Robustness of Lifeline Systems

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Robustness of Structures
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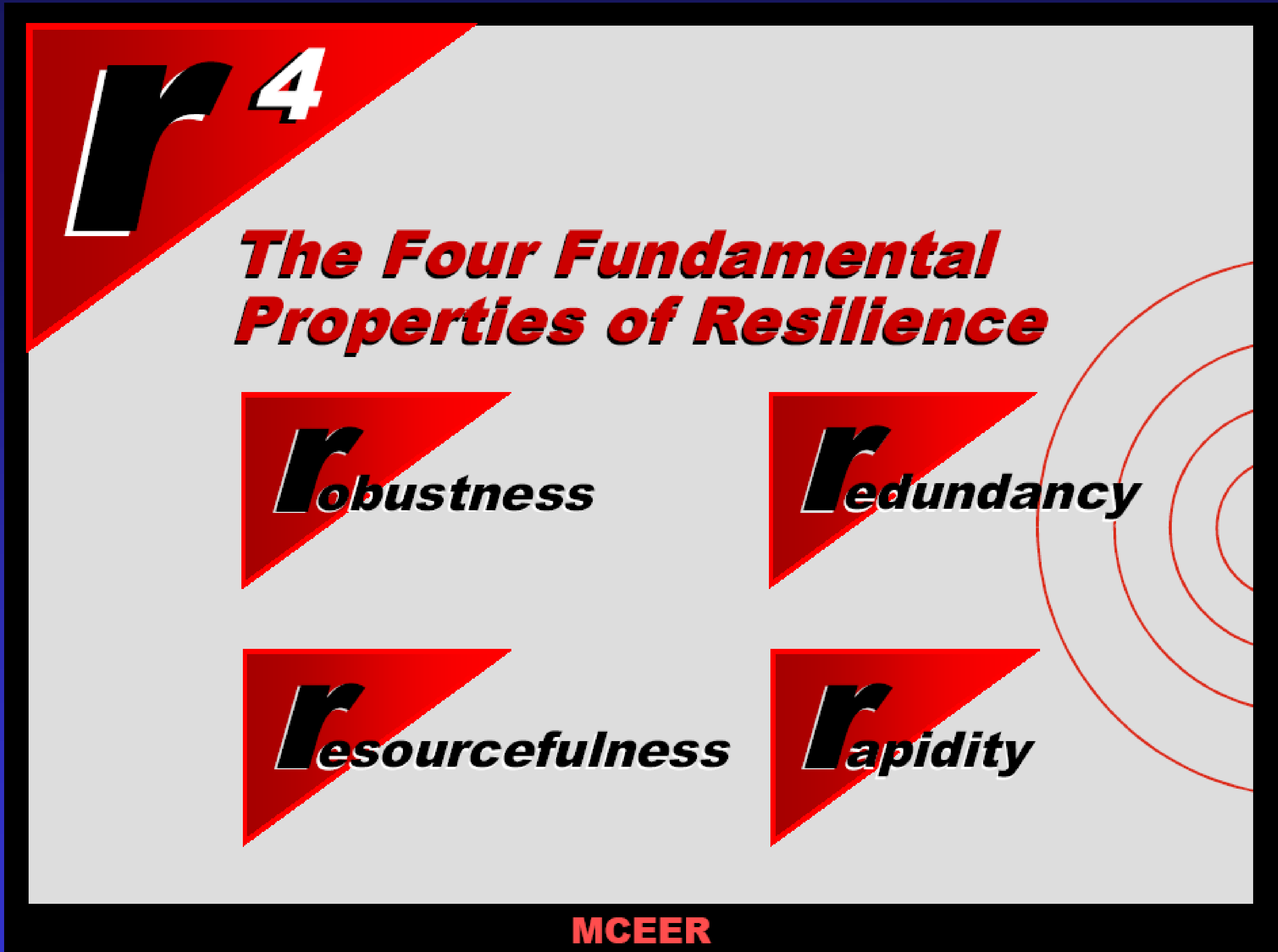
LIFELINE SYSTEMS

- Lifelines- Transportation Systems

- Lifelines- Utility Systems
  - Potable Water
  - Waste Water
  - Oil (crude or refined)
  - Natural Gas
  - Electric Power
  - Communication



From Bruneau M.

Dimensions, Components, or Properties of Resilience

- **Robustness**: Inherent Strength, Resistance
- **Redundancy**: System Properties That Allow for Alternative Options, Choices, Substitutions
- **Resourcefulness**: Capacity to Mobilize Needed Resources
- **Rapidity**: Speed With Which Disruption Can Be Overcome & Service, Income, etc., Restored

From Bruneau and Tierney

Robustness and Lifeline Systems

When robustness of a particular lifeline system is evaluated, both the components of the system and the whole system itself should be considered.

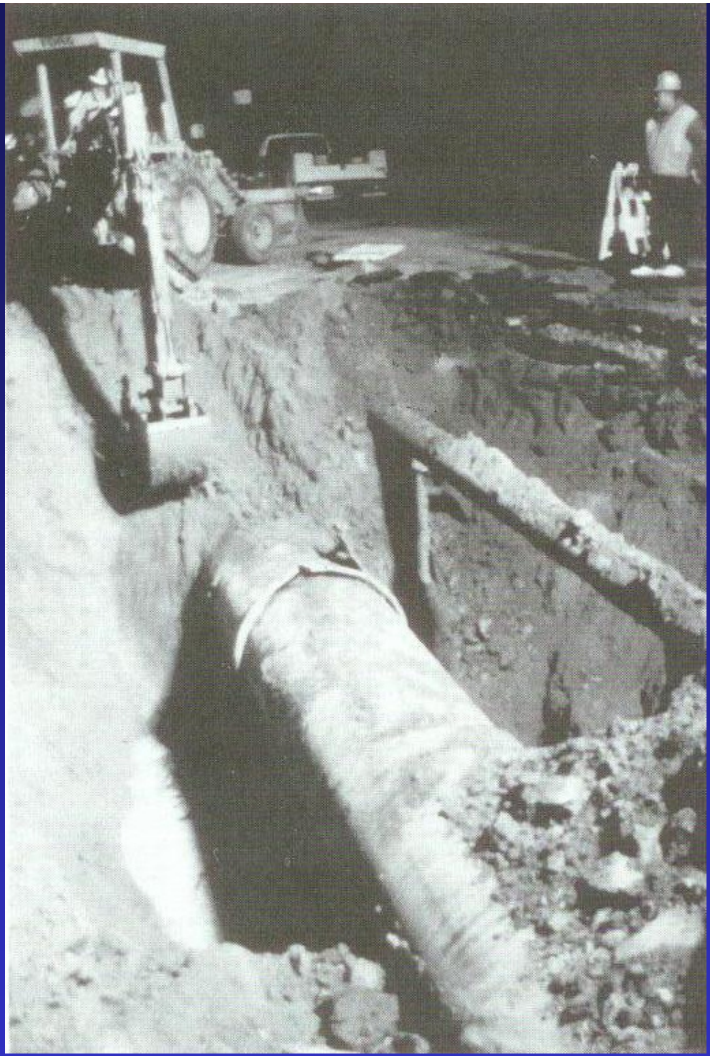
For example, system's components for a water supply system include tanks, aqueducts, water treatment plants, wells, pumping stations, distribution pipes, junctions, hydrants, and valves.

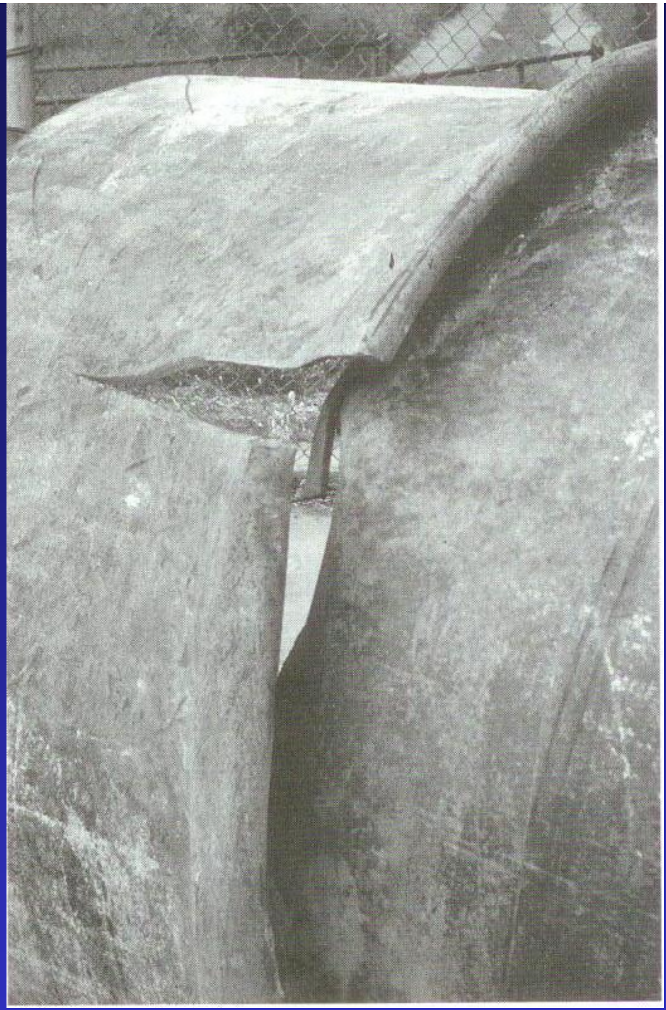
Each component will have a different vulnerability function.

Vulnerability Functions

In general, peak ground velocity (PGV) and permanent ground deformations (PGD) are primary parameters used for damage correlations of pipelines and related parts whereas peak ground acceleration (PGA) and PGD are primary parameters used for damage correlations of other water supply components such as tanks and pumping stations.

