41	51	43
45.98	56	29	54	52	43

Consolidation characteristics of the alluvium are determined on a number of samples obtained from borings. The results are given in Table 12.

Table 12. Consolidation characteristics of the alluvium.

Depth (m.)	C_c	C_α *	γ_n (kN/m^3)	w_n (%)	C_α / C_c
56	0.45	0.015	16.7	52	0.03
68	0.38	0.008	17.5	42	0.02
74	0.43	0.011	16.9	42	0.03
61	0.56	0.019	17.0	51	0.03
54	0.55	0.015	16.1	62	0.03
58	0.50	0.016	16.7	55	0.03
66	0.56	0.011	16.9	45	0.02

*) $\Delta p = 100 - 200\ kN/m^2$

When preparing Table 10, secondary compression index and related settlements are calculated as suggested by Mesri (1973) and Mesri and Godlewski (1977). The ratio between the secondary and primary consolidation indices are calculated by Mesri and Castor (1987) for clays and silty clays over a large interval as

$$C\alpha / Cc = 0.04 +/- 0.01 \quad (1)$$

From Table 4, the value of C_α / C_c for the alluvium could be given as 0.03 which is consistent with the values given by Mesri and Castor (1987).

Akgüner et al. (1996) have calculated the compression index of the alluvium on samples obtained from the western part of the Golden Horn as:

$$C_c = 0.141\ \gamma_s^{1.2}\ \{\ (1 + e_0)\ /\ \gamma_s\ \}^{2.38} \quad (2)$$

Through oedometer tests on alluvium samples at a pressure of 100 kPa (void ratio c. 1.00), the coefficient of consolidation is found to be:

$$c_v = 3.8 \times 10^{-8}\ m^2/s \quad (3)$$

Preconsolidation pressure of the alluvium was also studied by a series of oedometer tests using Casagrande's construction. The results indicated the possibility of under-consolidation, especially for the lower portion of the alluvium.

5.6 *Variation of shear strength with depth*

The properties of the fill layer were studied at Fatih Tunnel project. The results of pressuremeter tests performed in the fill are given in Table 13.

Table 13. Pressuremeter tests in the fill layer (1982).

Boring No.	Elevation (m.)	E_m (kPa)	p_L (kPa)	SPT
F1	+0.00	1121	90	25
"	-5.42	1157	200	7
F2A	-1.20	1986	350	20
"	-4.70	1136	190	27
F2B	-0.20	1948	320	5
"	-4.70	3635	435	11
F3	-1.43	3106	430	6

Pressuremeter tests were also carried out at Eyüp borings (Table 14).

Table 14. Pressuremeter tests in the soft clay at Eyüp

Boring No.	Elevation (m.)	E_m (kPa)	P_L (kPa)	SPT
E3	+0.51	1986	375	6
E4	-5.40	2965	315	2
"	-12.20	1140	200	-
"	-18.80	1433	290	3

During the construction of the New Galata Bridge, a number of pressuremeter tests were performed (Table 15).

Table 15. Pressuremeter tests made in five boreholes at the New Galata Bridge.

Boring No.	Elevation (m.)	Soil	E_m (kPa)	p_L (kPa)	SPT
B1	-5.48	Fill	1242	258	10
"	-11.48	"	2943	208	17
"	-17.48	"	2648	363	15
"	-23.48	"	1378	208	22
"	-29.48	"	4622	203	12
"	-37.48	"	1328	248	21
"	-45.48	Silty clay	1341	253	6
"	-56.48	"	-	503	10
"	-66.48	Graywacke	12927	1220	-
"	-69.98	"	13899	1490	-
SB1	-30.50	Fill	1500	225	-
"	-36.50	"	2283	540	3
"	-40.00	"	1649	325	-
"	-46.00	Silty clay	1825	325	-
"	-52.00	"	1757	375	-
"	-58.00	"	1838	200	-
"	-63.50	"	2038	425	-
"	-69.50	"	2270	425	-
"	-76.00	Shale	17500	1120	-
"	-78.00	"	13333	1120	-
	-82.00	"	9424	1440	-
"	-85.50	"	7433	1200	-
SB2	-93.00	Graywacke	35 078	1800	-
"	-95.00	"	81 197	2350	-
"	-96.40	"	102 257	2250	-
SB3	-53.00	Silty clay	680	590	-
"	-59.00	"	2179	590	-
"	-65.00	"	680	590	-
"	-75.00	"	5911	540	-
"	-88.50	Graywacke	63 826	1730	-
"	-92.00	"	76 342	1730	-
B2	-5.43	Fill	1967	338	7
"	-11.43	"	1920	308	13
"	-17.43	"	3069	463	7
"	-23.43	"	1479	398	11
"	-29.43	"	4078	468	9
"	-35.43	Graywacke	18 646	124	29
"	-41.43	"	28 530	1830	-

The results of the pressuremeter tests performed at the New Galata Bridge site will give the following average values:

Fill layer $E_m = 2300$ kPa, $p_L = 300$ kPa;

Silty clay $E_m = 2100$ kPa, $p_L = 500$ kPa.

The undrained shear strength values obtained from triaxial compression and direct shear tests when plotted against depth, lie below the line for s_u equal to 0.25 times the effective overburden pressure which also suggests under-consolidation. However, the results obtained from oedometer and strength tests could could also be interpreted as sample disturbance in a soil with a laminated fabric. Durgunoğlu and Akşit (1978) evaluate the findings of the borings made for the Third Golden Horn Bridge and found that the average $s_u / \sigma_{vo}' = 0.23$. In a later study of the alluvium, at the shallow part of the Golden Horn, the variation of shear strength with depth is given by Akgüner et al. (1996) as

$$s_u / \sigma_{vo}' = 0.2 \qquad (4)$$

Berilgen et al. reports the results of consolidated undrained tests of samples obtained from alluvium as

$$c' = 0, \text{ and } \phi' = 19^0 \qquad (5)$$

Various correlations have been attempted for the data obtained from the alluvium layer of the upper part of the Golden Horn. Standard Penetration Test results (both uncorrected and N_{60} values) give lower values with respect to the relationship given after Terzaghi ($c_u = 6.25$ N) (Figs. 11-13).

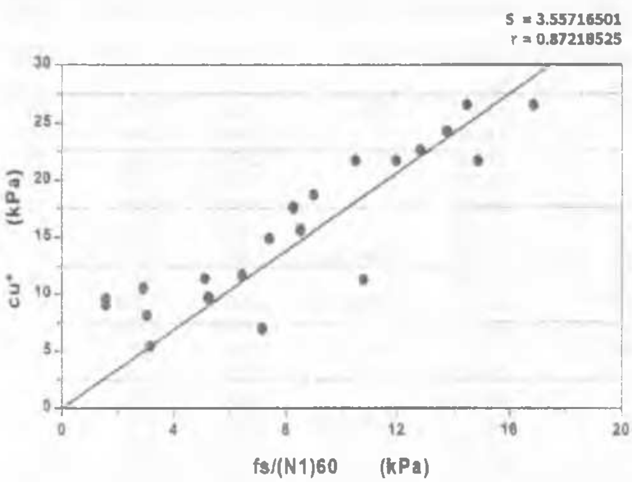

Figure 11. Relationship between vane strength and sleeve friction (Data provided by K. Özaydın, S. Yıldırım, and M. Berilgen).

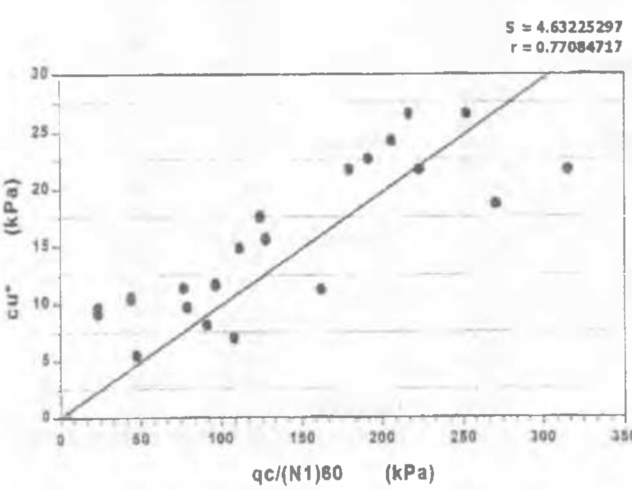

Figure 12. Relationship between vane strength and tip resistance (Data provided by K. Özaydın, S. Yıldırım, and M. Berilgen).

