The engineering geology of İstanbul, Turkey

ÖMER ÜNDÜL[1] & ATIYE TUĞRUL[2]

[1] *İstanbul University. (e-mail: oundul@istanbul.edu.tr)*
[2] *İstanbul University. (e-mail: tugrul@istanbul.edu.tr)*

Abstract: İstanbul is the oldest and the biggest city in Turkey. It has a rapidly growing population and therefore an intense building and construction programme. İstanbul embraces two continents Europe and Asia and therefore different types of rocks and soils are encountered across the city. Sound bedrock is located in the north-eastern and eastern parts of the 'European' side and in the most of Anatolian side of İstanbul. Here material is good quality for both construction and foundations. Soils are located in the south-western parts of the 'European' side. These generally form problematic ground for foundations. The main objective of this study is to present briefly the geological and geotechnical conditions of İstanbul. In particular the construction materials and foundation problems are discussed. Geological and geotechnical data were obtained from fieldwork, boreholes, underground constructions and experimental studies.

Résumé: Istanbul, le plus vieil et la plus grande ville dans Turquie, embrasse deux continents. La population rapidement croissante dans Istanbul a eu pour résultat le bâtiment intensifs et l'activité de construction. Il y a des types différents de rochers et les sols dans Européen et les côtés asiatiques d'Istanbul. Les fondements solides sont localisés dans les parties du nord-est et d'est du côté Européen et dans le la plupart de côté Anatolien d'Istanbul. Ils fournissent généralement le matériel dans la bonne qualité pour la construction et la fondation. Les sols sont localisés des parties du sud-ouest du côté européen. Ils sont matériels généralement de fondations des problématiques. Les objectifs principaux de cette étude seront obligé à présenter brièvement les géologiques et conditions de geotechnical d'Istanbul. Géologique et les données de geotechnical ont obtenu des travaux de champ, boreholes, les constructions souterraines et les études expérimentales. Ils ont été discutés du point de matériels de construction et des problèmes de fondation.

Keywords: Geology of Cities, engineering geology, rock and soil mechanics, İstanbul.

INTRODUCTION

In line with the increase in population of Istanbul many new engineering structures have been built. This has encouraged investigators to determine and clarify the engineering geological properties of the geological formations of İstanbul. For this reason many geological and geotechnical investigations were carried out in İstanbul and its vicinity. In this study, the data obtained from the investigations carried out in and around İstanbul are summarized (Figure 1).

Figure 1. Location map of the study area

Palaeozoic rocks are common on both the Asian and European sides of İstanbul, and many engineering structures have been constructed or will be constructed over these rocks. Therefore, all engineers who are working on the surface and subsurface excavations are familiar with both weathered and unweathered rocks.

The study area has irregular land morphology depending on the lithology and tectonics of the region. Lithological and structural characteristics of the different units have been reported by several investigators. (Altınlı, 1951; Sayar, 1969 ; Abdüsselamoğlu, 1963; Kaya, 1973; Önalan, 1981; Eroskay, 1985 and Ketin, 1991).

The sampling of the units has been performed from deep excavations, boreholes and tunnels. The engineering properties given in this study are physical and mechanical properties of both soil and rock. The main engineering geological problems encountered in İstanbul area are presented in this paper.

GEOLOGY

Palaeozoic, Mesozoic and Cenozoic formations are recognized in Istanbul (Table 1). The oldest rocks are Palaeozoic rocks that consist of quartz, quartz arenite and arkose. From the Ordovician to the middle of the Carboniferous, a several thousand meter thick, concordant rock sequence outcrops. This sequence, mainly consists of variable facies of clastic and carbonate rocks . Some of the main characteristics of the Palaeozoic sequence are horizontal and vertical transitions, alternations of different rocks and lenticular structures (Eroskay, 1985). Palaeozoic aged rocks cover large areas of İstanbul. Rocks of Ordovician, Silurian and Devonian age outcrop mostly on the Asian side, and Carboniferous rocks are located mostly on the European side (Figure 2). Granitic rocks have intruded into these rocks (Öztunalı and Satır, 1973). Andesitic and diabasic dykes are also present.

Palaeozoic rocks are overlain unconformably by Mesozoic units. These units outcrop in the main in the northern parts of İstanbul, both on the Asian and European side. Triassic formations are represented by conglomerate, sandstone, dolomite, dolomitic limestone, lump limestone and clayey limestone, and Cretaceous units by sandstone, shale, and limestone interbedded with lavas and pyroclastic rocks. The Mesozoic rocks, in turn, are covered by Tertiary units. These units are generally fossiliferous limestone, clayey limestone or marl, and uncemented or loosely cemented sand, silt and clay.

