Microzonation for earthquake hazards: 
Yenişehir settlement, Bursa, Turkey

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Abstract

Detailed geological, hydrogeological and geotechnical studies were performed for the assessment of the foundation conditions of the present and future settlement areas of Yenişehir. Yenişehir is located 50 km east of Bursa, Turkey, within an east—west trending elliptical sedimentary basin. The present and future development areas of Yenişehir cover 10 km². The topography of the settled area is quite smooth and the slopes are generally less than 10°. Yenişehir is located within a First-Degree Earthquake Zone of Turkey according to the seismic design code. The seismicity of the town is mainly controlled by the Geyve-Iznik and Bursa fault zones. The study also involves trial pitting, drilling, in situ testing and laboratory testing. Borehole logs, index properties of soils, standard penetration test results and groundwater level measurements were used for activity and liquefaction assessments of the foundation material. Based on the evaluation of the data, two geotechnical zones were distinguished. The northern part of the area is characterized by cohesive soils of high expansion behaviour and the southern part by alternation of cohesive and non-cohesive soils showing high liquefaction potential.

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1. Introduction

Urban planning becomes an important issue where urban areas expand as a result of an increase in urban population. The balance between human occupation and the natural environment becomes severely disrupted due to urbanization (De Mulder, 1996). The objective of urban planning is to reduce the number of conflicts and adverse environmental impacts so that the quality of life and the general welfare of the community are improved (Bell, 1998; Bell et al., 1987). Such planning requires a multidisciplinary approach for various human needs (De Mulder, 1996). However, in urban planning, geological and geotechnical data are becoming increasingly important for the recognition, control and prevention of geological hazards (Bell et al., 1987; Legget, 1987; Hake, 1987; Rau, 1994; Dai et al., 1994, 2001; Van Rooy and Stiff, 2001).

Yenişehir is a settlement area with a population of around 26,000. It is situated 50 km east of Bursa, Turkey (Fig. 1). The present and planned future settlement areas of Yenişehir cover 10 km². The rate of population growth is about 2.5% per year both in the...
almost half of the settlement area in Yenişehir is currently urbanized. Yenişehir is located within a First-Degree Earthquake Zone (highest hazard) of Turkey according to the seismic design code (GDDA, 1996). The seismicity of the area and its vicinity is mainly controlled by the southwestern strands of the North Anatolian Fault Zone (NAFZ). The August 17, 1999 İzmit earthquake ($M_s = 7.4$), which produced extensive structural damage and the loss of almost 18,000 lives in the Marmara region, was also felt rather strongly by the residents of Yenişehir. The earthquake produced no serious structural damage but caused significant ground vibrations and created panic among the people. The town received no migrants after the August 17, 1999 İzmit earthquake.

Following the August 17, 1999 event, the General Directorate of Disaster Affairs of the Ministry of Reconstruction and Resettlement of Turkey declared the commencement of geological and geotechnical review studies for all municipalities affected.

In this study, geological, hydrogeological and geotechnical investigations were performed for the assessment of the foundation conditions of the present and future settlement areas of Yenişehir. This paper describes the stages and details of the investigation of the urban geology aiming at the preparation of a microzonation map of Yenişehir.

2. Morphological setting

Yenişehir is located within a small elliptical sedimentary basin extending in the east–west direction (Fig. 2). Kocasu stream is the main stream of the basin. It flows from southwest to northeast and has a low discharge rate. An irrigation dam across the stream is currently under construction. The settlement area is bounded by ridges both to the north and to the south. The maximum elevation (350 m) corresponds to the northern margin of Yenişehir. The elevation gradually decreases to 220 m towards south. The study area has gentle slope: the average slope of the study area is generally less than 5° and it locally reaches up to 10° in the north (Fig. 3).

The small catchment area of the stream, historical records from the municipality, low discharge rate of the stream and field studies suggest that no flood hazard is
expected in the study area. Completion of the irrigation dam will further minimize any flood hazard. In the study area, no ancient and/or recent slope movements have been observed. The presence of gentle slopes throughout the settlement area precludes any kind of slope movements, except for liquefaction-induced lateral spreading.

