*Earthquake Geotechnical Engineering for Protection and Development of Environment and Constructions – Silvestri & Moraci (Eds)*
 *ISBN 978-0-367-14328-2*

# Seismic performance of new Turkish building code and eurocode for areas prone to liquefaction

E. Güler & K.B. Afacan
*Eskişehir Osmangazi University, Eskişehir, Turkey*

ABSTRACT: Soils susceptible to liquefaction behave like liquids under cyclic loading due to increasing pore pressure causing loss of the bearing capacity. Turkey is one of the most earthquake-prone countries in the Europe. In this study, five different boreholes representing the soil of Sakarya Akyazi in Turkey were investigated in terms of the risk of liquefaction for different scenarios. First, the liquefaction potentials were investigated for different profiles. Later, the spectral response proposed by the new Turkish Building Code was calculated using the new seismic maps. In order to evaluate the performance of TBC, the spectral response recommended by EUROCODE was estimated, and the non-linear response of soil profiles were compared with the versions offered by the codes. The performance of codes were determined by how well they represent the plateau between the corner frequencies of the response of the soil and the similarities and differences of the regulations were discussed.

## 1 INTRODUCTION

Turkey is located in an earthquake zone and it has been exposed to devastating earthquakes in the past years. Due to the strength loss and/or liquefaction as a result of these earthquakes, so many buildings were damaged (majority of them were collapsed) and over a hundred thousand of people died in the Northwest side of Turkey and neighbor regions also felt them greatly. In this study, Akyazi district of Sakarya province which was exposed to big earthquakes especially Kocaeli and Duzce Earthquakes in 1999 was chosen as the pilot region since liquefaction was observed for the mentioned earthquakes.

Liquefaction is the loss of rapid shear strength that occurs in cohesion-free saturated soils exposed to cyclic loading due to strong shakes (Mallomahmutoğlu and Babuçcu, 2006). As described, not all soils are susceptible to liquefaction, only sandy soils or sandy-like soils. The main idea ofliquefaction phenomena is actually related to the accumulation of excess pore water pressure by the reason of strong ground vibrations. The excess pore pressure reaches at a point that the soil is no longer capable of carrying any load and soil grains start moving freely causing a similar behavior of liquid.

In order for buildings to be constructed reliably and economically, it is crucial to estimate the soils dynamic behavior during an earthquake (Kramer et al, 2011). Is the soil susceptible to liquefy? Or is the soil stiffness strong enough to resist the big earthquake loads/displacements? In terms of soil liquefaction susceptibility, there are some models: 1) SPT-based models, 2) models describing the sandy-like behavior and 3) models estimating the excess pore pressure generation. Building codes generally propose possible seismic scenarios for a specific region or offer site site-specific analysis to get the realistic behavior of problematic soils.

In this study, we aimed to test the performance of the new Turkish Building Code, which was published at the end of 2016 and is effective by 2019 and compare it with the EUROCODE (EC8) for the soils prone to liquefaction in terms of soil amplification.

## 2 SEISMIC PERFORMANCE OF AREAS PRONE TO LIQUEFACTION

Liquefaction occurring in an earthquake zone is important for geotechnical engineers. Liquefaction can be defined as the fluidic behavior of the soils due to increased pore pressure in saturated granular soils resulting loss of strength and stiffness. This causes different settlement, tilting, rotation and such as deformations affect structure greatly and appear as significant damage on the structure or sinking/leaning of the building.

### 2.1 *Work zone*

In order to determine the performance of the new TBC on the liquefied soils, borings taken from the Akyazi district in Sakarya, Turkey were evaluated. The reason why it was chosen for the research is that liquefaction occurred during the Adapazari Eartquake in November, 1999, soil boils were observed a lot and so many buildings were greatly damaged in the area. Akyazi district is in the city of Sakarya neighboring Istanbul, Düzce, Yalova and Bilecik as seen in Figure 1. This region was also affected extremely in the Kocaeli Earthquake in August, 1999.

Akyazi plain consists of quaternary alluvial deposits mostly sand, gravel, clay and silt in order and the alluviums in the region were carried by the Sakarya River and Mudurnu Stream through the rocks of the North Anatolian Fault Zone and south of the stream (Komazawa et al. 2001).