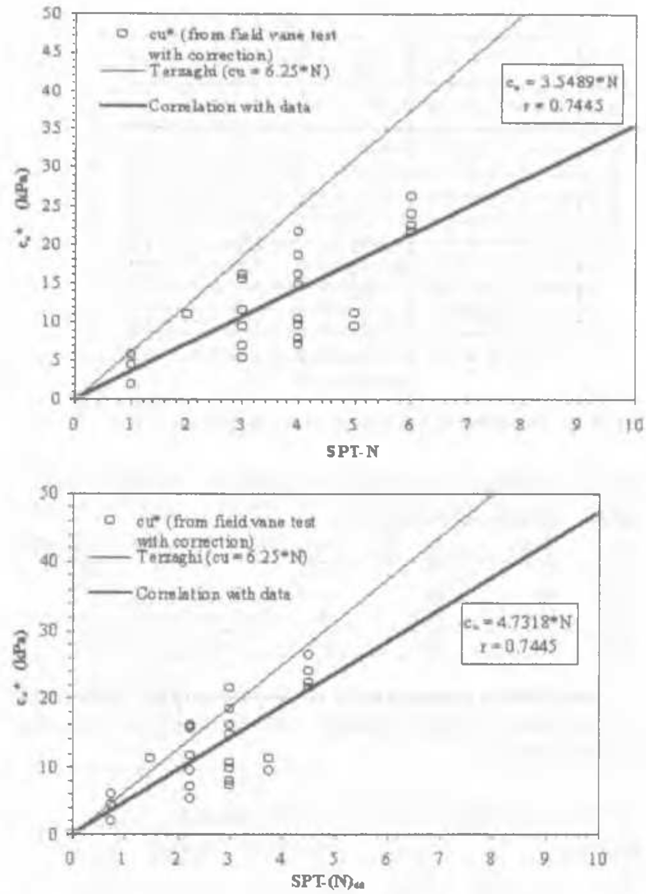

Figure 13. Relationship between and SPT values (Data provided by K. Özaydın, S. Yıldırım, and M. Berilgen).

Corrected vane strength values are best correlated (Coefficient of correlation = 0.87) with CPT sleeve friction values normalized by $(N_1)_{60}$. Corrected vane strength values are also correlated with cone resistance. The correlation coefficient was 0.77 between the values of "corrected vane strength" and "cone resistance/$(N_1)_{60}$" and also between the values of "corrected vane strength" and "cone resistance/overburden/ $(N_1)_{60}$".

5.7 *Sampling disturbance*

The natural water content of the alluvium is very close to its liquid limit. The effect of sampling disturbance is attempted to be verified from the results of the soil borings (Durgunoğlu & Akşit, 1978). In the first series of borings (Borings Nos.S7 and S9), samples were obtained from shelby tubes driven into soil by hydraulic pressure. In the second series of borings (Borings Nos.6R and 7L), samples were obtained by piston samplers. Samples obtained from neighbouring boreholes are compared for their shear strengths and disturbance ratios are determined (Table 16).

Table 16. Effect of samplers on the shear strength of the silty clay

Depth	Shear strength, s_u (kPa)					
(m.)	In the sea			On the land		
	S7	6R	R_D	S9	7L	R_D
5 – 10	-	-	-	9	21	2.3
10 – 20	5	18	3.6	10	25	2.5
20 – 30	9	38	4.2	36	42	1.2
30 – 40	13	35	2.7	-	-	-
40 – 50	15	15	3.7	-	-	-
>50	32	69	2.2	-	-	-

The disturbance ratio varied between 1.2 and 4.2 with an average value of R_D =2.8. These findings clearly indicated the importance of sampling methods for the soft clays of the Golden Horn.

6 OUTSTANDING EXAMPLES

6.1 The New Mosque

Yeni Cami (The New Mosque) was built between 1597 and 1664 along the Golden Horn (Figs. 14, 15). It is known that the construction of the mosque was interrupted for 58 years due to its foundation problems. The mosque was commissioned by Valide Safiye Sultan, the mother of Sultan Mehmet III. The original architect of the mosque was Davut Ağa, a pupil of the great Sinan, the architect who built most of the finest mosques in the city during the golden age of Süleyman the Magnificent and his immediate successors. Davut Ağa died in 1599 and was replaced by Dalgıç Ahmet Çavuş, who supervised the construction until 1603. For more than half a century, the partially completed mosque stood on the shore of the Golden Horn. Then in 1660, the whole area was devastated by fire, adding to the ruination of the mosque. Later in that year Valide Turhan Sultan, the mother of Mehmet IV decided to rebuild the mosque and the architect Mustafa Ağa was placed in charge of the reconstruction, and the construction continued in 1661.

A recent study (Peynircioğlu et al. 1978) has shown that the mosque was seated on a 10 m. thick man-made fill which is underlain by 20 m. thick sand and gravel series (alluvium) (Fig. 16). The depth of the bedrock varies between 40 and 42 meters. Between the sand and gravel series and the bedrock, a sandy silt layer was also encountered. The average foundation pressure is estimated as 220 kPa. The mosque has developed a tilt towards the Golden Horn with an average slope of 0.005. However, no damage is observed in the structure. Most probably the delay of the construction allowed the soil to complete the major part of its consolidation (Peynircioğlu et al. 1981).

6.2 Eighteenth century drydock

A sharp contest took place between French and Swedish engineers when the construction of drydock at the Golden Horn shipyard was put to tender in the late eighteenth century (Togrol & Aksoy, 1981) (Fig. 17). The construction of the drydock (now called Drydock No.3) started in 1796 and took three years to complete it. In the same shipyard, Drydock No.2 built in 1825 and Drydock No.1 built in 1870 employed the same principles of construction adopted from the earlier design.

A number of exploratory borings are recently made in the vicinity of drydocks to investigate the soil conditions. The soil profile consists of an artificial fill of 4 meters thick, and it is underlain by a 10 m. thick gray sandy silty clay layer. The sandy silty clay layer rests on the shale bedrock. The upper surface of the bedrock has a slope of 10 p.c. towards the Golden Horn. Borings also show that the properties of soft layers overlying the bedrock on and off shore are different. The grey sandy silty clay layer has an average liquid limit of w_L = 0.50, plastic limit, w_p = 0.27 and the natural moisture content of w_n = 0.33. The green silty clay that is encountered just off the shore has an average liquid limit of w_L = 0.90, plastic limit w_p = 0.45, and natural moisture content w_n = 0.60.

A soil investigation worthwhile to note took place before the construction of the first drydock. French and Swedish engineers presented their proposals to the authorities in 1796 (Togrol & Aksoy, 1981; Müller-Wiener, 1994).

The French engineers' plan involved sinking a construction caisson after preparing the required channel by dredging and underwater blasting. Then the water inside the caisson would have been pumped out to build the quay walls. This type of construction required a very large caisson. It seems that the French design was based on the experience gained in the construction of Drydock No.1 built between 1774 and 1777 at Toulon Harbour (Noel, 1850).

Swedish engineers proposed to drive sheet piles in order to seal the working area and to make both the excavation and the construction in a dry pit. The French proposal was found to be 2.2 times more expensive than the Swedish one, so the Swedish engineers won the contract (Arne, 1952).

In order to determine the exact location of the drydock, test pits were dug at the site. The pits were 18 m. by 18 m., with a depth of 10.50 m. Through those pits, not only the soil conditions, but also the choice of the drainage equipment was determined. Once the exact location of the drydock was decided, wooden sheet piles were driven along the shoreline, and the excavation work started. The size of the excavation was 37.50 m. by 75.00 m., with a depth of 10.50 m. Timbering was also used to support the walls of the excavation.

Floor slab and side walls of the drydock were made of good quality building stone from the Istinye quarries in Istanbul. This particular stone has been extensively used in marine works. The thickness of the floor slab is 0.75 m. and for most part it is understood to be resting on the bedrock. Side walls have stepped faces and vertical backs. Calculating the stability of the drydock and the pressures acting on the walls and foundations for dry and flooded conditions reveals a balanced and successful design. Stresses acting on masonry are within allowable values, and pressure distribution seems to be nearly uniform.

Ground water level controlled throughout the construction. Continuous drainage of water from the pit did not present serious problems except damage to two neighbouring storehouses. Cracks and settlements were observed in these buildings, and one of them had to be demolished later.

The drydock built in the Golden Horn shipyard about two centuries ago is one of the remarkable constructions of the eighteenth century. It has been in use until last year, and it has not been subjected to any serious deformation or damage. It constitutes an excellent example which emphasizes the importance of correct assessment of geotechnical problems. If had been built only a few meters closer to the shoreline than where it is now, it might have been sharing the fate of many other buildings along the Golden Horn which were heavily damaged by subsidence and sliding.

6.3 City walls

Byzantine sea-walls originally began at Sarayburnu, there joining the sea-walls along the Marmara Sea, and stretching along the shore of the Golden Horn to meet the land-walls of the northwestern corner of the city (Fig. 5). The sea-walls were originally built by Theodosius II in the fifth century. Sea-walls were repaired and reconstructed many times across the centuries. These fortifications consisted for the most part of a single line of walls 10 m. in height. Considerable stretches of the sea-walls are still standing. The sea-walls, once along the shoreline, now stand beyond reclaimed ground at places reaching the width of hundred meters.

