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DUZCE (M7.2, 1999) EARTHQUAKE: DAMAGE CORRELATION WITH THE MICROZONATION STUDY AND VULNERABILITY ASSESSMENT OF THE WATER SYSTEM IN DUZCE, TURKEY

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ABSTRACT

Duzce, in Turkey with a population of about 80.000 people, was severely damaged during the November 12th, 1999 earthquake (M_w=7.2), which followed the Kocaeli Mw=7.4 earthquake that happened only two months earlier in a close distance. In this paper, the main results of a pilot microzonation study conducted after the earthquake are presented in order to investigate whether the damages in buildings and lifelines (i.e. water system) are correlated with the local soil conditions. The vulnerability assessment of the water system in Duzce has been the final output of this study.

Keywords: Duzce earthquake, damages, pilot microzonation study, local soil conditions, peak ground acceleration, water system, vulnerability assessment

INTRODUCTION

The 12 November 1999 earthquake in Turkey caused considerable damage to residential and commercial buildings, public facilities and infrastructures with substantial casualties. The epicenter of the earthquake was located about 6km south of Duzce. Buildings, already moderately and lightly damaged by 17/8/1999 Kocaeli M7.4 earthquake, have been seriously damaged and many collapsed (Figure 1a). Office buildings, utility systems accounted additional serious damages The water and the sewage system were heavily damaged due to ground deformations and shaking. Damage to the transport infrastructure observed along the 60 km of the Ankara-Istanbul highway crossing the Duzce Fault; at Bakacak section (between Kaynasli and Bolu) two lanes of the four-lane highway collapsed due to land slide for a section of about 200m, as it is depicted in Figure 1b (Erdik, 1999).

Focusing in the city of Duzce, the present study aims to investigate the relation between observed damages and site effects. For this purpose, a pilot microzonation study was implemented in order to estimate the magnitude and spatial distribution of peak ground acceleration, velocity and displacement values as well as peak spectral acceleration values. Based on these results, the vulnerability assessment of the water system in Duzce was conducted and compared to actual reported damages.

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Figure 1a. A general view of building damage in Duzce (Erdik, 1999).

Figure 1b. Landslide on E5 highway in Duzce earthquake (Erdik, 1999).

THE NOVEMBER 12TH, 1999 EVENT

November 12th, 1999 Duzce M7.2 earthquake was associated with the North Anatolian fault, and in particular with the Duzce fault, which forms a morphological boundary at the south of the Duzce Plain. The Duzce fault, (Figure 2a), extends eastwards about 70km from the main branch of the North Anatolian Fault, having its terminus near the village of Kaynasli, located to the southeast of Duzce. It is a right lateral strike-slip fault.

The peak ground acceleration recorded at the Meteorological Station of Duzce was invariably large, ($PGA_{[EW]}$=0.51g), something that is not unexpected due to closer proximity of fault rupture. The long duration and the long period energy content in the time history of the Duzce record, (Figure 2c), is a strong indication of basin response and effect of soft soil behaviour (Sucuoglu, 2002). Moreover, from the shape of the corresponding acceleration response spectra, (Figure 2b), it is evident that the acceleration demands for periods between 0.1 to 1.0 seconds, which is the expected range for periods of most structures at the area, were considerably large. Due to these considerably high demands, the structures that survived the first 17/8/1999 Kocaeli quake were severely damaged and many of them collapsed in the Duzce 12/11/1999 earthquake.

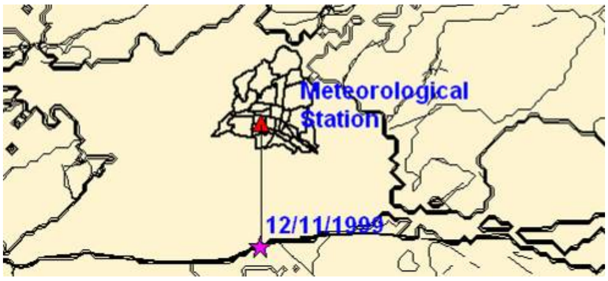


Figure 2a. The Duzce fault which caused the 12-11-1999, Duzce strong seismic event.

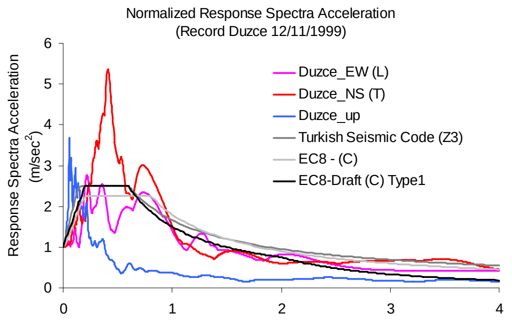


Figure 2b. 12-11-1999 Duzce earthquake response spectra at the Meteorological Station.

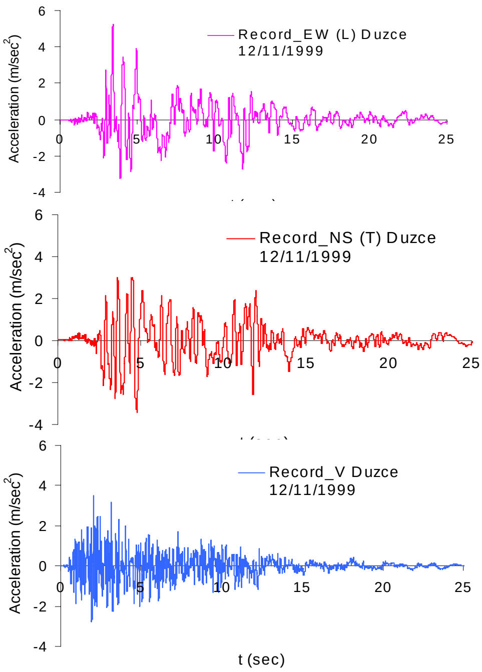


Figure 2c. 12-11-1999, strong motion recordings at the Meteor. Station.