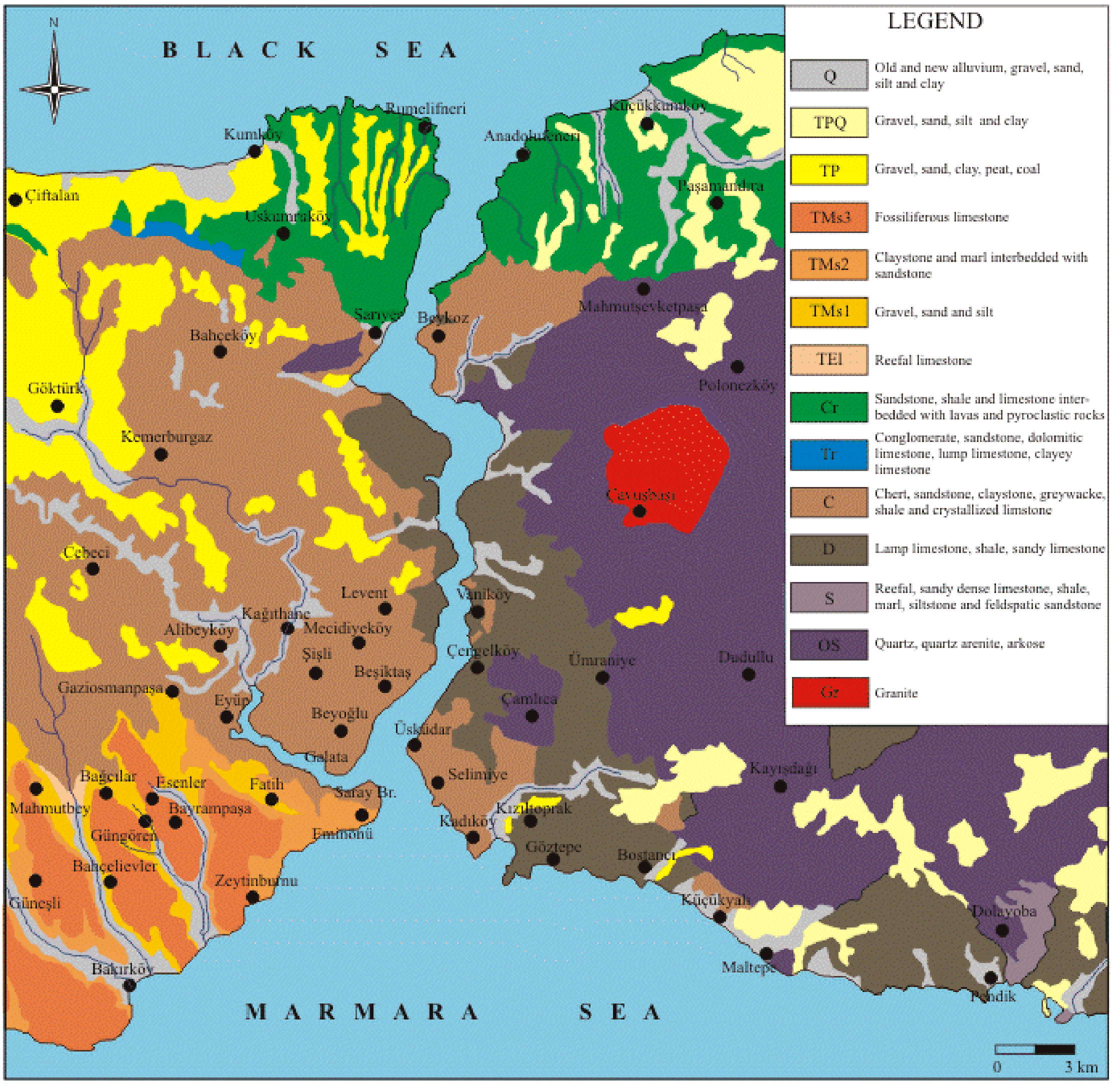

Figure 2. Map showing geological units in İstanbul (Modified from Ketin, 1991)

Haliç and Bosphorus sediments, old and new alluvium and artificial fill cover the other units in İstanbul. Haliç and Bosphorus sediments generally consist of black clay, sand and silt. The thickness of these materials is between 5 and 13 meters on the Marmara Sea coasts, and varies between 60 and 70 meters on the Haliç (Golden Horn) coasts. Old and new alluvium can be seen in the Baltalimanı, stinye and Bebek Valleys on the European side, and close to the Kurbağalı, Maltepe-Cevizli and Büyük Rivers on the Asian side. They consist of uncemented gravel, sand and clay which originate from other units in the area. The thickness of the alluvium varies between 8 and 20 meters. Artificial fill between 2-40 meters thick can be seen on the Historical Peninsula (Eminönü). It consists of gravel, sand, silt, clay, rubble, brick and tile fragments.

The area is affected by faulting. NW-SE and NE-SW trending faults are major structural features in the area. Usually, three or four clearly defined major sets of joints are found in the rocks. Minor sets or random joints also occur in study area.

Table 1. Geological characteristics of the rocks in İstanbul

Location	**Symbol**	**Age**	**LITHOLOGY**
Throughout all of İstanbul by river banks and sea sides	Q	Quaternary	Old and new alluvium - Gravel, sand, silt and clay
Mostly on the Asian side (on the relatively higher steeps).	TPQ	Plioquaternary	Gravel, sand, silt, clay
Mostly on the northern part of the European side (on the relatively higher steeps).	TPl	Pliocene	Gravel, sand, clay, peat,coal
Southern part of the European side (Especially on the slopes towards the Marmara Sea).	TMs3	Miocene	Fossiliferous limestone
Southern part of the European side of İstanbul (Bakırköy, Bahçelievler, Zeytinburnu their surroundings)	TMs2	Miocene	Claystone and marl interbedded with sandstone
Southern part of the European side (Especially surroundings of Esenler, Bağcılar, Fatih)	TMs1	Sarmacian	Gravel, sand and silt
Southern part of Europen side (between Bağcılar and Mahmutbey).	TEl	Lütecian	Reefal limestone
Northern part of İstanbul. (North of Sarıyer, surroundings of Uskumruköy and Rumelifeneri on the European side and surroundings of Anadolu Feneri on the Asian side.	Cr	Cretaceous	Sandstone, shale and limestone interbedded with lavas and pyroclastic rocks
Northwest of İstanbul (Eastern part of Uskumruköy).	Tr	Triassic	Conglomerate, sandstone, dolomitic limestone, lump limestone, clayey limestone and dolomite.
European side (from Bahçeköy to Eyüp-Gaziosmanpa a line). Asian side (Kadıköy, Üsküdar, Vaniköy and Beykoz)	C	Carboniferous	Chert, sandstone, claystone, greywacke, shale and crytallised limestone
Especially in Asian side (Surroundings of Ümraniye, Göztepe, Bostancı, Kartal and Gebze)	D	Devonian	Limestone, shale, sandy limestone, shale and sandstone
Eastern part Asian side (near Dolayoba).	S	Silurian	Reefal, sandy dense limestone, shale, marl, siltstone and feldspathic sandstone
Especially in Asian side (Kayışdağı, Dudullu, Çamlıca, Polonezköy and Mahmutşevketpaşa) European side (Sarıyer).	OS	Ordovician-Silurian	Quartz, quartz arenite, arkose
Asian side (Çavuşbaşı)	PGr	Permian	Granodiorite, granite