1994 Northridge Earthquake, USA, Balboa Blvd.





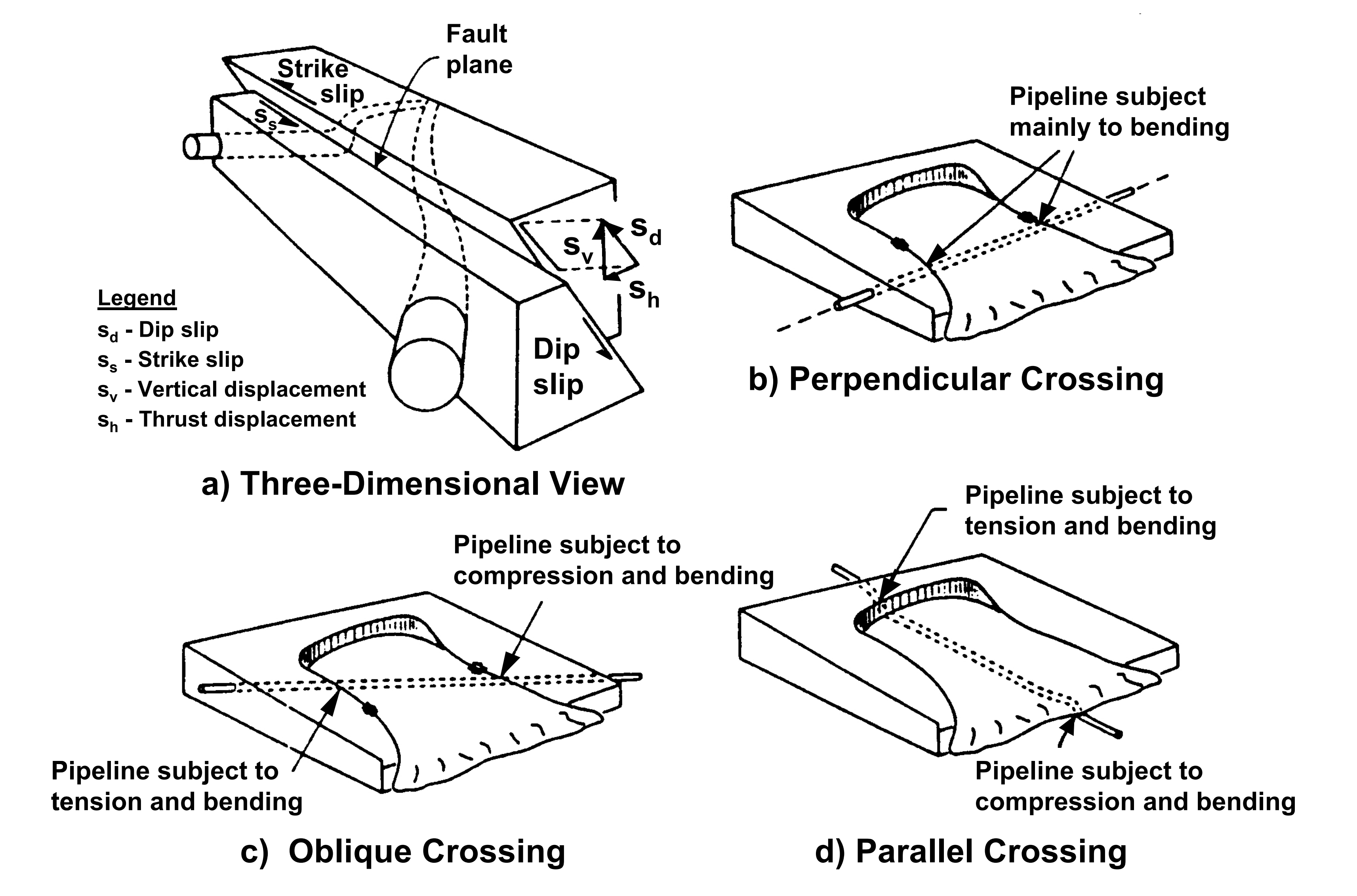
Backhoe uncovering compression damage to 48-inch welded-steel pipe in the zone of ground compression along Balboa Boulevard at Halsey during Northridge earthquake of January 17, 1994 Street (from Lund,1995)

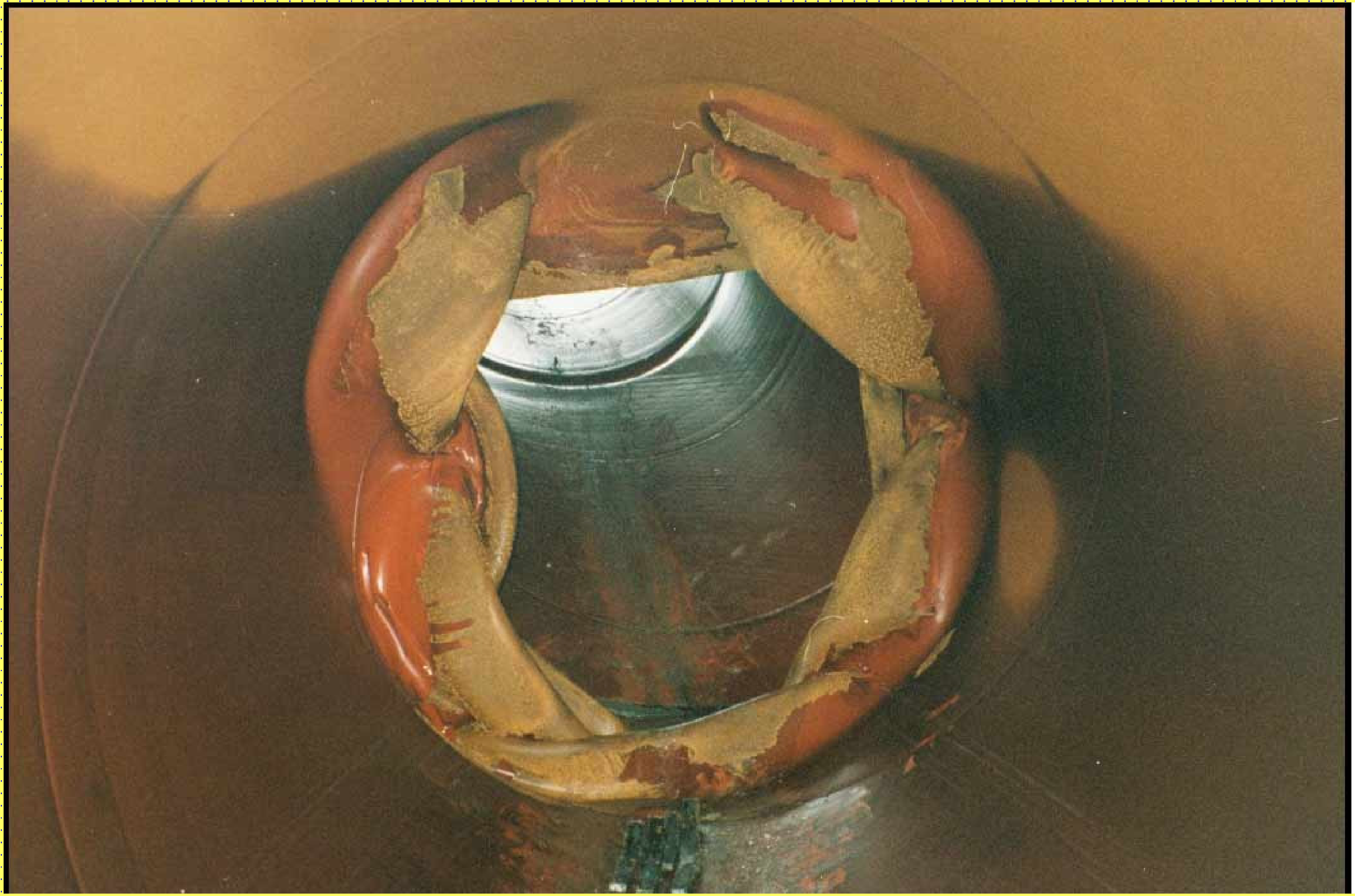
Primary Causes of Pipeline Damage:

- **Permanent Ground Deformation (PGD):** lateral spreads due to liquefaction, surface faulting, landslides, and differential settlement from consolidation of cohesionless soil

- **Transient Ground Deformation (TGD):** occurs as a result of seismic waves, primarily characterized by peak ground velocity (PGV)

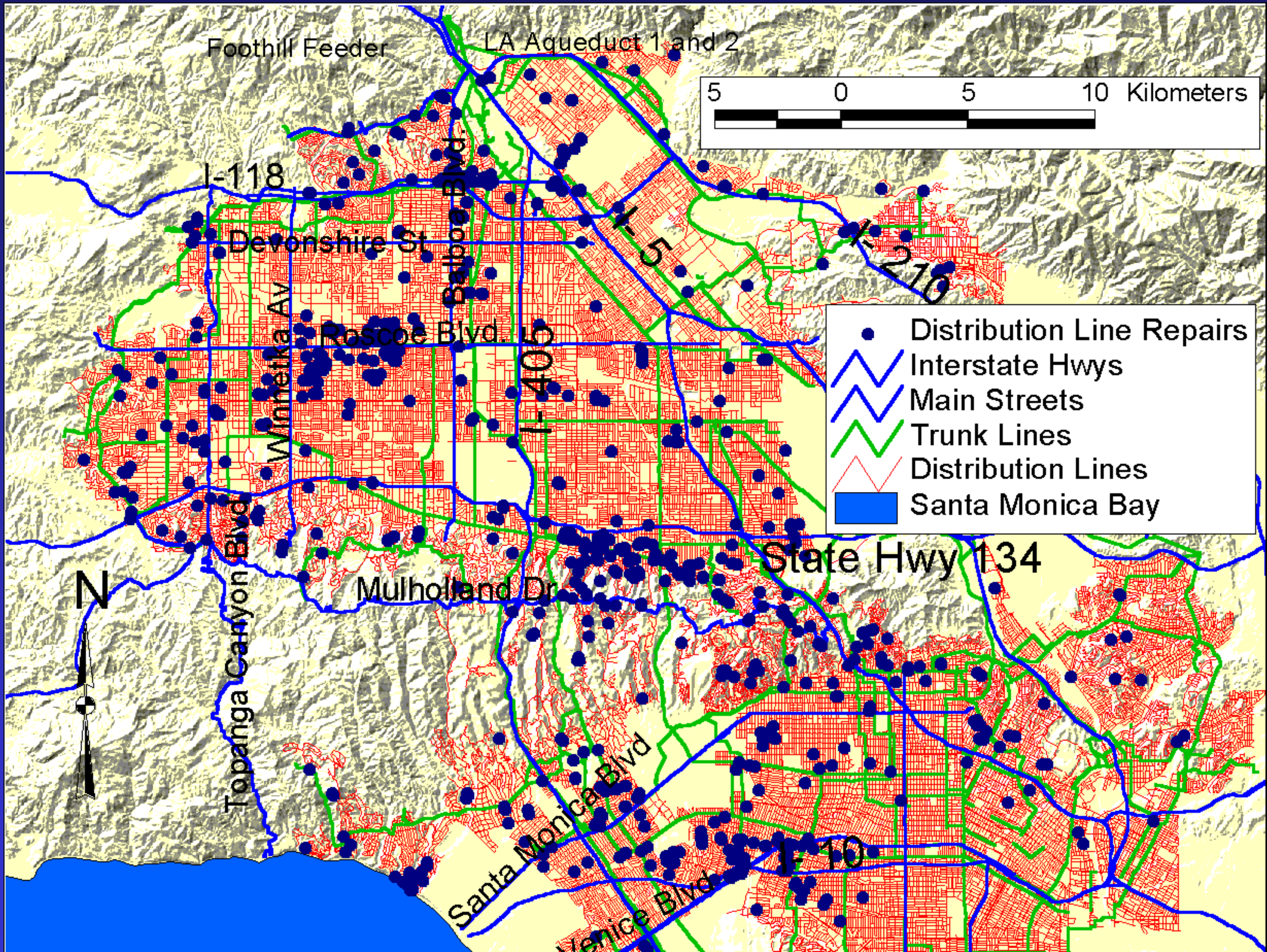
Principal Modes of Soil-Pipeline Interaction Due to Earthquake Induced PGD (O'Rourke, 1998)

