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DAMAGE TO WATER AND SEWAGE PIPELINES IN ADAPAZARI DURING 1999 KOCAELI, TURKEY EARTHQUAKE

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ABSTRACT

Vulnerability of pipeline systems were studied for the city of Adapazari based on available information on the performance of the water and sewage pipeline systems during 1999 Kocaeli, Turkey Earthquake. The water supply pipeline system in Adapazari experienced extensive damage. The main damage was observed in transmission and distribution systems primarily due to brittle asbestos cement (AC) pipes used in the system combined with the fracturing effect of ground deformations associated with liquefaction and softening of alluvial sediments. Recently, pipeline damage inventory was compiled based on repair reports and interviews with water works technicians. Since the entire system was replaced after the earthquake only limited number of repair reports was available. The geotechnical and geological site conditions were evaluated based on available borings, and in-situ tests. Vulnerability of water pipelines due to ground shaking and liquefaction was evaluated separately. Variation of earthquake characteristics on the ground surface was estimated based on 1D site response analyses using the outcrop motion recorded in Adapazari during the 1999 Earthquake as input motion. Liquefaction susceptibility was estimated based on a simplified liquefaction analysis and SPT blow counts obtained during the site investigations. Distribution of damage predicted by means of empirical vulnerability functions proposed in literature was compared to the pipeline damages observed during the 1999 Earthquake.

INTRODUCTION

Recent earthquakes have demonstrated that the failure of lifeline systems can have significant adverse impact on all post earthquake activities by prolonging the recovery and thus can cause economic disruption in urban environments. Therefore, reliable assessments of seismic vulnerability of these systems are essential for seismic risk mitigation and disaster preparedness in urban areas. Several methods have been developed over the past years for predicting the potential damage to lifeline systems during earthquakes. The accuracy of these methods needs to be continuously being improved based on the data compiled from recent earthquakes.

In this study, vulnerability of buried water and sewage pipelines in the city of Adapazari during 1999 Kocaeli Earthquake (Mw=7.4) was investigated in an attempt to provide a comparison of the observed damage with the predicted using available empirical methods proposed in the literature based on peak ground velocity (PGV) and permanent ground displacements (PDA).

Even though there were no extensive damage reports, efforts were made to compile what is available supplemented by interviews with technicians who worked in Adapazari during that period.

EARTHQUAKE DAMAGE TO BURIED PIPELINES

During the 1999 Kocaeli Earthquake, water supply system in Adapazari experienced extensive damage. The main damage was observed in the transmission and distribution systems mostly due to the effects of liquefaction induced ground deformations and softening of alluvial sediments on the brittle asbestos cement (AC) pipes. Damage to the steel transmission pipelines was only reported in areas of surface faulting. In contrast to the wide spread damage in pipeline network, the water treatment and storage facilities at Adapazari sustained only minor damage that was quickly repaired. The treatment plant and underground concrete reservoirs were located on stiff soil deposits underlain by bedrock at shallow depths.

A map of Adapazari illustrating the main water and sewage arteries of the pipeline systems in the city is shown in Fig. 1. Unfortunately it was not possible to locate detailed maps for the water and sewage pipeline systems with all the distribution lines. The system was mainly composed of 350mm and 600mm diameter asbestos cement pipelines. It was reported that 70% of these pipelines were damaged during the 1999 Kocaeli Earthquake, with some leakage detected in the remaining 30%. Most of the damage in AC pipelines was reported to be at the joints where rotation and axial slippage occurred [O'Rourke et al., 2000].