At the intersection of the historical sea-walls with the land-walls at Ayvansaray, large settlements have been observed in an area of 200 m. inside the shoreline. There the wall has been rotated considerably and caused serious damage.

6.4 Quay walls

The Eminönü quay of today in fact possesses a very long history. (Fig. 18). It served as the main port of the city during Byzantine period. Occasional fires and man- made fills occasionally interrupted the full usage of the port. It required some sort of dredging during 695-986 (Müller-Wiener, 1994).

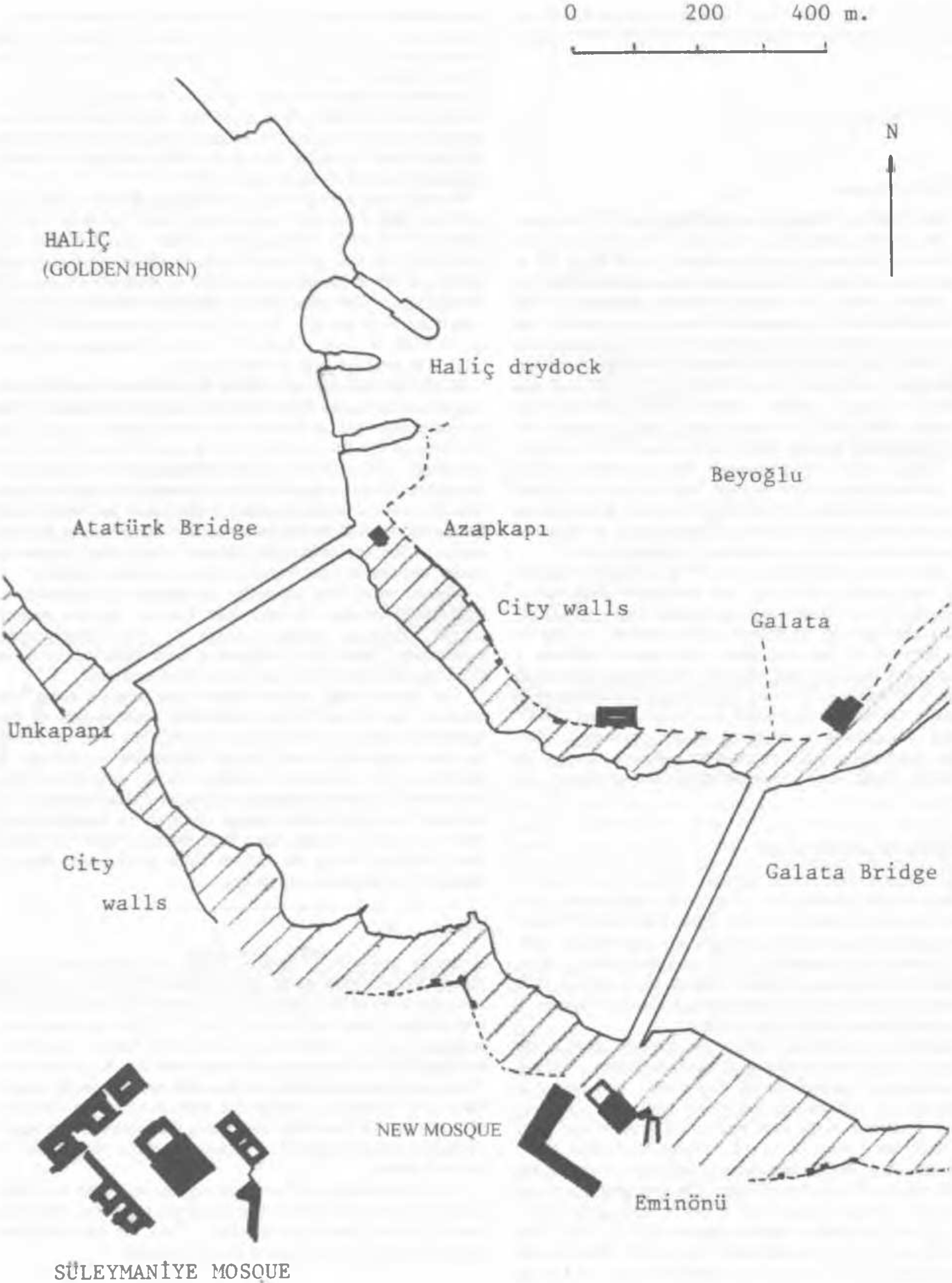

Figure 14. Plan of the New Galata Bridge area showing the reclaimed ground and New Mosque and Süleymaniye Mosque.

Figure 15. The New Mosque.

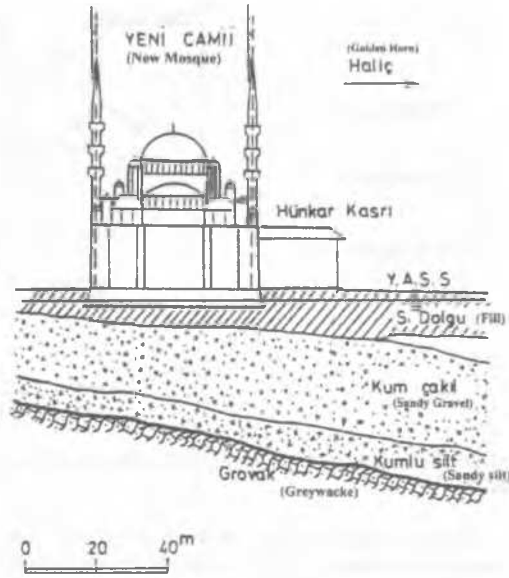

Figure 16. Soil profile at New Mosque site (Peynircioğlu et al., 1977).

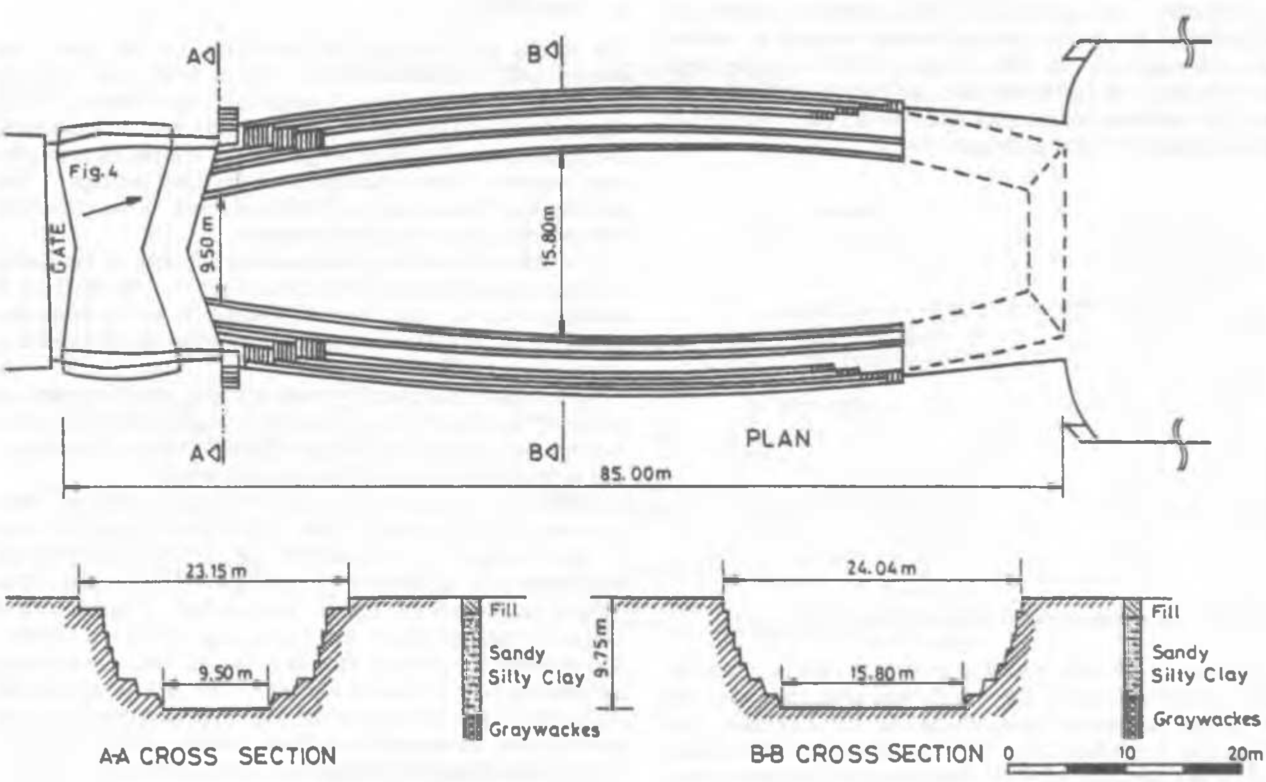

Figure 17. Plan of the drydock (Based on the original drawings).