Akyazi district was built on the plain of the same name. There are different rock formations such as Sultaniye Meta-morphites, Abant Yigilca and Çaycuma. Akyazi district located in the 1st degree earthquake zone is located near the North Anatolian Fault which is an active fault line. Three main rupture in the region extending a long way till Izmit and Akyazi is in the middle of these ruptures. The detailed information about the region can be found in the report called 'The Marmara, Turkey Earthquake of August 17, 1999: Reconnaissance Report' by Charles Scawthorn at al. published in 2000.

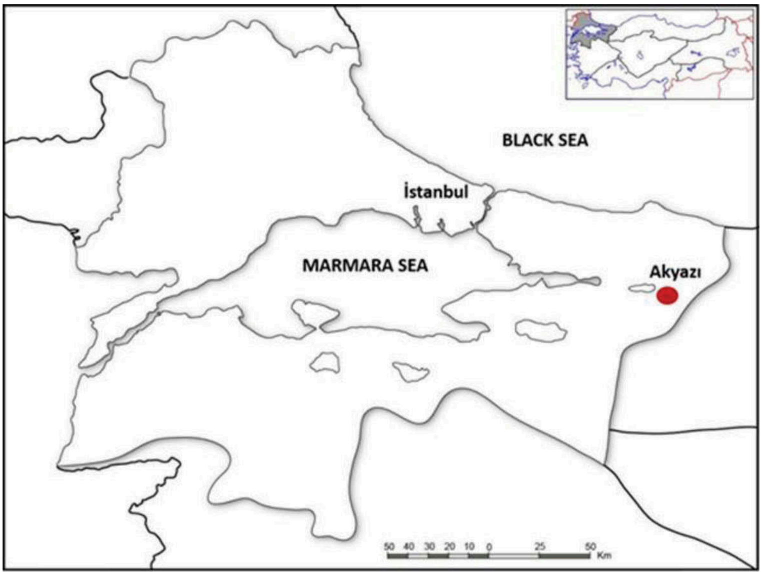


Figure 1. Work zone


Figure 2. Fault lines around the working area (Scawthorn et al., 2000)

Among the earthquakes occurred in the region, the Kocaeli Earthquake in August 1999 was one of the biggest in the province in the history and it was magnitude of 7.51 and felt in the large area, even in hundreds of kms away. According to the official information, 27781 people were wounded and 17480 people lost their lives. As a result of the investigations carried out in the region, many structures have been found to be damaged due to strong ground motion with a long duration. In a few months later, 2678 people were injured and 710 people died due to the earthquake that occurred in Adapazari (Duzce). At the end of the researches conducted in the Sakarya region, it was determined that liquefaction was observed as the main reason of the damage of the buildings and the fatalities. Neither any precautions were taken before the structures were built nor old Turkish Building regulations proposed anything about the liquefaction phenomena.

Figure 3. Building damaged due to liquefaction (Erdik, 2001)

## 3 MATERIAL AND METHOD

Five boring logs taken from in a small region in Akyazi plain were evaluated in this study. The soil layering and their index properties were determined in the laboratory. The shear wave velocity of the upper 30 m was seismically measured. Then the soil columns from the logs were subjected to the most recent 3 earthquakes occurred in Turkey and ground responses for each soil column were assessed. These earthquakes were chosen as Kocaeli Earthquake in 1999, Adapazari Earthquake in 1999 and Van Earthquake in 2011. The DEEPSOIL program was used for the liquefaction analysis and equivalent and non-linear site specific responses.

Due to brevity, the site and laboratory results are summarized here. As a result of the laboratory index testing of the samples from the boreholes, the soil classifications were determined for each depth and they are shown in Table 1. In terms of layering in a general sense, there is a 3 m layer of low plasticity clay on the top and the silty sand and clayey sand dominate the rest of the profile having some low plasticity clay and poor graded gravel. The water content throughout the soil profile were determined between 16% and 26% and the unit of the soil samples were estimated in a range of 16.5 to 18.0 kN/m$^3$.

From the site testing, the SPT-$N_{60}$ values recorded at the logs varied between 3-50 and the shear wave velocity for the upper 30 m ($V_{s,30}$) ranged between 150-180 m/s.

