SEISMIC VULNERABILITY ANALYSIS OF WASTE-WATER SYSTEM. METHODOLOGY AND APPLICATION FOR DÜZCE AND KOCAELI EARTHQUAKES BASED ON THE MICROZONATION STUDY OF DÜZCE

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ABSTRACT :

Two destructive earthquakes (Kocaeli, Mw=7.4, 17-08-1999 & Düzce, Mw=7.2, 12-11-1999) occurred in Turkey in 1999 and provoked extensive damages in water and waste-water system of Düzce. The scope of this paper is firstly to apply a seismic risk methodology for the waste-water system of Düzce using the loads derived from a series of site effect analyses that were performed using Kocaeli & Düzce main-shocks as input motions and secondly validate the fragility curve used in HAZUS methodology (O'Rourke & Ayala, 1993) using the obtained results for waste-water pipe vulnerability. The comparison between the estimated damages of waste-water pipes with real recorded data of waterpipe was based on the inventory database that was created in GIS format with the help of Düzce Municipality.

KEYWORDS: Waste-Water system, seismic vulnerability analysis, fragility curves, Düzce & Kocaeli earthquakes, G.I.S

1. INTRODUCTION

Düzce (Turkey) was struck by two strong earthquakes (Kocaeli, Mw=7.4, 17-08-1999 & Düzce, Mw=7.2, 12-11-1999), which were both associated with the North Anatolian fault. As a result, extensive damages were observed in lifelines (water and waste-water system) due to ground shaking and to their individual characteristics.

The aim of this paper is twofold: a) to apply a seismic risk methodology to assess the vulnerability of waste- water systems and b) to compare the estimated damages with the reported ones, in order to validate the existing fragility curves. Although some inventory data for waste-water system of Düzce were missing and the location of the damages was never actually pin-pointed, a reliable assumption of the possible sites of waste-water damages was made using the experience of Düzce Waste-Water Company and the recorded damages of water system. The comparative study presented herein is one of the few cases in Mediterranean region, where there is an important lack of data regarding lifeline damages during earthquakes.

At first, a detailed inventory of the waste-water system of Düzce was digitized in GIS environment. Afterwards, based on all the available geotechnical data and new geophysical measurements, a set of 1D EQL analysis in thirty (30) typical soil profiles along the city were performed using the deconvoluted records of Kocaeli & Düzce main-shocks. As a result, the magnitude and the spatial distribution of strong ground motion parameters (PGA and PGV values) were computed. Finally, selected fragility curves such as O'Rourke & Ayala (1993), were used for the estimation of the vulnerability of the waste-water system. Comparisons between the spatial distributions of estimated and recorded damages and of absolute numbers are presented in GIS maps and in Tables.

2. METHODOLOGY

The seismic risk assessment methodology used in this study includes the estimation of the: a) inventory of the system, b) typology, c) seismic loads, d) selection of the appropriate fragility curve and e) calculation of the damages in absolute numbers and in spatial distribution. Initially, a detailed inventory of the network is created to comprise the distinctive features of the components (e.g. geometry, material, age, etc) that are necessary for the estimation of their specific typology. It is a time and cost consuming process with large uncertainties. The spatial distribution of ground motion that serves as seismic load for lifeline system takes into account site-effects, geological conditions, basin edge and topographic effects (Pitilakis K, 2003 and Pitilakis et al 2004). The ground shaking can be described in terms of peak ground acceleration (PGA), peak ground velocity (PGV) or seismic intensity (MMI, MSK etc), as derived either by site-specific ground motion analysis or by seismic hazard study. Especially, for pipelines the seismic loading for wave propagation is described in terms of peak ground velocity (PGV) because it is directly proportional to the ground strain. A very challenging task is the selection of the appropriate fragility relationship, as it depends upon the construction technique, the type of the system, the available data from past earthquakes, the knowledge of the seismic input parameters etc. The fragility curve used in this paper to estimate waste-water pipelines vulnerability as result of wave propagation is O'Rourke & Ayala (1993)- Eq. 1. This relation is empirical and it is used in HAZUS 2004 (NIBS, 2004) for the estimation of pipes damages for the case of wave propagation. It is based on data collected from actual pipeline damages observed from USA and Mexican earthquakes. The predicted damages are given in terms of Repair Rate/ km and are correlated with the expected strong motion intensity parameters, PGV (cm/sec) as follows:

$$R.R\,/Km \cong K1*0.0001*(PGV)^{2.25} \qquad (2.1)$$

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

Two damage states for pipelines were considered, leak and break. In case of wave propagation, is assumed that 80% of damages are leaks and the rest 20% are breaks. Consequently, the vulnerability of the system is stemmed from the combination of the seismic ground motion and the fragility curves. The evaluation of network damages is defined in terms of pipe failures.

In the second part of the paper, a validation of the estimated damages of waste-water system for Kocaeli and Düzce earthquake is provided after the comparison with the damage data of water system failures as result of the two earthquakes per mahalla.

3. APPLICATION IN DÜZCE

3.1 Geotechnical-Geophysical Data

Düzce is situated in a tectonic basin filled over time with river and lake sediments. The plain consists 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. In order to estimate the soil stratigraphy of the area (Manou et al., 2007), careful consideration of the results of several geophysical, geotechnical and microtremors surveys (General Directorate of Disaster Affairs, 2000; Kudo et al., 2000; Kayabali et al., 2001; Rosenblad et al., 2001; Yamanaka et al., 2002; Tromans I., 2004) conducted after Düzce earthquake were taken into account (Figure 1a).

Within the framework of the Pilot Microzonation Study of Düzce, (Pitilakis et al., 2006), eight deep boreholes were drilled; in specific, six boreholes of 40m depth and two of 90m (Figure 1b). In every borehole, Standard Penetration Test (SPT) was applied in order to determine the dynamic and mechanical properties of typical soils. Moreover, 7 strong motion stations DNET array were installed along the city (Figure 1b), in order to be used for the processing of earthquakes for future studies. Afterwards, a full Microzonation Study of Düzce was conducted with a number of new geophysical and geotechnical measurements. More specific, noise measurements (by applying the HVSR method) was applied in thirty one (31) single stations in order to empirically estimate the resonant frequency (fres) and the amplification factor (Amax), and fifteen array microtremor measurements (by applying the SPAC method) to estimate the shear-wave velocity values (Vs) and the thickness of the soil formations (Figure 1b – data acquired in collaboration with Dr. M. Manakou).

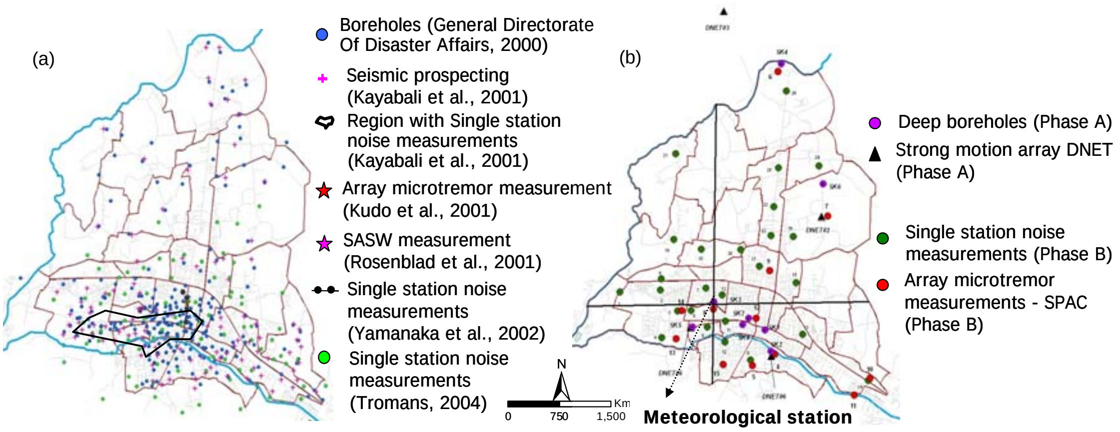


Figure 1 (a) Available and (b) new geophysical and geotechnical data
(in collaboration with Dr. M. Manakou).

