Systemic seismic vulnerability and risk analysis of urban systems, lifelines and infrastructures

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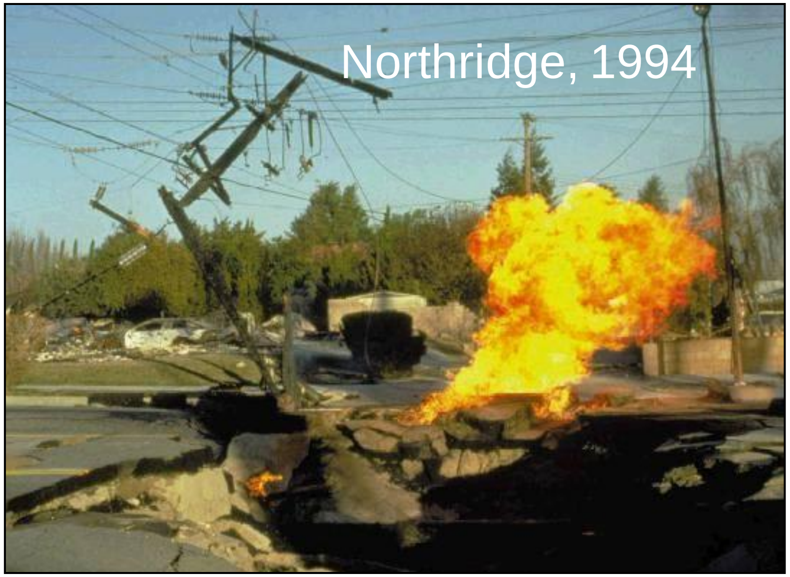
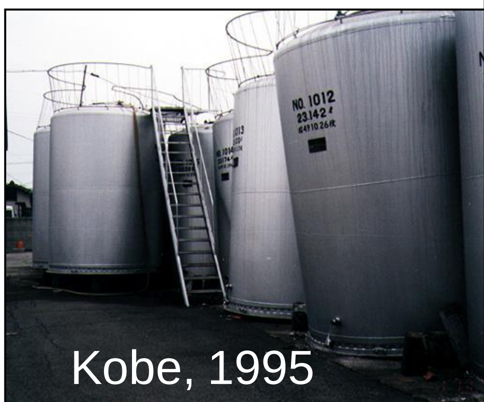
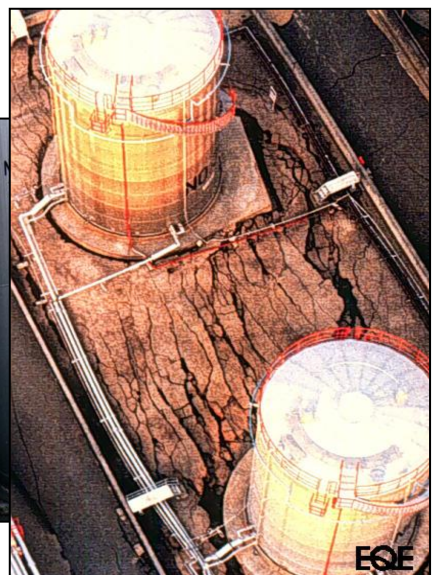
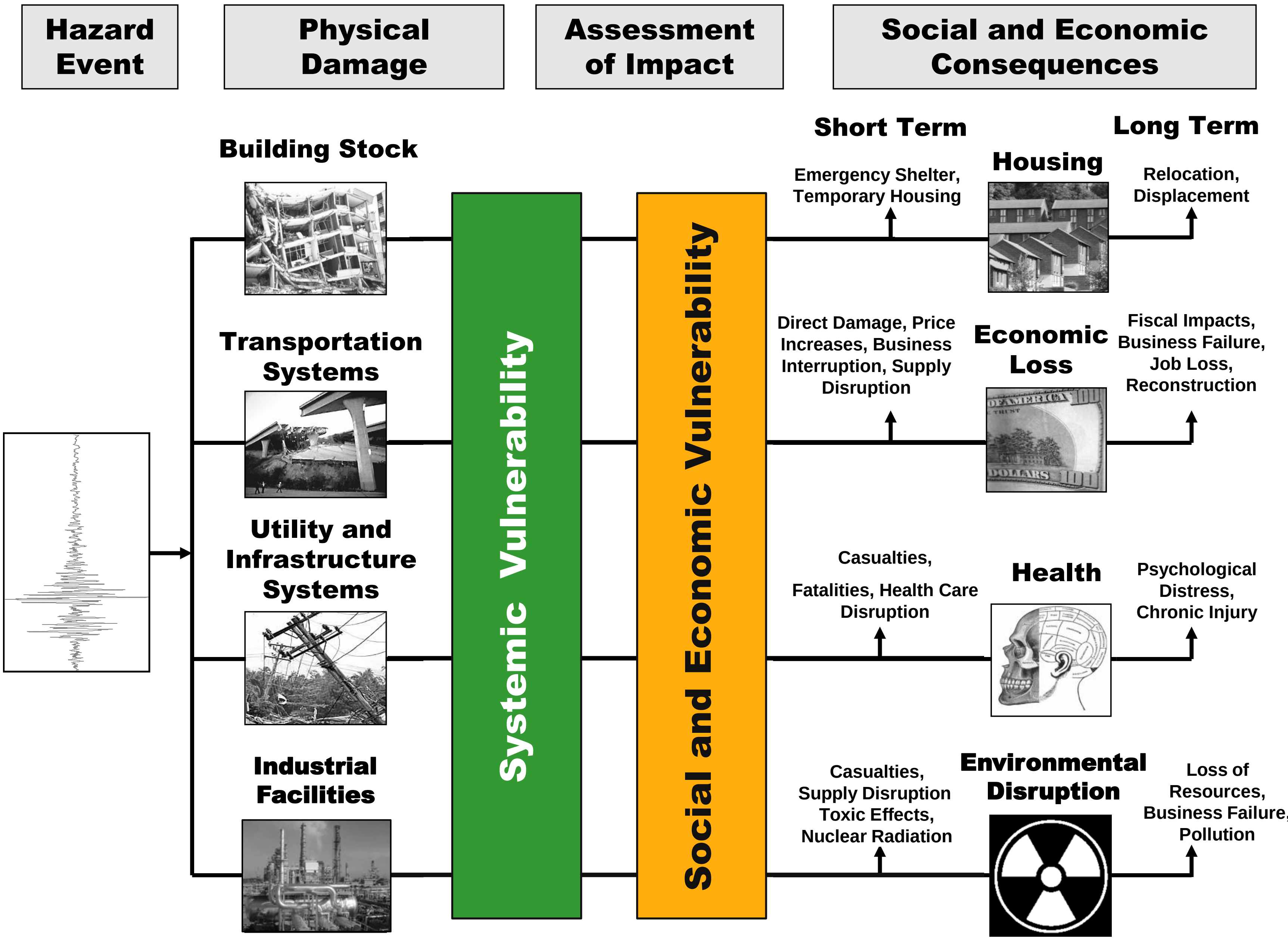
Earthquakes and Losses

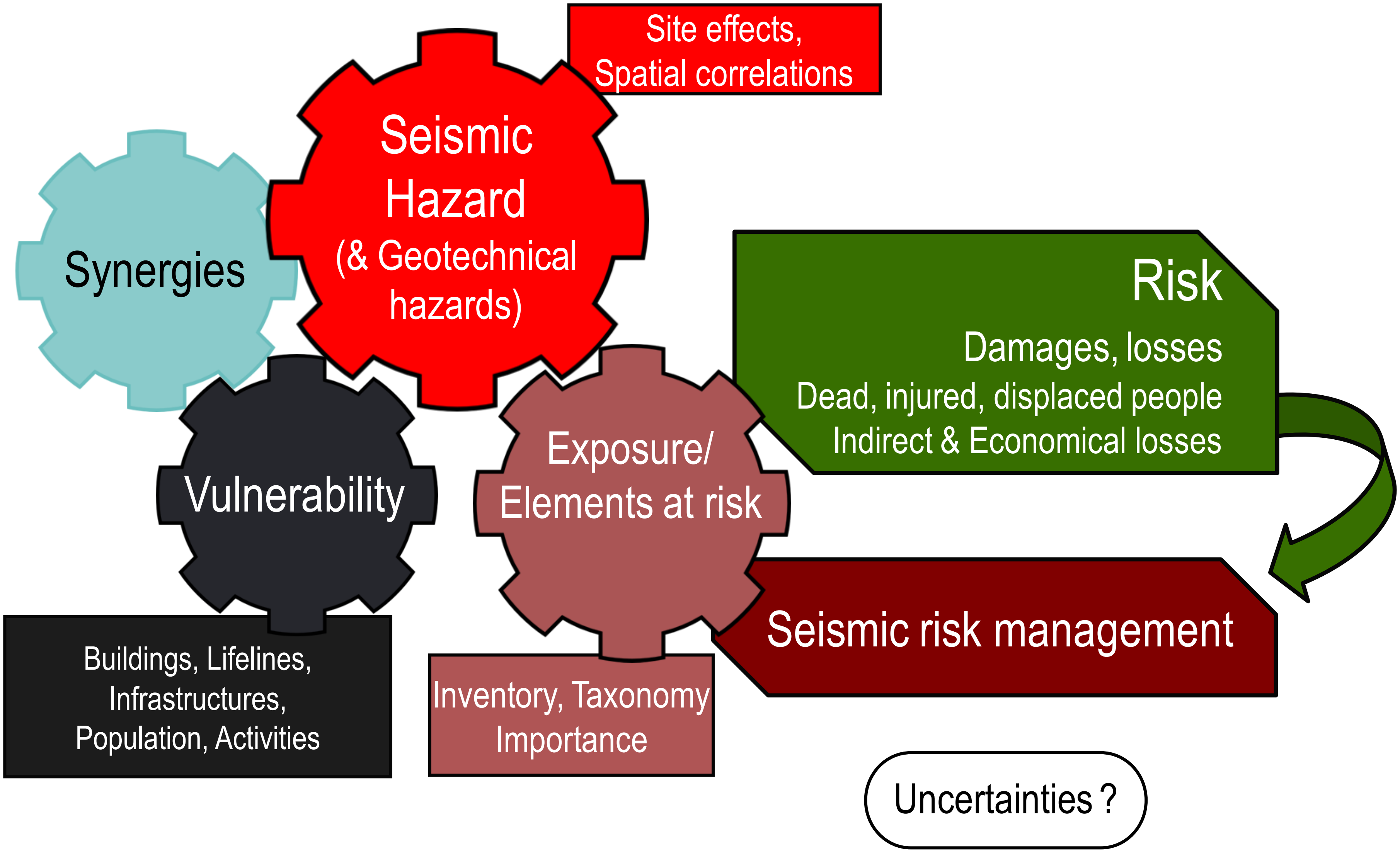







Hazard Event
Physical Damage
Assessment of Impact
Social and Economic Consequences
Short Term
Long Term
Building Stock
Housing
Emergency Shelter, Temporary Housing
Relocation, Displacement
Transportation Systems
Direct Damage, Price Increases, Business Interruption, Supply Disruption
Economic Loss
Fiscal Impacts, Business Failure, Job Loss, Reconstruction
Utility and Infrastructure Systems
Casualties,
Fatalities, Health Care Disruption
Health
Psychological Distress, Chronic Injury
Industrial Facilities
Casualties, Supply Disruption Toxic Effects, Nuclear Radiation
Environmental Disruption
Loss of Resources, Business Failure, Pollution
Systemic Vulnerability
Social and Economic Vulnerability

Seismic risk - Overview



Recent developments in Europe regarding seismic risk assessment and mitigation

SYNER-G www.syner-g.eu

REAKT www.reaktproject.eu

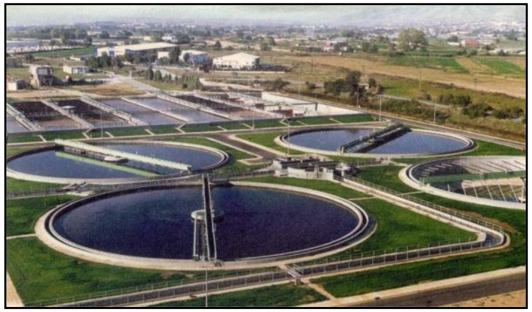
SHARE www.share-eu.org

NERA www.nera-eu.org

STREST www.strest-eu.org

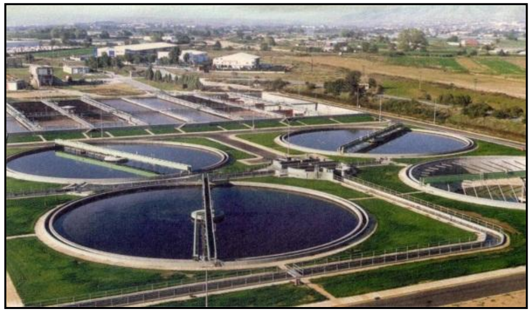
Contents

- Typology, inventory, classification
- Fragility curves
- Seismic hazard, site effects
- Vulnerability assessment, systemic analysis, real-time assessment
- Examples
- Risk management

Elements at risk

- Buildings
- Energy systems (gas/oil, electric power)
- Water and sewage systems
- Transportation and infrastructure systems (road, railway, port, subways)
- Critical facilities (e.g. hospitals, fire fighting system)
- Industrial facilities

Refineries sub-component:

- Centrifuges;
- Compressors;
- Cooling Towers;
- Crushers;
- Crystallizers;
- Distillation Towers and Pressure Vessels;
- Electric Power Generators;
- Transformers and Electric Motors;
- Electrolysis Cell;
- Evaporators;
- Filters;
- Furnaces;
- Gas Flares;
- Mixers and Blenders;
- Monitoring and Control Systems;
- Piping and Valves;
- Pumps;
- Steam Generators;
- Steam Turbines and Gas Turbines;
- Storage Tankers;
- Wastewater Treatment

➢ Water and Waste-Water Systems

Substation micro-components

ker;
rrester or discharger;
disconnect switch/horizontal sectionalizing switch;
connect switch/vertical sectionalizing switch;
r or autotransformer;
nsformer;
nsformer;
rol house;
ply to protection system;
t;
t or pothead;
ank

Buildings

FRM/FRMM/P/E/C-CM/D/FS-FSM/RS-RSM/HL-NS/CL

- Force Resisting Mechanism (FRM) Moment Resisting Frame, Bearing Wall..
- FRM Material (FRMM) Masonry, Concrete, Fired Brick, Stone..
- Plan (P) Regular, Irregular..
- Elevation (E) Regular/irregular geometry..
- Cladding (C) Regular/irregular vertically..
- Cladding Material (CM) Fired brick, glazing, open first floor..
- Detailing (D) Ductile, non-ductile, with tie-rods..
- Floor System (FS) Rigid, flexible..
- Floor System Material (FSM) RC, steel, timber..
- Roof System (RS) Peaked, flat..
- Roof System Material (RSM) Timber, thatch..
- Height Level (HL)/Number of Stories (NS) Low, mid, high-rise, 1, 2, 3..
- Code Level (CL) None, low code, mid code, high code..

Bridges

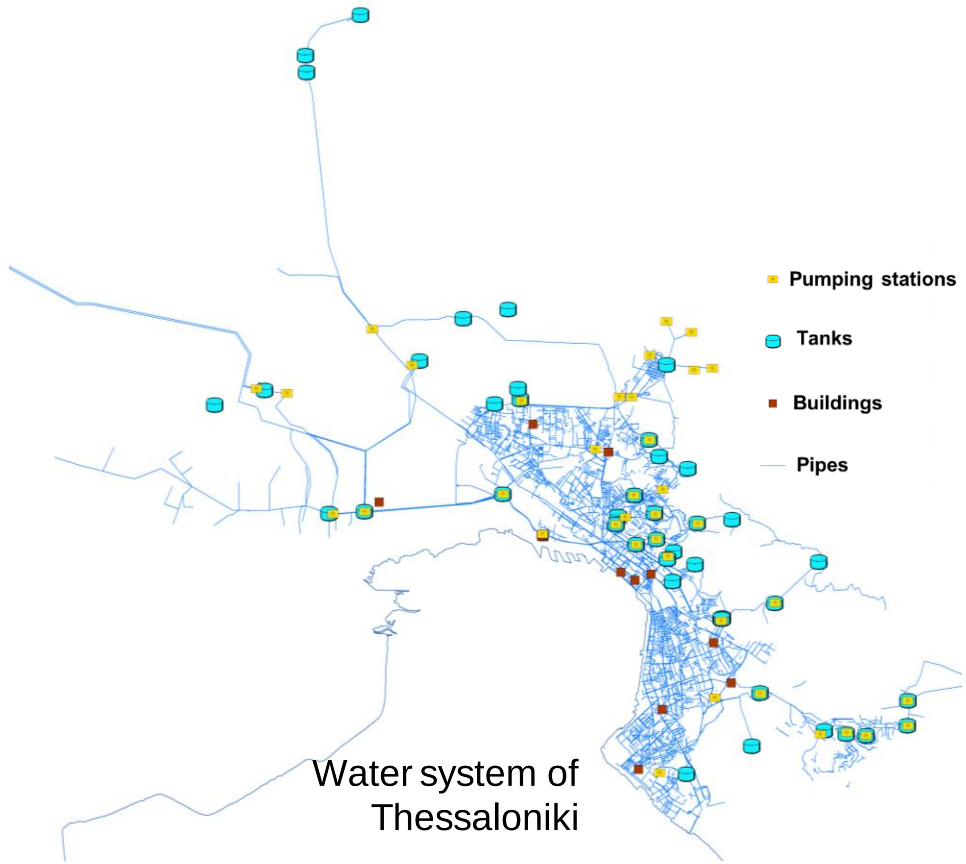
- Material – Concrete (C), Masonry (M), Steel (S), Iron (I), Wood (W), Mixed (MX)
- Type of Superstructure – Girder (Gb), Arch (Ab), Suspension (Spb), Slab (Sb)
- Type of Deck - Solid slab (Ss), Slab with voids (Sv), Box girder (B), Modern arch bridge (MA), Ancient arch bridge (AA)
- Deck Structural System – Simply supported (SSu), Continuous (Co)
- Pier-to-Deck Connection – Not Isolated (monolithic) (NIs), Isolated (through bearings) (Is)
- Type of pier to superstructure connection – Single-column pier (ScP), Multi-column piers (McP)
- Number of piers for column
- Type of section of the pier – Cylindrical (Cy), Rectangular (R), Oblong (Ob), Wall-type (W)
- Spans – Single span (Ssp), Multi spans (Ms)
- Type of Connection to the Abutments – Free (F), Monolithic (M), Isolated (Isi)
- Bridge Configuration – Regular (R), Semi-regular (SR), Irregular (IR)
- Type of Foundation – Shallow, Deep, Single/Multi-Pile, w/wo Caps
- Seismic Design Level – No seismic design (NSD), Seismic design (SD)

Taxonomy - Inventory: Census, Owner/Operators

- Urban Audit/EUROSTAT
- National Census
- Network operators databases

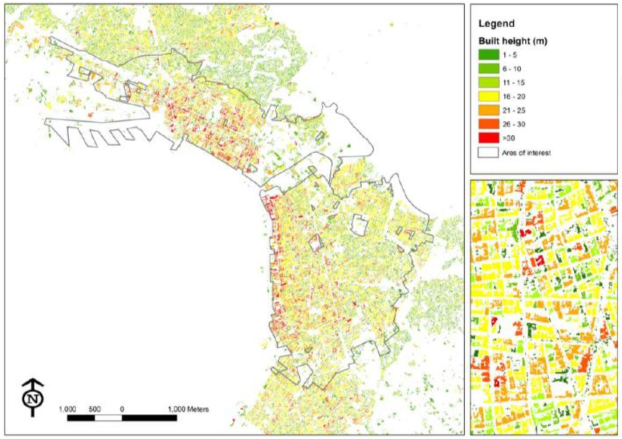
number	floors	loft	cellar	construction year	construction era	construction era exact	usage	fotolink
371	4	n	y		1848-1918	1881-1890	res	yes
372	4	n	y		1848-1918	1881-1890	res	yes
373	4	n	y	1877	1848-1918	1881-1890	res	yes
375	5	n	y		1848-1918	1891-1900	res	yes
376	5	n	y		1848-1918	1881-1890	res	yes
377	3	n	n		-1848	1841-1850	res	yes
378	2	n	n		1848-1918	1871-1880	res	yes
379	5	n	y		1848-1918	1901-1910	res	yes

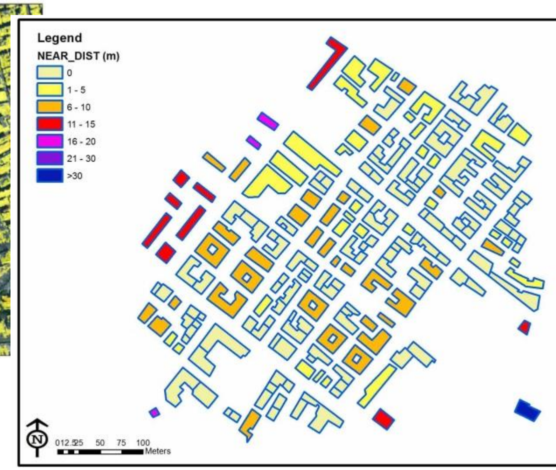
Buildings database of Vienna

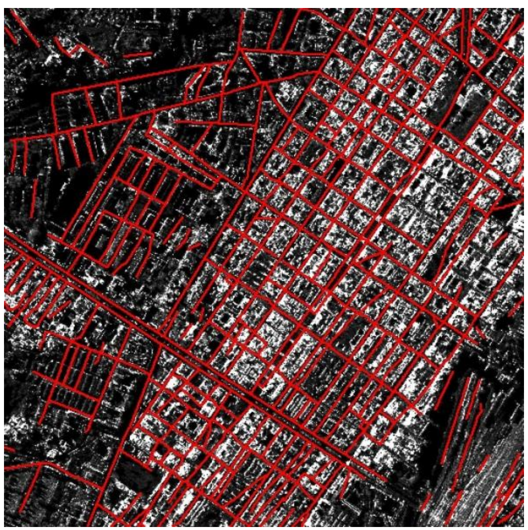


Water system of Thessaloniki

Inventory: Remote sensing techniques (optical, SAR etc)



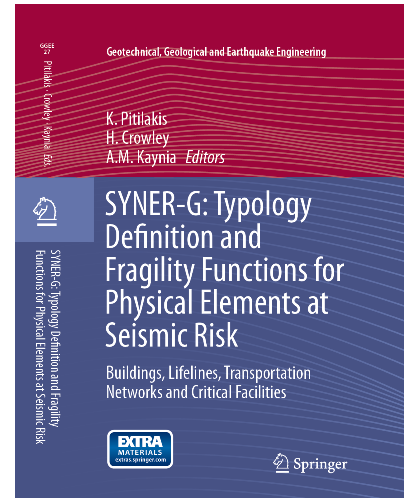




- Land-uses, build-up areas,
- Building geometry
- Utility & transportation network characteristics

Fragility Curves: Review

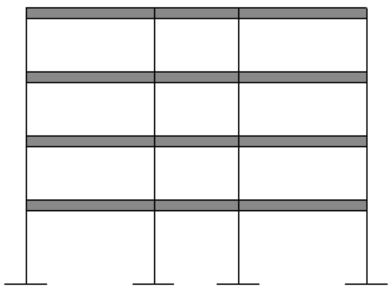
-



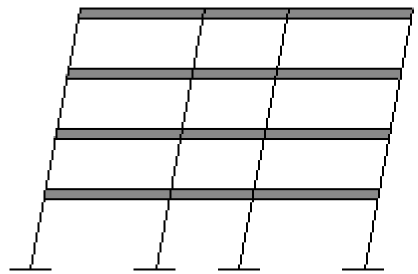
- National projects
- Methods: *Empirical, Analytical, Expert judgment, Fault tree, Hybrid*
- Taxonomy/Typology issues
- Need of fragility curves for industrial facilities
- Intensity measures
- Validation studies (limited data)

Fragility curves based on pushover analysis

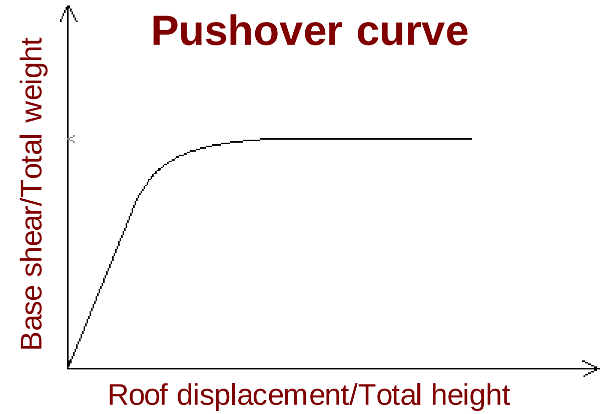
MDOF system



Pushover for appropriate lateral load distribution



Pushover curve

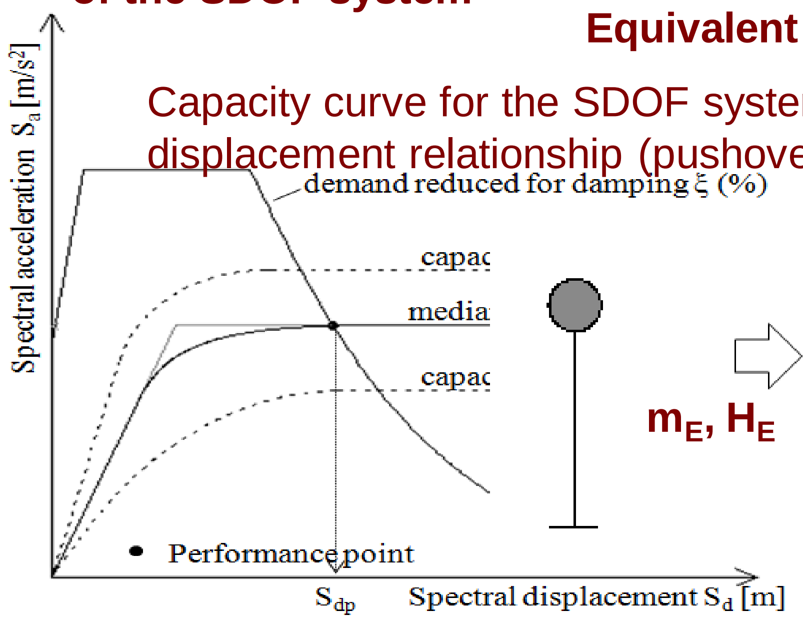


Capacity and seismic demand of the SDOF system

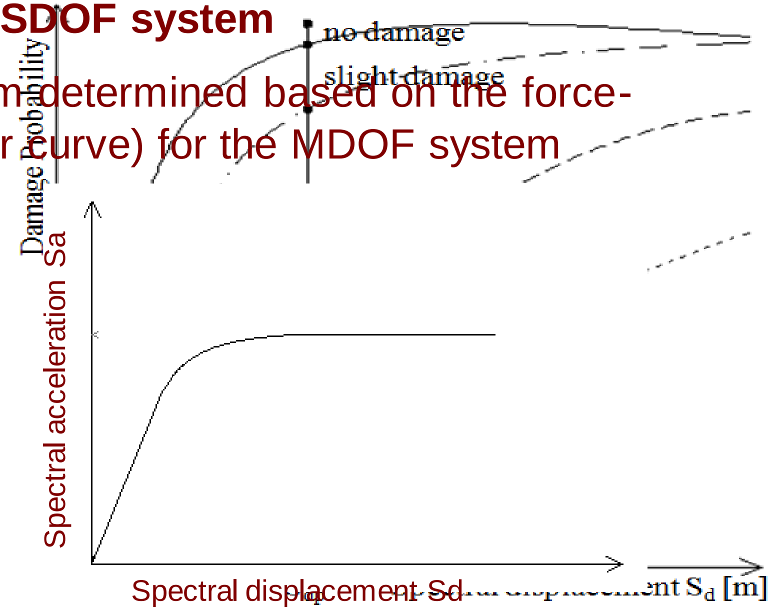
Equivalent SDOF system

Fragility curves

Capacity curve for the SDOF system determined based on the force-displacement relationship (pushover curve) for the MDOF system

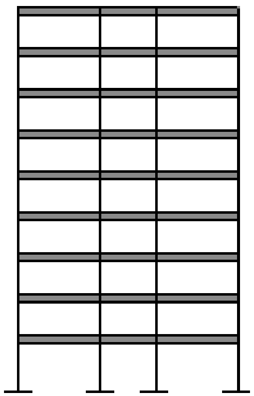


m_E, H_E



Fragility curves based on IDA

High rise – low code MRF



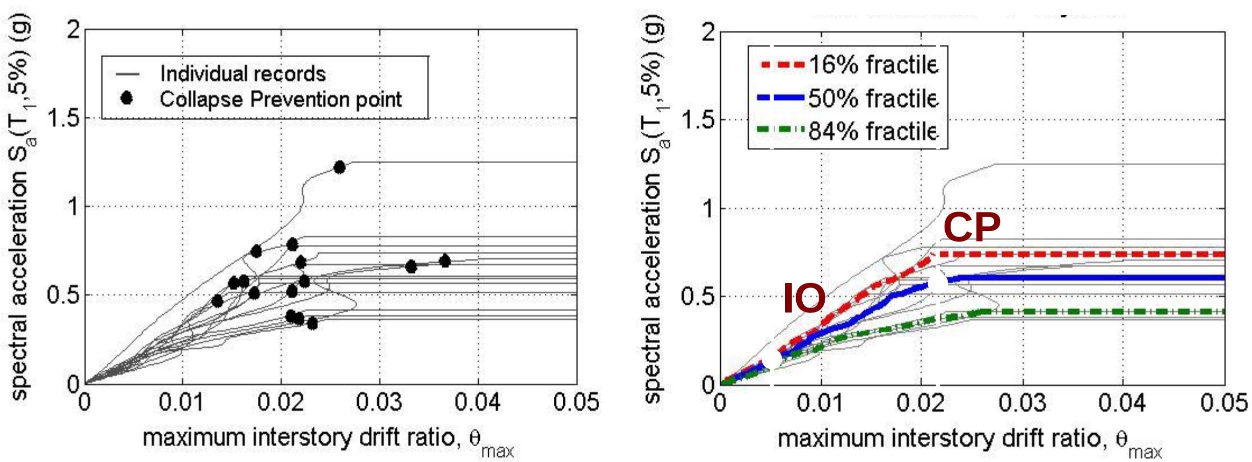
• a series of nonlinear dynamic analyses under a suite of multiply scaled ground motion records to cover the range from elasticity to global dynamic instability (*Vamvatsikos and Cornell 2002*).

• Limit states:

IO*: Immediate Occupancy*

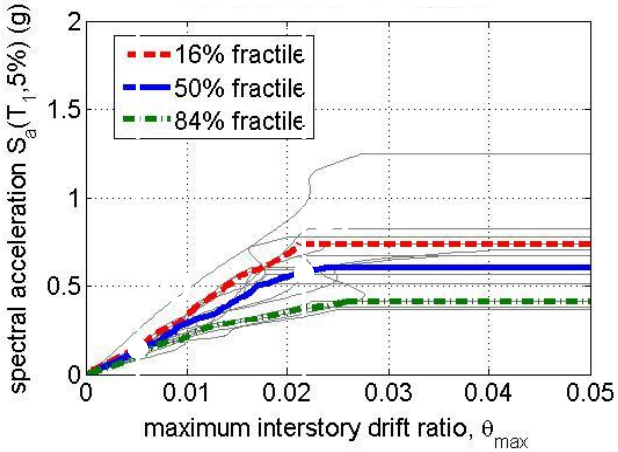
CP*: Collapse Prevention*

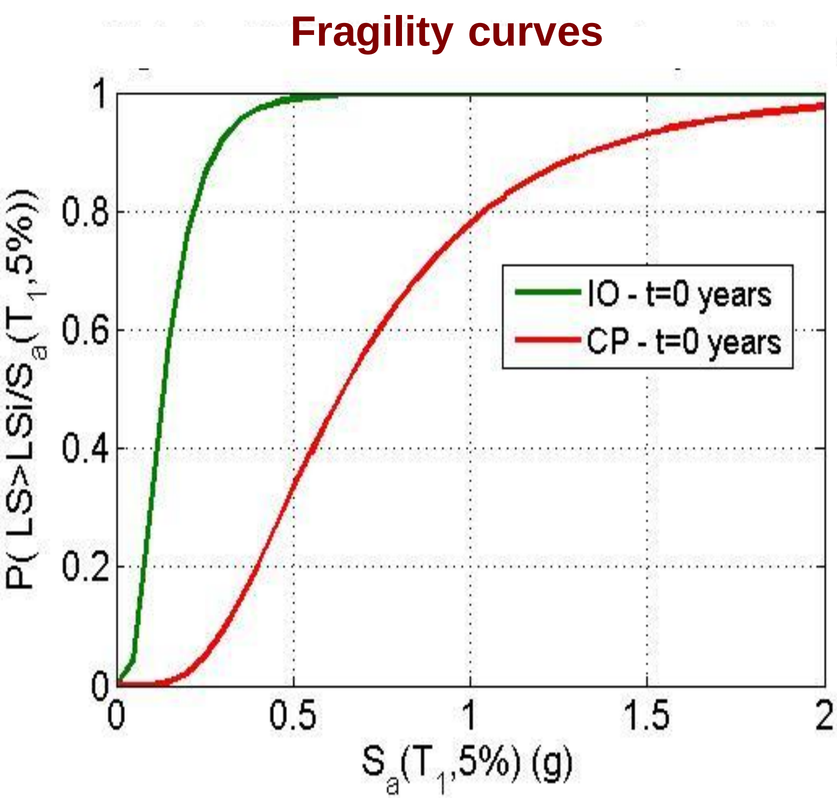
IDA curves – IO and CP limit state definition

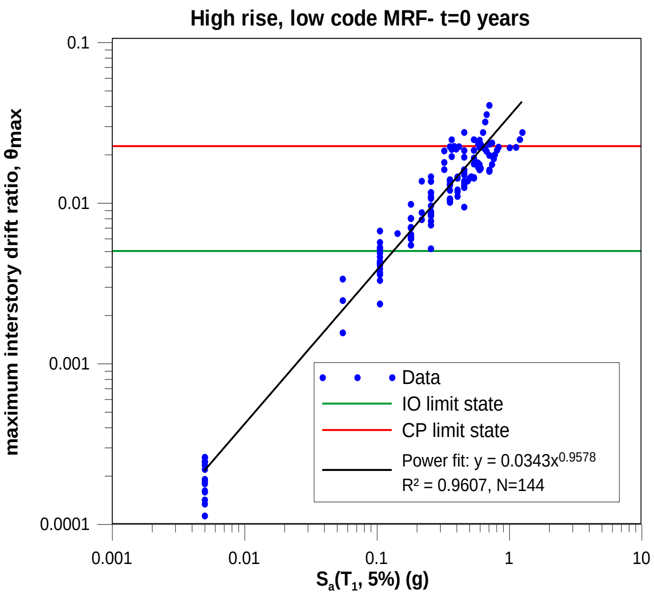


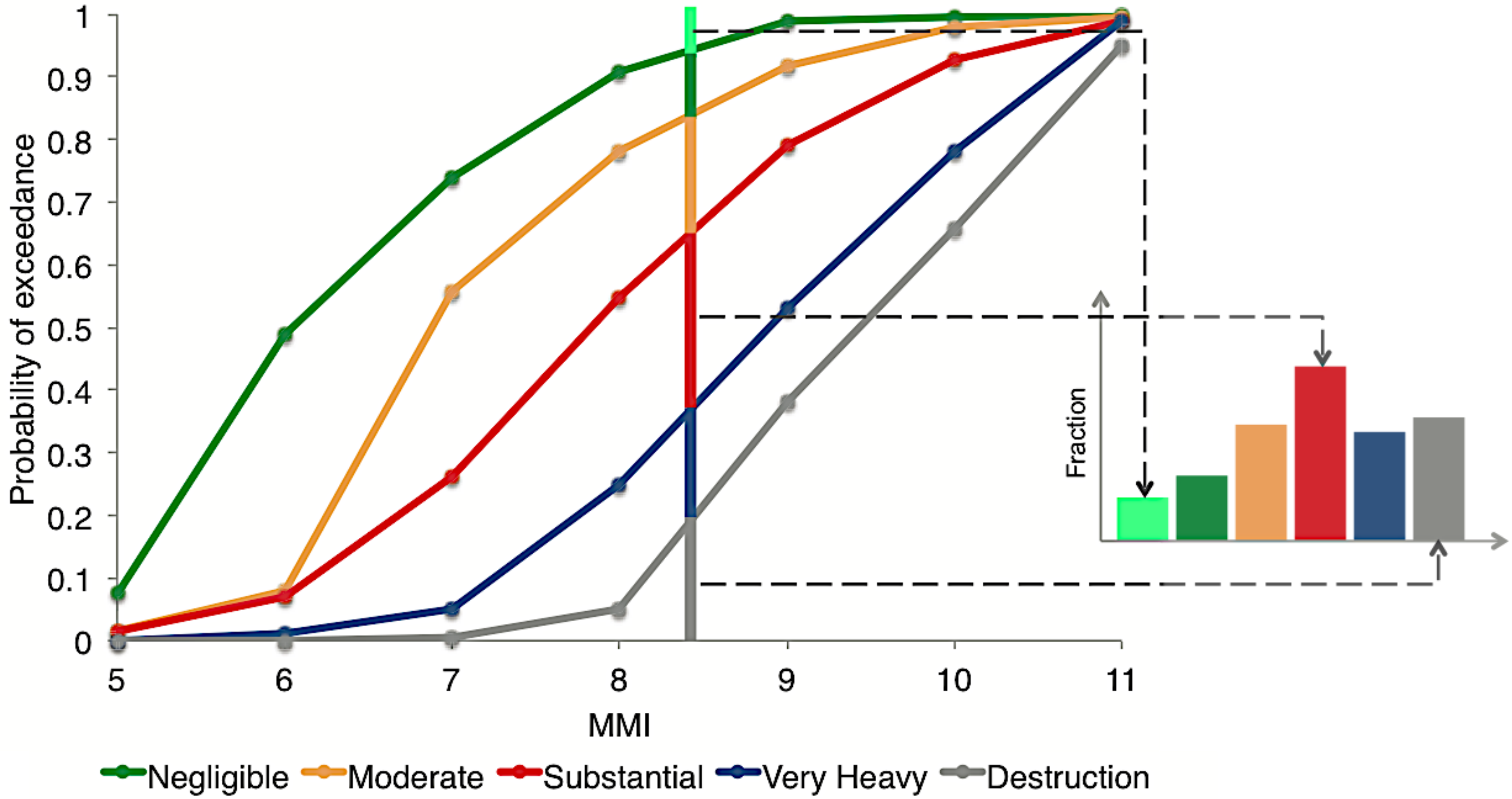
Fragility curves based on IDA

IDA curves – CP limit state definition



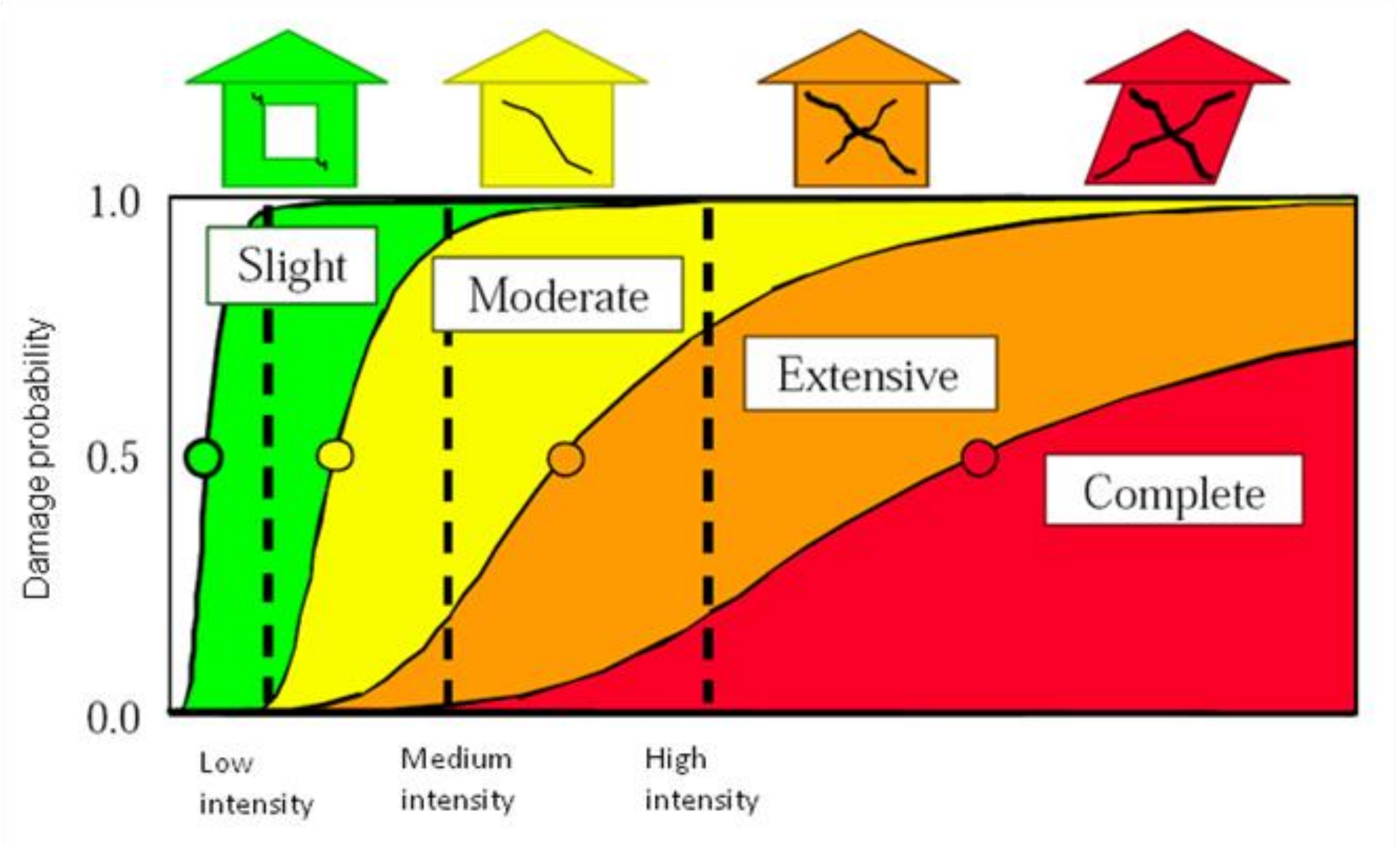





Probability of exceedance
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
5
6
7
8
9
10
11
MMI
Fraction
Negligible
Moderate
Substantial
Very Heavy
Destruction

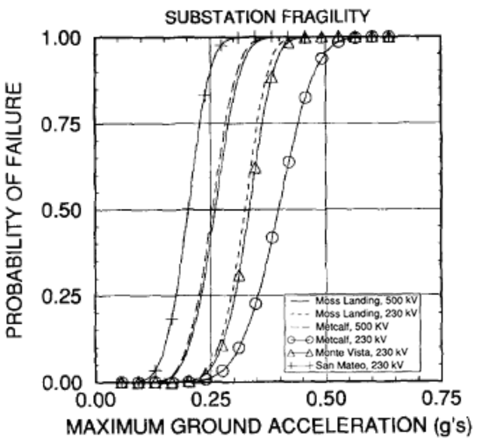
Quantitative estimation of physical vulnerability

Damage states for buildings

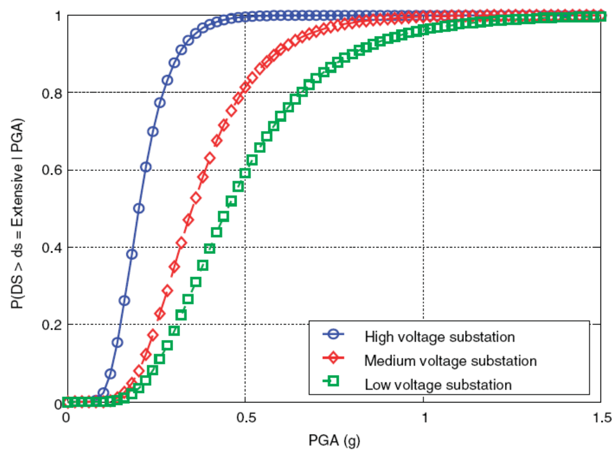


INPUT
- PGA, PSA(T), PGD, PGV, etc
- Depending on the element at

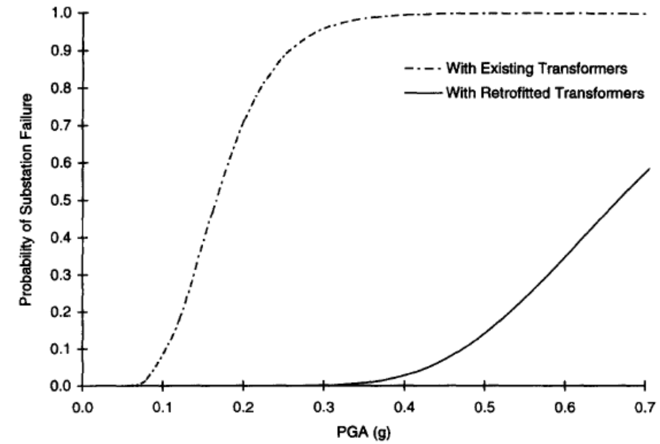
Electric power substations



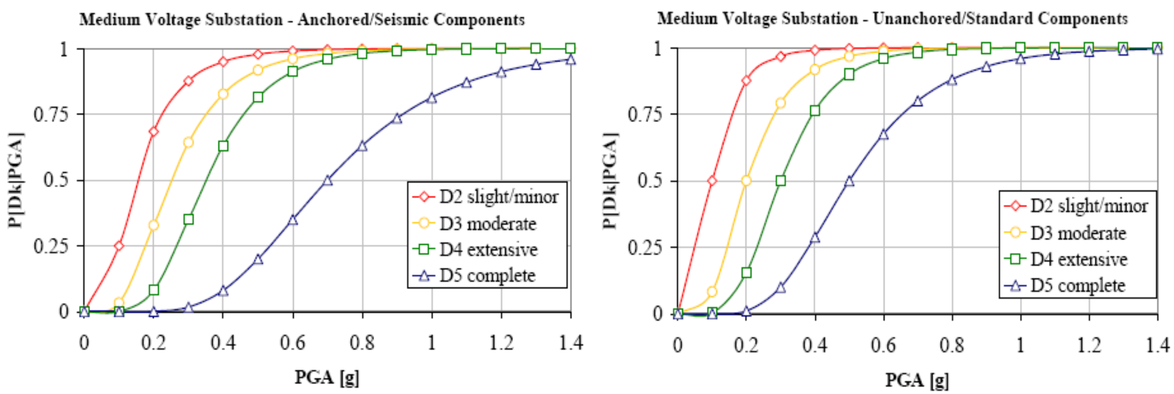
Ang *et al.* (US)