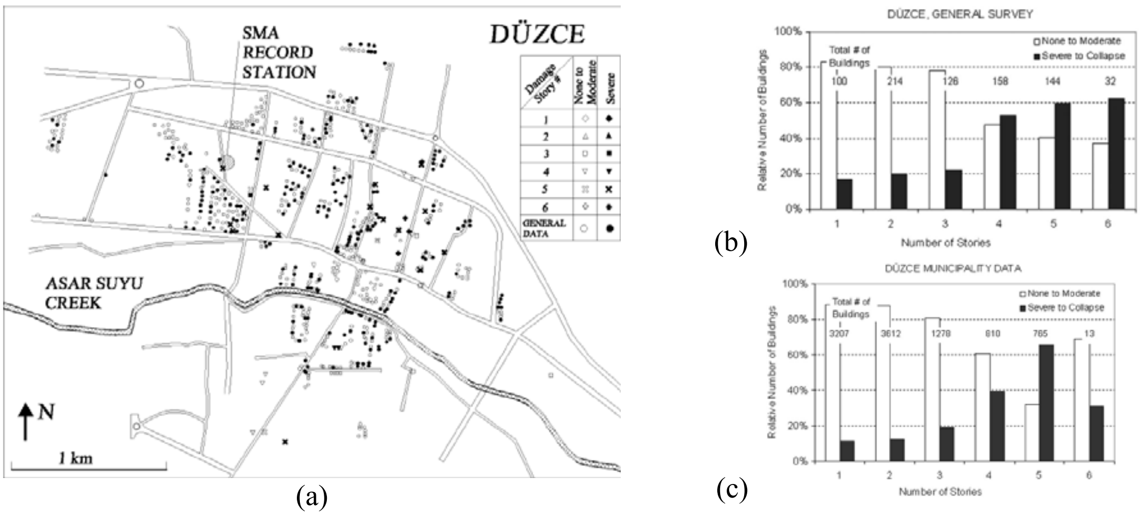
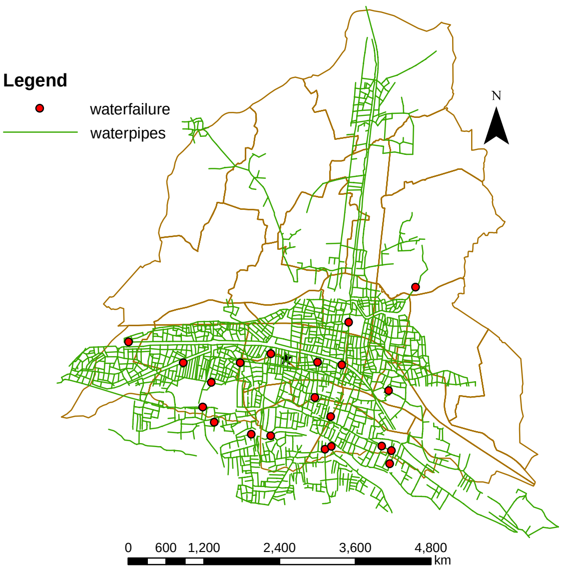


Figure 4. (a) Distribution of building damage in Duzce (b) Number of stories vs. damage (c) Number of stories vs. damage, reported by the municipality (Donmez and Pujol, 2005).

OBSERVED DAMAGES

An extensive survey study was carried out in Duzce to document the sustained damages of the reinforced concrete structures (Donmez and Pujol, 2005). Based on thse data, an interesting observation is the correlation between the spatial distribution of the damages observed in buildings and their location with respect to site conditions and the fault. The majority of the buildings that suffered great damage or collapsed are located at the centre of the city close to the river and closer to the fault trace. Soil formations are composed mainly of soft alluvial deposits (Figures 4a). However there is not a clear conclusion whether or not extensive damages are correlated to the soft soil conditions as we observe at least equal number of building with low to moderate damages. The quality and the performance of the building stock in Duzce has to played the critical role. Another interesting observation of the survey is the fact that taller buildings of 4-6 stories with To=0.3-0.4s according to Aydan et al., (2000), suffered relatively more damages. The fundamental period of these type of buildings is very close to the predominant period of the record in Metereological station (see Figure 2b). However based on the available records it is difficult to attribute the higher damages solely to a resonance effect, as actually the high spectral values are spreading in a wide range from 0.2s to 0.8s and the fundamental period of the site where the station is located is around 0.75s, as we will see later.



Duzce water network damage's database

ID	Diameter (mm)	Material
1	125	PVC
2	150	Asbestos
3	500	Steel
4	150	Asbestos
5	100	PVC
6	100	PVC
7	150	Asbestos
8	200	Asbestos
9	150	Asbestos
10	250	Asbestos
11	200	Asbestos
12	100	PVC
13	100	PVC
14	150	Asbestos
15	100	PVC
16	100	PVC
17	150	Asbestos
18	100	PVC
19	150	Asbestos
20	150	Asbestos
21	500	Asbestos

Figure 5. Water system damage in Duzce (Kocaeli & Duzce 1999 earthqks.) (Alexoudi, 2005).

The water system in Duzce was also severely damaged due the combined effects of Kocaeli (17/8/1999) and Duzce (12/11/1999) earthquakes. Tromans, (2004) developed a general database providing water pipe failures per district for three time periods; before Kocaeli earthquake, between Kocaeli and Duzce earthquake and after Duzce earthquake. In the present study another water system damage database is used, created by Alexoudi, (2005) (Figure 5), which provides a limited number of fully documented failures. As it can be observed, most failures are concentrated at the southern part of the city, around the river area, where -as already mentioned before- the soil conditions are dominantly soft and loose.