3. Seismotectonics

The seismicity of Yenisehir and its vicinity is mainly controlled by Geyve-Iznik Fault Zone in the north, Bursa Fault in the west and İnönü-Eskisehir Fault Zone in the south (Doyuran et al., 2000) (Fig. 4). Epicenter data for historical earthquakes used in Fig. 4 are taken from BOUN-KOERI (2002).

3.1. Geyve-Iznik Fault Zone

The Geyve-Iznik Fault Zone corresponds to the southern branch of the NAFZ, a major right-lateral strike-slip fault that extends all the way from the North Aegean Sea towards East Anatolia over a distance of approximately 1200 km with well-developed surface expression (Erdik et al., 1985). The zone includes parallel and subparallel active right-lateral strike-slip faults. The Geyve-Iznik Fault Zone is located 25 km north of Yenisehir. It is the nearest active fault zone to the settlement area. The Geyve-Iznik Fault Zone has a potential to generate an earthquake of magnitude 7.5 and a maximum horizontal ground acceleration of 0.5–0.6 g at the epicentral area (Erdik et al., 1985; Gülkan et al., 1993).
Explanation

Slope Categories

- **0 - 5°**
- **5 - 10°**
- **> 10°**

- ○ W-4: Water well
- △ SK-8: Geotechnical borehole
- □ MC-12: Trial Pit
- ○ USK-380: Existing borehole

Fig. 3. Slope map of Yenisehir settlement area.
3.2. Bursa Fault

The Bursa Fault extends in the west–east direction for a distance of 45 km between Ulubat Lake and Bursa municipality. It is essentially a right-lateral strike-slip fault with an appreciable normal component. The most recent earthquake on this fault occurred on February 28, 1855 with maximum modified Mercalli intensity IX (Coburn and Kuran, 1985), which caused extensive structural damage and loss of lives in Bursa and its vicinity. The fault is located 40 km away from Yenişehir and no damage was reported from the town.

3.3. İnönü-Eskişehir Fault Zone

The fault zone extends in the northwest direction for a distance of 380 km between Salt Lake and Bursa. The zone includes several discontinuous faults with lengths ranging between a few kilometres and up to 50 km. Small to medium earthquakes have been measured at different segments of the fault zone (Fig. 4). The nearest segment of the fault is about 40 km away from Yenişehir.

The small faults surrounding the sedimentary basin in which Yenişehir is located (Fig. 4) are the closest faults to the settlement area. The field studies indicated...
that Yenişehir settlement area is located within a fault-controlled Neogene basin and there is no field evidence suggesting that these faults are still active. At present, the faults are mostly concealed by post-Neogene deposits.

4. Geological setting

The main lithological units in the vicinity of Yenişehir are pre-Neogene, Neogene and Quaternary deposits (Fig. 5).

4.1. Pre-Neogene deposits

They are the oldest deposits underlying the Neogene basin. They form basement rocks consisting of schists, marbles, meta-volcanics, limestone and volcanics. None of the rocks outcrop in the study area. They are also not encountered during drilling.

4.2. Neogene deposits

These are essentially detrital sedimentary deposits consisting mostly of loosely cemented conglom-
erate, sandstone and claystone intercalations. The deposits show both lateral and vertical gradations. They contain four distinct zones. At the bottom, the deposits start with loosely cemented conglomerates. The gravel-boulder size particles (2–50 cm) are generally subrounded to angular. The particles are derived from the rocks of the pre-Neogene deposits. This zone has a thickness of 50–100 m. It does not outcrop in the study area. This basal conglomerate is followed by conglomerate, sandstone and siltstone alternations. The size of the particles forming the conglomerate of this second zone is relatively small ranging between 1 and 10 cm. These particles are also derived from the pre-Neogene deposits. Above this zone, a clay-dominant very thick deposit containing thin sand and gravel lenses exists. The thickness of this third zone ranges between 100 and 200 m. The zone is observed along the ridges at the north of the study area where future settlement is planned (Fig. 5). The uppermost part (the fourth zone) of the Neogene deposits is characterized by clayey calcareous materials like claystones and marls. These sediments have very local exposures and they have a thickness of less than 10 m. The Neogene deposits unconformably overlie the pre-Neogene deposits.