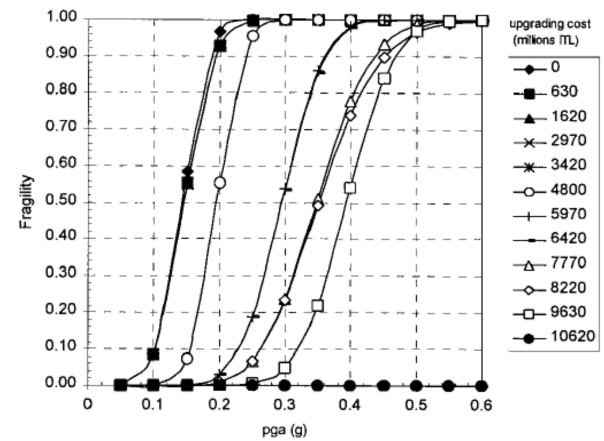
Dueñas-Osorio *et al.* (US)



Hwang *et al.* (US)

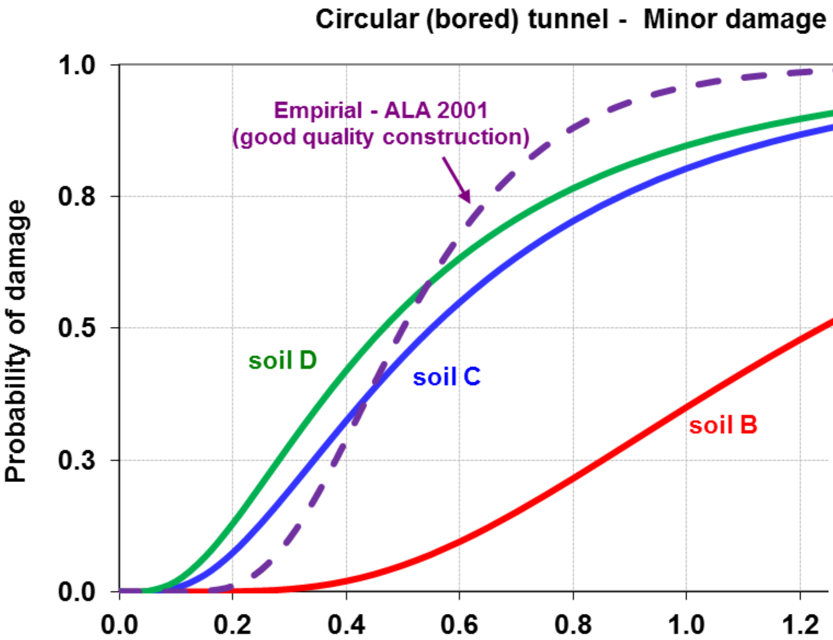


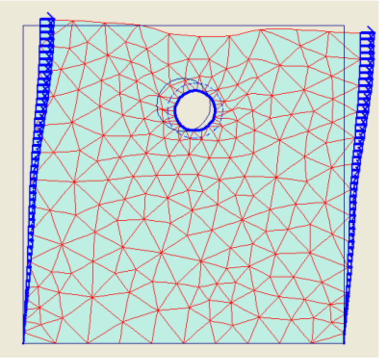
Giovinazzi *et al.* (US)

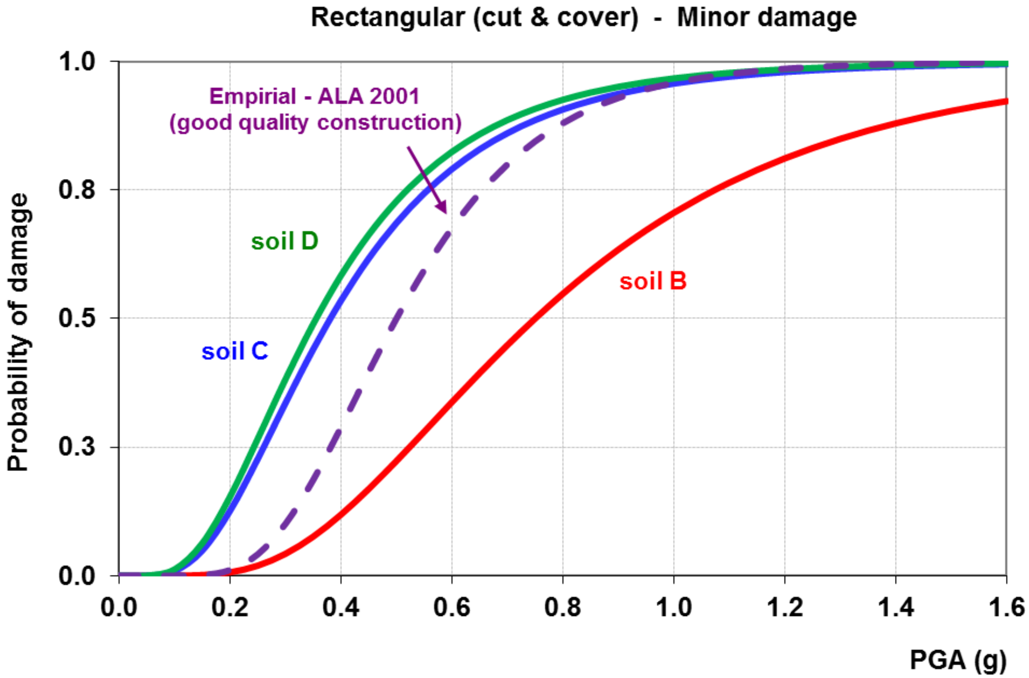


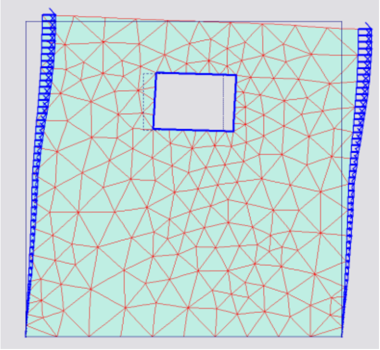
Vanzi (Italy)

Shallow Tunnels in alluvial



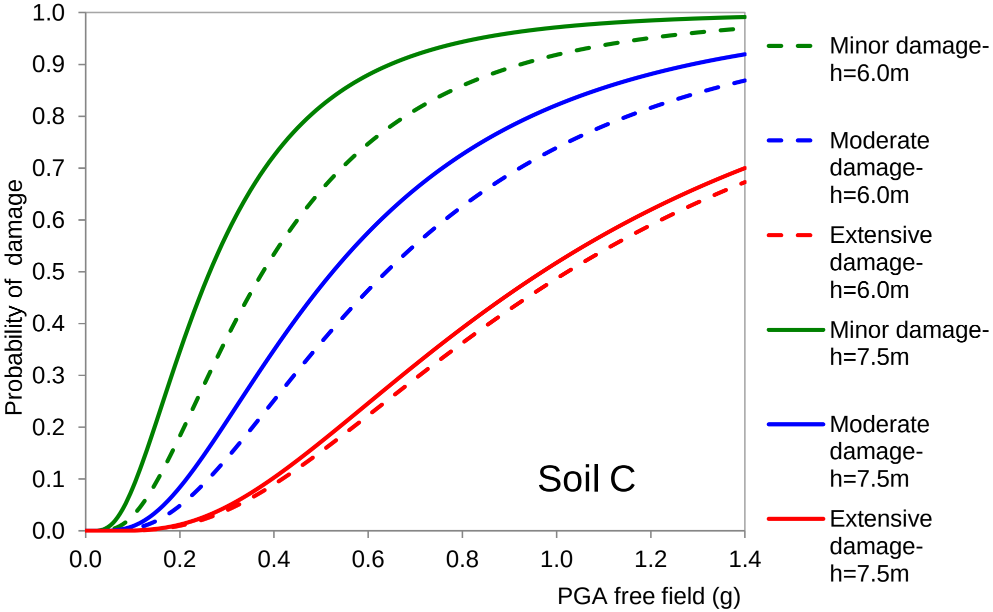


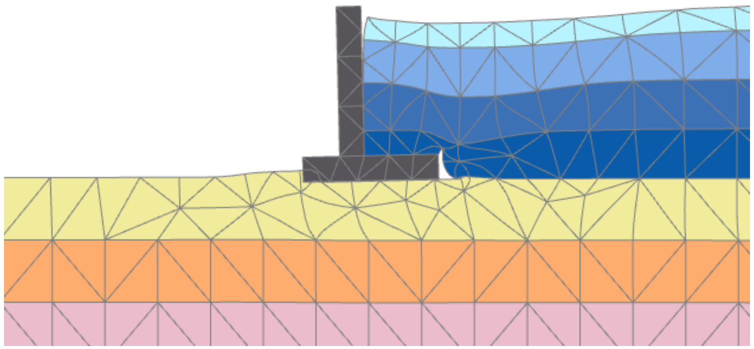


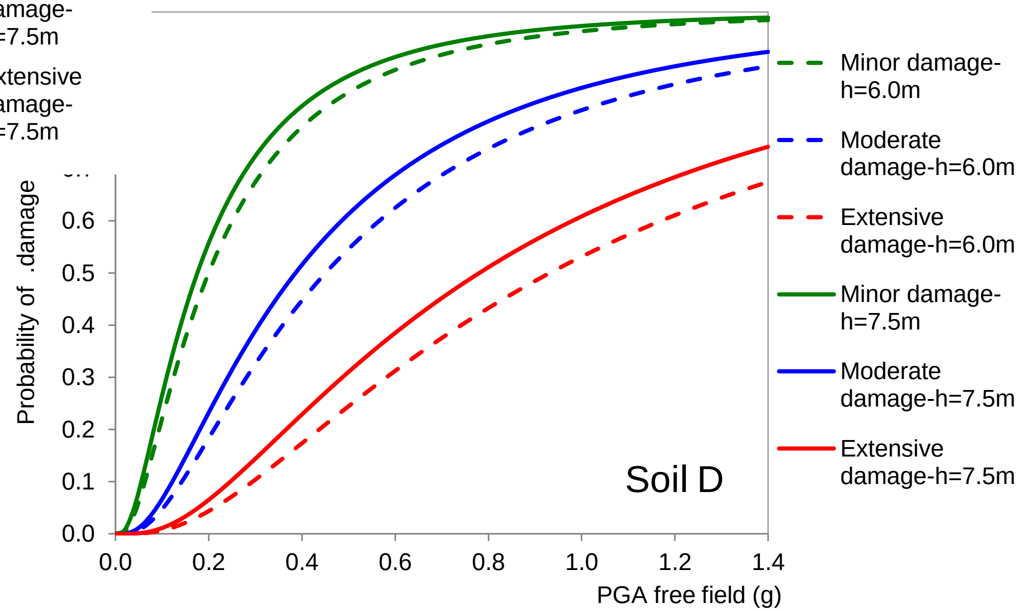


Argyroudis S, Pitilakis K (2012) Seismic fragility curves of shallow tunnels in alluvial deposits. Soil Dynamics and Earthquake Engineering 35: 1–12.

Bridge abutments

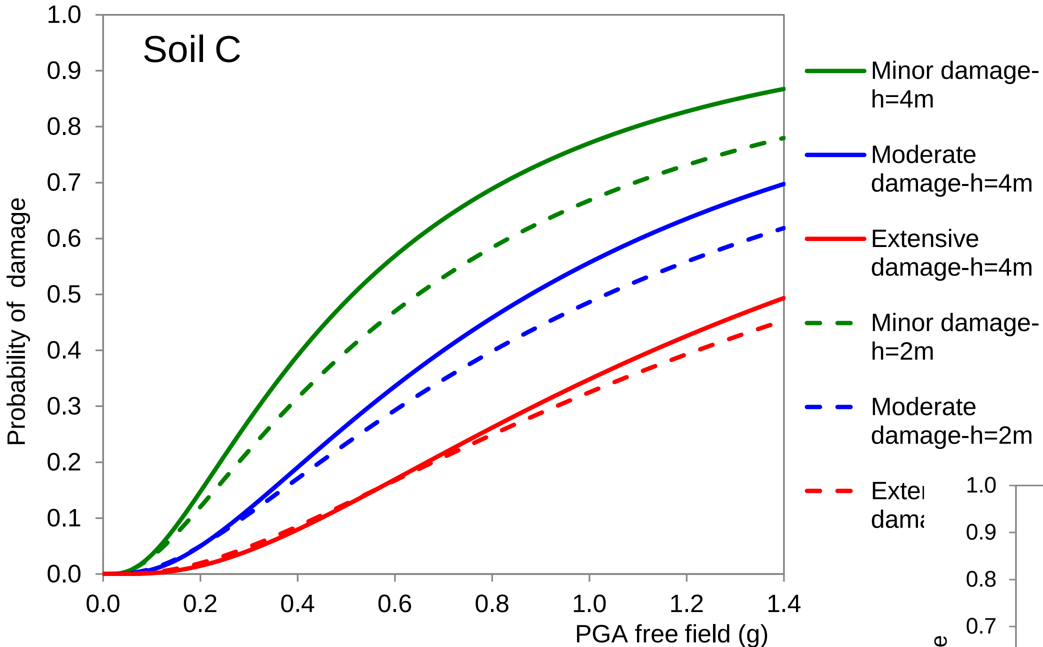




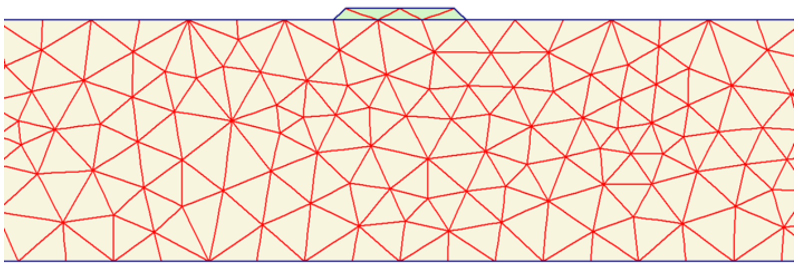


Argyroudis S, Kaynia AM, Pitilakis K (2013) Development of fragility functions for geotechnical constructions: application to cantilever retaining walls. Soil Dynamics and Earthquake Engineering 50: 106-116.

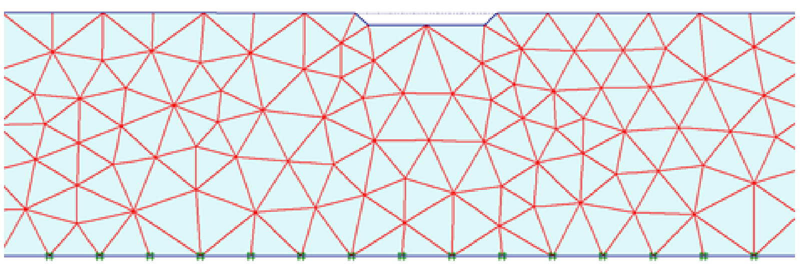
Road/railway embankments and trenches

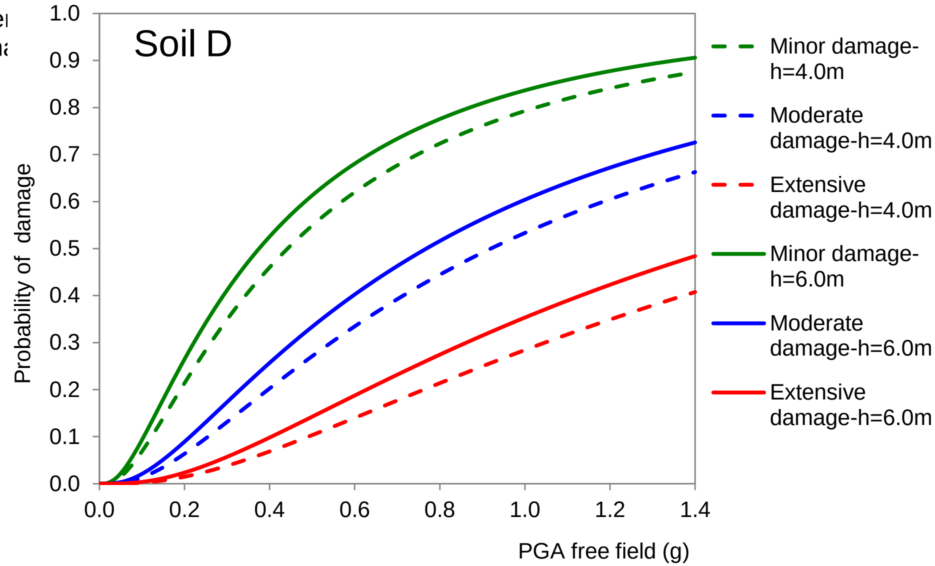


Embankments



Trenches

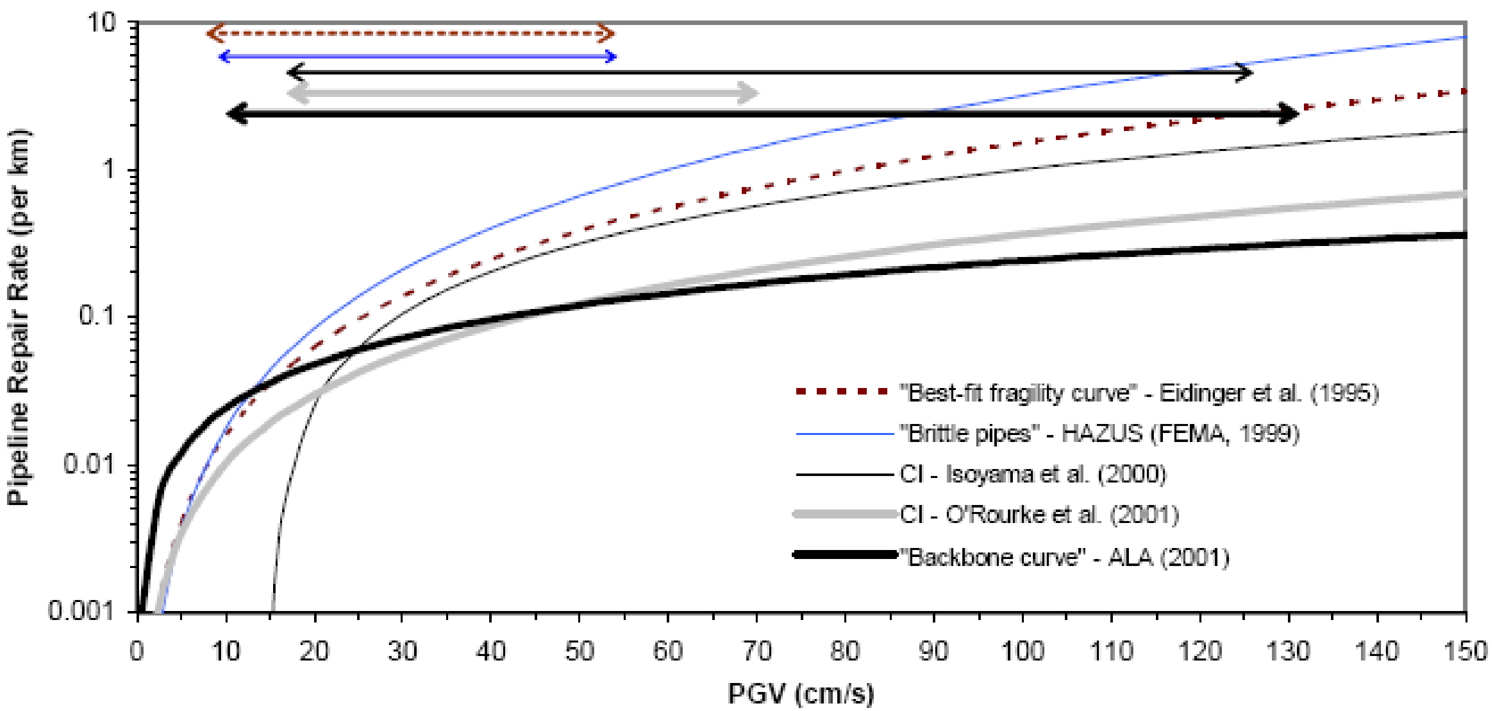




Argyroudis S, Kaynia AM (2013) Analytical fragility functions for roadways and railways on embankments and in cuts for seismic shaking. Bulletin of Earthquake Engineering (submitted).

Pipelines

	Permanent soil deformation	**Transient ground deformation**
Hazard	surface faulting, lateral spreading due to liquefaction, landsliding	R-waves, S-waves
EQ descriptor	PGD, ground strain	PGS (strain), PGV; PGA, PGV^2/PGA



Tromans (2004)

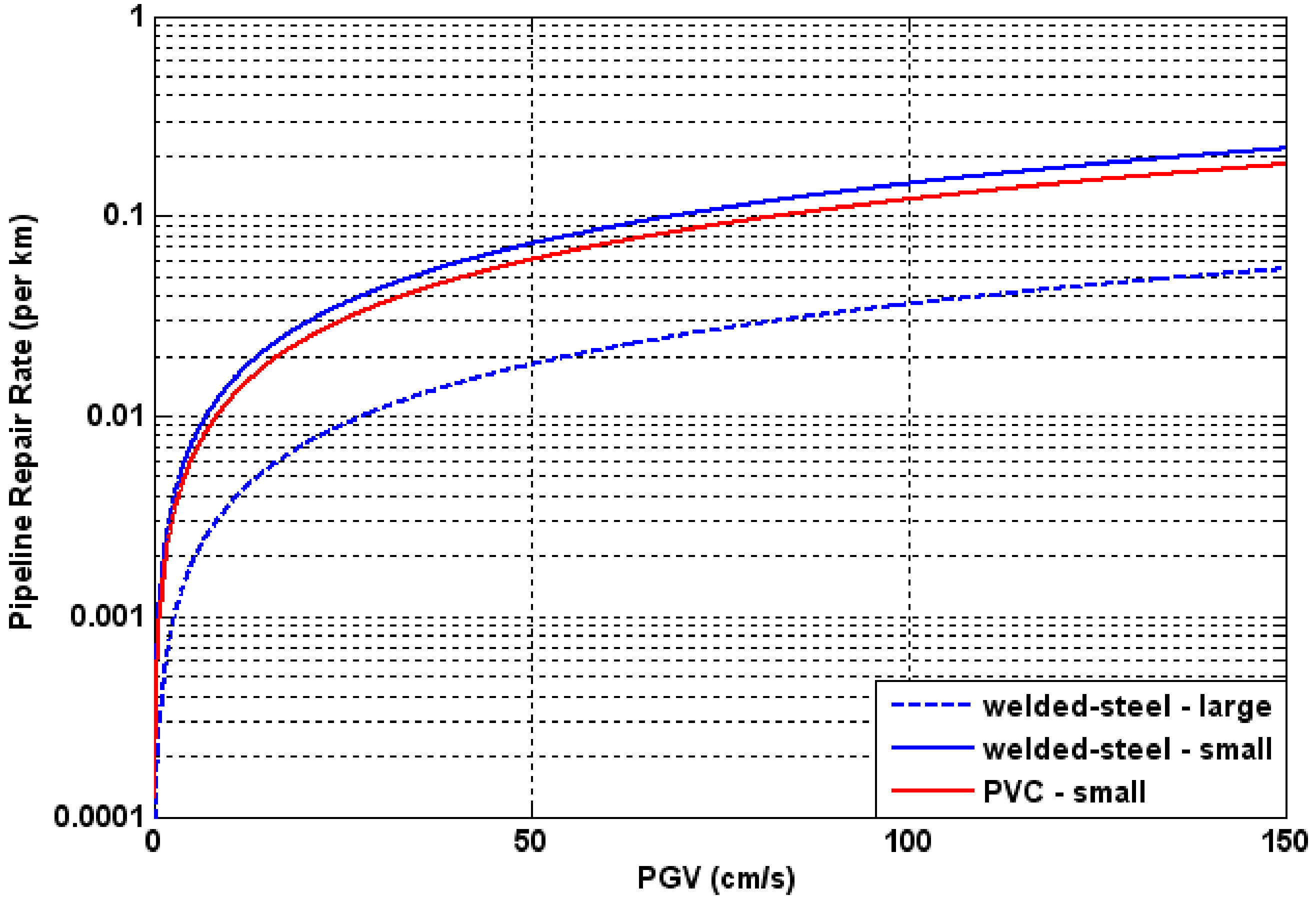
Pipelines

$$RR = K_1 0.002416 PGV$$

PGV in *cm/s*

Wave propagation

K1: corrective factor based on pipe properties



80% leaks
20% breaks

ALA (2001)

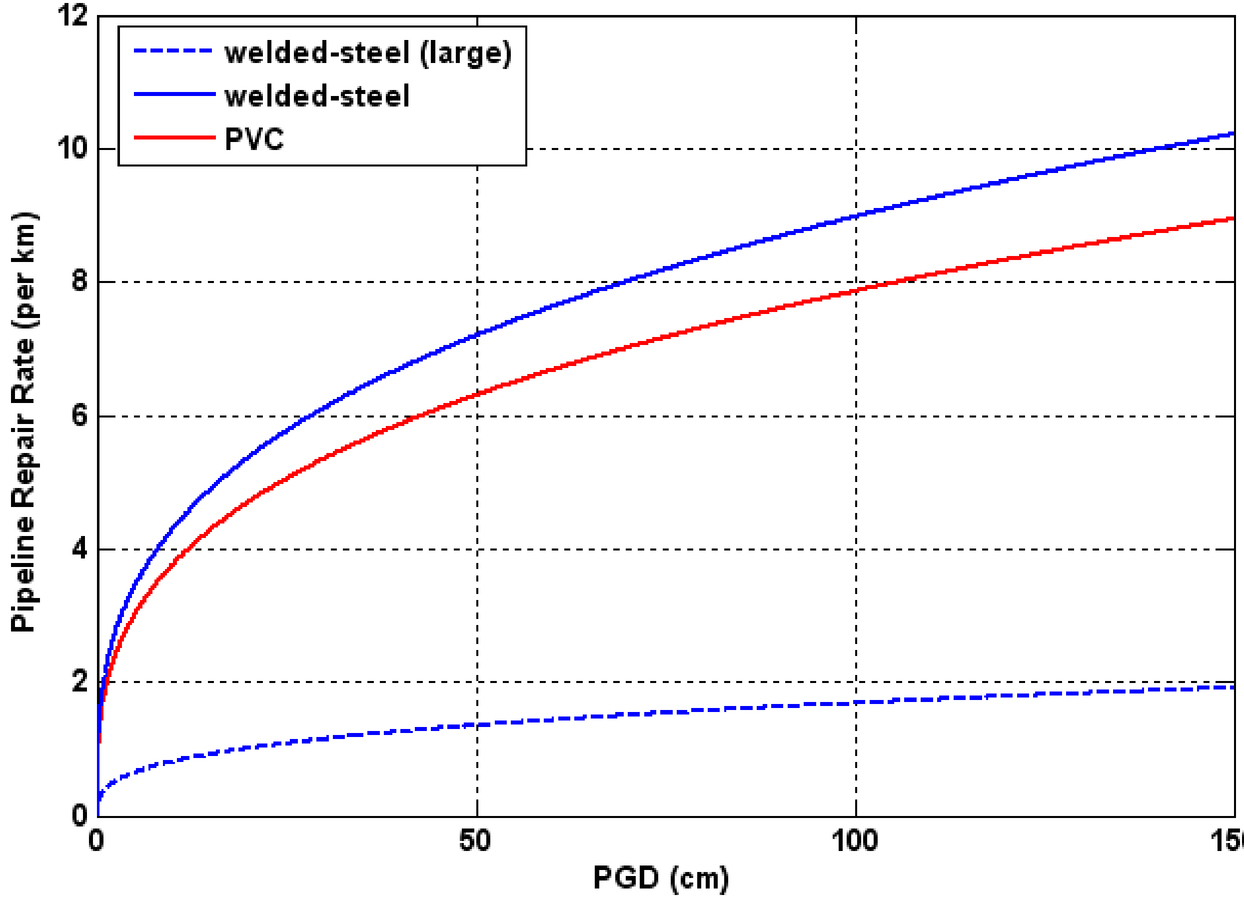
Pipelines

$$RR = K_2 \, 2.58 PGD^{0.319}$$

PGD in *cm*

Ground failure

K1: corrective factor based on pipe properties

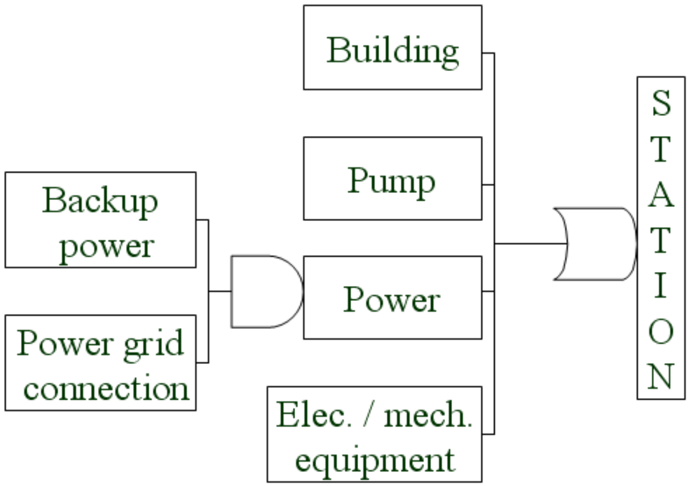


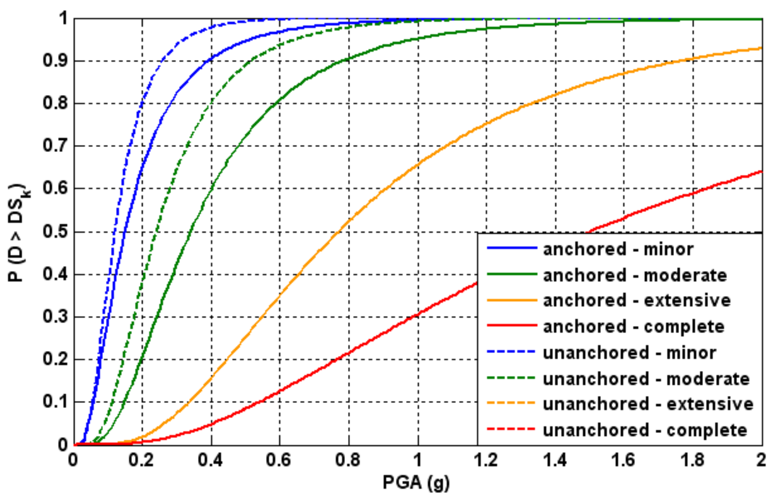
20% leaks
80% breaks

ALA (2001)

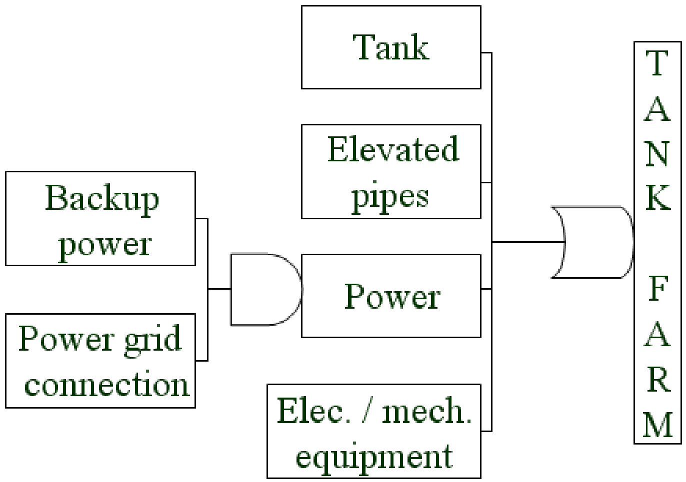
Fault tree analysis

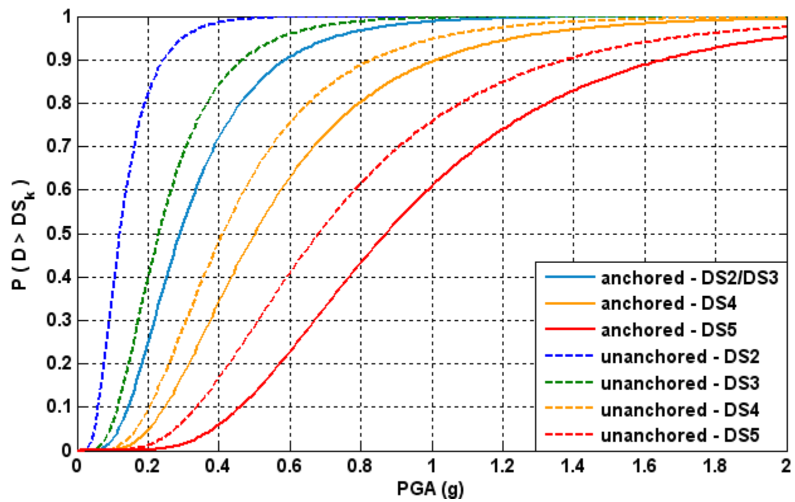
Pumping / Compressor stations





Storage Tanks



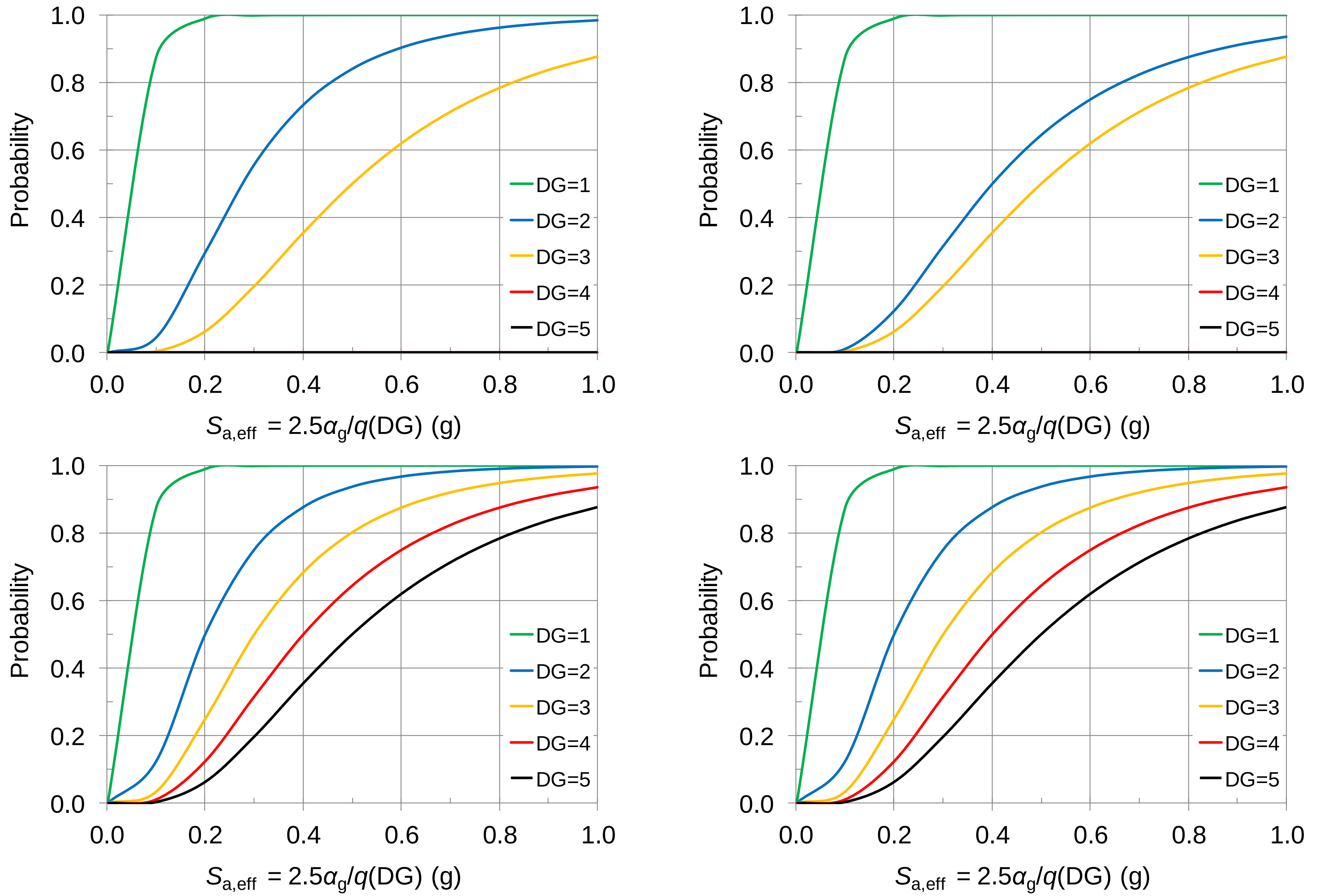


SYNER-G (2012)

2-storey Masonry Buildings

Rigid floors

Flexible floors



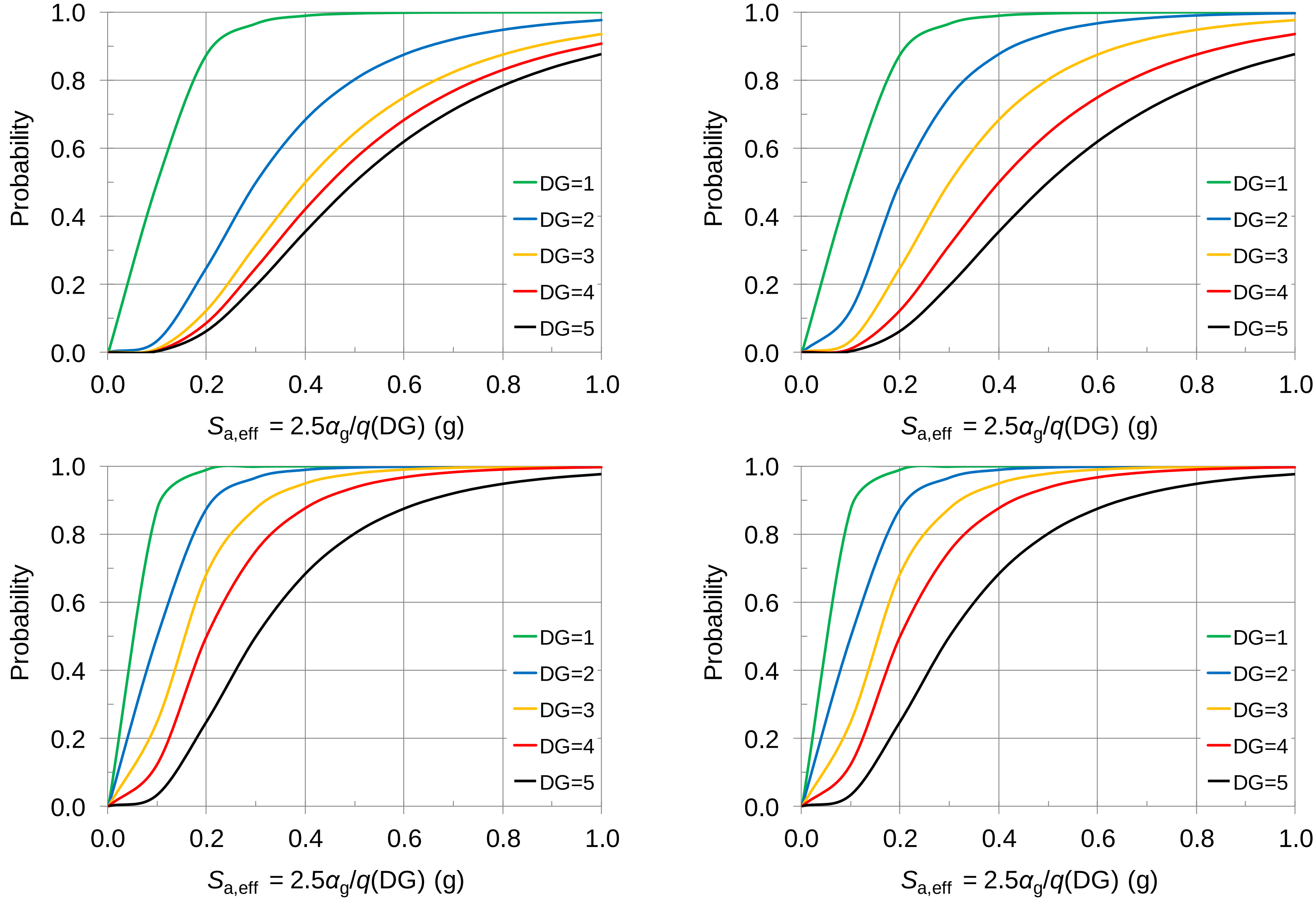
25% openings

35% openings

4-storey Masonry Buildings

Rigid floors

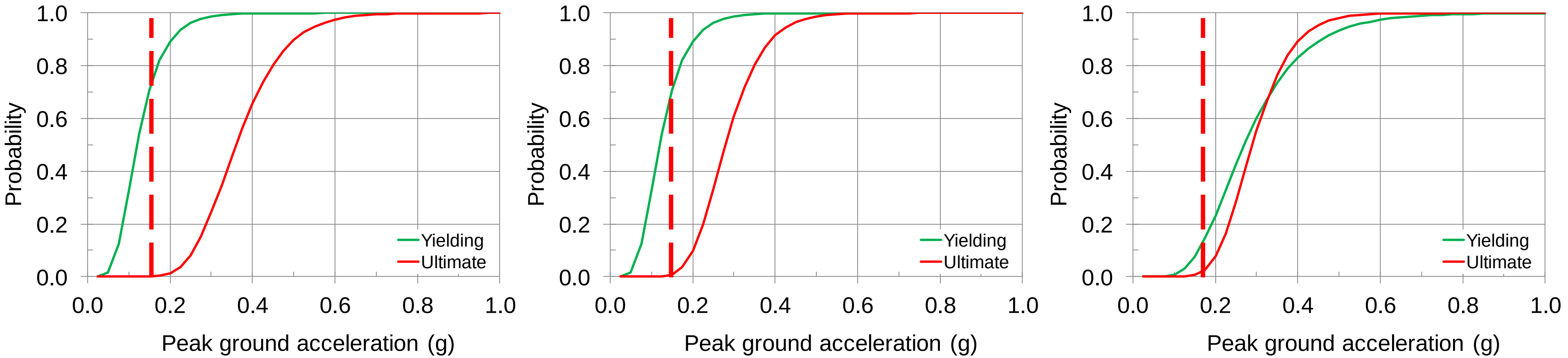
Flexible floors



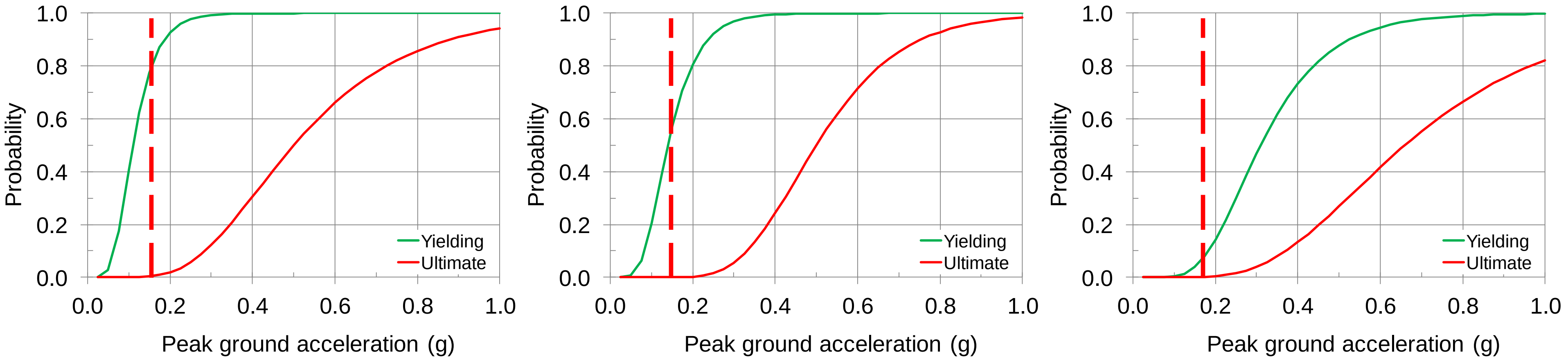
25% openings

35% openings

RC Buildings



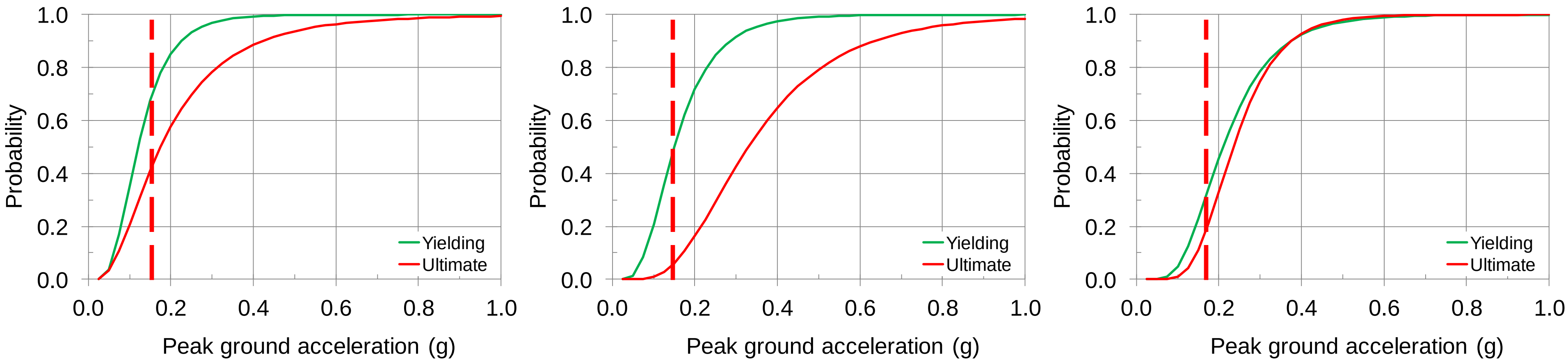
Frames with open ground-storey, low code



