Project funded by EUROPEAN UNION

REDACt
Rapid Earthquake Damage Assessment ConsorTium

Black Sea CROSS BORDER COOPERATION

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Earthquake damage assessment of gas pipelines

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Worldwide Natural Gas Pipelines Data

Country	Natural Gas Pipeline Length (KMs)
Turkey	**12,603**
United States	1,614,936
United Kingdom	28,603
Russia	163,872
India	17752
Germany	26,985
France	15,322
China	104,000
Brazil	17,312
Argentina	29,930
Australia	30,054
Iran	20,794
Italy	20,223
Mexico	18,074
Ukraine	36,720

https://www.cia.gov/library/publications/the-world factbook/fields/2117.html

Examples of Gas Pipeline Failures in Previous Major Earthquakes

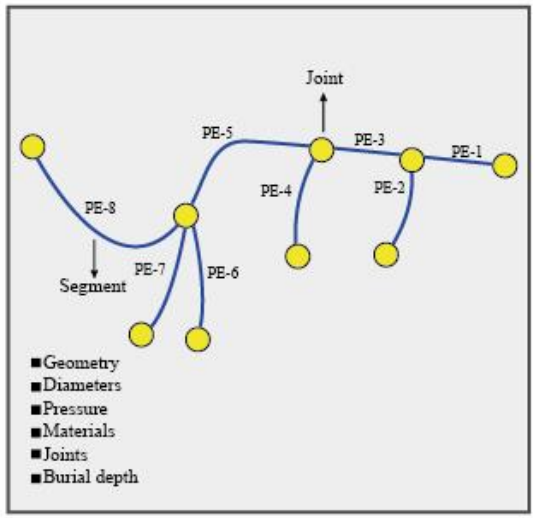

a) 1989 Loma Prieta Earthquake


b) 1999 Kocaeli Earthquake

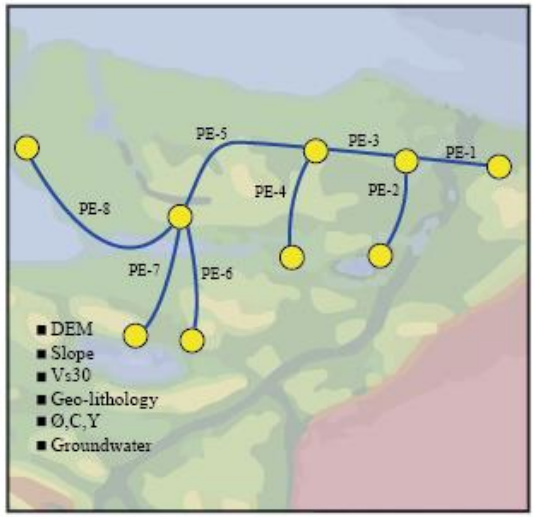

c) 2011 Tohuko, Japan Earthquake

d) 2014 Napa Earthquake

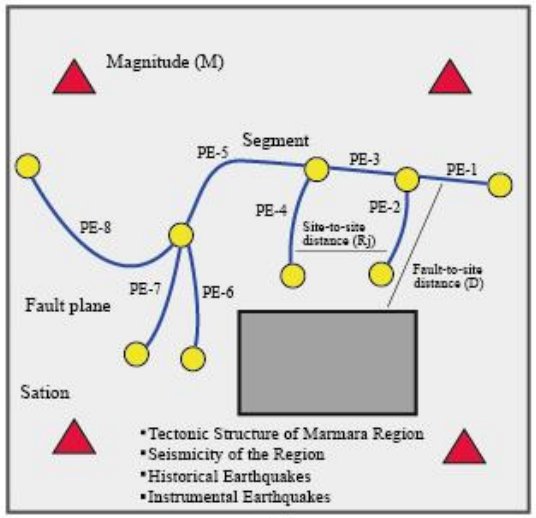
Methodology for seismic hazard evaluation



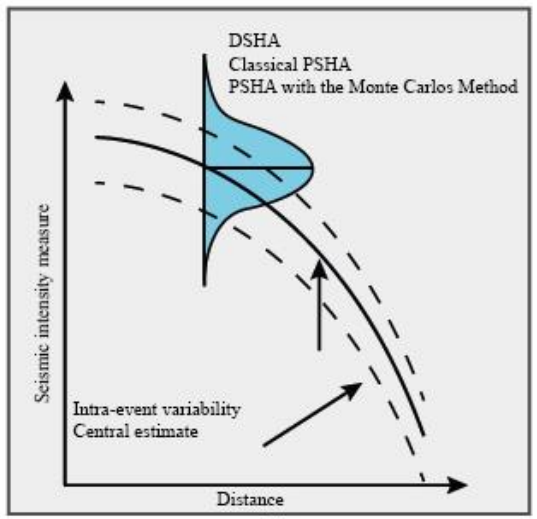
(I)



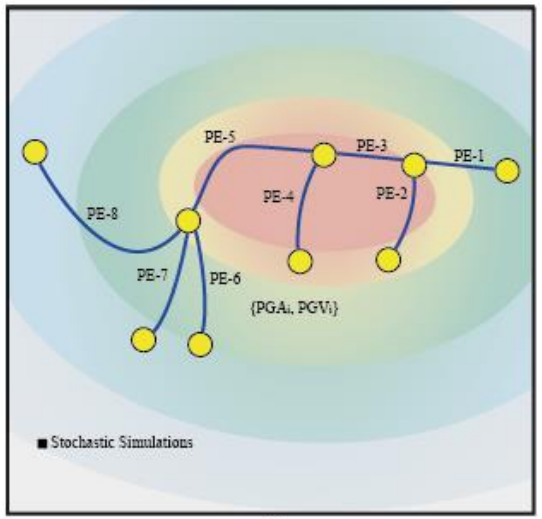
(II)



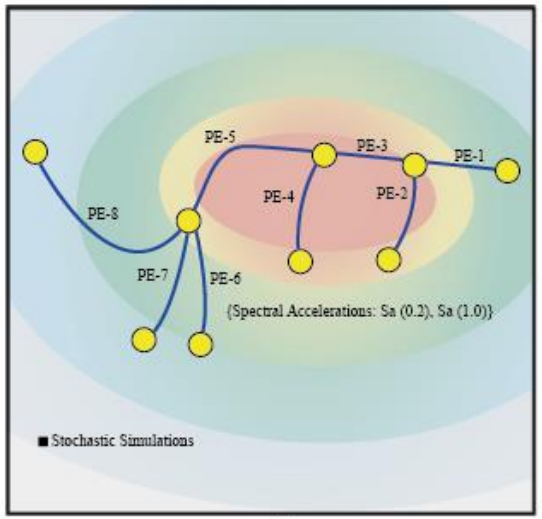
(III)



(IV)