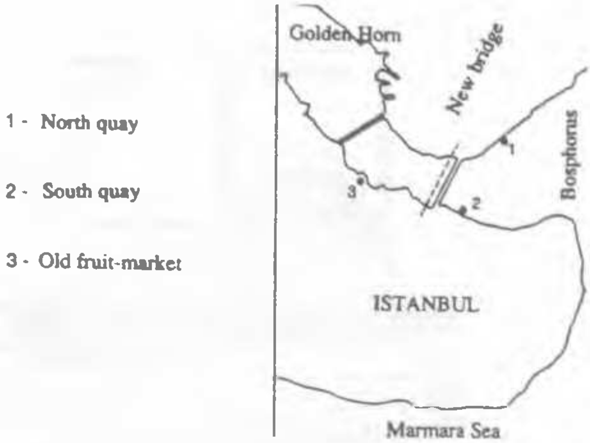

Figure 18. Location map of the north and the south quays and the fruit market.

The area continued to serve as the major port of the city during the Ottoman period. In an old engraving (1558-1561) of the area, wooden piles are seen driven along the shore and strengthened by tying wooden wales from behind. In the same period, houses were also found in the same area along the Golden Horn built on wooden piles.

Towards the end of the nineteenth century, great lengths of quay walls were built along the Golden Horn. Although the necessity for quay walls was badly felt during the Crimean Campaign (1856), it was not possible to find a willing contractor ready to deal with the site conditions. Therefore, 758 m. long north (Karaköy) quay walls were built between 1892-1895, and 370 m. long south (Sirkeci) quay were built between 1894-1900.

For the quay walls at Karaköy, 232 000 m^3 material for foundations and 157 000 m^3 fill were used. During the winter of 1893-1894, the construction was continued despite the difficulties of the season, and settlements occurred at various parts of foundations. In 1894, blocks of 340 m. of the north quay were laid. On September 1895, the first ship berthed at the quay. The settlement of the quay wall between 1895 and 1930 is given in Figure 19 (Kann & Suman, 1941).

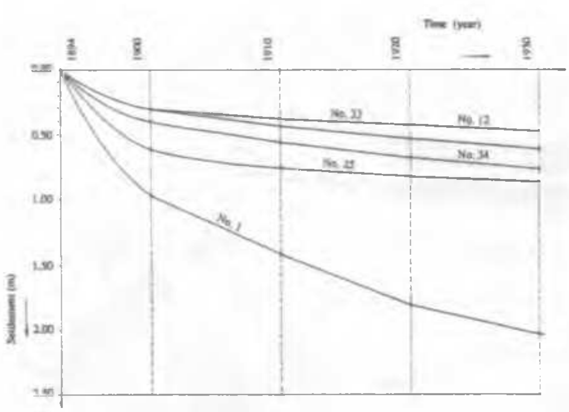

Figure 19. Time-settlement curves of the north quay wall.

Quay walls at Sirkeci started to be built in 1894 on a rock fill base. The construction of the rock fill took about two years, and most of the fill material sank into the soft silty clay base. The water depth is between 26 to 37 m., and the rock fill was laid upon a soft clay layer of 14 to 19 m. thick. A foundation stress of 200 to 250 kPa is transferred to the clay. In 1896, large settlements were observed in the rock fill layer, and in July of the same year, the quay wall slid, moved 4 m. forward, and subsided 8 m. (Fig. 20). Construction continued by adding further rock fill. However, in October of the same year, further slides took place. The final cross section was reached in 1900 only after making a counter weight fill in front of the wall (Peynircioğlu, 1961). Then the rock fill base was extended to 195 m., and the height of the heaved clay has reached 14 m. The rate of settlement in 1900 was 15 cm./year and in 1930, 1.7 cm./year (Peynircioğlu, 1976). The settlement of the south quay wall between 1900 and 1930 is given in the Figure 21 (Kann & Suman, 1941).

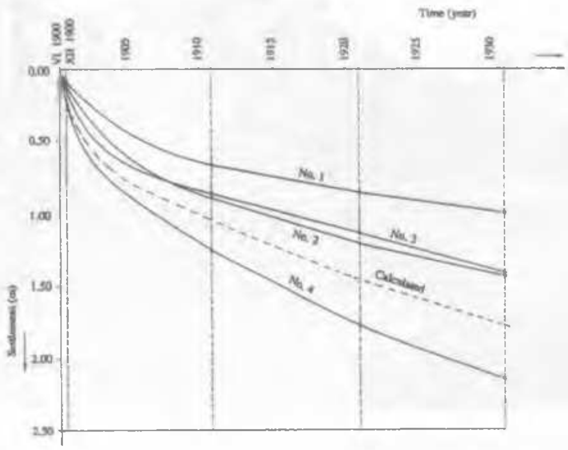

Figure 20. Observed and calculated settlements of the south quay wall.

The soil profile at the site of the south quay wall is better known than that of the north quay. Thus a settlement calculation is attempted for that location. The total settlement of the quay wall is calculated as 3.60 m. and the 95 p.c. consolidation would be reached in 190 years. Calculated settlements are consistent with the observed ones.

6.5 *Fruit Market*

The coastal strip between the Sea Walls and the shore was densely built. Measurements in 1975 at Sebze Hali showed movement of the building towards the sea (Baykal, 1975). Meyve Hali (Fruit market) was built in 1935, next to Sebze Hali, over a floor area of 6 300 m^2 (Figs.22, 23). Hinged frames of the main structure were founded on individual footings. The building was demolished in 1986 as a result of the green-belt development project of the Municipality.

The footings rested on the man-made fill layer of increasing thickness towards the sea, from 25 m. to 36 m. The fill layer is underlain by a silty clay layer (alluvium) of varying thickness. The depth of the bedrock changes from 33 m. to 69 m. with a general slope of 20° towards the sea.

Differential settlements between the axes were measured in 1962, 1975, and in 1985 (Tan, 1976; Togrol,1991) (Fig. 24). Reliable measurements of total settlements could not be obtained due to the difficulty of securing reference points.

Measurement indicated that the settlements continued over the years. The maximum differential settlements were 225 mm. in 1962, 340 mm. in 1975, and 380 mm. in 1985. The rotations were 2/500 in 1962, 2.7/500 in 1975, and 2.9/500 in 1985. The differential settlements caused considerable distortions and damage in the building. It was interesting, however, to observe that settlements continued after fifty years of the construction, and then the building was still in use. If we take the differential settlement as three-quarters of the maximum settlement, then the probable total settlements of the Fruit Market building should be at least 340 mm in 1962, 453 mm in 1975, and 507 mm. in 1985.

The designers of the Fruit Market were compelled to estimate settlement on the basis of semi-emprical rules since an extensive soil investigation had not been available. They were obviously aware of the magnitude of the total settlements. Accordingly, the upper structure was designed to withstand distortions. Settlement calculations were made by assuming a loading of 20 kPa