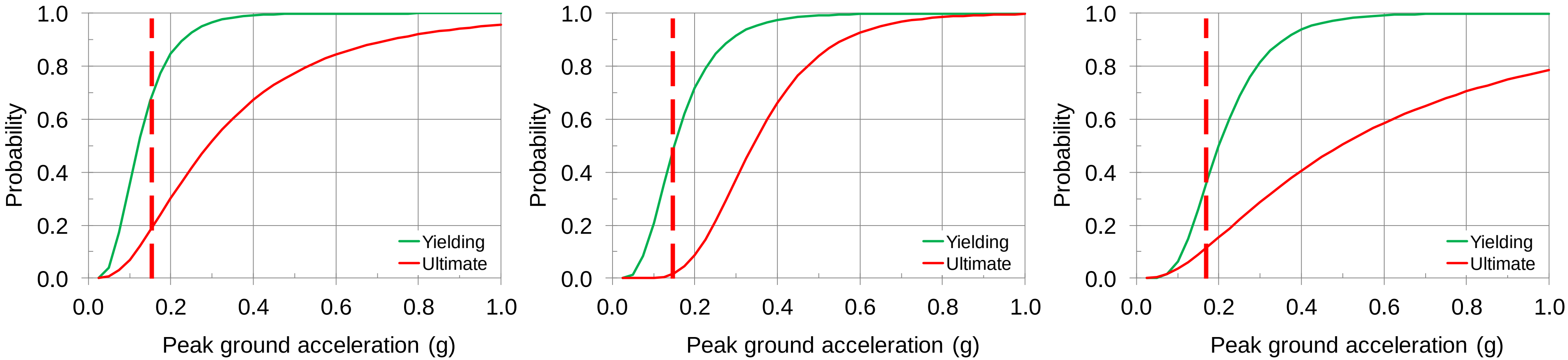
Frames with open ground-storey, high code

Fardis MN, Papailia A, Tsionis G (2012) Seismic fragility of RC framed and wall-frame buildings designed to the EN-Eurocodes. Bulletin of Earthquake Engineering, 10(6): 1767-1793

RC Buildings



Dual buildings, low code



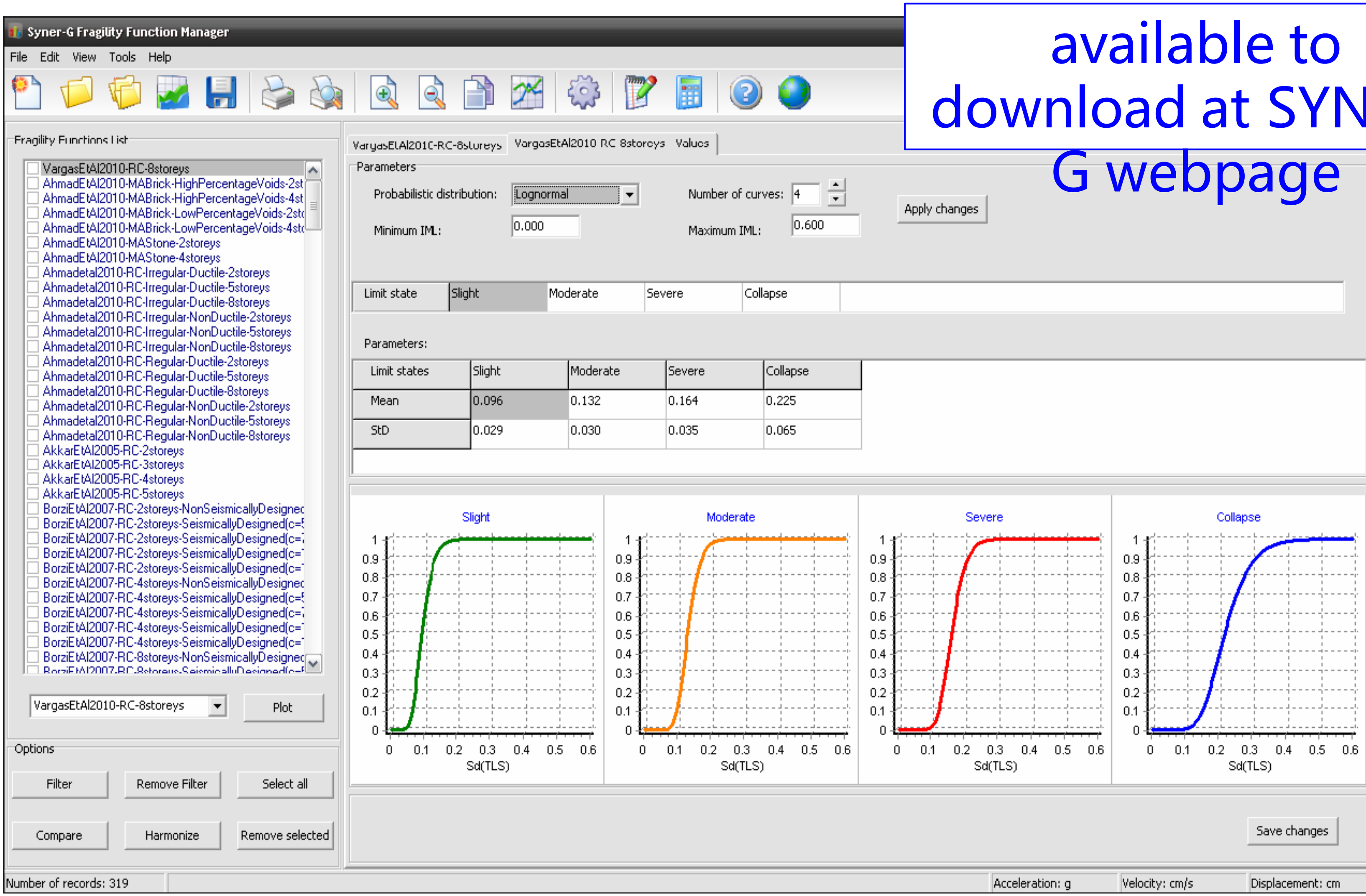
Dual buildings, high code

Fardis MN, Papailia A, Tsionis G (2012) Seismic fragility of RC framed and wall-frame buildings designed to the EN-Eurocodes. Bulletin of Earthquake Engineering, 10(6): 1767-1793

Fragility Function Manager Tool

Store, Visualize, Manage large number of fragility functions sets

available to download at SYNER-G webpage



Fragility Function Manager Tool

http://www.vce.at/SYNER-G/files/downloads.html

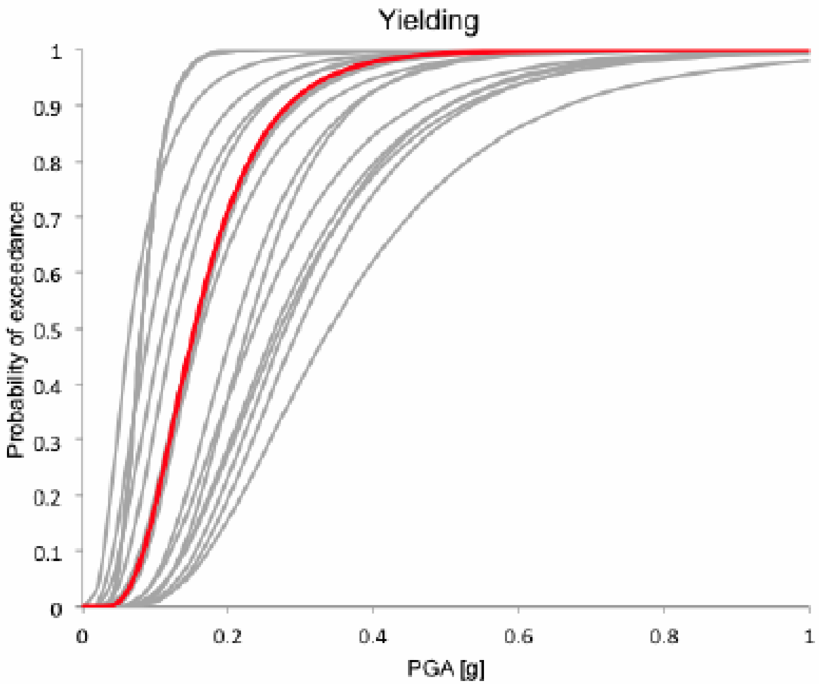
Scope of Tool

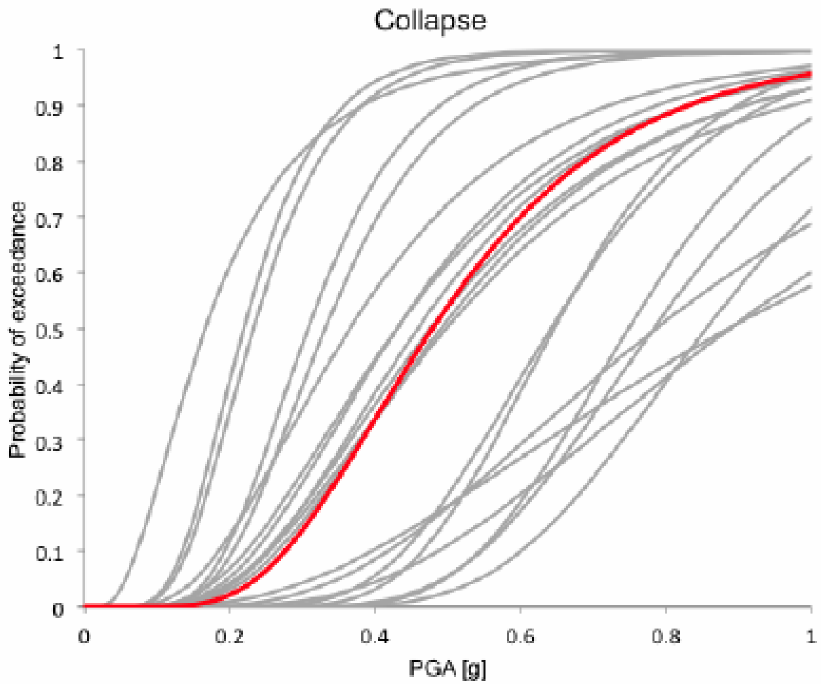
- Allows fragility functions (currently for buildings and bridges) to be stored in a common format (xml).
- Functions can be uploaded with the tool, and stored in terms of a given taxonomy classification.
- Functions can be further harmonised in terms of intensity measure type and yield and collapse limit state definition.
- Following harmonisation, functions can be compared.
- Epistemic uncertainty can be estimated from the extracted functions (such functionality will be added to future versions of the tool).

Fragility Function Manager Tool: Buildings

Comparison of Functions

RC, MRF, mid-rise, seismically designed

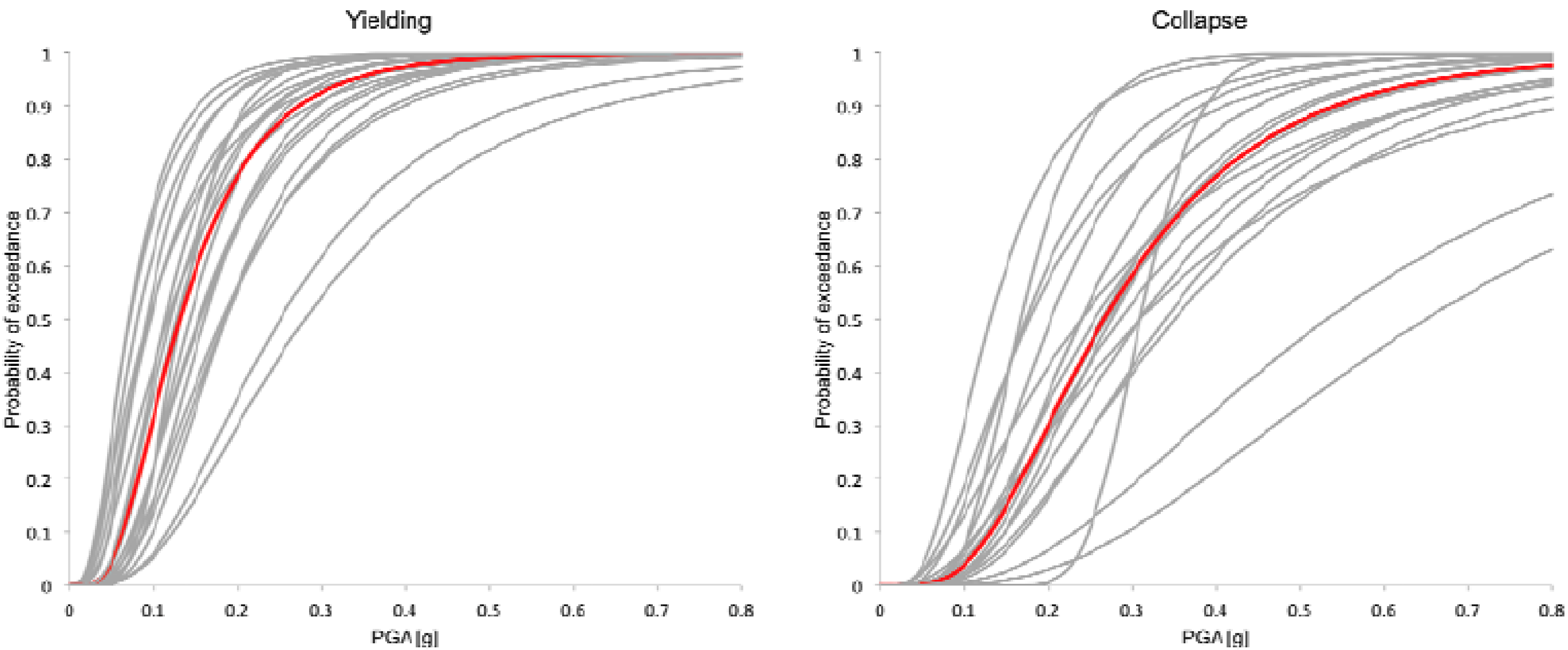




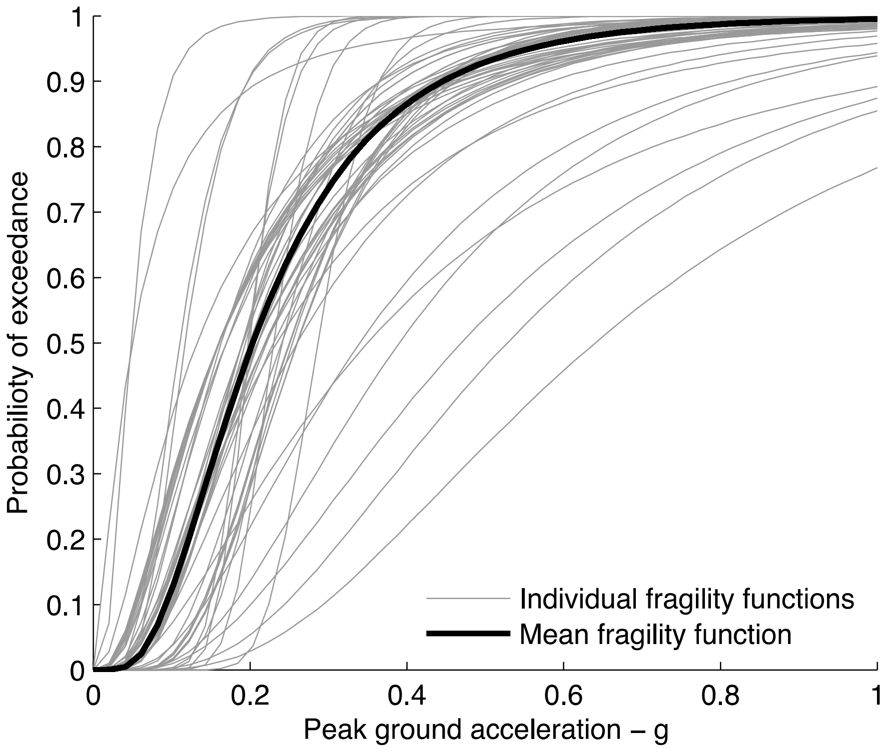
Fragility Function Manager Tool: Buildings

Comparison of Functions

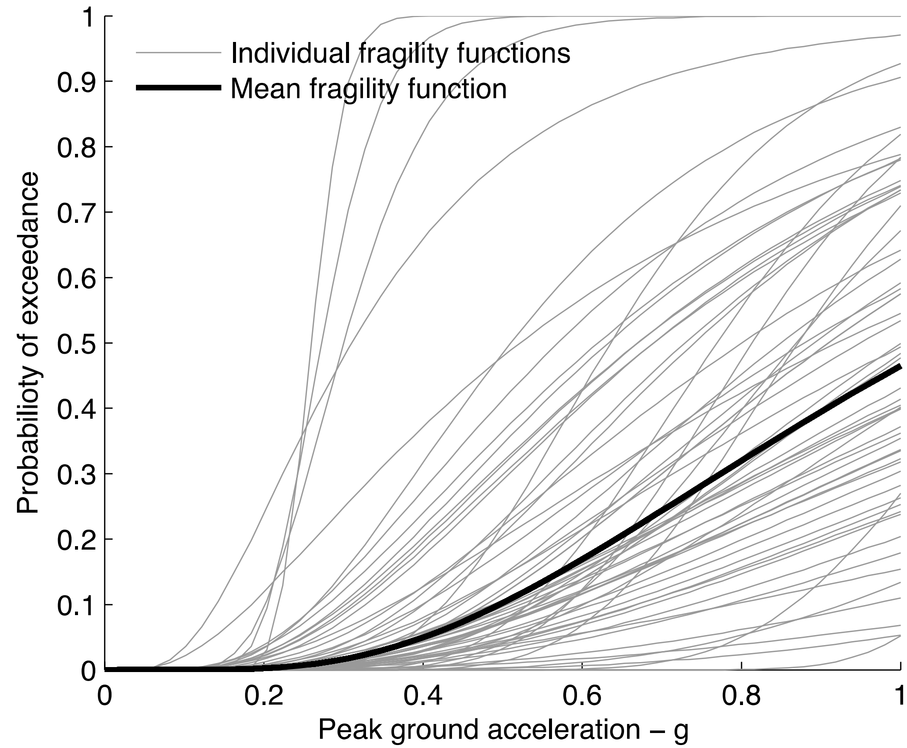
Masonry, Low Rise



Harmonization of European fragility functions for Bridges



(a)

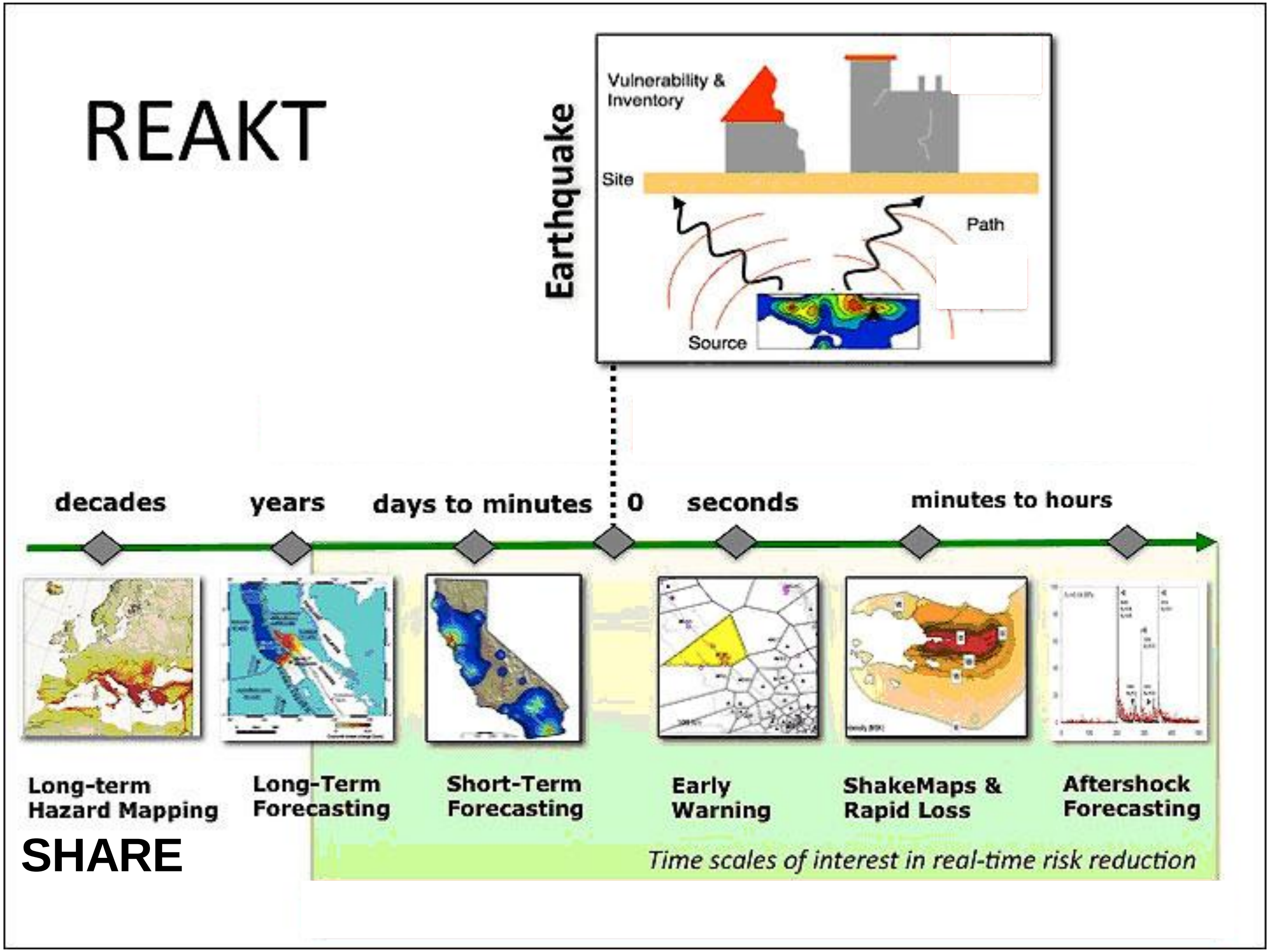


(b)

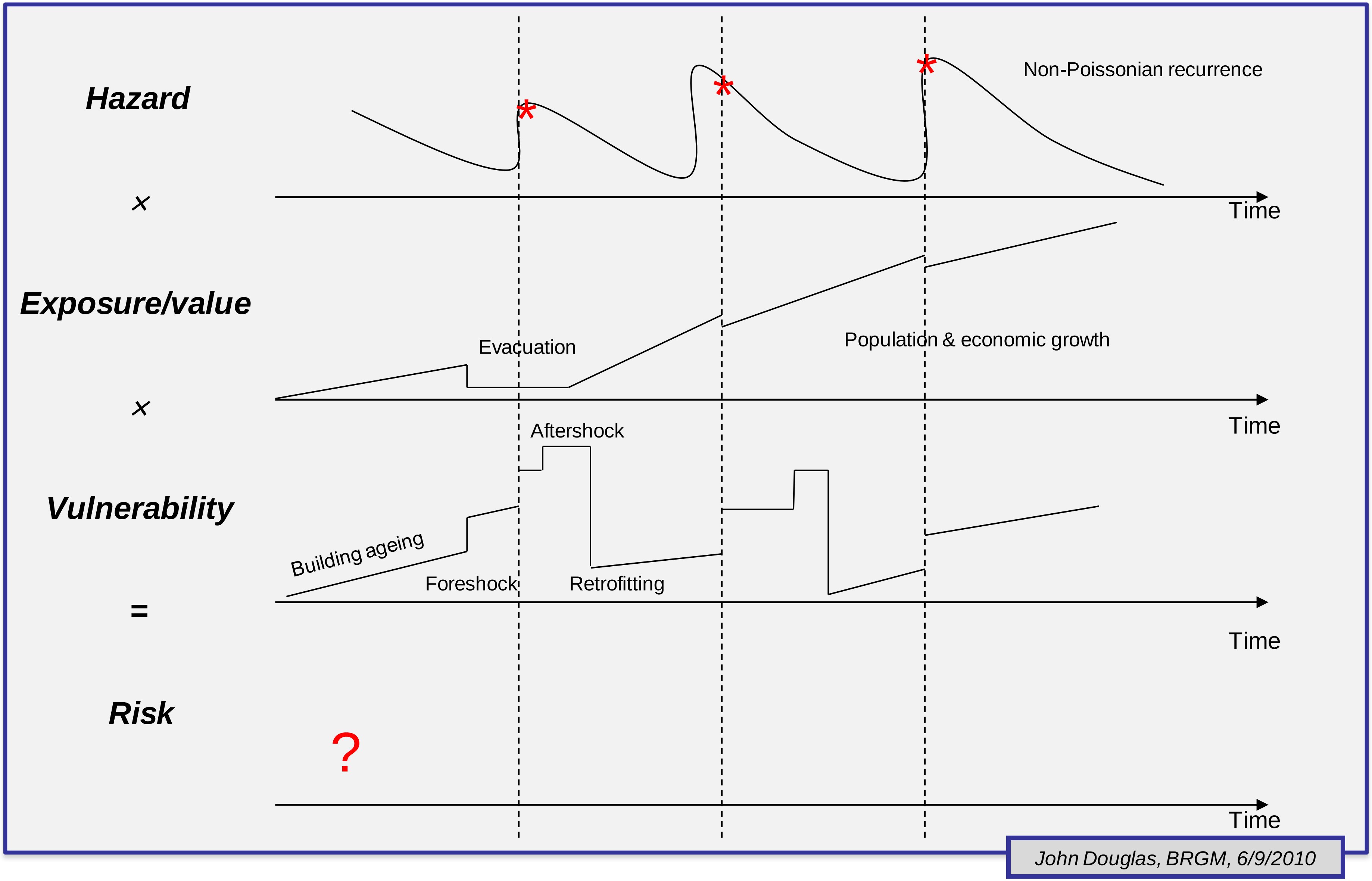
Minor damage state (a) and collapse damage state (b)
harmonised fragility functions for reinforced concrete, isolated, regular/semi-regular bridges

REAKT

Strategies and Tools for **R**eal Time **EA**rthquake Ris**K** Reduc**T**ion



Time dependent risk assessment



Time-dependent vulnerability

Aging effects

- progressive deterioration of the material properties caused by aggressive environmental attack

- strength degradation: reduction in the overall stiffness and ductility

State vulnerability (cumulative effects)

- effects of cumulative seismic damage

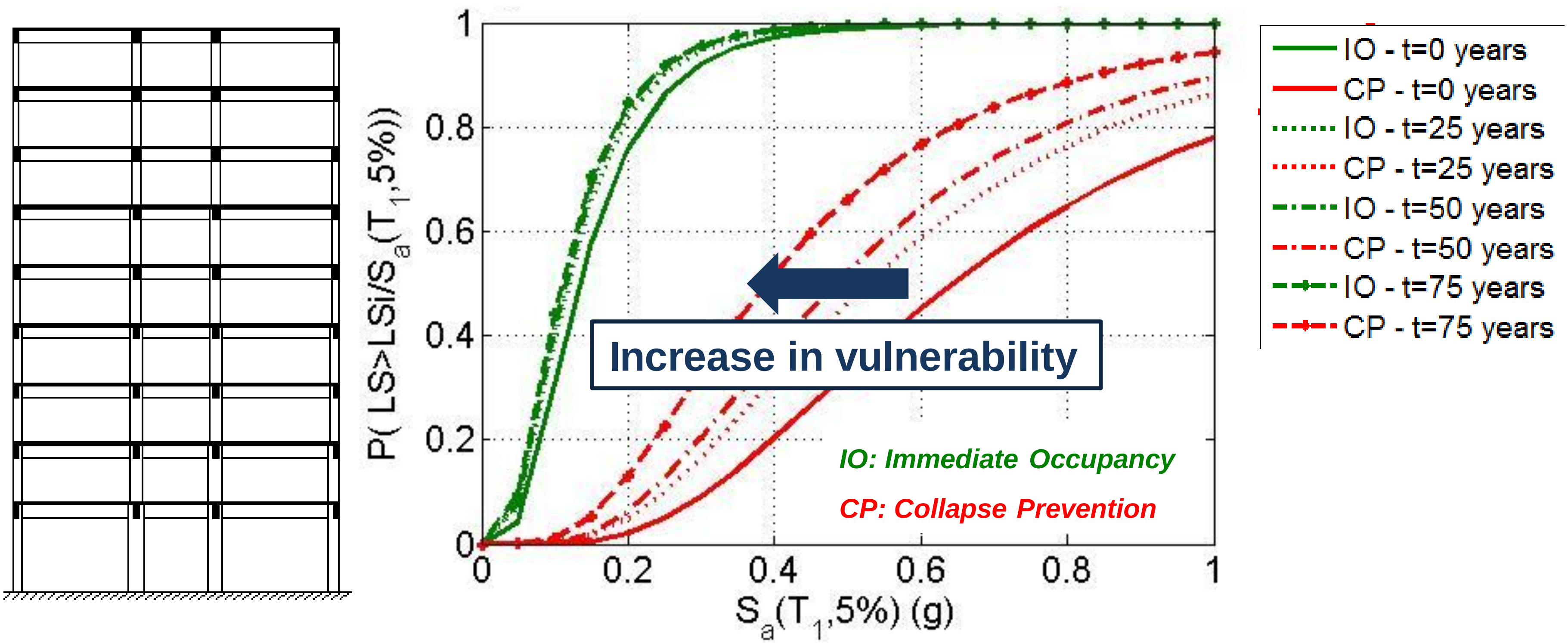
- capacity reduction, degradation of mechanical properties

Presently available fragility curves for civil engineering structures subjected to seismic hazard *do not account* for these two important parameters.

Time - dependent fragility curves for fixed base RC MRF structures

Effect of corrosion (t= 25, 50, 75 years)

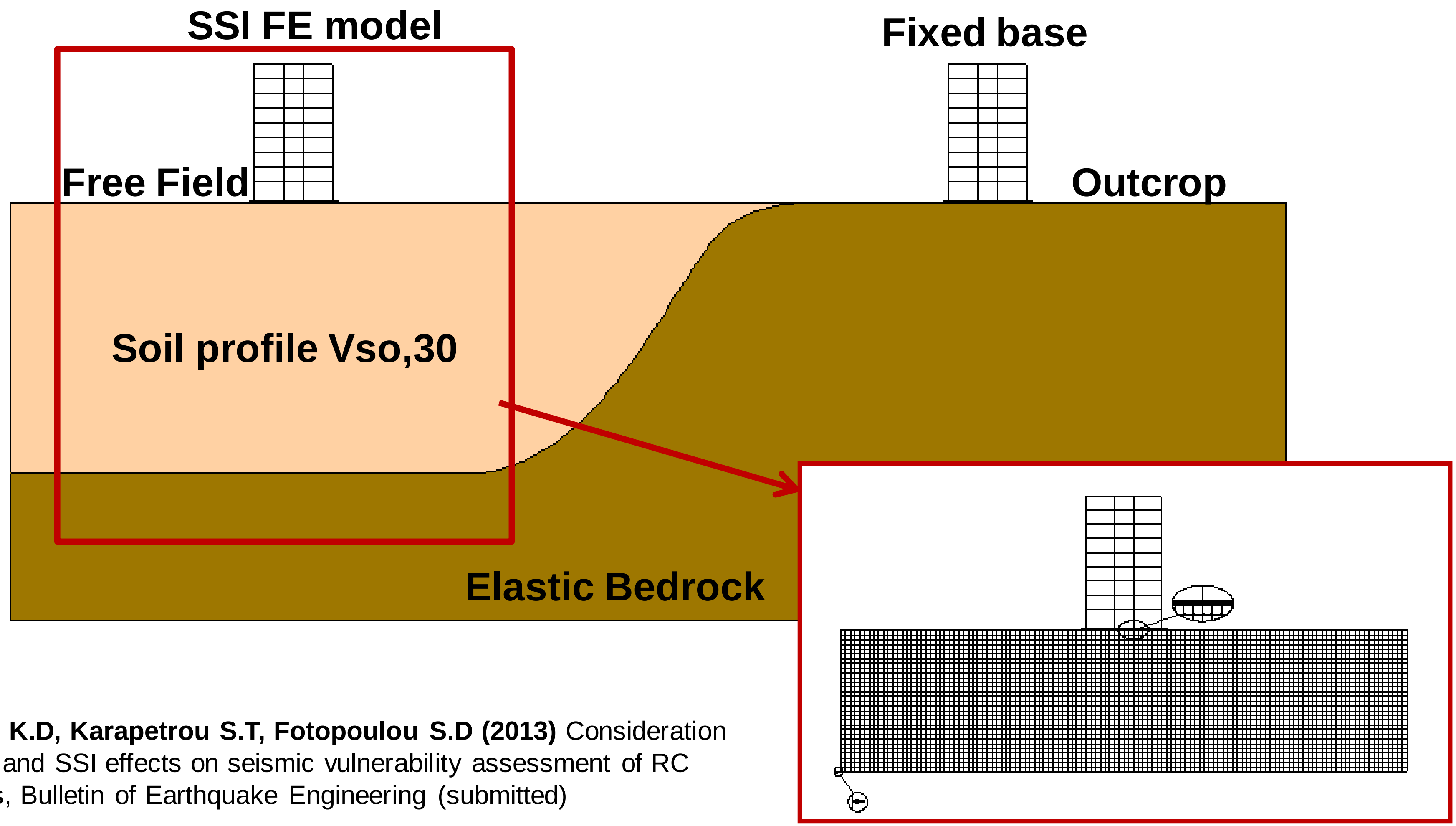
Fixed base high rise MRF with low code seismic provisions



Pitilakis K.D, Karapetrou S.T, Fotopoulou S.D (2013) Consideration of aging and SSI effects on seismic vulnerability assessment of RC buildings, Bulletin of Earthquake Engineering (submitted**)**

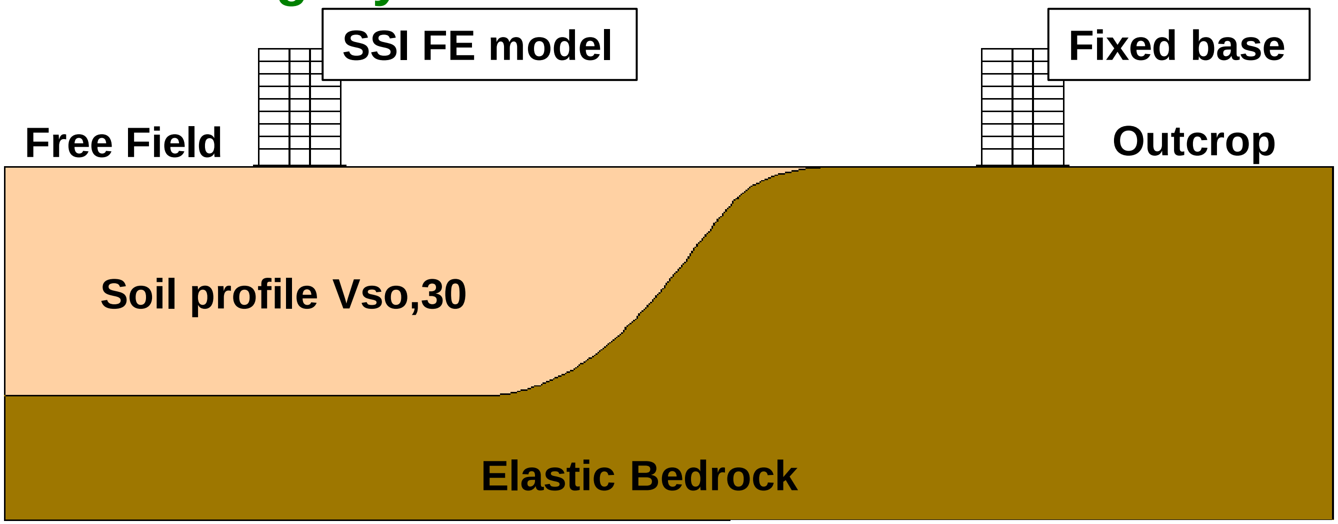
Time - dependent fragility curves with SSI

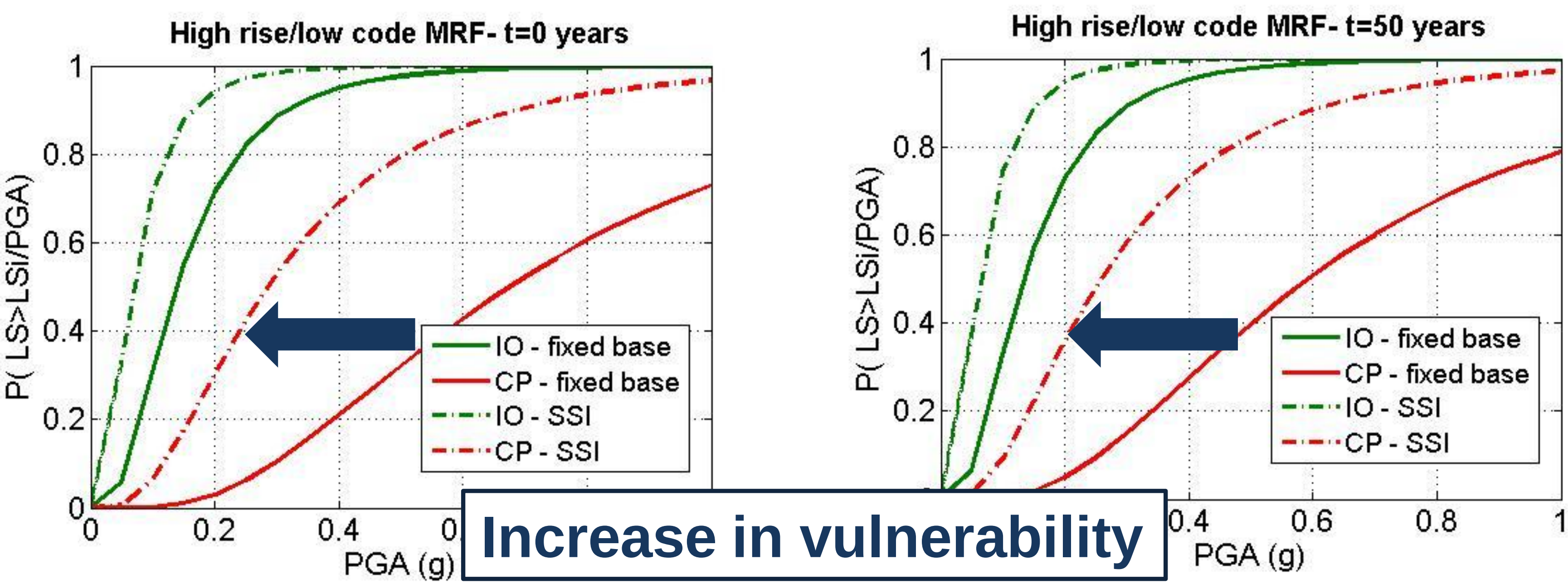
Time-dependent fragility curves in terms of PGA for the analyzed *fixed base and SSI structural configurations of the high rise structure designed with low seismic code provisions* for the initial (t=0years) and corroded (t=50years) scenario



Pitilakis K.D, Karapetrou S.T, Fotopoulou S.D (2013) Consideration of aging and SSI effects on seismic vulnerability assessment of RC buildings, Bulletin of Earthquake Engineering (submitted)

Time - dependent fragility curves





Increase in vulnerability

Vulnerability assessment based on field monitoring data

NERA

Operational modal analysis (OMA)

Finite Element Modeling (FEM)

OMA/FEM correlation techniques

Sensitivity analysis: Variation in parameters for FEM updating → *Modulus of Elasticity*, *Mass density*, *Moment of Inertia*

Modal analysis

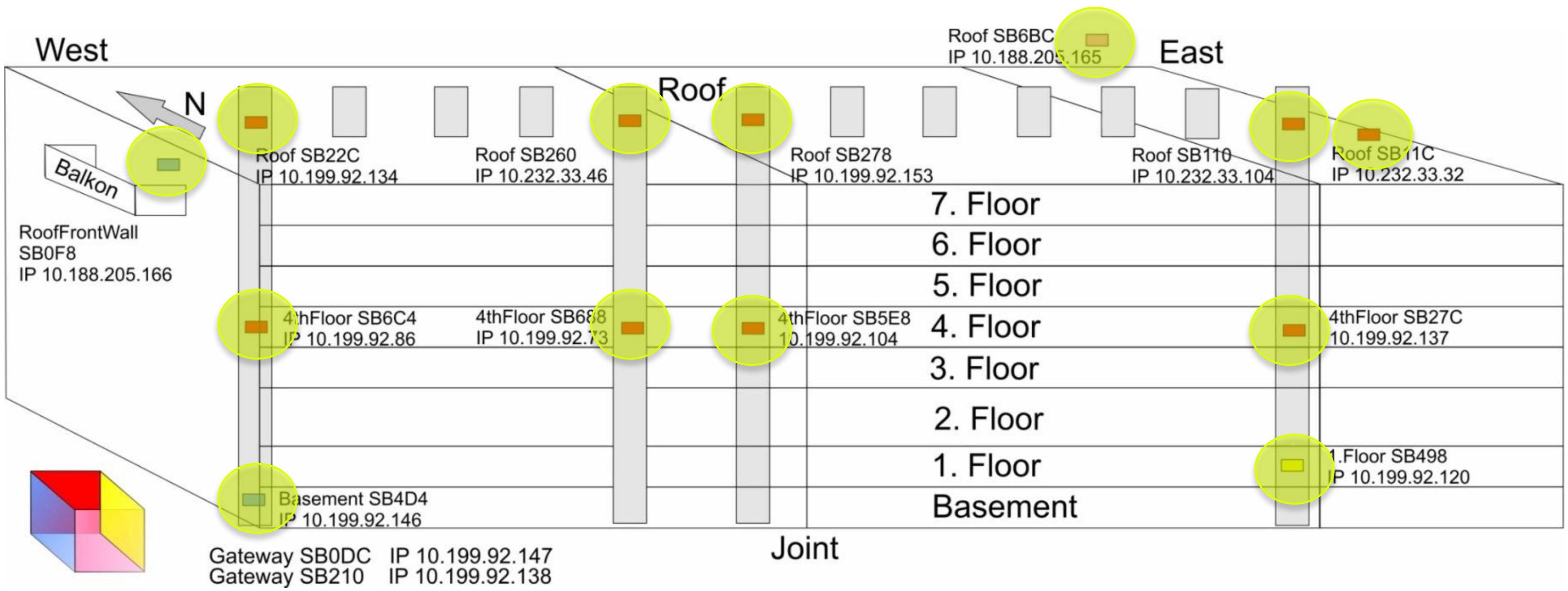
Comparison between numerical and experimental model → Evaluation of MAC values

Selection of the “best” model → Nonlinear Static or Dynamic Analyses

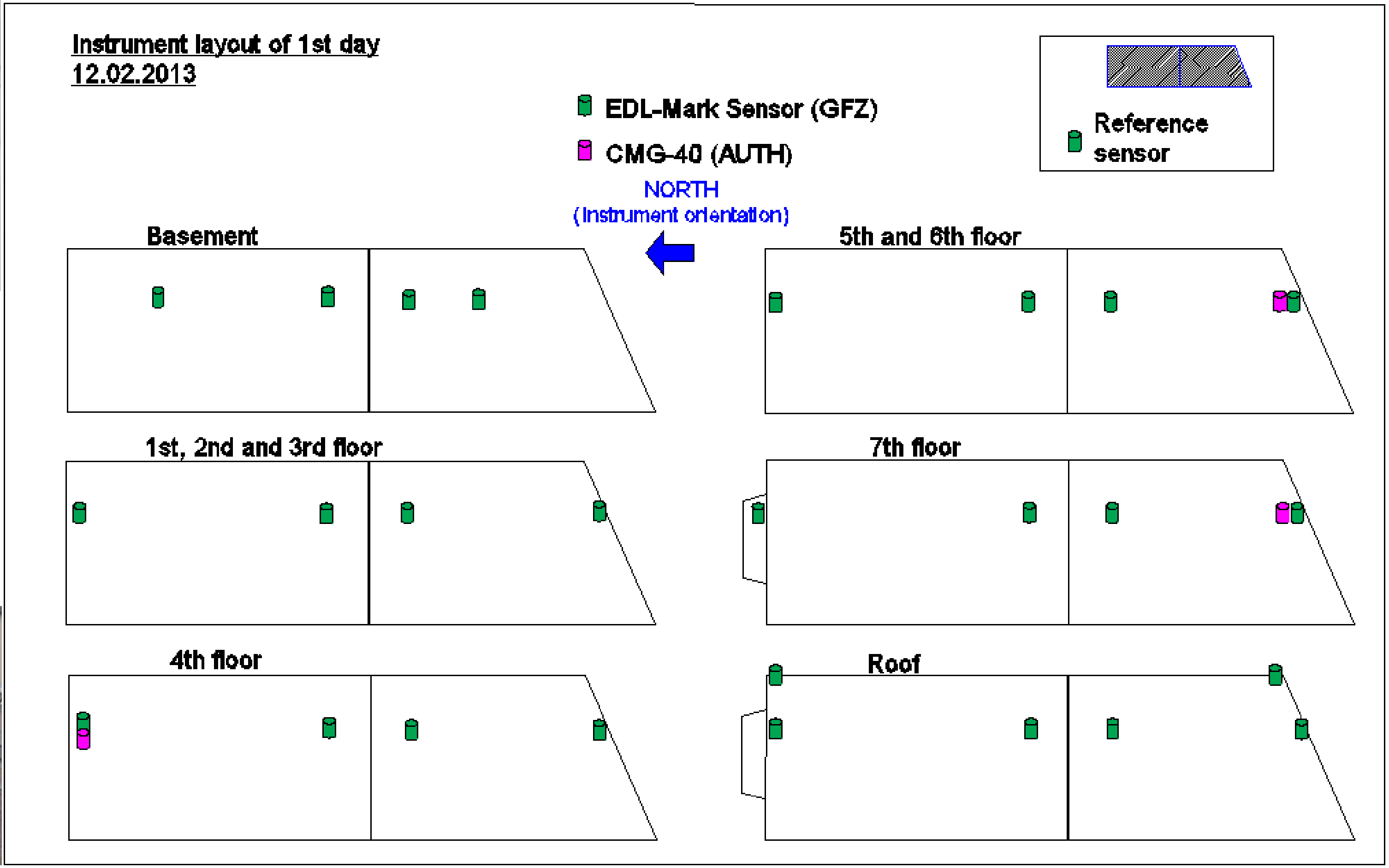
“Real-Time” fragility curves

13 nodes installed in the hospital
1 node installed in a nearby building as bridge
2 (gateways) in the University