As mentioned before three local earthquakes were used in the site response analysis. Records used in the analysis were taken from the Pacific Earthquake Engineering Research Center (PEER) and the National Strong Motion Data Base of Turkey (TR-SGMD). Detailed information about the ground motions can be found in Table 2.

In order to give an example about the earthquakes used in the anaysis, the acceleration time series, velocity time series and displacement time series of Düzce Earthquake (1999) are presented in Figure 4. The focal depth of the earthquake is 14 km which is considered very shallow and the surface fracture observed on the land is around 45-50 km. (http://www.duzce.gov.tr/12-kasim-duzce-depremi). As seen in the figure, the peak ground acceleration is around 0.4g and the record has some high frequency content which would possibly initiate the pore pressure generation. In terms of displacement, the peak to peak difference happened to be around 80-85 cm being extremely high.

Having the engineering properties of the soil and ground motions determined, the site response analyses with the equivalent linear and non-linear models were run using the DEEPSOIL program generated by Youssef Hashash and his team. For the dynamic properties of the soil layers, Darendeli's (2001) approach used to estimate the modulus reduction values and damping values at different shear strains for both sandy and clayey soils. Since the objective region is a liquefaction prone zone, the pore pressure generation during the shaking were recorded for the non-linear model. The equivalent linear model is not capable of assessing the liquefaction analysis. In

Table 1. Classification of floors obtained as a result of borehole

| D(m) | 1.5 | 2.5 | 3.0 | 4.5 | 5.0 | 6.0 | 7.5 | 9.0 | 10.5 | 12.0 | 13.5 | 15.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BH-1 | CL | CL | CL | CL | CL | SC | SM | SC | SC | SC | SC | SM |
| BH-2 | CL | CL | SC | SC | SC | SM | CL | CL | SM | SM | SM | GP |
| BH-3 | CL | CL | CL | SC | SC | SC | CL | SM | SM | SM | SM | GP |
| BH-4 | CL | CL | CL | SM | SM | SM | SM | SM | GP | SM | GP | GP |
| BH-5 | CL | CL | CL | SM | SM | SM | SM | SM | GP | SM | GP | GP |

Table 2. Earthquakes used in analysis

| Resource | Record Seq. # | Event | Year | Station | Mag | Rjb(km) |
|---|---|---|---|---|---|---|
| PEER | 1176 | Kocaeli, Turkey | 1999 | Yarimca | 7.51 | 1.38 |
| PEER | 1605 | Duzce, Turkey | 1999 | Duzce | 7.14 | 0 |
| TR-SGMD | 6503 | Van, Turkey | 2011 | Van | 6.7 | 19.2 |

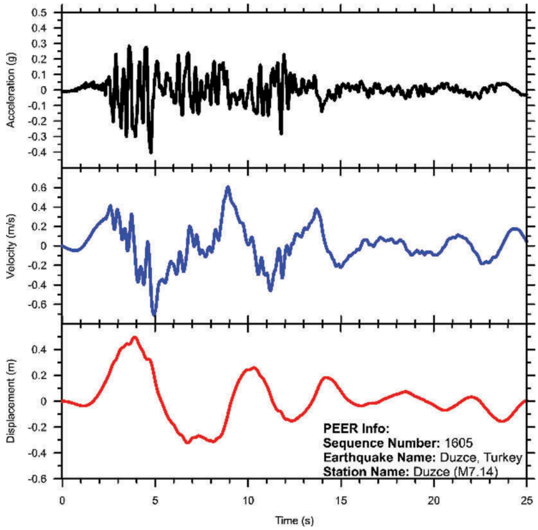


Figure 4. Acceleration, velocity and displacement time series of the Adapazari (1999) Earthquake

terms of liquefaction potential, Dobry and Matasovic's (1997) model for the excess pore pressure generation was chosen due to being easy to assess with the information gathered.