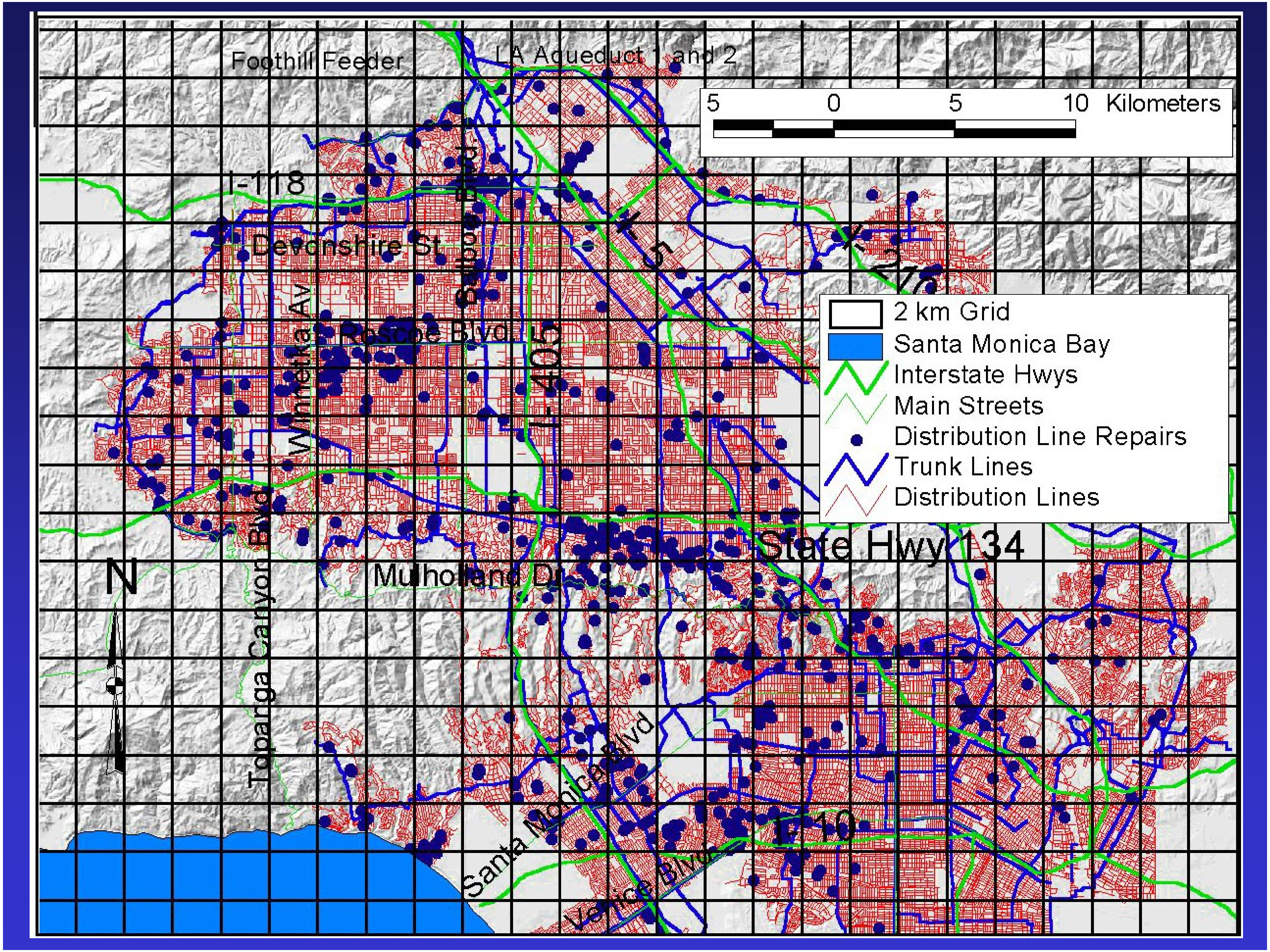




Pipeline Damage Due to Fault Movement (Eidinger et al., 2002)

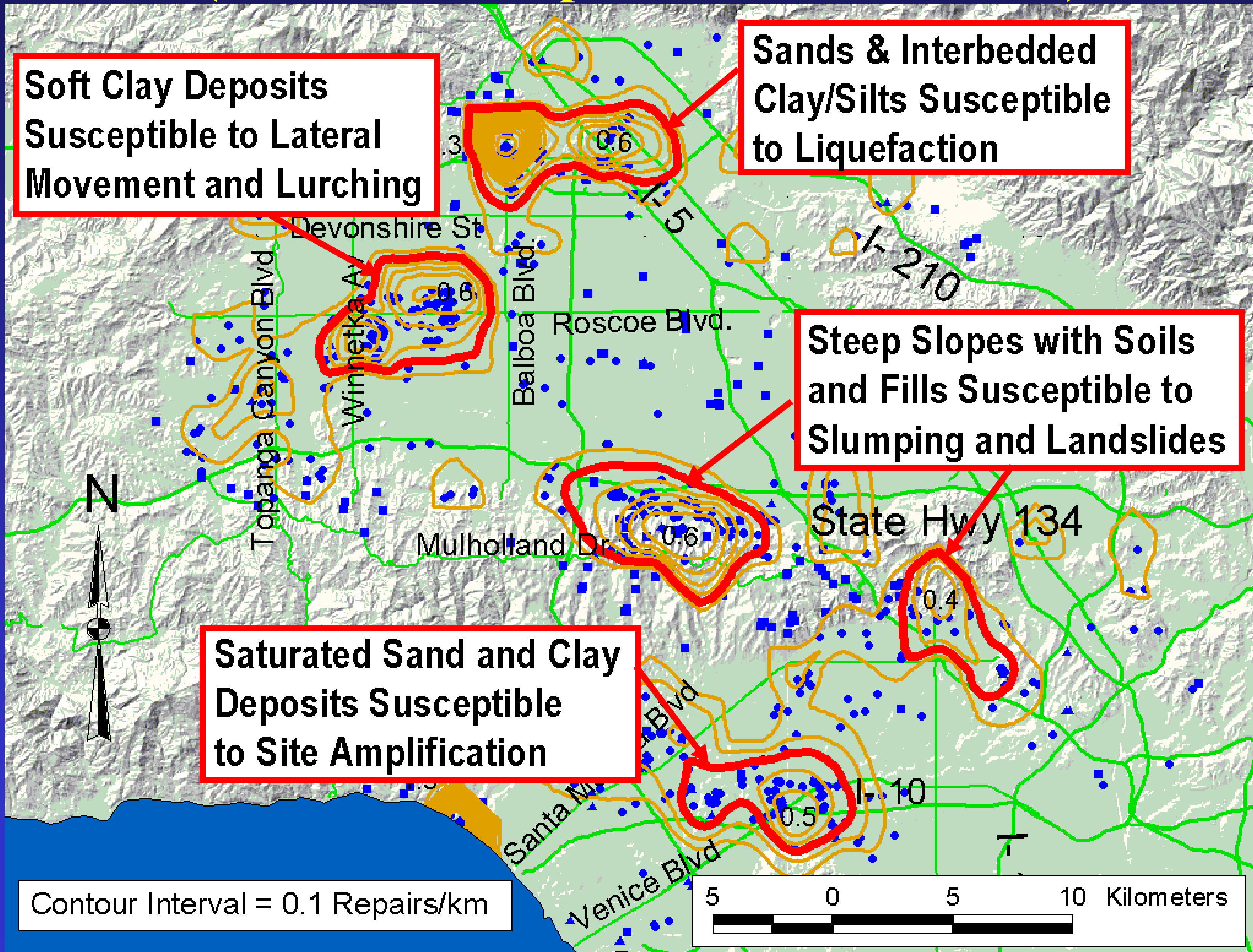
Los Angeles Water Supply System Damage, 1994 Northridge Earthquake (O'Rourke and Toprak,1997)





Foothill Feeder
LA Aqueduct 1 and 2
5 0 5 10 Kilometers
I-118
Devonshire St
Balboa Blvd
I-5
I-210
Winnetka Av
Roscoe Blvd.
I-405
2 km Grid
Santa Monica Bay
Interstate Hwys
Main Streets
Distribution Line Repairs
Trunk Lines
Distribution Lines
State Hwy 134
Mulholland Dr
N
Topanga Canyon Blvd
Santa Monica Blvd
I-10
Venice Blvd

Pipeline Damage and Geotechnical Conditions (O'Rourke, Toprak, and Jeon, 1999)

