ASSESSMENT OF BURIED PIPELINE RESPONSE TO EARTHQUAKE LOADING BY USING GIS

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ABSTRACT :

Evaluation of pipeline systems against future earthquakes is very important for the efforts to build earthquake-resistant infrastructures. Continuous service of pipeline systems or getting their functionality quickly back right after an earthquake is very important and crucial for the urban societies. In this study, pipeline damage relationships obtained from the 1994 Northridge earthquake and Los Angeles water supply data are revisited. ShakeMap peak ground velocity (PGV) values are used and effects of PGV contour intervals on damage relationships are evaluated. The relationships developed herein can be utilized in pre-earthquake evaluation of buried pipeline systems as well as immediate post-earthquake applications such as ShakeCast. Development of a software program which works with GIS is presented. The program is part of an extensive study with the objective to develop a new methodology for the assessment of earthquake effects on buried pipeline systems by integrating geographical information systems (GIS) with analytical methods. At this initial phase, the software performs Stage 1 checks by evaluating whether the given pipeline system satisfy certain seismic design and code requirements. Some inputs to the program are seismic information (e.g., ground shaking maps) and soil data (e.g. soil type maps, liquefaction hazard maps, etc.). Both transient and permanent ground deformation effects are considered. The program provides users the pipelines that need further seismic evaluation. Applications of the program are also presented.

KEYWORDS: Damage, Geographical Information Systems (GIS), Pipelines, Seismic, ShakeMap

1. INTRODUCTION

Existing pipeline damage correlations with seismic parameters such as peak ground acceleration (PGA) and peak ground velocity (PGV) are primarily empirical and obtained from past earthquakes. Such correlations are important for loss estimation analyses that are employed to assess the potential damage during future earthquake and develop corrective measures and emergency response procedures to reduce the projected losses (e.g., Whitman, 1997).

An overview of damage correlations can be found in Toprak (1998) and Toprak and Taskin (2007). The recent correlations obtained from the 1994 Northridge earthquake improved the state of damage correlations significantly because of the largest databases ever assembled in U.S. of spatially distributed transient and permanent ground displacements in conjunction with damage to water supply and transportation lifelines (O'Rourke and Toprak, 1997). The 1994 Northridge earthquake caused the most extensive damage to a US water supply system since the 1906 San Francisco earthquake. Three major transmission systems, which provide over three-quarters of the water for the City of Los Angeles, were disrupted. Los Angeles Department of Water and Power (LADWP) and Metropolitan Water District (MWD) trunk lines (nominal pipe diameter ≥ 600 mm) and the LADWP distribution pipeline (nominal pipe diameter < 600 mm) system were damaged. Comprehensive treatment of the earthquake-induced damage to water pipelines and the database developed to characterize this damage can be found at Toprak (1998) and O'Rourke, et al. (1998). In their studies as well as this study, 944 distribution line repairs were identified and used for which there are data pertaining to pipe composition and size.

Figure 1 shows the water distribution lines of Los Angeles and locations of repairs made to the pipelines after the 1994 Northridge earthquake. The repair data shown herein are slightly different than those used in previous studies as pipe type and pipe size of some repairs have been changed to match the existing pipelines at respective locations. The total length of the distribution lines is 10,750 km. About 76%, 11%, 9%, and 4% of the distribution lines are composed of cast iron (CI), steel, asbestos cement (AC) and ductile iron (DI), respectively. Out of 944 distribution line repairs, about 78%, 17%, 3%, 1%, and 1% are cast iron, steel, asbestos cement, ductile iron and other pipe type repairs, respectively.

During the development of pipeline repair rate (number of repairs divided by the length of the pipelines in the same area)-PGV relationships by Toprak (1998), the records from 241 Northridge earthquake strong motion instruments at free field rock and soil stations were examined and the data from 164 corrected records were used to evaluate the patterns of pipeline damage with the spatial distribution of various seismic parameters. In the current study, PGV values from ShakeMap for the 1994 Northridge earthquake were used. The PGV contours are shown in Figure 1 along with distribution lines and repairs. The pipeline damage relationships obtained from this study and previous studies are compared herein. In addition, the effects of using different PGV intervals on the pipeline damage relationships are explored.