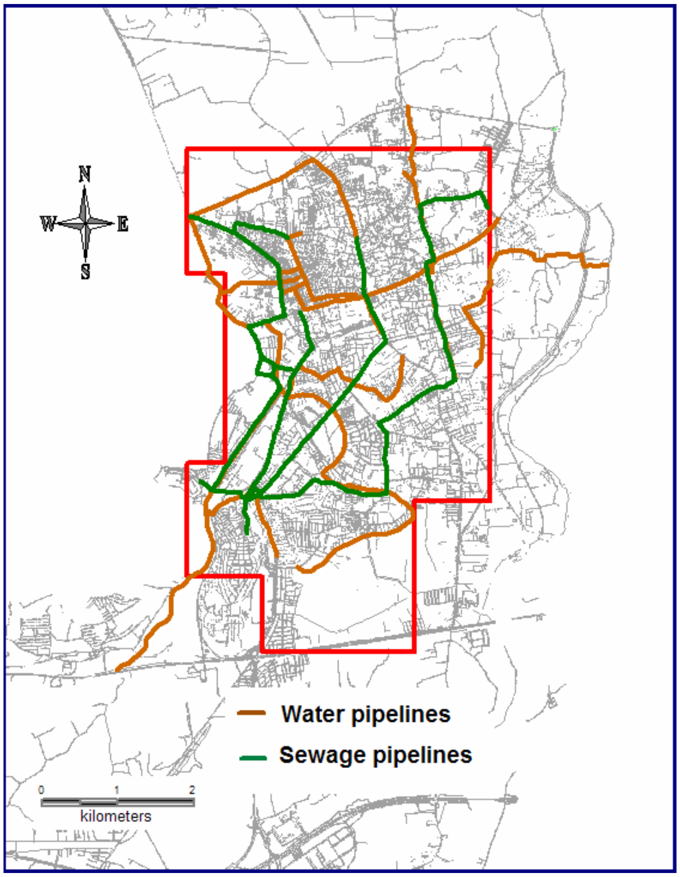

Fig. 1. *Water and sewage pipeline system in Adapazari*

A study on damage distribution in Adapazari water pipeline system after 1999 Kocaeli Earthquake has been carried on recently with the support of Adapazari Water Works Division. The damage was determined through the available limited number of repair reports and based on interviews with water works personnel. A map of Adapazari showing recently compiled information on the damage observed in water and sewage pipelines during 1999 Kocaeli earthquake, where pipeline damages reported by O'Rourke et al. [2000] are also taken into consideration is presented in Fig. 2

In Fig. 2, red dashed areas show high damage where blue areas show slight damage zones. Since the entire distribution system was replaced after the earthquake, only limited repair reports were available. This increased the importance of the observations and opinions of the technicians of the Adapazari Water Works Department which can be summarized as follows: The water supply network was composed of mostly AC pipelines with some exception of steel pipelines. As also mentioned by O'Rourke et al. [2000], almost 70-80% of the pipelines were damaged. Most damage was observed in the AC pipelines, especially at the joints. Fig.3 shows a photo of typical AC pipeline replacement/repair five days after the August 17, 1999 Kocaeli Earthquake.

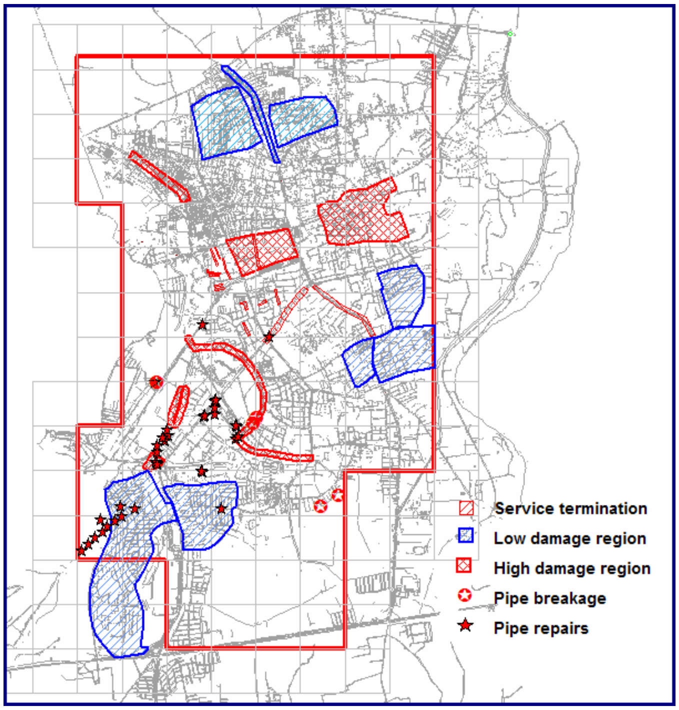

Fig.2. *Damage distribution in pipelines in Adapazari*

Fig. 3. *Repair and replacement studies on damaged AC pipeline after earthquake.*

PIPELINE VULNERABILITY ANALYSES

A vulnerability study was carried out to predict the damage in AC water and sewage pipelines in Adapazari during the 1999 Kocaeli Earthquake. Vulnerabilities of pipelines due to ground shaking and liquefaction induced deformations were evaluated separately.

Site Response Analyses for Ground Shaking Intensity

Variation of earthquake characteristics on the ground surface was estimated by performing 1D site response analyses. The outcrop motion recorded in Adapazari during the 1999 Kocaeli Earthquake which contained only EW component was used as input motion. The acceleration-time history and elastic response spectrum of this record is shown in Fig. 4.

In order to analyze and evaluate the available geotechnical data, the area within central part of Adapazari city was divided into cells with dimensions of 500m×500m. For each cell a representative soil profile was determined based on detailed assessment of available geotechnical data [Ansal et al., 2004].

Soil profiles at each cell contained information about soil stratification, depth of bedrock, ground water elevation and variations of total unit weight, thickness, shear wave velocity with depth and shear modulus reduction and damping ratio relationships for each soil type.