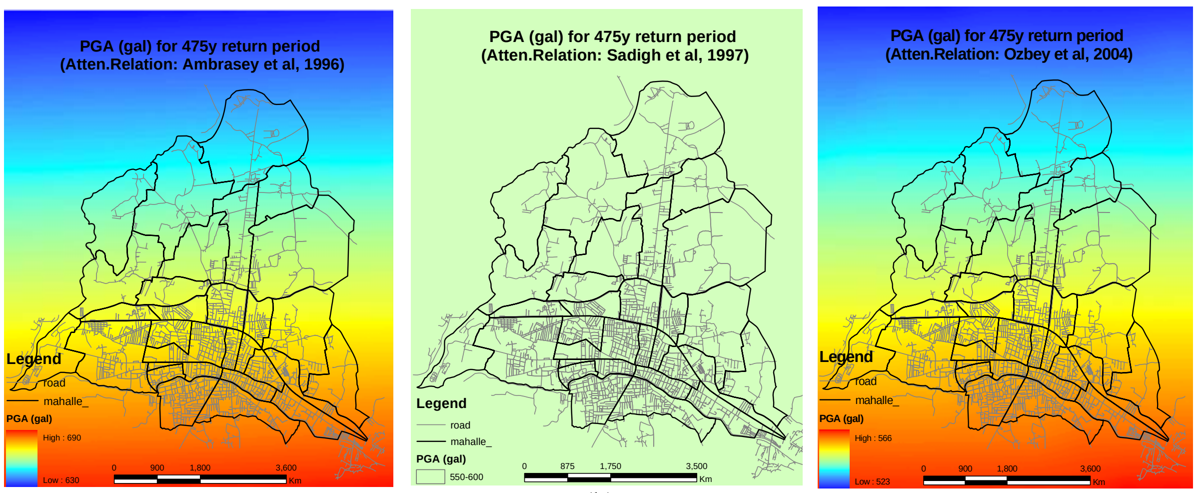
Finally, although no surface indication of liquefaction was reported in Düzce after the 12/11/1999 strong seismic event, in several buildings settlements were observed, a fact that may be attributed to partial liquefaction of some thin silty soil layers (Aydan, 2000). Considering the spatial distribution of structure and lifeline damages in Duzce the present study aims to investigate the role of site effects on damage distribution and magnitude. The work presented herein is part of he Pilot Microzonation Study performed by Pitilakis et al., (2006) after the November 12th, 1999 earthquake.

SEISMIC HAZARD ASSESSMENT OF DUZCE

Seismic hazard analysis of Duzce has been estimated applying a probabilistic approach, using code CRISIS 99 and considering the seismic zones affecting Duzce (Kayabali, 2002). The probabilistic seismic hazard analysis has been performed using three different attenuation relations proposed by Ambraseys, (1996), Sadigh et al., (1997) and Ozbey, (2004), estimating the distribution of PGA values in case of rock conditions for a mean return period of 475 years. The resulting PGA maps (Figure 6) have been validated with existing results from previous studies already performed in the area. PGA values for outcrop conditions according to Ambraseys, (1996) relation give higher values compared to Ozbey, (2004) and Sadigh et al., (1997) relations, as they are presented in Table 1. However, they could be used as the peak input motion values for the site response analysis. It is also estimated that the 475 year mean return period earthquake is similar to the November 1999 earthquake.

Table 1. Comparison between different relations (Probabilistic seismic hazard) – Rock site

	ROCK475
Ambraseys, (1996)	0.630-0.690 g
Sadigh et al., (1997)	0.550-0.600 g
Ozbey, (2004)	0.523-0.566 g



(a) (b) (c)

Figure 6. PGA (gals) values for Duzce - Probabilistic scenario for mean return period of 475 years. Attenuation relations (a) Ambraseys (1996), (b) Sadigh et al., (1997), (c) Ozbey (2004). Soil conditions: Rock.

AVAILABLE GEOPHYSICAL AND GEOTECHNICAL DATA

Duzce is situated in a tectonic basin filled over time with river and lake sediments. The plain (Figure 2a) is now consist of layers of clay, sand, and gravel. The basin sediments, which at the centre of the plain attain up to 250 m, are generally looser and soft when reaching the surface.

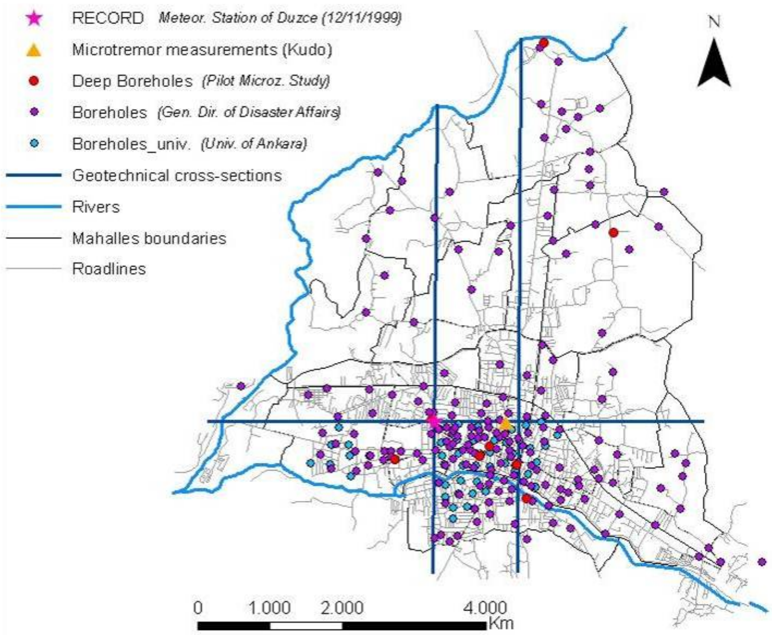


Figure 7. Available geophysical and geotechnical data in Duzce.