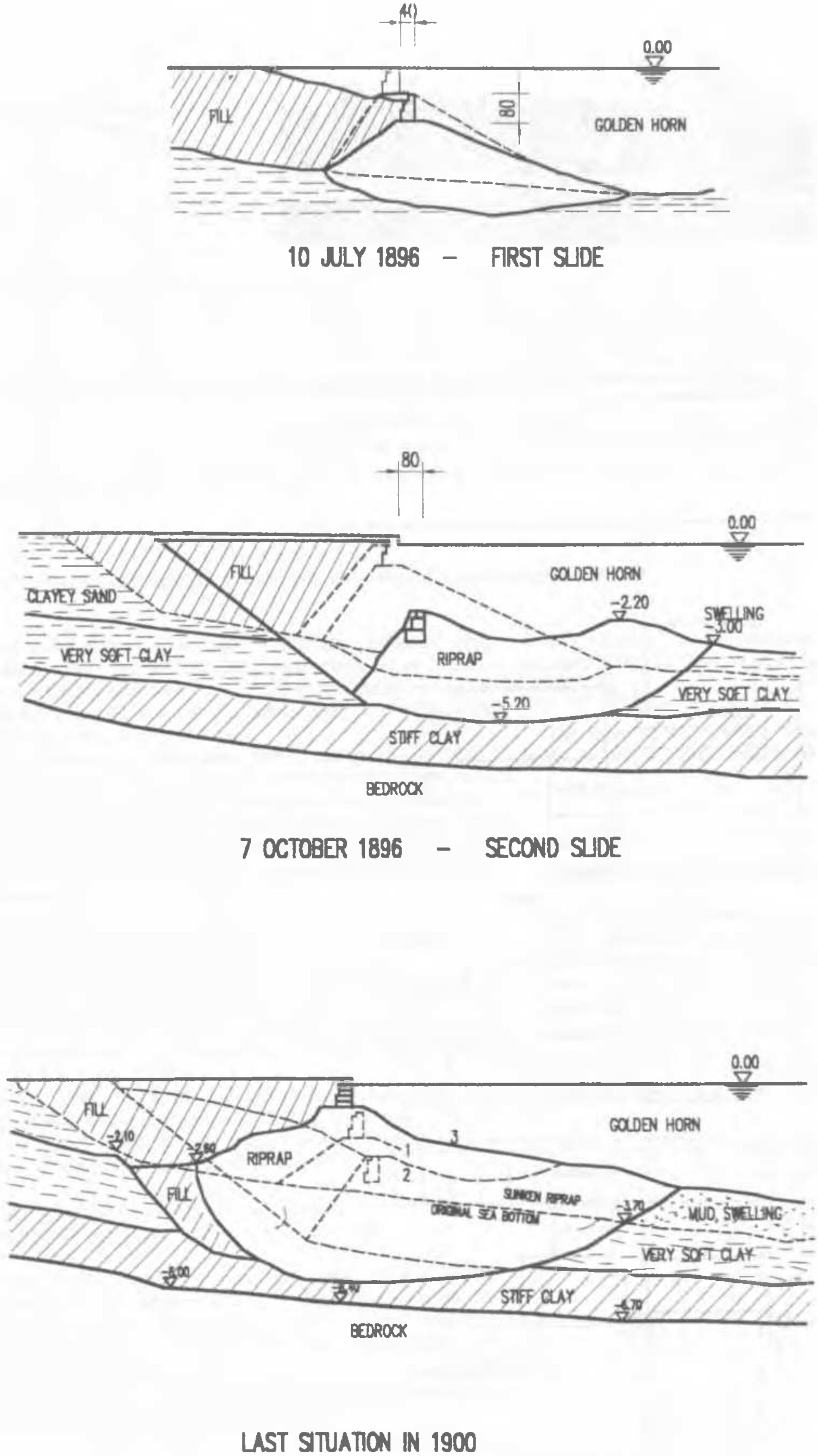

Figure 21. Settlements and slides of the south quay wall (Based on the drawings of Peynircioğlu, 1976).

Figure 22. Fruit Market.

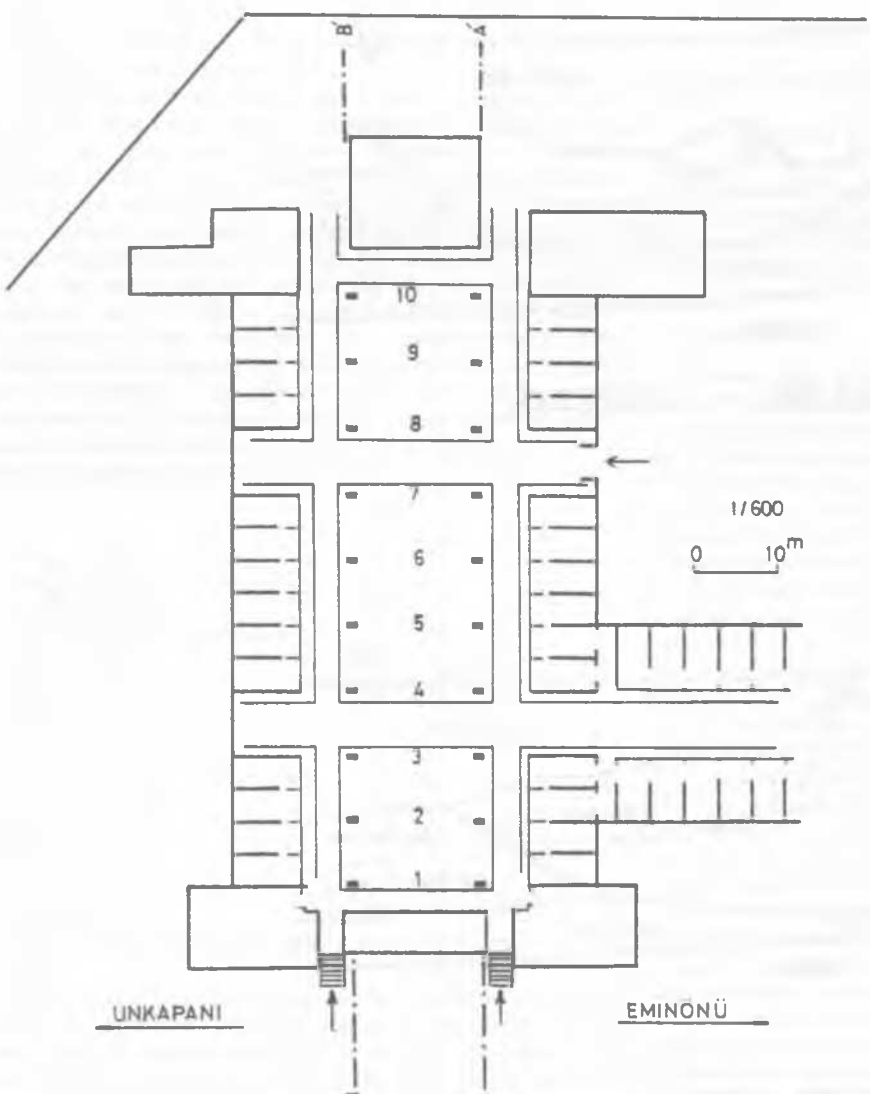

Figure 23. Plan of the Fruit Market (Tan, 1976).

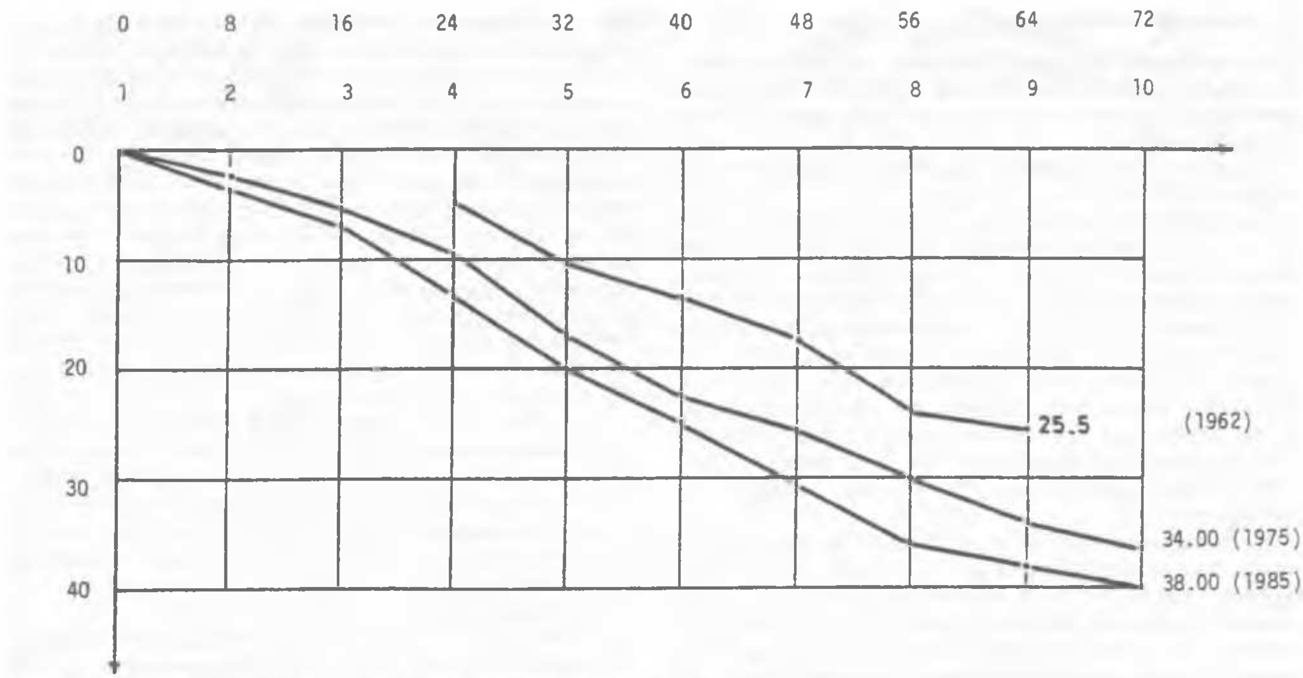

Figure 24. Measured differential settlements of the Fruit Market (Togrol & Aksoy, 1981).

on the soil surface. The total maximum settlement was calculated as 100 mm. and the differential settlement as 50 mm. It was considered that the 95 p.c. of the consolidation would be completed within 11 years at the farthest axis and within 140 years at the nearest axis to the sea.

The observed and calculated settlements widely differed. When settlements are exceedingly or uncontrollably large, it is usually said that the foundation has broken into the ground or has experienced a bearing capacity failure. However, the distinction between excessive settlements and failure by breaking into the ground, in many instances, is quite arbitrary as in the case of the old Fruit Market.

6.6 Silahtar Power House Extension

Samples were obtained from the borings made at Silahtar Power House area. The natural water content of the soil in situ was close to the liquid limit which created sampling problems. In this particular study, 12 samples were selected with the same fines content (Togrol, 1967).