SEISMIC ACTIVITY

İstanbul metropolis is located in a tectonically highly active region. The North Anatolian Fault zone is only a few kilometers away from İstanbul city center (Figure 3). Smaller scale active faults also exist in the eastern Anatolian side of İstanbul.

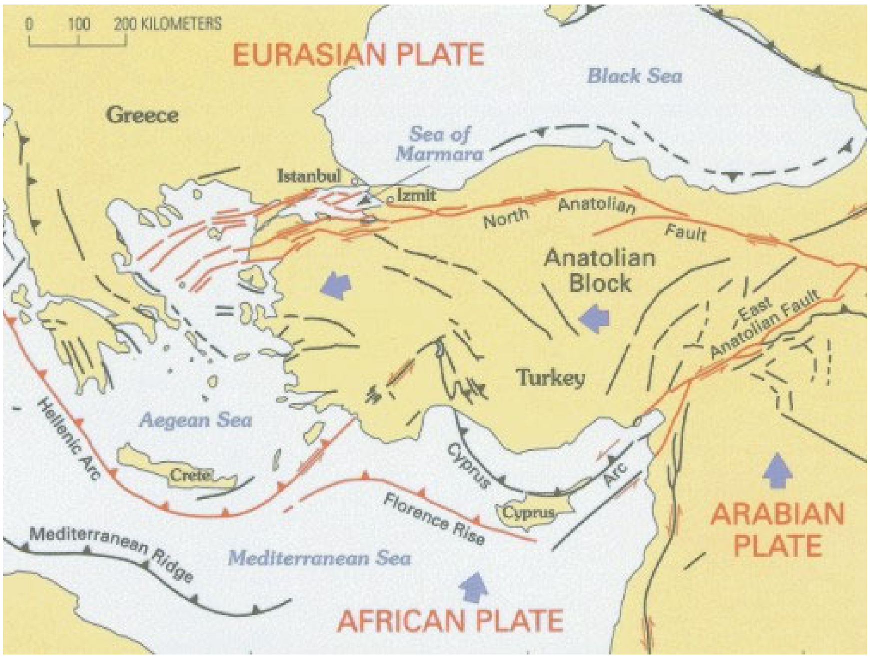

Figure 3. Tectonic map of Turkey Modified from Barka (1992) and Rockwell and others (2000)

Many historical earthquakes have affected İstanbul and caused serious damage. In Figure 4 historical and recent earthquakes occurring in the North Anatolian Fault Zone, around İstanbul are plotted.

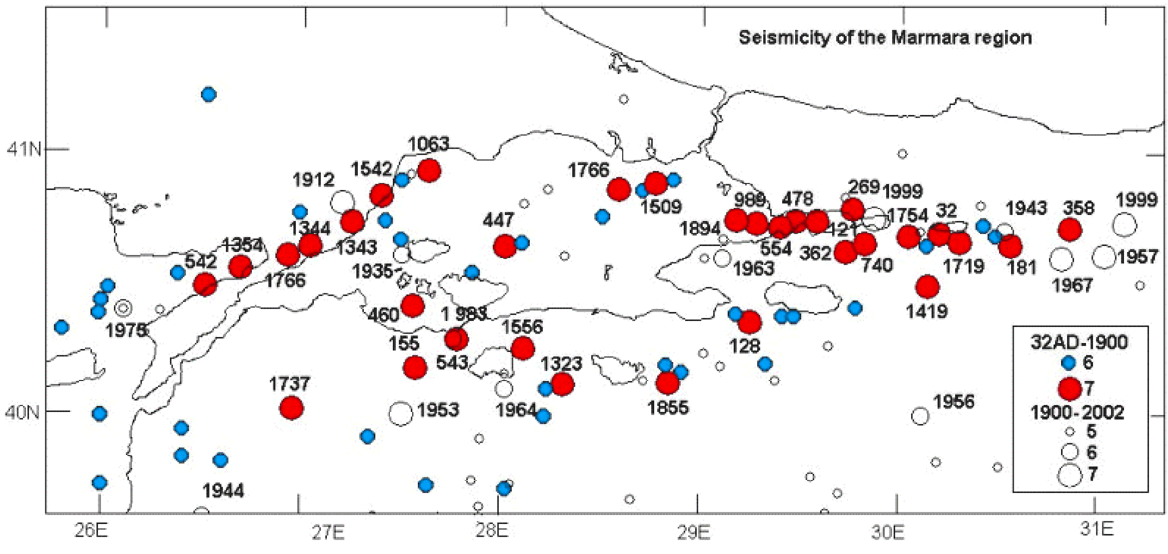

Figure 4. Seismicity of the Marmara Region (Ambraseys and Finkel, 1991)

According to the earthquake risk map of İstanbul (Figure 5); the southern parts of İstanbul are the main areas under high earthquake risk. From South to the North, earthquake risk gradually decreases, because the active faults are in the Marmara Sea and also relative to the lithological characteristics of the weak rocks and soils. However these maps do not consider local soil conditions. The maps are widely used in small scale studies.

