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ASSESSMENT OF SLOPE MOVEMENTS, DAMAGES ON BUILDINGS, SITE EFFECTS AND LIQUEFACTION FAILURES OF THE 12 NOVEMBER 1999 DUZCE EARTHQUAKE (*M*W=7.2) IN VICINITY OF EFTENI LAKE AREA (DUZCE-TURKEY)

Keywords: *Building damage/Duzce earthquake, liquefaction index, soil amplification*

Abstract

Duzce Province, in the Western Black Sea Region of Turkey, is in a tectonically active location that is particularly affected by the northern branch of the North Anatolian Fault Zone. The 12 November 1999 Duzce earthquake (M_W of 7.2) caused huge destruction and loss of life in the provincial capıtal city of Duzce and the surrounding villages. This study presents a field survey and assessment of the building damage that occurred in the vicinity of the Efteni Lake area of the province. Site effects, poor construction quality, soft and weak soil, soil liquefaction, liquefaction-induced settlement and inappropriate selection of residential areas were considered as contributing factors. Using the deterministic

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approach, earthquake magnitudes obtained from local seismicity were used to determine the liquefaction-induced settlement, site effects and soil amplifications and to detect building damage for several earthquake parameters. Magnitudes were estimated via deterministic seismic risk analysis for a model of the North Anatolian Fault Zone with two different rupture lengths (fault lengths of 36 and 74 km), and the earthquake magnitudes and accelerations were calculated. The local fault length was considered alternatively as 6.9 and 7.2 for magnitude and 0.42g and 0.52 g for acceleration. The soil liquefaction potential index (LPI), the liquefaction-induced soil settlement, site effects and soil amplification were estimated according to local seismicity. It was established that most of the damaged buildings were not suitable for residential areas and were not designed or constructed in accordance with the Turkish earthquake code.

1. Introduction

Dynamic movement occured due to earthquakes lead to the development of important soil behaviour, especially in fully cohesionless soils. For instance, liquefaction and correlated with soil unstabilities have a crucial roles on building hazards. As a whole, the damages developing during the earthquaake are formed due to liquefaction induced settlement and site effect. At the end of the liquefaction phenomenon, soil loses its shear strength and can not bear the structures and cause to settling the structures, tilting and/or overturning of structures and various kinds of damages. Further more, liquefaction can cause spreading, flow failure for the structures. It was observed that some buildings were settled, tilted, and overturned in Efteni Lake area in Duzce city after the 1999 November Duzce Earthquake. The findings reveal that they well satisfy the structural practices. This study is to establish a relationship between the performance of the buildings and liquefaction, soil amplification in the vicinity of Eftetini settlement area (Düzce-Turkey)due to the earthquake of November 12, Turkey.

Some investigation studies have been devoted to investigating the performance of structures during earthquakes such as reinforced concrete buildings and other type of building. Regarding this subject, Watanable et al. [1998] introduced a study related to damages to steel structures during the 1995 Hyogoken- Nanbu earthquake. Performance of reinforced concrete buildings during the 1999 Kocaeli earthquake was evaluated by Sezen et al. [2003]. Liquefaction related building damages in Adapazarı during the Turkey earthquake of August 17, 1999 was evaluated by Mollamahmutoglu et al.[2003]. Bruneau [2002] described the damages of reinforced concrete, masonary, and steel structures during the 17 August 1999 Marmara earthquake in Turkey. Site conditions have an important role as one of the triggers of earthquake damage [Seed et al.,2001; Ozel et al.,2002]. The determination of site conditions requires, identification of the soil stratification and properties of soil layers based on detailed geotechnical and geophsical tests [Ozçep et al., 2014].

Further more, additional studies have been investigated; such as site effects, both liquefaction induced settlements and earthquake damage. Gueguen et al. [1998] reported on the site effetcs and damage distrubution in Pujili (Ecuador) after the earthquake on 28 March 1996. Juang et al. [2005] estimated the severity of liquefaction-induced damage near foundations. This study is to determine the how important the role of soil properties play causing the earthquake damages in Duzce provision, and reveal the influence of the two kinds of soil problems; (1) soil amplification and (2) liquefaction about earthquake damage. This paper displays and discusses the reasons of the earthquake damage in the Duzce region involved to soil liquefaction (as shown by PLI and settlement quantities) and soil amplification (earthquake motion and Vs 30), site effect.