The new Turkish Earthquake Code 2018 (TEC2018) was compared with the site response analyses to examine the performance of the new regulations. In fact, the new regulations were published in December 2016 but it is officially effective by 2019. One of the main differences compared to the previous version (TEC2007) is the soil classification system. In the older version of the regulations, the soils were divided into 4 classes in terms of shear wave velocity for upper 30 m of soil column, the Z1 being the highest (over 700 m/s) and the Z4 being the lowest (lower than 200 m/s) whereas the new regulations propose of 6 classes starting ZA ($V_{s,30}$>1500 m/s), ZB, ZC, ZD, ZE ($V_{s,30}$<180 m/s), and ZF. The ZF class refers to the soils that require site-specific analysis and evaluation for the soils 1) susceptible to liquefaction, 2) having peaty soils over than 3m, 3) having clayey soils with high plasticity over than 8 m and finally 4) having soft clayey deposits of over 35m.

In addition, the new TEC2018 proposes a new spectrum envelope with different corner frequencies and the maximum spectral acceleration. We did not go over the details due to briefness but the spectrum envelopes both TEC2018 and TEC2007 recommend for the site were also obtained in order to give the general comparison to readers.

## 4 RESULTS

The DEEPSOIL program is a one-dimensional analysis platform that enables for engineers to run equivalent and non-linear analyses in the frequency and time domains. In this study, site response analyses with equivalent linear and nonlinear approaches were conducted with DEEPSOIL program, the ground response were evaluated for both models and the liquefaction potential was investigated for the nonlinear model. The soil amplification was obtained to see the difference between the base acceleration and the surface.

As mentioned before, there are 3 different earthquakes used in the analyses but only the response data recorded for the Duzce Earthquake was chosen as an example. The acceleration time series for the base and the recorded at the ground and corresponding response spectra for the equivalent linear model (EL Model) and nonlinear model (NL Model) are shown in Figure 5. In terms of the acceleration, the EL Model amplified the base acceleration whereas NL Model de-amplified the motion. The peak base acceleration is about 0.4g at around 5

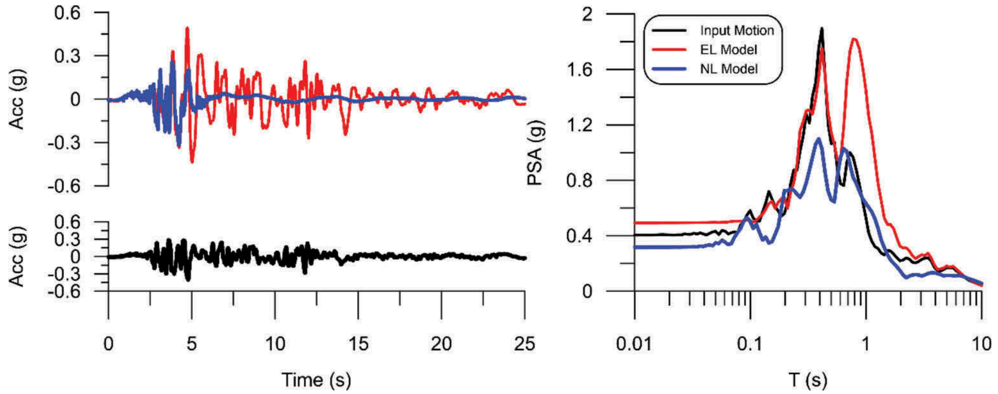


Figure 5. Acceleration time series and corresponding response spectra for EL and NL models

seconds but it happened to be 0.52 g around 5 seconds for the EL Model and it was estimated about 0.33g around 4 seconds for the NL Model. For the spectral accelerations, the initial part is almost flat at short periods up till 0.1s and they peak around 0.4s being the predominant period for the case. The peak is almost 1.8g for the EL Model and matches with the base motion however it was recorded as 1.1g for the NL Model. Both models have second spikes but they occur at different times with different amplitudes. The spectral behaviors are very similar for longer periods over 4s.

In order to evaluate the findings better obtained in Figure 5, the excess pore pressure generation was allowed to build up while NL analyzes were carried out. The liquefaction potential of the soil can be estimated by the DEEPSOIL program in time domain with different approaches. The pore pressure generations during cyclic loading for clayey and sandy soils were model by the approach Matasovic offered in 1995. It is desired here to discuss the importance of modeling liquefaction potential because EL models do not perform liquefaction analyses and the it totally affects the site response.