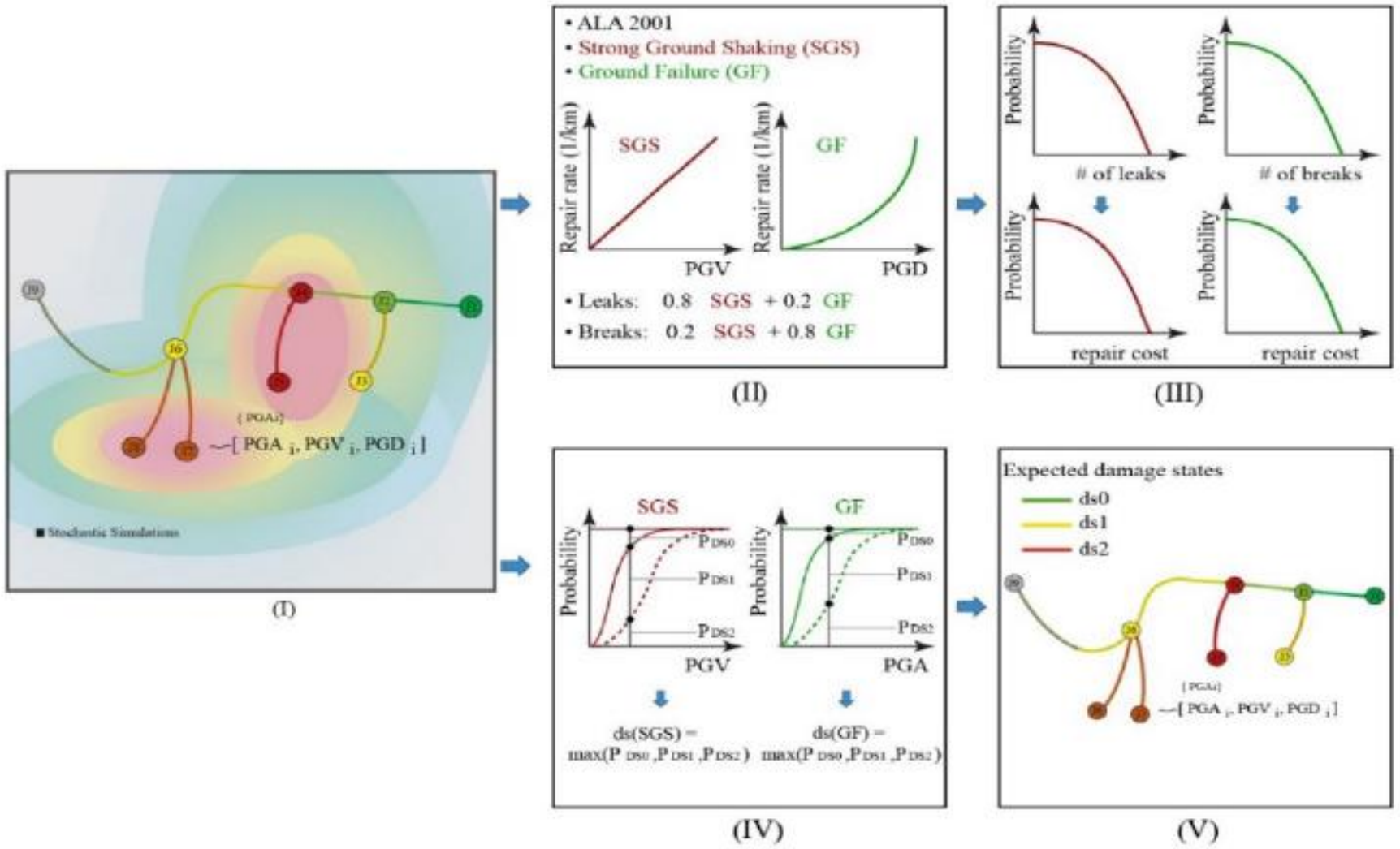
(V)



(VI)

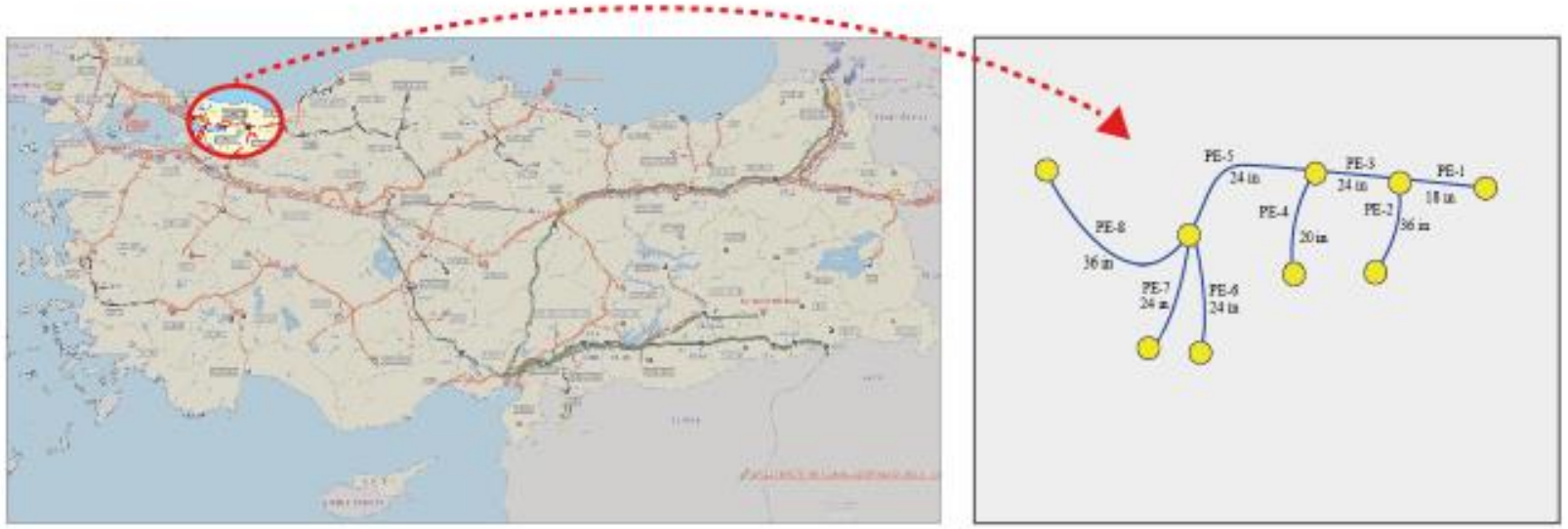
Methodology for seismic hazard evaluation: **I)** Pipe inventory, **II)** available maps of the region, **III)** hazard factors, **IV)** GMPEs, **V)** PGA, PGV, **VI)** Sa (0.1), Sa (0.2)