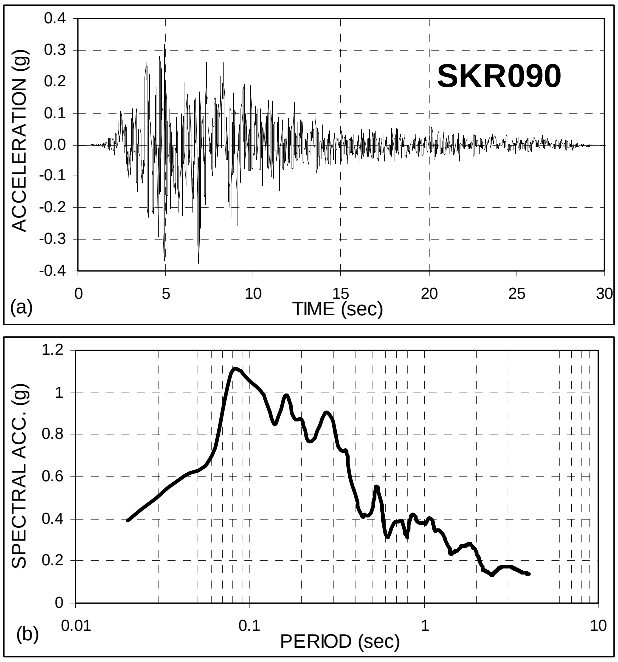

Fig. 4. Sakarya record during 1999 Kocaeli Earthquake: (a) acceleration-time history, and (b) elastic response spectrum.

The variation of shear wave velocities with depth were determined from SPT blow counts using an empirical relationship proposed by Iyisan [1996]

$$V_S = 51.5\ N^{0.516} \tag{1}$$

in terms of uncorrected standard penetration blow counts, N. The calculated shear wave velocities were compared with insitu seismic shear wave velocity measurements where available and were revised accordingly. Shear wave velocity profiles were established down to the engineering bedrock with estimated shear wave velocity of 760m/s. Empirical relationships available in the literature were used to define variations of G/G_{max} and damping ratio with strain. A zonation map for the investigated portion of Adapazari city showing the variation of site classification according to NEHRP [2001] and the investigated water and sewage pipe line systems are presented in Fig. 5.

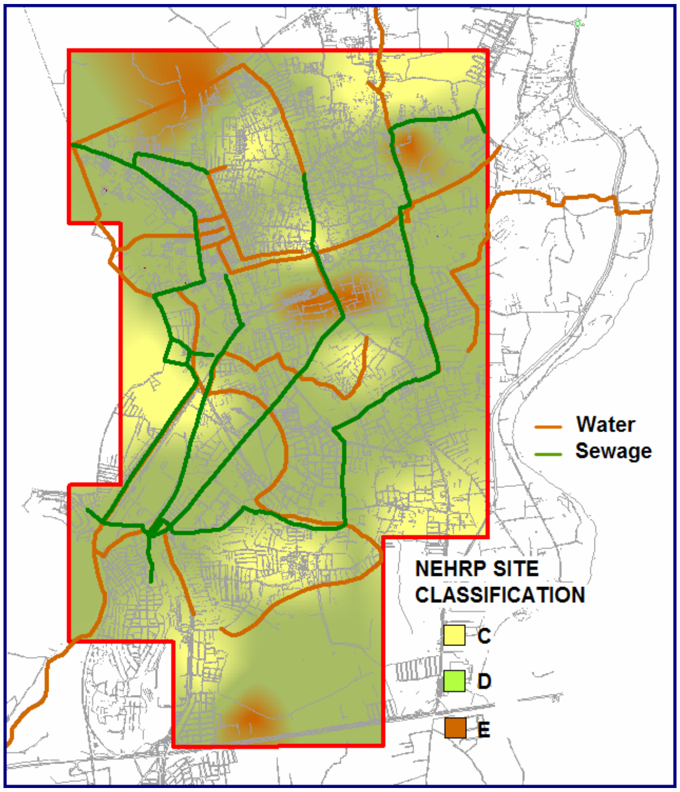

Fig. 5. Site classification according to NEHRP [2001]

Shake91 [Idriss and Sun, 1992] was utilized to perform site response analysis for each soil profile using acceleration-time history recorded at Sakarya station during the 1999 Kocaeli Earthquake as rock outcrop input motion. Acceleration-time histories and the elastic response spectra on the ground surface were calculated for each soil profile.

Peak ground velocity (PGV) values were obtained through integration of acceleration-time histories on the ground surface. The map showing variations of PGV in Adapazari is illustrated in Figs. 6.