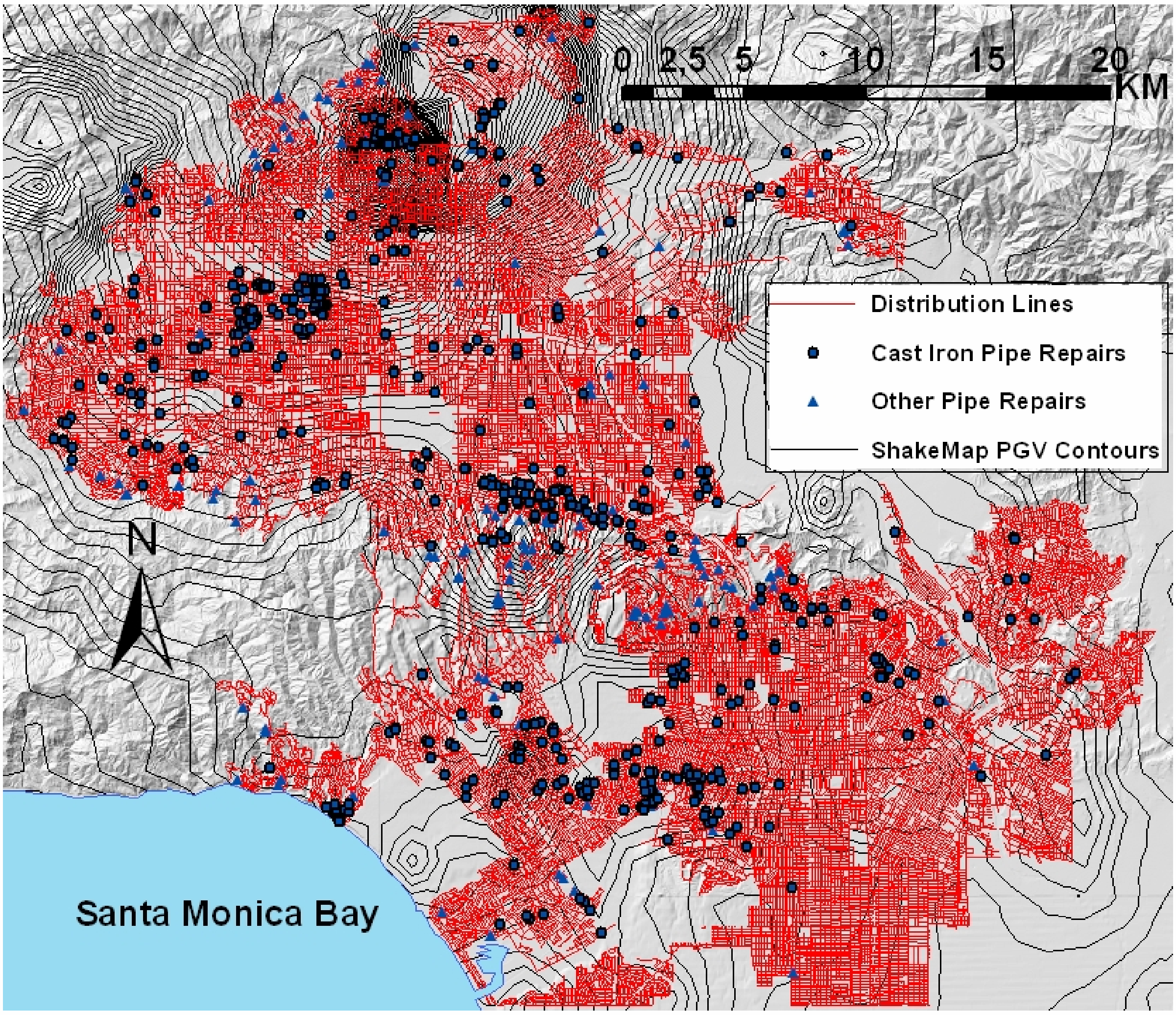


Figure 1 LADWP distribution lines and repairs superimposed on the 1994 Northridge earthquake ShakeMap PGV contours