Based on all the available geological and geotechnical data and considering especially the estimated detailed Vs profiles from the in situ geophysical survey performed in Düzce (data acquired in collaboration with Dr M. Manakou), 2D geotechnical cross-sections were composed, showing that the alluvial deposits have variable thickness of a few meters (30-50m) at the northern part of the basin, while they increase progressively at the southern part (200-250m) (Figure 2). In Figure 3b, the detailed Vs (m/sec) profile at the Meteorological Station (DZC station) of Düzce is presented, where the seismic bedrock is defined at 240m depth.

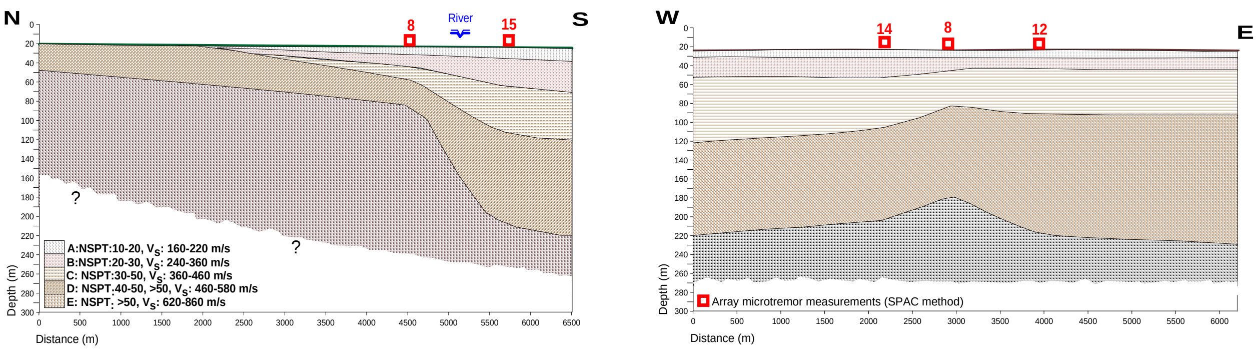


Figure 2 2D geotechnical cross-section at the NS and WE direction
(in collaboration with Dr. M. Manakou).

3.2 Site effect analyses

A series of 1D equivalent linear analysis has been performed in Düzce by applying the code EERA (Bardet et al., 2000) on thirty (30) typical soil profiles (Figure 3a), produced from the 2D geotechnical cross-sections. The dynamic soil properties and the Vs (m/sec) profiles were derived from the synthesis of previously mentioned surveys and studies. Considering the fact that there was no record available of the 17-08-1999 Kocaeli and 12-11-1999 Düzce earthquakes in "outcropping" rock conditions in or near Düzce, we proceeded in the deconvolution of the available records at the Meteorological Station of Düzce in order to estimate the records at the "seismic bedrock" (Figures 3b & 3c).

Site specific response analysis led to the estimation of the ground motion characteristics using as input motions the bedrock obtained from the deconvoluted time histories of Kocaeli (17-8-99) record (PGA = 0.28g) and Düzce (12-11-99) record (PGA=0.41g), at the Meteorological Station of Düzce (Figure 3c). As a result of the analyses, the peak ground acceleration at the surface ($PGA_{Kocaeli}$ = 02.9- 0.49g, $PGA_{Düzce}$ = 0.42-0.69g) and the spatial distribution of velocity values in depth of -2m (Figure 4), depth of waste-water pipes, were computed for the Kocaeli and Düzce records, respectively. As it can be noticed, the larger PGV values were observed in southern part of the city for both earthquakes. Moreover, their spatial distribution of the strong ground motion is similar.