An alternative method to determine PGV values is to use the HAZUS [2003] formula given as:

$$PGV = \left(\frac{386.4 * SA_{(1s)}}{2\pi} \right) \frac{1}{1.65} \tag{2}$$

where SA(1s) in units (g) is the spectral acceleration at 1s calculated based on NEHRP amplification factors, and PGV is in (in/sec). Variation of PGV values calculated using Eq. 2 is shown in Fig. 7. It is evident from Figs. 6 and 7 that the PGV values determined by simplified HAZUS formula using NEHRP amplification factors were much lower than those computed from 1D site response analyses.

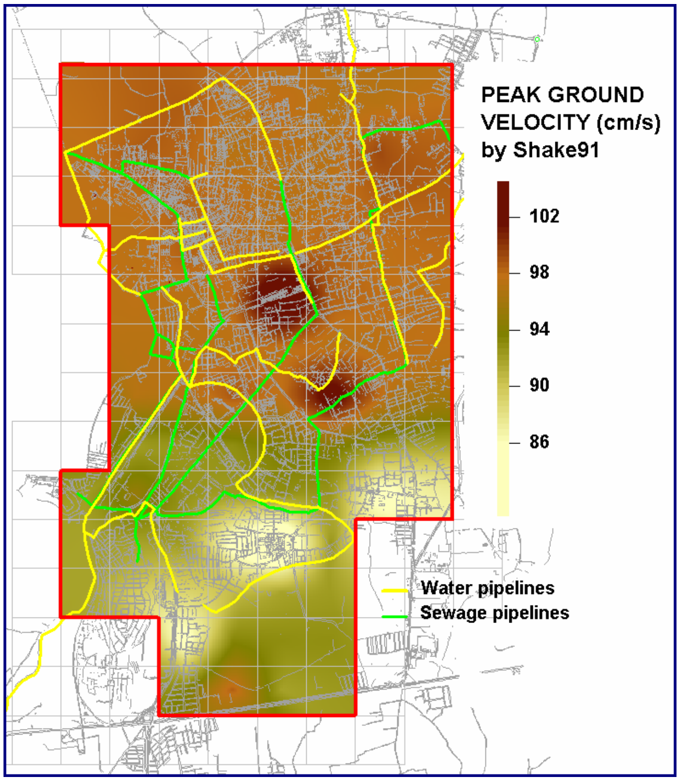

Fig. 6. Estimation of the variation of PGV in Adapazari during 1999 Kocaeli Earthquake computed by 1D site response analyses.

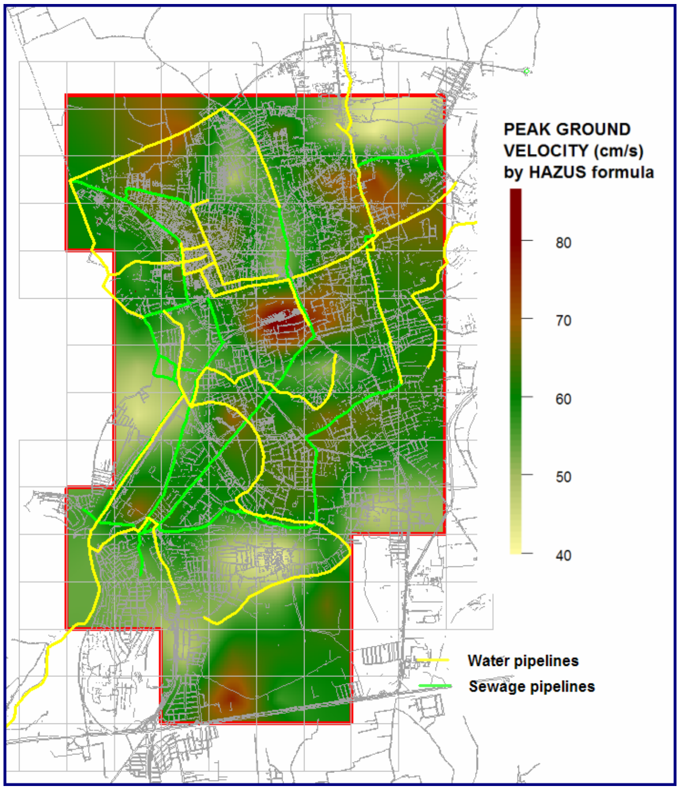

Fig. 7. Estimation of the variation of PGV in Adapazarı during 1999 Kocaeli Earthquake computed by simplified HAZUS formula

A parametric study was conducted (Ansal et al., 2006) to compare the PGVs calculated by integrating the acceleration time histories obtained from site response analysis with the PGV determined by using the HAZUS formulation Eq. (2) as shown in Fig.8.

There seems to be very significant trend for almost all cases studied that the PGV values obtained by site response analysis are higher than those determined by HAZUS formulation.