This study revealed that a relationship with field geotechnical data for evaluating ground damages triggered by liquefaction and soil amplification at buildings in the study area of Efteni Lake (Duzce city) during the 1999 Duzce earthquake November 12, in Turkey. Duzce is just situated between Ankara and Istanbul motorway; Ankara is 240 km away to the East and Istanbul is 228 km away to the West (Fig. 1)

Fig. 1. Location map of the study area

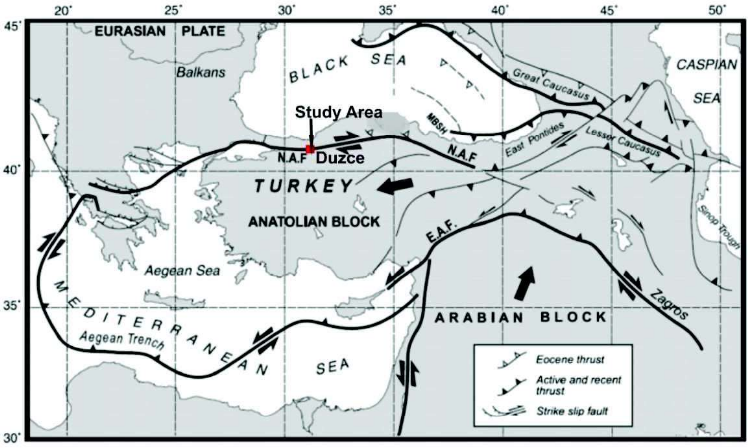
2. Geology and Seismotectonics of the Study Area

Duzce provisional plain is a pull apart type basin that is controlled by the lateral strike slip fault system in the NAFZ [Gökten et al.,1998]. Paleo and Neo-tectonic period of active faults exist at the north and south of the plain. There are several faults which are parallel and oblique to these major faults. During the 12 November, 1999, Duzce earthquake, the surface rupture ranged through Golyaka on the south towards to Kaynaşlı district on the east, ending in the Asarsu valley and the Bolu Tunnel. The city of Duzce is situated in the middle of the plain on a pressure ridge type hill and is probably tectonically controlled (Fig. 2).

Fig. 2. View of the Study Area

The study area is located at the Pontides, is one of Turkey's tectonic units. Pontids are a part of Alpine mountain formation which starts from Czechoslovakia, Carpathians and passes through Romania, Yugoslavia and Bulgaria and eastward along the Black Sea shores to the Little Caucasus, Iran and extending to the Indian platform (Fig 3). According to the theories of plate tectonics, Alpine mountain formation system was formed by the collision of island arcs and continents [Dewey and Bird, 1970]. Alpine system which is a collision orogenic belt is a result of the extinction of the former Tethys Ocean [Şengor, 1981]. The island arc series volcanics around the Alpine mountain formation was developed throughou this entire belt.

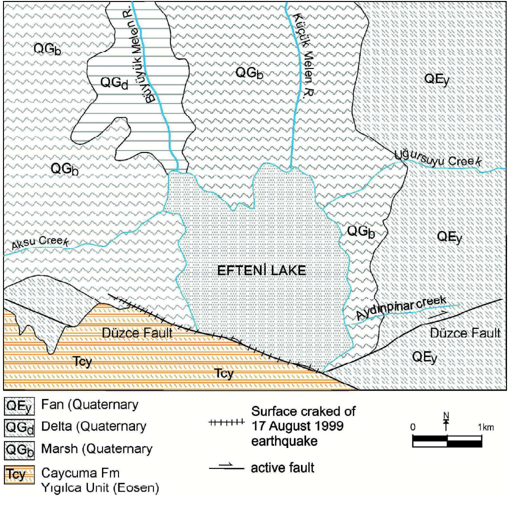
Fig. 3. Tectonic sketch of the Arabia/Eurasia collision zone [Rangin et al.,2002]



Study area is an active subsidence and deposition area controlled by lateral strike slip faults surrounded by pre-Quaterney-aged rocks. Detailed descriptions of these studies around the plane before Quaternary units are excluded from the scope. Şimşek and Dalkiliç [1997] investigated the alluvial deposits existed in the study area under the three different groups and the general properties of each groups were summarized below (Fig.4).

Rivers alluvial deposits (Qall); They are the coarse and granular materials that contain well graded various particles, rounded shape and high strength, mostly blocked materials which formation by gypsium and magmatic structure depending on the floodind regime of the flat plain of Asarsu and Ugursu. Lake sediments (Sand gravel elavations;Qal2): This unit is placed in the part of north and north east and east basin. It is mostly consists of silty clayey sand and gravel levels and is brown cloured and is placed in the deep of soil stragraphy. Besides, clayey surfaces have approximately 5 meters clayey elavations on the account of side transitions. The gravels are fine and coarse grained, corner and half spherical shapes and is grouped in the class of soft and firm. Lake sediments (clay, silty clay and elavations of clayey silt:Qal3): These sediments are observed in central the part of flat plain and in the west of Duzce provision. The thickness of the unit is changing between 3 and 8 meters and is observed as brown cloured upper part and grey cloured bottom part according to the knowledge taken from sections of along the river and the research drilling. The unit formed from clay, silty clay and sandy silt is soft and moderate solid state and is higly plastic and contain some amouns of supplements.