4.3. Quaternary deposits

The Quaternary deposits are mainly observed in the middle of the basin. These consist of alluvium and detritus transported from northern and southern ridges of the basin as sheetwash. They form flat topography in the study area. Yenişehir is mainly located within this unit. The deposits include clay and silt with occasional sand and gravel interbeds and/or lenses. Thick clay and silt deposits are dominant at the north of the basin and they are derived from the existing Neogene deposits. However, clay and silt deposits get thinner at the south of the basin near the Kocasu stream where thick sand and gravel layers become dominant. This part corresponds to the old flood plain of the Kocasu stream. However, due to extensive settlement and farming, it is not possible to precisely distinguish the boundary between fine and coarse deposits. Based on the field observations, the thickness of the Quaternary deposits exceeds 100 m.

5. Geotechnical evaluation

Geotechnical studies were performed for the assessment of the foundation conditions of the present and future settlement areas of Yenişehir. The geotechnical studies involved trial pitting, drilling, in situ testing and laboratory testing (Doyuran et al., 2000).

At Yenişehir a total of 17 boreholes and 36 trial pits were opened. The maximum depths of individual boreholes and trial pits are 20 and 8.5 m, respectively. In addition to these, 36 borehole data belonging to previous investigations were also used. Standard Penetration Tests (SPT) were conducted at 1.5 m intervals. The SPT samples were used to determine the index properties of the soils. During drilling and trial pitting, groundwater levels were also measured. Laboratory testing includes determination of water content, specific gravity, unit weight, sieve analyses and Atterberg limits of soils obtained from boreholes (Table 1). The evaluation of the index properties of the Neogene and Quaternary deposits shows similar index properties. However, their SPT-N and \(V_s\) values differ considerably. This may imply that the Neogene deposits serve as a better foundation material for the settlement area.

Groundwater level data were obtained by measurements in geotechnical boreholes, trial pits and exist-

<table>
<thead>
<tr>
<th>Properties</th>
<th>Quaternary deposits*</th>
<th>Neogene deposits*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water content (%)</td>
<td>21.15 ± 7.64 (49)</td>
<td>19.53 ± 6.86 (5)</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>2.70 ± 0.02 (17)</td>
<td>2.70 ± 0.01 (2)</td>
</tr>
<tr>
<td>Unit weight (kN/m²)</td>
<td>19.20 ± 0.80 (35)</td>
<td>20.50 ± 0.50 (17)</td>
</tr>
<tr>
<td>Liquid limit</td>
<td>48.18 ± 14.62 (45)</td>
<td>51.60 ± 13.92 (5)</td>
</tr>
<tr>
<td>Plastic limit</td>
<td>20.98 ± 2.22 (45)</td>
<td>19.80 ± 1.64 (5)</td>
</tr>
<tr>
<td>Plasticity index</td>
<td>27.20 ± 14.52 (45)</td>
<td>31.80 ± 12.52 (5)</td>
</tr>
<tr>
<td>SPT-N value</td>
<td>26 ± 16.98 (127)</td>
<td>71 ± 25.54 (17)</td>
</tr>
<tr>
<td>Shear wave velocity</td>
<td>266.61 ± 31.54 (127)</td>
<td>370.77 ± 5.92 (17)</td>
</tr>
</tbody>
</table>

* Values in parentheses represent number of tests.
S.D. = standard deviation.

\(V_s\) Estimated from SPT-N value using the equation \(V_s = 97\times N^{0.314}\) suggested by Tonouchi et al. (1983).
Fig. 6. Geological cross-sections based on lithological properties through Yenişehir settlement area.
ing dug and drilled wells. The groundwater levels are deeper (≥ 14 m) in the north and shallower (2.2 – 7.15 m) in the south of the study area (Fig. 5). The groundwater occurs within the sand and gravel lenses and/or interbeds of the Quaternary alluvial deposits. Thus, during foundation excavation water inflow problems are expected in the southern part of the study area.

Distribution of different lithological units is determined on the basis of field observations, trial pits and drillings. From the geological map (Fig. 5), it is seen that Neogene deposits cover a small area in the north; however, the rest of the study area is underlain by Quaternary deposits.