Methodology for SeismicRisk Evaluation



Seismic risk evaluation: **I)** hazard parameters **II)** vulnerability analysis, **III)** loss figures, **IV)** fragility functions (methodology), and V) Damage maps

Urban Earthquake Risk of Buried Pipeline



a) Turkish regional map and buried gas pipelines network **b)** High-pressure gas network of Düzce – Gebze regions as a test-bed scenario

Pipe Element	Diameter (m)	Thickness (m)
PE-1	0.4572	0.0041
PE-2	0.9144	0.0088
PE-3	0.6096	0.0064
PE-4	0.5080	0.0048
PE-5	0.6096	0.0064
PE-6	0.6096	0.0064
PE-7	0.6096	0.0064
PE-8	0.9144	0.0088

Pipelines diameter and thickness
(Ref: www.botas.gov.tr)

Fragility Relationships: Japan Waterworks Association (1998)

$Rm(PGV) = R(PGV) \times Cp \times Cg \times Cl$

where

Rm(PGV): damage ratio (points/km)

PGV: Peak Ground Velocity (kine = cm/sec)

$R(PGV) = 3.11 \times 10^{-3} \times (PGV-15)^{1.3}$

Cp: pipeline material coefficient

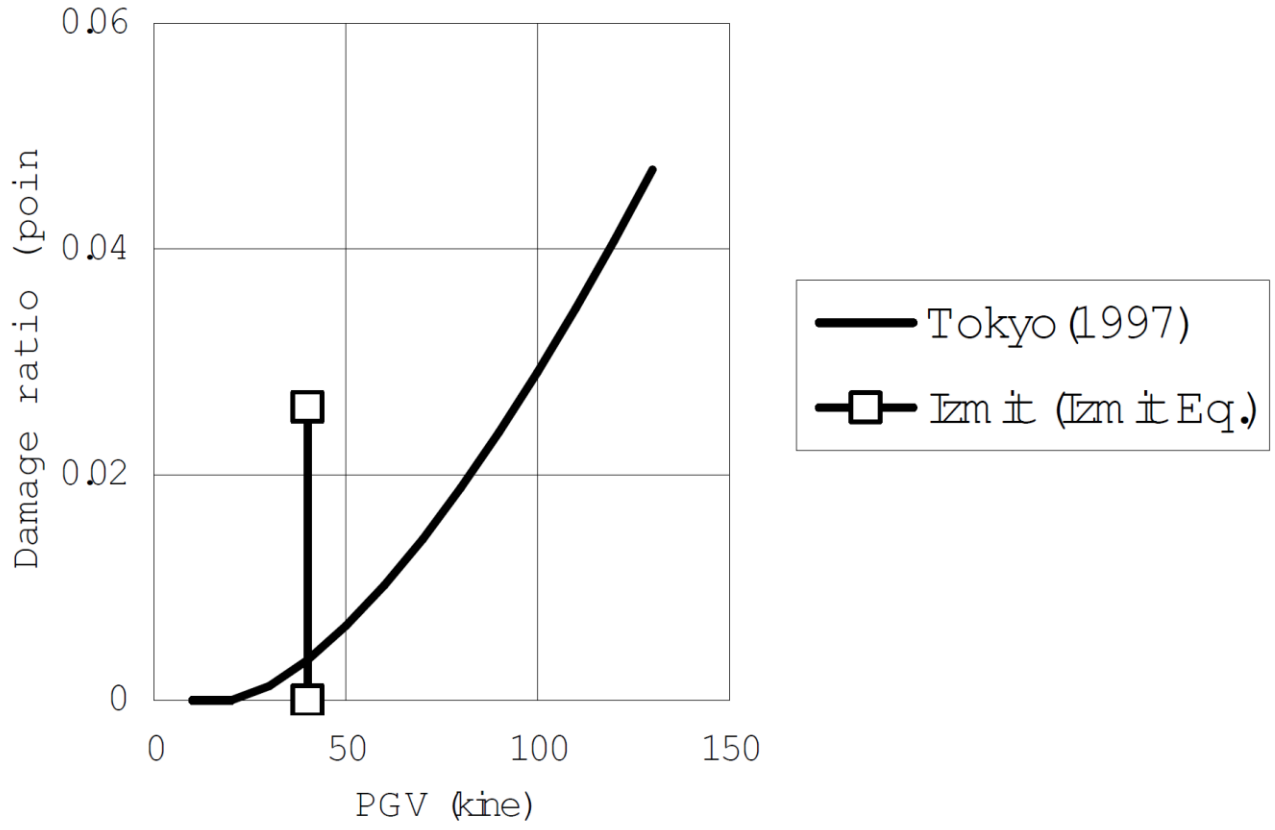
- 0.01 for Steel
- 0.00 for Polyethylene

Cg: ground condition coefficient

- 1.5 for Yd, Sd, Ym
- 1.0 for Qal, Ksf, Oa, Q
- 0.4 for others

Cl: liquefaction coefficient

- 2.0 for Ym, Yd, Sd, Qal, Ksf, Oa, Q
- 1.0 for others



Botas Natural Gas Pipeline Risk Assessment Results

Tokyo Metropolitan Area (1997) was implemented for BOTAS natural gas pipeline system in pilot area (Kocaeli) to test the REDAS (Please see the next slides).

	A	B	C	D	E	F	G	H	I
1	ID	LAYER	NAME	TYPE	D	Uzunluk_Km	CP	CL	K1
2	1	Unknown Line Type	GEBZE RMS/A	Gas Pipeline	0	3.49178000000	0.30000000000	1.00000000000	0.50000000000
3	2	Unknown Line Type	GEBZE RMS/A	Gas Pipeline	0	3.49178000000	0.30000000000	1.00000000000	0.50000000000
4	3	Unknown Line Type	GEBZE RMS/A	Gas Pipeline	0	3.49178000000	0.30000000000	1.00000000000	0.50000000000
5	4	Unknown Line Type	GEBZE RMS/A	Gas Pipeline	0	3.49178000000	0.30000000000	1.00000000000	0.50000000000
6	5	Unknown Line Type	YARIMCA SERAMIK	Gas Pipeline	0	0.89140000000	0.30000000000	1.00000000000	0.50000000000
7	6	Unknown Line Type	CS3-Pendik DGBH	Gas Pipeline	36	25.80650000000	0.30000000000	1.00000000000	0.50000000000
8	7	Unknown Line Type	CS3-Pendik DGBH	Gas Pipeline	36	25.80650000000	0.30000000000	1.00000000000	0.50000000000
9	8	Unknown Line Type	CS3-Pendik DGBH	Gas Pipeline	36	25.80650000000	0.30000000000	1.00000000000	0.50000000000
10	9	Unknown Line Type	CS3-Pendik DGBH	Gas Pipeline	36	25.80650000000	0.30000000000	1.00000000000	0.50000000000
11	10	Unknown Line Type	CS3-Pendik DGBH	Gas Pipeline	36	25.80650000000	0.30000000000	1.00000000000	0.50000000000
12	11	Unknown Line Type	CS3-Pendik DGBH	Gas Pipeline	36	25.80650000000	0.30000000000	1.00000000000	0.50000000000
13	12	Unknown Line Type	CS3-Pendik DGBH	Gas Pipeline	36	25.80650000000	0.30000000000	1.00000000000	0.50000000000
14	13	Unknown Line Type	CS3-Pendik DGBH	Gas Pipeline	36	25.80650000000	0.30000000000	1.00000000000	0.50000000000
15	14	Unknown Line Type	CS3-Pendik DGBH	Gas Pipeline	36	25.80650000000	0.30000000000	1.00000000000	0.50000000000
16	15	Unknown Line Type	CS3-Pendik DGBH	Gas Pipeline	36	25.80650000000	0.30000000000	1.00000000000	0.50000000000
17	16	Unknown Line Type	CS3-Pendik DGBH	Gas Pipeline	36	25.80650000000	0.30000000000	1.00000000000	0.50000000000
18	17	Unknown Line Type	CS3-Pendik DGBH	Gas Pipeline	36	25.80650000000	0.30000000000	1.00000000000	0.50000000000