Fig. 4. Geological map of the study area and some borehole locations [Şimşek and Dalkılıç, 1997]



Historical earthquakes have been recorded on the Abant-Bayramoren segment in the south of the region. There were 12 earthquakes between 1967 and 1890. The great earthquake of 17 August, 1668, (M_S =8) caused a disaster in Anatolia [Demirtaş et al., 2000], with aftershocks continuing for 6 months [Ambraseys, 1998]. The Bolu-Gerede earthquake (M_W=7.3) on January 2, 1944, was a major one, recorded after the implementation of instruments for scientific measurement of magnitude. It was noted that 2,381 people died and 50,000 houses were damaged [Tasman, 1944]. Although the 17 August, 1999, Marmara and 12 November, 1999, Duzce earthquakes occurred on the western segment of the North Anatolian Fault, the measured average value of the horizontal ground acceleration was 0.51 g in Duzce provision [Demirtaş et al.,2000].

2.1. Geomorphology

It is established that recurrence of liquefaction at the same area is likely [Youd, 1984]. Thus, it should be taken into consideration that localities of past liquefaction might be considered as potential areas in prospective earthquake [Mollamahmutoglu et al.,2002]. Especially, if a correlation was between past occurrences liquefaction and geological and geomorphological criteria, then this may be utilized to conclude the likely area of liquefaction vulnerability. That kind of study was archieved by Iwasaki et al. [1982] and revealed the criteria in Table. 1. Thus, if geological and geomorphological criteria are supposed, it should be comprehended that Efteni Lake area as aforementioned under the geology of the study area is highly succeptible to liquefaction. The study area and its sorroundings are given in the Fig.5

Fig.5. Geomorphological features of the Düzce basin [Pucci et al.,2007]

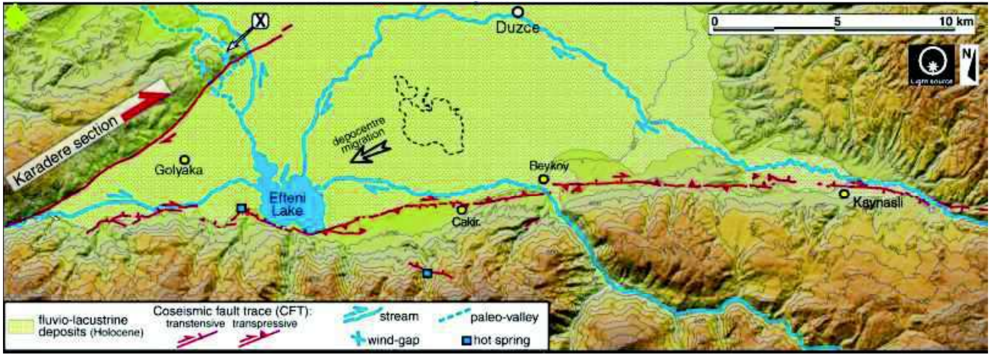


Table 1. Susceptibility of geotechnological units to liquefaction [Iwasaki et al.,1982]

Rank	Geomorphological units	Liquefaction Potentail
A	Present River Bed. Old River Bed. Swamp. Reclaimed land. Interdune lowland	Liquefaction likely
B	Fan. Natural Levee. Sand Dune. Flood Plain Beach. Other Plains	Liquefaction Possible
C	Terrace. Hill. Mountain	Liquefaction Unlikely

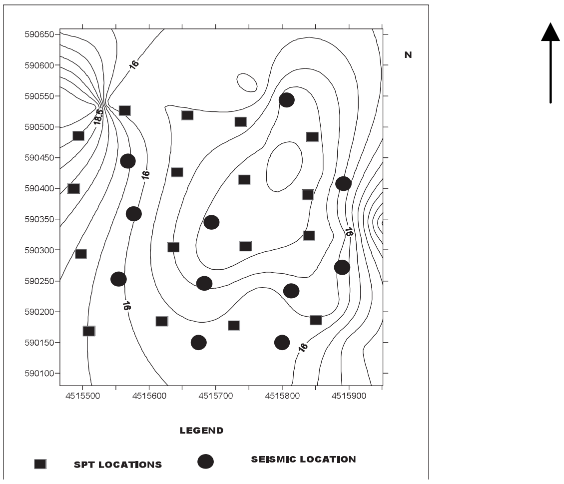
3. Materıal and methods

3.1.Field Studies

Geotechnical bore holes at 17 locations with depths ranging between 10.95-16.95 m (totally) 244.65 m have been drilled to determine the consistency of fine grained soils, stiffness of the coarse soils to have the undisturbed and disturbed samples (Fig.6). Standart penetration test–SPT [ASTM] D 1586-99 has been carried out during the drillings and SPT N blow counts were obtained in the boreholes. Then, representative soil samples have been obtained in order to determine the geomechanical properties of the soils. The 244.65 m thick alluvium is so heterogeneous including unconfined and confined aquifers. Groundwater level is mostly at the surface ranging between 1.4-4.5 m. Throughout the Duzce provision, different soil types are observed. The lowest SPT blow counts are observed in regions close to the Asarsu River flowing through the Efteni lake in the vicinity of Duzce provision.