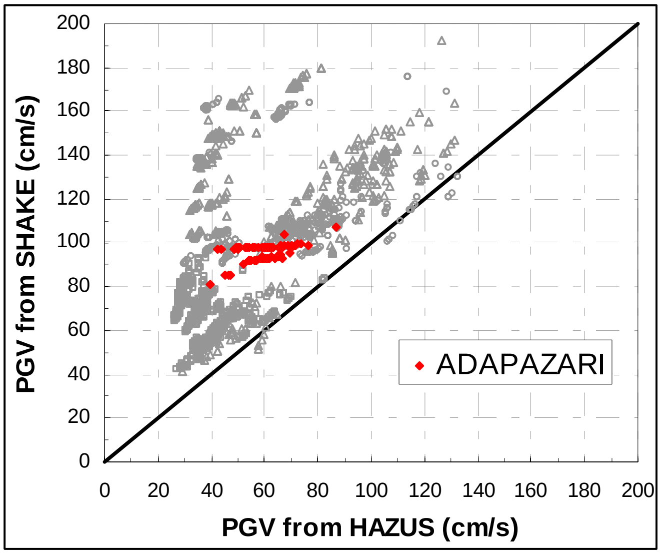

Fig. 8. Comparison of PGV calculated from site response analyses and from HAZUS formula using NEHRP amplification factors

Estimation of Pipeline Damage due to Ground Shaking

Vulnerability of pipelines due to wave propagation was evaluated through empirical correlations that relate PGV and pipeline damage. The empirical correlations used in this study are listed in Table 1. PGV values computed from site response analyses were used to determine expected repair rate and number of repairs in the pipeline system.

Table 1. Empirical pipeline vulnerability relations for ground shaking

Empirical Relation	**Factors**	**Reference**
RR(repair/km)= $0.0001*K*PGV^{2.25}$	PGV (cm/s) K: 1 if brittle material, K: 0.3 if ductile material	O'Rourke and Ayala [1993]
RR(repair/1000ft)= $0.00032*K*PGV^{1.93}$	PGV (in/sec) K: coefficient depending on material type	Eidinger and Avila [1999]
RR(repair/1000ft)= 0.00187*K*PGV	PGV (in/sec) K: coefficient depending on material type	ALA [2001]
RR(repair/km)= $K*513*PGS^{0.89}$	PGV (cm/s) PGS=ground strain K= 1 if brittle material, K=0.3 if ductile material	O'Rourke and Deyoe [2004]

Among the relations shown in Table 1, ALA [2001] relation has the largest database and contains significant scatter. O'Rourke and Deyoe [2004] have shown that scatter can be significantly reduced if ground strain (instead of PGV) is used as seismic shaking parameter to relate wave propagation and repair rate.

Liquefaction Susceptibility Analyses

Liquefaction susceptibility of the study area was evaluated based on PGA values computed from 1D site response analyses and SPT blow counts. Safety factors along the top 20m depth of soil profile containing liquefiable sand or silt layers were calculated using the simplified method proposed by Youd et al. [2001].

The liquefaction potential for each soil profile was determined according to the procedure proposed by Iwasaki et al. [1982]. In this procedure the severity of possible liquefaction at any site was quantified by introducing a factor called "liquefaction potential index", PL defined as

$$P_L = \int F(z) w(z) dz \qquad (3)$$

where z is the depth below the ground water surface, measured in meters; F(z) is a function of the liquefaction resistance factor (i.e. safety factor), FL, where F(z)=1-FL if FL<1.0, F(z)=0 if FL>1.0 and w(z)=10-0.5z. Eq. (3) gives values of PL ranging from 0 to 100.

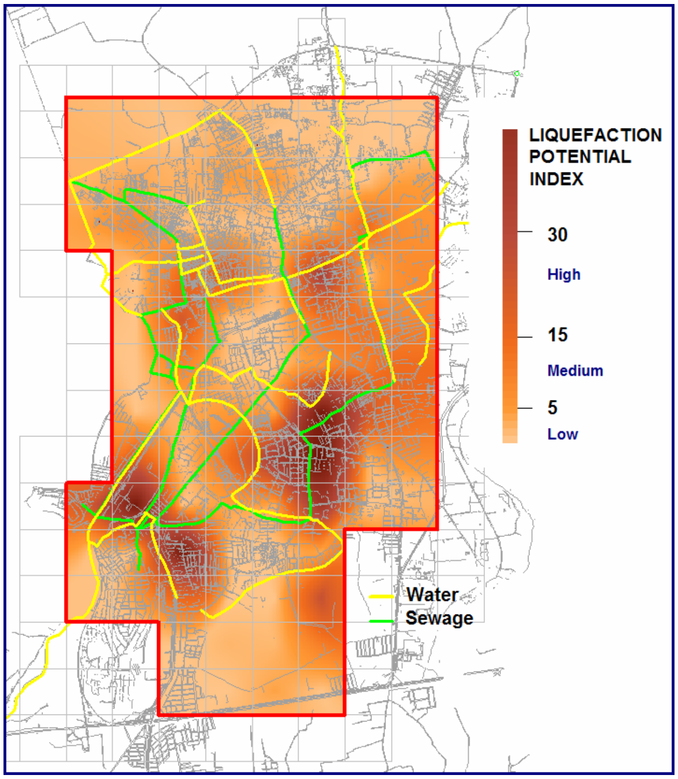

Fig. 9. Estimation of the variation of liquefaction potential index in Adapazari during 1999 Kocaeli Earthquake