The liquefaction initiation can be estimated by the excess pore pressure ratio ($r_u$). This ratio is defined as the ratio of the excess pore pressure ($\Delta u$) over the initial effective overburden stress ($\sigma'_{vo}$). When the ratio reaches to value 1, it indicates the potential of the liquefaction at the depth that specific excess pore pressure series were recorded. For the NL Model run for the Duzce Earthquake, the excess pore pressure at different depths for different borings were monitored during excitation and the $r_u$ values are shown in Figure 6. As seen in the figure, $r_u$ values reached to 1 at least at one depth for different borings meaning liquefaction initiation would be possible for such loading for this site. Another result obtained from the graph is that the excess pore water pressures start building up after approximately 3 seconds and trigger the liquefaction at 5 seconds the earliest 5 s and some happened later. It was important to see the liquefaction susceptibility here to validate the analyses since liquefaction occurred in 1999 during Duzce Earthquake in this region.

The example data for Duzce Earthquake was shown above in Figures 5 and 6. Figure 7 shows the ground spectral accelerations of 5 different soil columns excited by 3 different earthquakes for two different approaches. The results of EL-Model is presented on the left side whereas NL-model results can be seen on the right side of the figure. In order to see the performances of the building codes, the design response spectra that TEC2007, TEC2018 and EC8 recommend for the specific region studied here were calculated and they are also presented in the figure with the EL and NL models.

As seen in the figure, the response spectra that the TEC2018 and EC8 offer are very close to each other at short to medium periods but they differ at longer periods for this site. The one TEC2007 recommends is different than other two but it matches with the TEC2018 at longer periods. In terms of peak spectral acceleration, it is increased almost 50% for the TEC2018

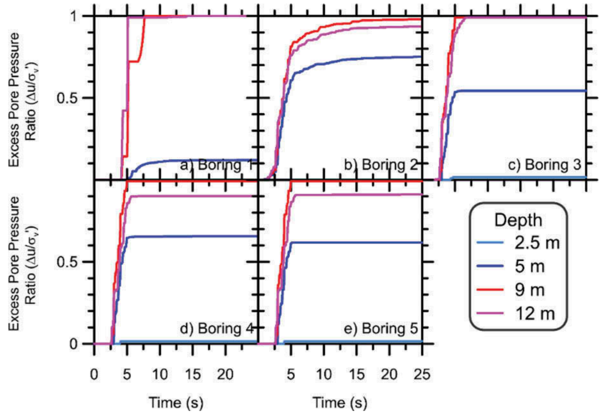


Figure 6. Excess pore pressure buildups at different depths

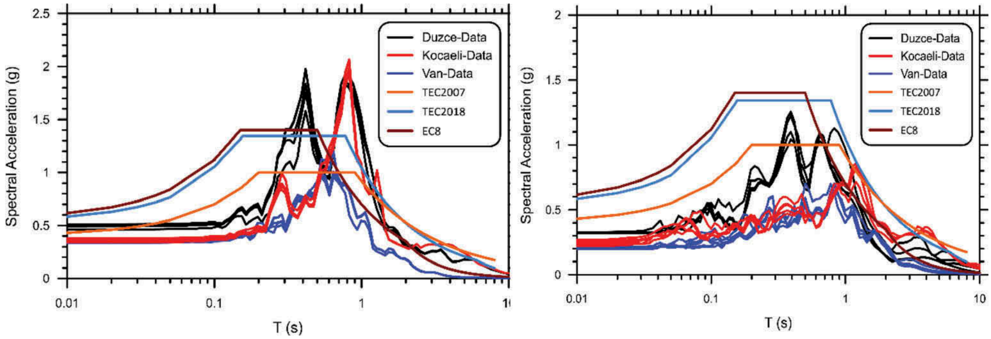


Figure 7. Response spectra obtained by EL-NL model analysis

having a similar value for EC8 compared to the TEC2007. Considering the ground response of the soil columns for 3 different earthquakes for the EL Model, the TEC2018 and EC8 estimate the average peak acceleration accurately except the corner periods. There would have been a better match if the plateau were shifted on the right about 0.1-0.2 seconds. The TEC2007 does a bad job matching the data and underestimates the ground response. The ground response obtained by NL analysis was not well predicted by the 3 different regulations. The main reason for this is that the buildup of excess pore water pressure is allowed during loading and the energy absorbed by the movement of the grains did not let all the energy transmitted through the soil from bedrock to ground surface. For this reason, lower response spectra were obtained for all the data and the peak spectral acceleration lengthen for a long period of time unlike the equivalent linear analysis forming a single peak (except Duzce which has two spikes) with a single period dominant period.