At the some places at the top layer with a depth of 5.0 m, the average value of SPT is 10-12, even at some places the values increases above 15. At the lower layers, the SPT counts are obviously high and the density of the distrubution of the formation at these levels can be cathogorized as dense to harder dense. In the study area in lower depths and especially along the Asarsu River, low SPT counts are observed. Where as the deeper levels, except in regions close to the Asarsu river towards to leading to Efteni lake, high SPT values are recorded. At the levels between 8-15 m, dense sand and sandy gravel are distingushed, however, sandy silts, clayey soils, silty soils are observed. At lower levels the SPT blow counts are observed as 35-48. Finally, the SPT indicates the presence of some layers vulnerable to liquefaction in regions especially close to the Asarsu River.

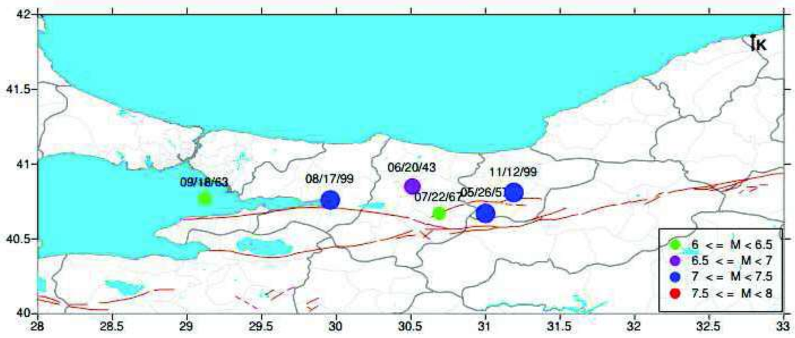
Fig. 6. Borehole locations in the study area



3.2. Earthquake hazard analysis of Duzce region

Duzce provision is located nearby the North Anatolian Fault (NAF) and next to Duzce fault that is tiny branch of NAF. Earthquakes on the North Anatolian fault are caused by the northwards motion of the Arabian plate against the Eurasian plate, squeezing the small Turkish microplate westwards. The earthquake source was supposed to be the North Anatolian Fault and its local branch. Historical and instrumental seismicities of major earthquakes in the area were shown in the Fig. 7.

Fig. 7. Historical and instrumental seismicities of major earthquakes in the study area [Demirtaş et al.,2000]



3.3. Seismic hazard analysis of Duzce city

The earthquake parameters to be obtained from the active faults in the area will be used in determinning the seismic hazard analysis. For this reason, two models have been proposed and shown in Fig.8 for this area. Model A: Approximately 74 km rupture length. Model B: Approximately 37.5 km rupture length. The earthquake magnitudes calculated given in the Table 2 and Table 3 displays these model predictions of expected earthquake magnitudes. The mentioned models (Fig.8) figure out the fault segments for different structural, tectonic and geoometrical properties and historical earthquake occurances for the effective Duzce Fault. The magnitudes of the scenario earthquakes were calculated for this area according to the both fault lengths (Model A, and B) as shown in Fig.8.

Fig.8. Fault models A, B, for deterministic seismic hazard analysis in the study area A: Approximately 74 kmrupture length: B: Approximately 37.5 km rupture length

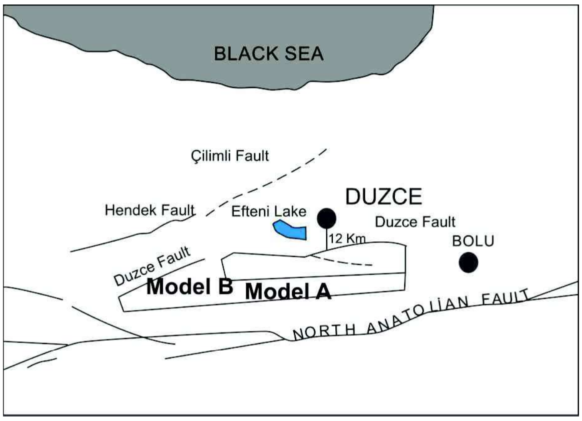


Table 2. Earthquake magnitude calculations for models, Model A: approximately 74 km rupture length; Model B:approximately 37.5 km rupture length [Mark, 1977]

Researcher	**M (magnitude) Ranges for Model A (L=75)**	**M(magnitude) Ranges for Model B (L/2=37.5)**
Ambraseys and Zatopck (1968)	7.2	6.9
Douglas and Ryall (1975)	7.2	6.9
Patwardan et al., (1980)	7.2	6.9
Wells and Coppersmith (1994)	7.2	6.9

The earthquake magnitude parameters given in Table 3 were obtained in the study area within the 100 km radius of Duzce city. Earthquake data were obtained from Kalafat et al. [2007], who catalogued seismic activity in Turkey since 1900 up to now. Regarding with this study, about 81 earthquakes of magnitude M>4.5 occured during the periot. The catalogue includes the areas with high seismic activity in Turkey and its environment [Özçep et al.,2014].