Three zones (A, B, and C) were identified with respect to the possible effects of liquefaction on the ground surface based on the liquefaction potential index. Zone A is where the liquefaction potential index is PL>15% indicating high liquefaction susceptibility, zone B is the intermediate zone where the liquefaction potential index is 5% ≤ PL ≤ 15%, and zone C is the safest zone where liquefaction potential index is PL<5% indicating low liquefaction susceptibility. A map showing the variation of PL that indicates level of liquefaction susceptibility in Adapazari is presented in Fig. 9.

Estimation of Pipeline Damage due to Liquefaction Induced Ground Deformations

Liquefaction induced ground deformations (PGD) were estimated using empirical methods that are based on statistical analysis of case histories. The relationships proposed by Youd and Perkins [1987], Barlett and Youd [1995] and Bardet et al. [2002] were used in this study. Average of all three PGD values calculated using these relationships was assumed to represent PGD at each location. A map showing the variation of liquefaction-induced PGD in Adapazari is shown in Fig. 10.

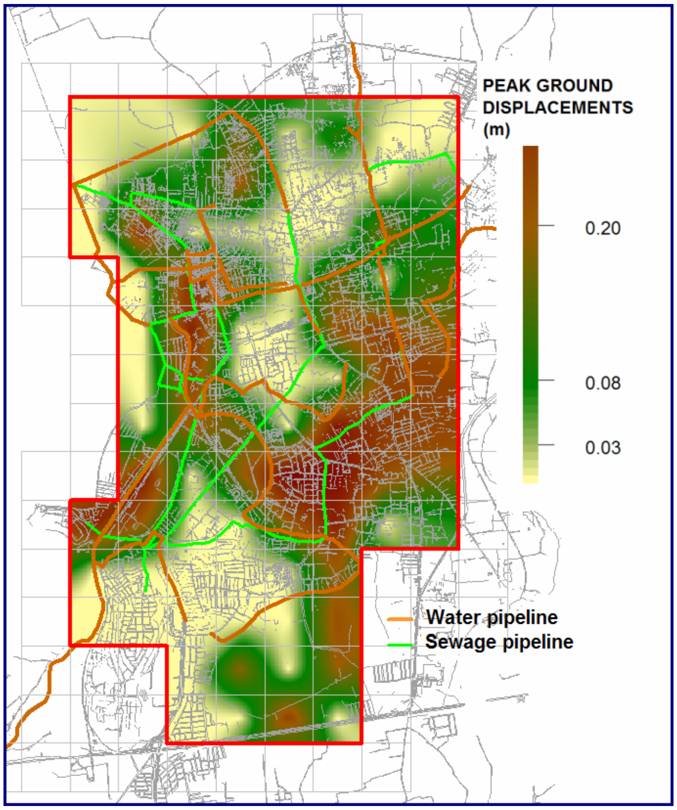

Fig. 10. Estimation of the variation of liquefaction-induced PGD in Adapazari during 1999 Kocaeli Earthquake

Expected repair rate and number of repairs in the pipeline system due to liquefaction induced ground deformations were determined using empirical correlations that relate PGD and pipeline damage. The empirical correlations used in this study are given in Table 2.

Average of repair rates calculated from empirical relations listed in Table 2 was assumed to represent the median predicted pipe damage due to liquefaction-induced ground deformations. Number of expected repair at each location was calculated by multiplying repair rate by the total length of pipelines at that location.

Table 2. Empirical pipeline vulnerability relations for permanent ground deformations

Empirical Relation	**Factors**	**Reference**
RR(repair/1000ft)= $1.03*K*PGV^{0.53}$	PGD (in/sec) K: coefficient depending on material type	Eidinger and Avila [1999]
RR(repair/1000ft)= $1.06*K*PGV^{0.319}$	PGD (in/sec) K: coefficient depending on material type	ALA [2001]

COMPARISONS OF PREDICTED AND OBSERVED DAMAGE

Predicted and observed pipeline damages in Adapazari are compared by superimposing available information of observed damage during 1999 Kocaeli Earthquake on the zonation maps of expected pipe repairs due to ground shaking intensity and liquefaction induced ground deformations.

Average of all four repair rates calculated from empirical relations listed in Table 1 was assumed to represent the predicted median pipe damage due to ground shaking. Number of expected repair at each location was calculated by multiplying repair rate with the total length of pipelines at that location.