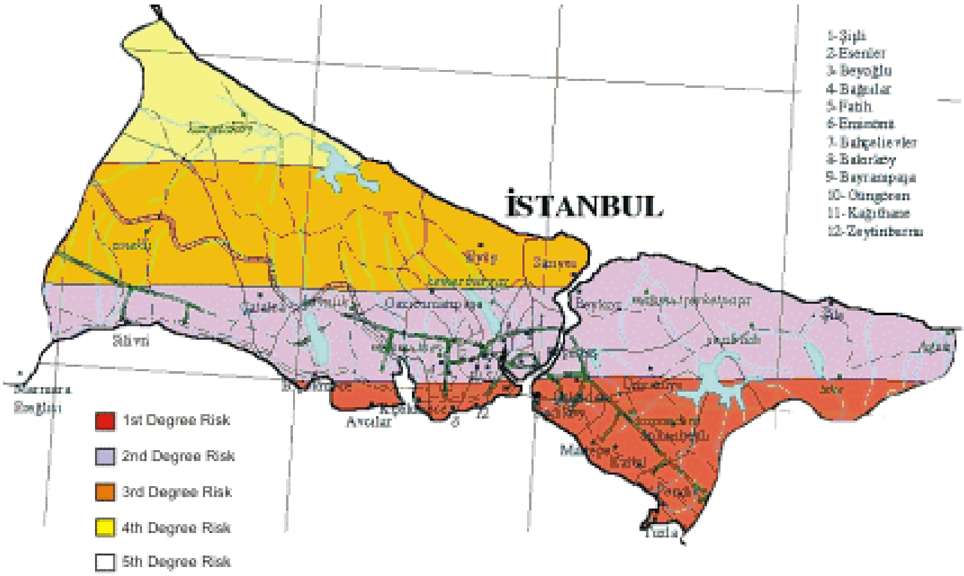

Figure 5. Earthquake risk map of İstanbul (General Directorate of Disasters Affairs)

ENGINEERING GEOLOGICAL CHARACTERISTICS OF THE ROCKS AND SOILS

İstanbul is one of the oldest, biggest and most crowded cities in the world. In the city most of the population is located away from the industrial areas, which are mostly accumulated around the shore line, Historical Peninsula and the Mahmutbey-Güneşli Region (Figure 6). For this reason transportation becomes a big problem. To solve the problem and satisfy the transport needs, many engineering structures have been built and there are many on-going projects such as highways, tunnels, large buildings etc. To enlighten the engineers in these projects, geological and geotechnical studies have accelerated in the last three decades.

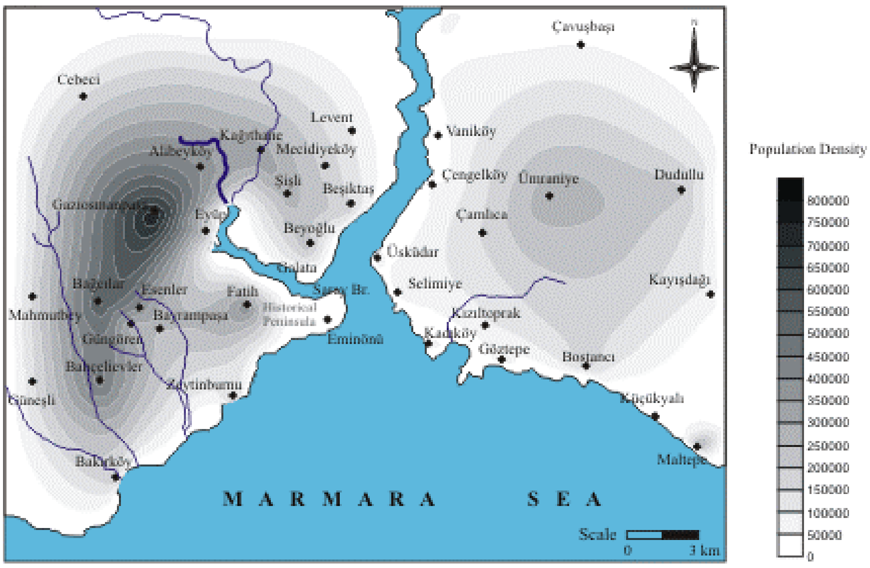

Figure 6. Distribution of population in İstanbul (State Institute of Statistics, 2000)

On the basis of available geological and geotechnical data, lithological units that outcrop in İstanbul can be divided into two groups. These are; rock units and soil units. As seen in Figure 2, soils are generally observed on the south-east part of the European side. Rocks outcrop in remaining areas.

Geological and geotechnical data obtained from field works, boreholes, underground constructions and experimental studies were interrogated from the point of deep foundation problems, underground excavations, other new constructions and aggregate resources (Tables 2, 3, 4 and Figure 7).