The destructive and damaging earthquake pertinent with Mw>7.0 occurred in this area during that period of 105 yaers.

Table 3. Earthquakes within roughly 100 km radius of study area according to the historical and instrumental registrations

Magnitudes	4.5≤M≤5.0	5.0≤M≤5.5	5.5≤M≤6.0	6. 0≤M≤6.5	7.0≤M≤7.5
Numbers	56	17	11	4	2

Regarding with the design earthquake moment magnitudes were chosen as 6,9 and 7.2 which present the seismicity of Duzce city.

At Düzce provision, the recorded peak ground accelerations are 412 cm/s 2 (NS) and 510 cm/s 2 (EW).

Peak ground accelerations (a_{max}) is an important factor for design earthquakes. In this study, Aydan et al [1996] offered following formula to calculate the hozrizontal peak ground acceleration.

$$a_{max} = 2.8\,(e^{0.9M}\,.e^{-0.025R}-1) \qquad (1)$$

Where M is magnitude, R is the distance from the focus of an earthquake.

Liquefaction potential is usually assessed by obtaining consistent measure of earthquake forces and liquefaction resistance. It has become common to base the comprision on cyclic shear stress amplitude, usually normalized by initial vertical effective stress and expressed in the form of cyclic tress ratio, CSR, for loading and a cyclic resistance CRR, for resistance. The liquefaction potential index is then described in terms of an index against liquefaction according to Iwasaki et al. [1981] approach.

5. Liquefaction susceptibility of the study area

5.1. Liquefaction analysis

In order to assess the liquefaction potential at the Efteni Lake area of Duzce city, data from geoetechnical boreholes with SPT which were performed for building purposes. A total of 17 boreholes were taken into account varying the depths between 15 and 10 meters respectively.

Firtsly, susceptibility to liquefaction of soils in the area was assessed based on the using the simplified SPT-N method proposed by Seed et al.[2001].

On assessing the liquefaction phenomenon, the factor of safety against liquefaction per layer, FS, was calculated as ratio of CRR (cyclic resistance ratio) to the CSR (cyclic stres ratio), based on the deterministic procedure, was known as the "*simplified procedure*" [Seed and Idriss, 1971; Seed et al., 1985; Youd et al., 2001].

Youd et al [2001] proposed the cyclic resstance ratio (CRR) using the following equatins (Eq.2).

$$\mathrm{CRR} = \frac{1}{34-\mathrm{N}_{1(60)}} + \frac{\mathrm{N}_{1(60)}}{135} + \frac{50}{\left(10\mathrm{x}\mathrm{N}_{1(60)}+45\right)^2} - \frac{1}{200} \tag{2}$$

The normalized SPT-N value is influenced by the measured standard penetration resistance N, the overburden pressure factor Cn, the correction for borehole diameter, Cb the correction factor for rod length Cr and the correction for samplers with or without liners. The Cn was calculated according to the equation proposed by Liao and Whitman [1986], while the borehole correction factors were estimated using the parameters suggested by Youd et al. [2001]. Afterwards, a "*fine content*" correction was applied to the calculated N1(60) value in order to obtain an equivalent clean sand value N1(60)cs is given by the equations proposed by Youd et al. [2001].
The CSR defines the seismic demand and is expressed as Eq.3

$$\mathrm{CSR} = 0.65\frac{\mathrm{a_{max}}}{\mathrm{g}}\frac{\sigma_\mathrm{V}}{\sigma_\mathrm{V}^{'}}\mathrm{r_d} \tag{3}$$

Where σ vo: total vertical stress at depth z,
$\sigma_{vo}^{'}$: effectictive vertical stress at the same depth, amax: peak hozintal ground acceleration, g: acceleration due to gravity and r_d: stress reduction factor; estimated using the Liao and Whitman [1986] equation. In the end, the CSR values have been divided by the magnitude scalling factor, MSF, which is calculated using the equation proposed by Youd et al. [2001].

In this study, the magnitudes were equally calculated for different length of faults according to be likely cracked occurring possible earthquake, and a_{Max} that were employed for all the calculations including different equalities being valid for Turkey. The severity of liquefaction can be furthermore evaluated based on a weighting procedure proposed by Iwasaki et al. [1982]. Iwasaki et al. [1982] proposed a procedure to evaluate liquefaction potential index (LPI), based on the in situ test data over the entire borehole (or more accurately, the top 20 m). The liquefaction potential index is defined as follows Eq.4.

$$\mathrm{LPI} = \int_0^{20} \mathrm{F_{(Z)}W_{(Z)}\,d_Z} \tag{4}$$

Where z is the below the ground surface in meters and is calculated as w(z)=10−0.5z; F(z) is a function of the factor of safety against liquefaction, FS, where F(z)=1-FS when FS<1 and if FS>1 than F(z)=0. The depth of soil layers is limited to 20 m. Equation (4) gives the values of LPI ranging from 0 to 100.