In Fig. 11, distribution of repair rates calculated from vulnerability analyses of pipelines due to ground shaking is illustrated together with the observed damage during earthquake. The figure indicates that the damage due to wave propagation was essentially low. An agreement of some degree between the predicted and observed damage can be observed since most of the repairs were in cells with relatively higher calculated repairs rates.

In Fig. 12, estimated distribution of repair rates due to liquefaction-induced settlements is shown together with the observed damage. The figure indicates that the predicted repair rates in the pipelines due to liquefaction-induced deformations are much higher than those caused by wave propagation. One of the reasons for such a difference is due to the relatively high amplitude of the calculated liquefaction induced ground deformations (PGD) that was also observed as large settlements in the Adapazari city after the earthquake

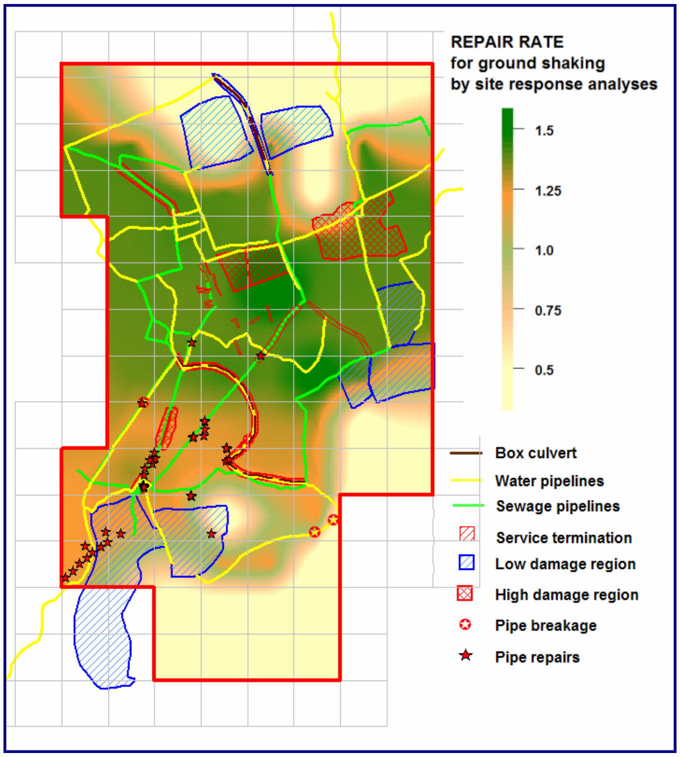

Fig. 11. Estimated distribution of repair rate in Adapazari pipeline system due to ground shaking during 1999 Kocaeli Earthquake with observed damage

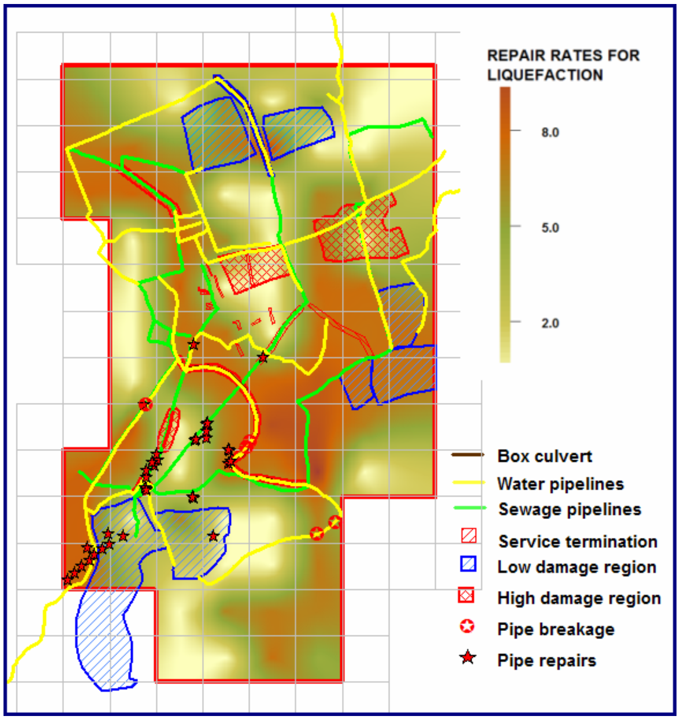

Fig. 12. Estimated distribution of repair rate in Adapazari pipeline system due to liquefaction-induced ground deformations during 1999 Kocaeli Earthquake with observed damage

CONCLUSIONS

An effort was made to evaluate the water and sewage pipeline damages observed during the 1999 Kocaeli earthquake. The earthquake characteristics on the ground surface were calculated using 1D site response analysis with the recorded single component at the Sakarya strong motion station was used as bedrock out crop motion. Repair rates for the investigated region were calculated both for ground shaking in terms of peak ground velocities and for liquefaction with respect to permanent ground deformations based on the empirical formulation reported in the literature.