Neogene deposits consist of light to reddish brown silty clay with occasional sand lenses. The clay is very stiff to hard having high plasticity and high expansion potential (Figs. 7 and 8). Quaternary deposits consist of light brown silty clay with sand of very stiff to hard consistency. The clay layers generally form the upper part of the deposits. Below it, medium dense to loose, silty sand with gravel of variable thickness is also observed (Fig. 6). The sand layer is fully saturated and forms a confined aquifer. The laboratory studies reveal that the clay layers of the Quaternary deposits have both low and high plasticity and expansion potential (Figs. 7 and 8).

The influence of local site conditions on the intensity of the ground shaking and earthquake damage has long been recognized as a contributing factor. The potential for significant ground amplification in any period range is a function of geologic, seismological and geotechnical factors (Ferritto et al., 1999; Kramer, 1996). For the sake of providing input data to a comprehensive microzonation of Yenisehir based on site specific soil response, the soil profiles observed in the study area are characterized in terms of US National Earthquake Hazard Reduction Program's (NEHRP) soil classification. Average shear wave velocity ($V_s$) of the uppermost 30 m of the ground is an important parameter (Borcherdt, 1994; Street et al., 1997; Ferritto et al., 1999) for ground characterization. The shear wave velocities are either measured directly using geophysical techniques or estimated from established correlations for each foundation soil. In this study, $V_s$ is estimated
from SPT data. There are many empirical correlations between $V_s$ and SPT (Imai and Yoshimura, 1970; Ohta and Goto, 1978; Tonouchi et al., 1983; Okamoto et al., 1989). The empirical equation ($V_s = 97 N^{0.314}$, where $N$ is the number of blows for the last 30 cm penetration) suggested by Tonouchi et al. (1983) is preferred in this study. Although the average $V_s$ value for the upper 30 m of the soil is required for the soil classification, the boreholes in the area are planned for 10–20 m depths because in most of the boreholes, the SPT tests give high $N$ values or refusal below these depths. Based on the NEHRP's soils classification, the Quaternary deposits have an average $V_s$ value of 267 m/s, corresponding to D-type stiff soil. On the other hand, average $V_s$ value of the Neogene deposits is 371 m/s, which indicates C-type very dense soil. Recent building seismic code provisions proposed by Dobry et al. (2000) indicate that soil properties more readily available than the average $V_s$ value, such as SPT-N value or undrained shear strength can be used to characterize the upper 30 m of soil. The use of the SPT-N values for both the Quaternary deposits and the Neogene deposits in the new seismic code also yields the same site categories as the NEHRP's soils classification.

In order to assess the behaviour of the granular soils under dynamic loading conditions, the liquefaction potential of the study area has been investigated using the procedure proposed by NCEER (1997). In this method, cyclic stress ratio and corrected SPT-$(N_1)_{60}$ values are considered. In Turkey, limited strong ground
motion accelerometers exist. In the vicinity of the site, four accelerometers in Bursa, İzni̇k and Sakarya were installed recently. The strong ground motion data reveal that the maximum peak horizontal ground acceleration for the close vicinity of Yenı̇sehir was 0.40 g. This was recorded during the August 17, 1999 İzmit earthquake. The General Directorate of Disaster Affairs of Turkey also suggests the use of 0.40 g for areas located in the First-Degree Earthquake Zone of Turkey. Therefore, the expected horizontal ground acceleration is taken as 0.4 g for liquefaction analyses. The analyses were conducted for 5%, 15% and 35% fine fractions (Figs. 9–11).

Liquefaction related sand boils and surface settlement may be observed during earthquake shaking. The development of sand boils is a complicated process. It depends on the magnitude of the excess pore pressure; the thickness, density and depth of liquefiable zone, and the thickness, permeability and intactness of any soil layers that overlie the liquefiable zone. At great depth or in thin layers, liquefaction may not produce sand boils, but at shallow depth, lower excess pore pressures in thick layers may (Kramer, 1996). Based on the examinations of soil conditions and liquefaction-related damage reports from two earthquakes (1983 Nihonkai-chubu and 1976 Tangshan earthquakes), the thickness of the overlying layer required to prevent level-ground liquefaction related damage is estimated by Ishihara (1985). This approach is used for the study area because the liquefaction-prone area is almost flat. The areas having liquefaction potential are re-evaluated using the procedure described by Ishihara (1985) for liquefaction-related surface damage poten-

![Fig. 9. Liquefaction potential of soils for <5% fine fraction.](image-url)
Based on the analyses, the southern part of the study area, where Quaternary deposits are located, is found to be susceptible to liquefaction. In addition to this, the southern part of the liquefaction-prone area is susceptible to liquefaction-related surface damage (Fig. 13). Therefore, liquefaction-related settlement is expected in this zone. Thus, during planning and foundation design stages, the liquefaction susceptibility of the foundation materials must be given due consideration.