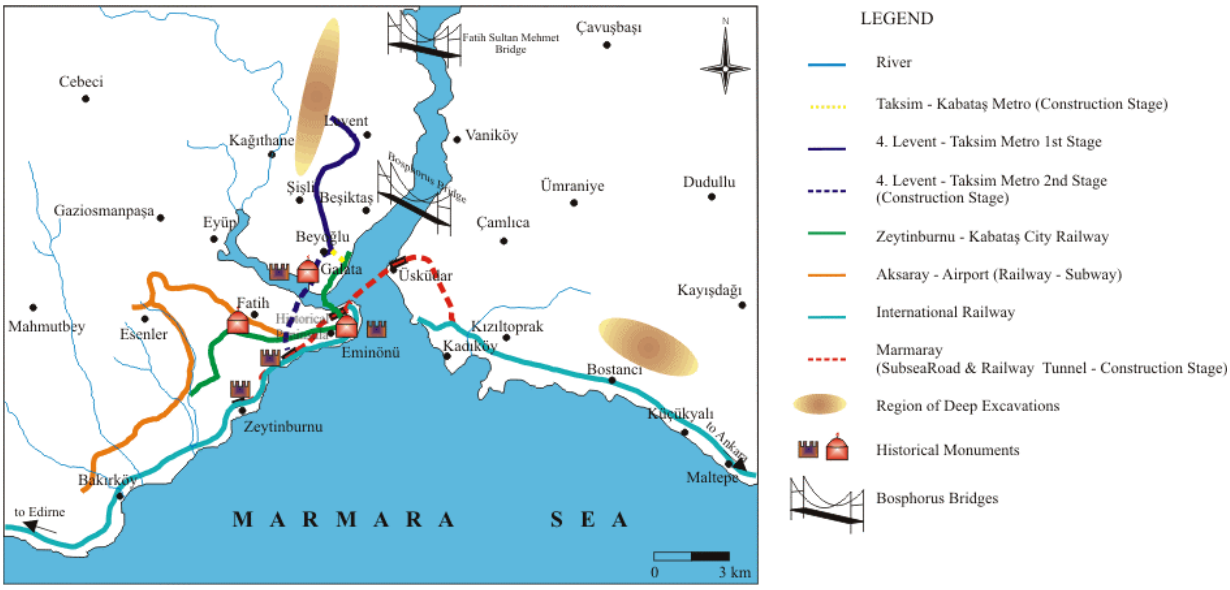

Figure 7. Engineering structures in İstanbul

Table 2. Physical properties of the rocks

Symbol	Lithology	Weathering	Specific Gravity	Dry Unit Weight (g/cm^3)	Water Absorption (%)	Effective Porosity (%)	Total Porosity (%)
TMs3	Fossiliferous Limestone	UW	2.60-2.64	1.93-2.31	5.80-13.20	-	10.81-26.89
	Clayey Limestone	UW	2.63-2.64	2.24-2.38	4.10-4.50	-	9.51-14.83
Cr	Dolomitic Limestone	UW	2.66	2.62	0.71	1.97	-
	Dolomitic Micritic Limestone	UW	2.69	2.62	0.65	2	-
Tr	Dolomite	UW	2.82-2.84	2.78-2.82	0.47-0.92	1.55-2.56	-
	Dolomitic Limestone	UW	2.7	2.62	0.73	1.94	-
	Dolomitic Lump Limestone	UW	2.71	2.71	0.3	0.98	-
C	Mudstone - Shale	W	-	2.46-2.59	1.29-2.67	-	2.66-6.88
		UW	-	2.63-2.69	0.51-0.97	-	1.29-2.49
	Fossiliferous Limestone	UW	2.73	2.66	0.42	-	1.1
	Limestone	UW	-	2.59 - 2.69	0.18 - 0.70	0.4 - 1.81	-
	Sandstone	W	-	2.6	2.8	-	7
		UW	-	2.72	0.22	0.65	2
	Siltstone	W	-	2.5	2	-	4
	Mudstone	UW	-	2.68	0.8	2	2.5
D	Clastic Sandstone	UW	2.66-2.73	2.56-2.61	0.58-1.13	1.55-2.35	2.20-3.95
	Fossiliferous Micritic Limestone	UW	2.69	2.68	0.77	1.84	-
	Micritic Lump Limestone	UW	2.65-2.68	2.57-2.63	0.12-0.71	0.45-1.62	1.14-2.42
		W	2.69	2.56	1.25	2.82	4.12
	Lump Limestone	UW	-	2.73	0.34	-	0.92
OS	Lithic Arkose	UW	2.64-2.65	2.36-2.61	1.12-3.38	-	1.51-1.61
		W	2.62-2.63	2.23-2.45	3.21-7.80	-	6.84-14.89
	Quartzite	UW	-	2.55-2.65	-	2.3	0.93
PGr	Granodiorite	UW	2.71-2.72	2.54 - 2.58	1.35-1.41		5.57-6.48
		W	2.70-2.71	2.33 - 2.41	1.93 - 4.02		8.88-10.49

UW: Unweathered-slightly weathered, W: Weathered
(Data compiled from Erguvanlı, 1985; Arel and Tuğrul, 2001; Tugrul and Zarif, 2000 and 2002; Zarif and Tuğrul, 2002; Zarif and Tugrul, 2004.)