The relationships developed herein can be utilized in immediate post-earthquake applications such as ShakeCast for buried pipeline systems (Wald, et al, 2008). ShakeCast facilitates the complicated assessment of potential damage to a user's widely distributed facilities by comparing the complex shaking distribution with the potentially highly variable damageability of their inventory to provide a simple, hierarchical list and maps of structures or facilities most likely impacted. ShakeCast is a freely available, post-earthquake situational awareness application that automatically retrieves earthquake shaking data from ShakeMap, compares intensity measures against users' facilities, sends notifications of potential damage to responsible parties, and generates facility damage maps and other Web-based products for both public and private emergency managers and responders.

Furthermore, as part of an extensive study which involves a TUBITAK (The Scientific and Technological Research Council of Turkey) funded Project entitled "Evaluation of Earthquake Effects on Buried Pipeline Systems Using Geographical Information Systems (GIS)", a software program development has been undertaken. The software works with GIS (e.g. ESRI, 2001). The objective of this project is to develop a new methodology for the assessment of earthquake effects on buried pipeline systems by integrating geographical information systems (GIS) with analytical methods. At this initial phase, the software performs Stage 1 checks by evaluating whether the given pipeline system satisfy certain seismic design and code requirements.

2. PIPELINE DAMAGE RELATIONSHIPS WITH SHAKEMAP PGV VALUES

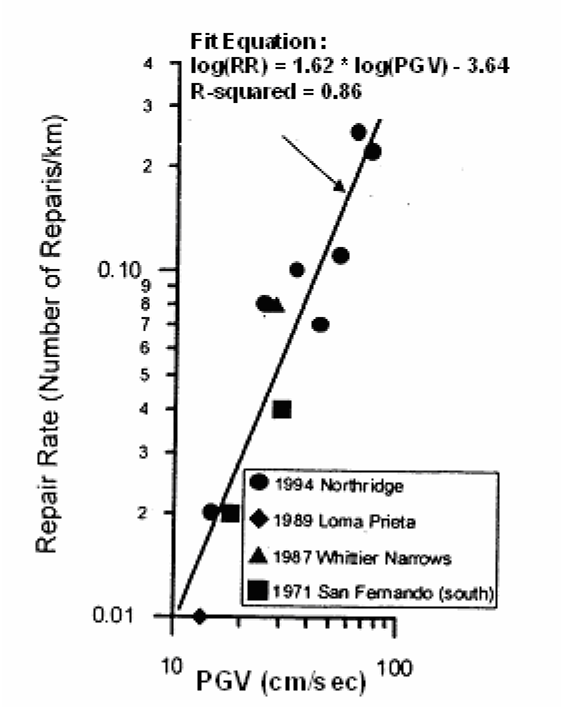
ShakeMap (http://earthquake.usgs.gov/eqcenter/shakemap/)—rapidly, automatically generated shaking and intensity maps—combines instrumental measurements of shaking with information about local geology and earthquake location and magnitude to estimate shaking variations throughout a geographic area (Wald et al., 2005). The results are rapidly available via the Web through a variety of map formats, including Geographic Information System (GIS) coverages. The fundamental output product of the ShakeMap processing system is a finely sampled grid of latitude and longitude pairs with associated amplitude values of shaking parameters at each point. These amplitude values are derived by interpolation of a combination of the recorded ground shaking observation and estimated amplitudes at locations that fill in gaps, with consideration of site amplification at all interpolated points. The resulting grid of amplitude values provides the basis for generating color-coded intensity contour maps, for further interpolation to infer shaking at selected locations, and for generating GIS-formatted files for further analyses.