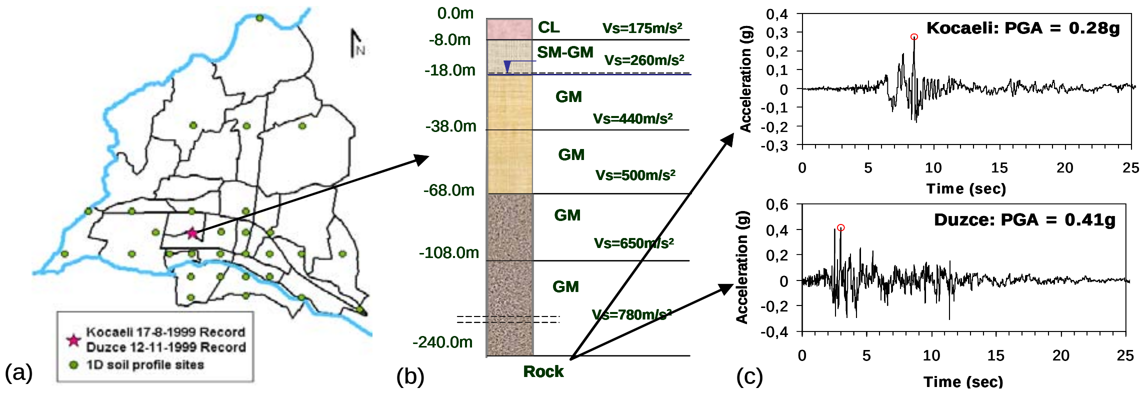


Figure 3 (a) Location of 1D site response analyses, (b) Vs (m/sec) profile at the Meteorological Station and (c) deconvoluted time histories of Kocaeli and Düzce earthquakes, used as input motions for the 1D EQL analyses

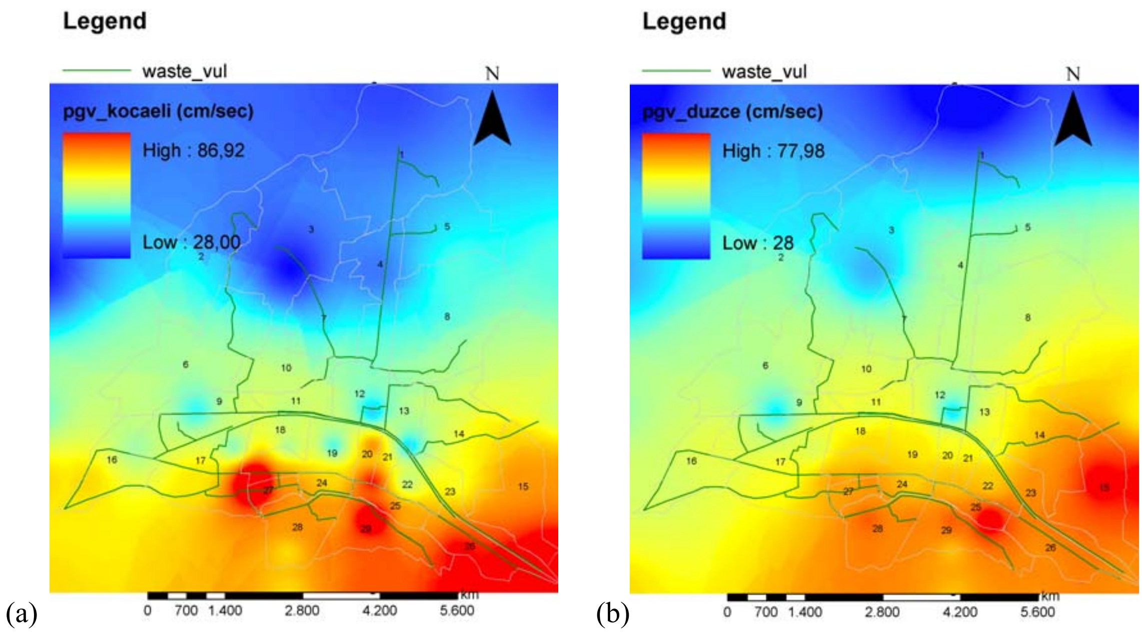


Figure 4 Spatial distribution of PGV values (cm/sec) (a) for the deconvoluted time history of Kocaeli record and (b) the deconvoluted time history of Düzce record, at the Meteorological Station of Düzce.