Table 3. Mechanical properties of the rocks

Symbol	Lithology	Weathering	Uniaxial Compressive Strength (kg/cm^2)	Modulus of Elasticity (kg/cm^2)	Poissons Ratio
TMs3	Clayey Limestone	UW	80-440	20000-50000	0.17-0.29
Cr	Dolomitic Limestone	UW	650	110000	-
	Dolomitic Micritic Limestone	UW	760	95000	-
Tr	Dolomite	W	530	79830	-
	Dolomite	UW	1280	420000	-
	Dolomitic limestone	UW	500	82550	-
	Dolomitic lump limestone	UW	1050	180000	-
C	Mudstone-shale	W	184-445	56250-184848	0.16-0.21
	Mudstone-shale	UW	586-661	992335-1011881	0.16-0.20
	Fossiliferous limestone	UW	820	271600	-
	Limestone	UW	618-698	-	-
	Sandstone	UW	669	375000	0.19-0.21
	Mudstone	UW	782	295000	0.16-0.21
	Mudstone	W	447	170000	0.15-0.20
D	Clastic limestone	UW	816-900	-	-
	Fossiliferous Micritic limestone	UW	950	330000	-
	Micritic lump limestone	UW	906-1218	197400-404200	-
	Lump limestone	W	742-850	125000-166800	-
OS	Litic arkose	UW	260-630	-	-
	Litic arkose	W	110-280	-	-
	Quartzite	UW	350	690000	-
PGr	Granodiorite	UW	981-1263	-	-
	Granodiorite	W	162-470	-	-

UW: Unweathered-slightly weathered, W: Weathered
(Data compiled from Erguvanlı, 1985; Arel and Tuğrul, 2001; Tugrul and Zarif, 2000 and 2002; Zarif and Tuğrul, 2002; Zarif and Tugrul, 2004.)

Table 4. Physical properties of the soils

Symbol	Lithology	Location	Specific Gravity	Natural Unit Weight (g/cm^3)	Water Absorption (%)	Liquid Limit (%)	Plasticity Index (%)	Classification (USCS)
TMs3	Silty clay	Eminönü	2.42-2.70	1.65-1.91	17.4	-	7-50	42%CL 37% CH 10% MH 4% CL –ML 7% ML
TMs2	Green clay	Eminönü	2.60-2.79	1.60-2.0	15-52	35-98	11.7	67% CH 19% CL 14% MH
	Green clay	Yenikapı - Unkapanı	-	-	22-45	65-95	34-42	CH - OH
	Green clay	Gaziosmanpaşa	-	-	35-57	59-67	41-46	CH

Historical sites and monuments in İstanbul

İstanbul, capital of the east Roman, Byzantine and Ottoman Empires embraces two continents, one arm reaching out to Asia, the other to Europe. It is therefore, a rich city in terms of monuments and historical sites. Many historical buildings such as water structures, mosques etc. were constructed on Carboniferous graywackes in the historical Peninsula (Eminönü), because of their higher bearing capacity than Tertiary units in the area (Figure 8). Fossiliferous limestones of the Upper Miocene were used as building stone in the majority of the monuments in İstanbul because of their attractiveness, availability and workability.

(A) (B) (C)

Figure 8. Famous Historical structures in İstanbul (A) Hagia Sofia (B) Galata Tower (C) Water Arc in Bahçeköy

Foundation Problems

The bearing capacity of the unweathered rock units is generally high. Many skyscrapers were built on Paleozoic rocks. These buildings are located especially in the North of Levent and Bostancı regions (Figure 2, 7). However the slopes of deep excavations should be supported. Excavations and embankments which are going to be constructed on slopes consisting of dense fractured and weathered graywackes should be investigated in detail (Figure 9).

Figure 9. Foundation excavation in graywackes

Over-consolidated Tertiary units do not have bearing capacity problems but they do experience stability problems. Slope inclinations are towards the Marmara Sea to the south of İstanbul and they are located in Avcilar, Küçükçekmece, Büyükçekmece and Beylikdüzü region. Marl and/or clayey limestone, clay, sand and clay sequences in Tertiary units, and also sand lenses in clay layers play an effective role in decreasing the bearing capacity, increasing instability and amplifying ground motion after earthquakes. This problematic situation causes damage in the south-western parts of İstanbul on the European side.

Table 5. Bearing capacities of different types of unit

Units	**Bearing Capacity (kg/cm^2)**
Artificial Fill	Not considered for structural loads
Uncemented Tertiary Sediments	1-1,5
Carboniferous Sandstone, Claystone and limestone	3-3.5
Devonian Limestone, Lump limestone	3-4
Ordovisian – Silurian Arkose-quartzite	5-6

Unfortunately the bearing capacity of the alluvium is very low, and Artificial fills, Bosphorus and Haliç sediments have negligible bearing capacity. The foundations of buildings constructed on these sediments generally have instability and settlement problems (Table 5).

Dams of İstanbul

The water needs of İstanbul have been increasing day by day. Many water projects were carried out in the history of İstanbul as it is today. The water sources were enough to supply water in ancient İstanbul. But increasing population density has caused an increase in water need. Therefore some small dams have been constructed. Today seven dams are in use (Figure 10, 11, Table 6) and new projects have been developed to carry fresh water from neighbouring cities.