Following the 12/11/1999 earthquake, a number of geophysical surveys were conducted in Duzce. Kudo et al., (2000) carried out array measurements of microtremors aiming to determine the S-wave velocity structures at the DZC (Duzce) strong motion site (Figure 7); based on his results, the site is a sedimentary basin of thick and soft sediments at the surface (Vs~260 m/sec) and intermediate depths (Vs~460-510 m/sec), while the depth of the bedrock reaches -750m. Rosenblad et al., (2001) applied the spectral-analysis-of surface-waves (SASW) to characterize small-strain shear wave velocity profiles, using in situ seismic measurements. The SASW profile indicates that the velocity of the near-surface materials is less than 200 m/sec, but the velocity quickly increases to 400 m/sec at 15m depth. Kudo et al., (2000) profile shows a constant shear wave velocity of 260 m/sec extending from the surface to a depth of 35m. At depths below about 40m, both profiles show a shear wave velocity between 400 and 450 m/sec. Yamanaka et al., (2002) conducted single-point measurements and array measurements of microtremors at 25 sites in Duzce along a line from the south to the north. He proposed a 7-layer model according to which the shear-wave velocity is Vs=769 m/sec at a depth of approximately 100m. Finally, a site specific microtremor survey has been conducted by Tromans, (2004) applying the horizontal-to-vertical spectral ratio technique. According to this study the predominant HVSR frequency f_p varies between 0.5–1.5 Hz in a rather wide area which covers the southern part of the city of Duzce, while the value of f_p at the record site (Meteorological Station) was defined at f_p = 0.73 Hz.

In addition to the geophysical surveys, borehole investigations (10-15m and rarely 20m depth) have been performed at 185 proposed locations by the Ministry of Settlement and Public Works, General Directorate of Disaster Affairs, (2000) in the provincial centre of Duzce (Figure 7). Moreover, the Department of Geology and Geophysical Engineering of Ankara University (Kayabali et al., 2001) performed in the research area, approximately 60 drillings with a maximum depth of 15m each. Within the framework of the Pilot Microzonation Study of Duzce (Pitilakis et al., 2006) eight deep boreholes were drilled which are presented in Figure 7; in specific, six boreholes of 40m depth and two of 90m. Six boreholes (four of 40m and the two of 90m) were drilled at the southern part of the city, where as already mentioned before, the major damages were observed after November 12th, 1999 earthquake.

The two remaining boreholes of 40m depth were drilled at the northern part of the city. In every borehole, Standard Penetration Test (SPT) was applied at equal intervals of 1.5m and disturbed samples were collected in order to determine the soil properties. The dynamic properties of typical soils in Duzce have been determined trough resonant column tests perform by Assoc. Professor Th.Tika in Aristotle University (Pitilakis et al 2006).

SYNTHESIS OF GEOPHYSICAL AND GEOTECHNICAL DATA

Based on all the available geological, geotechnical and geophysical data and considering especially on the deep boreholes drilled in Duzce and the results of the dynamic laboratory tests, it was possible to estimate the soil stratigraphy of the area by producing 2D geotechnical cross-sections along Duzce (Figure 7). Representative 2D geotechnical cross-sections, along the NS and EW direction, are illustrated in Figure 8. Results from Kudo et al., (2000) and Rosenblad et al., (2001), as well as results from the microtremor measurements campaign conducted by Yamanaka et al., (2002) and Tromans, (2004) were also taken into account for the construction of the 2D geotechnical cross-sections (Figure 8). According to geological and geotechnical evidence and relative geophysical information (Kudo et al., 2000) the rock basement should be very deep (a few hundred meters), while Aydan et al., (2000) states that the seismic bedrock's depth varies between 50m to 250m. Yamanaka et al., (2002) have come to the same conclusion, since according to the assumed 7-layer model which he is proposing, the seismic bedrock is defined around 200-250m depth at the centre of Duzce basin, where the shear wave velocity values are estimated around 1000 m/sec.

In the frame of the Pilot Microzonation Study, the compilation of a number of aftershocks at the record site (Meteorological Station of Duzce) and the estimation of the HV spectral ratio has been conducted in order to define the outcropping bedrock's depth, the results of which are analytically presented in Figure 9b. As a result of the HV spectral ratio computation, the predominant HVSR frequency was estimated at the value of f_o = 0.75 Hz, and it was possible to estimate the depth of the "seismic bedrock" which should be approximately at -120m. Taking under consideration that the estimated value of the predominant frequency f_o is in full agreement with the f_p value estimated by Tromans, (2004) who performed array measurements of microtremors in the field and also validating this results with data from topographic maps of the area as well as with published reports [Kudo et al., (2000), Rosenblad et al., (2001) and Yamanaka et al., (2002)], we have finally accepted that the "seismic bedrock" for the site effects analyses, (Vs≥750m/sec), lies in this depth of around 120m (Figure 9a).