In this paper, the data obtained from the study area were used for evaluating the soil liquefaction potential and settlements in the Efteni Lake of Duzce provision. Herein, some locations logs belogs to SPT-N, and geological soil lithology and ground water tables in the field were displayed in Table.4. In analysing the liquefaction as an earthquake scenario parameters, both integrated the deterministical analysis was performed to predict the degree of ground motion. Upon the analysing the liquefaction, magnitudes of 7.2 and 6.9 and acceleration of 0.42, and 0,51 were utilized for the theoritical earthquake and then liquefaction map was obtained. For liquefaction induced settlement, earthquake moment magnitude of 6.9 and 7,2 with accelaration of 0.42, 0.51 were used and the settlement maps were obtained according to the [Ishihara and Yoshimine, 1992]. As a sample one of the liquefaction and settlement maps were given below (Fig 10).

Table 4. Some borehole logs in the study area

Depth (m)	**SPT (N)**	**Lithology**	**Water Table**
BH1			
1.50	6	GC	1.1
3.00	6	SC	1.1
4.50	10	SP	1.1
6.00	12	SP	1.1
7.50	17	SW	1.1
9.00	22	SW	1.1
10.50	24	SM	1.1
12.00	**27**	**SM**	**1.1**

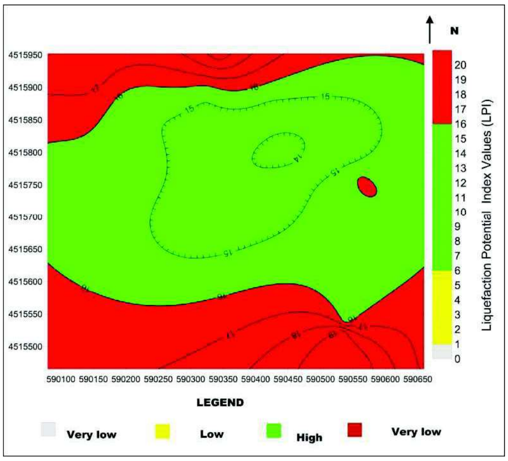
Depth (m)	**SPT (N)**	**Lithology**	**Water Table**
BH2			
1.50	5	GC	1.4
3.00	5	SC	14
4.50	8	SM	1.4
6.00	12	SM	1.4
7.50	14	CH	1.4
9.00	17	CL	1.4
10.50	27	SM	1.4
12.00	**27**	**SM**	**1.4**

Depth (m)	**SPT (N)**	**Lithology**	**Water Table**
BH10			
1.50	6	GC	1.6
3.00	7	SM	1.6
4.50	9	SC	1.6
6.00	11	SC	1.6
7.50	21	CL	1.6
9.00	17	CL	1.6
10.50	27	CL	1.6
Depth (m)	SPT (N)	Lithology	Water Table

	BH16		
1.50	6	SW	1.8
3.00	7	SW	1.8
4.50	9	SW	1.8
6.00	11	SW	1.8
7.50	21	SW	1.8
9.00	17	SW	1.8
10.50	**27**	**SW**	**1.8**

GWL=Ground water level, S=Sand, C=Clay, MC=Silty clay, CS=Clayey sand.

Fig. 9. Variation of liquefaction potential index (LPI) values (0,51 g and M_W=7.2), using Iwasaki et al. [1982] approach



6. Site Effects From Geotechnical Data For Duzce Provision

6.1. Site effect estimation of period

The charecteristic site period (T_S) at a site is the period of vibration corresponding to the fundemental lowest natural frequency [Dixit et al., 2012]. This parameter takes into account the effects of stiffness and density of soil, thickness of soil layers and the depth of the soil column. T_S values also give knowledge about charecteristics of different sites that inflence the site response during events [Kramer, 1996]. It can be either measured directly or can be computed as four times the travel time of the shear wave through the soil profile above the bedrock. For soil sites with multiple horizontal layers, it can be computed from available geotechnical data at different sites using Eq. (6), [Kramer, 1996]. In order to evaluate the site periods, the shaer wave velocities were obtained from geotechnical studies in the Efteni Lake area of Duzce provision and site periods were predicted by using the equation below (Eq.6).

$$T_{S=}\sum \frac{4H_{\text{i}}}{V_{S\text{i}}} \tag{6}$$

Where Hi is the thickness of i-th layer and Vs_i is the average shear wave velocity of i-th layer. The spatial distrubution of site period (T_S) at Efteni Lake of Duzce provisional area was presented in the form of the contour map in Fig. 10.