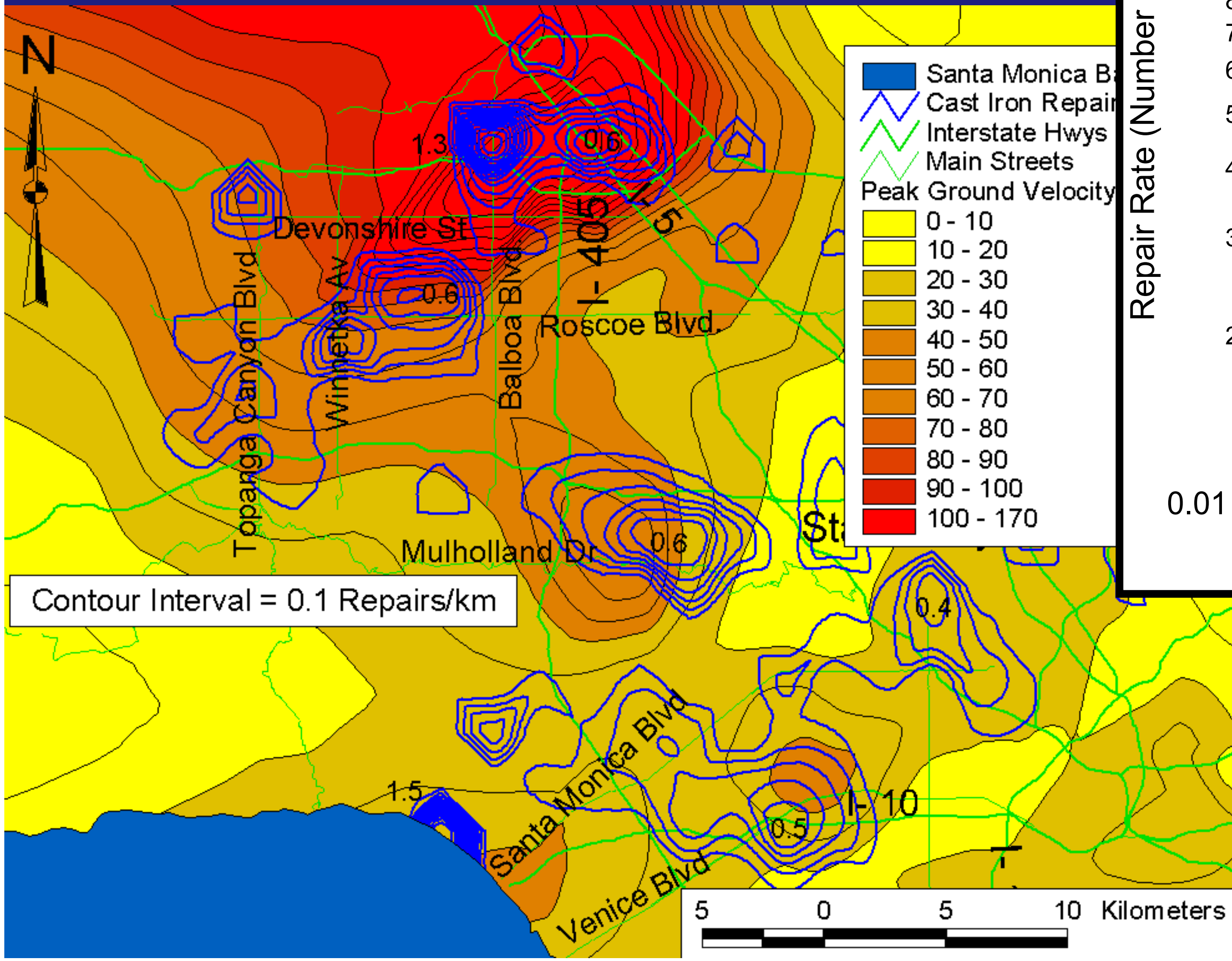


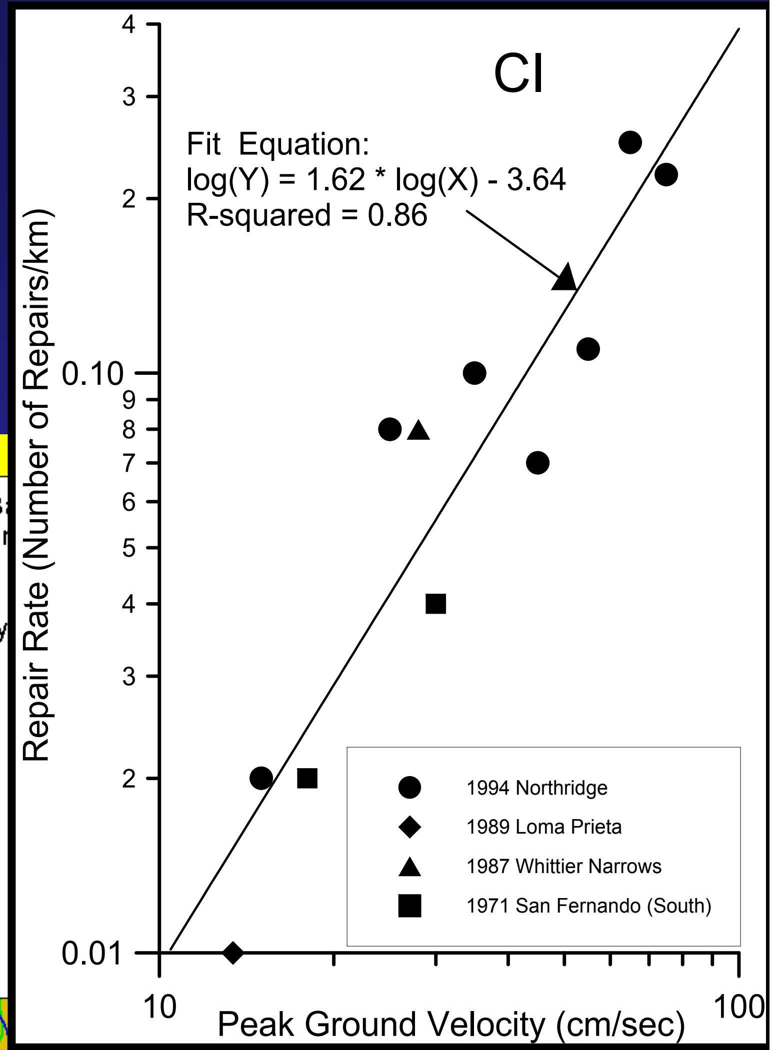
Pipeline Damage Correlation with Seismic Parameters

Selected Parameters:

Peak Ground Acceleration (PGA)
Peak Ground Velocity (PGV)
Peak Ground Displacement
Spectral Acceleration and Velocity (SA and SV)
Spectrum Intensity (SI)
Arias Intensity (AI)

Pipeline Damage Correlation with Peak Ground Velocity (PGV)

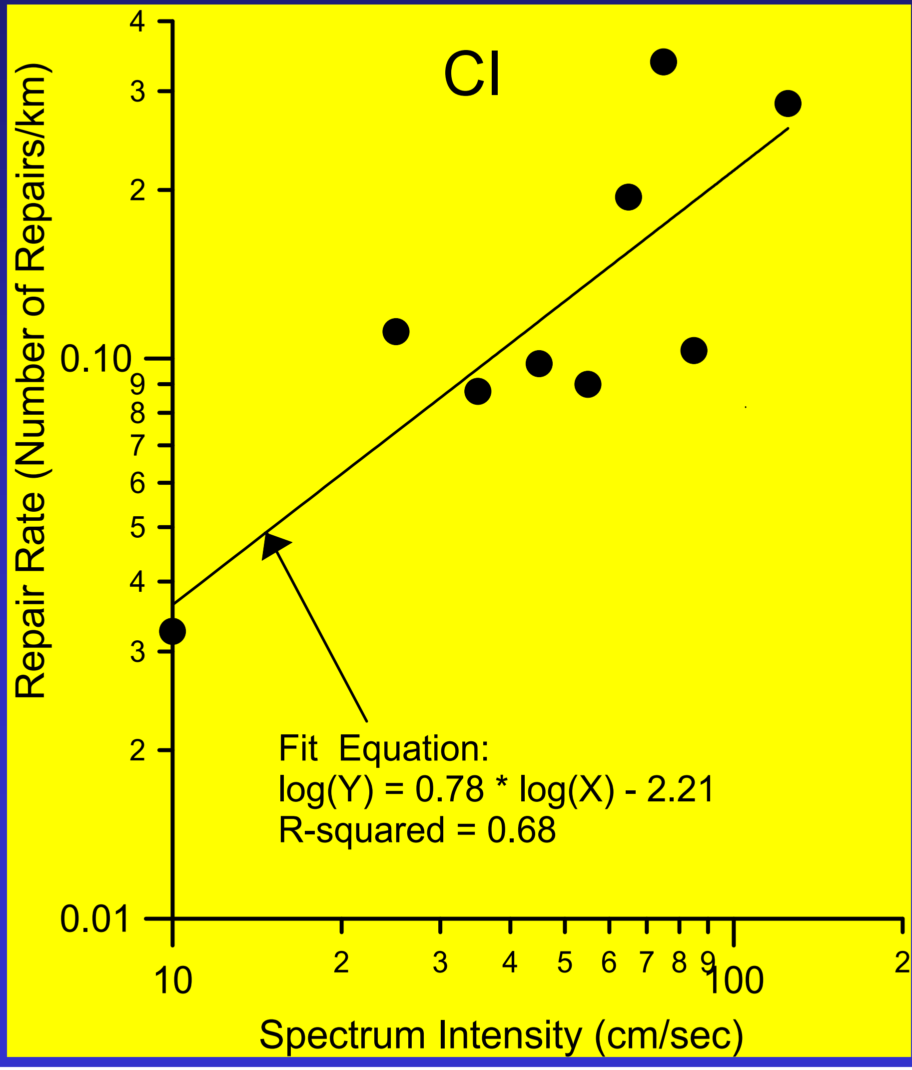




Repair rate: The number of repairs/km

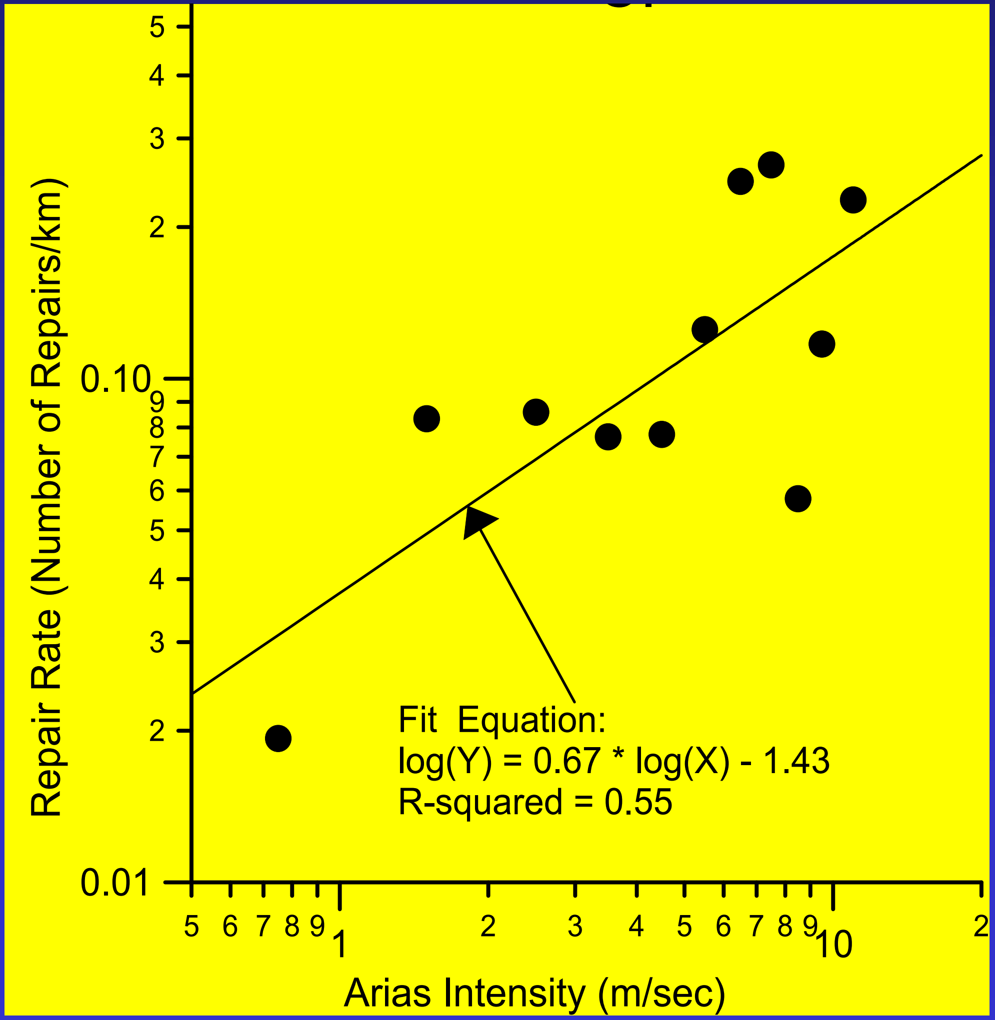
Repair Rate with respect to Spectrum Intensity