From the 2D geotechnical cross-sections (Figure 8) it is evident that at the southern part of Duzce the shear wave velocity at the surface (10m) varies between 250-300 m/sec and the soil configurations

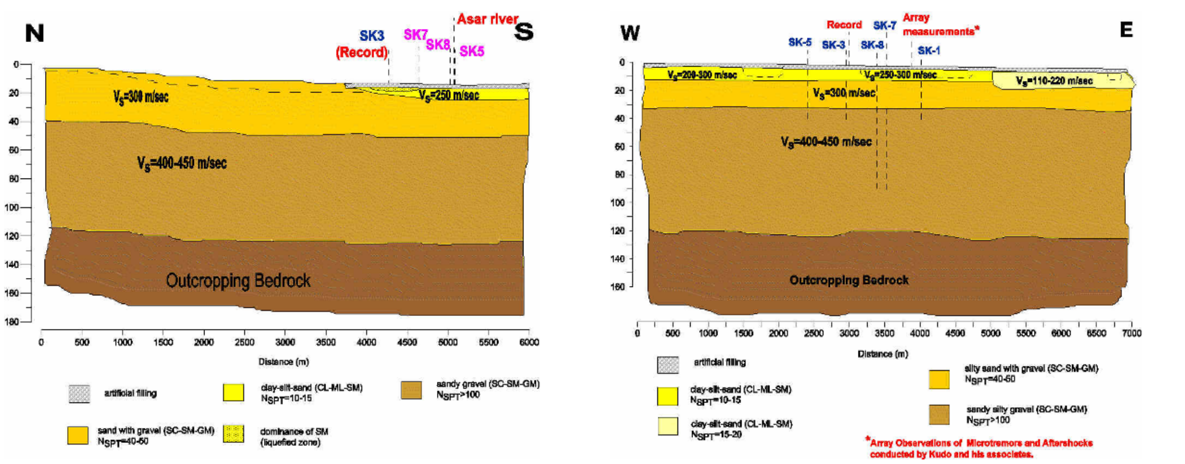


Figure 8. NS-left and WE 2D geotechnical cross-sections along Duzce.

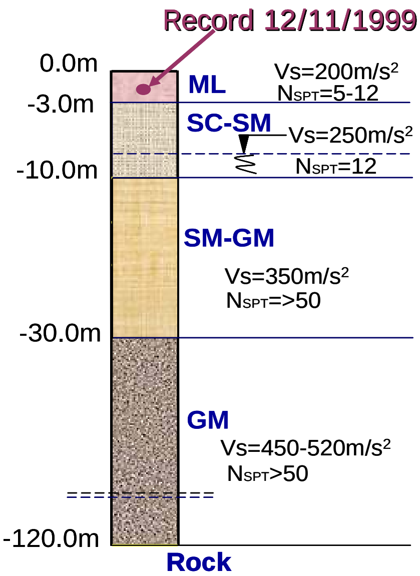


Figure 9a. 1D soil profile at the Meteorological Station of Duzce.

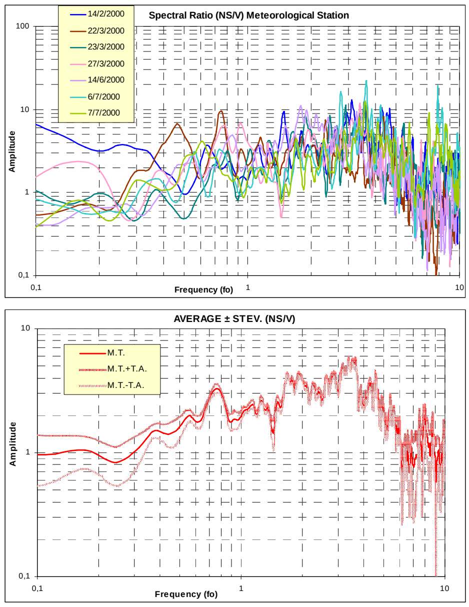


Figure 9b. H/V spectral ratio of the aftershocks recorded at the Meteorological Station of Duzce.

consist from soft alluvial clay, loose sand and gravel river sediments. At depths between 10-30m, the shear wave velocity values increase up to 300 m/sec, and the soils are composed of alterations of silt and clay with generally soft–medium consistency and loose–moderately compact fine-grained sand. Finally, at the depth between 30-120m, the shear wave velocity values (Vs) have been estimated around 400-450 m/sec, and the soil gradually change into relatively moderately stiff-stiff clay or silt and moderately compact to very compact sand, clay and gravel. Based on all the above data and information we estimated 1D soil profiles, (Figure 9a), to perform a set of 1D equivalent linear analyses.

SITE EFFECT ANALYSES

A series of 1D EQL analysis has been performed in Duzce on thirty (30) typical soil profiles (Figure 10). 1D analysis must be quite suitable for the case of Duzce as the plain is very large and there are not apparently strong lateral discontinuities except at the souther part at the fault area. The dynamic soil properties and the soil profiles were derived from the synthesis of previously mentionned surveys and studies (Pitilakis et al., 2006). Considering the fact that there was no record available of the 12-11-1999 Duzce earthquake in “outcropping ” conditions in or near Duzce, in order to be used as the input motion, the selection of the appropriate input motion was a major problem. This problem was encountered by proceeding at first in the deconvolution of the available record at the Meteorological Station of Duzce in order to estimate the 12-11-1999 record at the “seismic bedrock”. Except the deconvoluted time history of the Duzce earthquake record, four (4) other seismic motions recorded in “outcropping ” conditions were also selected, among them the Gebze record of the 17-8-1999 Kocaeli earthquake, two records from the 1994 Northridge earthquake (Pacoima Dam and Wonderland records) and the Sturno record of the 1980 Campano Lucano earthquake in Italy. The specific selection of these five input motions was based on the processing and analysis of all aftershocks recorded at the Meteorological Station, and in other sites around Duzce (Pitilakis et al., 2006).

The computed normalized acceleration response spectra in each site were compared to the design response spectra acceleration of the Turkish Seismic Code and EC8. A set of thematic maps were produced illustrating the spatial variation of peak ground acceleration PGA (g), (Figure 11), and peak spectral acceleration PSA (g) for various period values (To=0,3 sec and To=0,6 sec), (Figure 12). These maps led to the seismic zonation for the city of Duzce, and aim to investigate whether the parts of the city in which peak ground motion values were observed, suffered as well extensive damage.