Botas Natural Gas Pipeline Risk Assessment Results

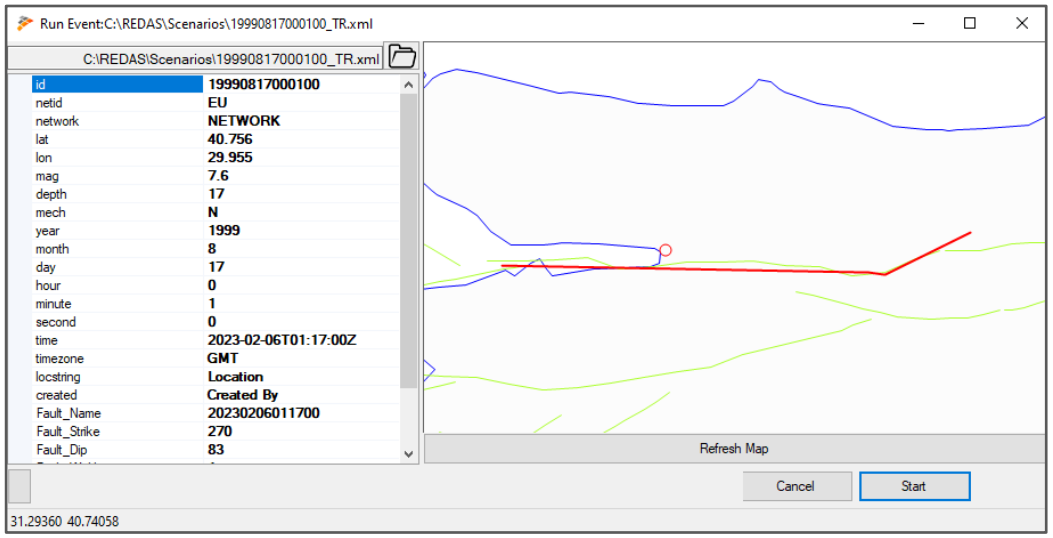


Fig. 1: Kocaeli Eartquake Event and Fault Information in Run Interface

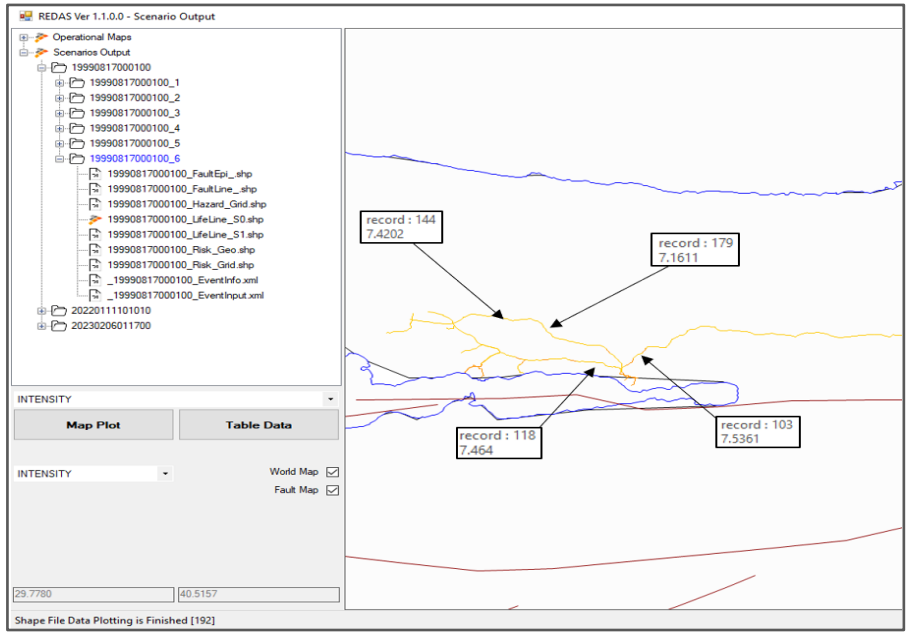


Fig. 2: Intensity Distribution Map

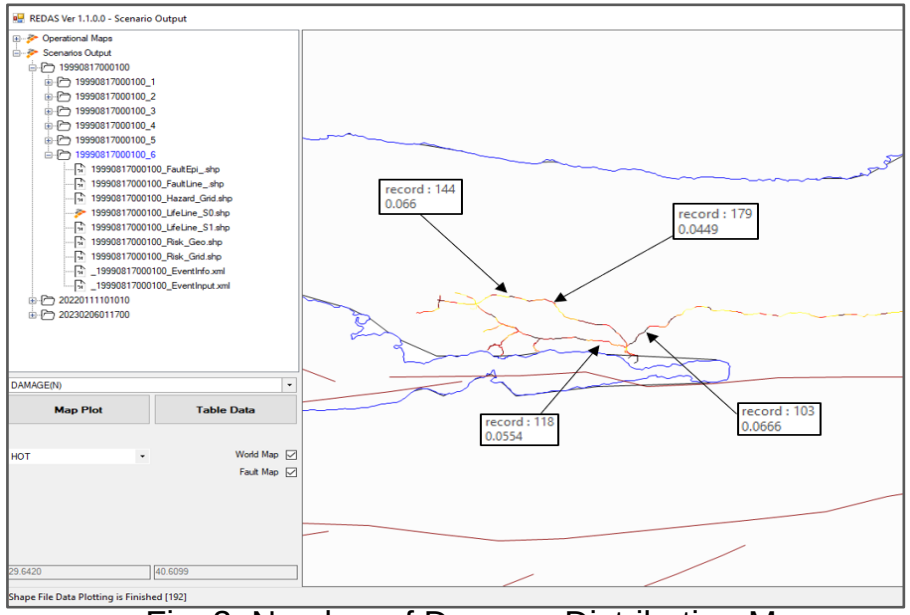