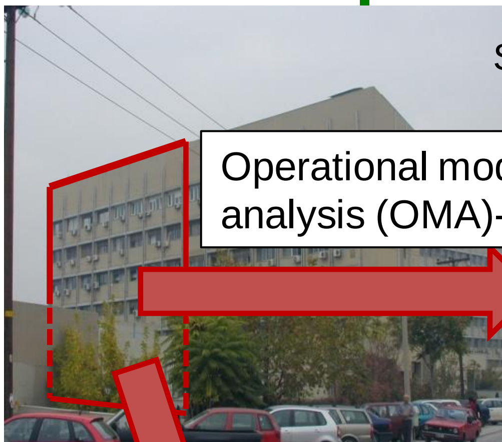
AHEPA hospital – instrumentation



AHEPA hospital – Ambient noise

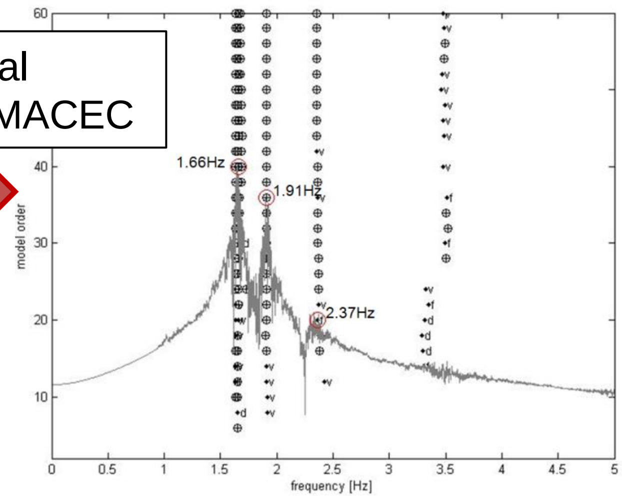


AHEPA hospital – Modal parameter identification

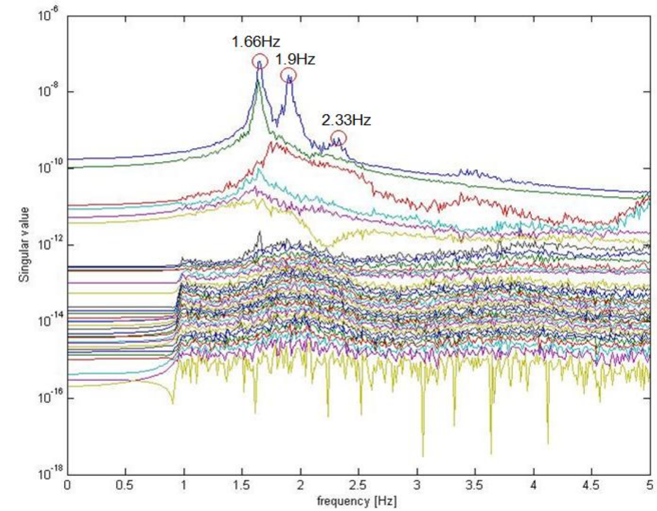


Operational modal analysis (OMA)-MACEC

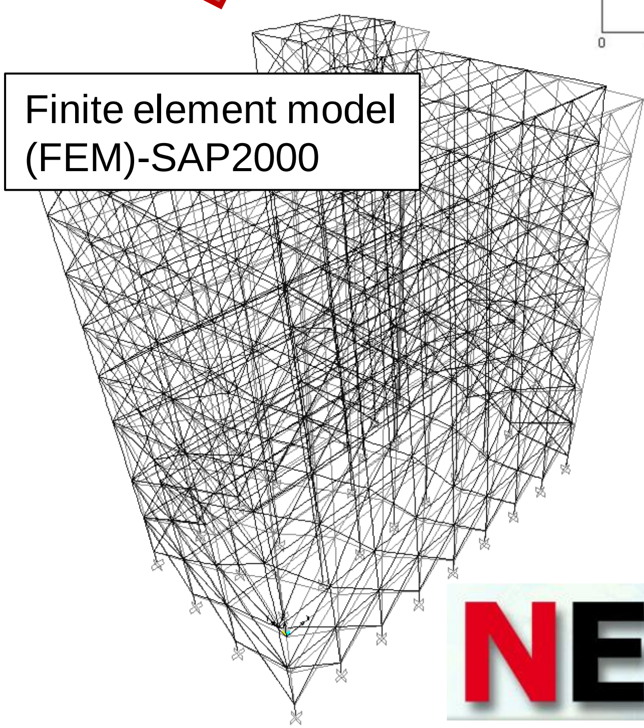
Stochastic subspace identification (SSI)



Frequency domain decomposition (FDD)



Finite element model (FEM)-SAP2000



- Comparison of the fundamentals periods between OMA and FEM

	FEM	FDD	SSI
T_1 (sec)	0.65	0.60	0.60
T_2 (sec)	0.46	0.53	0.53
T_3 (sec)	0.35	0.43	0.42

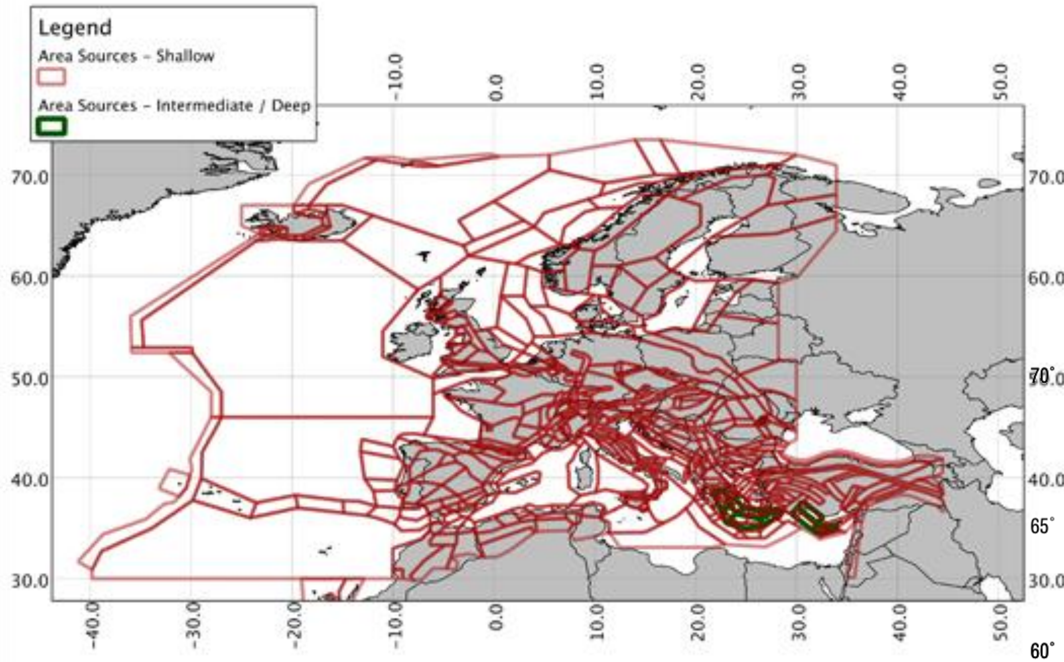
AHEPA hospital – Modal parameter identification

NERA

- Extensive parametric study of the hospital building considering the variation in structural parameters (e.g. Modulus of elasticity) investigating the sensitivity of the model to material properties and how the latter affect the overall stiffness of the structure.

- "New" updated FE model derived from the extended parametric study, that is closer to the experimental data than the initial model. More reliable modeling using field monitoring data taking into account material strength degradation and potential existing structural damage.

- Non-linear dynamic analysis (IDA) of the "new" updated FE model of the hospital building to derive the **"real-time" fragility curves.**



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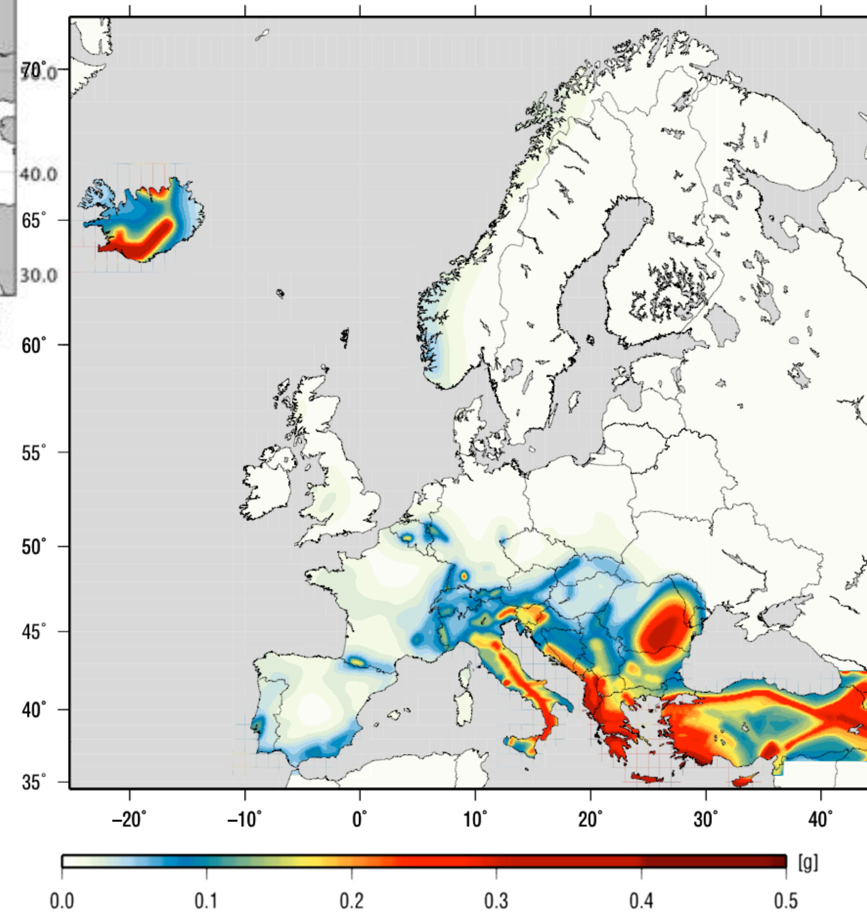
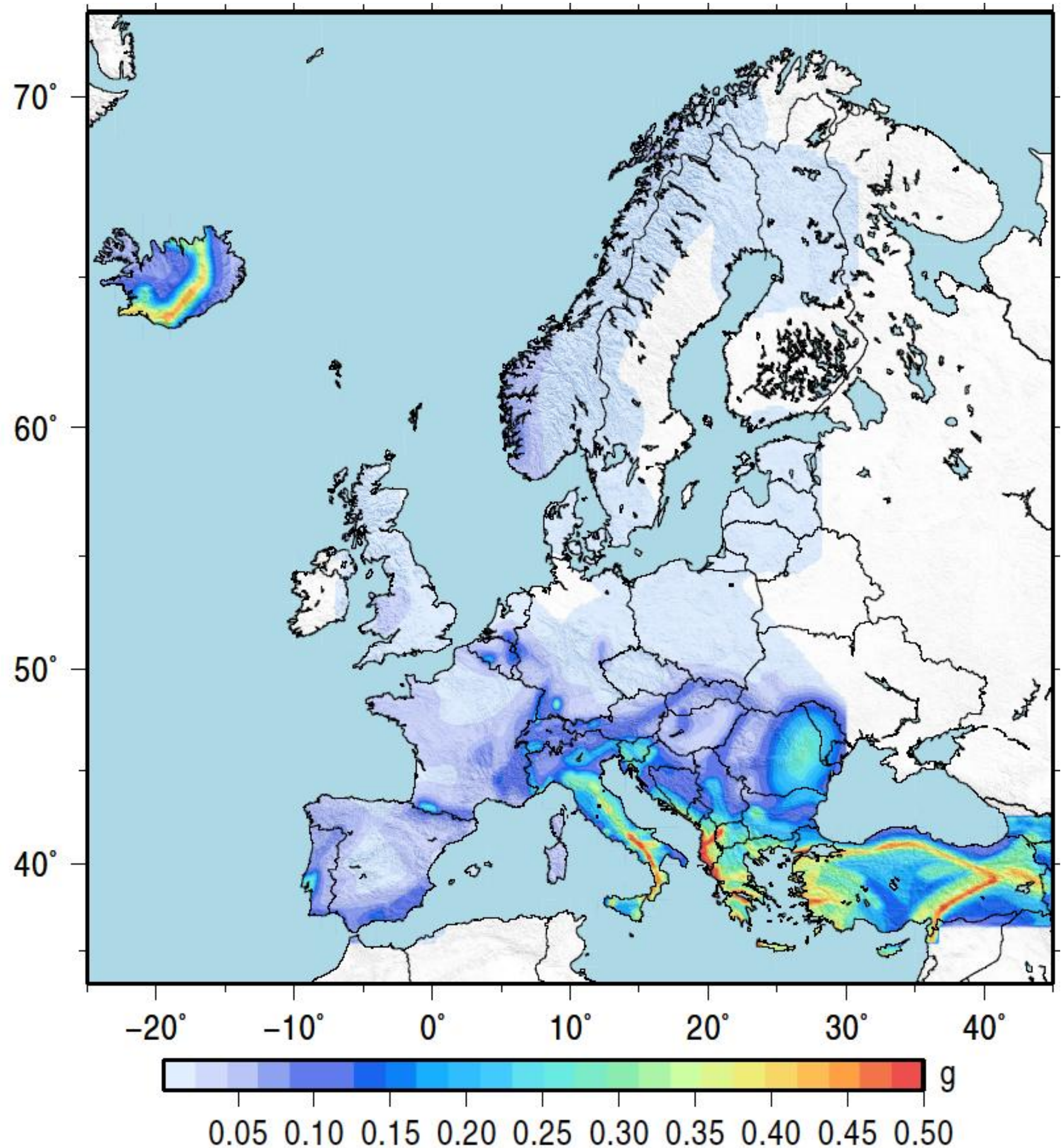
www.share-eu.org



Seismic Hazard Maps



Area Source Branch

Return Period = 475 years

Period = **PGA**

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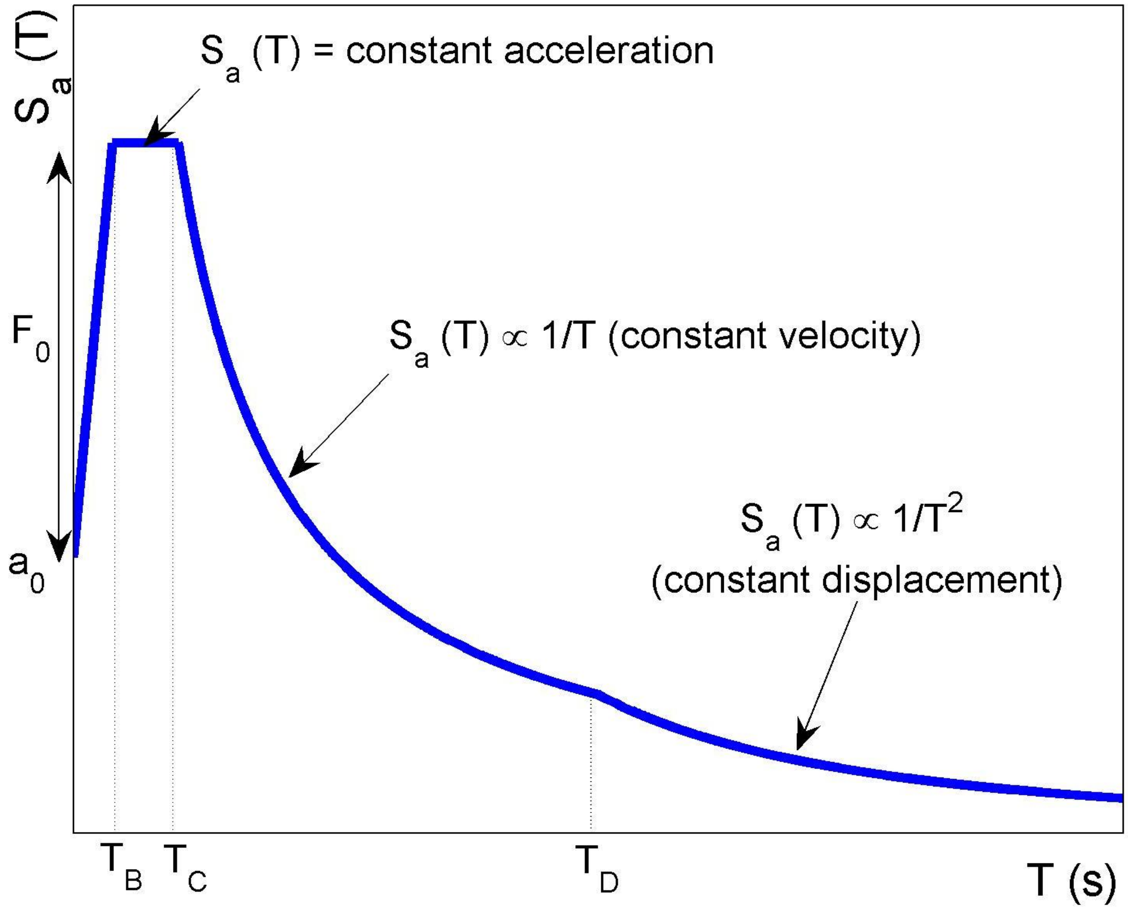
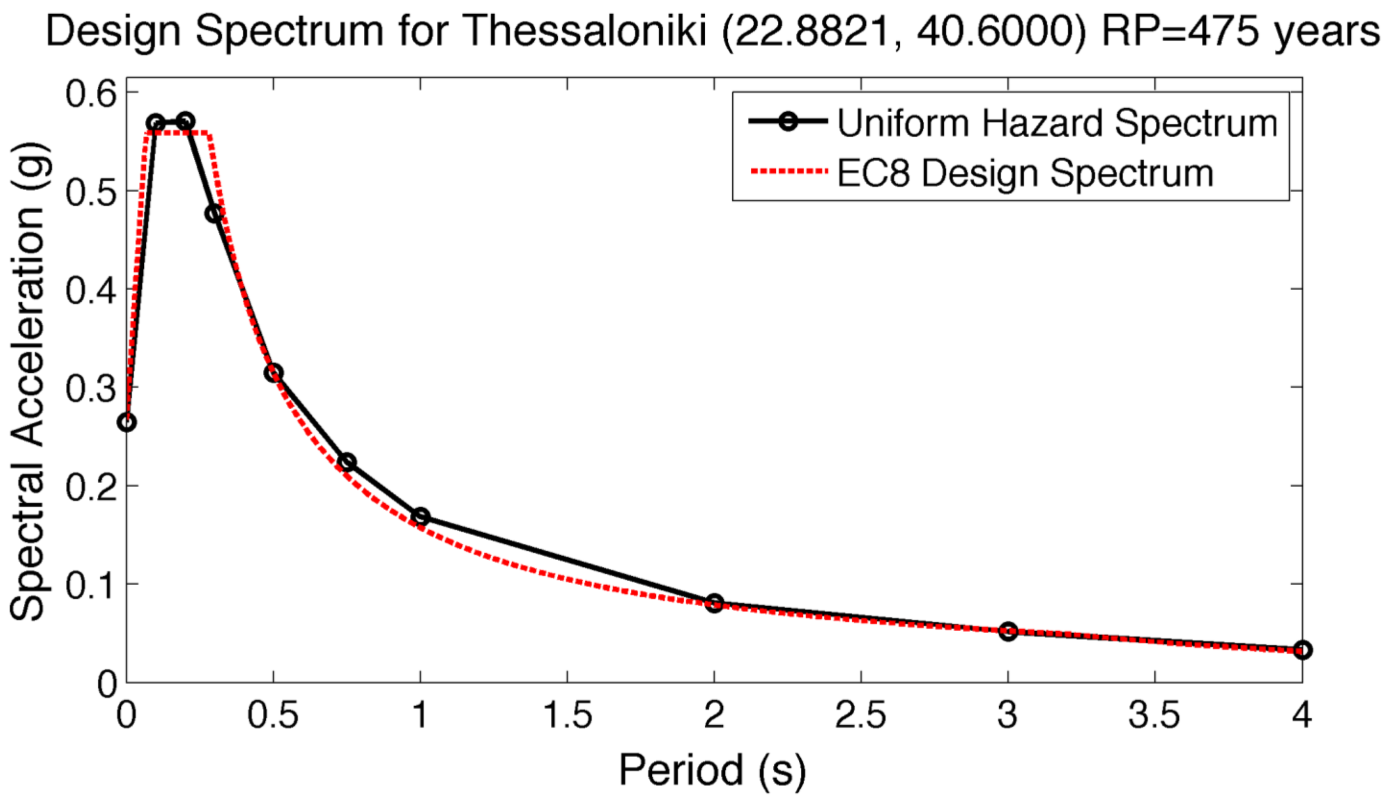
Deriving Design Spectrum Parameters

Design spectrum (for shorter periods) is defined by four parameters:

- F0 (Effective Amplification)
- TB (Constant Acceleration corner period)
- TC (Constant Velocity corner period)
- TD (Constant Displacement corner period)



Design Spectrum for Thessaloniki



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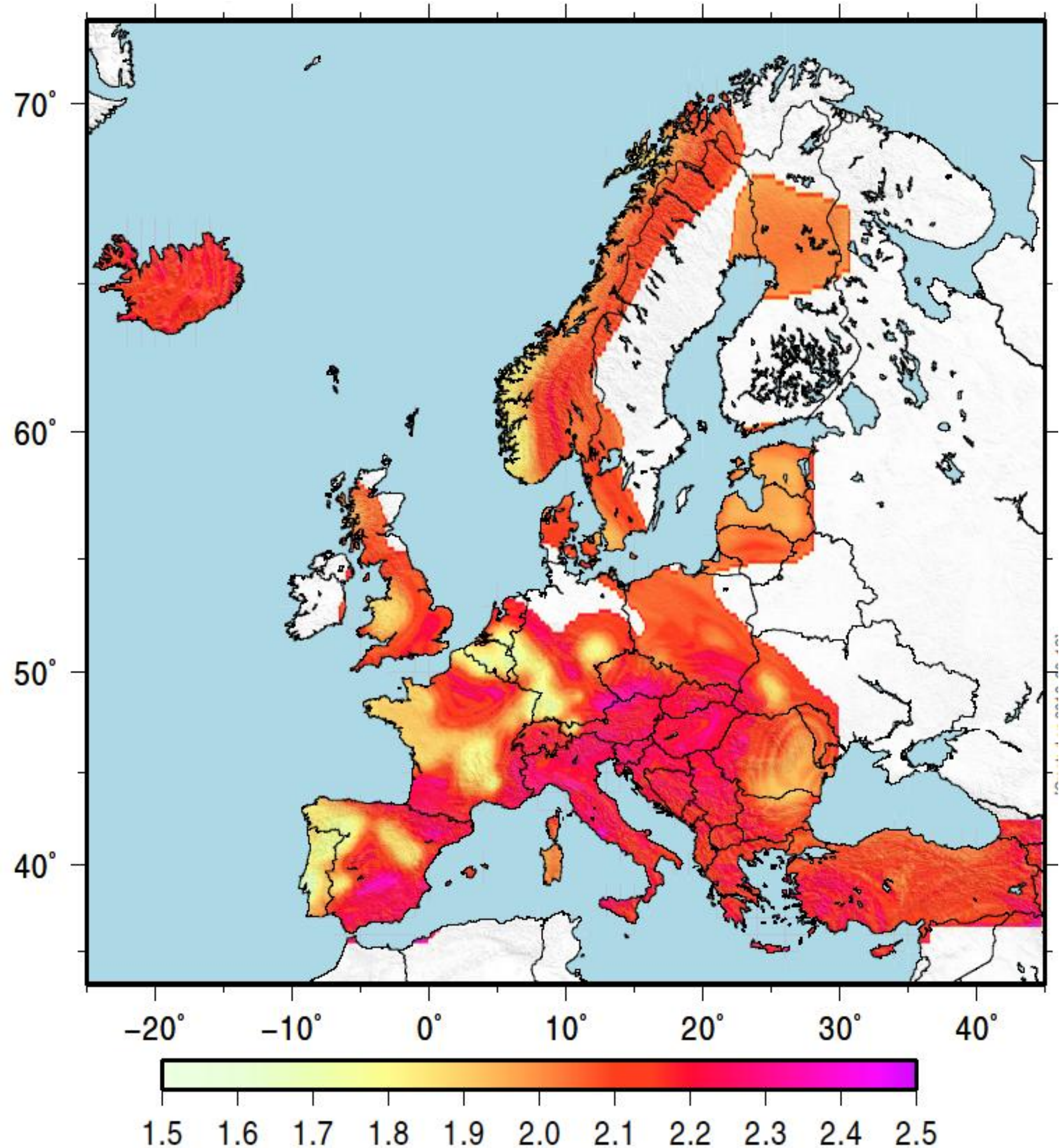
Design Spectrum Parameters



Amplification Factor (F0)

(Based on 475 year UHS)

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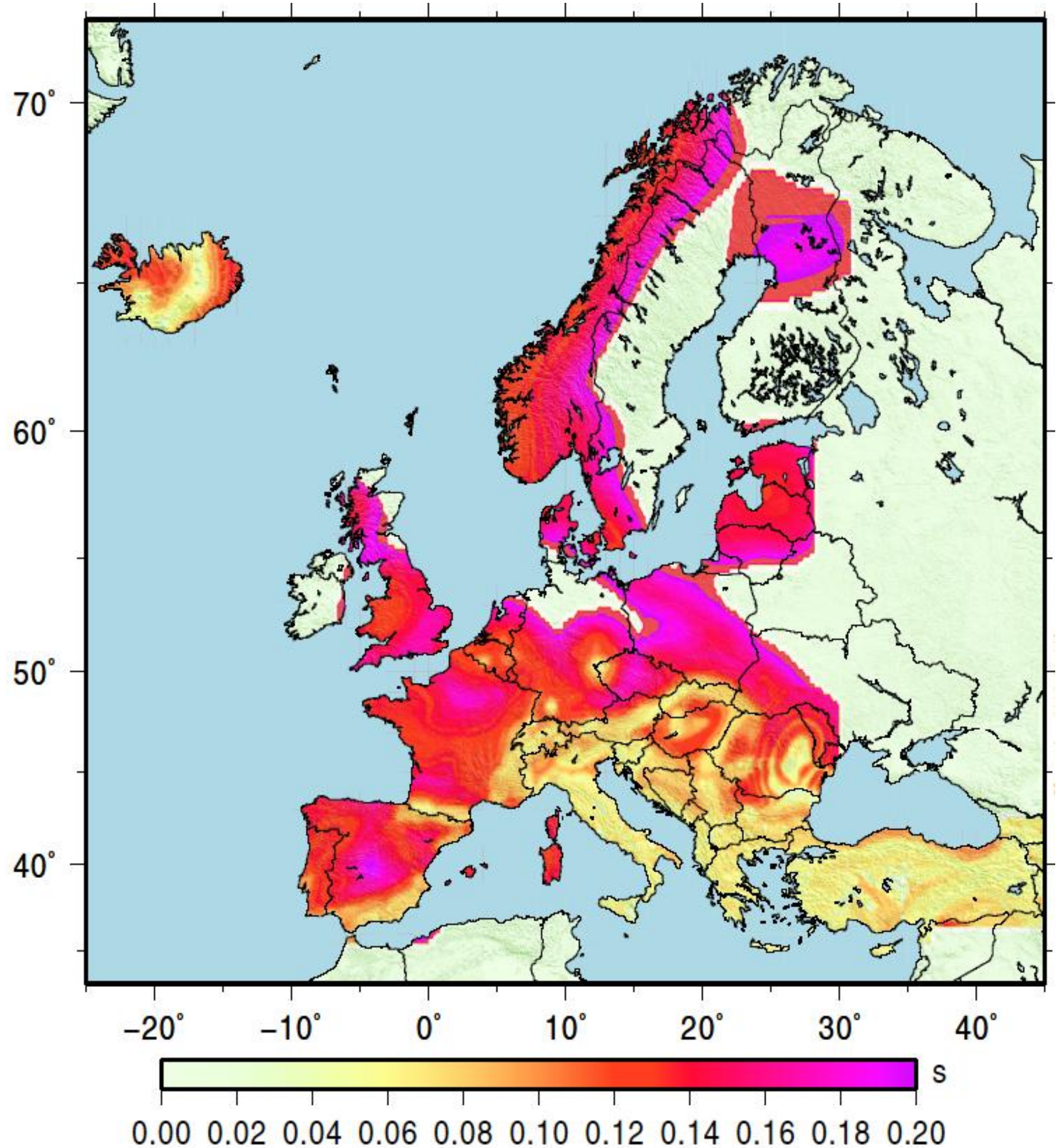
Design Spectrum Parameters



Tb

(Based on 475 year UHS)

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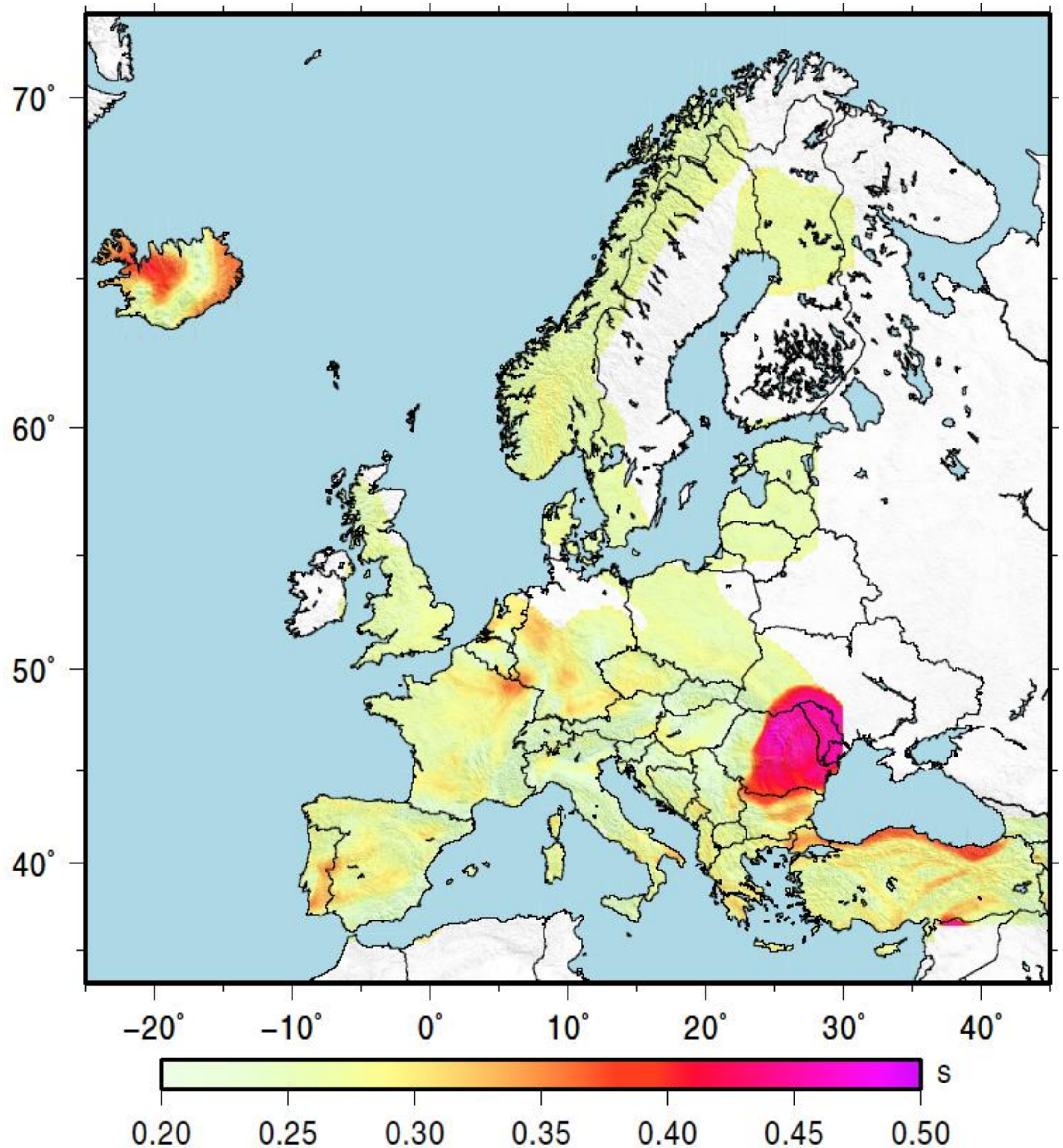
Design Spectrum Parameters



Tc

(Based on 475 year UHS)

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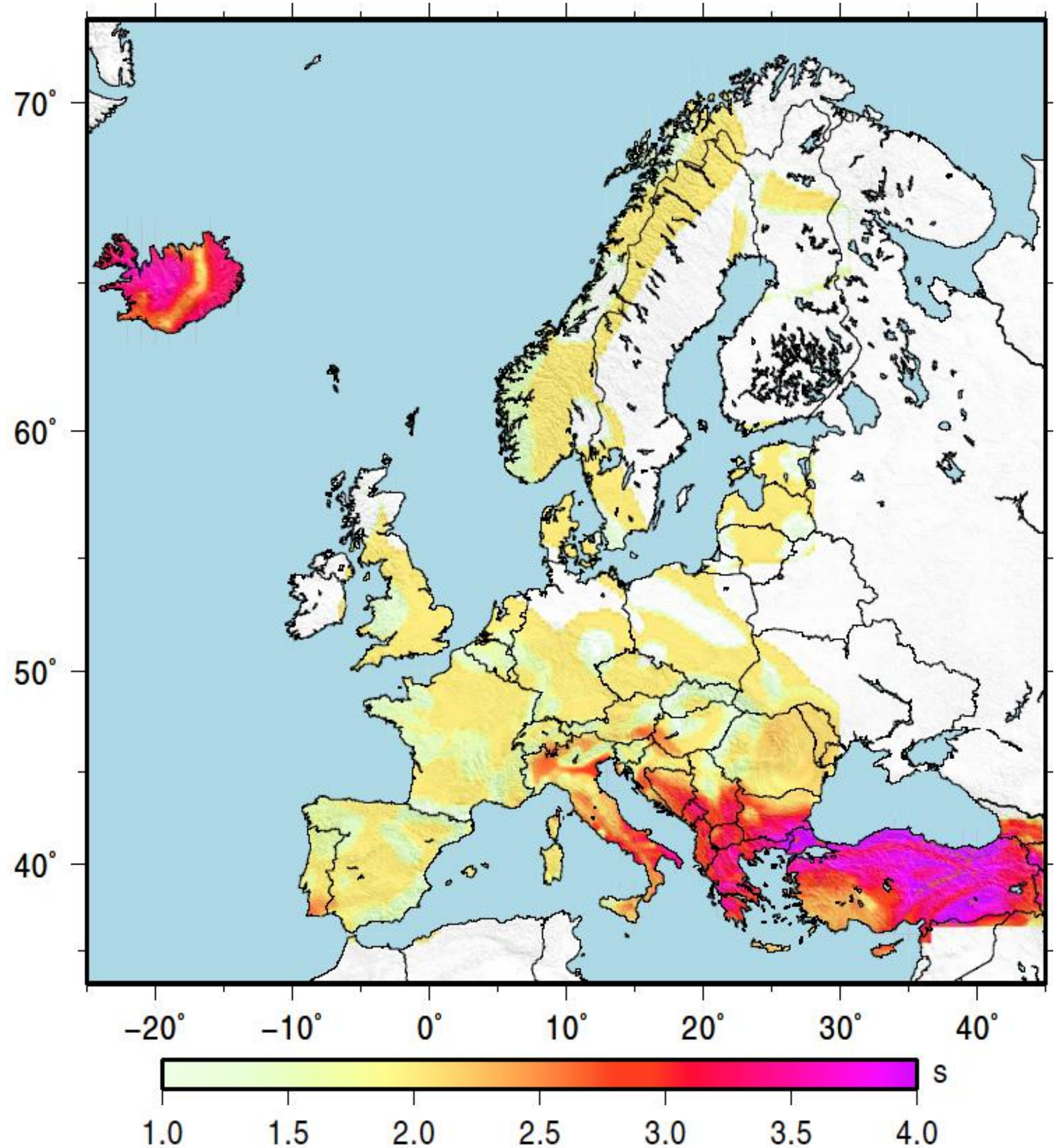
Design Spectrum Parameters



Td

(Based on 475 year UHS)

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Design Spectrum Parameters

Sd (10.0 s)

Return Period = 475 years

Active Shallow regions only, with
Cauzzi & Faccioli (2008)
and
Chiou & Youngs (2008) each with 0.5 weighting

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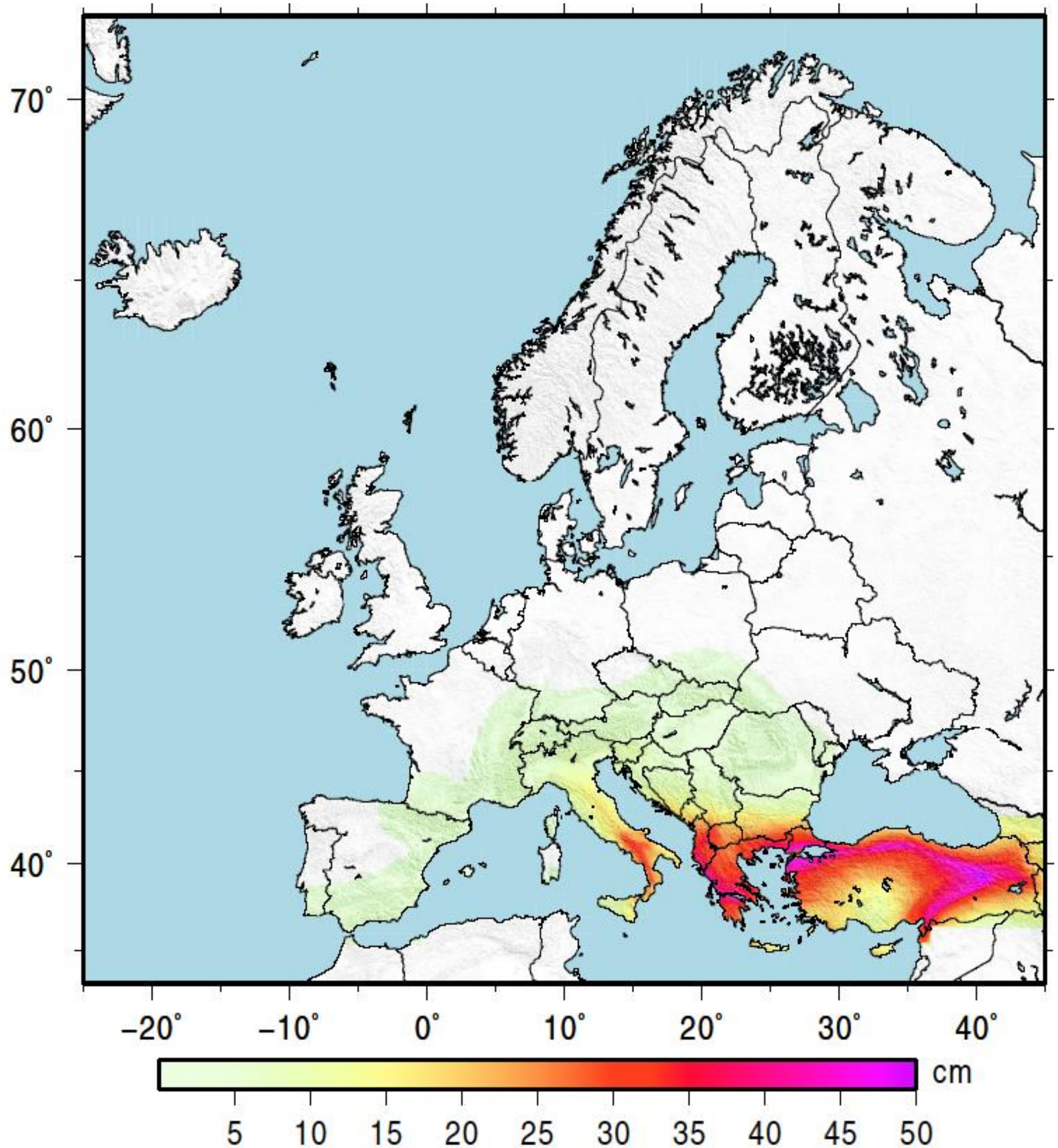
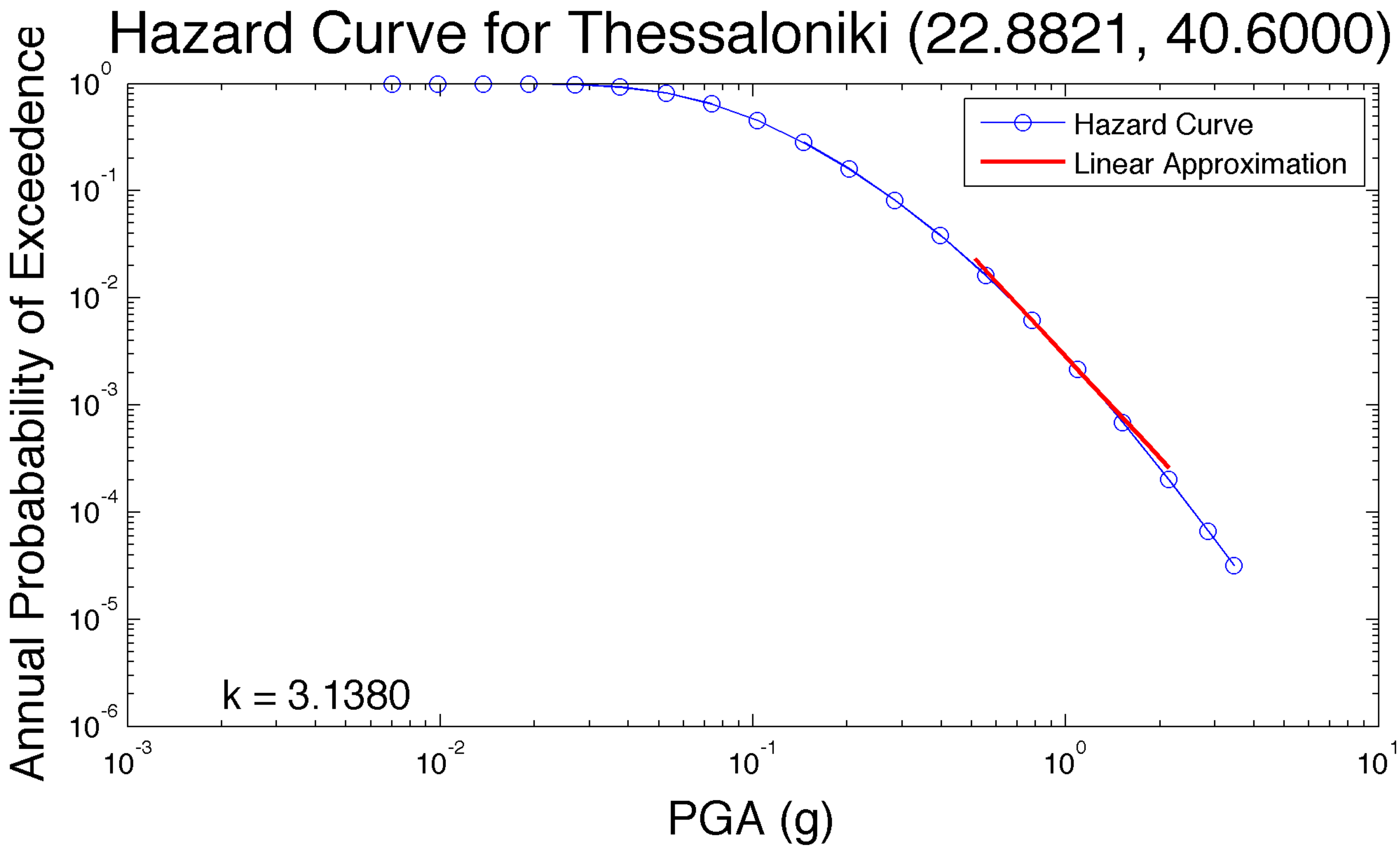