## 5 CONCLUSION

Under cyclic loads, saturated sandy soils can act as liquids due to increased pore pressure and lose their rigidity/strength. Therefore, site specific analyses are of great importance in earthquake country like Turkey. In this study, 5 boring logs from Akyazi region of Sakarya province were selected and liquefaction analyses were performed under different earthquake loads and response spectra were obtained on the ground for both equivalent linear and nonlinear approaches. The studied area is a liquefaction susceptible region since liquefaction observed during Duzce Earthquake in 1999 and the liquefaction was modeled by the NL model with the pore pressure buildup monitoring. The ground response spectra from for the relevant region were obtained according to TEC2007, TEC2018 and EC8 and important points are summarized below:

- Liquefaction in earthquake zones is an important issue and liquefaction triggering should be determined by using more complex models in advance and necessary precautions should be taken.
- Site specific analyses are very crucial in the earthquake zones and regulations should encourage site-specific analysis as much as possible, so the dynamic behavior and the ground response are better determined in order not to have any damage occur during an earthquake.
- The soil amplification and the regional response spectrum are one of the basic elements proposed by the regulations, but as seen above, the presence of liquefaction is not taken into account by the regulations.
- TEC2018 was shifted to the safer side than the old Turkish regulation, and the new regulation proposed similar behavior with the EC8 for the studied region.
- In addition to the ease of use of equivalent linear analyses, it is necessary to prefer nonlinear models to estimate the dynamic behavior of the soil and the energy transmission through the soil column better. Furthermore, the liquefaction triggering with the excess pore pressure buildup can be modeled by the nonlinear models.

## REFERENCES


AFAD. Disasterand Emergency Management Presidency Earthquake Department http://kyhdata.deprem.gov.tr/2K/kyhdata_v4.php

Darendeli, M. B. 2001. *Development of a new family of normalized modulus reduction and material damping curves*, Department of civil, architectural and environmental engineering, The university of Texas, Austin, Texas.

Erdik M. 2001, Report on 1999 Kocaeli and Duzce (Turkey) earthquakes, *Structural Control For Civil and Infrastructure Engineering*. pp149–186.

Hashash, Y.M.A., Musgrove, M.I., Harmon, J.A., Groholski, D.R., Phillips, C.A., & Park, D., 2016. DEEPSOIL 6.1, *User Manual*. Urbana, IL, Board of Trustees of University of Illinois at Urbana-Champaign.

Information of Düzce Earthquake http://www.duzce.gov.tr/12-kasim-duzce-depremi

Kramer, S., Hartvigsen A.J., Sideras S.S., Ozener P.T. 2011. *Site response modeling in liquefiable soil deposit, 4th IASPEI/IAEE international symposium*. Effect of surface geology on seismic motion.

Komazawa M, Morikawa H., Nakamura K., Akamatsu J., Nishimura K., Sawada S., Erken A., Onalp A., 2002. Bedrock structure in adapazarı, Turkey- A possible cause of severe damage by the 1999 Kocaeli earthquake. *Soil Dynamic And Earthquake Engineering*. No.22, Issues.9-12. pp.829–836

Matasovic, Neven, & M. Vucetic, 1995. Generalized cyclic degradation-pore pressure generation model for clays, *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 121, No. 1, pp 33–42.

Mollamahmutoğlu, M. & Babuçcu, F. 2006. *Zeminlerde sıvılaşma analiz ve iyileştirme yöntemleri*. Ankara.Gazi kitabevi.

PEER. Pacific earthquake engineering research center. https://ngawest2.berkeley.edu/

Scawthorn, C, 2000. *The Marmara earthquake of August 17 1999 Reconnaissance Report*. MCEER technical report, Buffalo NY., MCEER.