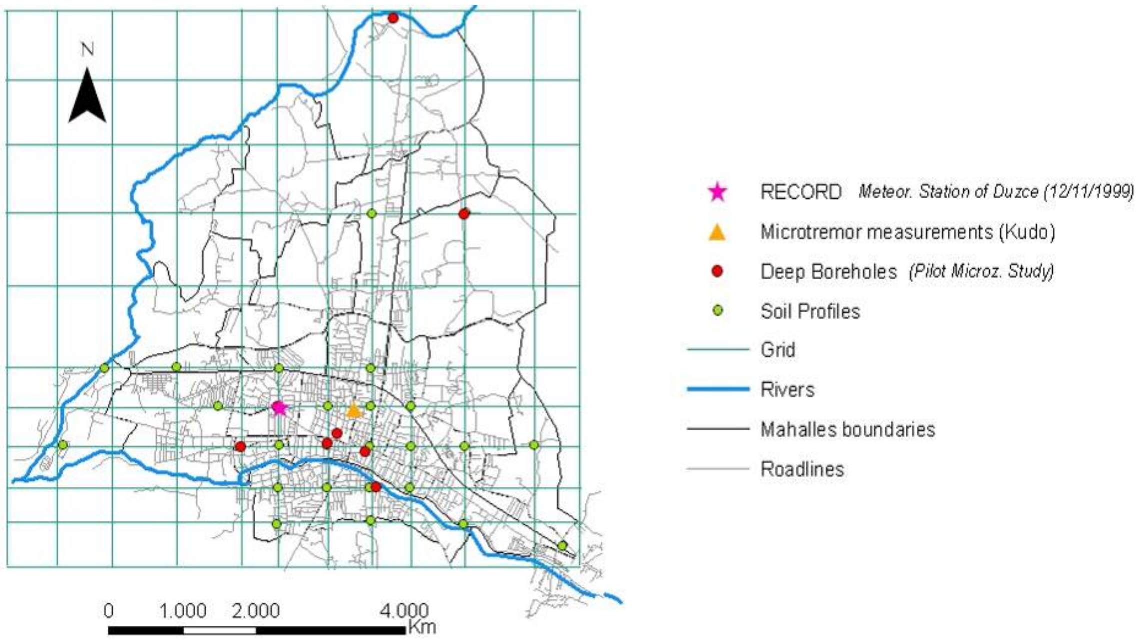


Figure 10. Location of 1D soil profiles sites in Duzce.

As it is observed in Figure 11a, the computed PGA values vary between 0.37–0.50g when 12-11-1999 Duzce deconvoluted time history is used as input motion, and between 0.39-0.56g, when the average values of the five input motions used are depicted (Figure 11b). The maximum PGA values are observed at the south-west and south-east part of the city, mainly around and close the Metereological Station (DZC station) and around the river. Comparing these results with the effective ground acceleration coefficient (A_o=0.40g) that applies for Duzce according to the Turkish Seismic Code, we conclude that they are generally in good agreement, although both recorded and computed PGA values reach 0.50g at the southern parts of the city where the soft river sediments are dominant. The average value for the whole city of Duzce is effectively of the order of 0.40g. Some spots of higher values are observed at the rivers zone where actually more damages were observed. Considering now the computed PSA values they vary between 0.75g and 1.5g for To=0,3 sec (Figure 12a) and between 0.85g and 1.3g for To=0,6 sec (Figure 12b). The highest spectral values at these two characteristic periods are concentrated at the area of major damages and certainly this is a persuasive observation of the role of local soil conditions on the magnitude and the spatial distribution of damages.