6. Microzonation

Based on the geological, geotechnical, hydrogeological and seismotectonic characteristics of the Yenik regret and its vicinity, the foundation materials are grouped into different zones. The General Directorate of Disaster Affairs of Turkey (GDDA, 2000) recommended the following subdivisions:

Zone I: Areas suitable for settlement—normal residential developments can be planned without any further precautions.

Zone II: Provisional settlement areas—development can take place provided certain precautionary measures against heave, excessive settlements, shallow water table, etc. are taken.

Zone III: Areas requiring detailed geotechnical investigations—conditions are such that individual investigations are required and prescribed standard precautions to be taken against very high heave, very high settlement, very shallow water table, liquefaction, flood, etc.

Zone IV: Areas not suitable for settlement—no settlement of any kind is allowed in areas where
seismicity, landslides, floods, water table at the surface, steep slopes, etc. pose serious risks to residential development. Such areas may be used for recreational purposes.

During microzonation studies, special emphasis is given to natural hazards such as earthquake, landslide and flood, as well as to the response of the foundation materials to static and dynamic loading conditions. Considering the earthquake risks and geological/geotechnical characteristics of the foundation material, the following zones are identified.

6.1. Zone II: Provisional settlement areas

In the north of the study area, Neogene and Quaternary deposits are exposed. Here, silty clays with sand having very stiff to hard consistency, high plasticity and high to very high expansion potential are observed. This part of Yenişehir is considered to be in Zone II (Fig. 13). In this area, foundation-related deformation is expected for light structures having shallow foundation depth. Therefore, in this area, shallow foundations should be avoided and the buildings should preferably have basement floors extending below the zone of cyclic wetting-drying.

6.2. Zone III: Areas requiring detailed geotechnical investigations

Zone III covers an area in the south of Yenişehir (Fig. 13). It is mainly underlain by Quaternary deposits, which contain both clayey and sandy soils with a shallow groundwater table. Both high and low plasticity clays (CH-CL type) exist (Fig. 7). Low plasticity clays generally show low expansion behaviour whereas high plasticity clays show high expansion behaviour (Fig. 8). The analyses of sandy soils reveal
that this area is susceptible to liquefaction. The southern part of Zone III has higher liquefaction susceptibility with a risk of liquefaction-related surface damage (Zone IIIIB) due to settlement. However, the northern part of Zone III has a thicker clayey surface layer where liquefaction-related surface damage (settlement) is not expected (Zone IIIA).

The subdivision of Zone III is based on a limited number of drillings and trial pit data. Therefore, during the design stage, detailed geotechnical investigations are recommended in order to check the settlement, expansion and liquefaction potential of the foundation materials.

7. Conclusions and recommendations

The Yenişehir settlement area is located within a First-Degree Earthquake Zone of Turkey. Thus, it will suffer from ground shaking in the future as it did in the past. The town is located over a gently sloping topography formed by Neogene and Quaternary deposits. Within the Quaternary deposits clays and sands are the dominant soil types.

In the study area, no landslide or flood problems are expected. However, the northern sector of Yenişehir is characterized by clayey soils with high expansion. In this area shallow foundations should be avoided and
Explanation

Zone II:
- Provisional Areas

Zone III:
- III A: Liquefaction - no surface damage
- III B: Liquefaction - surface damage

Areas requiring detailed geotechnical investigation

- W-4: Water well
- Δ SK-8: Geotechnical borehole
- □ MC-12: Trial Pit
- ○ USK-380: Existing borehole

Fig. 13. Microzonation and liquefaction potential map of Yenisehir settlement area.
the buildings with basement floors should be preferred. In the southern sector, medium to loose saturated sand lenses and layers are common within the clayey foundation. Thus, this part of the area is susceptible to liquefaction under dynamic loading conditions. Considering the earthquake potential of the area, the design stage must include geotechnical investigations for detailed assessment of the foundation conditions.

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