$$SI = \frac{1}{2.4}\int_{0.1}^{2.5} SV(T,\zeta)\,dT$$



Repair Rate with respect to Arias Intensity

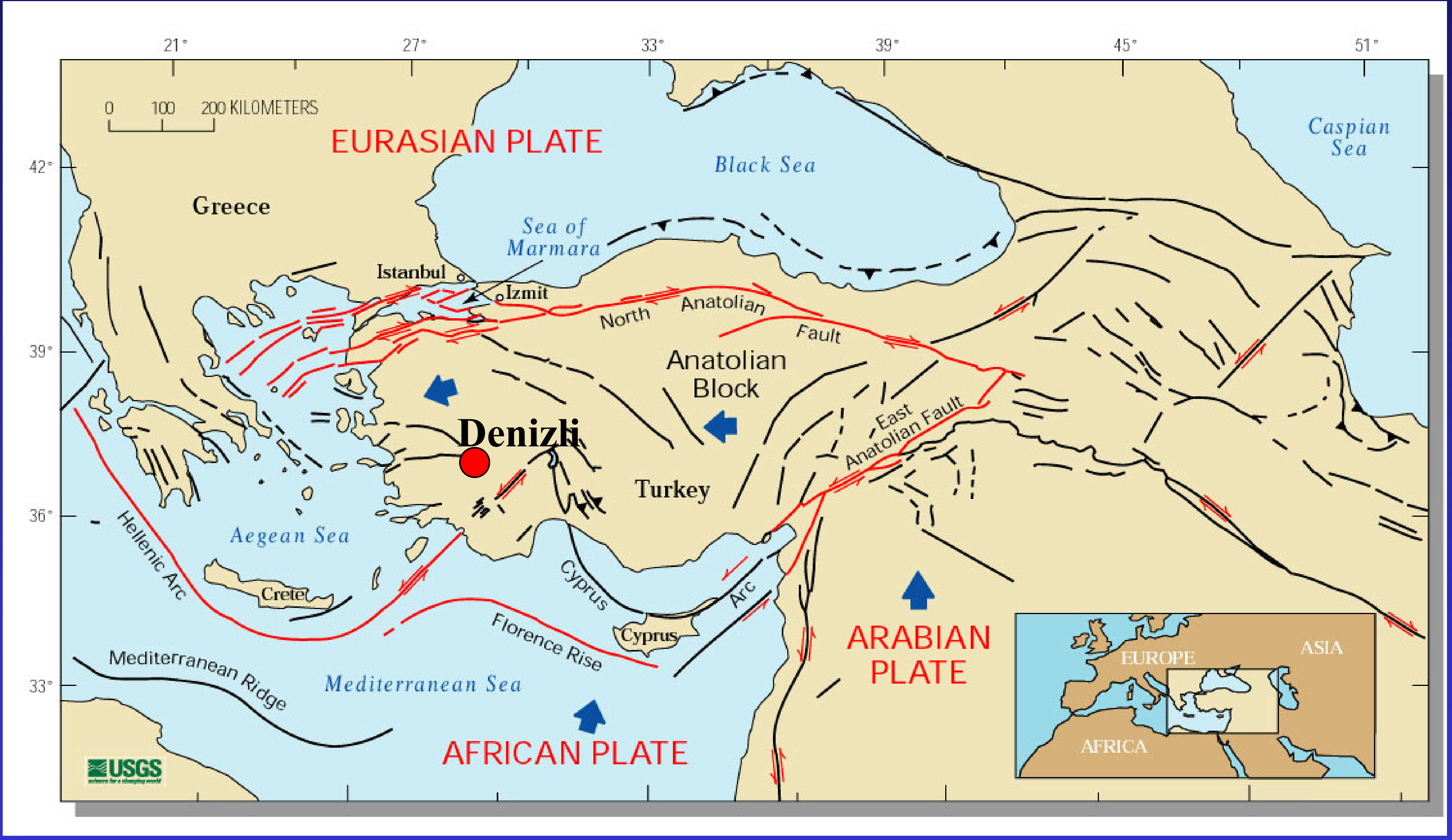
$$AI_h = AI_{xx} + AI_{yy} = \frac{\pi}{2g}\int_0^{t_0} a_x^2(t)dt + \frac{\pi}{2g}\int_0^{t_0} a_y^2(t)dt$$



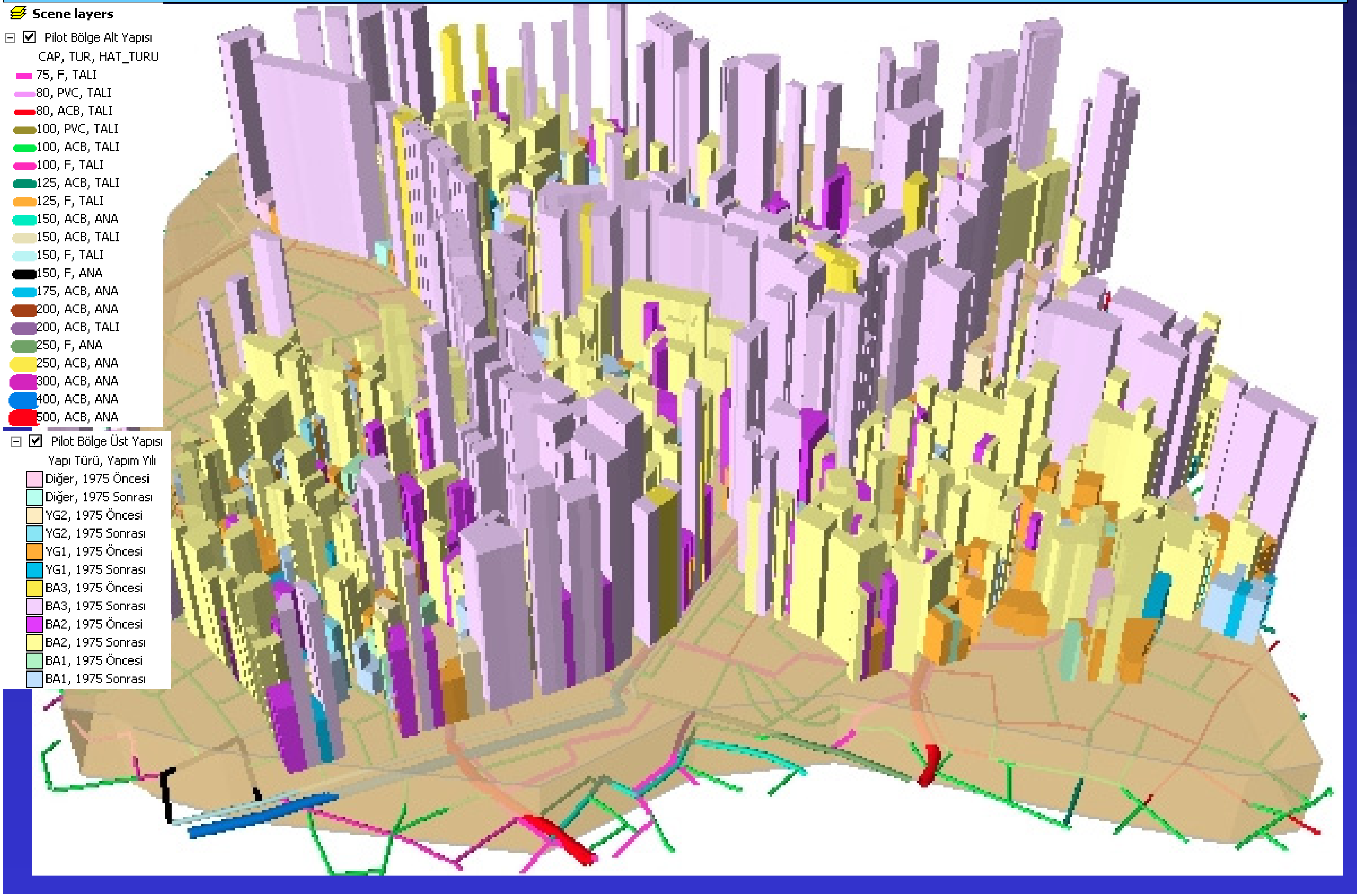
Seismic Parameters	Equation	r^2
Peak Ground Velocity	Log (RR)= 1.62 Log (X) - 3.64	0.86
Peak Ground Acceleration	Log (RR)= 1.36 Log (X) - 0.61	0.81
Modified Mercalli Intensity	Log (RR)= 0.52 X - 5.26	0.74
Spectrum Intensity	Log (RR)= 0.78 Log (X) - 2.21	0.68
Arias Intensity	Log (RR)= 0.67 Log (X) - 1.43	0.55
Spectral Acc., T=0.3 sec.	Log (RR)= 0.9 Log (X) - 1.07	0.45
Spectral Acc., T=1 sec.	Log (RR)= 0.49 Log (X) - 0.91	0.43
Peak Ground Displacement	Log (RR)= 0.64 Log (X) - 1.8	0.39