Liquid limit vs plasticity index distribution fits into Casagrande's A-line (Casagrande, 1932). The liquid limits of samples varied within a wide range (between 0.96 and 0.38) whereas plastic limits were almost the same:

average liquid limit, $w_L = 0.67$ ($n = 12, \sigma = 0.19$),
average plastic limit, $w_p = 0.31$ ($n = 12, \sigma = 0.04$).

Unconfmed compressive strength and unconsolidated undrained triaxial compression tests were carried out on the specimens of those samples. Very low values such as, $c_u = 10$ kPa, $\phi_u = 0$ were obtained in spite of the specimen's high natural water content.

The relationship between void ratio and consolidation pressure was determined with oedometer tests.

$$e_1 - e_2 = - A_c (\ln p_2 - \ln p_1) \quad (6)$$

The value A_c in the equation varied for each specimen between 10 and 34. The average value of A_c is

$A_c = 24$ ($n = 12, \sigma = 7$)

The value of A_c increases with increasing liquid limit. The following relationships were obtained for Silahtar clays:

$$w_L = 2.5 A_c + 8 \quad (7)$$

$$A_c = 0.3 w_L + 3 \quad (8)$$

Skempton et al. (1944) have given the compression index as

$$C_c = 0.009 (w_L - 10) \quad (9)$$

The experimental results can be compared with C_c values obtained from the empirical Equation 9 (Table 17).

The mean value of the experimentally determined compression index is $C_c = 0.56$, and its standard deviation is $\sigma = 0.16$; the mean value of the compression index a determined from the empirical equation is $C_c = 0.52$, with a standard deviation of $\sigma = 0.17$. The difference between the two means is statistically insignificant.

Table 17. Natural water contents, liquid limits, shear strengths, and compression indices of Silahtar samples

Depth (m.)	w_n (%)	w_L (%)	s_u (kPa)	C_c (*)	C_c (**)
9	82	96	10	0.78	0.77
17	79	94	10	0.78	0.76
5	88	91	13	0.76	0.73
20	67	83	10	0.60	0.66
18	73	77	10	0.48	0.60
18	61	61	10	0.58	0.46
14	60	60	10	0.51	0.45
8	92	56	5	0.55	0.41
12	61	55	12	0.54	0.41
12	46	51	20	0.37	0.37
4	55	45	45	0.48	0.32
2	39	38	40	0.40	0.25

*) Cc = % 2.3 A_c
**) From Equation 9.

6.7 *Waste water collectors*

At various times in the history of the town, waste water collector systems around the Golden Horn area were built. The enormous growth in the population and services required bigger and better systems to be built.

Extensive soil investigations were carried out in planning the new system (Tables 2- 4).

Especially in the historical parts of the city where the streets are narrow, and traffic is dense, an open trench construction was thus out of question. In one of the oldest inhabited and crowded areas of Istanbul, the Eminönü district, 1400 m. long waste water collector with an 1450 mm. inner diameter was successfully built by pipe-jacking technology (V. Eroğlu et al., 2001). The purpose of the construction of this tunnel is to collect waste waters of the old city and carry them to the treatment plant along the Sea of Marmara. The tunnel passed under many historical structures above and below the ground level, including Yeni Cami without causing any displacement, damage, or inconvenience.

The construction was not an easy one. The tunnel passed through the uncontrolled man-made fill between Unkapanı and Eminönü. Occasionally it was necessary to cut through wooden piles left from already demolished buildings or from old shore protection. The speed of contruction was 4.23 m/day instead of planned 7.5 m/day due to the unforeseen difficulties encountered when passing through the fill layers.

Rehabilitation of the Golden Horn has been a major environmental project of Greater Istanbul Municipality. During the recent years the upstream part of the Golden Horn had become the environmental headache of Istanbul. Water depth in this part was reduced to less than 1.00 m., Alibey and Kağıthane Creeks could no longer flow freely into the Golden Horn; and a polluted environment with a dense odor was the result. The project successfully realized by dredging the polluted bottom sediments at the upstream half of the Golden Horn to provide a water depth of 5.00 m. Stability analysis to determine the new geometry of the sea bottom indicated that 6 (horizontal) : 1 (vertical) slopes would posses a sufficient degree of safety against sliding (Berilgen et al., 1991).

6.8 *New Galata Bridge*

The New Galata Bridge is founded on large diameter (2.00 m.) tubular steel piles with closed ends, and a relatively thin wall (20 mm.). The design for the superstructure has led to the arrangement of four-pile bents with a spacing of 22.30 m. (Fig. 25).

The abutments and the bascule piers located on both sides of the 80 m. wide shipping channel are also massive structures to resist high intensity seismic loads and impact of shipping.

The piles are designed to carry working loads of up to 120MN. The criterion for the maximum allowable settlement of piles was given as residual settlement of 10 mm. after the second application of the proof load of 1.5 times of the working load. The severe limitation imposed on the allowable settlement is mainly due to the sensitivity of superstructure to the differential settlements both in longitudinal and transverse directions.

Most of the piles are installed in the cobbly gravel layer. It was not considered easy to drive piles open-ended through this layer to bedrock. Neither it was considered likely that the limiting settlement criteria would have been satisfied if open-end piles had been used because of the high stress concentration on steel around the periphery of a stiffened toe. The adoption of a closed-end pile having a diameter as large as 2.00 m. is well suited to the soil conditions and the design requirements – the damage of the pile tip is prevented, settlement criteria are satisfied.

Pile bridge has also the advantage of not being an obstacle to the free flow of water. The sea floor surveys indicated that a 8.00 m. high threshold was created just below the old pontoon bridge, possibly because of the role of the bridge as a barrier.

A driveability analysis was performed for a number of piles in order to select a pile hammer with sufficient energy to ensure penetration of the pile to the dense gravel and also to ensure that driving stresses were within acceptable limits. The hammer considered for the analysis was Delmag D100 diesel hammer, with a maximum energy of 340 kN/m. Driveability analysis showed that the Delmag D100 diesel hammer, operating maximum efficiency, is capable of driving the 2000 mm. diameter pile in the order of 18 000 kN. In order to achieve the ultimate bearing capacity of 20 000 kN it was necessary to use a drop hammer of 250 kN dropping from a height of up to 3.00 m. Pile stresses remained within acceptable limits, i.e. below 90 p.c. of yield for hard driving conditions.

The effects of pile driving in soft cohesive soils are not always easily understood. In spite of the soil disturbance that takes place immediately after a pile is driven into soft clay or soft plastic silt, a recovery in strength is usually expected. There are a few unusual cases, however, in which significantly smaller values have been experienced (Peck, 1961). Such a relaxation effect is also experienced during the pile driving at the New Galata Bridge foundations.

For the lowest 5 to 10 m. of the penetration the relaxation effect was much more notable. The driving resistance increases steeply to virtual refusal of 400 to 600 blows per 250 mm. and falls back to 100 and 200 blows per 250 mm. when driving re-starts after a waiting period. It has been necessary to make an average of 10 re-drives to achieve the final set of 300 blows for 40 mm. penetration.

The reduction observed in the penetration resistance is obviously a complex phenomenon. Pile capacity analysis based on penetration records might be misleading by indicating high bearing capacities. The effect of re-driving was observed in alluvium and to a greater extend in its lower part where the silt is the dominant fraction of the soil. One explanation, could be found in Peck et al's (1974) statement: "If the fine sand or silt is dense, it may prove highly resistant to penetration of piles because of the tendency of dilatancy and the development of negative pore pressure during the shearing displacement associated with insertion of piles".

The design assumptions were tested by carrying out sufficient number of full scale loading tests. One of the test piles had a length of 74.58 m. .under the water. Its end bearing capacity was estimated as 121 MN. The test pile was surrounded by soft to firm alluvium 47 m. thick. When the pile is loaded to 1.5 times the working load (to 17.6 MN) about 10 MN of the load is possibly carried by the skin friction. Yet the amount of residual settlement at the second application of the proof load was the determining factor. When the test was carried out the settlement of the pile head after the second loading was as small as 1 mm., i.e. one tenth of the settlement criteria. Similar results were obtained with the other test piles.

An extensive soil investigation carried out for the design and construction of the new Galata Bridge which is built near the entrance of the Golden Horn. The borings drilled along the axis of the bridge provided accurate information concerning the deeper layers of the soil profile (Fig. 26).

On the Eminönü (south) side of the Bridge, the alluvium is underlain by a few meters of weathered shale. Over the deeper part of the waterway towards the Karaköy (north) side, the alluvium is underlain by cobbly gravel. The sandstone bedrock which belongs to Paleozoic underlies the whole area of the bridge crossing. From pressuremeter tests which were carried out in the bedrock, the following results are obtained:

$E_m = 1341 - 101618$ kPa,

$p_L = 1120 - 2430$ kPa.

Figure 25. Entrance of the Golden Horn: New Galata Bridge, Atatürk Bridge, city walls, reclaimed ground.