Using the GIS database, a pipeline repair rate (RR) was calculated for each PGV zone, and correlations were made between the repair rate and average PGV for each zone. Pipeline damage relationships were developed by using the modified repair database and ShakeMap PGV values. Because of the space limitations, results of only CI relationships are shown and discussed here. Figure 2c shows the pipeline damage relationship obtained herein whereas Figures 2a and b show the relationships of O'Rourke et al. (1998) and O'Rourke and Jeon (1999). All relationships were obtained by using PGV contours with 10 cm/sec intervals. PGV contours of mentioned studies including ShakeMap utilize the larger of the two horizontal components at strong motion recording stations. The comparison of the relationships (Figure 2d) shows that the difference between the relationships derived in this study and others is not significant.

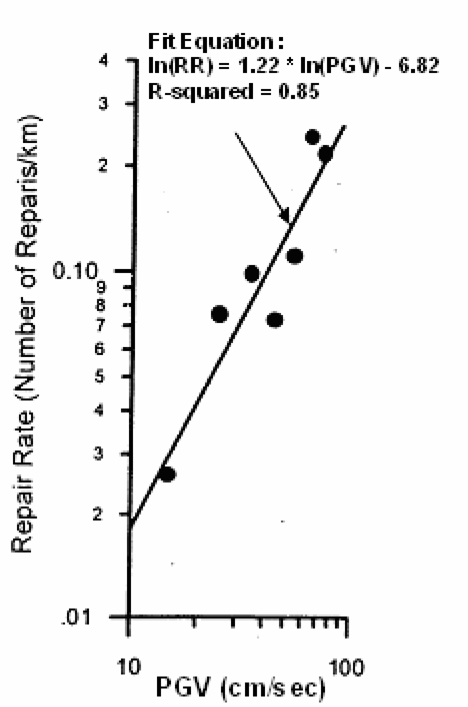
3. EFFECTS OF PGV CONTOUR INTERVALS ON DAMAGE RELATIONSHIPS

The strong motion database of 1994 Northridge earthquake had provided the most extensive data of its type up to 1994 for pipeline damage correlations. Yet, the spacing between stations was tens of kilometers in most of the cases. The ShakeMap processing system, however produces a finely sampled grid of latitude and longitude pairs (about 1.5 km spacing) with associated amplitude values of shaking parameters at each point. These amplitude values are derived by interpolation of a combination of the recorded ground shaking observation and estimated amplitudes at locations that fill in gaps, with consideration of site amplification at all interpolated points. Hence, the PGV values should be more close to the reality as opposed to just statistically interpolating PGVs using sparsely distributed stations. The PGV values as a grid system and as a map of PGV contours for the 1994 Northridge earthquake were obtained from the following web site: http://earthquake.usgs.gov/eqcenter/shakemap/sc/shake/Northridge/#Peak_Ground_Velocity.

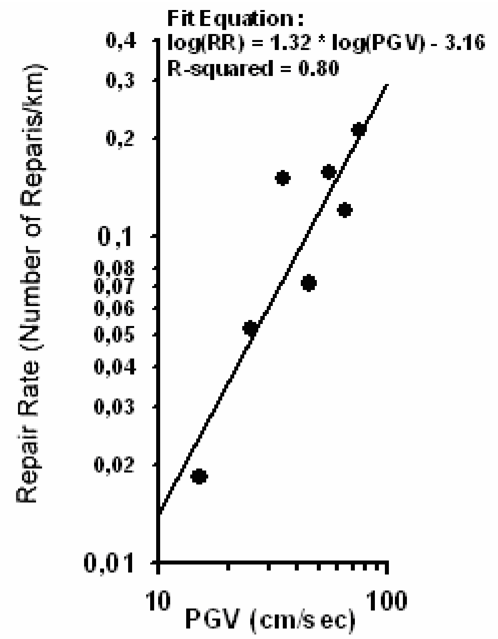
Toprak et al. (1999) discussed the visualization of spatially distributed pipeline damage using GIS and emphasized the effect of grid size on pipeline repair rate values. In this study, above mentioned PGV database and pipeline damage data from the 1994 Northridge earthquake were used to study effects of PGV contour intervals on damage relationships. As stated previously, the relationships in Figure 2 used a PGV interval of 10 cm/sec.