Earthquake Hazard Assessment in Denizli City, Turkey

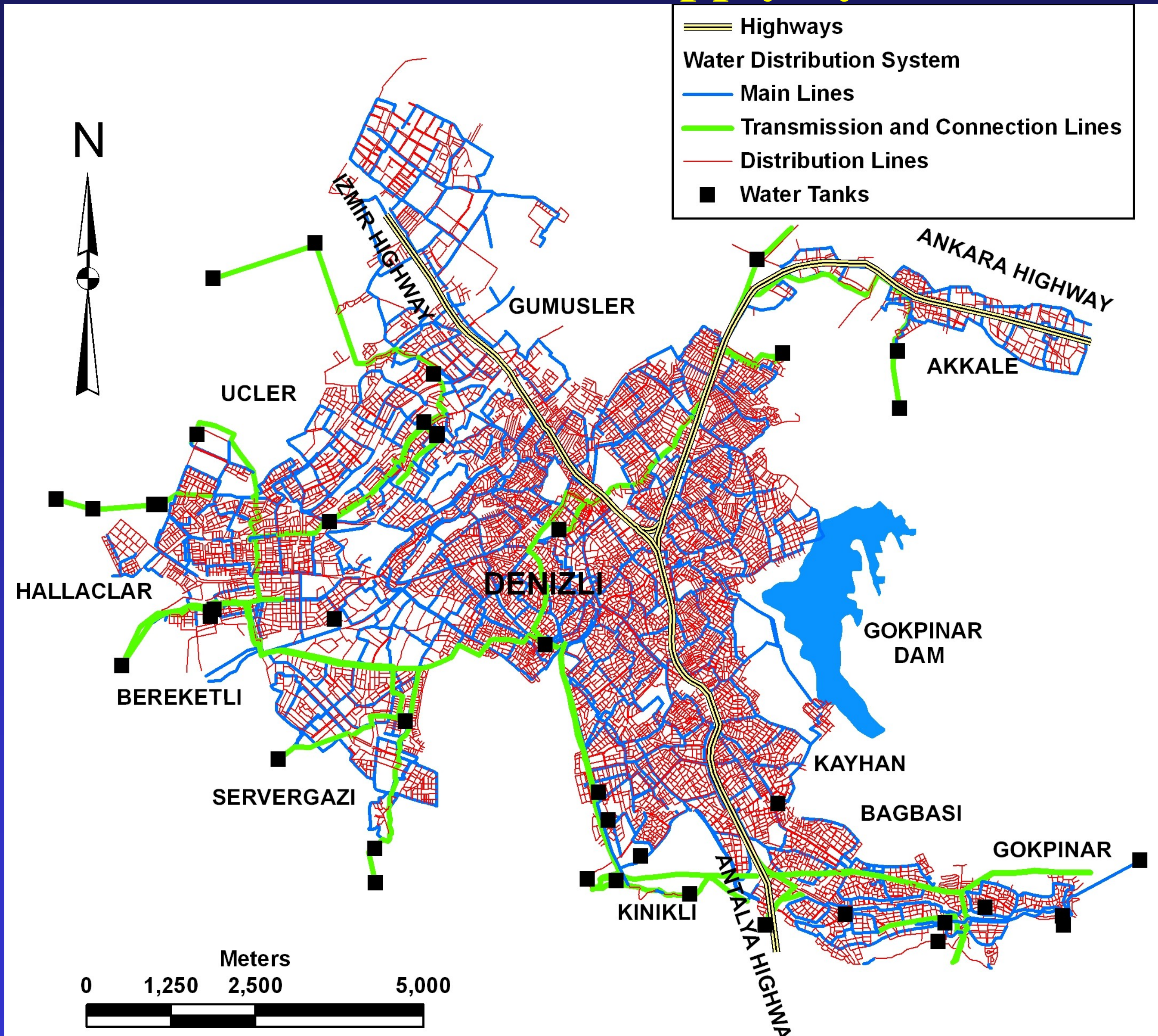
Seismicity of Turkey



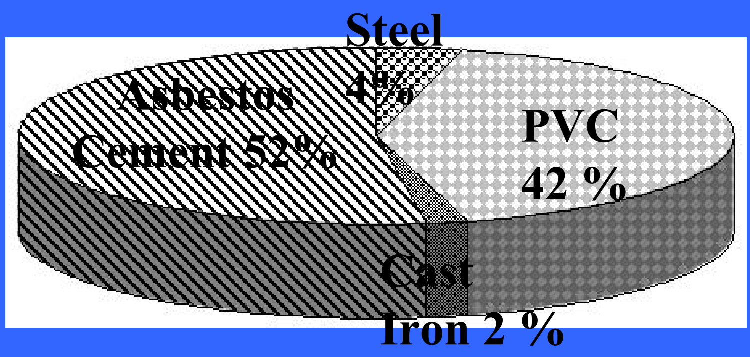
EARTHQUAKE DAMAGE ESTIMATION WITH GEOGRAPHICAL INFORMATION SYSTEMS (GIS): DENİZLİ CASE STUDY

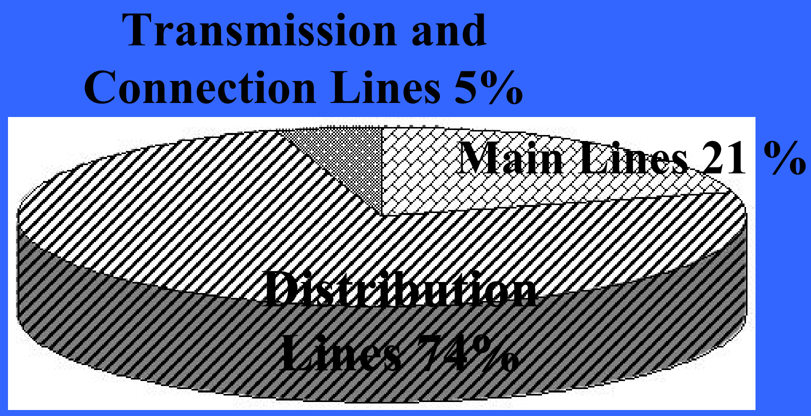


Denizli Water Supply System

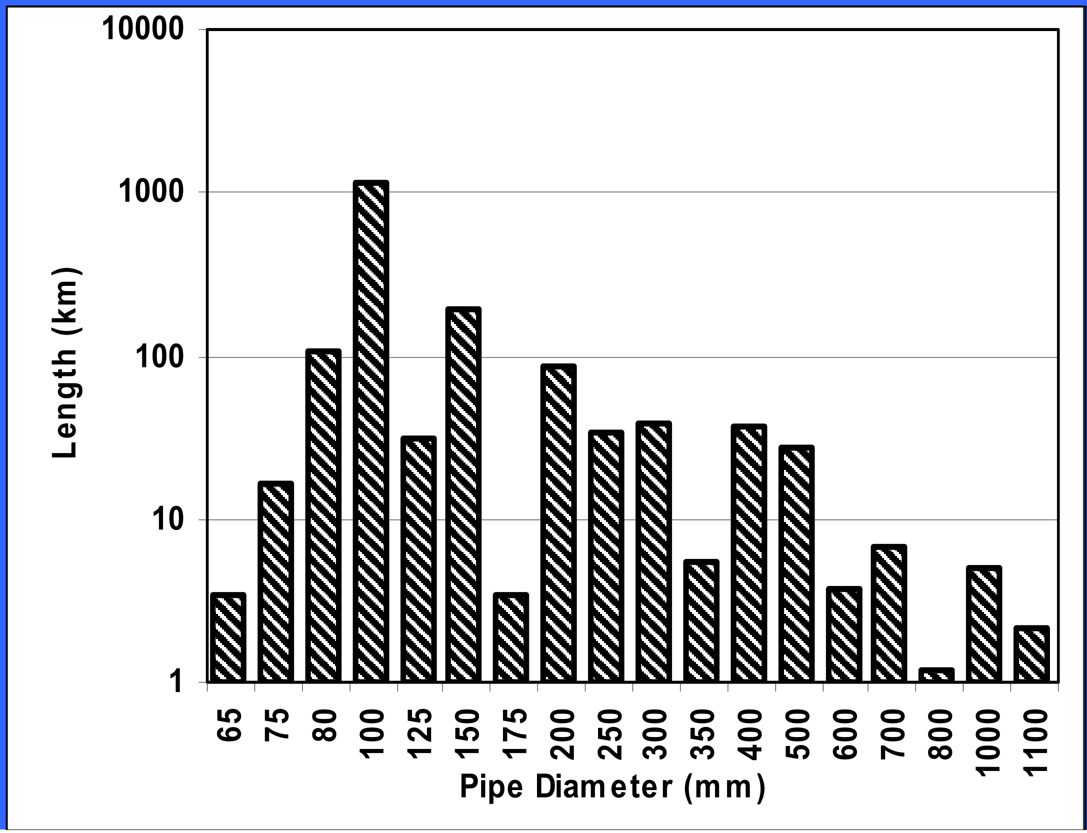


Composition Statistics of Pipelines in the Water Supply System





Total Pipeline Length: 1745 km



PIPELINE DAMAGE PREDICTION

Primary Causes of Pipeline Damage:

- Transient Ground Deformation (TGD Effects): characterized by peak ground velocity (PGV)
- Permanent Ground Deformation (PGD Effects): (e.g., lateral spreads due to liquefaction)

Damage Parameter

- Repair rate: The number of repairs/pipeline length, km

Pipeline Types

- Brittle versus Ductile

Damage States

- Leaks and breaks

Damage Analyses

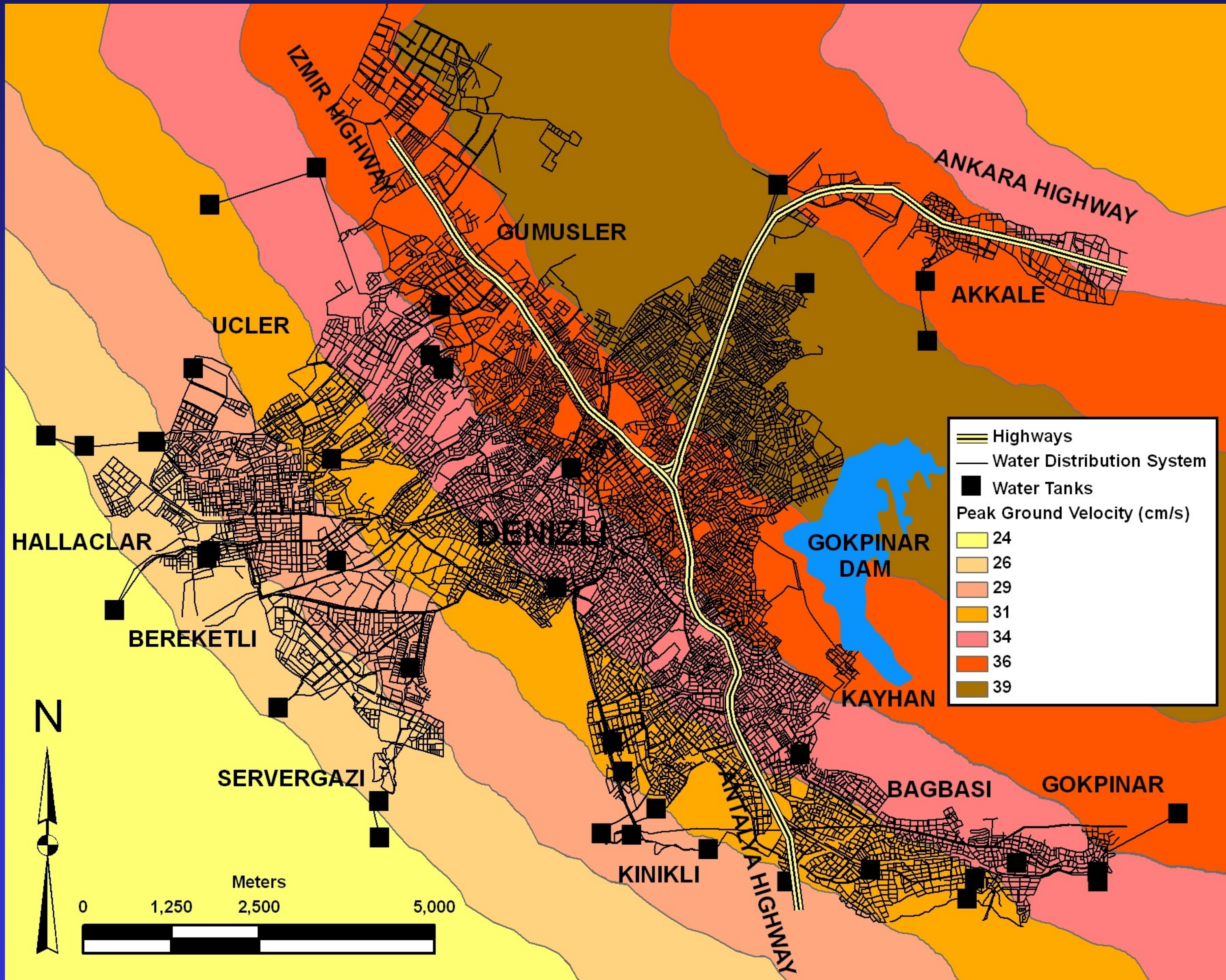
Scenario earthquakes with magnitudes Mw = 6.0, 6. 3, 6.5 and 7.0 caused by Pamukkale and Karakova-Akhan fault ruptures were used in this project. M6.3 represents the most probable earthquake whereas M7.0 represents the maximum probable earthquake