Fig. 3: Number of Damage Distribution Map

Botas Natural Gas Pipeline Risk Assessment Results

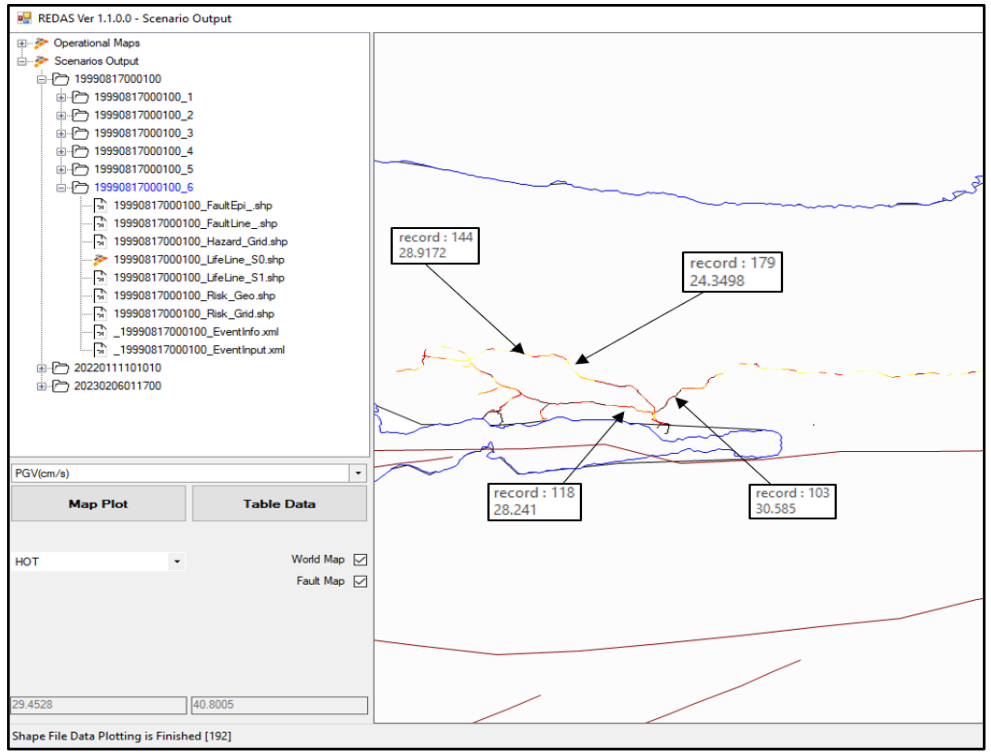


Fig. 4: PGV(cm/s) Distribution Map

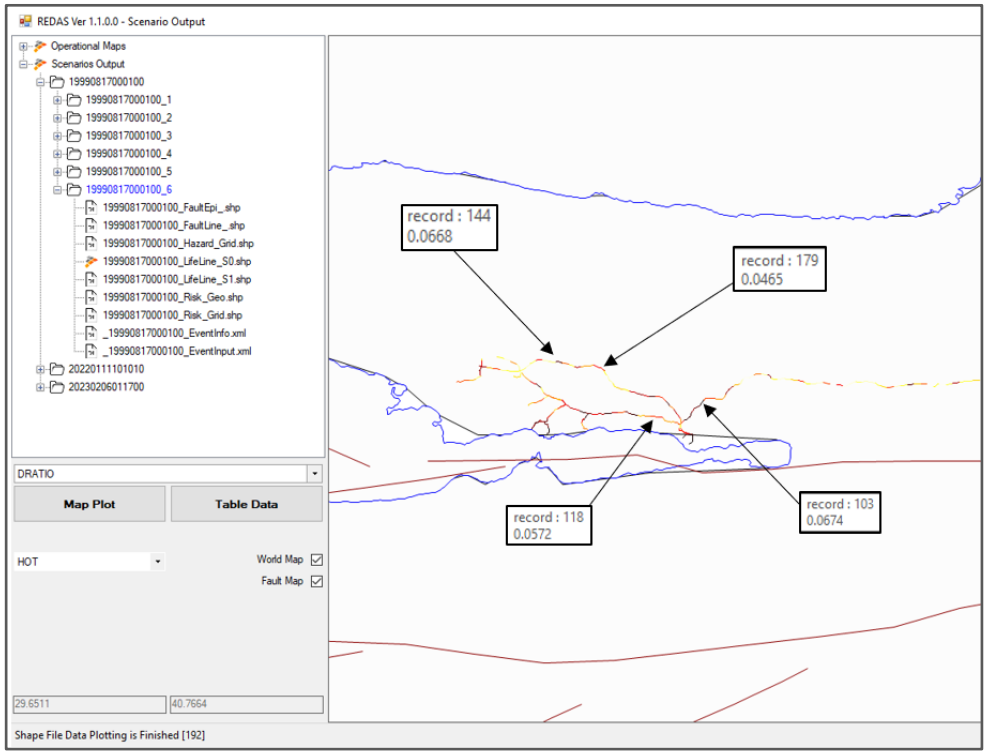
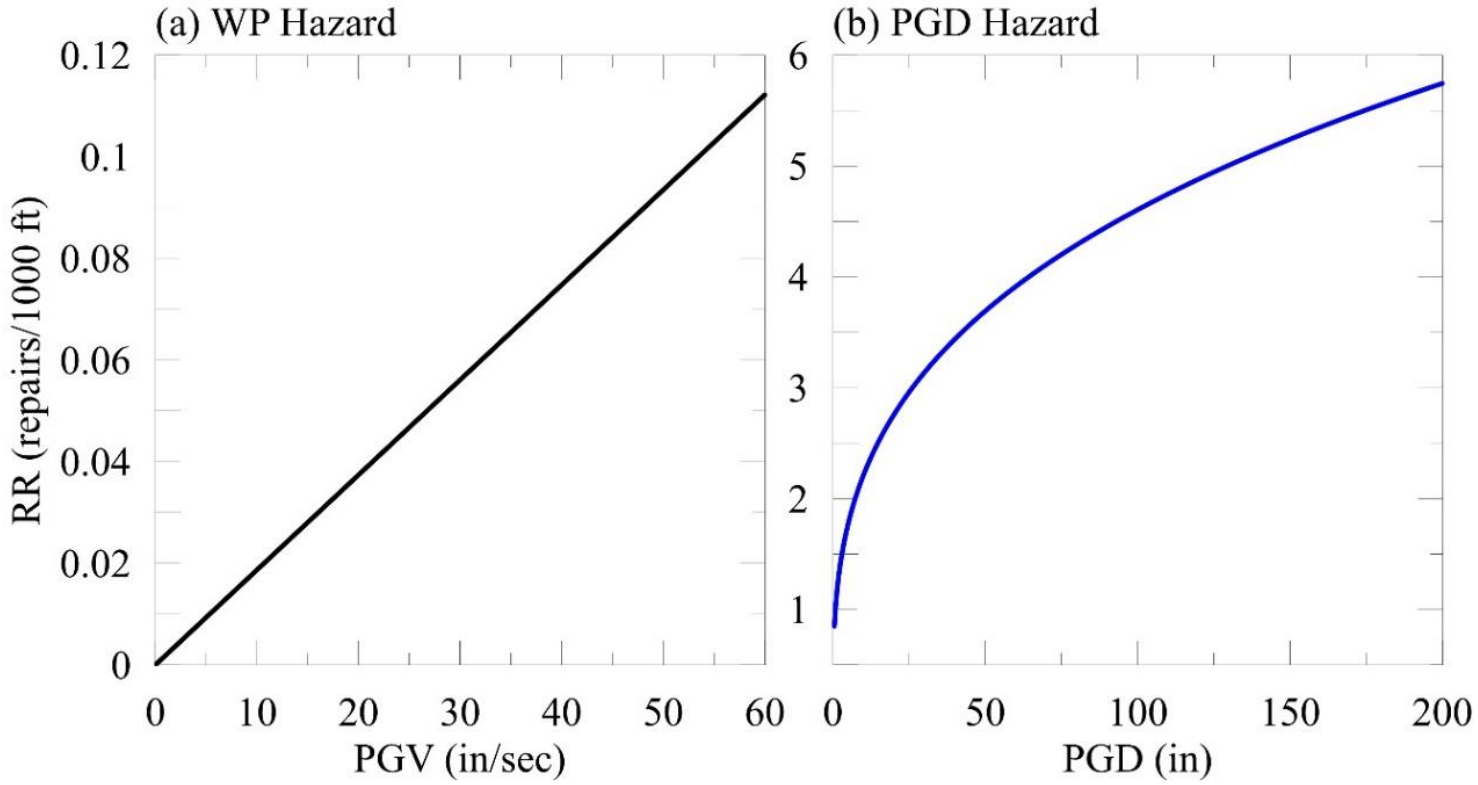