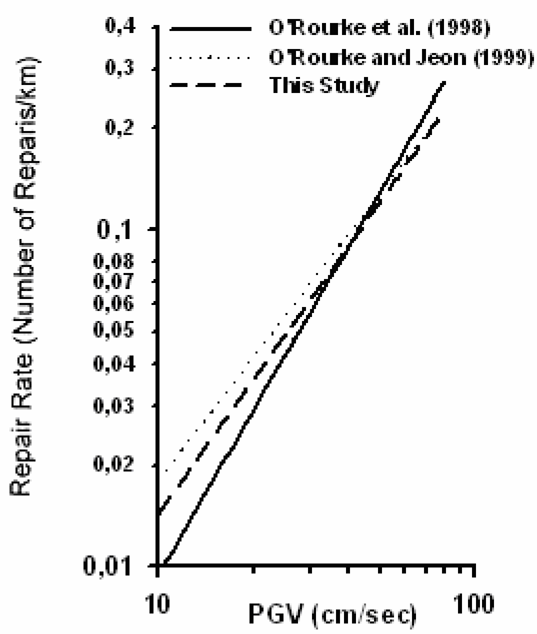
a) After O'Rourke et al. (1998)



b) O'Rourke and Jeon (1999)

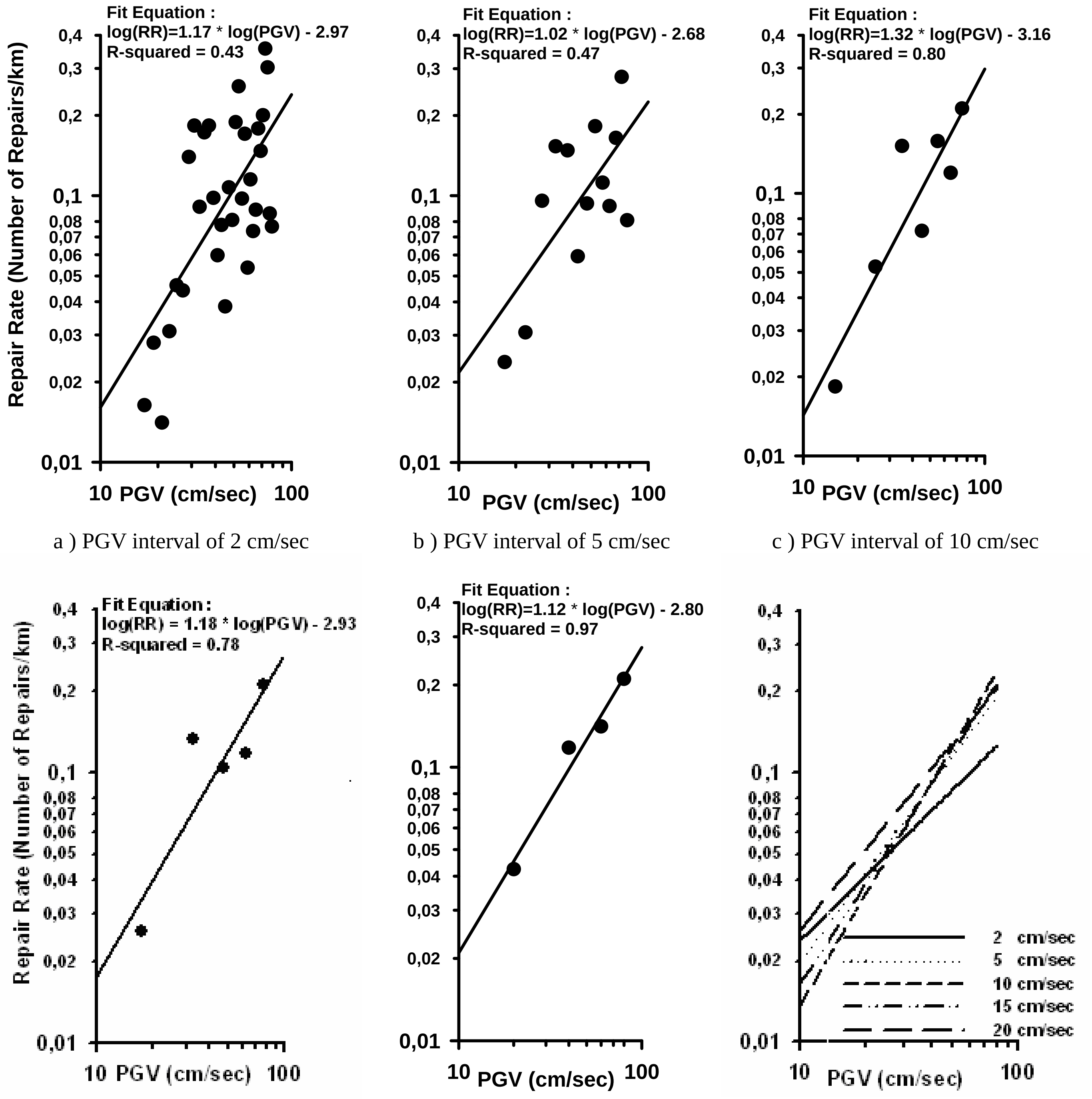


c) This study



d) Comparison of the damage relationships

Figure 2 Damage relationships for CI pipelines



a) PGV interval of 2 cm/sec   b) PGV interval of 5 cm/sec   c) PGV interval of 10 cm/sec

d) PGV interval of 15 cm/sec   e) PGV interval of 20 cm/sec   f) Comparison of the relationships

Figure 3 Pipeline damage correlations obtained using PGV contours with various intervals

Figure 3 shows the pipeline damage correlations obtained by using PGV contours with different intervals changing from 2 to 20 cm/sec. The comparison of the relationships illustrated that the difference between the repair rate values for the same PGV value can be as much as 2 times. In general, the quality of the regression increases as PGV contour interval increases. This is expected because the effects of geology, local soil conditions, and amplification factors are smoothed over with use of larger PGV intervals.

4. A SOFTWARE FOR EVALUATION OF PIPELINES AGAINST EARTHQUAKE LOADING

As part of an extensive study which involves a TUBITAK (The Scientific and Technological Research Council of Turkey) funded Project entitled "Evaluation of Earthquake Effects on Buried Pipeline Systems Using Geographical Information Systems (GIS)", a software program development has been undertaken. The software works with GIS. At this initial phase, the software performs Stage 1 checks by evaluating whether the given pipeline