K-value (PGA) for Thessaloniki



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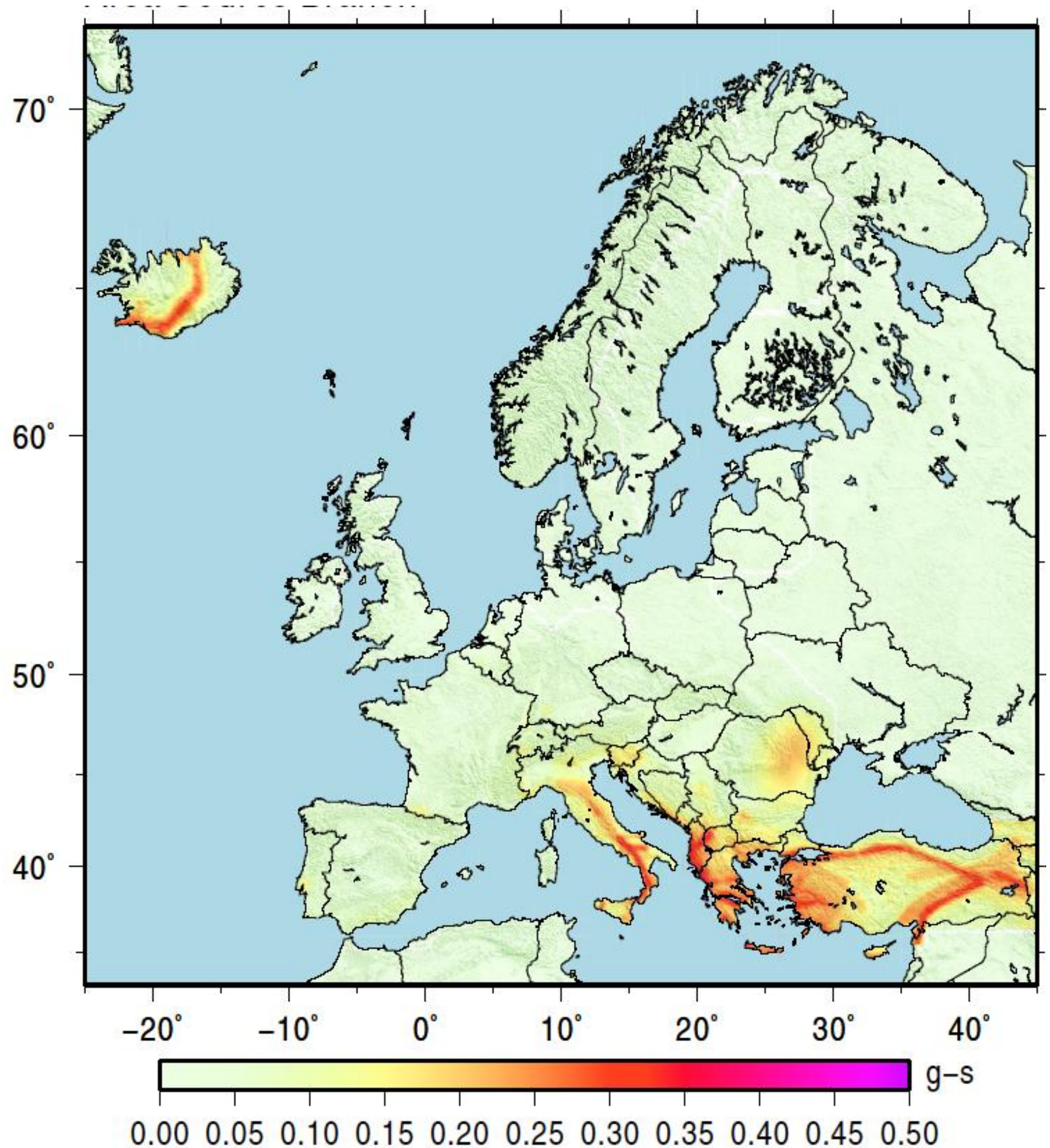
Acceleration Spectrum Intensity



- Area Source Model
- Derived from UHS for 475 year return period

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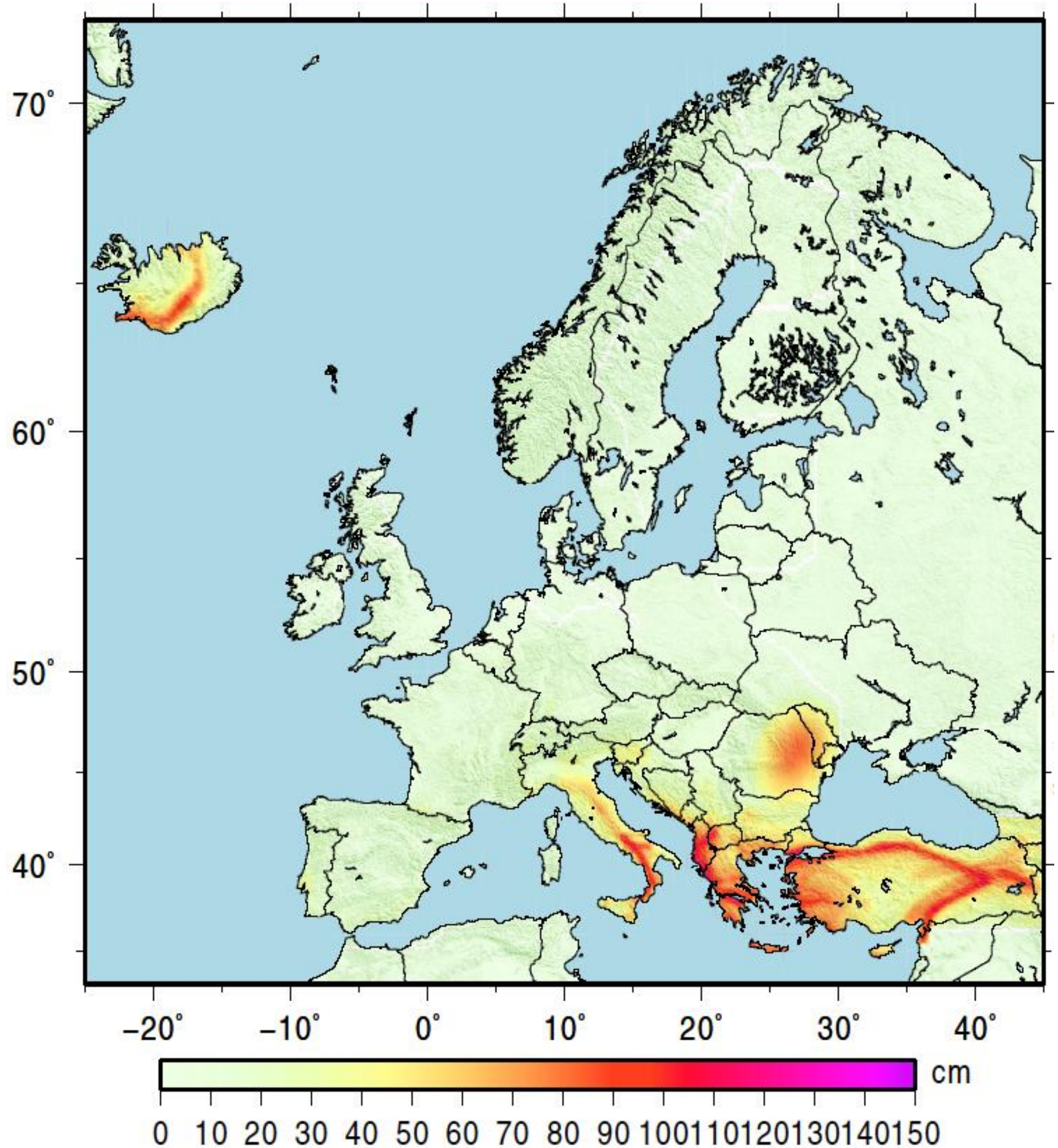
Velocity Spectrum Intensity



- Area Source Model
- Derived from UHS for 475 year return period

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Improved Soil Factors for EC8 soil classification

Proposed soil factors

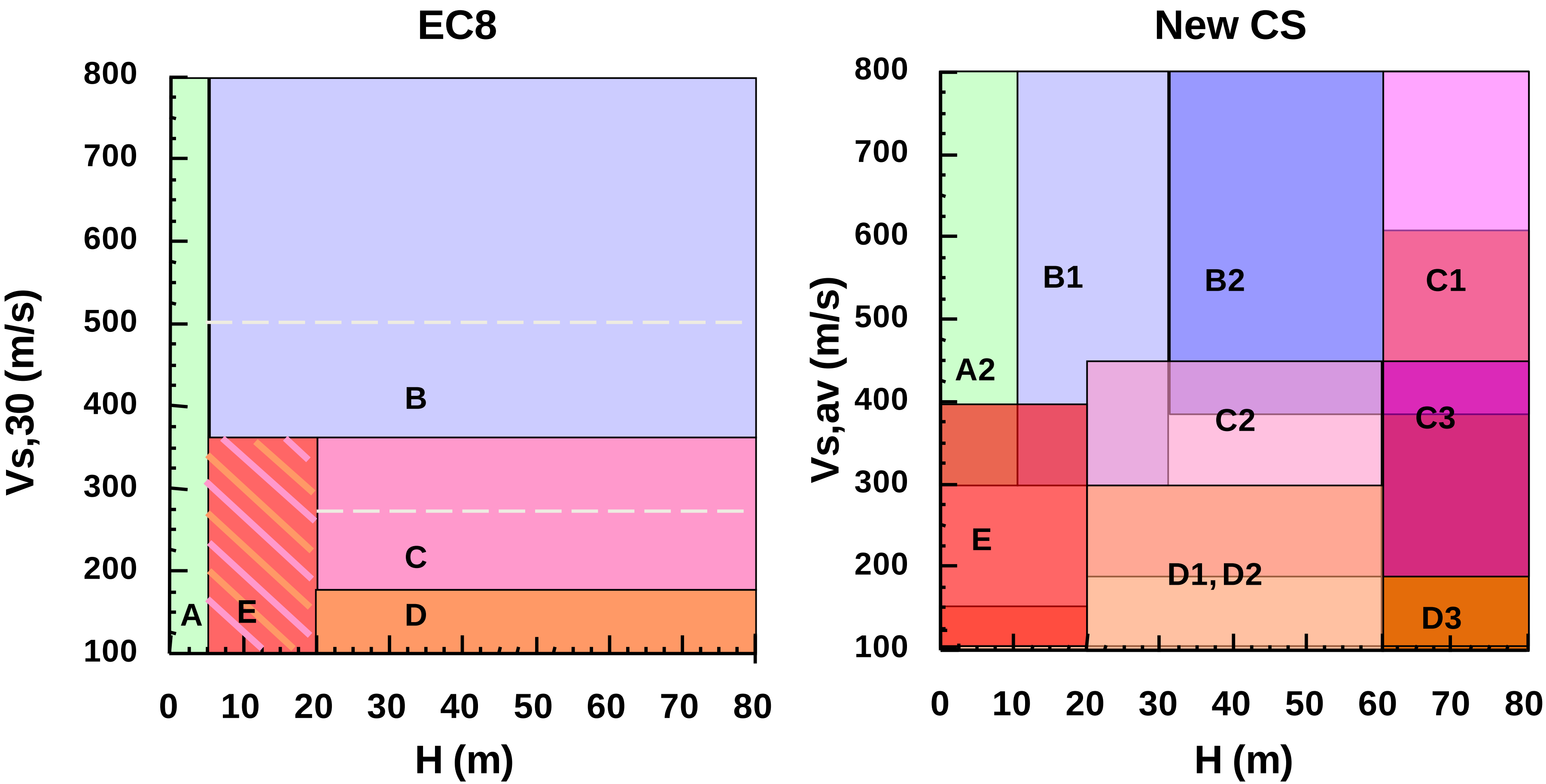
Table 14 Soil factors for EC8 soil classes

Soil class	Type 2 ($M_s \leq 5.5$)		Type 1 ($M_s > 5.5$)	
	Proposed	EC8	Proposed	EC8
B	1.40	1.35	1.30	1.20
C	2.10	1.50	1.70	1.15
D	1.80[a]	1.80	1.35[a]	1.35
E	1.60[a]	1.60	1.40[a]	1.40

[a] site specific ground response analysis required

Pitilakis K, Riga E, Anastasiadis A (2012) Design spectra and amplification factors for Eurocode 8, Bulletin of Earthquake Engineering 10(5): 1377-1400.

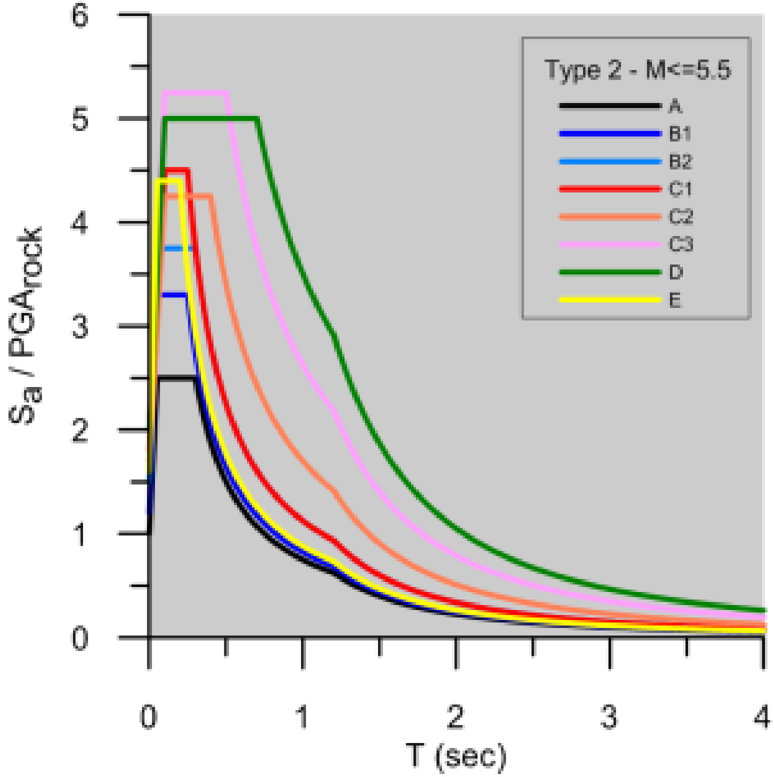
New soil classification scheme

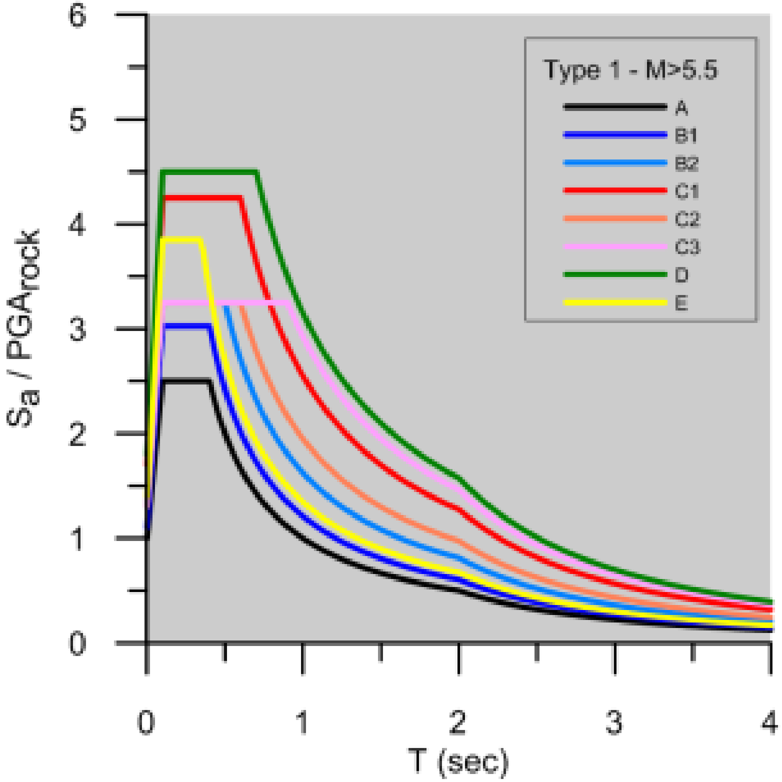


Pitilakis K, Riga E, Anastasiadis A (2013) New code site classification, amplification factors and normalized response spectra based on a worldwide ground-motion database. Bulletin of Earthquake Engineering 11(4): 925-966.

New soil classification scheme for EC8

New elastic acceleration response spectra for EC8

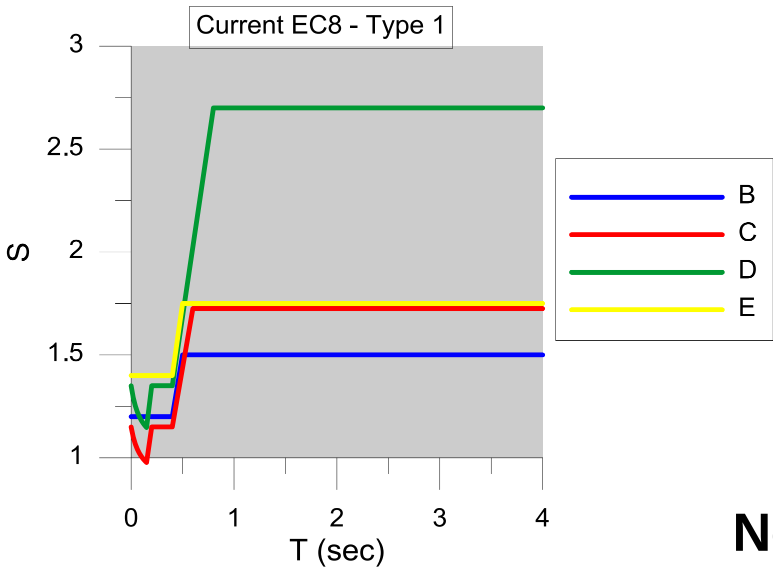




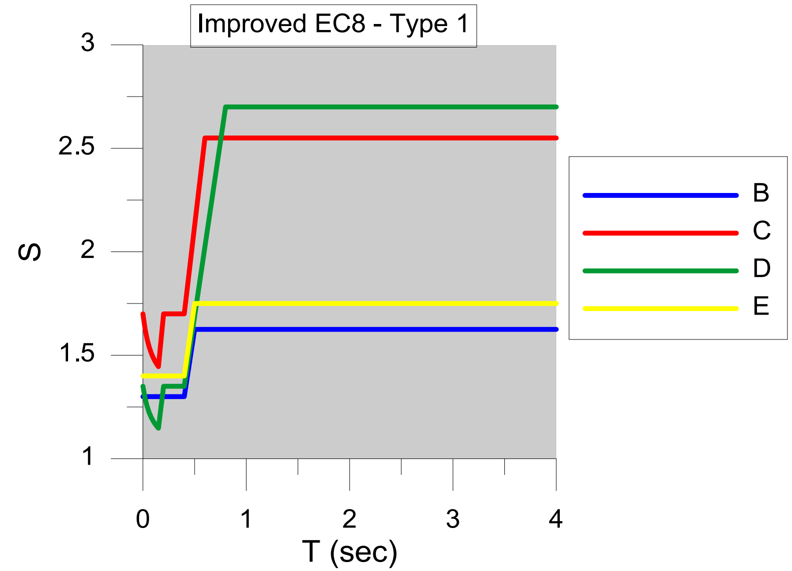
Pitilakis K, Riga E, Anastasiadis A (2013) New code site classification, amplification factors and normalized response spectra based on a worldwide ground-motion database. Bulletin of Earthquake Engineering 11(4): 925-966**.**

Period-dependent amplification factors

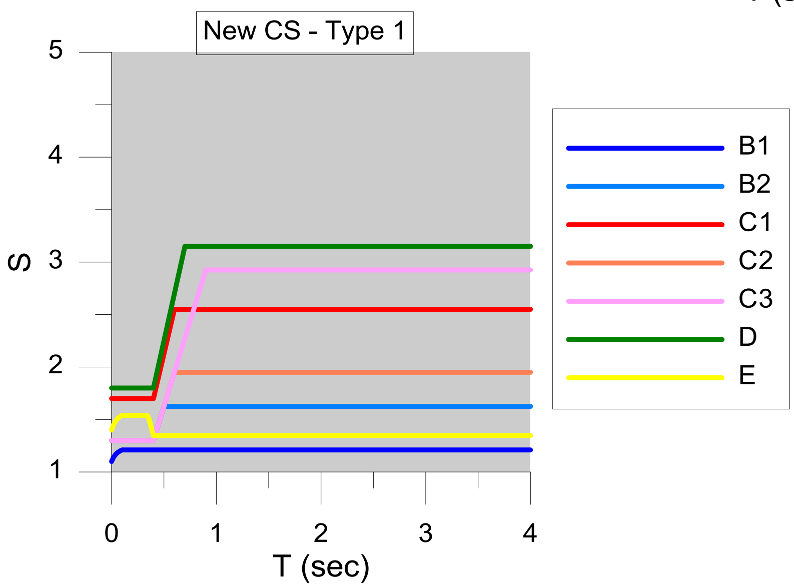
EC8



Improved EC8

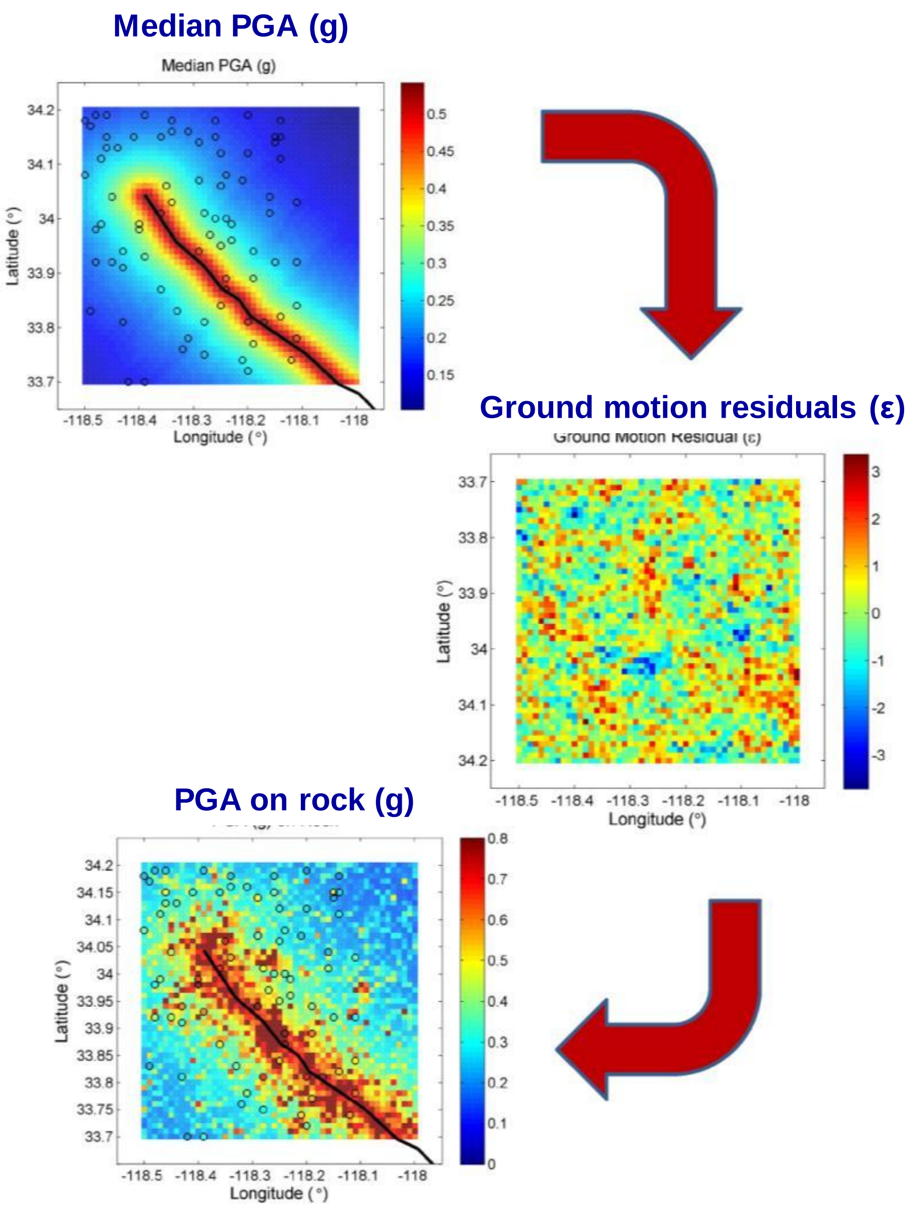


New CS



Pitilakis et al. (2012, 2013)

Development of Shake-Fields



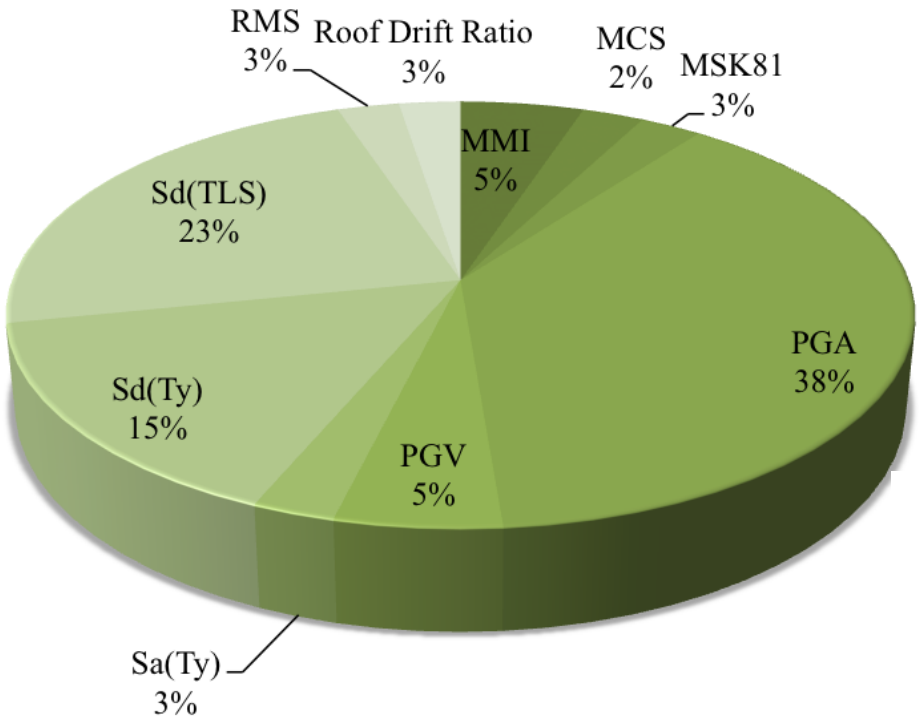
- Stochastic Simulation
- Generation of **spatially correlated and cross-correlated fields for ground motion** intensity measures (IMs) – i.e. PGA, PGV, Sa, etc
- Multiple source typologies
  - Area Sources
  - Simple Fault Sources
  - Complex Fault Sources
- Site effects
- Extension to geotechnical hazard (liquefaction, fault crossing, landslide displacements)

System	Sub-System	Common IM's	Recommended IM
Building	Masonry	S_a, S_d, PGA, I_{EMS}	S_a [S_d]
	Reinforced Concrete	S_a, S_d, PGA, PGV, I_{EMS}	S_a [S_d]
	Steel	S_a, S_d	S_a [S_d]
	Timber/Wood	S_a, S_d, PGA, PGV	S_a [S_d]
Transportation	Bridges	PGA, PGV, S_a, SI, PGD_f	PGA, S_a, PGV_f
	Tunnels	PGA, PGD_f	PGA, PGD_f
	Roads	PGD_f, PGV	PGD_f
	Railway Tracks	PGD_f	PGD_f
	System Facilities	PGA, PGD_f	PGA, PGD_f
Water [Potable and Waste]	Source (wells)	PGA	PGA
	Treatment Plant	PGA	PGA
	Pumping Station	PGA	PGA
	Storage Tanks	PGA, [PGD_f if below ground]	PGA
	Pipelines	PGV, PGD_f, PGA, ε,	PGV, PGD_f
	Canal	PGV, PGD_f	PGV, PGD_f
	Tunnel	PGA	PGA
	Waste Water Treatment	PGA	PGA
Harbour	Waterfront Structures	PGA, PGD_f	PGA, PGD_f
	Cargo Handling/Storage	PGA, PGD_f	PGA, PGD_f
	Fuel Facilities	PGA	PGA
Electrical	Substations and Components	PGA, S_a, PGD_f	PGA
	Distribution Circuits	PGA	PGA
Gas and Oil	Production	PGA, PGD_f	PGA, PGD_f
	Storage	PGA, [PGD_f if below ground]	PGA
	Pipelines	PGV, PGD_f, ε, PGA, SI	PGV, PGD_f
	Pumping/Compression	PGA	PGA
Miscellaneous	Non-structural	PGA, PFA	PFA [S_a or S_d to define structural response]
	Hospitals	PGA, PFA, S_a, I_{MM}	PGA, PFA
	Communication	PGA	PGA, PFA
	Airport	PGA, PGD_f, S_a	PGA, PGD_f [runways], S_a [irregular buildings – e.g. control towers]

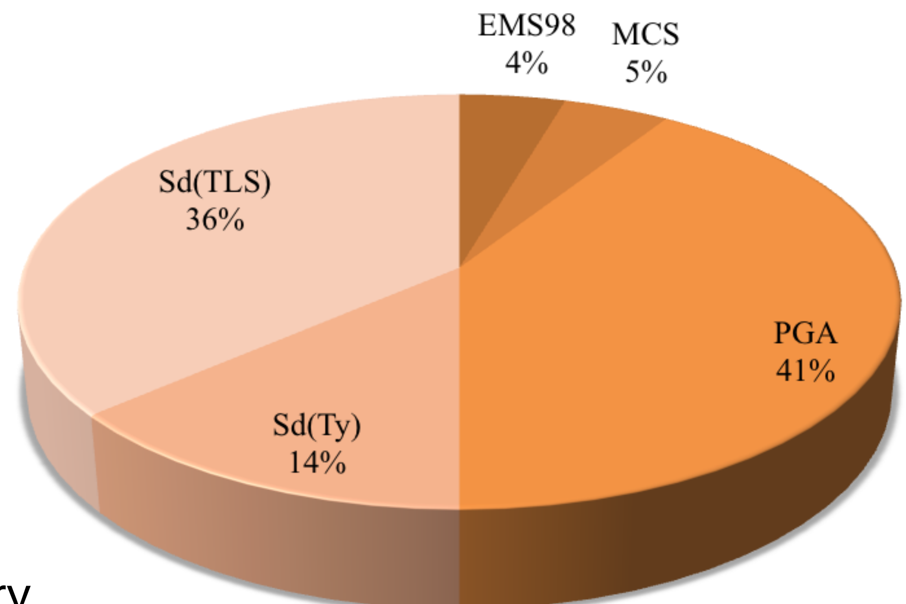
Appropriate earthquake intensity measures (IM)

- **best captures the response of each element**
- **minimizes the dispersion of response**
- **depends on the approach for derivation of fragility curves**

Intensity Measure Types- Fragility functions for Buildings

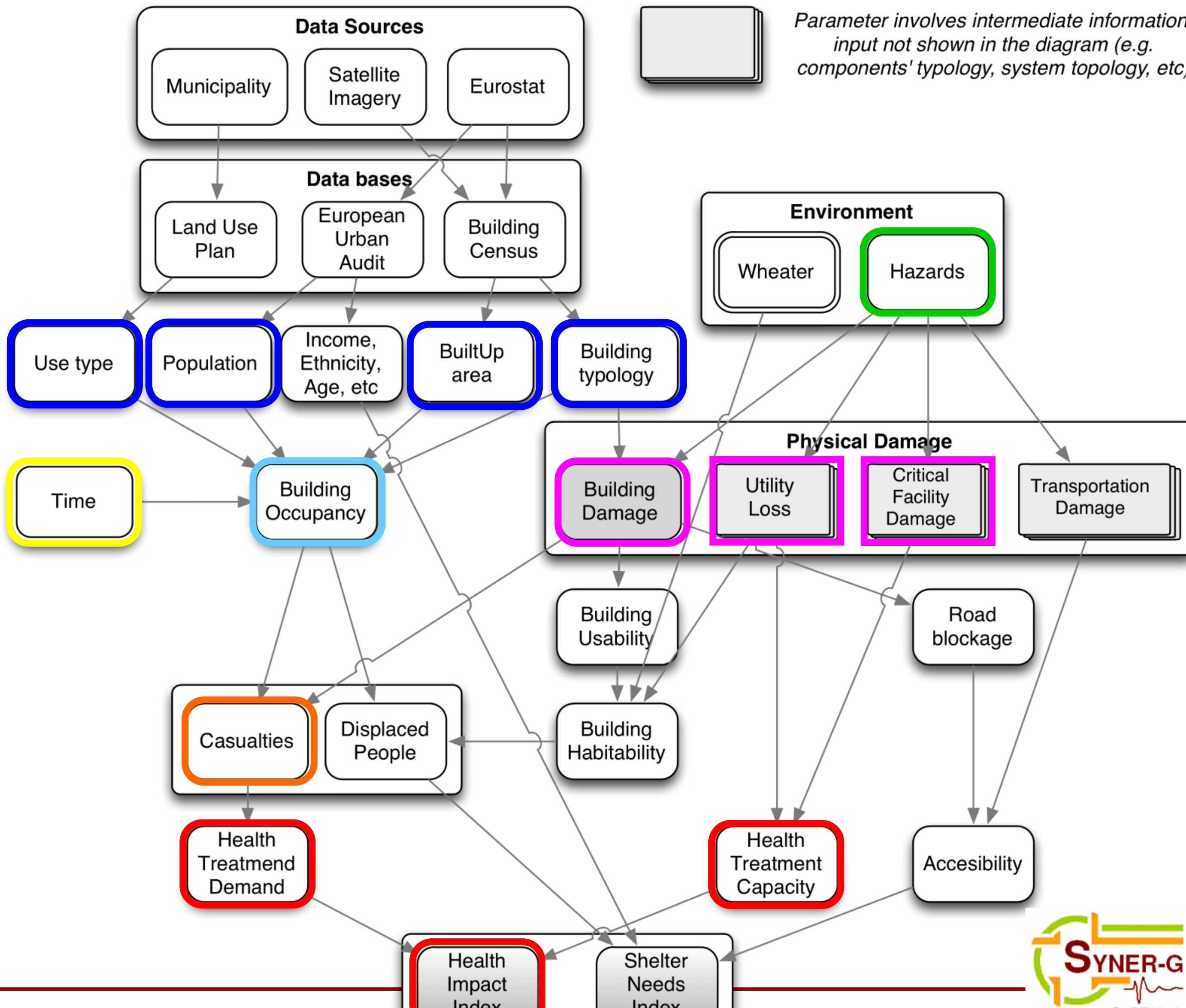


Reinforced Concrete



Masonry

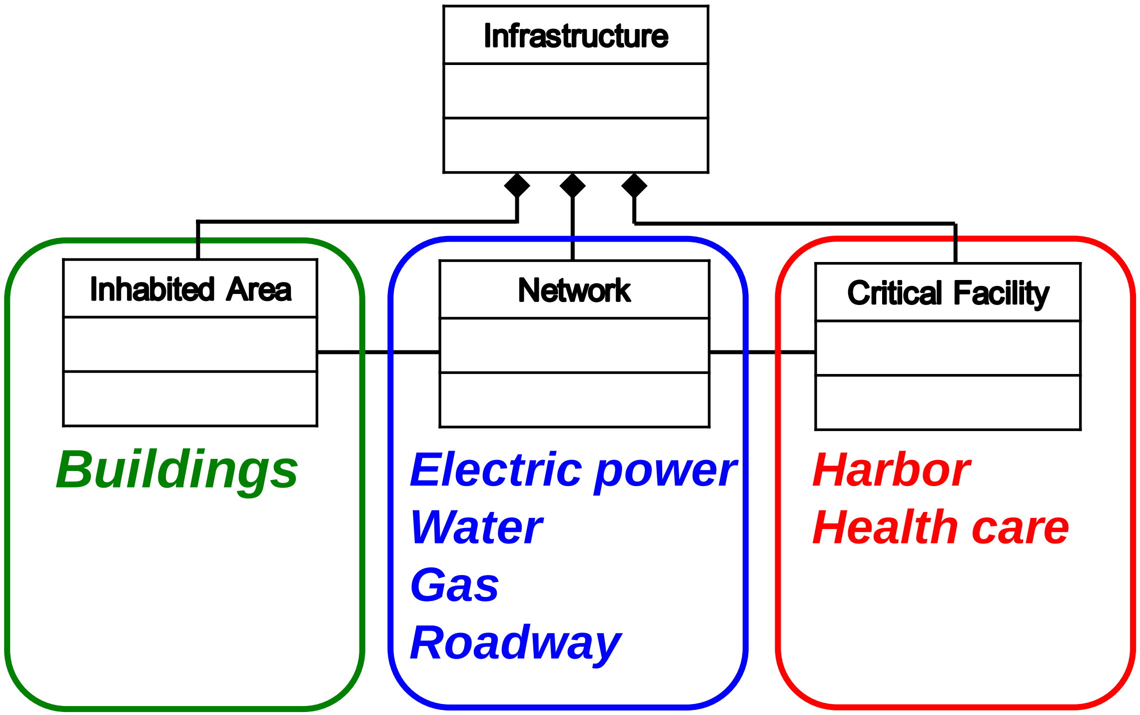
SYNER-G methodology



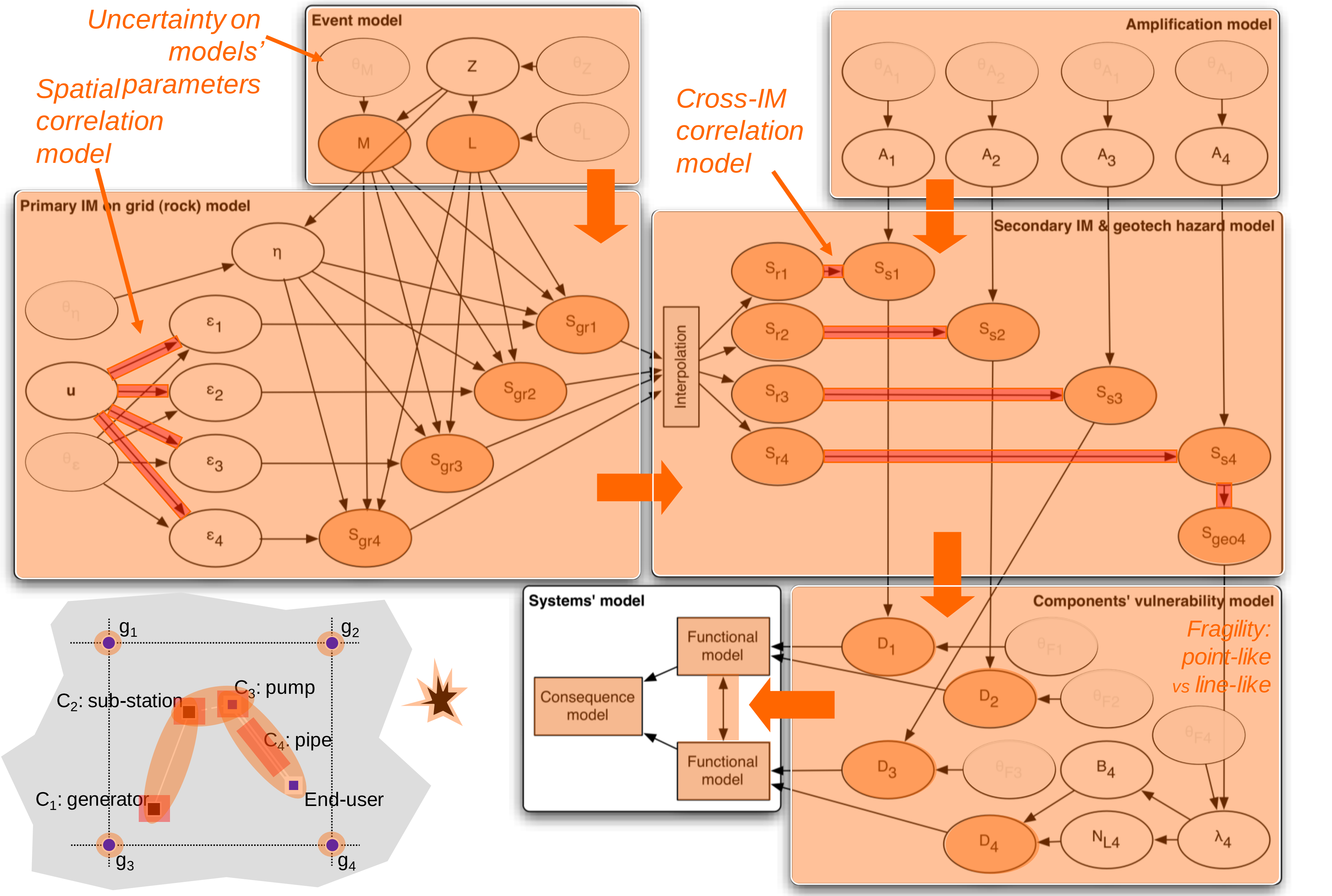
The SYNER-G integrated methodology

Each system is specified with its:

- Components
- Solving algorithms – Interactions between components
- Performance indicators
- Interactions with other systems



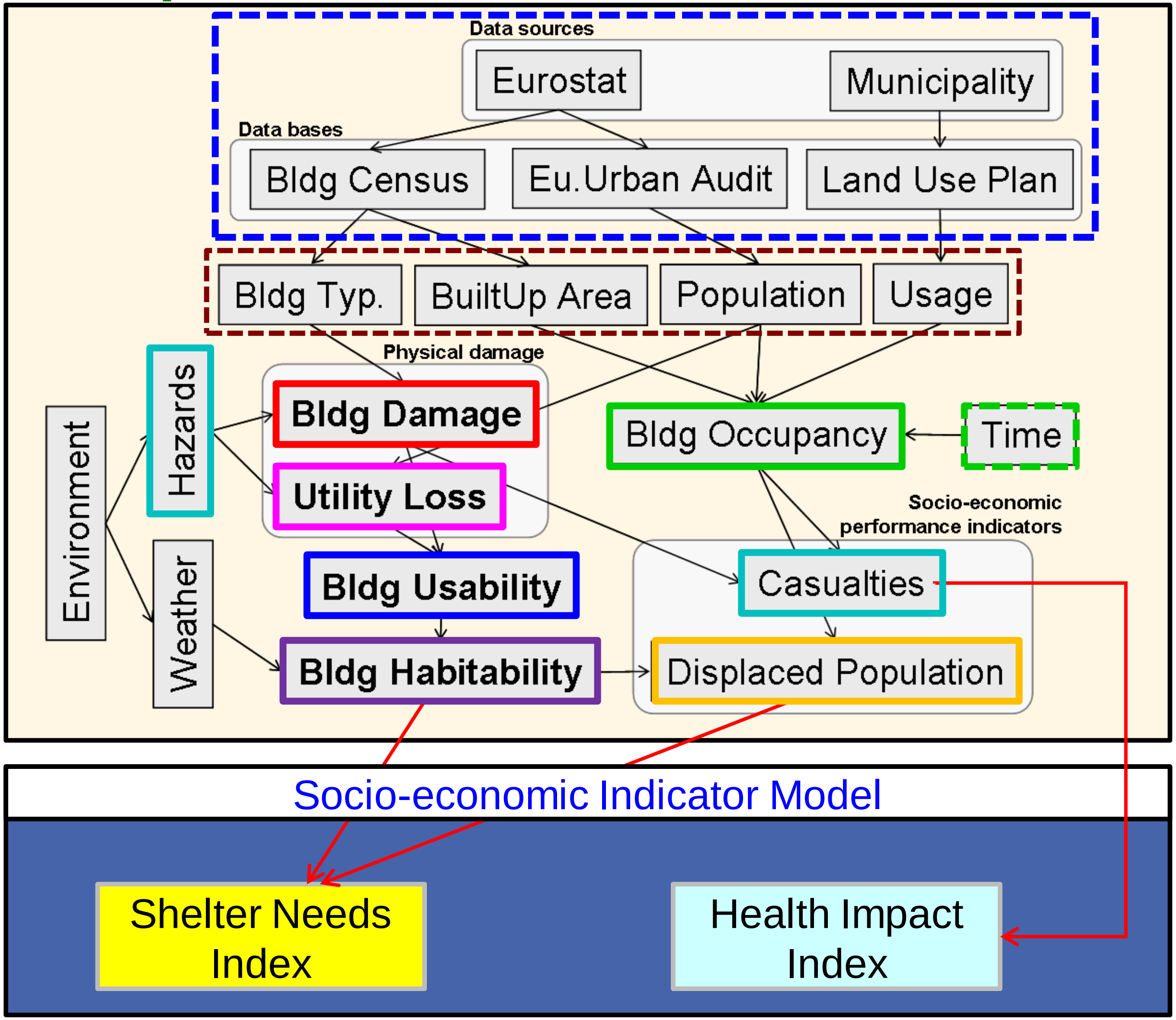
Uncertainty



Interactions - Impacts

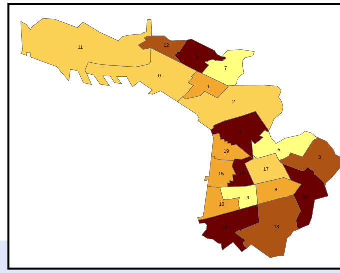
Direct losses

Indirect losses



SDGEE

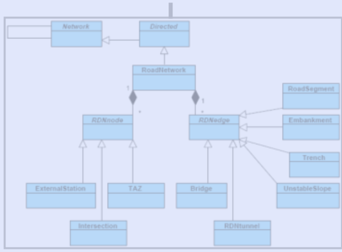
Methodology
& Software tools



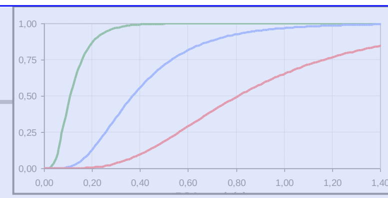
Decision Support

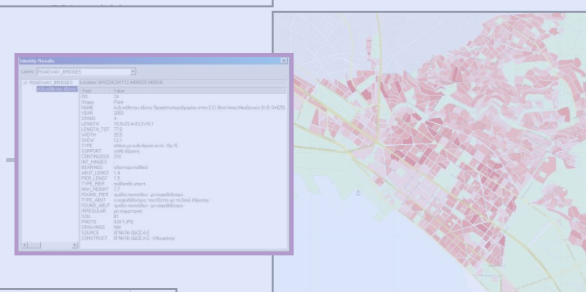
OOFIMS: Object Oriented Framework for Infrastructure Modeling and Simulation