Fig. 5: Ratio of Damage Distribution Map

Fragility Relationships: ALA (2001)

- Proposed two different vulnerability functions for wave propagation using the data from O'Rourke and Ayala (1993), Toprak (1998), and Isoyama et al. (2000).



$Wave$ Propagation:

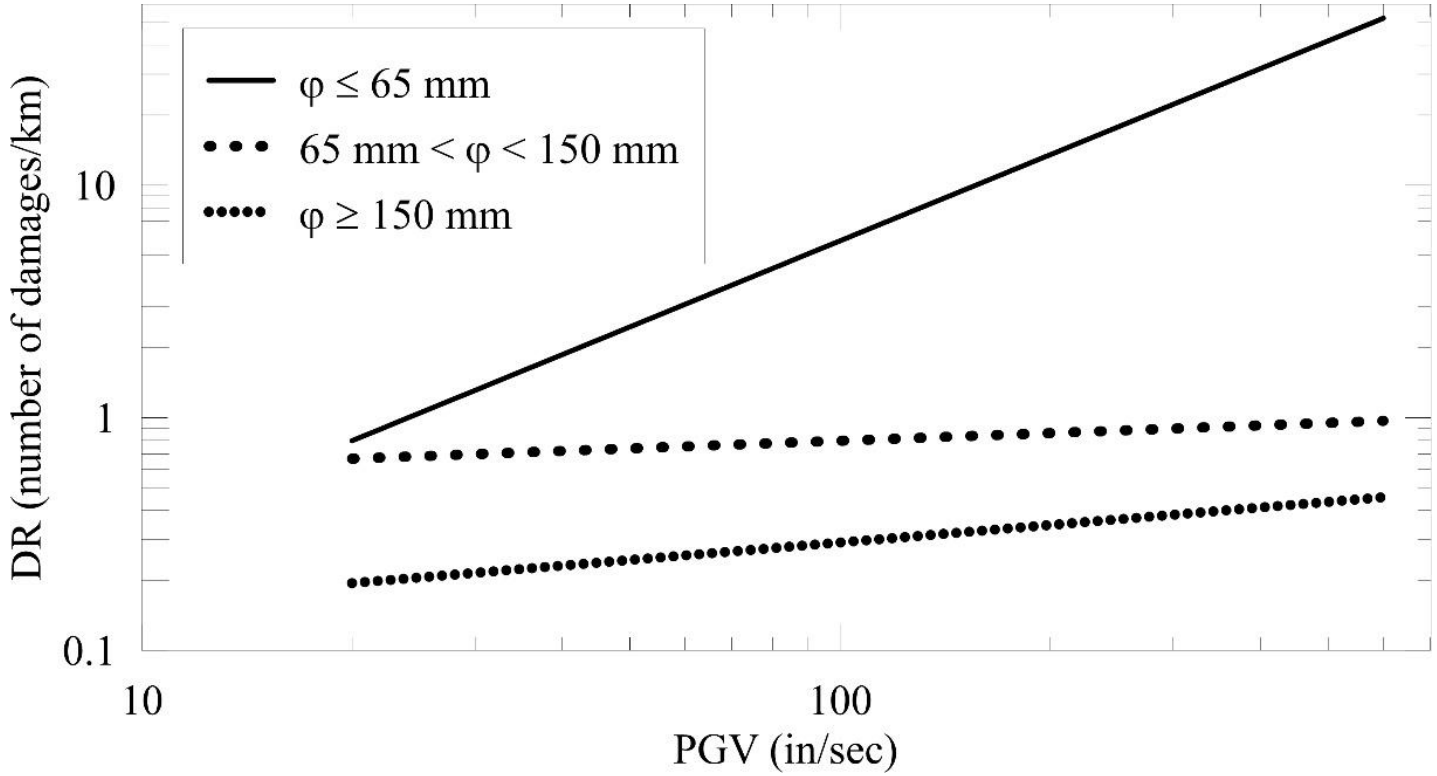
$$RR\ (repairs/1000\ ft) = K_1 \times 0.00187 \times PGV$$

$Permanent$ Ground Deformation:

$$RR\ (repairs/1000\ ft) = K_2 \times 1.06 \times PGD^{0.319}$$

Fragility Relationships: Chen et al. (2002)