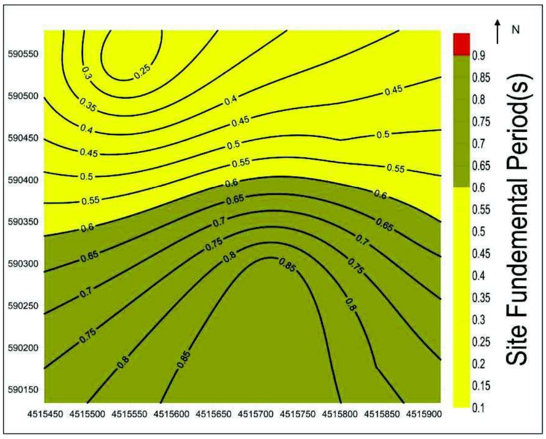


Fig. 10. Site Fundementa Periods

6.2. Soil amplification calculated from geotechnical data

In this study, geotechnical data about 17 boreholes obtained from field were evaluated and SPT- N values were converted into equivalent shear wave velocity values using the equations given below (Eq.7), [Iyisan, 1996].

$$V_S=51.5\ (SPT)^{0.516} \tag{7}$$

Where V_S is an index property for evaluating soil amplifications. The amplification due to the shear values were obtained from relations by Midorikawa [1987]. The shear waves and soil amplification maps were obtained and shown in Fig. 13 and 14.

Fig. 11. Contour map of the spatial distrubution of the mean shear wave velocities in the study Area

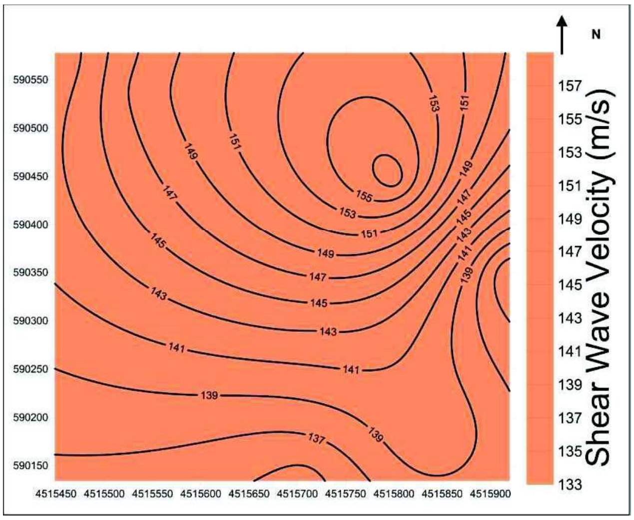
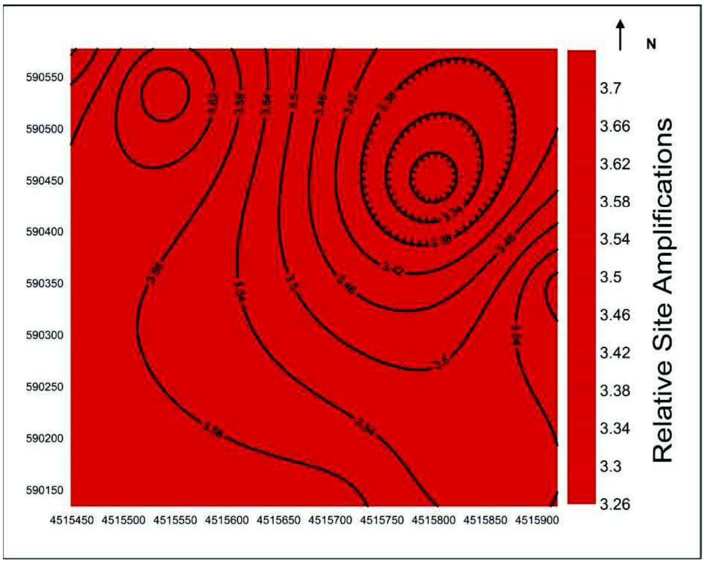


Fig. 12. Soil Amplification Map For the Region According to Midorikawa [1987]



7. Determinatinon of seismic ground motions and damage around Efteni Lake area

Following the earthquake, a field survey was investigated around Efteni Lake on the Duzce Fault zone. Some apparent failures or collapses of buildings were observed in the study area. Herein, ground failure related with lateral spreading was develpoed and was attributed to earthquake and liquefaction (Fig. 13, 14). Observed ground motions and field survey of damages due to flow failure and liquefaction induced settlements around Efteni Lake were displayed below. The lateral spreading due to earthquake that is occurred in the study area can be anticipated by the formula given below (Eq.8) [Hamada et al.,1986].

$$D_h = 0.75\ H^{1/2}\ \Theta^{1/3} \qquad (8)$$

Where D_h is the amount of ground motion (m), H is the thickness of the liquefaction layer, Θ represent the ground inclination.