3.3 Inventory – Typology of Waste-water system

The waste-water supply system in Düzce is a gravity network that dates back to the 1940's although several parts of the system are dating back to the early 1900's. The pre-existing network is thought to be about 300 km in length, although no maps exist to confirm this. Both old and new network were in use at the time of Kocaeli and Düzce earthquakes. The parts of the network that was digitized consist of 50,60km pipes-conduits with circular shape while the rest (3.44km) have different shapes (rectangular, oval, and orthogonal. The material of waste-water pipes is concrete and the distribution of the diameters is illustrated in Figure 5. Information about the dimension, the shapes and the material for the rest network is not available. Taking into account the 93% of the material type of waste-water pipes, whole network can be characterized as a brittle network (Alexoudi, M, 2005).

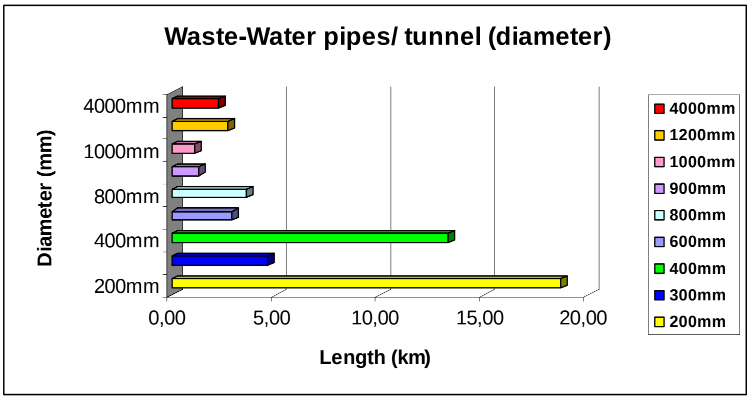


Figure 5 Digitized Waste- Water network (left), distribution of waste-water pipe/ conduits diameters (up)

3.4 Vulnerability assessment

Applying, Eqn 2.1 we estimate a total number of 52 damages (10 breaks, 42 leaks) and 44 damages (9 breaks, 35 leaks) as result of ground shaking for Düzce and Kocaeli earthquake accordingly (Figure 6).

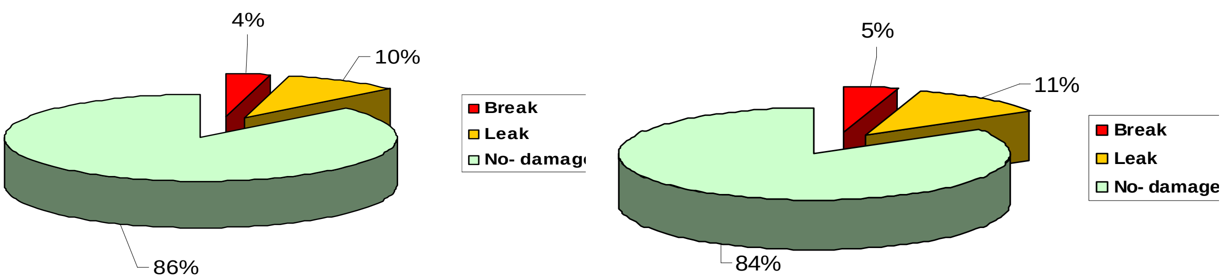


Figure 6 Estimated damages of waste-water network as percentage of the total length of the network for Kocaeli (left) and Düzce (right) earthquake

The spatial distribution of the damages of waste-water network as result of Düzce and Kocaeli earthquake is illustrated in Figure 7.