Based on the past earthquake data and the crustal deformation measurements by GPS (Aydan, et al 2001)

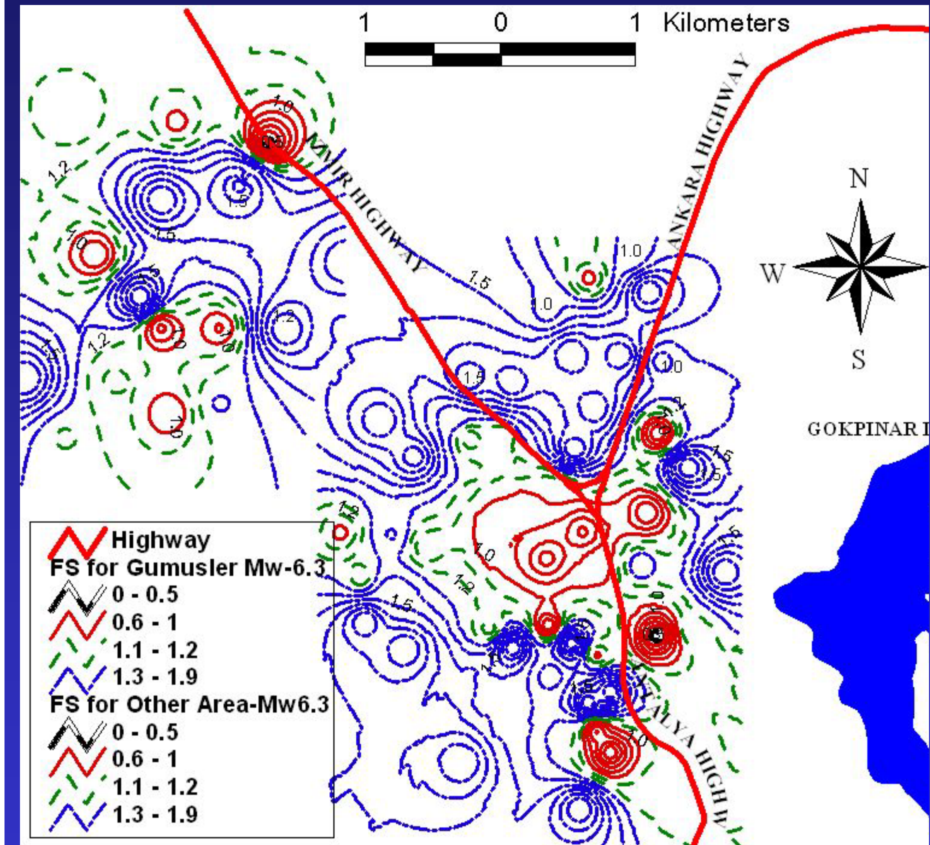
Damage Analyses

- Campbell and Bozorgnia (2003), Campbell (1997) Attenuation Relationships for PGV and PGA Distribution
- Various Pipeline Damage Correlation for TGD Effects
  - Toprak (1998)
  - O'Rourke and Jeon (1999, 2000) Diameter Scaled PGV
  - ALA (2001)
  - M.O'Rourke ve Deyoe (2004)
- Various Pipeline Damage Correlations for PGD Effect
  HAZUS
  ALA (2001)
- Ductile Pipelines are assumed to have 30% of the vulnerability of brittle pipelines

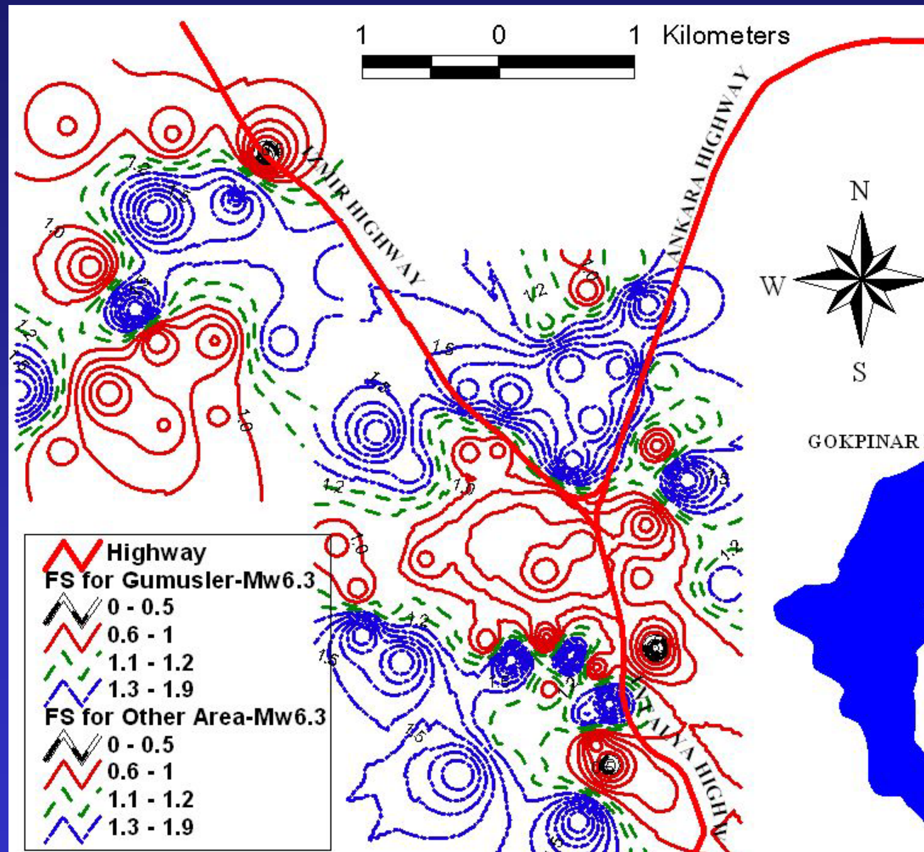
Water Supply System Superimposed on the PGV Zones from M6.3 Karakova-Akhan Fault Rupture Scenario Earthquake