Figure 10. Locations of the dams of İstanbul

Table 6. Characteristics of the Dams of İstanbul

	Ömerli Dam	**Sazlıdere Dam**	**Alibey Dam**	**Darlık Dam**	**Elmalı Dam (Göksu) 1**	**Elmalı Dam (Göksu) 2**	**Terkos Dam**
Purpose	Domestic and Industrial	Domestic and Industrial	Domestic and Industrial	Domestic and Industrial	Domestic and Industrial	Domestic and Industrial	Domestic
Location	Beykoz	K.Çekmece	Eyüp	Şile	Göksu	Göksu	Durusu
Type	Earth fill with clay core	Rock fill with clay core	Earth fill with clay core	Rock fill	Earth fill and stone gravity	Concrete gravity	Concrete with steel outer shell
Crest Elevation (m)	67	27	34	57,5	34	68,5	-
Crest (m)	372	432,84	304	308	298,4	238,75	46
Height from foundation (m)	54	-	30	-	22	48,5	-
Height from talveg (m)	52	23	28	45,5	19,75	42,5	4
Date of Construction	1973	1996	1972	1989	1893	1955	1972
Geological description of the foundation	Devonian and Triassic units	Limestones of Thracian Basin	Alluvium	Cretaceous and Plio-quaternary. units	Ordovician, Devonian and Carboniferous units and Granadiorite	Ordovician, Devonian and Carboniferous units and Granadiorite	Pliocene units

(A) (B)

Figure 11. (A) Ömerli Dam (B) Reservoir Area of Ömerli Dam

Underground Excavations

The first excavation stage of the İstanbul Metro is through the Carboniferous sandstone and shale sequence (Figure 12). The second excavation stage of the Metro is mostly in the same unit. The remaining excavation is through Tertiary units. During the excavation of the first stage, the tunnel route is close to the surface (averaging 22m), but there were no large scale collapse problems. Only some small scale over breaks occurred during excavation due to the discontinuity planes, particularly fault zones and highly weathered zones. But in the second stage, especially through the clay zones in Tertiary units, there were examples of severe damage.

Figure 12. Construction stage of İstanbul Metro

Other New structures

One of the biggest problems in İstanbul is transportation between European side and Asian side. Although there are two bridges on the Bosphorus these are insufficient. For this reason the Marmaray project was developed (Figure 7). Historical buildings are vulnerable on the route of this project and many existing residential and office buildings are old and constructed on minimal foundations. As a consequence, it is vital that any drawdown of groundwater and any ground settlements have to be minimized. In addition, the connection between the immersed and bored tunnels will be made directly and totally underground, without the usual intermediate shafts and beneath the deep waters of the Bosphorus Strait. This operation needs the utmost control of the tunnel excavation face to ensure its stability and to minimize water ingress (Sakaeda, 2005).

Aggregate Resources

Both on the Asian and European sides of İstanbul Paleozoic aged rocks have been widely using as aggregate. Mesozoic and Cenozoic aged rocks have also been used. There are three regions in the western part of İstanbul. The first region, Cebeciköy, Kemerburgaz, İkitelli and İstinye, consists of limestone, sandstone, and shale. The second region, Çatalca consists of microcrystalline limestone and in the third region, on the Black Sea coast, aggregate exploitation is made in sand dunes (Figure 13).

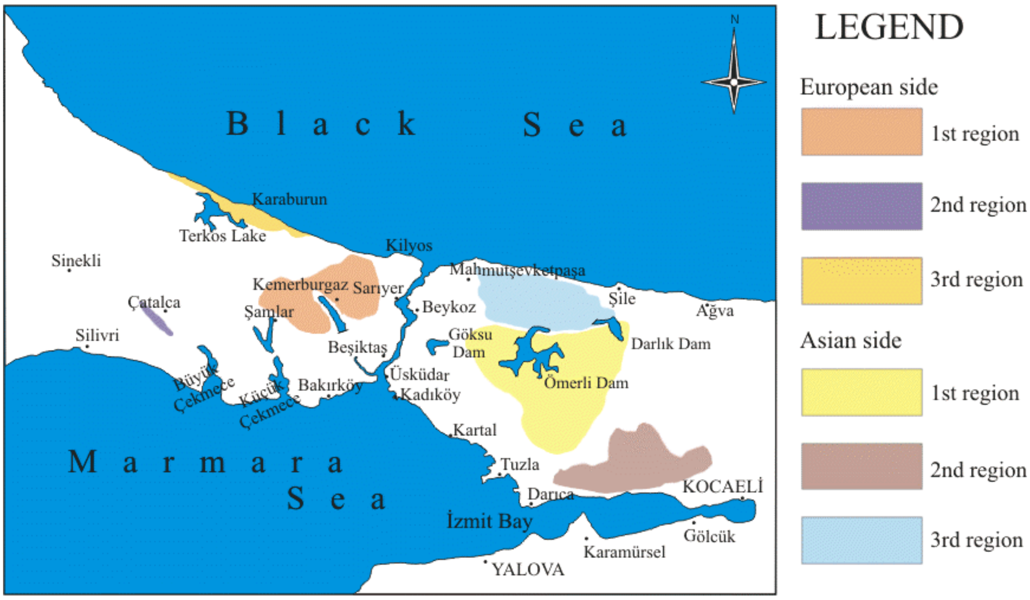

Figure 13. Aggregate production areas in İstanbul

There are also three regions in the eastern part of İstanbul. The first region, Ömerli, consists of Silurian, Devonian and Triassic age dolomitic limestones, clayey limestones, limestones and dolomites. The second region, Gebze – Hereke, consists of similar rocks to the first region. The third region, Şile-Riva, consists of basalt, limestone and sand-gravel. Marine sand in the coastal regions of the Black Sea is also used.

The main aggregate production today is from limestones and sandstones. The abundance of these rocks varies in the different parts of İstanbul, but in general it can be concluded that in the most densely populated areas, much of the good quality limestone and sandstone has already been used up. In general, the İstanbul aggregates that are mainly used in the concrete industry are of sufficient quality, as far as material requirements are concerned. In addition to their use as crushed rock aggregate, limestone and sandstone have been using as the basic raw material of the construction industry. Fresh rocks are used as first-class aggregate and not as general rubble fill, and lesser rock grades designated as upper course road base, sub-base and select fill as their quality decreases. Some parts of the deposits, especially those are very close to the city in the western part of İstanbul, are exploited even though it is prohibited for environmental reasons. Most current limestone quarries may disappear in the next few years because of urban development or lack of reserves.