Fig. 13. Land slide developed around thermal spring of Efteni Lake [Demirtaş et al, 2000]

Fig. 14. Ground movement displacement of 1.5 m to the right side in dried creek in Golormani [Demirtaş et al, 2000]

8. Assessment of observed damage on building due to earthquake

Buildings having structural damages were suffered severly from liquefaction in Efteni Lake area of Duzce provision after the Turkey earthquake of November 1999. The mentioned area of Duzce provision was investigated in such that both the buildings and their related damages were occured. Those buildings have subjected to lose bearing capacity and move the lateral spreading, so they have settled and tilted about 30-35 cm. In some locations, some buildings have collapsed due to liquefaction (Fig. 15). These damages occured on the account of the alluvial weak soil. The soil existing around the pertinent Efteni Lake is weak and mud, fluvial deposits. Ground water in this area is nearly close to surface. The seismic waves were amplified by the local deposits because of weak soil. The deposits have high liquefaction potentail. In this context, simialiarly, site investigations showed that Duzce basin and shore of Efteni Lake area have high liquefaction risk. As viewing this earthquake phenomena really, lateral spreading and traces of liquefaction were observed around the Efteni Lake under the effect of the 1999 Duzce earthquake November 12. Moreover, evidence of ground deformations caused by soil liquefaction and horizontal movement were obsserved in the area. However, liquefaction triggered deformation were not the main cause of the structural damages comparing with that triggered by the shaking. The shaking during the Duzce earthquake devastatingly destroyed the alot of number of the buildings in this region. That earthquake destroyed the nearly most of the buildings; some of building were collapsed and damaged in varying levels. The existing amount of damages around the Efteni Lake were created due to soil amplificaton effect of soft soil deposits. These investigations revealed that ground failures develpoed by the amplifications around the Efteni Lake area contributed to the substantial damages (Figs.15-16).

Fig. 15. Ground movement displacement of 1.4 m right side sliding between wall of garden and pool channel in Golormani [Demirtaş et al, 2000]

Fig. 16. The view of embedded the building with one storey after the liquefaction induced Duzce earthquake 1999 [Demirtaş et al, 2000]

9. CONCLUSION

In this study, liquefaction related with the ground movements and settlements due to earthquake from field survey having the geotechnical data were investigated for Efteni Lake area of Duzce city in order to correlate them to the damage to buildings triggered by 1999 Duzce earthquake. Efteni Lake area are located over the young deposits and ground water levels in some locations is so close to the ground surface. The structural damages in the study area were mainly related to earthquake relating with the beaviour of the soft soils. The shaking induced duzce earthquake destroyed a great number of buildings in Efteni Lake area of Duzce region. In the scope of this study, the following conclusions can be drawn.

- The field observations clearly revealed that the fault rupture between Kaynaşlı and Gölyaka fault zone yielded high level of ground shaking on the account of the underlying alluvial deposits. In this context, soil liquefactions and associated deformations occured within this region.
- Densely populated area such as Duzce city and Golyaka district are mainly situated on the alluvial deposits that have high liquefaction potentail. Lateral ground motion and trace of liquefaction were also observed around Efteni Lake during the 1999 Duzce earthquake.
- Site amplifications in the deposits those are in this area has an important role increasing building damage during the 1999 Duzce earthquake November 12. Obtained amplification values show that effect of ground motion may be increased up about 3.4 times for alluvial deposits in this region.

- It was concluded that quaternary deposits in the study are sustained damage levels, has a major damages occuring with increasing values of earthquale parameters.
- Significant amplifications were observed at all of locations situated on very thick sediments. This soil amplifications shows that those higher frequencies, that could overlap the resonance frequencies of structures. Specially, heavy damage condensed on the period range was 0.38-0.58 seconds, while moderate damage was sustained for 0.4-0.7 second periods.
- Observed damages to this area could be associated with liquefaction (approximately 10 and 25 cm). As it was known from foundation engineering, settlements up to 25 mm can bu omitted in terms of building damage. Vs 30 values in this area exceeded 200 m/s. This value is enough to cause liquefaction. For this reason, it may be deduced that site amplification and liquefaction were responsible for damage in the study area. If it is compared between damage and site amplification for strong motion for this region show that site amplication values differentiates 1,8 and 4 and the period values, denotes to have a threshold value of 0.4 seconds. The site soil with period values greater than 0.8 second may be related to the soil liqufaction induced damage, and soil sites where the period lesss than 0.8 second caused damage relating with the soil amplification and resonance.
- Site amplifications and liquefaction have a direct effect on soil behaviour and building damages. In this area of Duzce region, the site amplification effect could dominate the sandy soil sites. In natural conditions, there is a tendency to liquefaction in sandy soils. In the provision of the Duzce, soil behaviour is in the complex status. That is why, there is no clear difference between these types of soil behaviour around Efteni Lake in Duzce region. Regarding with the damage, the main difference between the the soil amplification and soil liquefaction can be identified by shear wave velocity, Vs, and resonance period; if shear wave velocity less than 200 m/sn, liquefaction is dominant; if resonance period less than 0.8 second, soil amplification and resonance may occur.

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