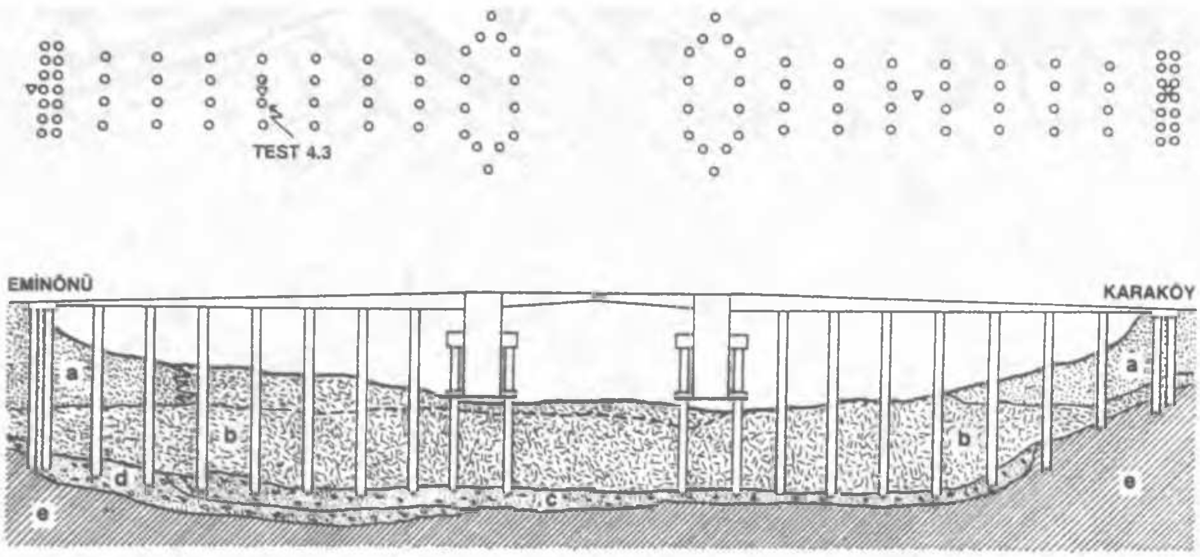

Figure 26. Cross section of the New Galata Bridge: (a) Man-made fill. (b) Alluvium. (c) Cobbly gravel. (d) Weathered shale. (e) Sandstone/limestone bedrock.

The total recovery of 75 mm. cores was low and not exceeding 0.41 with an average of about 0.20. The RQD values were generally zero with a maximum value of 0.13. The results suggest that the crust of the sandstone is friable and heavily fractured.

The extent of the cobbly gravel layer is encountered for the first time in the New Galata Bridge boreholes. The thickness of the layer was 12 m. at boring No.SB2, 10 m. at boring No.SB3, 5 m. at boring No. SB4, 7.5 m. at boring No. SB9, and 9 m. at boring No. SB10. It would be worth noting that in the middle part of the bridge crossing, between borings Nos. SB11 and SB16, the surface of the cobbly gravel is almost flat, at a depth of 76 m. below the sea level (Fig. 27).

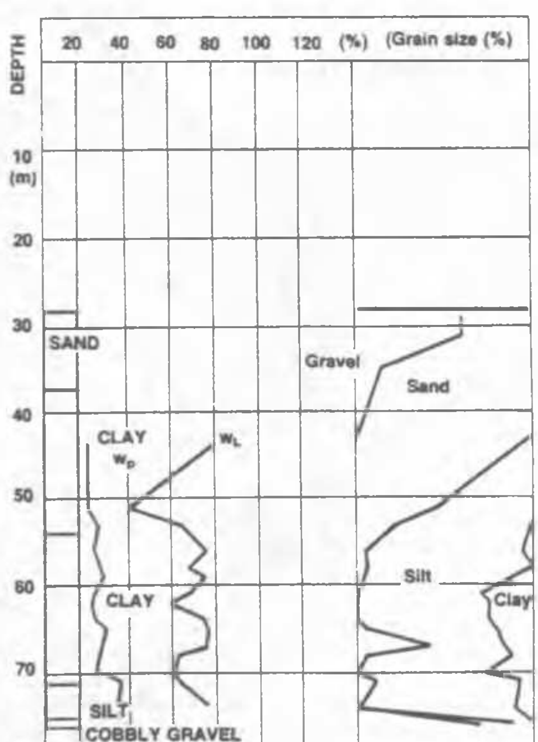

Figure 27. Variation of soil properties at the New Galata Bridge site.

The average consistency limits of the samples recovered from the alluvium are given in Table 18.

Table 18. Natural water content and consistency limits of the alluvium

Property	Mean (%)	Standart error (%)	Number of samples
w_n	49	6	30
w_L	64	8	30
w_P	28	3	30
I_p	44	14	30

It should be noted that the silt content of alluvium increases over the depths from 60 to 80 m. below the sea level. Therefore a more accurate description of the alluvium between 70 m. to 80 m. should be sandy clayey silt.

More attention was focused on the properties of the alluvium. The results of Pressuremeter tests in the silty clay layer showed a large variation :

$E_m = 680 - 2170$ kPa,

$p_L = 200 - 590$ kPa.

In-situ vane test results have also shown a significant variation :

$(s_u)_{vane} = 69 - 124$ kPa.

The undrained shear strength values obtained by field vane tests appeared to be relatively higher than those reported in the literature for normally consolidated sensitive marine clays. This may suggest an over-consolidated clay, but the high values are probably due to the presence of laminations of silt and sand. Standard Penetration Test results are found to be in the range of 7 to 23.

7 CONCLUSIONS

The geological formations and geotechnical properties of the Golden Horn area have been studied by many investigators in the past. Carefully conducted geotechnical investigations have also helped to the better understanding of the geological conditions of the area.

Glossop in his Rankine Lecture in 1968 said *"If you do not know what you should be looking for in a site investigation, you are not likely to find much of value."* (Glossop, 1968). Many of the earlier investigations were aimed at solving construction problems of a limited nature. The number and location of boreholes and the number and nature of the tests to be made were proportional with the size and the budget of the investigation. The first, probably most extensive soil investigation in the area, was carried out for the construction of the New Galata Bridge.

The records of that investigation showed that the man-made fill along the shores does not extend to the center line of the waterway. For the first time it was also possible to know what sort of a foundation existed under the thick soft silty clay deposits. The valleys and the shoreline are covered with a man-made fill reaching to a thickness of 40 m. Artificial fills overlie marine deposits along the shores of the Golden Horn. They contain boulders, gravel, sand, silt, shells, wood, pieces of concrete and, mortar and all kinds of municipal and industrial debris.

The oldest rock in the area is the Paleozoic Formation of shales and graywackes. At the contact zone between the intact rock and alluvial deposits, usually a clayey gravel layer is encountered.

The presence of the soft silty clay layer overlying the bedrock presents enormous geotechnical problems. A reliable soil investigation is required for any structure to be built on that soil. Establishment of a green belt along the shores of the Golden Horn and closure to construction of areas with problematic ground conditions and tighter building regulations are welcomed developments

The last point I should make concerns the once threatening problem of pollution. During the recent years extensive efforts were made to curb pollution. Sources of pollution have been largely put under control. Waste water collection systems on both side of the Golden Horn are completed. At the upper Golden Horn area, large amounts of polluted sediments have been dredged and transported elsewhere. Thus the recent soil investigations are also closely involved with environmental geotechnics.

ACKNOWLEDGEMENT

The author is grateful to Professor M. Vardar for his constructive review the part concerning the geology of Istanbul area. Professors V. Eroğlu and K. Özaydın have kindly supplied data of the recent investigations performed in the Golden Horn area. The patient and expert help of Miss S. Gok and Miss A. Kurtulus in preparing the text to publication is also gratefully acknowledged.

REFERENCES

Akgüner, C., Yıldırım, S., Kılıç, H., İpekoğlu, P. 1996. Haliç güncel çökellerinin geoteknik parametreleri. *6. Ulusal ZMTM Kongresi.*

Aksoy, I.H. 1982. Istanbul'da tarihi yapılarda uygulanan temel sistemleri. *Ph.D. Thesis*, I.T.U İnşaat Fak, XIII+98.

Arne, T.J. 1952. Svenskt-turkist Vapenbrödraskap. *Kapital 8*, Svenskarna I Osterlandet, Stockholm, 92-103.

Barka, A.A. 1992. The North Anatolian Fault Zone. *Ann.Tecton.*,6, 164-195.

Baykal, O. 1975. Haliç kıyısındaki yapı hareketlerine iki örnek. *I.T.U. Haliç Semposium*, II, 87-93.

Burton, P. W.; McGonigle, R.; Makropoulos, K.C. & Üçer, S.B. 1984. Seismic risk in Turkey, the Aegean and the eastern Mediterranean: the occurance of large magnitude earthquakes. *Geophys. J. R. Astr. Soc.* 78::2, 475-506.