system satisfy certain seismic design and code requirements. Some inputs to the program are seismic information (e.g., ground shaking maps) and soil data (e.g. soil type maps, liquefaction hazard maps, etc.). Both transient and permanent ground deformation effects are considered. The program provides and shows users the pipelines that need further seismic evaluation. At its current state, the program utilizes Earthquake Resistant Design Codes in Japan (JSCE, 2000) and international standarts such as Earthquake-and-Subsidence-Resistant Design of Ductile Iron Pipelines (ISO, 2006).

Denizli is selected as a primary pilot area for the application of the software and methodology. Denizli is an important industrial, tourism, and export center in the Aegean region of Turkey which extends from the Aegean Sea coast to the inner parts of western Anatolia. According to 2007 Census data, Denizli city has a population of 323,151 which makes it the second largest city in the Aegean region. Because Denizli is located in a seismically active region, earthquake disaster prevention and mitigation studies are very important to reduce risk from earthquakes and to prepare for emergency response and recovery from an earthquake. Figure 4 shows part of the gas pipeline system in Denizli city, Turkey. ARCGIS was used in the application. The software developed herein adds additional buttons as shown in the Figure (e.g., table, constants, calculate). Figure 5 shows the results of Stage 1 analysis and identifies the pipelines that require further evaluation.