Systemic Analysis



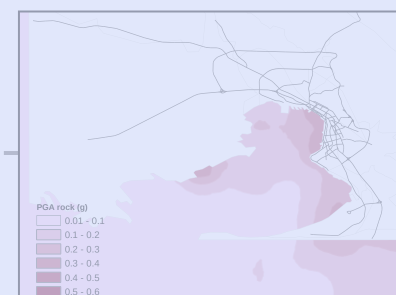
Fragility Models





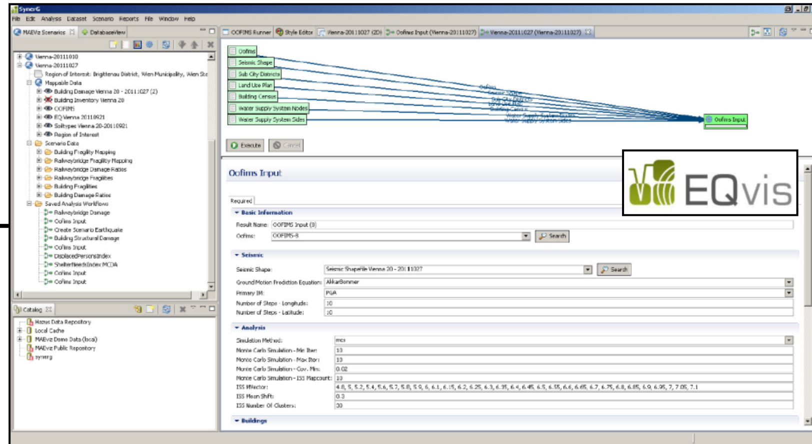
Inventory Selection

Hazard Definition & Seismic Intensity Measures (IM)



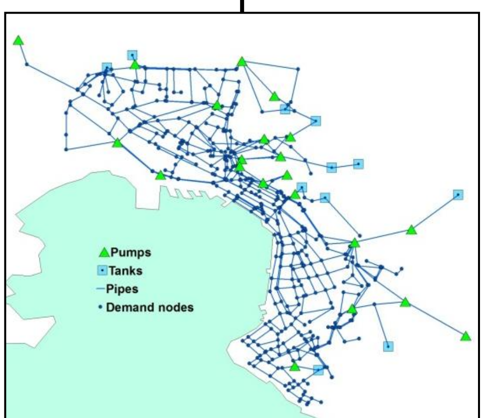
SYNER-G platform

SYNER-G platform



Pre-processing

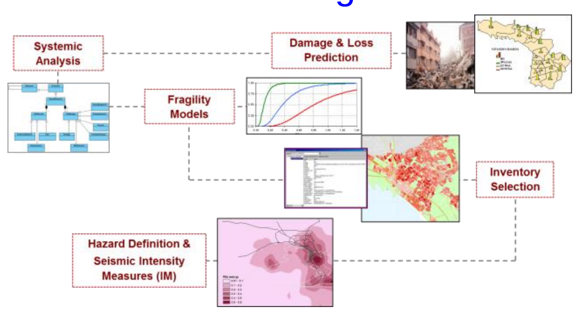
Inventory /GIS database Input for OOFIMS



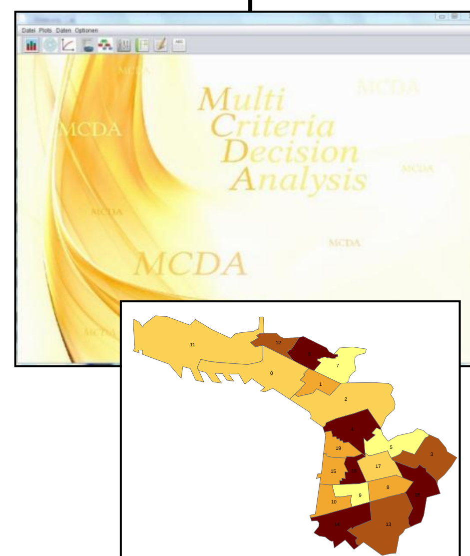
Computation modules

OOFIMS:

Object Oriented Framework for Infrastructure Modeling and Simulation



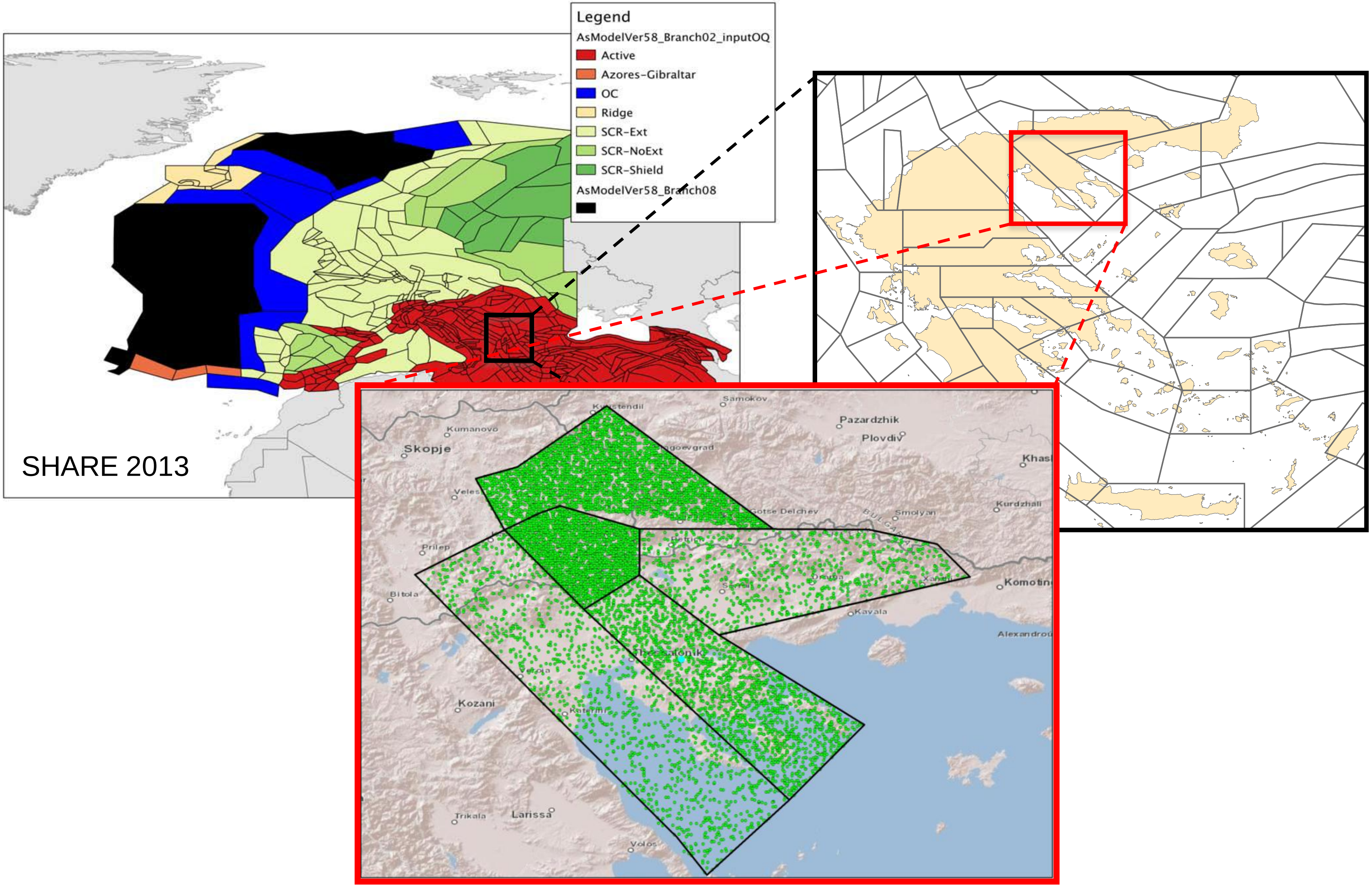
Post-processing & Mapping



Application in Thessaloniki

Hazard Definition &
Seismic Intensity
Measures (IM)

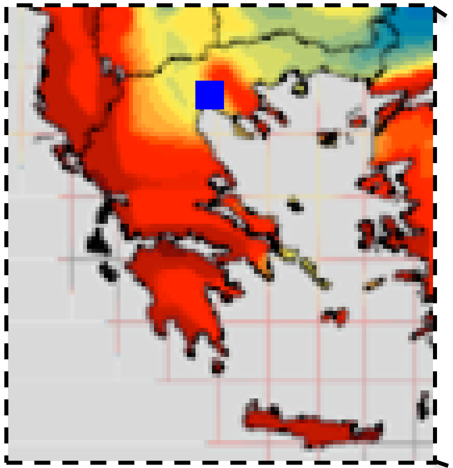
Seismic zones - Thessaloniki

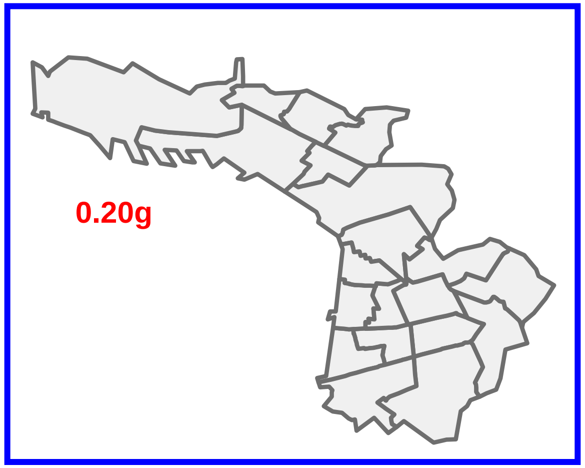


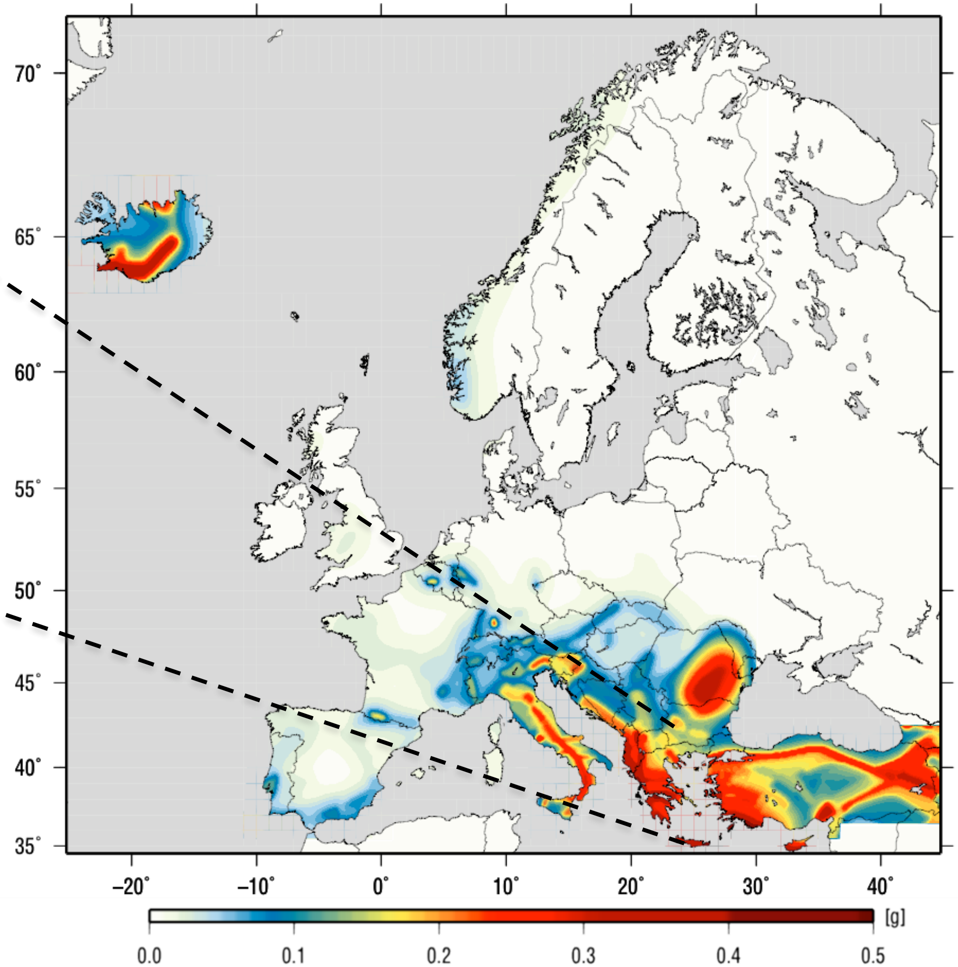
SDGEE

Seismic hazard – PGA at rock (Tm=500 years)

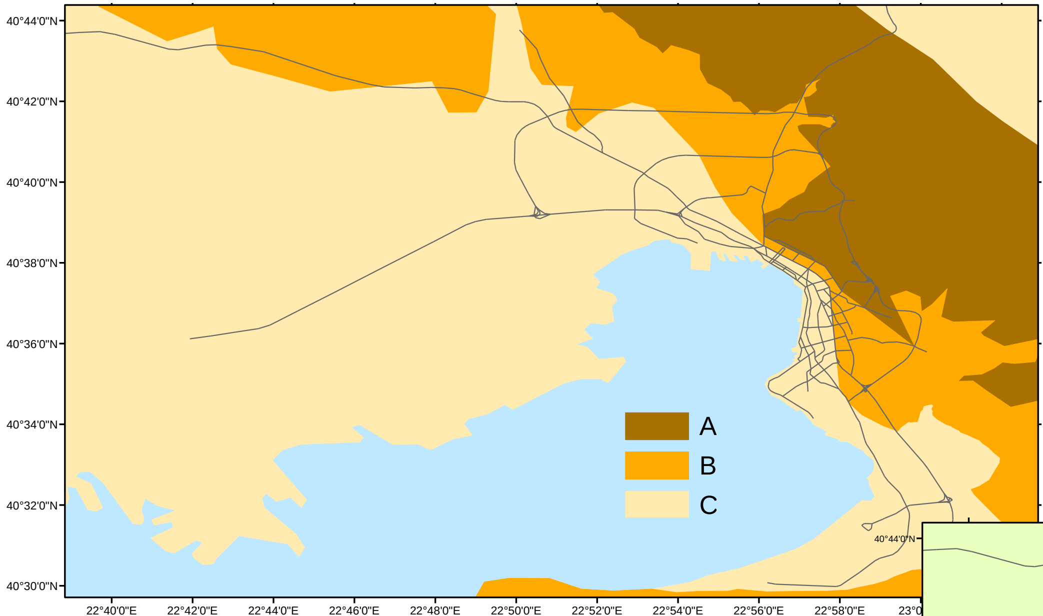
SHARE 2013



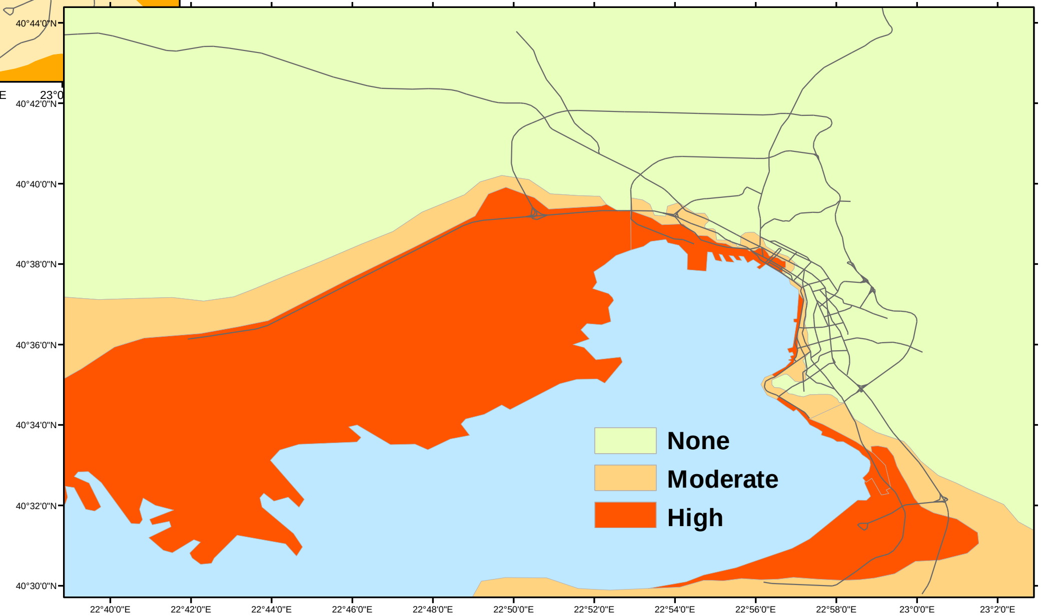




Geotechnical classification according to EC8

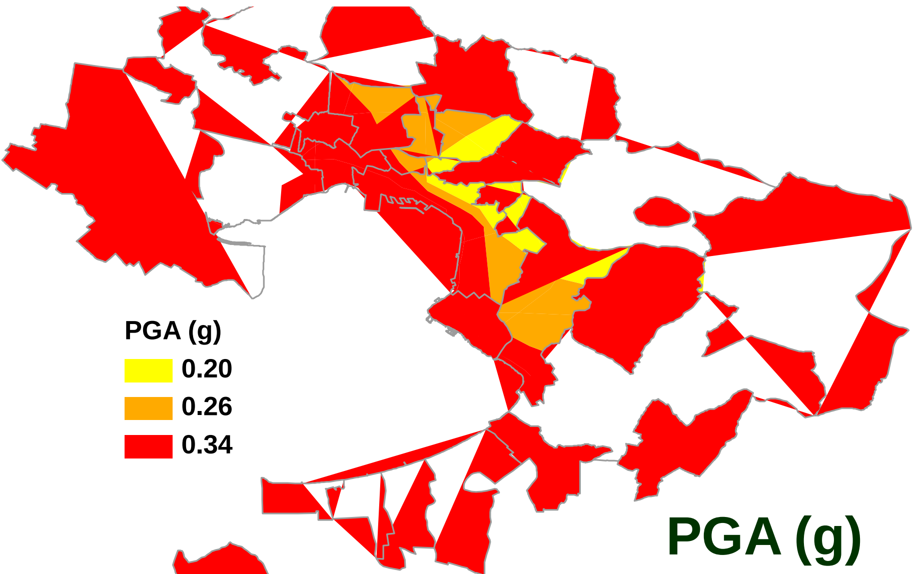


Geotechnical classification (EC8)

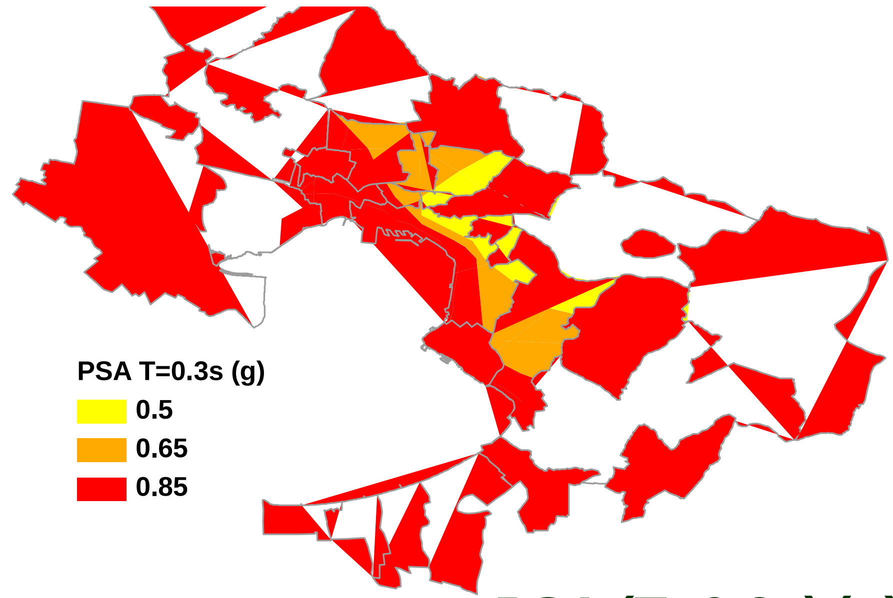


Liquefaction susceptibility (HAZUS, NIBS 2004)

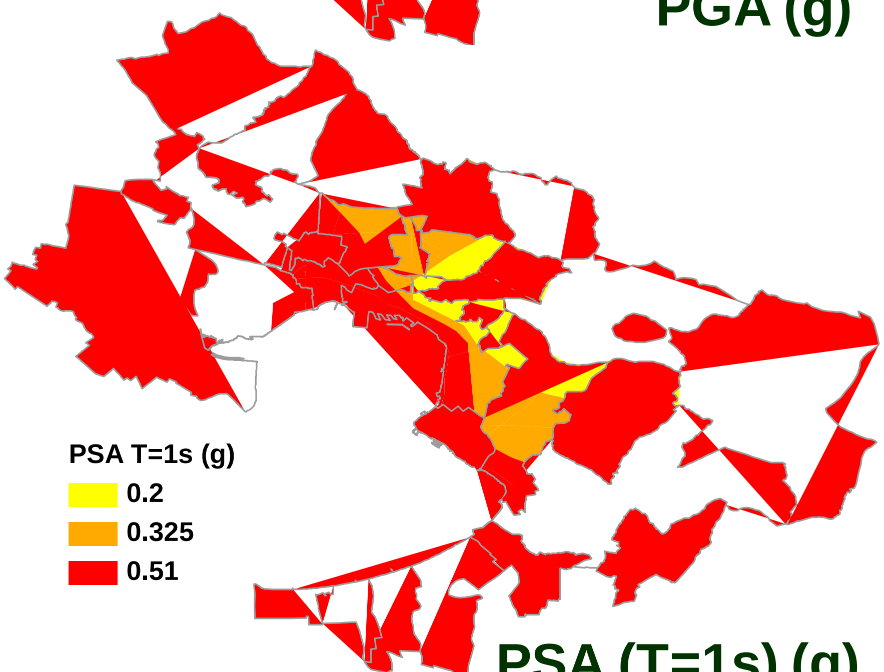
Seismic ground motion – Tm= 500 years



PGA (g)



PSA (T=0.3s) (g)



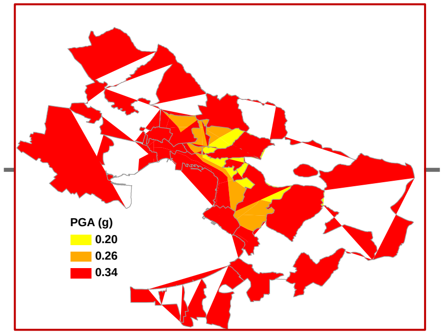
PSA (T=1s) (g)

SHARE 2013 (EC8)

Application in Thessaloniki

Inventory Selection

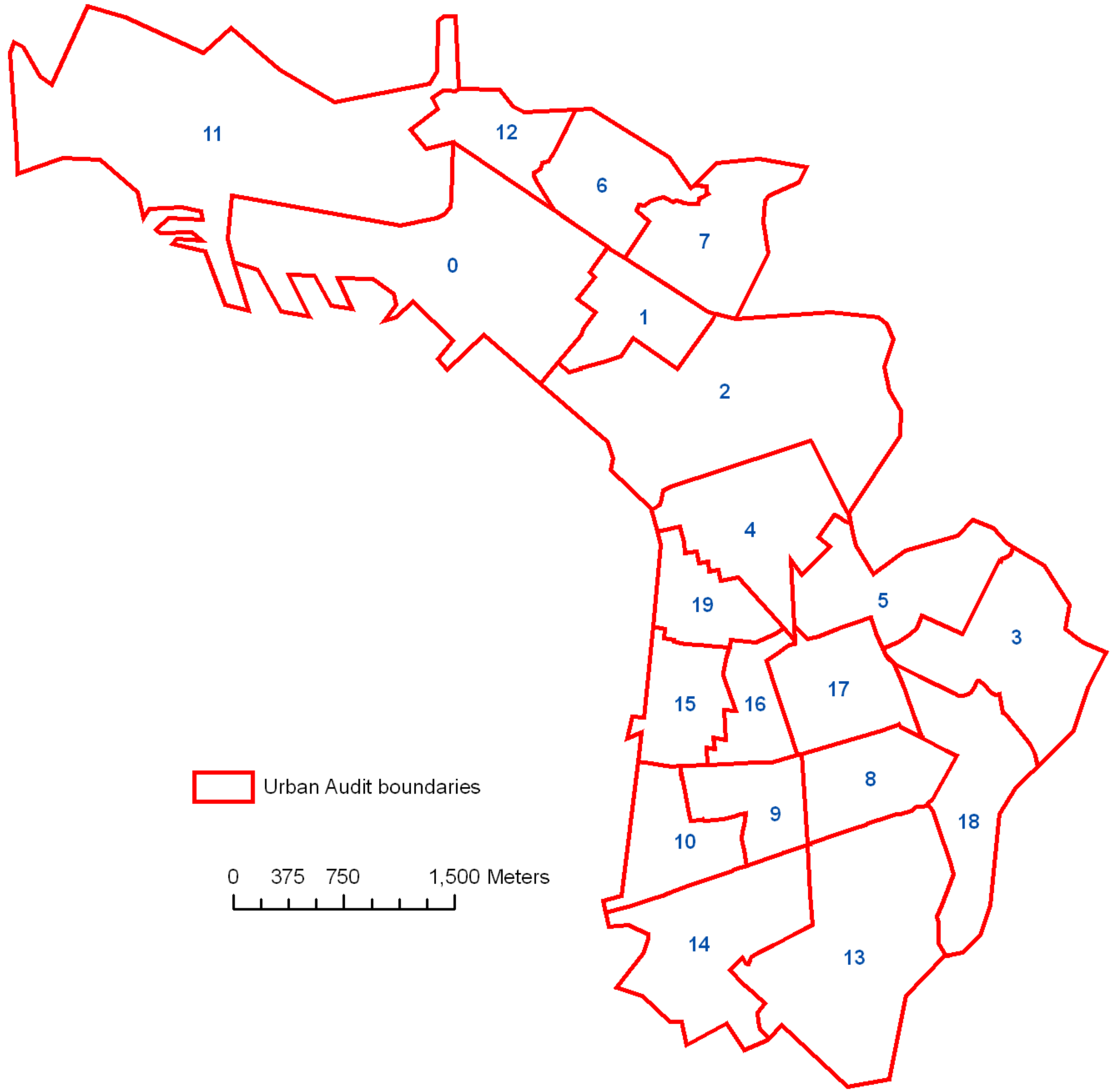
Hazard Definition & Seismic Intensity Measures (IM)



Sub-City Districts – European Urban Audit (Eurostat)

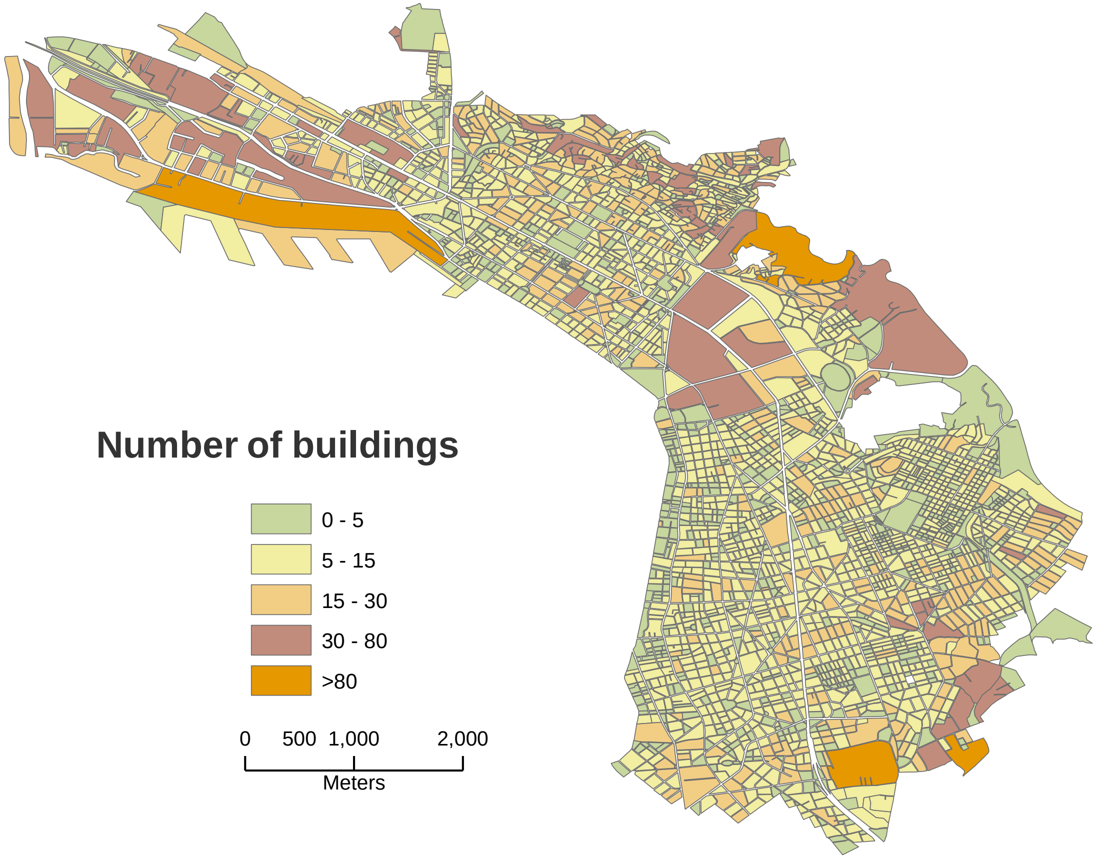
20 Sub Districts

ID	SCD name	Population
0	Ladadika-Dikastirion squ.	15868
1	St.George-Rotonda	19260
2	University-Int.Exhib.Center-White Tower	21376
3	PAOK-Malakopi	21376
4	Papafio-St.Constantine-Military Hospital	17385
5	Toumba-St.Fanourios-Ydragogio	18542
6	Vlatadon-St.Dimitrios-Lachanagora	16319
7	Municipal Hospital-Fylakes (Penitentiary)	16709
8	Athinon	18860
9	Analipsi-Dermatologiko	19619
10	Nea Paralia-Municipal Library	20134
11	Railway Station-Xirokrini	16669
12	Pasha Hamam-Tyroloi	15454
13	Charilaou-Exohes	26815
14	Nomarchia-Vafopoulio-Depau	25455
15	School for the blind-Sailing Club	15822
16	Constantinoupoleos-Delfon-Botsari	16761
17	Ippokratio	16712
18	Ecclesiastic School-Kato Toumba	20724
19	Makedonia Palace-Paedagogiki Academia	16729

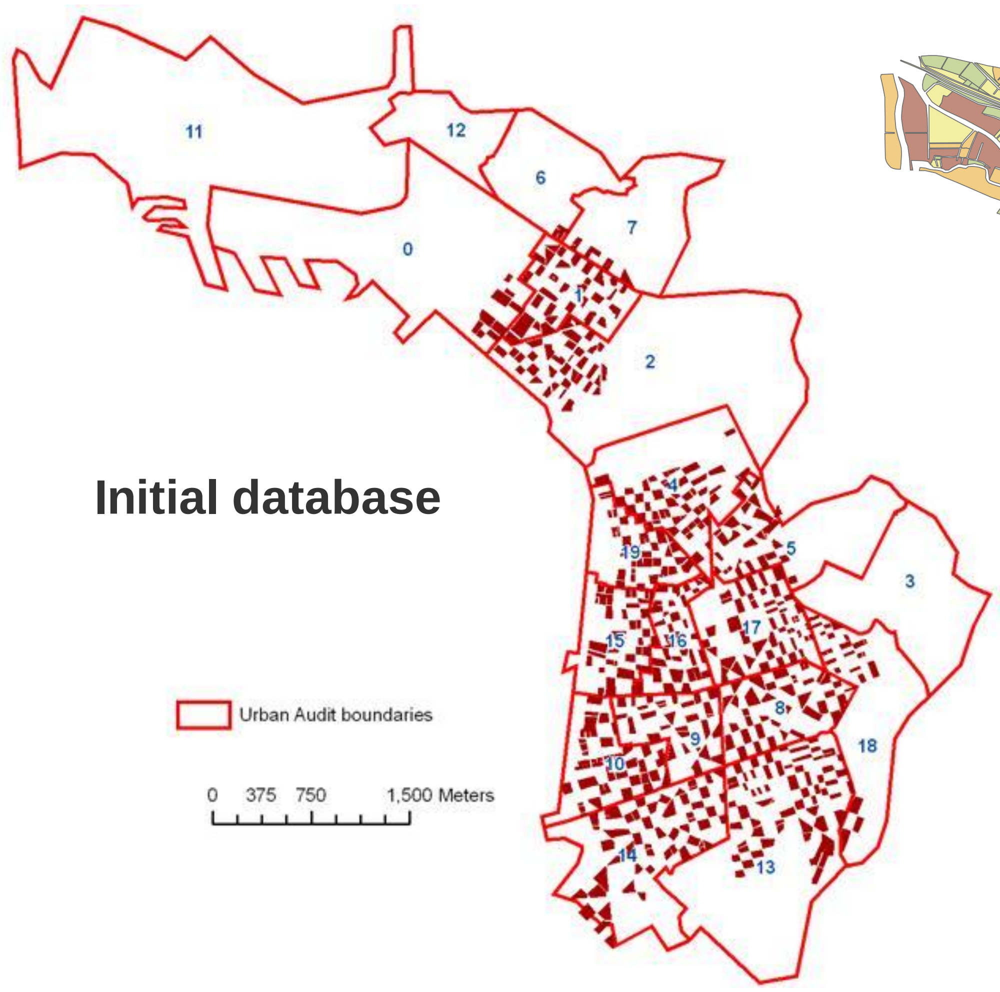


Building Stock – Study area

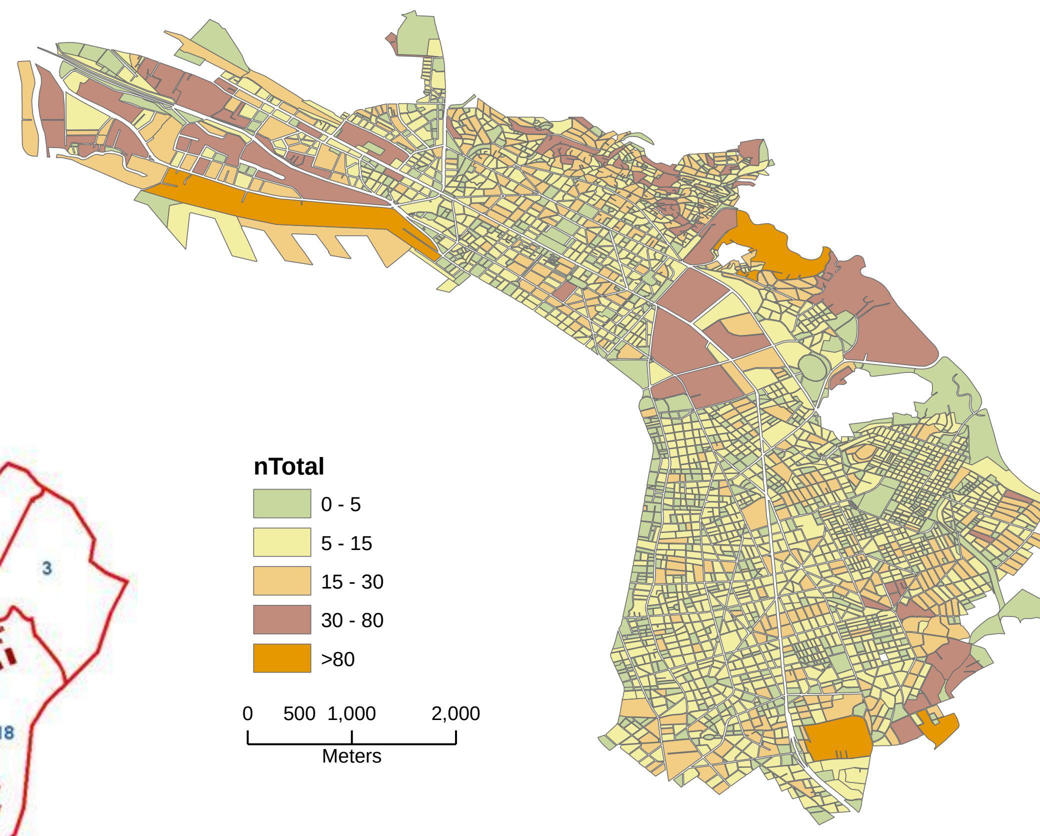
- buildings blocks (study area): 2,893
- buildings (study area): 27,738 (92% R/C, 8% masonry)
- inhabitants: 376,589 (municipality), 790,824 (city)



Building inventory – Typology

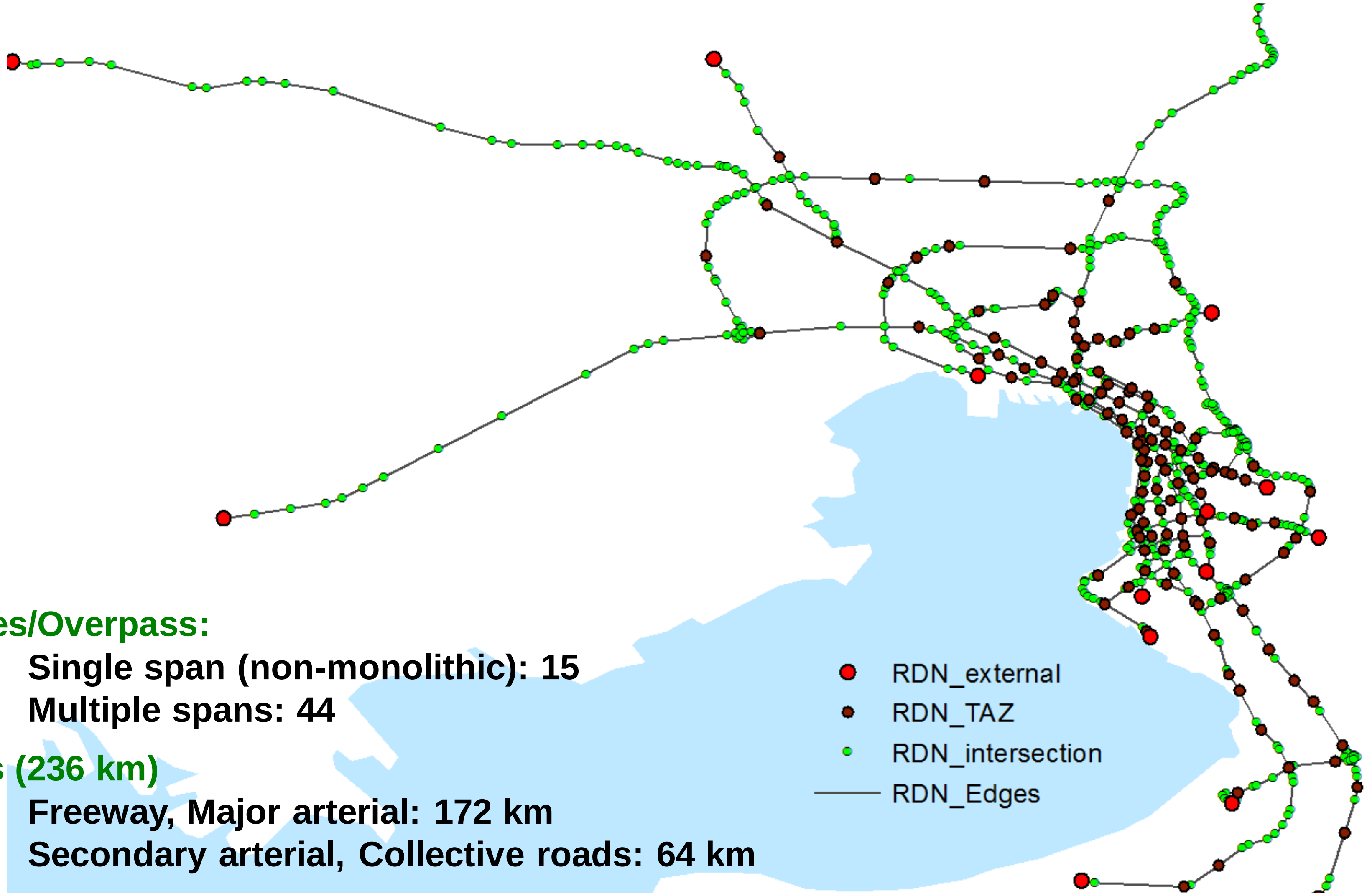


Initial database



Data expansion

Road Network of Thessaloniki



Bridges/Overpass:

- **Single span (non-monolithic): 15**
- **Multiple spans: 44**

Roads (236 km)

- **Freeway, Major arterial: 172 km**
- **Secondary arterial, Collective roads: 64 km**
- **Road distance <= 5m from buildings: 20 km**

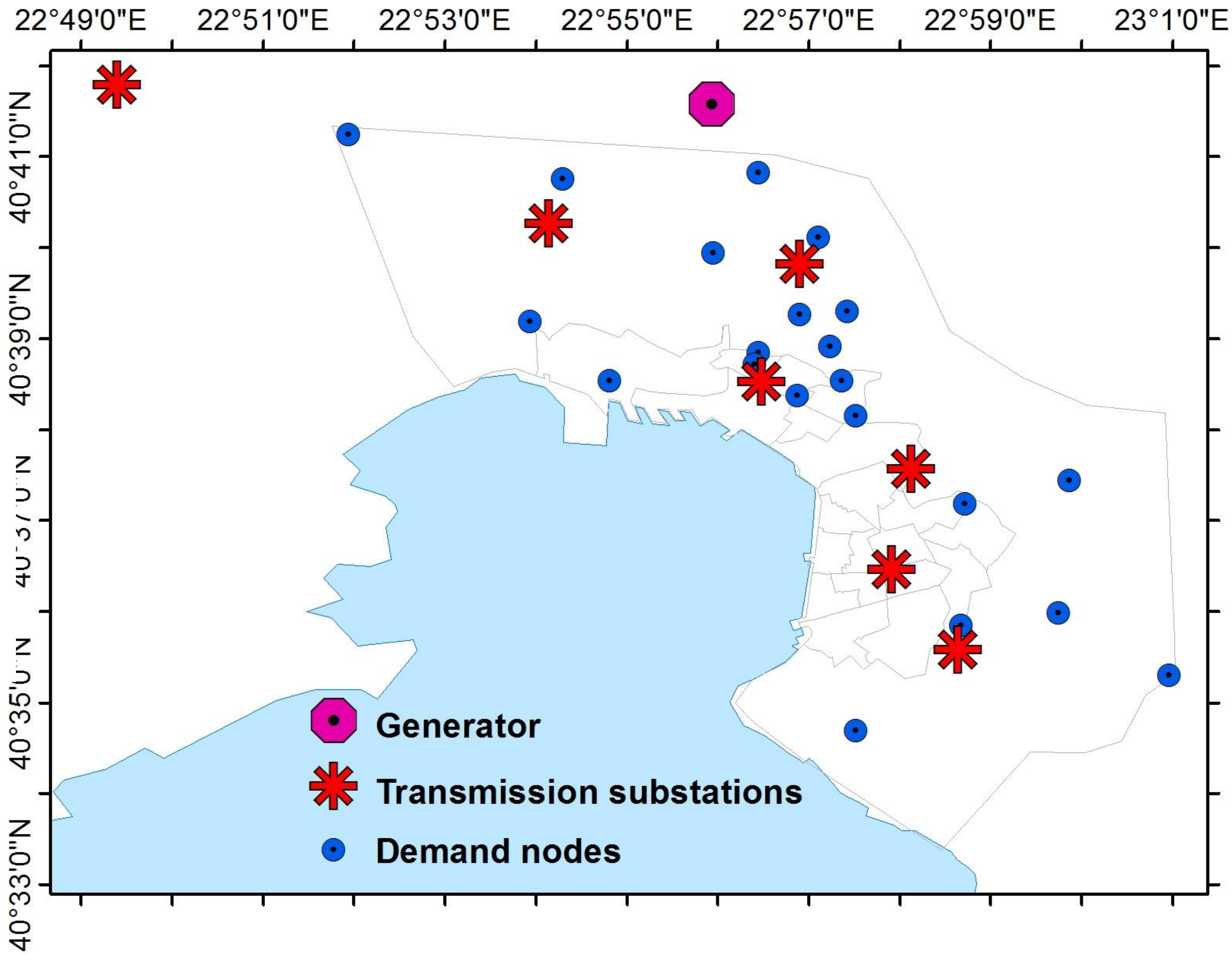
Electric Power Network of Thessaloniki

Features:

- 1 generator
- 8 transmission substations
- 21 demand nodes

Interactions with:

- Water supply system
- Port
- Buildings

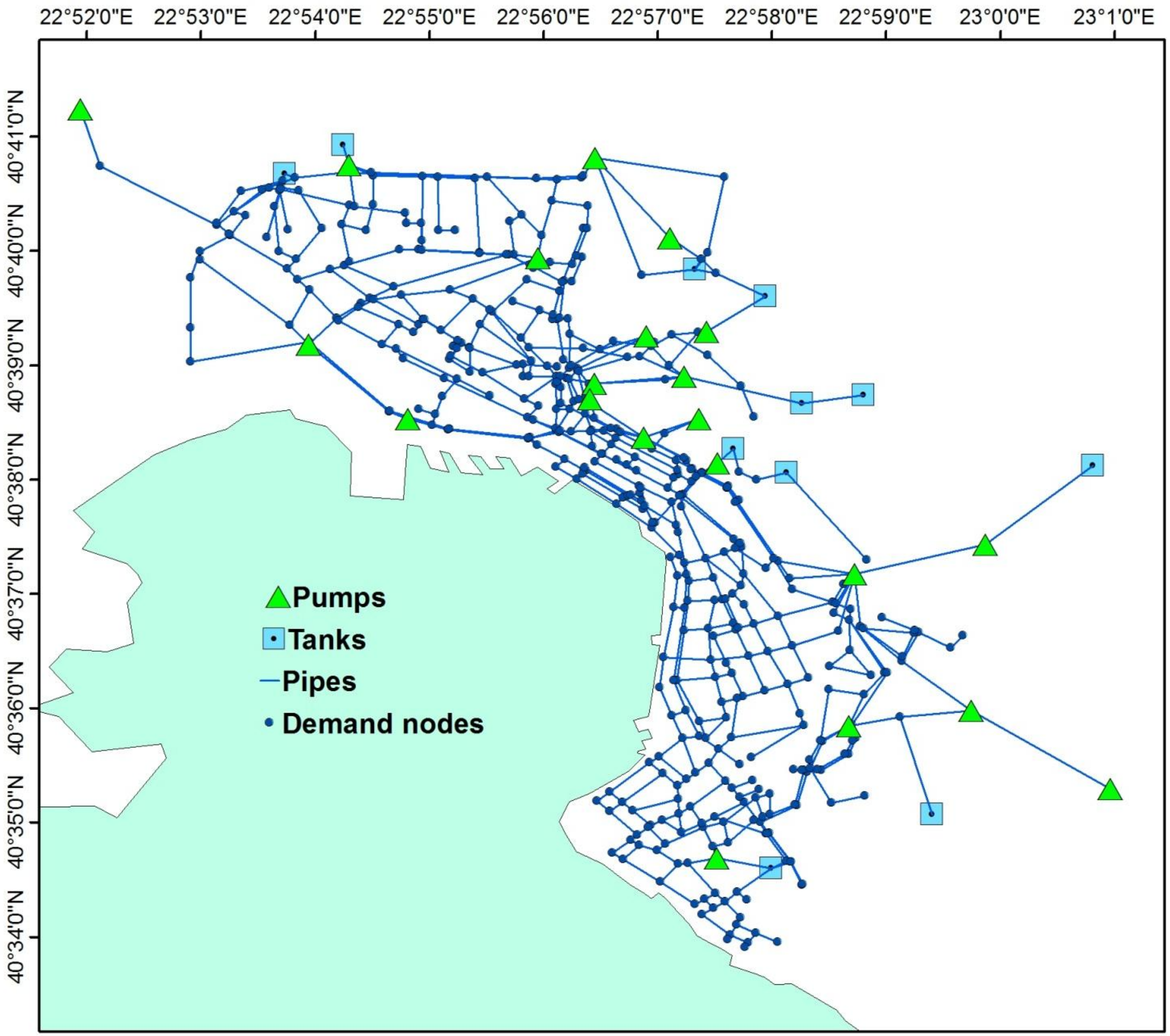


Water Supply System of Thessaloniki

Simplified network

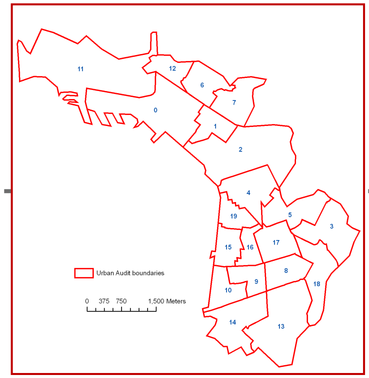
Features:

- *21 pumps*
- *11 tanks*
- *pipes ~280 km*
- *437 demand nodes*



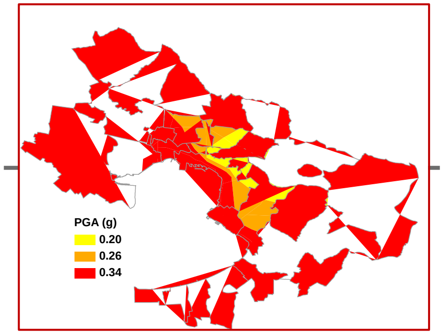
Application in Thessaloniki

Fragility Models

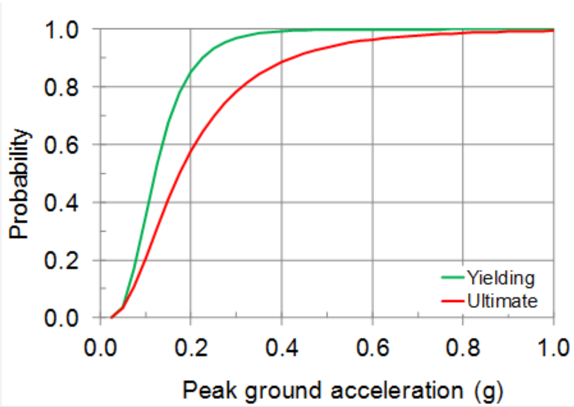


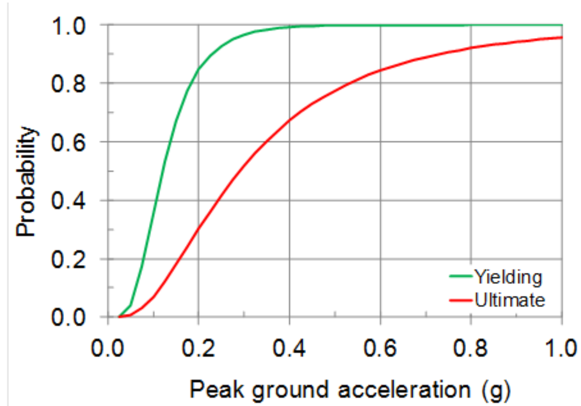
Inventory Selection

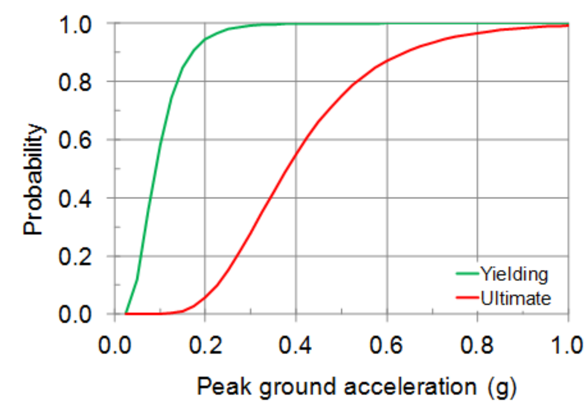
Hazard Definition & Seismic Intensity Measures (IM)



Buildings in Thessaloniki – Fragility curves







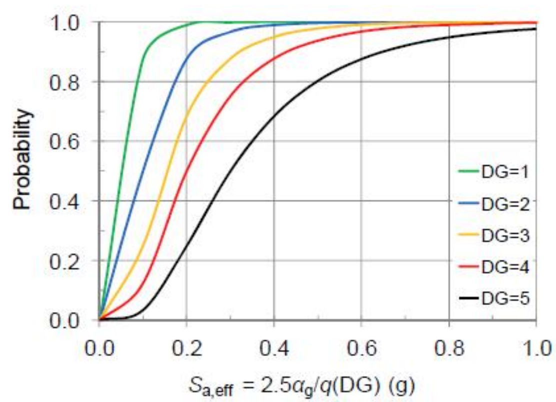
low-rise wall-frame RC buildings

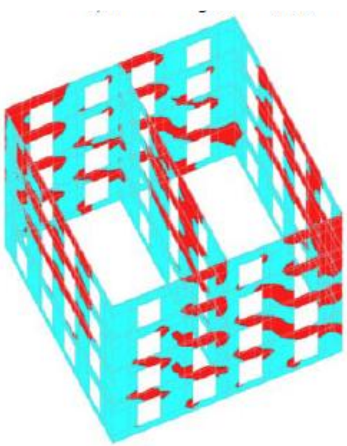
low-level

medium-level seismic code

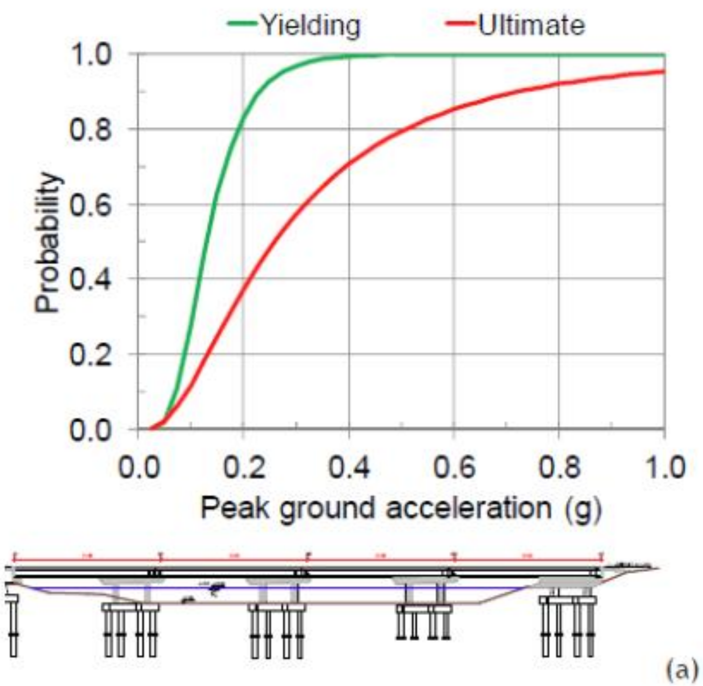
high-level

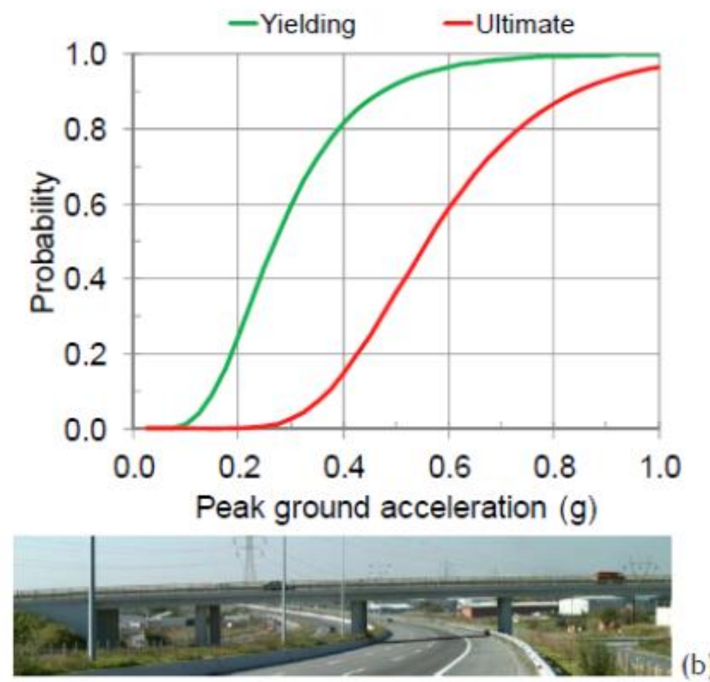
Four-storey masonry building w/flexible floors





Bridges in Thessaloniki – Fragility curves



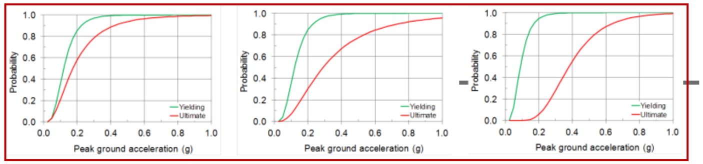


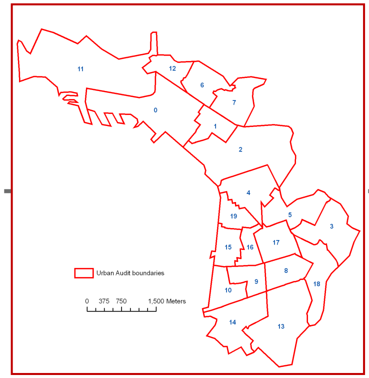
(a) bridge with the deck supported on bearings, constructed in 1985 with the old seismic code
(b) overpass with monolithic deck-pier connection, constructed in 2003 with the new seismic code

Application in Thessaloniki

Systemic Analysis

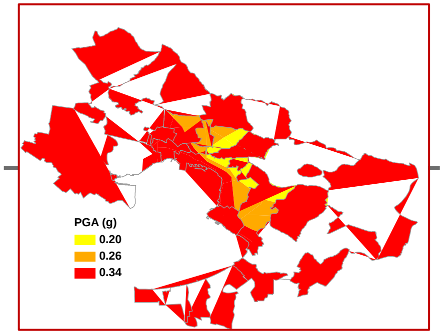
Fragility Models



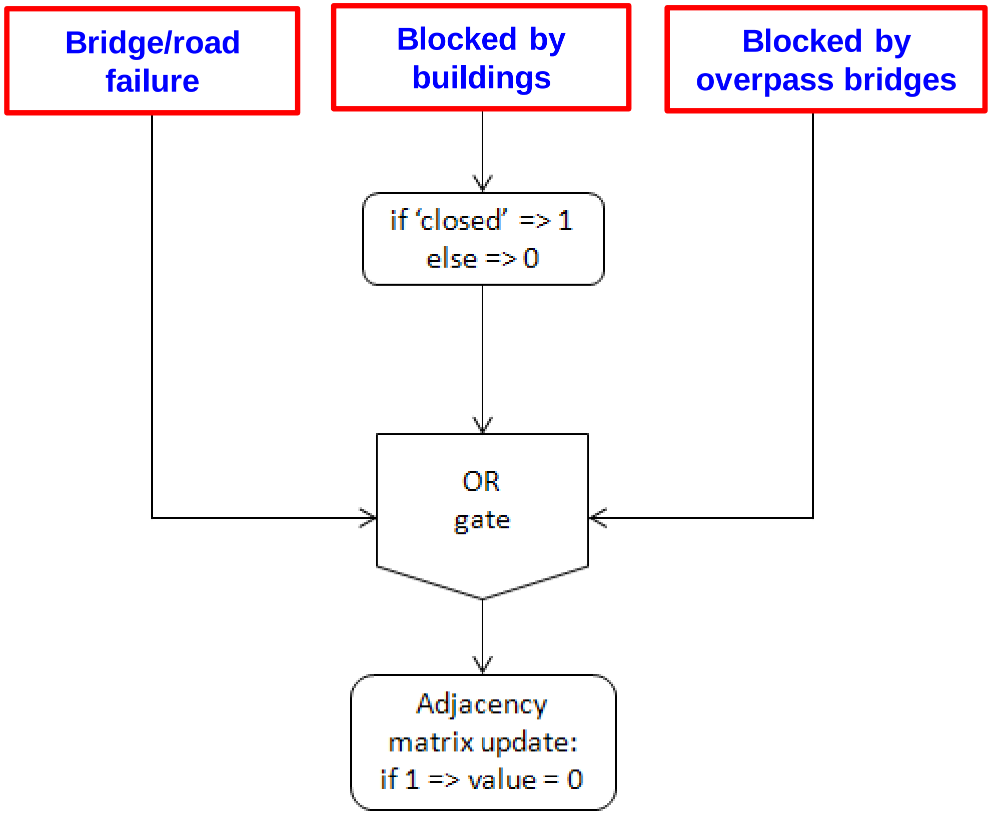


Inventory Selection

Hazard Definition & Seismic Intensity Measures (IM)



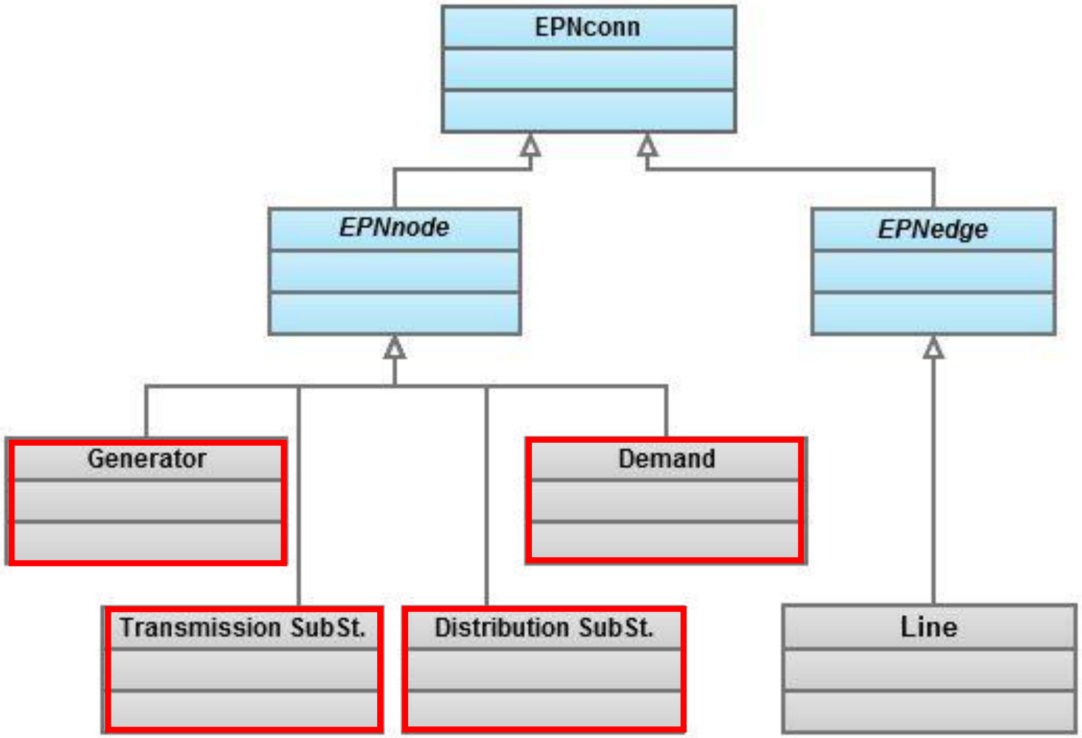
Road network connectivity



Simple Connectivity Loss (SCL): Connectivity loss between TAZs

Weighted Connectivity loss (WCL): Weighted (over travel speed) connectivity loss between TAZs

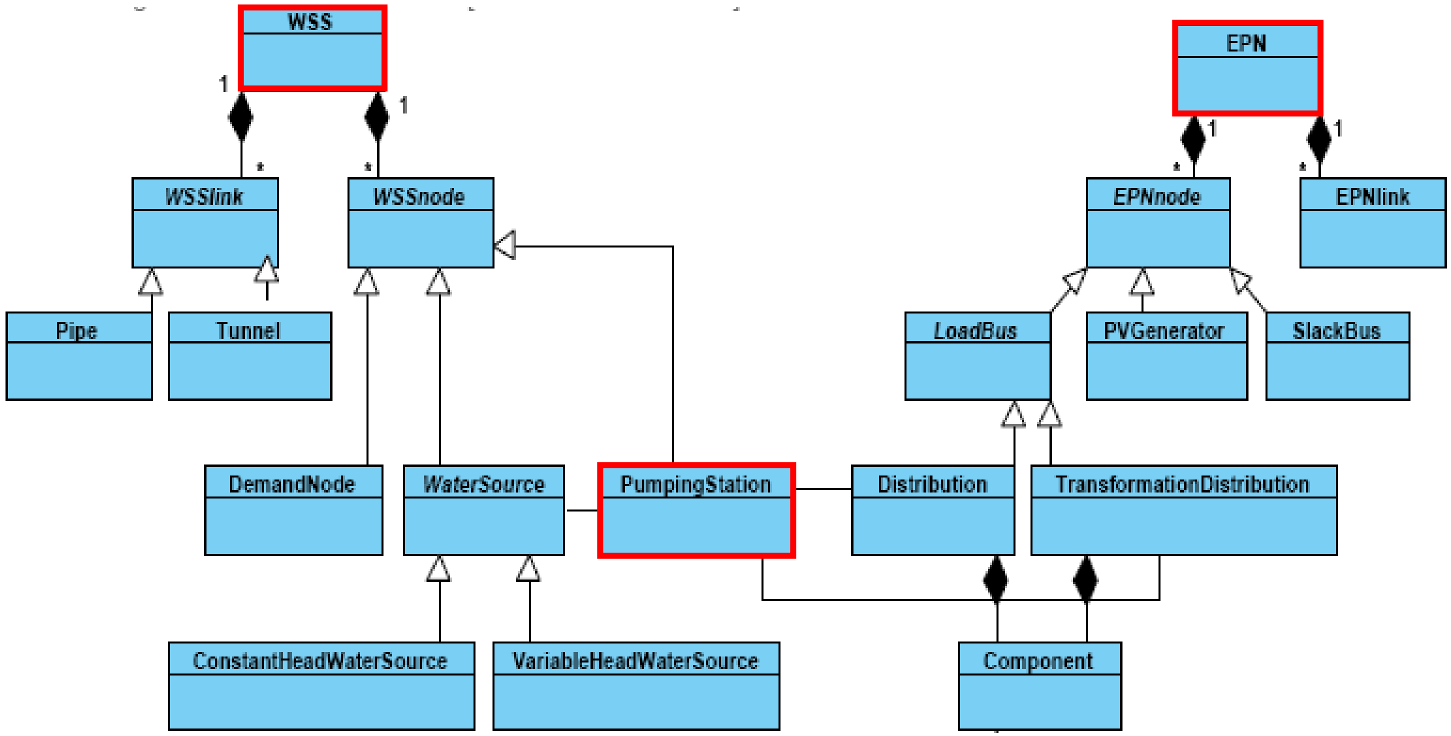
Electric power network connectivity



- *Three **nested sub-networks** with independent connectivity analyses:*
    - *generators – transmission subst.*
    - *transmission subst. – distribution subst.*
    - *distribution subst.– demand nodes*

- ***PI = fraction of supplied (non-isolated) demand nodes***

Water supply network connectivity



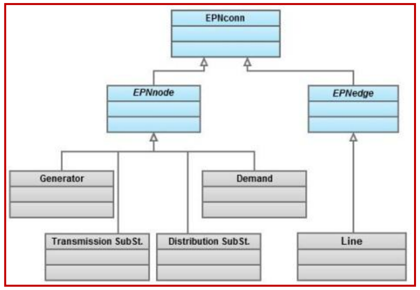
WSS and EPN simulation graph

Connectivity analysis ➜ **Interaction with: Electric Power Network**

PI = fraction of supplied (non-isolated) demand nodes

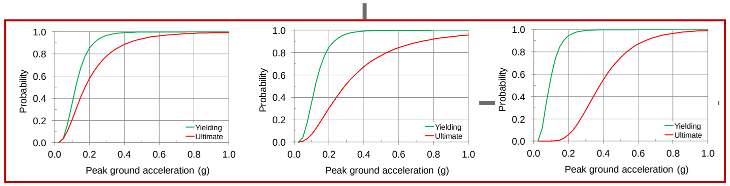
Application in Thessaloniki

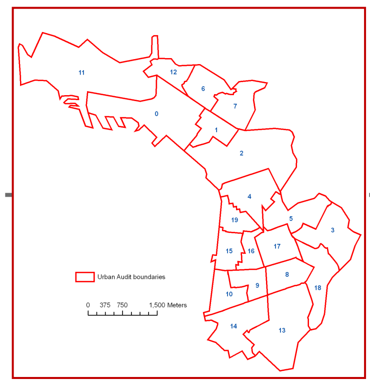
Systemic Analysis



Damage & Loss Prediction

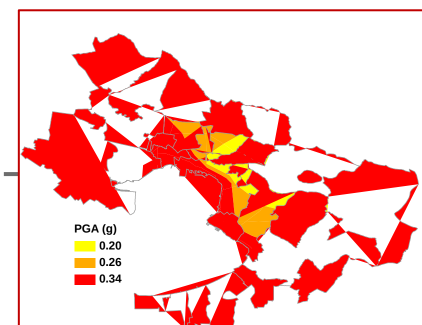
Fragility Models



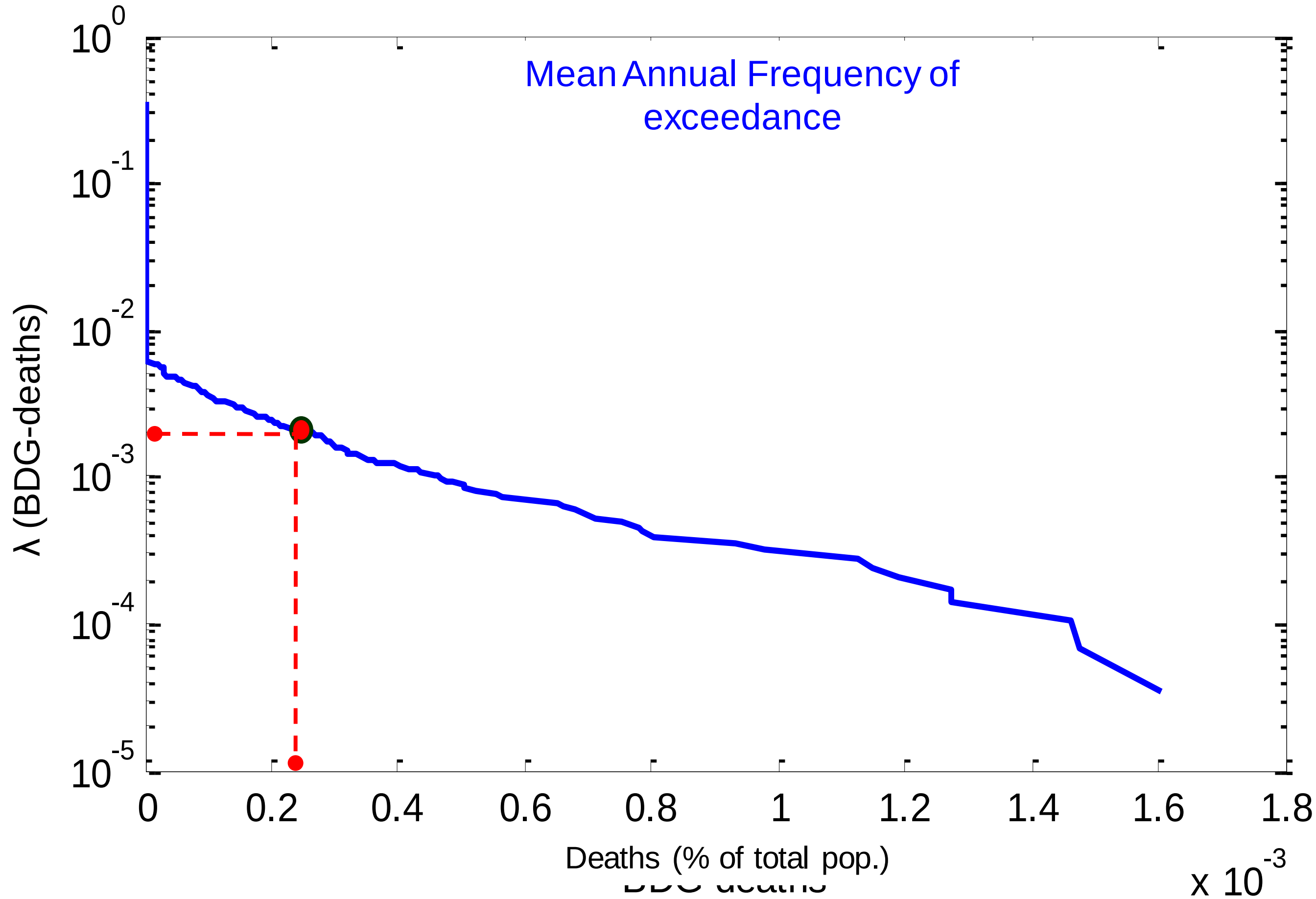


Inventory Selection

Hazard Definition & Seismic Intensity Measures (IM)



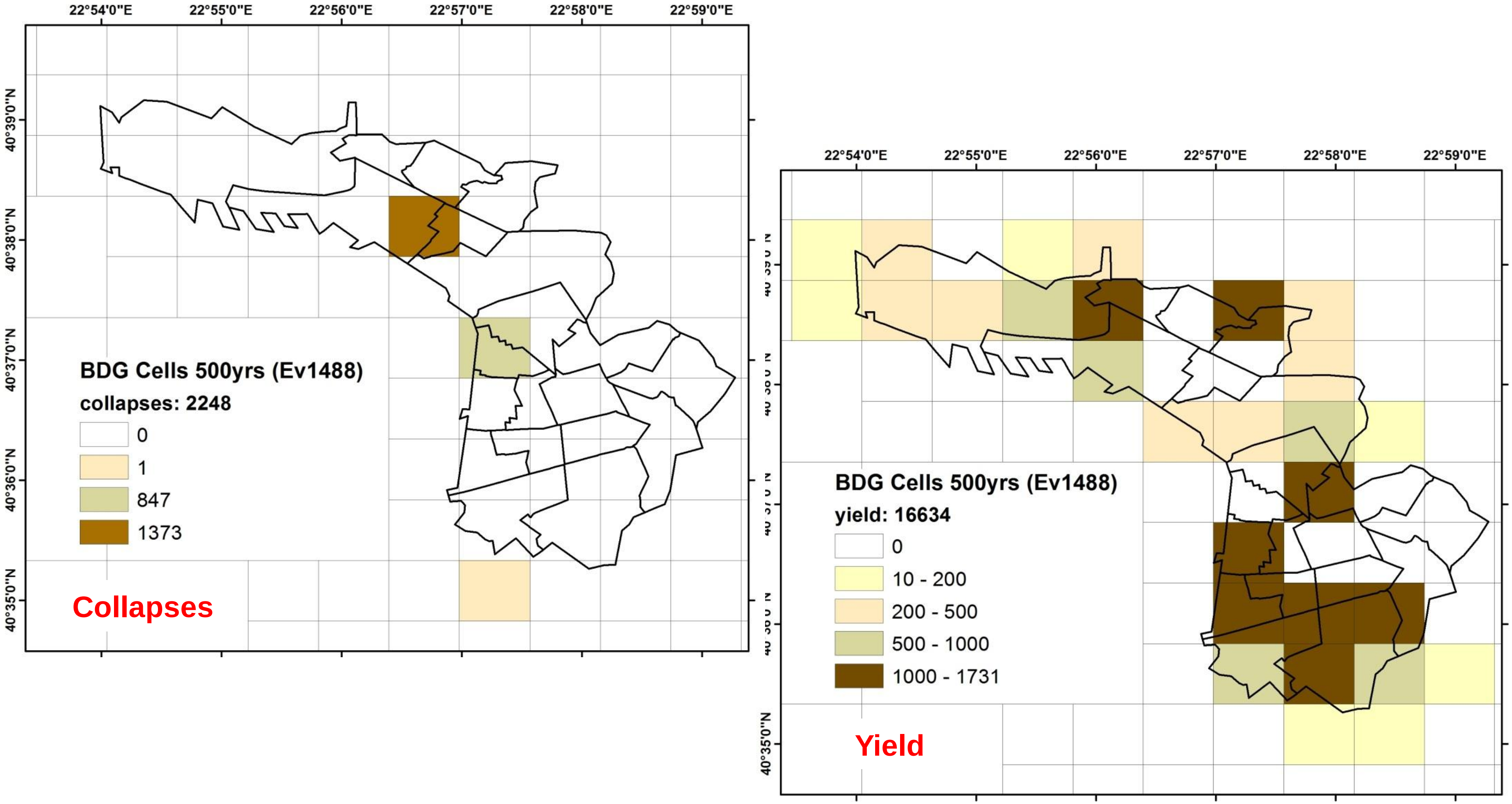
Building stock – Average Losses (Deaths)



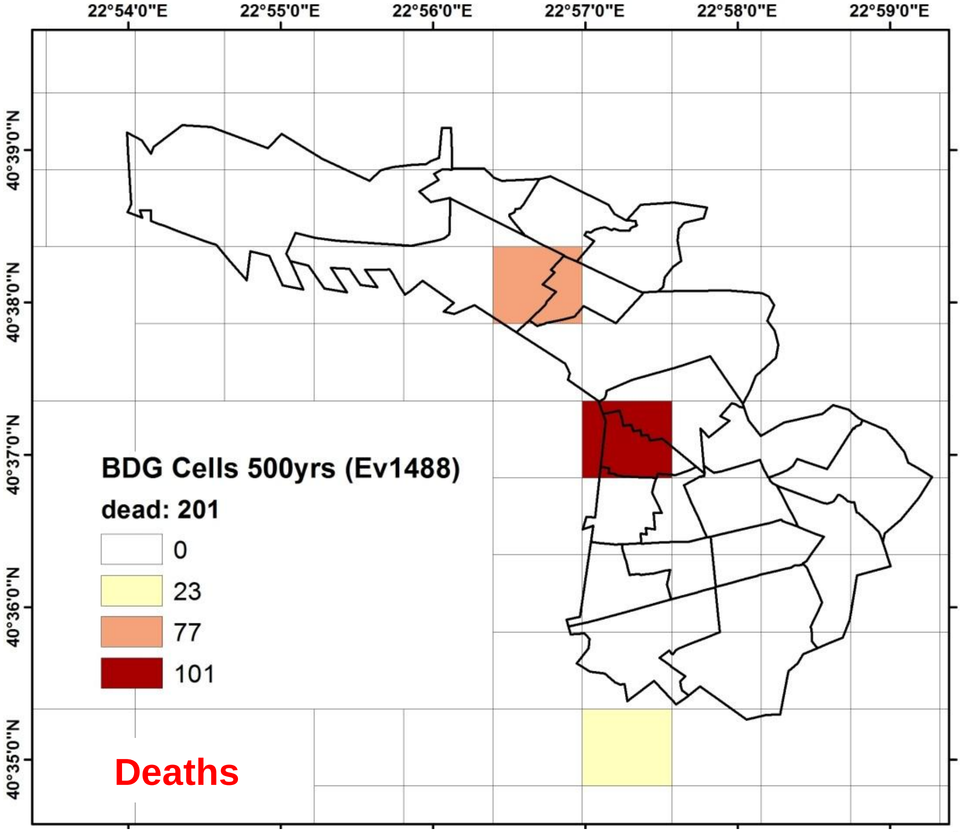
Deaths for Tm= 500 years (λ=0.002)

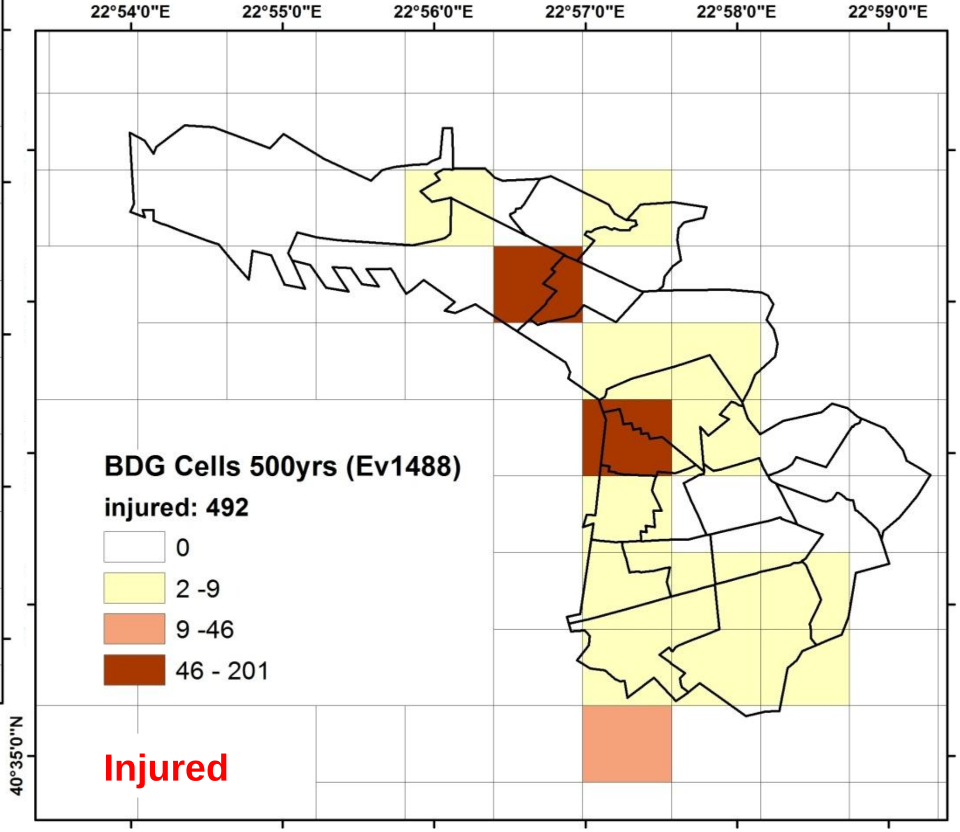
$0.255 \times 10^{-03} \times 790.824 =$ 201 deaths

Losses for Tm=500yrs (Building damages)
5 seismic zones (10,000 runs)

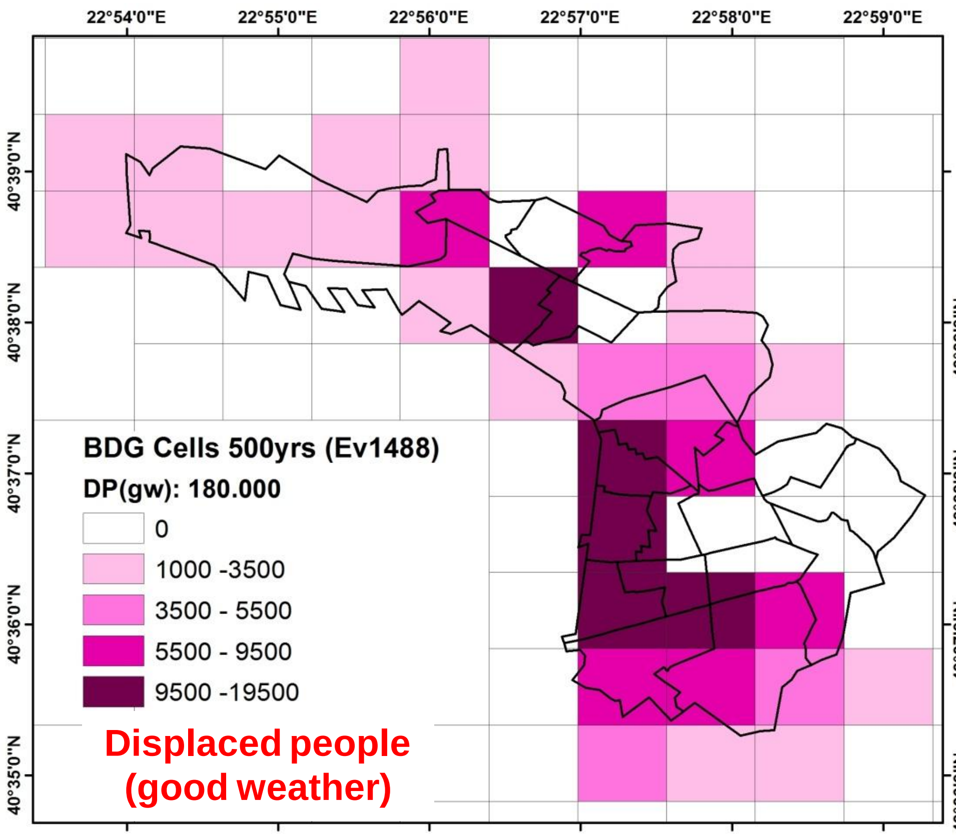


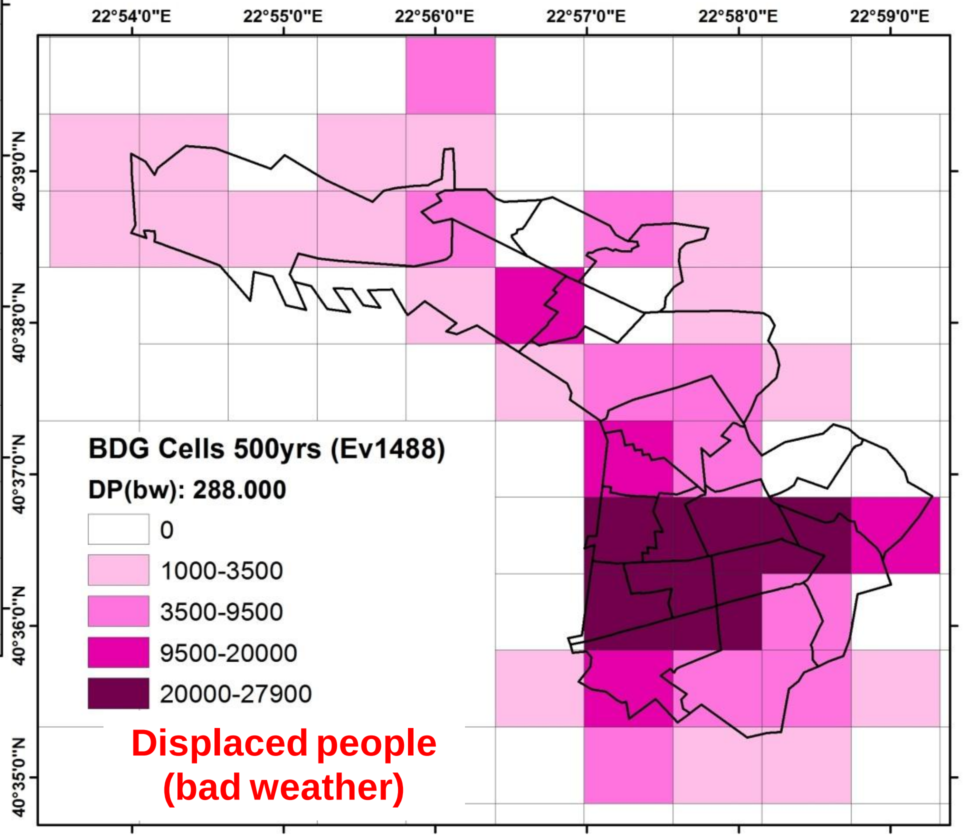
Losses for Tm=500yrs (Deaths)
5 seismic zones (10,000 runs)





Losses for Tm=500yrs (Displaced people)
5 seismic zones (10,000 runs)

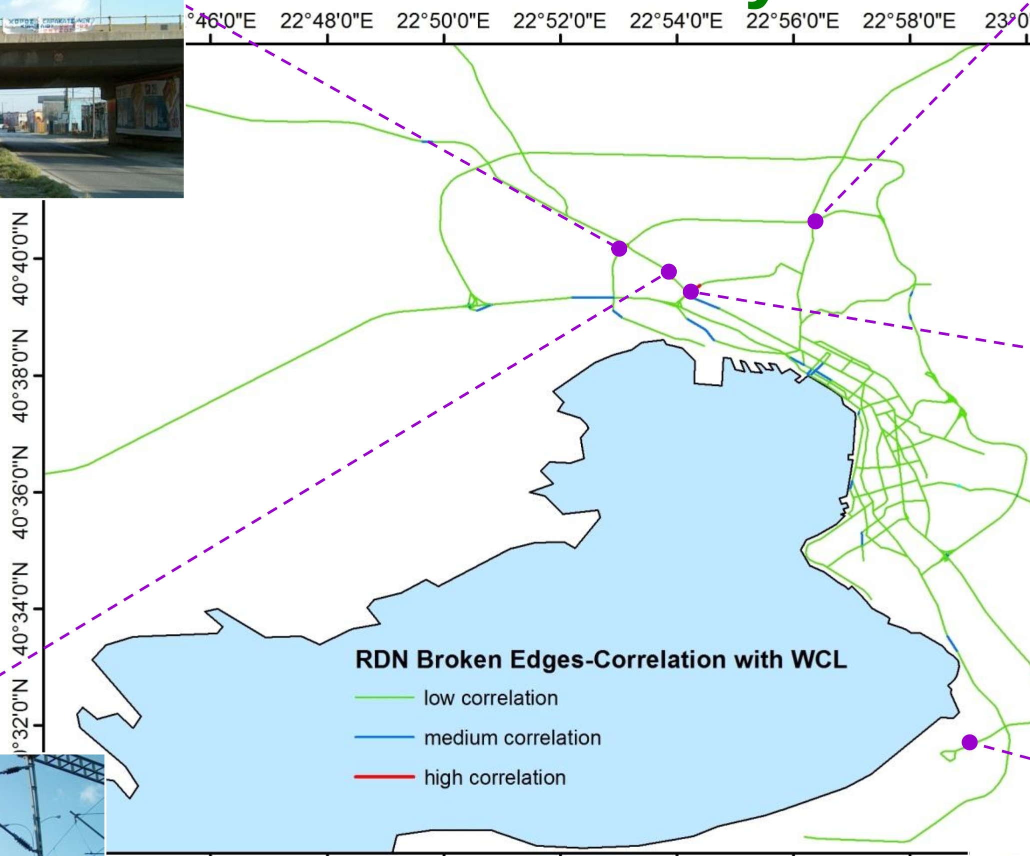




Correlation of broken bridges to network connectivity

Ring road
Interchange K17

Ring road
Interchange K18

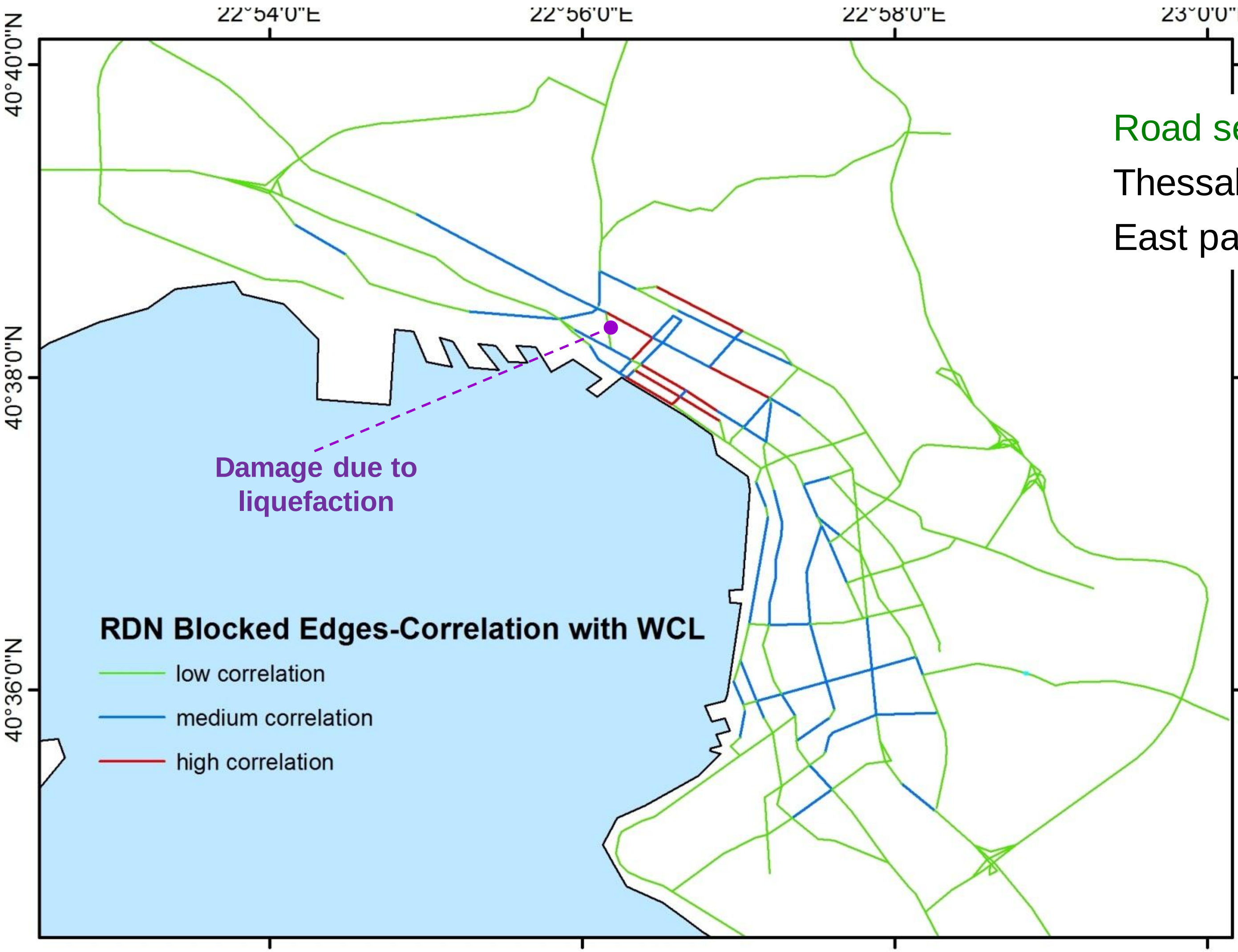


Interchange
(Monastiriou)