Berilgen, M.M.; Özaydın, I.K. & Edil, T.B. 1999. Geotechnics of high water content materials. *ASTM STP 1374.*

Casagrande, A. 1932. Research on the Atterberg limits of soils. *Public Roads*, 13, 121-136.

Chaput, E. 1936. Voyages d'études géologiques et géomorphogénique en Turquie. *Mém. L'Inst. France d'Archéol. d'Istanbul*, II, VIII+312, Paris.

Crampin, S.& Üçer, B. 1975. The seismicity of the Marmara Sea region of Turkey. *Geophys. J. R. Astr. Soc.*, 40, 269-288.

Durgunoğlu, T. & Akşit, H. 1978. Geotechnical evaluations for the Istanbul's Golden Horn. *Journal of the Boğaziçi University*, 6, 37-56.

Eroğlu, V.; Baştürk, A.; Şen, Z.; Sarıkaya, H. & Altay, A. 2001. Pipe trust technique application in historical part of Istanbul. *(Private communication).*

Glossop, R. 1968. The rise of geotechnology and its influence on engineering practice. *Géotechnique*, June, 107-150.

Kann, F., Suman, A. R. 1941. *Jeoteknik.* Ankara, Nafia Vekaleti Neşriyatı, 6, 3, 108+4 pp.

Ketin, İ. 1953. Tektonische Untersuchungen auf den Prinzeninseln nahe Istanbul (Türkei). *Geol. Rundsch. 41*, 161-172.

Ketin, İ. 1966. Tectonic units of Anatolia. *Bull. Miner. Res. Explor. Inst.*, Turkey, 66, 23-34.

Maden, S. 1975. Haliç köprüsünün bulunduğu yerde Haliç'in geoteknik özellikleri. *I.T.U. Haliç Semposium*, 133-138.

Mc Kenzie, D.P. 1972. Active tectonics of the Mediterranean region. *Geophys. J. R. Astr. Soc.*, 30, 109-185.

Meriç, E. (Ed). 1990. Istanbul Boğazı güneyi ve Haliç'in Geç Kuvaterner (Holosen) dip tortulları. Ankara, 114 pp.

Mesri, G. 1973. Coefficient of secondary compression. *ASCE Journ. SMFE*, 99, 123-127.

Mesri, G. & Castor, A. 1987. C_α/C_c concept and K_0 during secondary compression. *ASCE Journ. Geotechnical Engrg.*, 113, 3, March, 230-247.

Mesri, G. & Godlewski, P.M. 1977. Time and stress compressibility interrelationship. *ASCE Journ. SMFE*, 103, 417-430.

Müller-Wiener, W. 1994. Die Hafen von Byzantion Kostantinupolis Istanbul. *Ernst Wasmuth Verlag*, Tubingen, 68.

Noel, C. 1850. Sur la construction des trois Bassins de Radoub du Port du Toulon. *Annales des Ponts et Chaussées*, Memoires, 175-224.

Okay, A.I.; Kaşlılar-Özcan, A.; İmren, C.; Boztepe-Güney, A.; Demirbağ, E. & Kuşçu, İ. 2000. Active faults and evolving strike-slip basins in the Marmara Sea, northwest Turkey: a multichannel seismic reflection survey. *Technophysics*, 321,.189-218.

Paeckelmann, W. 1925. Beitrage zur Kenntnis des Devons am Bosporus. *Abh. Preuss. Geo. Lands.*, Berlin, N.F., 186.

Paeckelmann, W. 1983. Neue Beitrage zur Kenntnis der Geologie, Paleontologie und Petrographie der Umbebung von Konstantinopel. *Abh. Preuss. Geo. Lands.*, N.F. 186, Berlin, 202.

Peck, R.B. 1961. Records of load tests on friction piles. *Hwy. Res. Board Special Report*, 67, 418 pp.

Peck, R.B., Hanson, W.E:, Thornburn, T.F. 1974. *Foundation Engineering*, pp.325.

Penck, W. 1919. Grundzuge der Geologie des Bosporus. *Veröff. Inst. f. Meersk.*, Berlin, N.F.4.

Peynircioğlu, A.H. 1961. Settlement of buildings in Istanbul. *Proc. 5th ICSMFE*, Paris, 1, 771-778.

Peynircioğlu, A.H. 1962. Istanbul Haliç sahillerinin geotekniği. *Türkiye İnşaat Mühendisleri Odası I. Teknik Kongresi*, Ankara, R. No. 20, 1-24.

Peynircioğlu, A.H. 1965. Adustable box foundation as a measure against excessive settlement and tilting. *Proc. of the 6th ICSMFE*, Montreal, 2, 174-178.

Peynircioğlu, A.H. 1973. Terzaghi in Istanbul and his Studies on Golden Horn clays. *Terzaghi Memorial Lectures*, Boğaziçi University, Istanbul, 117-150.

Peynircioğlu, A.H. 1975. Haliç sahillerinin geotekniği. *I.T.U. Haliç Semposium*, 391-401.

Peynircioğlu, A.H. 1976. Haliç sahillerinin temel ve stabilite sorunları. *Boğaziçi Üniversitesi Haliç Sorunları Sempozyumu*, 355-370.

Peynircioğlu, A.H., Aksoy, I.H., Özüdoğru, K. 1978. Eminönü Süleymaniye Unkapanı bölgesinin geoteknik etüdü ve Yeni Camii temellerinin incelenmesi. *İTÜ Teknik Rapor*, 31, 47.

Peynircioğlu, A.H., Togrol, E. & Aksoy, I.H. 1981. Istanbul'da Osmanlı Döneminde inşa edilen camilerin temelleri.(Foundations of mosques built during Ottoman period). *Bilim ve Teknoloji Tarihi Kongresi*, I.T.U., 37-46.

Sayar, C. 1976. Haliç civarının jeolojisi. *Boğaziçi Üniversitesi Haliç Sorunları Sempozyumu*, 355-374.

Sayar, M. 1951. Istanbul civarında Üst Miosen omurgalılarına ait yeni müşahadeler. *Journal of I.T.U.*, 9, 3, 9-12.

Sayar, M. & Sayar, C. 1962. Istanbul'un Surlar İçindeki Kısmının Jeolojisi. *I.T.U. Maden Fakültesi*, 26, 3 plts.

Skempton, A.W. 1944. Notes on the compressibility of clays. *Quart. Journal Geol. Soc.*, London, C, 119-135.

Soydemir, Ç. 1973. Terzaghi's period in Turkey. *Terzaghi Memorial Lectures*, Boğaziçi University, Istanbul, 212-229.

Şengör, A.M.C. 1979. The North Anatolian transform fault: its age, offset and tectonic significance. *J. Geol. Soc. London*, 136, 269-282.

Straub, C. & Kahle, H.G. 1995. Active crustal deformation in the Marmara Sea region, NW Anatolia, inferred from GPS measurements. *Geophys. Res. Lett. 22*, 2533-2536.

Straub, C.; Kahle, H.G. & Shindler, C. 1997. GPS and geologic estimates of the tectonic activity in the Marmara region, NW Anatolia. *J. Geophys. Res. 102*, 27 587 – 27 601.

Suzanne, P.; Lyberis, N.; Chorowics, J.; Nurlu, M.; Yürür, T. & Kasapoğlu, T. 1990. La géométrie de la faille nord anatolienne a partir d'images Landsat-MSS. *Bull. Soc. Géol. Fr.* 6(8), 589-599.

Tan, O. 1976. Haliç sahillerinin geoteknigi ve uygulanan temel sistemleri (İstanbul Meyve Hali oturma etüdü), *MMLS Thesis*, İ.T.Ü. İnş. Fak., 45.

Togrol, E. 1967. Zeminlerin mekanik davranışı. *Doçentlik Thesis*, ITU, 163.

Togrol, E. 1975. Haliç'in geoteknik sorunları. *İ.T.Ü. Haliç Sempozyumu*, 95-114.

Togrol, E. & Aksoy, I.H. 1981. An eighteenth century drydock in Istanbul. *Proc. 10th ICSMFE, Stockholm*, 3, 163-166.

Togrol, E.; Güler, E.; Özüdoğru, K.; Ersoy, T. & Aksoy, I.H. 1986. Haliç'in geoteknik sorunları ve çözüm yolları (Geotechnical problems of the Golden Horn area). *Boğaziçi University*, Istanbul, 106 p.

Togrol, E.; Aksoy, I.H. & Tan, O. 1991. Examples of excessive deformations of structures around Galata Bridge. *Proc. 10th ECSMFE*, Firenze, 2, 615-618.

Ülgen, A.; Dedeoğlu, R.; Sonuç, T. & Karsan, A. 1968. Haliç deniz ve karayolu ulaşımı hakkında ön rapor, *Technical report*, 12 sf.

Yalçınlar, I. 1976. Türkiye Jeolojisine Giriş, *İ.Ü. Edebiyat Fakültesi*, 280 p.