Contours of Factor Safety against Liquefaction for M6.3 Scenario Earthquake



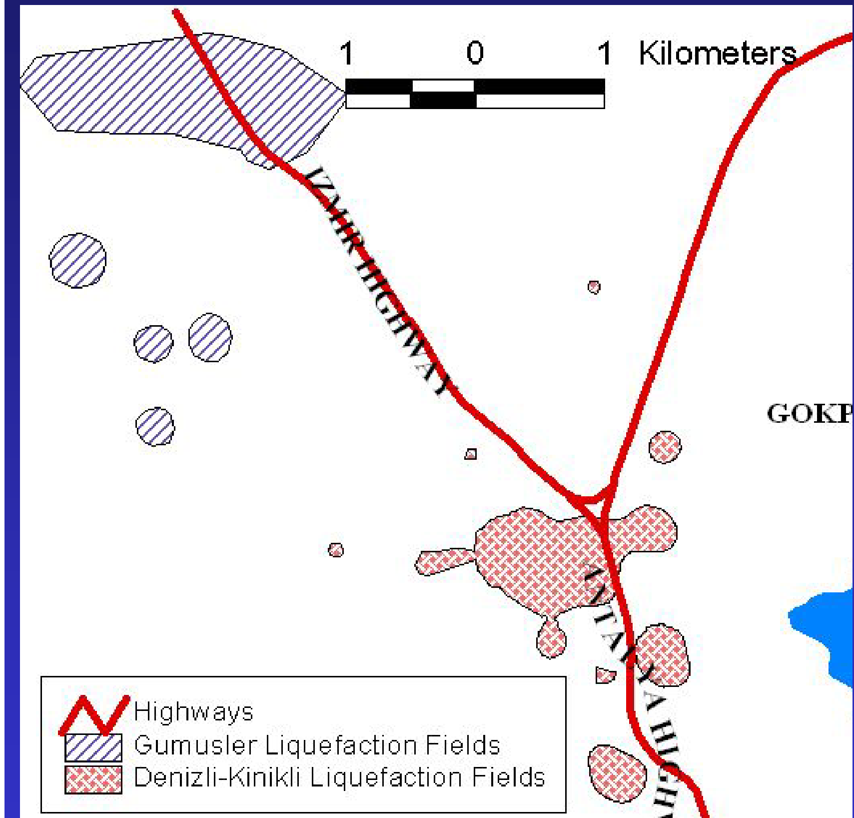
a) Pamukkale Fault

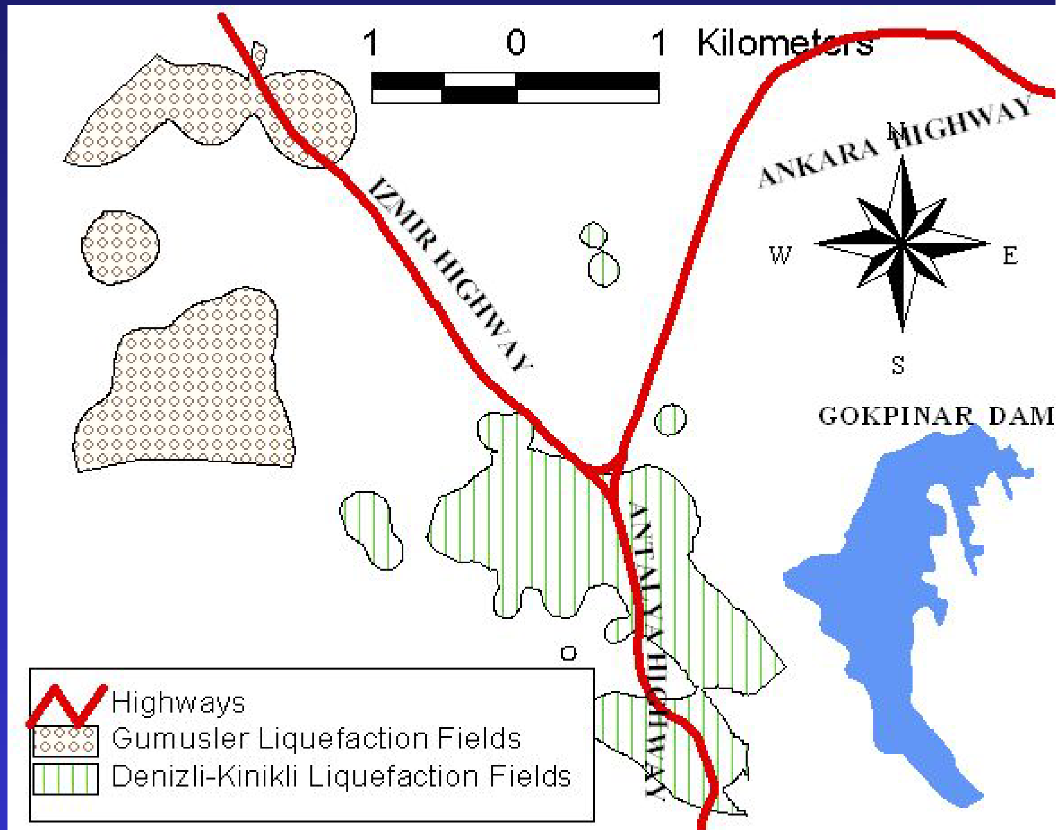


b) Karakova-Akhan Fault

Using Seed and Idriss (1971) procedure with modifications from Youd et al (2001)

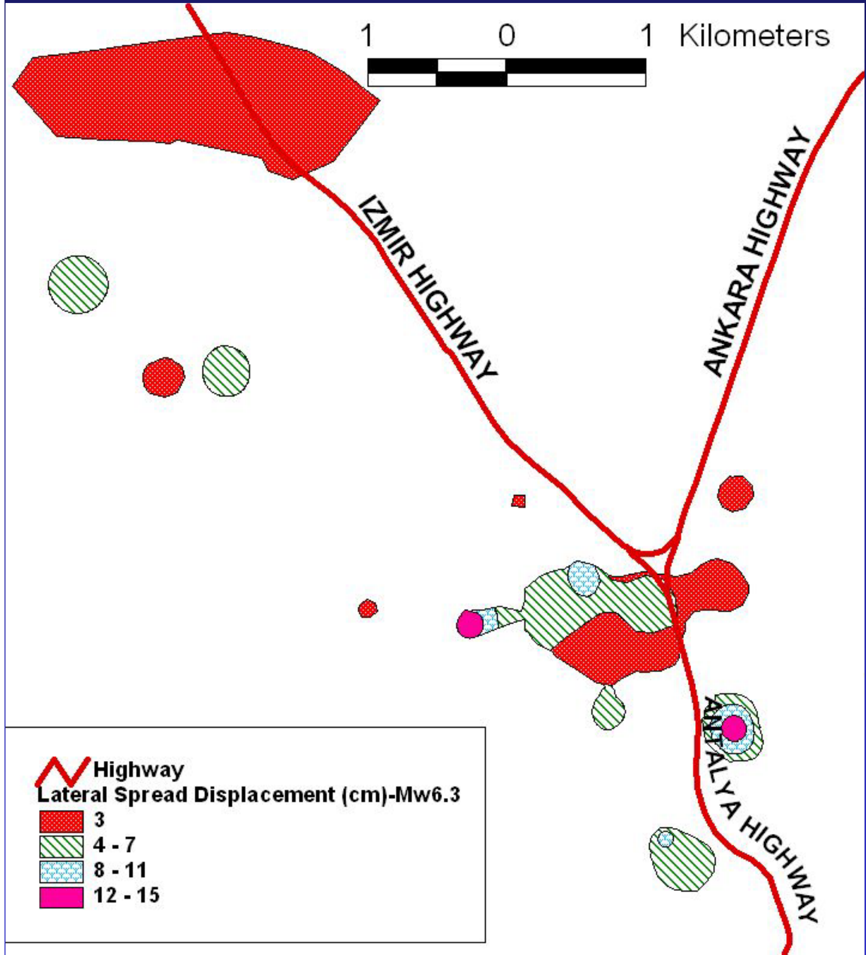
Predicted Areas of Liquefaction for M6.3 Scenario Earthquake



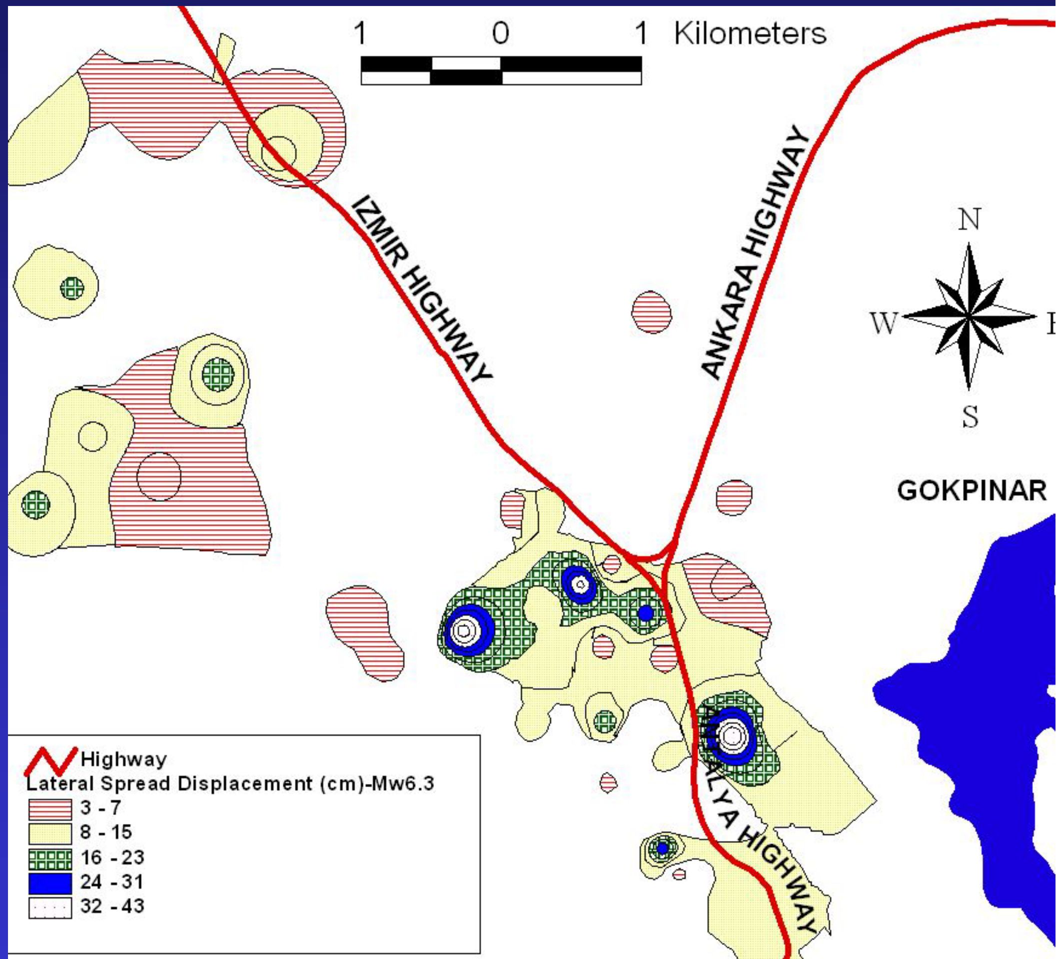


a) Pamukkale Fault **b) Karakova-Akhan Fault**

Predicted Lateral Displacements for M6.3 Scenario Earthquake



a) Pamukkale Fault



b) Karakova-Akhan Fault

Using Youd, T. L., Hansen, C. M., and Bartlett, S. F. (2002) procedure

Results

		TGD Methods	Number of Repairs PGD Methods		Serviceability Index (%)	
	Fault		ALA	HAZUS	ALA	HAZUS
CASE I	Pamukkale	Toprak (1998)	297 + 64	91+ 64	34	80
		O'Rourke and Jeon (1999, 2000) Diameter Scaled PGV	297 + 151	91+ 151	34	75
		ALA (2001)	297 + 76	91+ 76	34	80
		M.O'Rourke ve Deyoe (2004)	297 + 91	91+ 91	34	80
	Karakova-Akhan	Toprak (1998)	1096 + 113	418 + 113	4	20
		O'Rourke and Jeon (1999, 2000) Diameter Scaled PGV	1096 + 225	418 + 225	4	20
		ALA (2001)	1096 + 108	418 + 108	4	20
		M.O'Rourke ve Deyoe (2004)	1096 + 127	418 + 127	4	20
CASE II	Pamukkale	Toprak (1998)	228 + 64	79 + 64	46	85
		O'Rourke and Jeon (1999, 2000) Diameter Scaled PGV	228 + 151	79 + 151	45	80
		ALA (2001)	228 + 76	79 + 76	46	85
		M.O'Rourke ve Deyoe (2004)	228 + 91	79 + 91	46	80
	Karakova-Akhan	Toprak (1998)	841 + 113	366 +113	5	24
		O'Rourke and Jeon (1999, 2000) Diameter Scaled PGV	841 + 225	366 + 225	5	24
		ALA (2001)	841 + 108	366 + 108	5	24
		M.O'Rourke ve Deyoe (2004)	841 + 127	366 + 127	5	24

Some of the Results

- A replacement program, in addition to other mitigation methods, especially around PGD zones is recommended.

- The results suggest significant reduction in the system performance right after the earthquake. Alternative systems should be prepared to fight post-earthquake fires.

- It is important for municipalities to have appropriate supplies and back up systems for emergency repair and restoration.

- Although not considered in this study, failure of other structures during an earthquake can also have some effect on the water supply system performance. Building failure can damage the connections between the distribution line and the buildings, resulting in substantial water loss. Consequently, the system performance can be reduced significantly. Also water supply restoration can be affected by the extensive building damage as in the case of Adapazari after the 1999 Kocaeli earthquake.

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