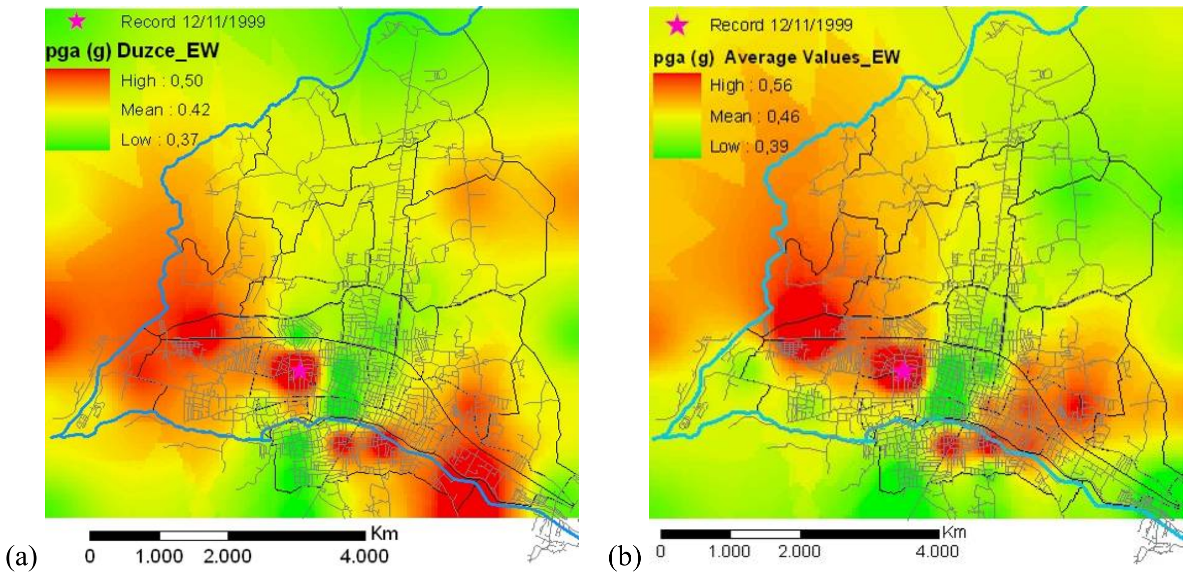
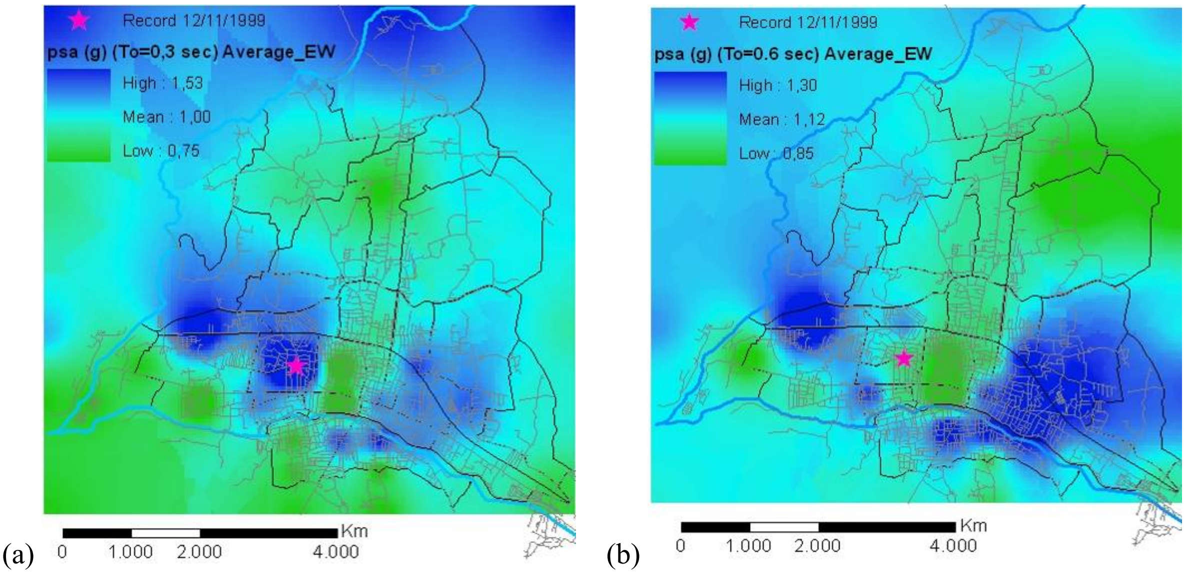


Figure 11. Spatial distribution of the computed PGA (g) values, EW component
(α) Deconvoluted 12/11/1999 Duzce record (b) Average values of the 5 input motions used.



(a) (b)

Figure 12. Spatial distribution of the average computed PSA (g) values (EW component) (a) To=0,3 sec (b) To=0,6 sec.

VULNERABILITY ASSESSMENT OF THE WATER SYSTEM IN DUZCE

The aim of a typical vulnerability analysis of a water system is to assess its seismic performance, to identify and localize the weak links-pipes and to make a pre-assessment of the serviceability reduction in case of a strong earthquake, like the 12/11/1999 that struck the city of Duzce. A detailed inventory of the network is the basic parameter defining the accuracy of the assessment and it has to be admitted that this is a very difficult task almost in all over the world. However in Duzce we had a reasonably good inventory and the whole network has been made in a GIS format. The vulnerability is then calculated using appropriate relations that correlate the seismic load with the repair rate (RR/km). Fragility curves describe the probability of reaching or exceeding each damage state given the level of ground motion or ground permanent displacements caused for example from liquefaction.

A set of well documented water system failures in Duzce caused by the 12-11-1999 M7.2 earthquake have already been presented in Figure 5 (Alexoudi, 2005). In Figure 13a, the above set of failures are plotted with the average reported damages per district (mahalle). This set of data is one of the rare cases of reported damages in water systems in Europe and Turkey. In the following paragraph we examine if the available vulnerability relationships and the associated damage states could reproduce accurately the reported damages in Duzce. The necessary spatial distribution of PGV for the M7.2 earthquake in Duzce has been estimated from the pilot microzonation study using as outcrop input motion the deconvolution of the recorded ground motion at the Metereological Station. After proper validation it was decided to apply in this study the fragility function of O'Rourke & Ayala (1993) proposed also in HAZUS 2004. This is an empirical relationship based on data collected from actual pipeline damages observed in four USA and two Mexican earthquakes. Two damage states for pipelines were considered, leaks and breaks. The Repair Rate according to O'Rourke & Ayala (1993) for wave propagation is given as follows:

$$\text{Repair Rate [Repairs/Km]} \cong K1*0.0001*(PGV)^{2.25} \qquad (1)$$

- PGV (cm/sec) peak ground velocity values
- K1: coefficient depending on the type of pipeline (brittle, ductile)

For ductile pipelines (steel, ductile iron and PVC), K1=0.3, while for brittle pipeline (asbestos cement, concrete and cast iron pipes) K1=1.0. Welded steel pipes with arc-welded joints are classified as ductile, while welded steel pipes with gas-welded joints and pre-1935 steel pipes are classified as brittle.