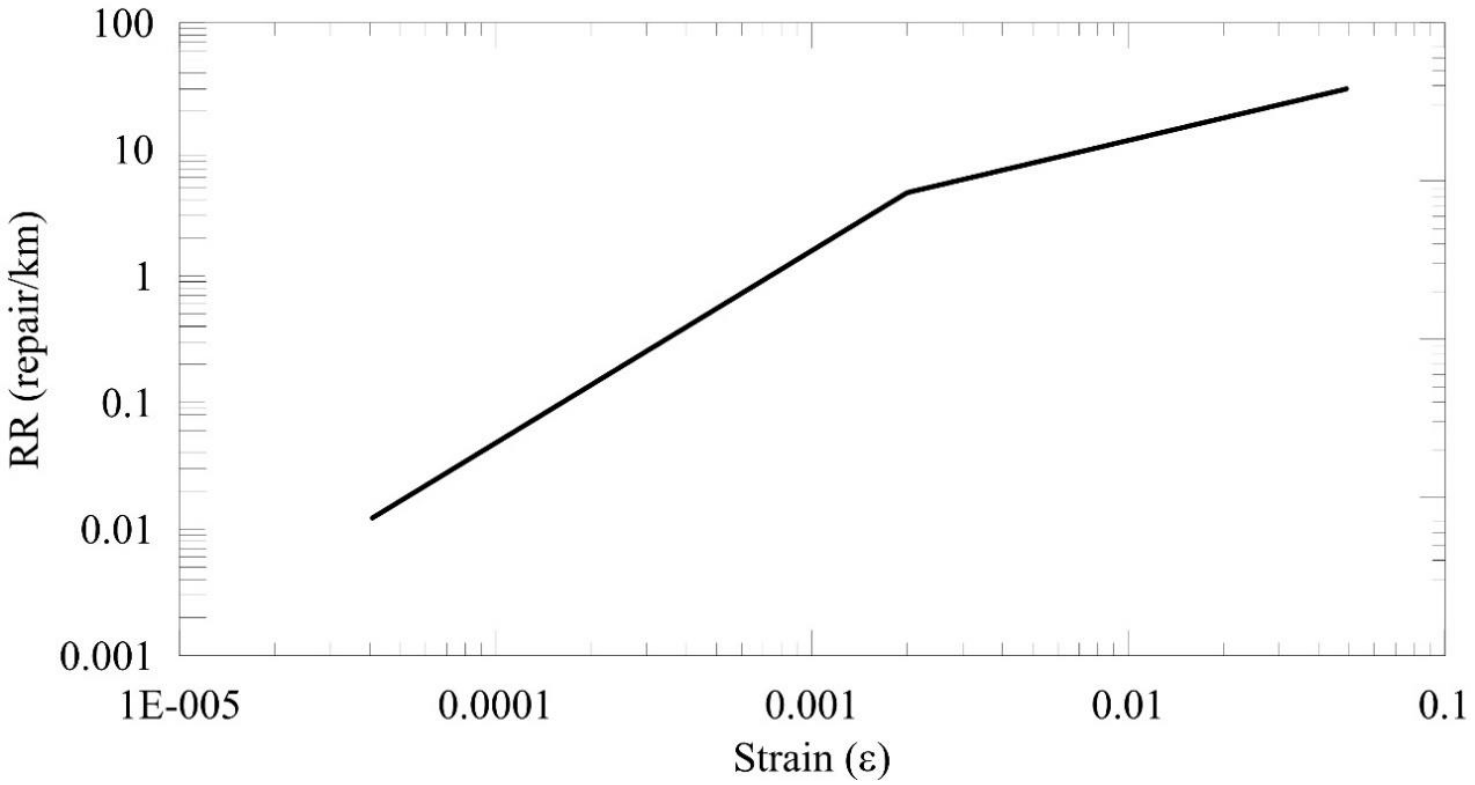
- Assessed the performance of natural gas (types of polyethylene (PE), steel, and cast iron, CI) and water pipelines during Chi-Chi earthquake.



PGV (cm/sec)	Pipeline Diameter
$0.02 \times PGV^{1.23}$	$\varphi \leq 65$ mm
$0.48 \times PGV^{0.11}$	$65 < \varphi < 150$ mm
$0.092 \times PGV^{0.25}$	$\varphi \geq 150$ mm

Fragility Relationships: O'Rourke et al. (2015)

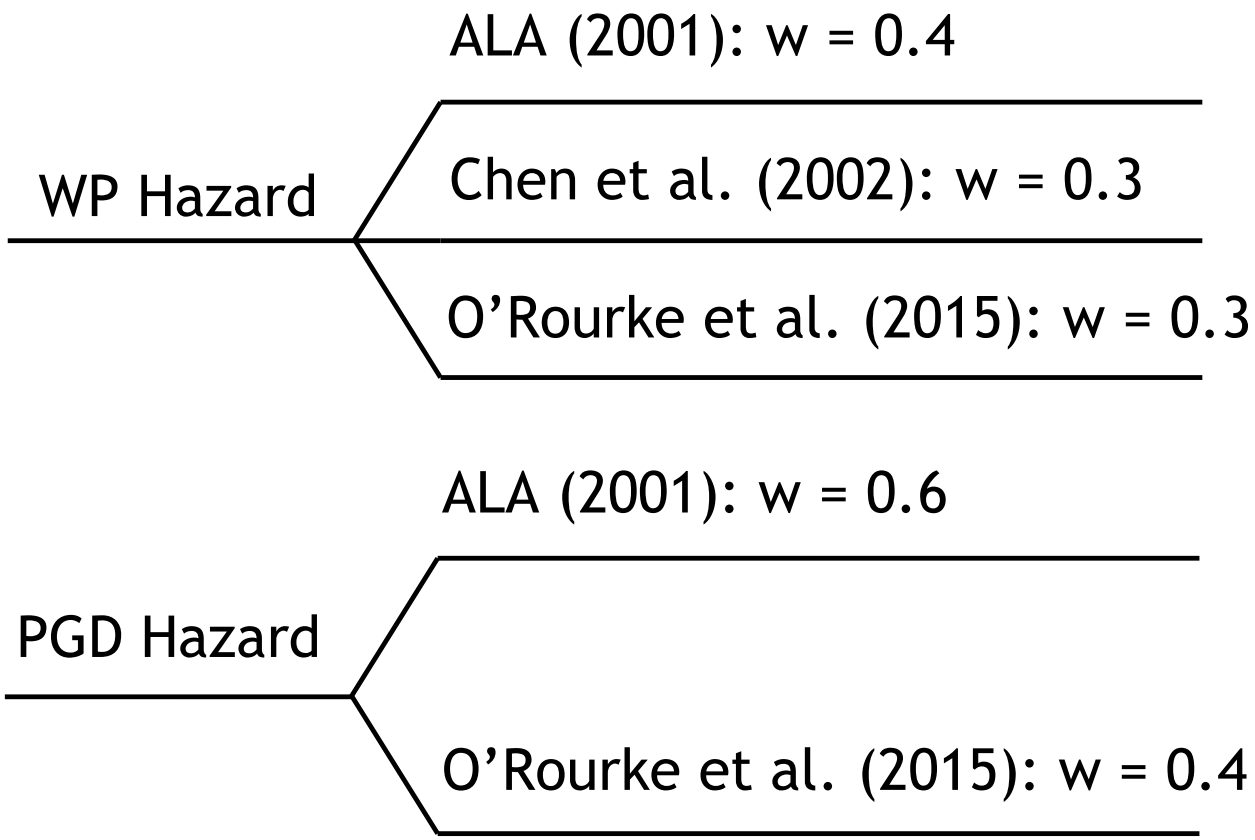
- Ground-strain based fragility relations of buried segmented pipelines using the data from 10 different earthquakes.
- The pipeline damage data observed in Adapazari due to 1999 Kocaeli Earthquake is included.