CONCLUSIONS

İstanbul is one of the most famous historical cities in the world. Many engineering structures have been built in the city. In this study, the engineering geological characteristics of İstanbul have been presented and the main conclusions are given below;

- From the point of engineering geological problems, Paleozoic and Mesozoic rocks generally provide good ground conditions. But fractured and weathered zones should be investigated in detail.
- Over-consolidated Tertiary units generally do not have bearing capacity problems whereas they have stability problems especially in Avcilar, Küçükçekmece, Büyükçekmece and Beylikdüzü Regions.
- The bearing capacity of the alluvium is very low, and artificial fills, Bosphorus and Haliç sediments have negligible bearing capacity. Foundations of buildings constructed on these sediments generally have instability and settlement problems.
- Earthquake risk gradually decreases from South to the North in the European side,. because of the active faults in the Marmara Sea and also the lithological characteristics of the weak rocks and soils.

Corresponding author: Ömer Ündül, İstanbul University, Eng. Faculty, Dept. of Geol. Eng. Avcılar, İstanbul, Turkey, TR-34320, Turkey. Tel: +90 212 473 72 95. Email: oundul@İstanbul.edu.tr.

REFERENCES

ABDÜSSELAMOĞLU, Ş., 1963, Nouvelles observations stratigraphiques et paleontologique sur les Terrains Paleozoques affleurent a l'est du Baspore, MTA Dergisi, s. 60.
ALTINLI, İ.E., 1951, Kayışdağı Bölgesinin Jeolojisi, İ.Ü. Fen Fak. Mec., SeriB. XIV, s.2.
AMBRASEYS N.N., FINKEL, C.F., 1991, Long-term seismicity of İstanbul and of the Marmara Sea region. *Terra Nova*, **3**:527–39.

AREL, E and TUĞRUL A. 2001, Weathering and it is relation to geomechanical properties of Çavuşbaşı Granitic rocks, in Northwestern Turkey, *Bulletin of Engineering Geology and Environment* Vol **60** No 2. 123-133

BARKA, A. 1992, The North Anatolian fault zone: Annales Tectonicae, V.**6**, suppl., p.164-195.

EROSKAY, S.O., 1985, Graywackes of İstanbul Region, *Derin Kazılar ve İksa Metodları Sempozyumu*, Boğaziçi Üniv., 141-144.

ERGUVANLI, K., 1985, The graywacke problem related to İstanbul area, *Proceedings of International Symposium on Design of Supports to Deep Excavations*, Turkish Group of Soil Mechanics, Bosphorus University, 19-39.

HİDEKİ SAKAEDA, 2005, Marmaray project: Tunnels and stations in BC contract, Tunnelling and Underground Space Technology, in press

KAYA, O., 1973, *Paleozoic of İstanbul*, E.Ü.F.F. Kitapları, Sayı 40.

KETİN, İ., 1991, *İstanbul Jeoloji Haritası*, MTA Jeoloji Veri Bankası, Ankara.

ÖNALAN, M., 1981, İstanbul Ordovisiyen ve Silüriyen İstifinin Çökelme Ortamları, *İ.Ü. Yerbilimleri Fak.*, s.3-4.

ÖZTUNALI, Ö. and SATIR, M., 1973, Petrography and petrology of Çavuşbaşı crystalline rocks: *Proceedings of Earth Science Congress in the 50th Anniversary of Republic of Turkey*, Ankara, pp.445-456 (in Turkish).

ROCKWELL, T., BARKA, A., DAWSON, T., THROUP, K. and AKYÜZ, S., 2000, Paleoseismicity of Gaziköy – Saros segment of the North Anatolian fault northwestern Turkey – Comparison of the historical and paleoseismic records, implications of regional seismic hazard, and models of earthquake recurrence: *International Journal of Seismicity,* June 2001 issue.

SAYAR, C., 1969, Boğaziçi Arazisinde Ordovisiyen Conularialari, *TJK Bülteni*, S.12

STATE INSTITUTE OF STATISTICS, 2000, Census of Population of İstanbul. Republic of Turkey Prime Ministry of State Institute of Statistics, www.die.gov.tr

TUĞRUL, A. ZARİF, H., 2000, The influence of the weathering on the geological and geomechanial cahracteristcs of a sandstone in İstanbul ,Turkey. *Environmental and Engineering Geosciences*, Vol **VI**. No:4, 403-412.

TUĞRUL, A, ZARİF, H., 2002 Evaluation of selected limestones for use as concrete aggregate, İstanbul, Turkey, Engineering Geology for Developing Countries, *Proceedings of 9th Congress of The International Association for the Engineering Geology and The Environment*, Durban, South Africa, 2678 – 2686.

ZARİF, İ.H. and TUĞRUL, A., 2002, *Eminönü Belediyesi (İstanbul) Kent Alanının Jeolojisi ve Yerleşime Uygunluk Değerlendirmesi*, İstanbul Üniversitesi Eğitim Araştırma ve Yardım Vakfı Projesi.

ZARİF, İ.H. And TUĞRUL, A. 2004 Aggregate Properties of Devonian limestones for use in concrete in İstanbul, Turkey, *Bulletin of Engineering Geology and Environment* Vol **62** No 4, 379-388