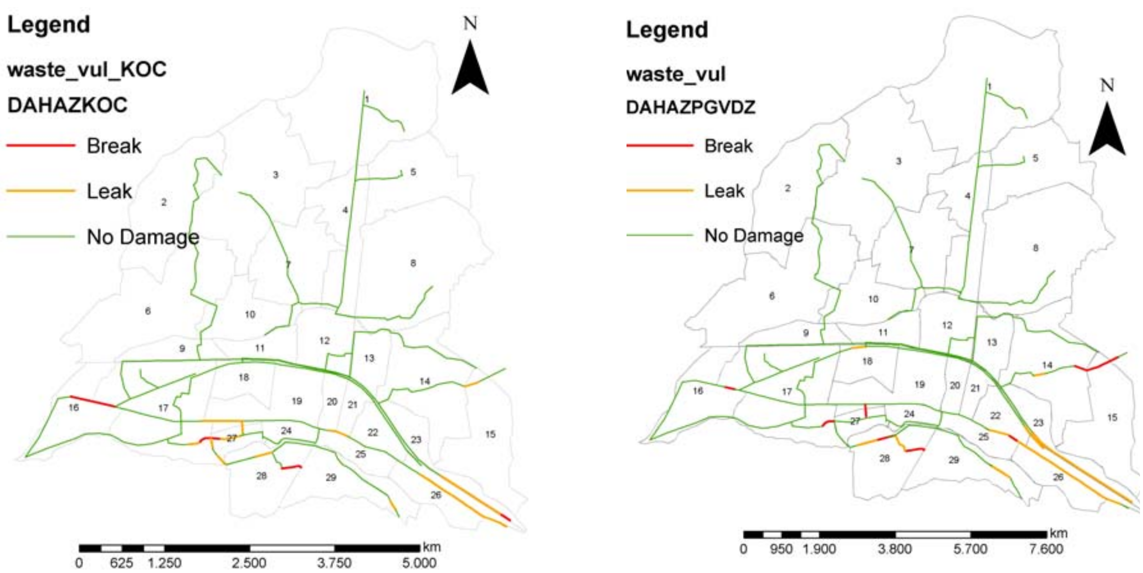
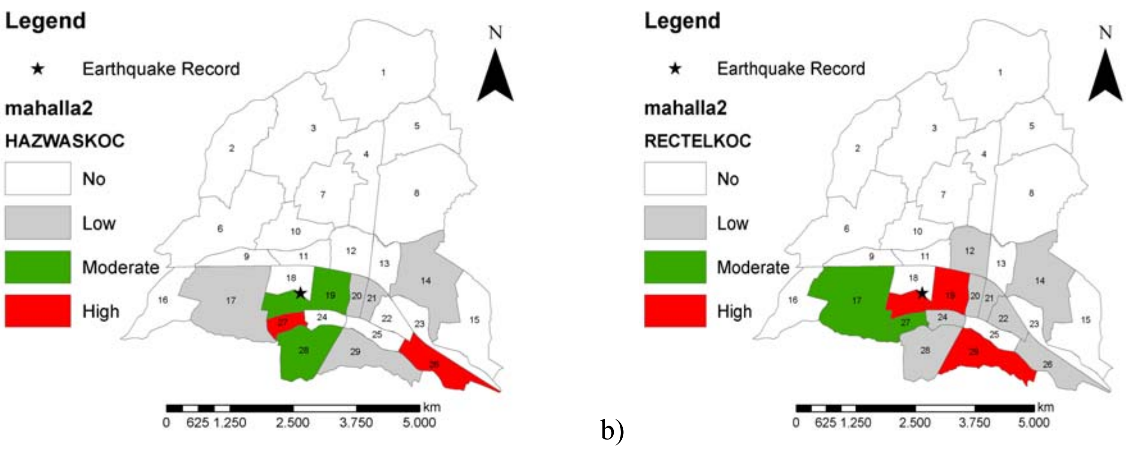