A comparison was made among the peak ground velocity calculated from site response analysis and from HAZUS formula based on NEHRP site classification. It was observed that PGV values calculated by site response analysis were much higher than those calculated by HAZUS formulation.

The repair rates calculated for ground shaking and for liquefaction showed significant differences. The predicted distribution of repair rates indicated that most of the damage came from liquefaction-induced settlements.

Even though there appears to be a general agreement of the observed pipeline damages with the distribution of repair rates calculated for ground shaking, the agreement between the observed damage and liquefaction susceptibility looks better.

REFERENCES

ALA, American Lifelines Alliance [2001] “Seismic fragility formulations for water systems, Part 1-Guideline”, http://www.americanlifelinesalliance.org

Ansal, A., Laue, J., Buchheister, J., Erdik, M., Springman, S., Studer, J., and Koksal, D. [2004] “Site characterization and site amplification for a seismic microzonation study in Turkey,” 11th Int. Conference on Soil Dynamics and Earthquake Engineering and 3rd Earthquake Geotechnical Engineering, San Francisco

Ansal, A., Tönük, G., Demircioglu, M., Bayraklı, Y., Sesetyan, K., Erdik, M. [2006], “Ground Motion Parameters for Vulnerability Assessment,” Proceedings of the First European Conference on Earthquake Engineering and Seismology, Geneva, Switzerland, Paper Number: 1790.

Bardet., J.P., Tobita, T., Mace, N. & Hu, J. [2002] “Regional Modeling of Liquefaction-Induced Ground Deformation”, Earthquake Spectra, [18]1:19-46.

Barlett, S.F. and Youd, T.L. [1995] “Empirical Prediction of Liquefaction-Induced-Lateral Spreads”, Journal of Geotechnical Engineering, ASCE, [121]4:316-329.

BSSC-Building Seismic Safety Council [2001], NEHRP [National Earthquake Hazards Reduction Program] Recommended Provisions for Seismic Regulations for new buildings and other structures, 2000 Edition, Part 1: Provisions [FEMA 368], Ch. 4, Washington, D.C.

Eidinger J, Avila E [1999] “Guidelines for the seismic upgrade of Water Transmission Facilities” ASCE, TCLEE, Monograph No. 15.

HAZUS [2003], Multi-hazard loss estimation methodology earthquake model, Technical Manual, FEMA

Idriss, I. M. and Sun J. I. [1992] Shake91, A Computer Program for Conducting Equivalent Linear Seismic Response Analysis of Horizontally Layered Soil Deposits Modified based on the original SHAKE program Published in December 1972 by Schnabel, Lysmer and Seed.

Iwasaki T, Tokida K, Tatsuoka F, Watanabe S, Yasuda S, Sato H. [1982] “Microzonation of Soil Liquefaction Potential Using Simplified Methods.” Proceedings of 3rd International Conf. on Microzonation, Seattle, 1982; 3: 1319-1330.

Iyisan, R. [1996] “Correlations between Shear Wave Velocity and In-situ Penetration Test Results”, Technical Journal of Turkish Chamber of Civil Engineers, Vol. 7, No. 2, pp.1187-1199 (in Turkish)

O’Rourke M. J. and Alaya G., [1993] “Pipeline damage due to wave propagation” Journal of Geotechnical Engineering, ASCE, 119, 9, 1490-1498,.

O'Rourke, T. D., Erdogan, F.H., Savage,W.L., Lund, L.V. , Tang, A, Basoz, N., Edwards,C., Tezel,G., and Wong, F. [2000] “Water, Gas, Electric Power and Telecommunications Performance”, 1999 Kocaeli, Turkey, Earthquake Reconnaissance Report, EQ Spectra Supplement A to V.16.

O’Rourke M. J. and Deyoe E. [2004] “Seismic damage to segmented buried pipe,” Earthquake Spectra ISSNo 8755-2930, Vol. 20, N. 4, 1167-1183,.

Youd, T.L. & Perkins, D.M. [1987] “Mapping of Liquefaction Severity Index”, Journal of Geotechnical Engineering, (11):1374-1392.

Youd TL, Idriss IM, Andrus RD, Arango I, Castro G, Christian JT, Dobry R, Finn WDL, Harder LF Jr, Hynes ME, Ishihara K, Koester JP, Liao SSC, Marcuson WFIII, Martin GR, Mitchell JK, Moriwaki Y, Power MS, Robertson PK, Seed RB, Stokoe KHII. “Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils.” ASCE, Journal of Geotechnical and Geoenvironmental Engineering 2001; 127(10) 817-833.