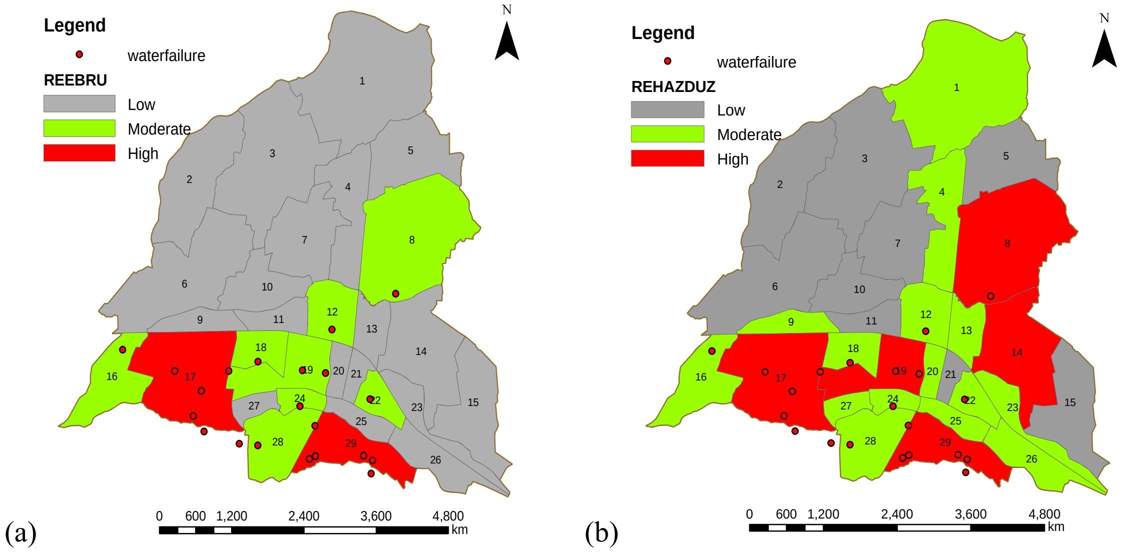


Figure 13. Mahalle with low (grey), moderate (green) and high (red) damages as result of Duzce earthquake (a) Marmara damage database, (2005), (b) Fragility curve: O'Rourke & Ayala, (1993) *(With red color are illustrated the documented specific failures/ mahalle).*

In Figure 13b the computed damage states (low, moderate and major damages) are illustrated per district, applying as already mentioned before the O'Rourke & Ayala (1993) fragility relation for pipeline failures.

In Figure 14a the number of water pipe damages per district are presented, while in Figure 14b the computed damages in the water system of Duzce are depicted. In general, it is observed that O'Rourke & Ayala (1993) relation presents a good correlation of damages both in regards of the total number of damages and their spatial distribution, as it is illustrated in Figure 13. Most damages are observed at the southern district and the western part of Duzce which is in good agreement with the actually reported damages. Soil conditions at these area are rather soft and loose which produced higher peak ground velocities and consequently damages as well.

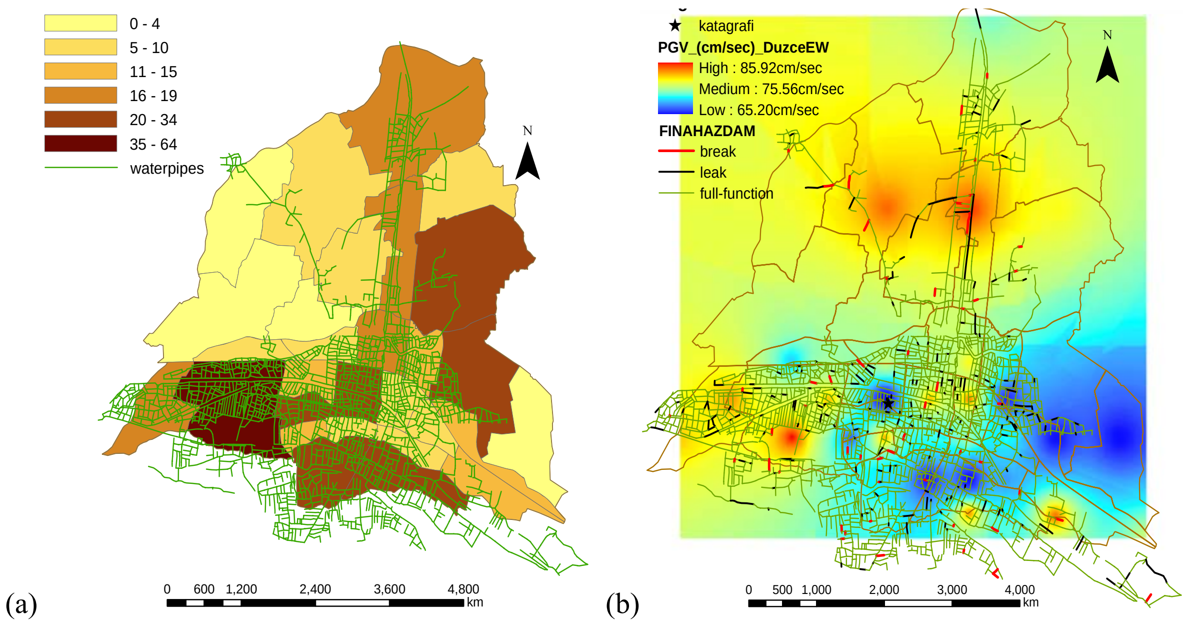


Figure 14 Vulnerability assessment of water system in Duzce after 12-11-1999 earthquake (a) Average number of damages per district (mahalle), O'Rourke & Ayala (1993), (b) Specific spatial distribution of damages using the O'Rourke & Ayala 1993 relation and the results of the pilot microzonation study in terms of ground velocity.

CONCLUSIONS

Duzce, located in north-west Turkey, suffered great damage during the 12/11/1999 strong earthquake (Mw=7.2) that hit the area. The study presents the main results of the pilot microzonation study performed in Duzce after the earthquake and investigates the role of soil conditions to the spatial distribution and the intensity of reported damages in buildings and the water system. The correlation of the damage intensity and spatial distribution of damages for the residential buildings and the water system with the recorded ground motion and the computed spatial distribution of ground motion is in general very good. This fact is encouraging concerning the reliability of methodology applied and the fragility relationship used.

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