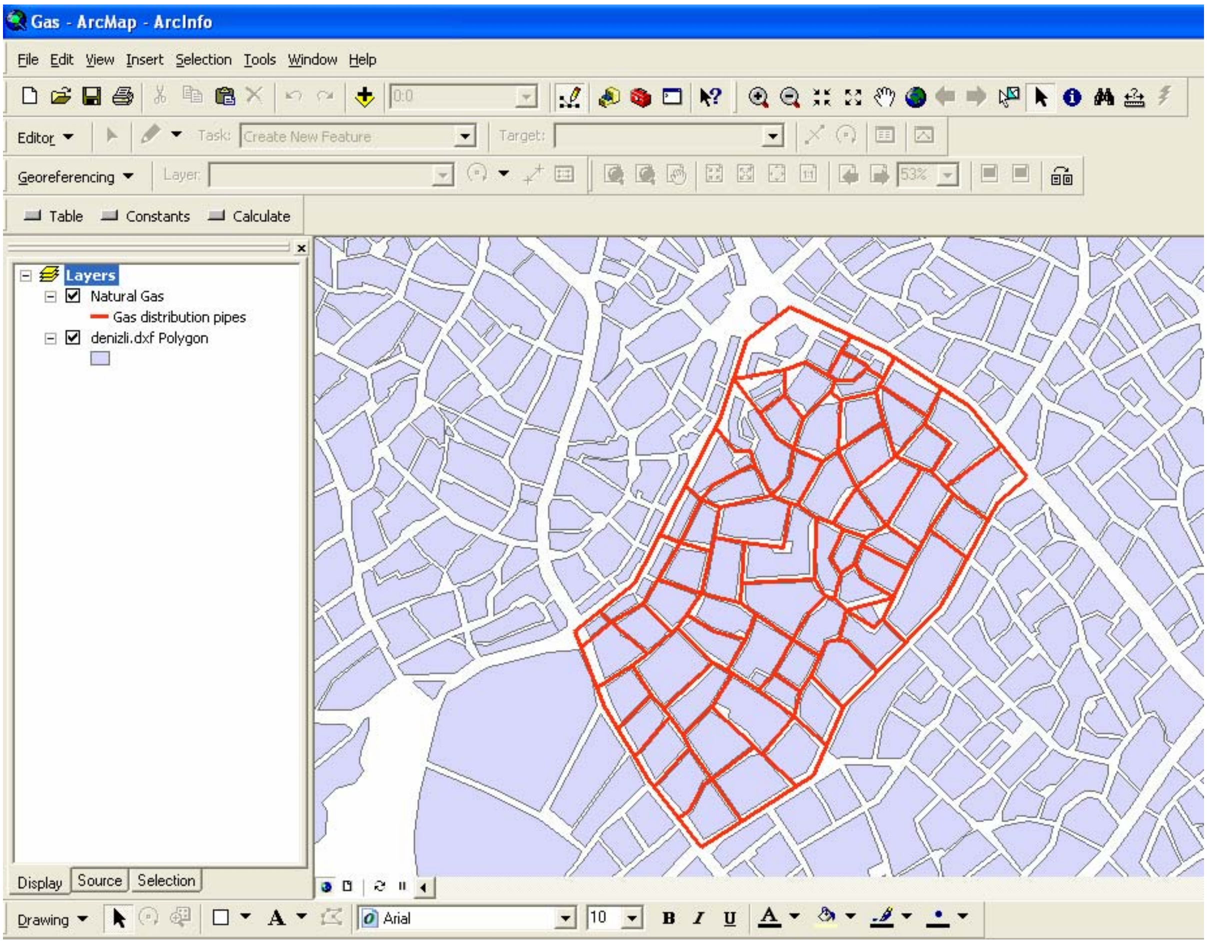


Figure 4 Part of the gas pipeline system in Denizli, Turkey

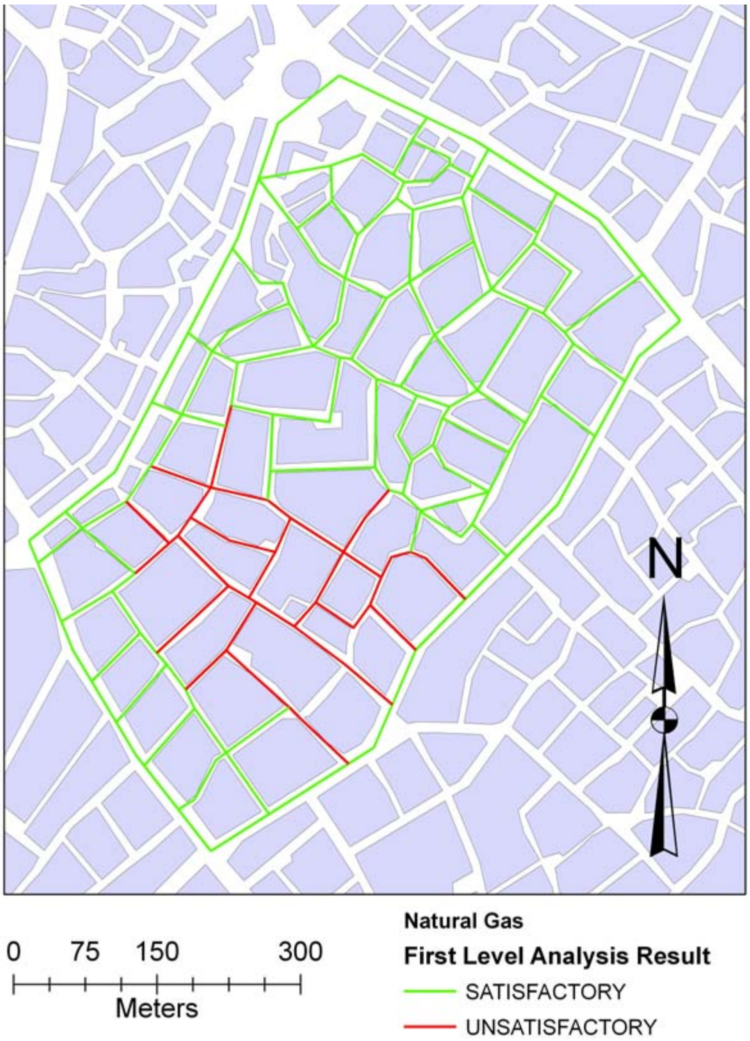


Figure 5 Stage 1 analysis results for the part of the gas pipeline system in Denizli, Turkey

5. CONCLUSIONS

In this study, pipeline damage relationships obtained from the 1994 Northridge earthquake and Los Angeles water supply data are revisited. Pipeline damage relationships were developed by using the modified repair database and ShakeMap PGV values. The comparison of the relationships shows that the difference between the relationships derived in this study and previous ones is not significant. Also effects of PGV contour intervals on damage relationships are evaluated for the Northridge earthquake database. The comparison of the relationships illustrates that the difference between the repair rate values for the same PGV value can be as much as 2 times. The relationships developed herein can be utilized in pre-earthquake evaluation of buried pipeline systems as well as immediate post-earthquake applications such as ShakeCast (Wald, et al, 2008).

Furthermore, initial results of a TUBITAK (The Scientific and Technological Research Council of Turkey) funded Project entitled "Evaluation of Earthquake Effects on Buried Pipeline Systems Using Geographical Information Systems (GIS)" is presented. The objective of this project is to develop a new methodology for the assessment of earthquake effects on buried pipeline systems by integrating geographical information systems (GIS) with analytical methods. A software program development has been undertaken. The software works with GIS. At this initial phase, the software performs Stage 1 checks by evaluating whether the given pipeline system satisfy certain seismic design and code requirements.

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