Figure 7 Spatial distribution waste-water pipe damages for Kocaeli (left) and Düzce (right) earthquake

3.4 Validation of the estimated damages

Tromas J (2004) database for water pipes was used for the validation of the estimated damages of waste-water system resulted from the conducted vulnerability assessment of Kocaeli and Düzce earthquakes. It is assumed that the failures of water system of Düzce are quite similar to the damages of waste-water system, an estimation made by the Waste - Water Company of Düzce, although, some individual characteristics of the two networks can enlarge the different seismic response of the two network. More specific, the material, the oldness of the network and the construction practice can alter greatly the response of the pipe.

A comparison between the recorded water pipe damages from Tromas J (2004) database and the estimated damages of waste-water system as result of Kocaeli earthquake are illustrated in Figure 8a and 8b. It can be noticed that the expected damages from the two earthquakes are located in the southern part of the city in almost the same mahallas that important damages in potable water system were observed and large PGV values were calculated. For the Düzce earthquake the corresponding Figures 8c and 8d have some minor differences, mainly due to the limited time for recovery between the two earthquakes. Moreover, the damages in waste-water system are very hard to recognize as they don't connect with the reduction of pressure or even flow and there were no available records before and after the earthquakes.



a) b)

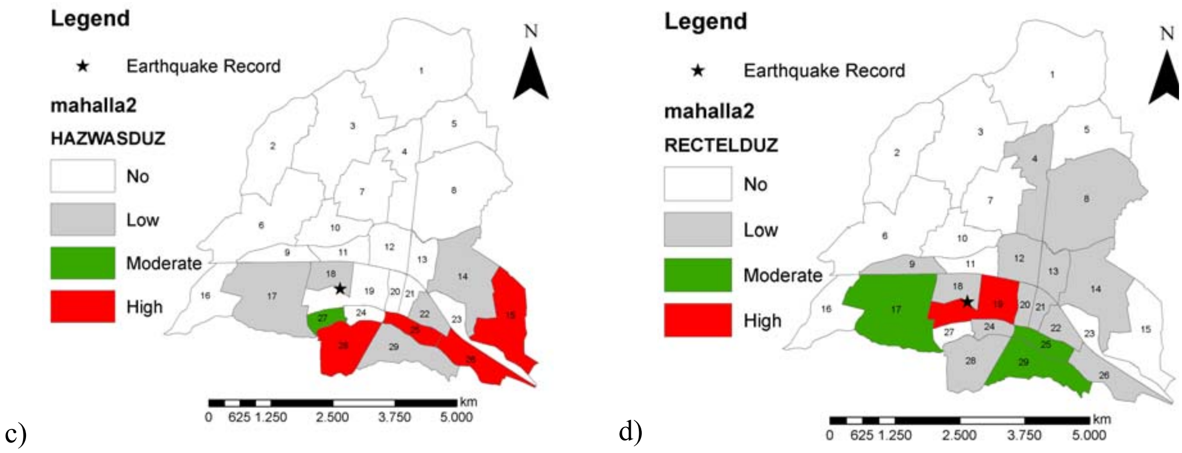


Figure 8 Estimated waste-waterpipe damages per mahalla for Kocaeli earthquake (a), after Düzce earthquake (c) and Recorded waterpipe damages per mahalla after Kocaeli earthquake (b)

4. CONCLUSIONS

The scope of this paper is to illustrate the basic features of the seismic risk assessment methodology for waste-water networks, using as a case study Düzce's waste-water system. Moreover, the seismic scenarios used was the real records of Düzce and Kocaeli earthquake in order to validate the commonly used fragility curve (O'Rourke & Ayala, 1993) with the real recorded damages for water system. The methodology can be applied to develop a coherent mitigation strategy and preparedness policies.

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