$$RR = \begin{cases} 56{,}970 \times \varepsilon_g^{1.52} & \varepsilon_g < 0.002 \\ 178 \times \varepsilon_g^{0.59} & \varepsilon_g > 0.002 \end{cases}$$

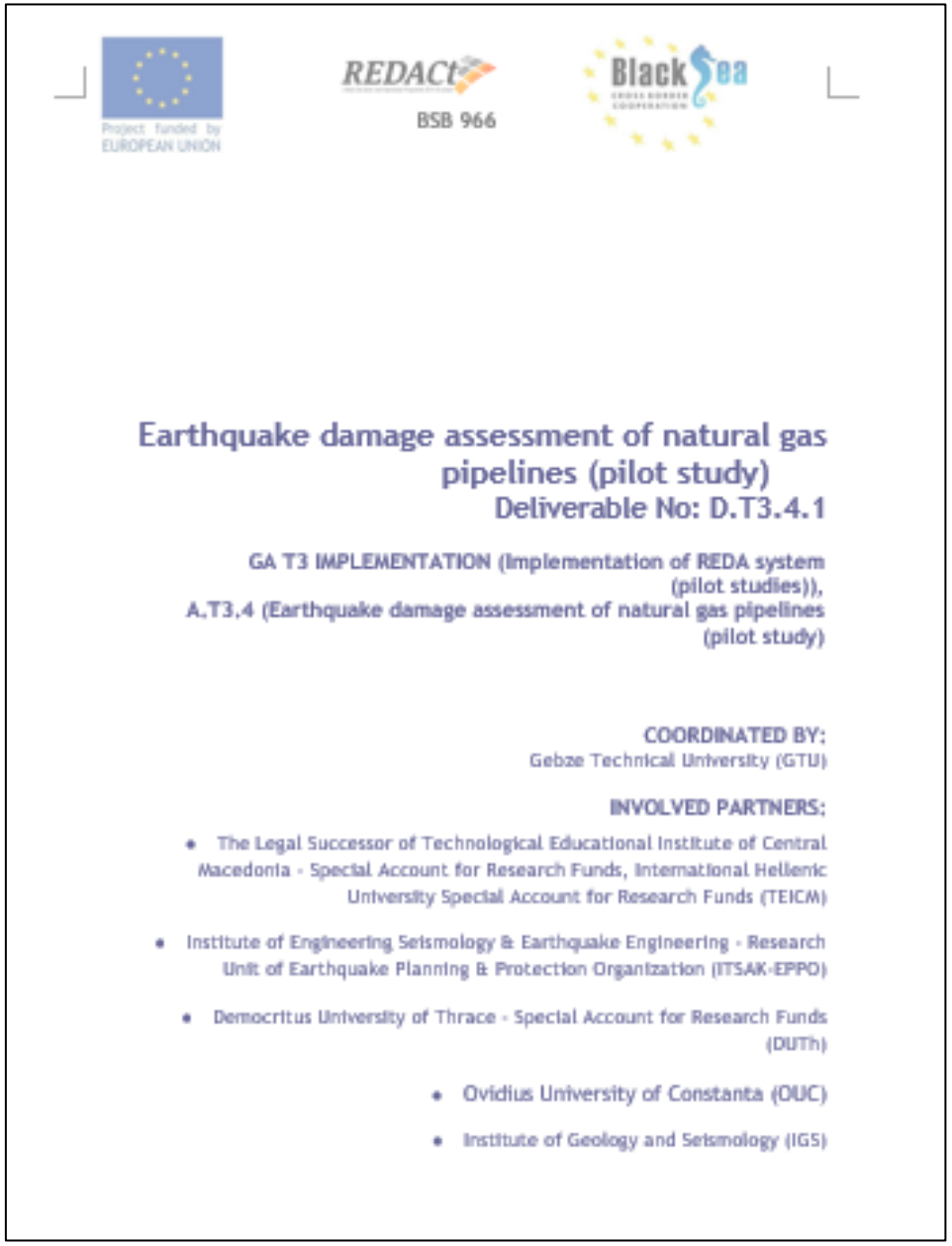
ε_g is ground strain

Fragility Relationships: Logic Tree



- Considering all the fragility relations presented, a logic tree of fragility curves will be constructed to account for epistemic uncertainty in the damage assessment to buried pipelines.
- **Current Status:** The application of these relationships through REDAS...

Deliverable D.T3.4.1: Earthquake Damage Assessment of Natural Gas Pipelines (Pilot Study)



Project funded by EUROPEAN UNION

REDACT

BSB 966

Black Sea

Earthquake damage assessment of natural gas pipelines (pilot study)
Deliverable No: D.T3.4.1

GA T3 IMPLEMENTATION (Implementation of REDA system (pilot studies)),
A.T3.4 (Earthquake damage assessment of natural gas pipelines (pilot study)

COORDINATED BY:
Gebze Technical University (GTU)

INVOLVED PARTNERS:

- The Legal Successor of Technological Educational Institute of Central Macedonia - Special Account for Research Funds, International Hellenic University Special Account for Research Funds (TEICM)
- Institute of Engineering Seismology & Earthquake Engineering - Research Unit of Earthquake Planning & Protection Organization (ITSAK-EPPO)
- Democritus University of Thrace - Special Account for Research Funds (DUTh)
- Ovidius University of Constanta (OUC)
- Institute of Geology and Seismology (IGS)

Chapter	Chapter Title	Status
1	Background of the Document	Done
2	Types of Hazard on Buried Pipelines	Done
3	Performance of Pipelines in Past Earthquakes	Done
4	Empirical Fragility Curves for Pipeline Hazard Assessment	Done
5	Recommended Fragility Curves	Done
6	Implementation of Recommended Fragility Curve to Pilot Area	Ongoing

Thank you

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