Interchange
with railway

Road to airport

Correlation of blocked roads to network connectivity

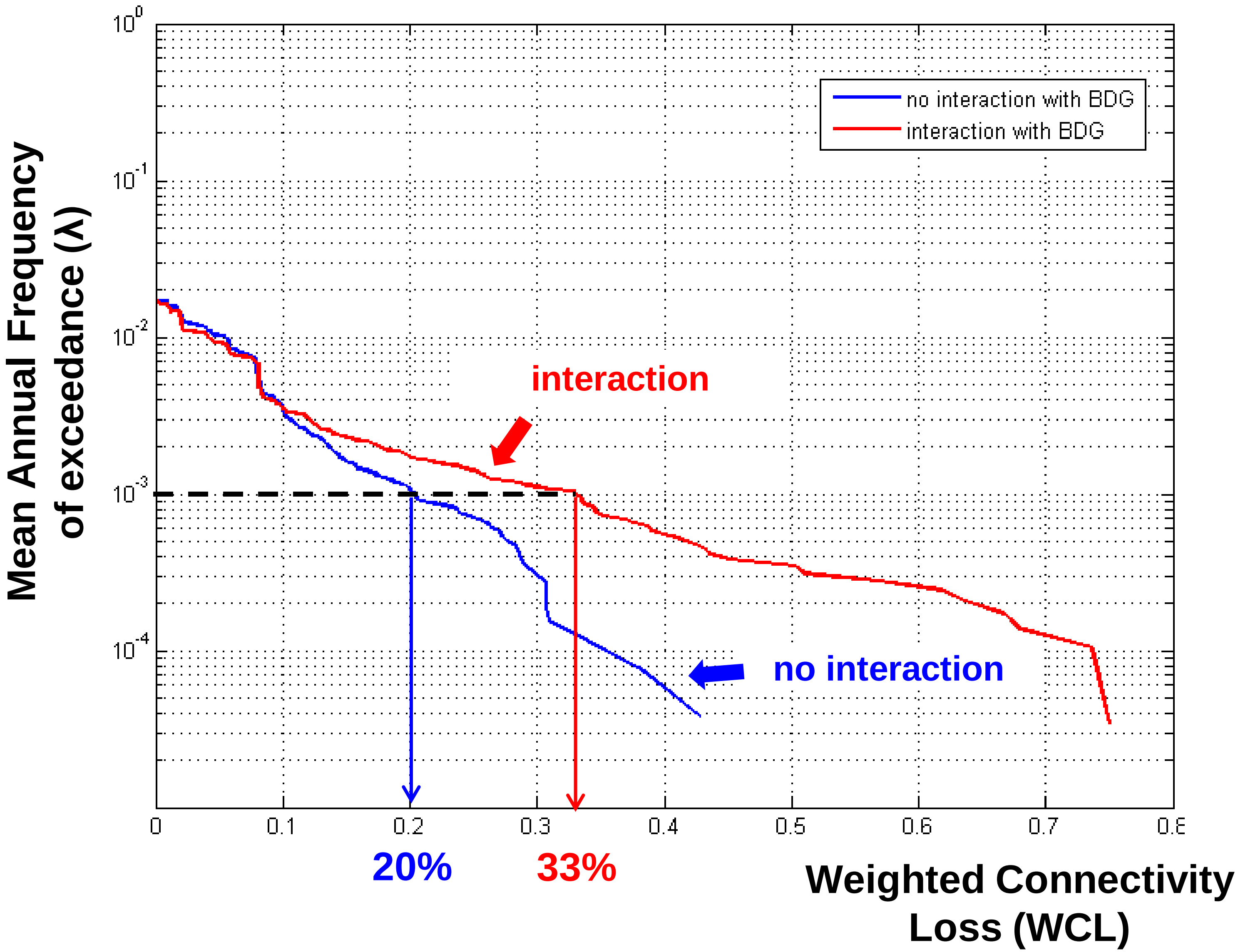


Road segments:

Thessaloniki historical center

East part of the city

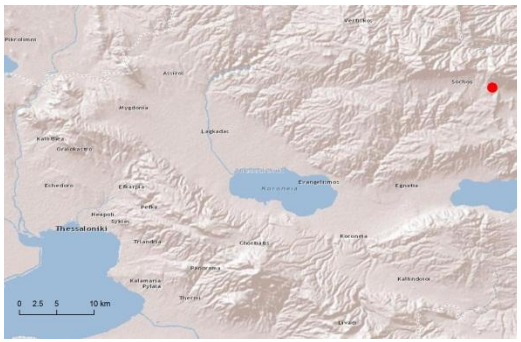
Road Network Risk Curve

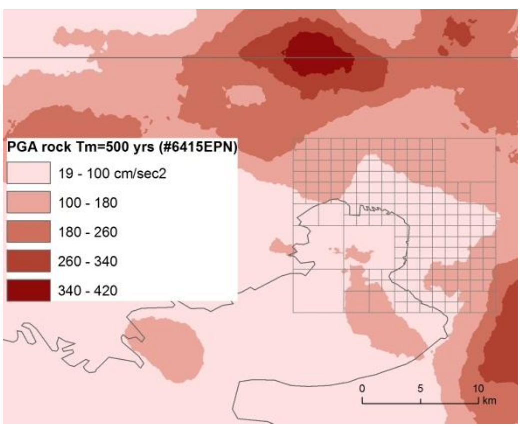


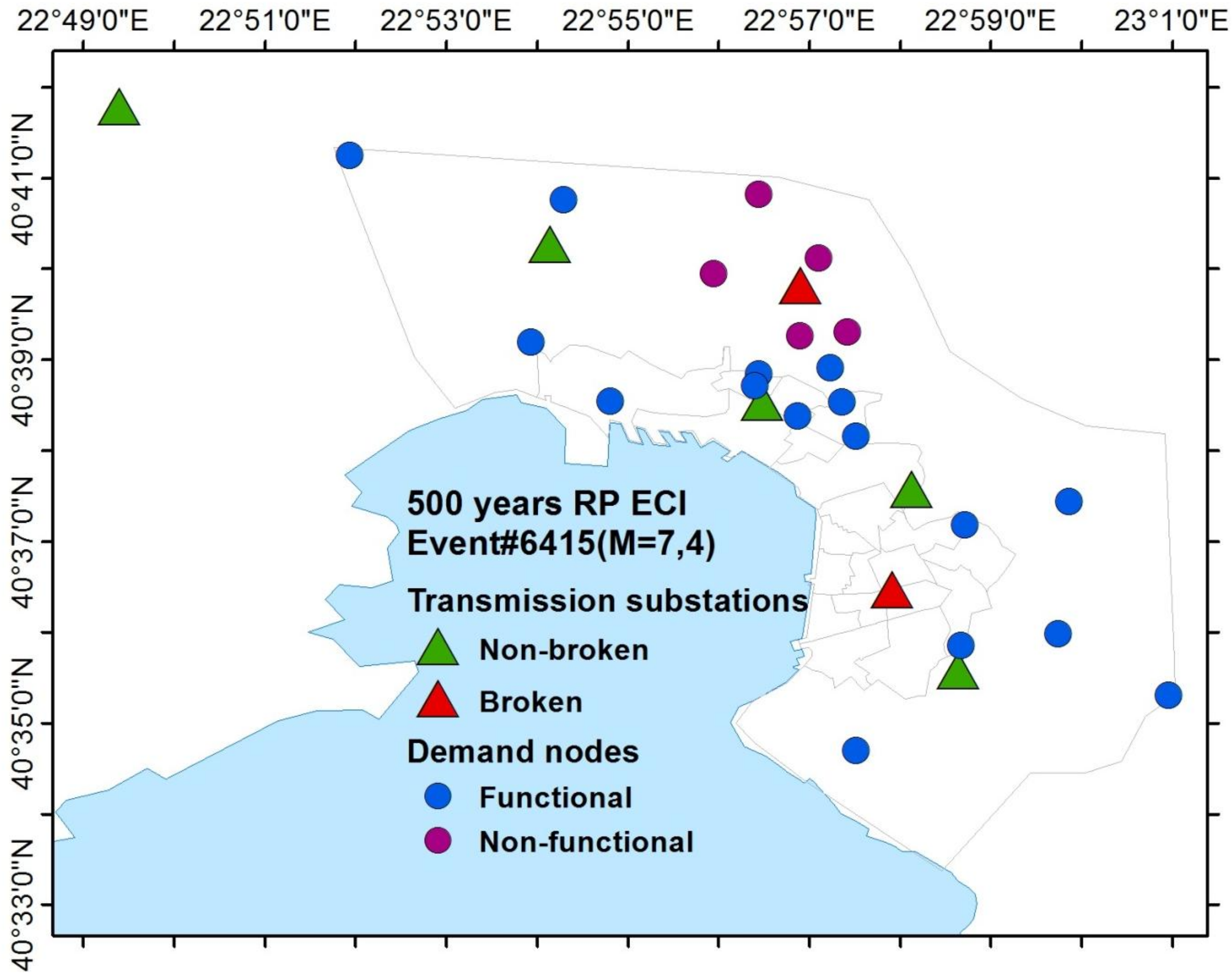
SDGEE

Electric Power Network
Losses for Tm=500 years of ECL

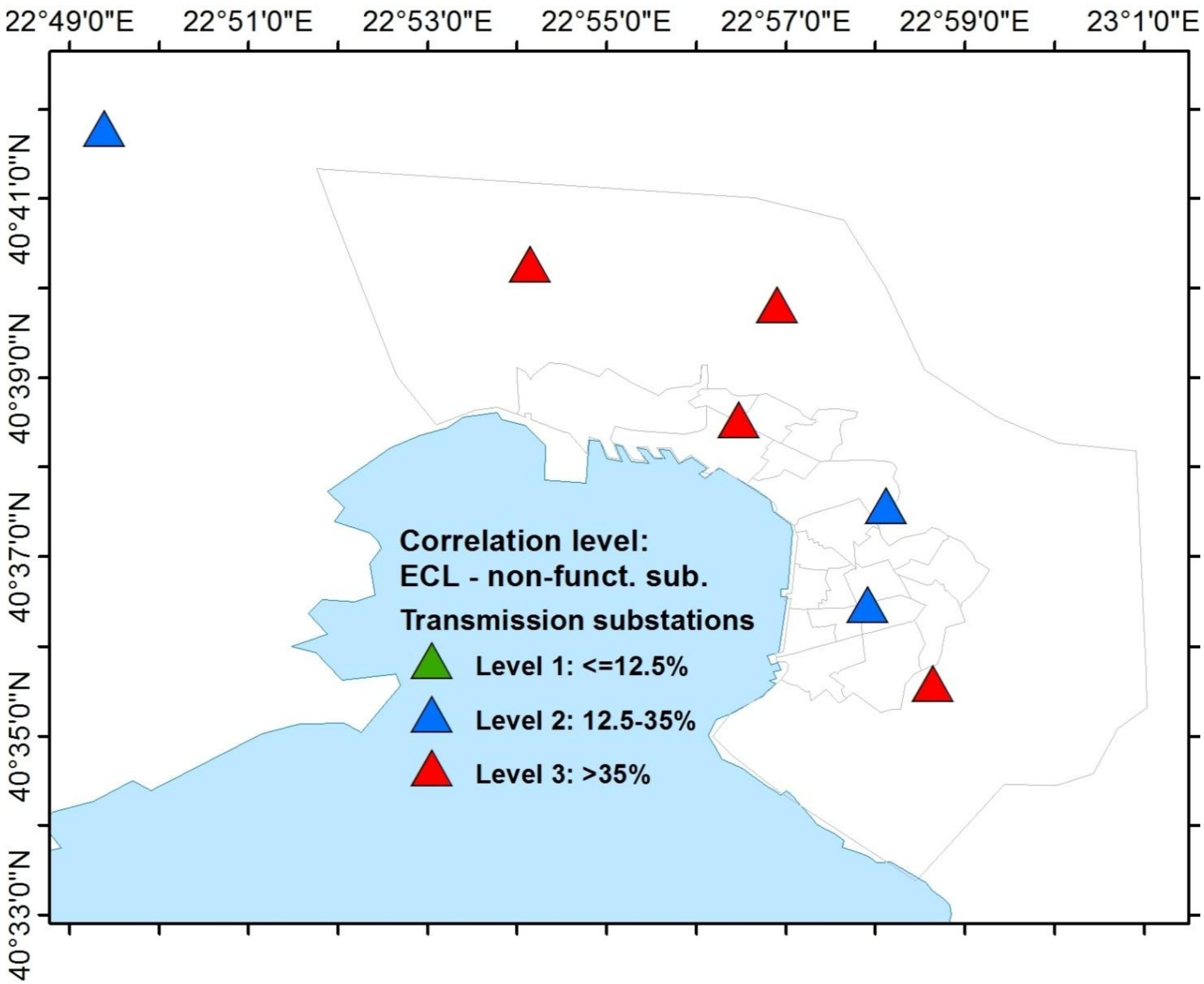
Connectivity loss: 24%



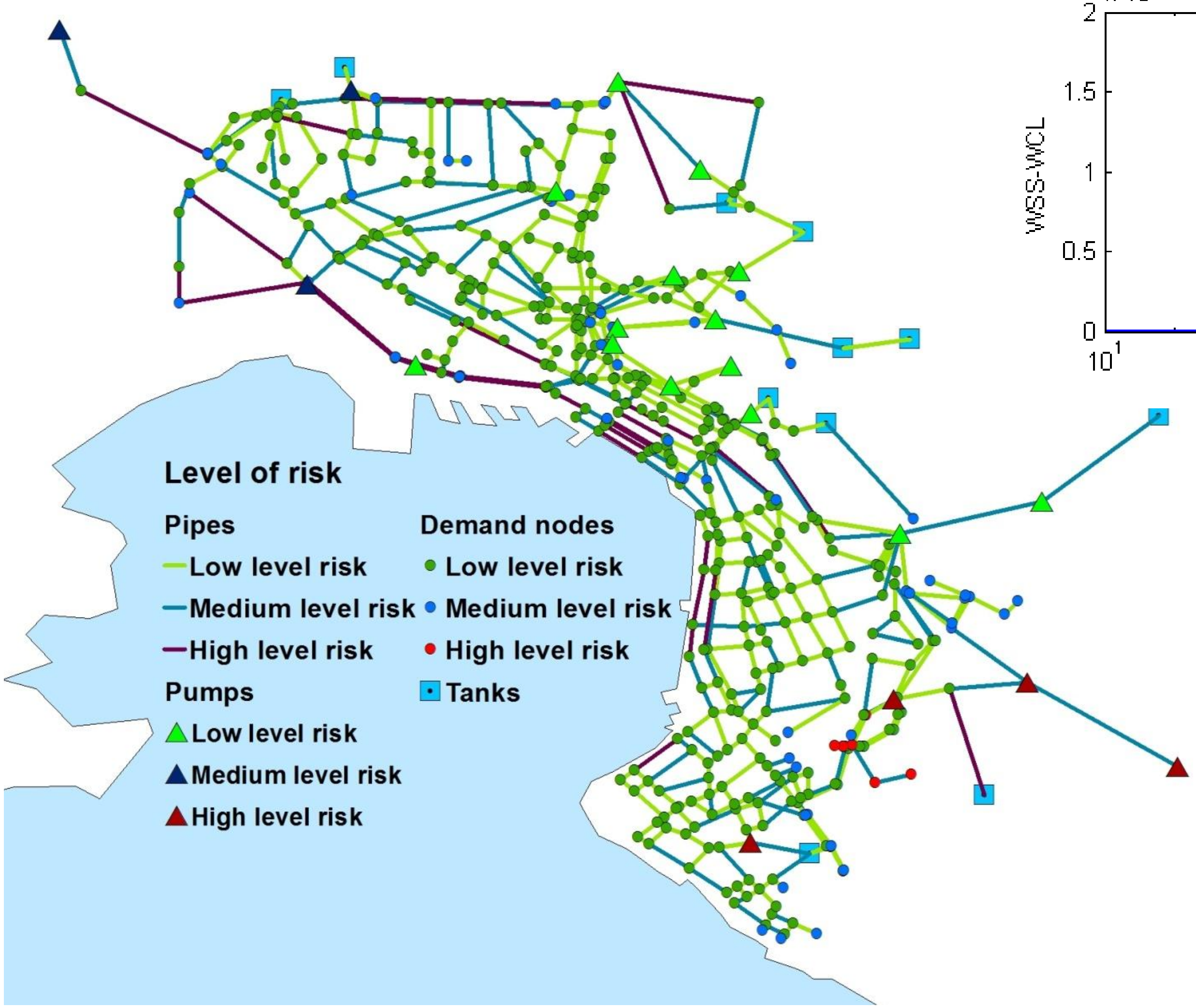


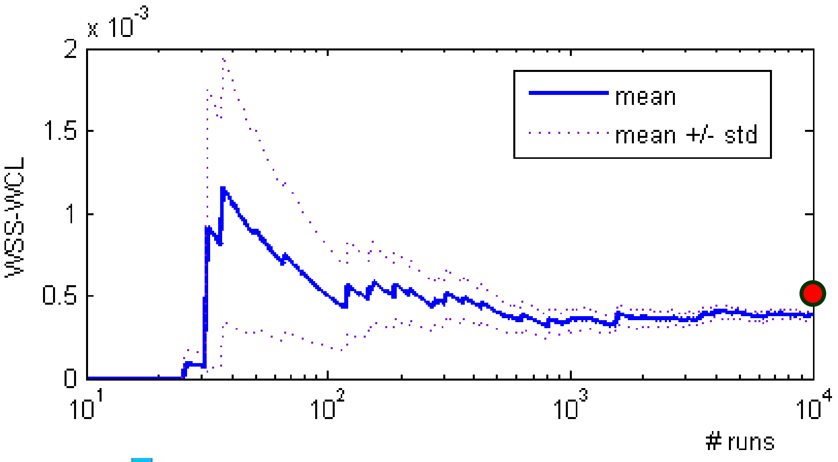


Correlation of broken substations to network connectivity



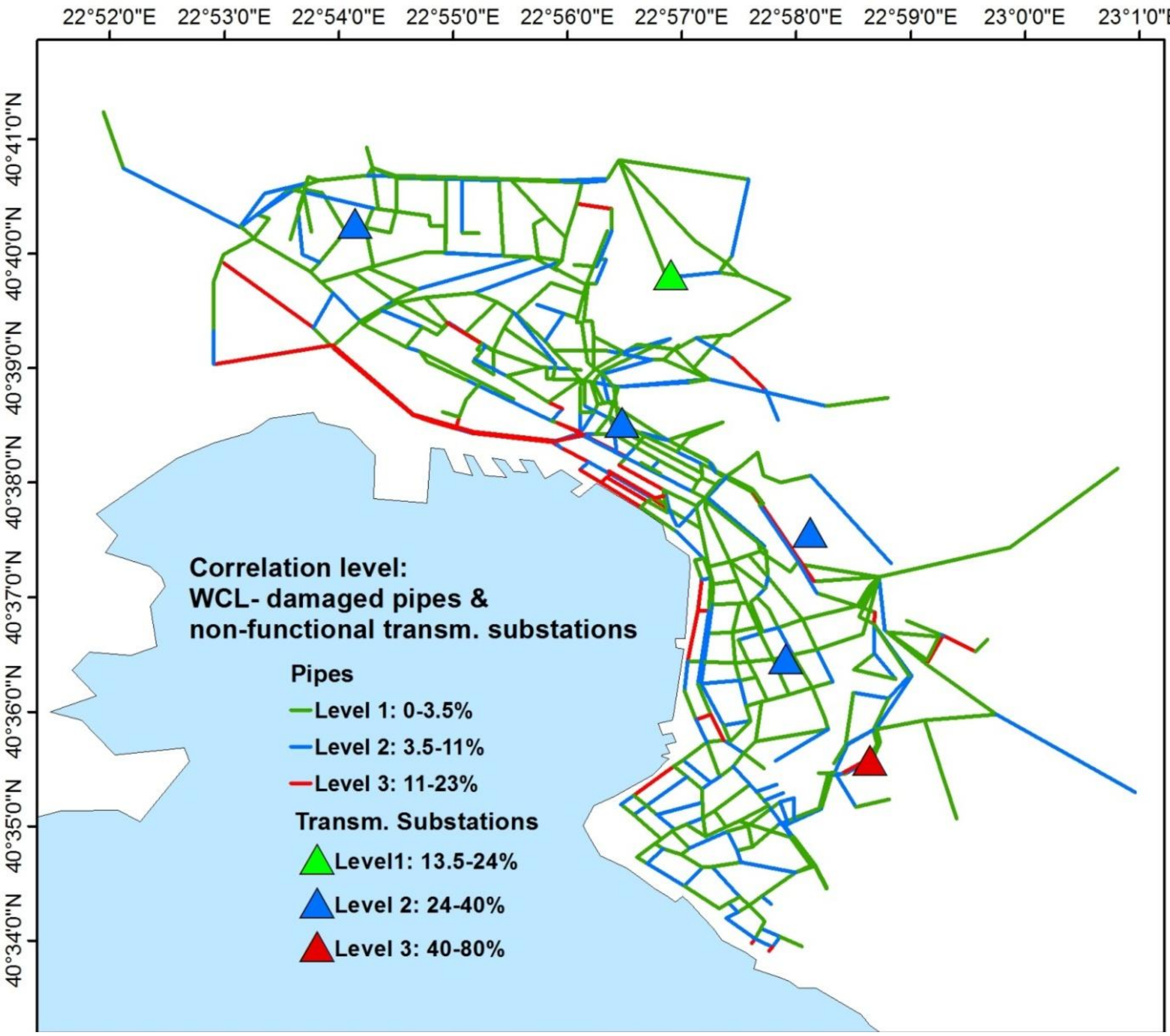
Water Supply System of Thessaloniki - Average Losses



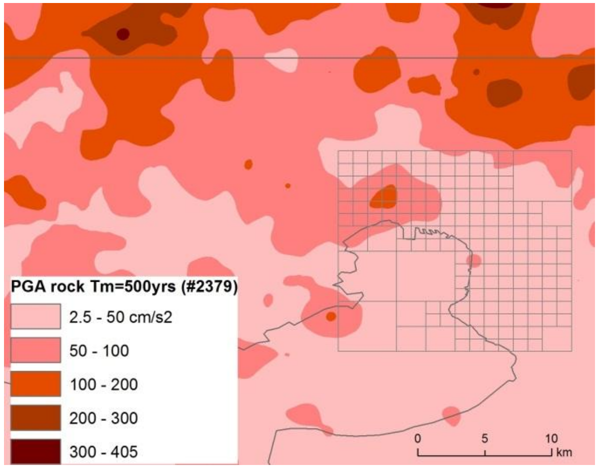


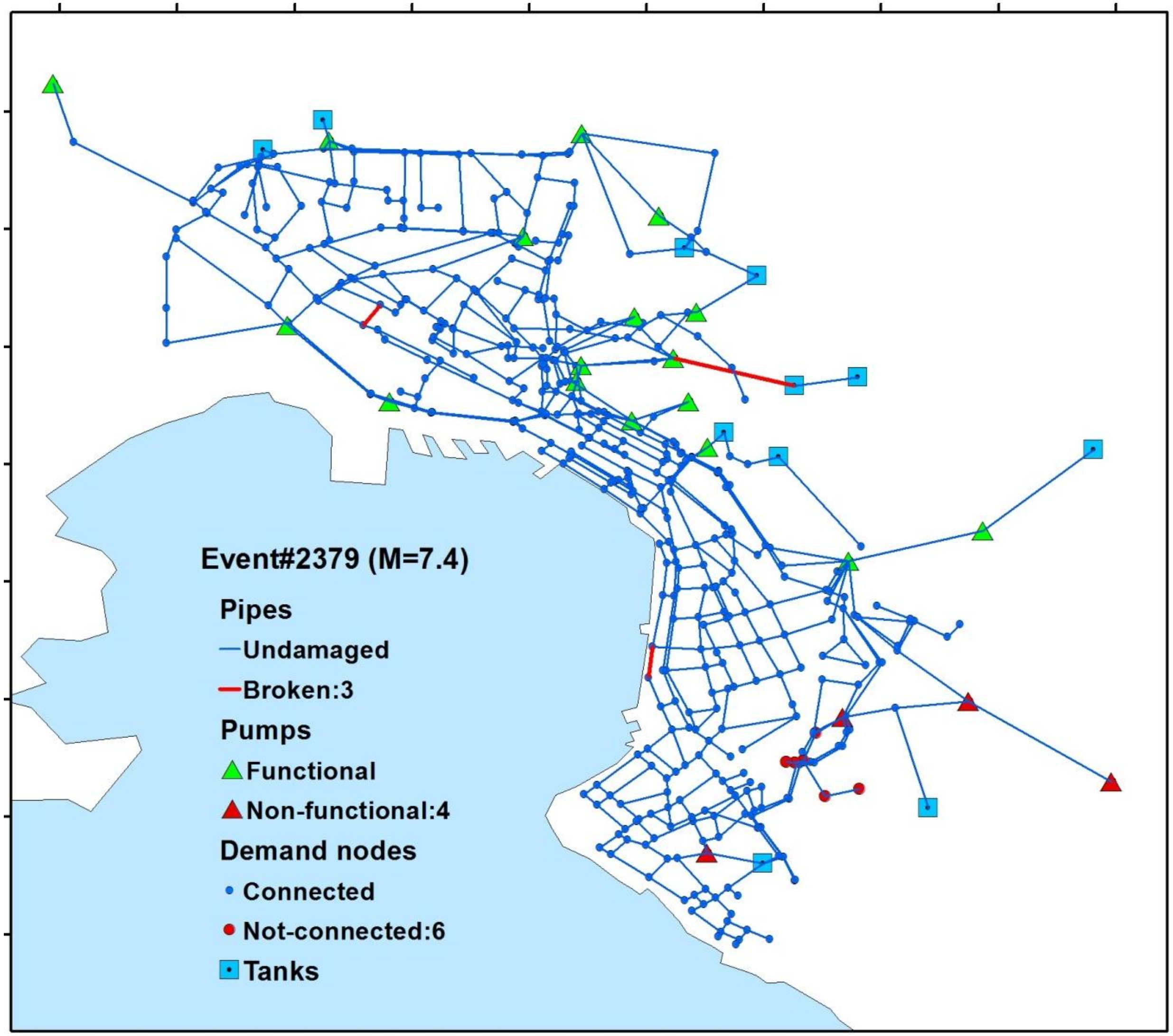
Average connectivity loss:
0.35%

Correlation of damaged pipes & broken EPN transmission stations to network connectivity



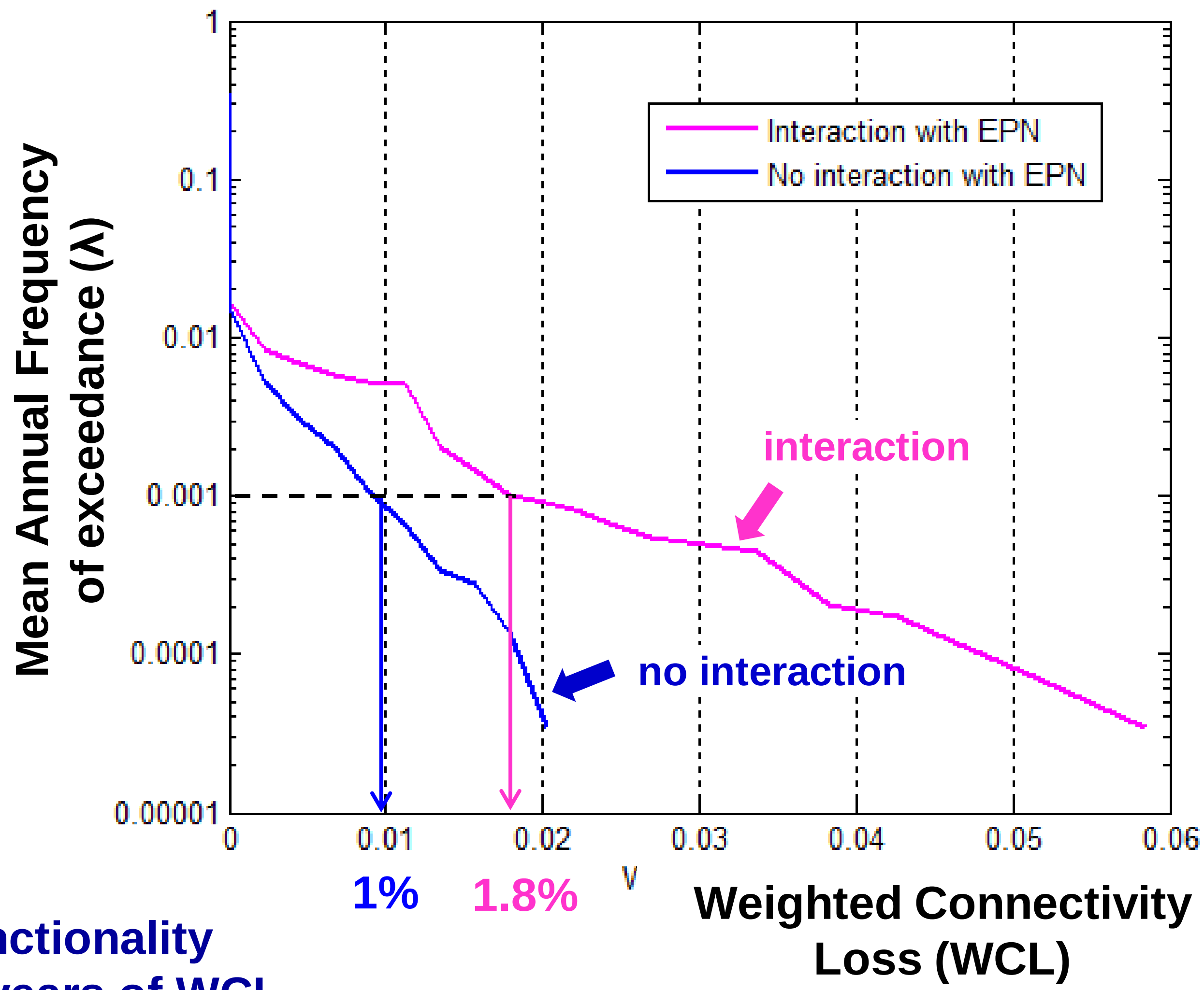
Water Supply System - Losses for Tm= 500 years of WCL





Water Supply System Risk Curve

Effect of interaction with Electric Power Network



System functionality
Tm= 1000 years of WCL

Thessaloniki Harbor

General description:

Size of served area ~ 80km^2

Size of area: 1,500,000 m^2

Trade cargo: 16,000,000 tons

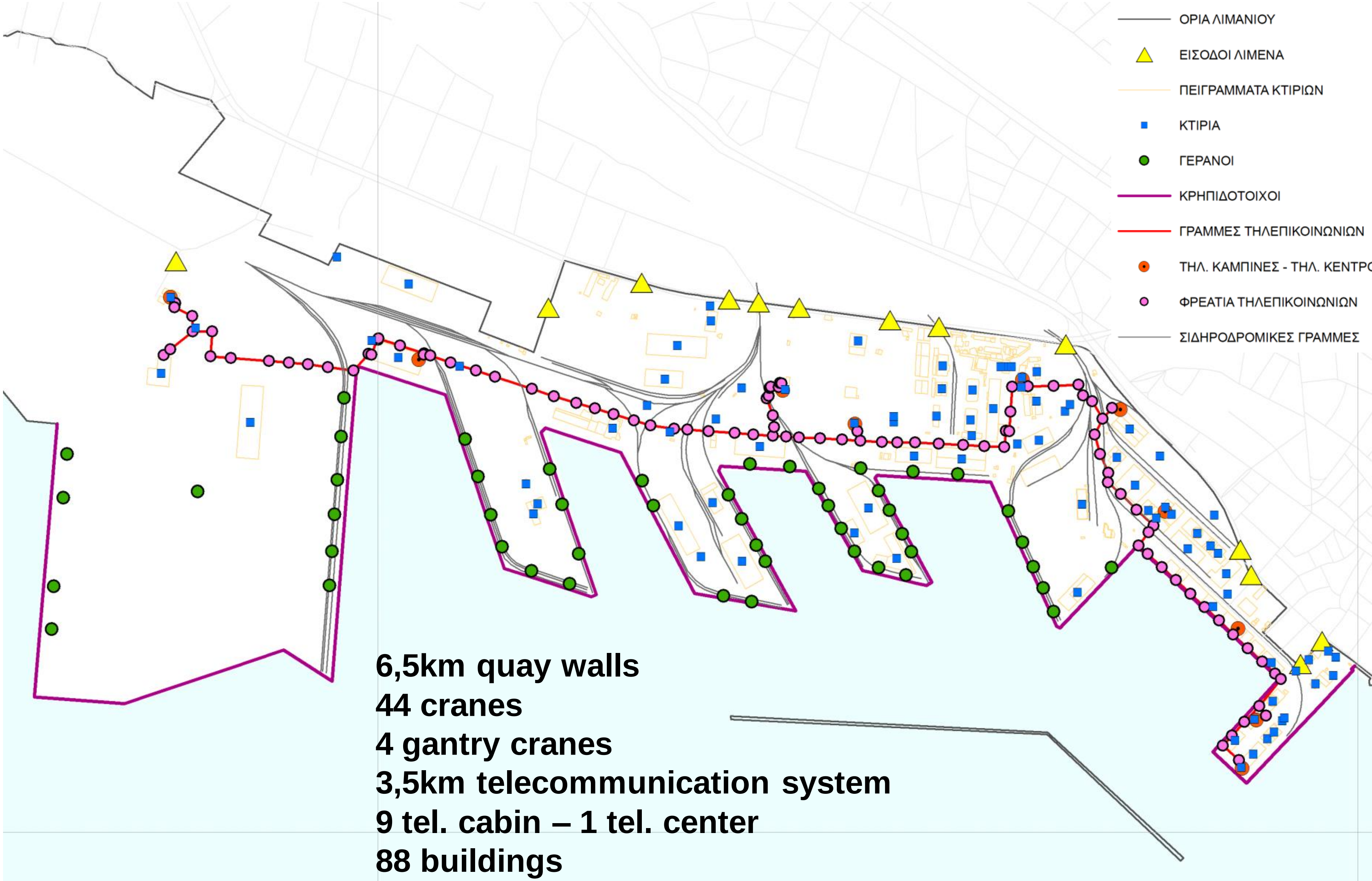
Capacity: 370,000 TEUs containers

6 piers

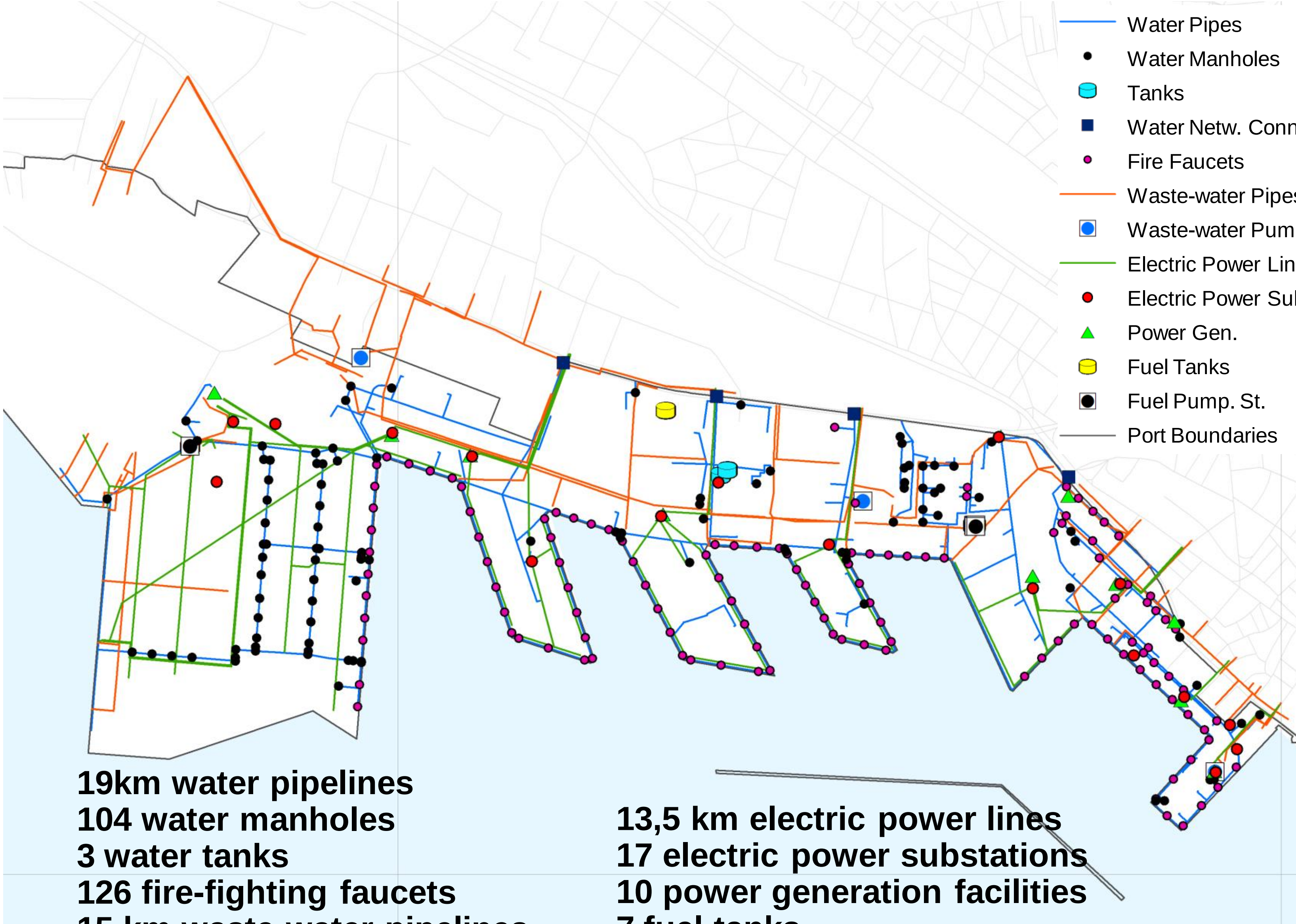
6,500m waterfronts length

Elements at risk

- Waterfront structures
- Cargo transfer & handling equipment
- Electric power network
- Potable & waste water networks
- Telecommunication system
- Railway & roadway systems
- Buildings & critical facilities



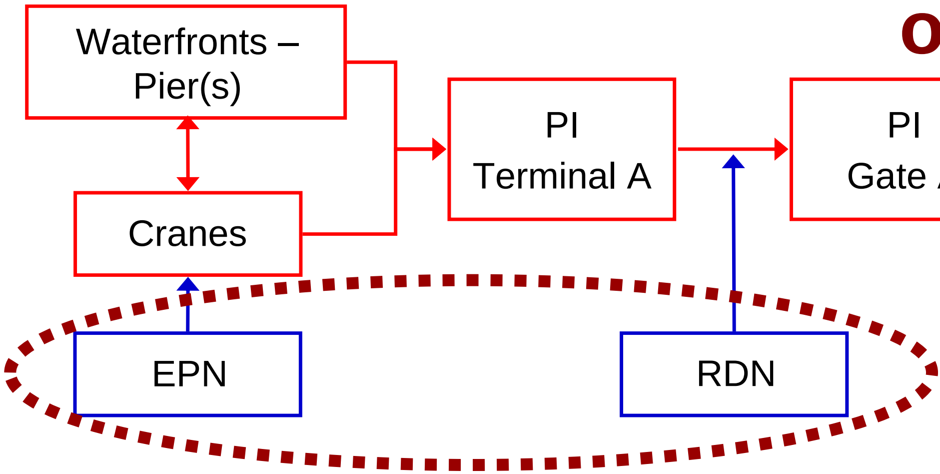
6,5km quay walls
44 cranes
4 gantry cranes
3,5km telecommunication system
9 tel. cabin – 1 tel. center
88 buildings



19km water pipelines
104 water manholes
3 water tanks
126 fire-fighting faucets
15 km waste-water pipelines
3 waste-water pumping stations

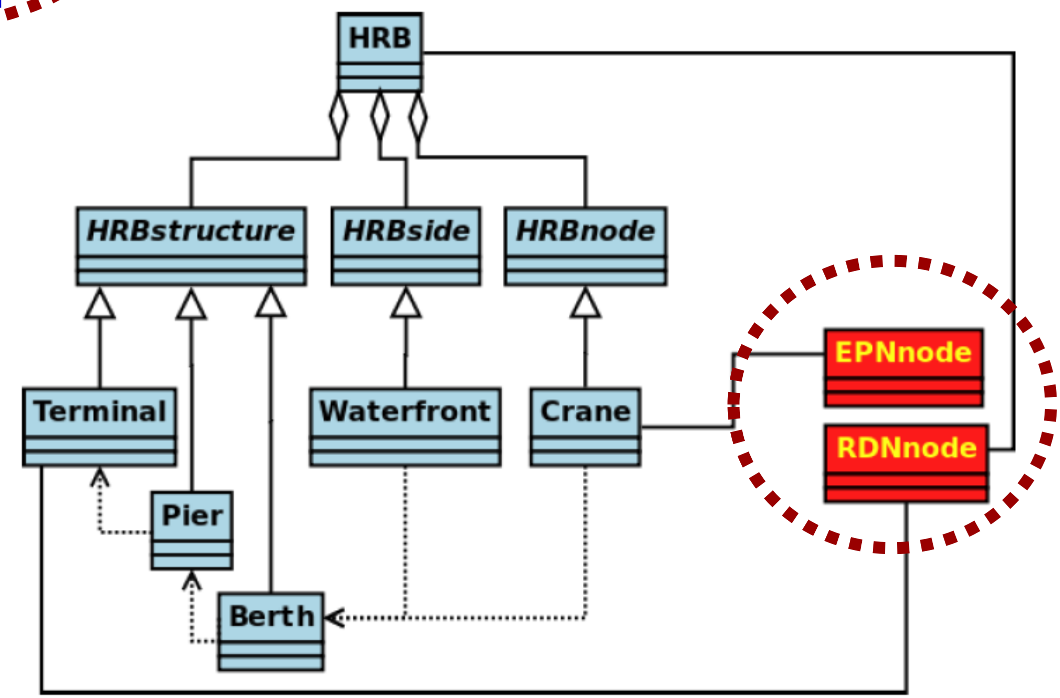
13,5 km electric power lines
17 electric power substations
10 power generation facilities
7 fuel tanks
6 fuel pumping stations

Seismic vulnerability and functionality of port system



Functionality simulation of port facilities

Considered interactions



Class diagram for the harbor classes

Performance Indicators

➢ **Container terminals**

Containers handled (loaded and unloaded) per day, in TEUs

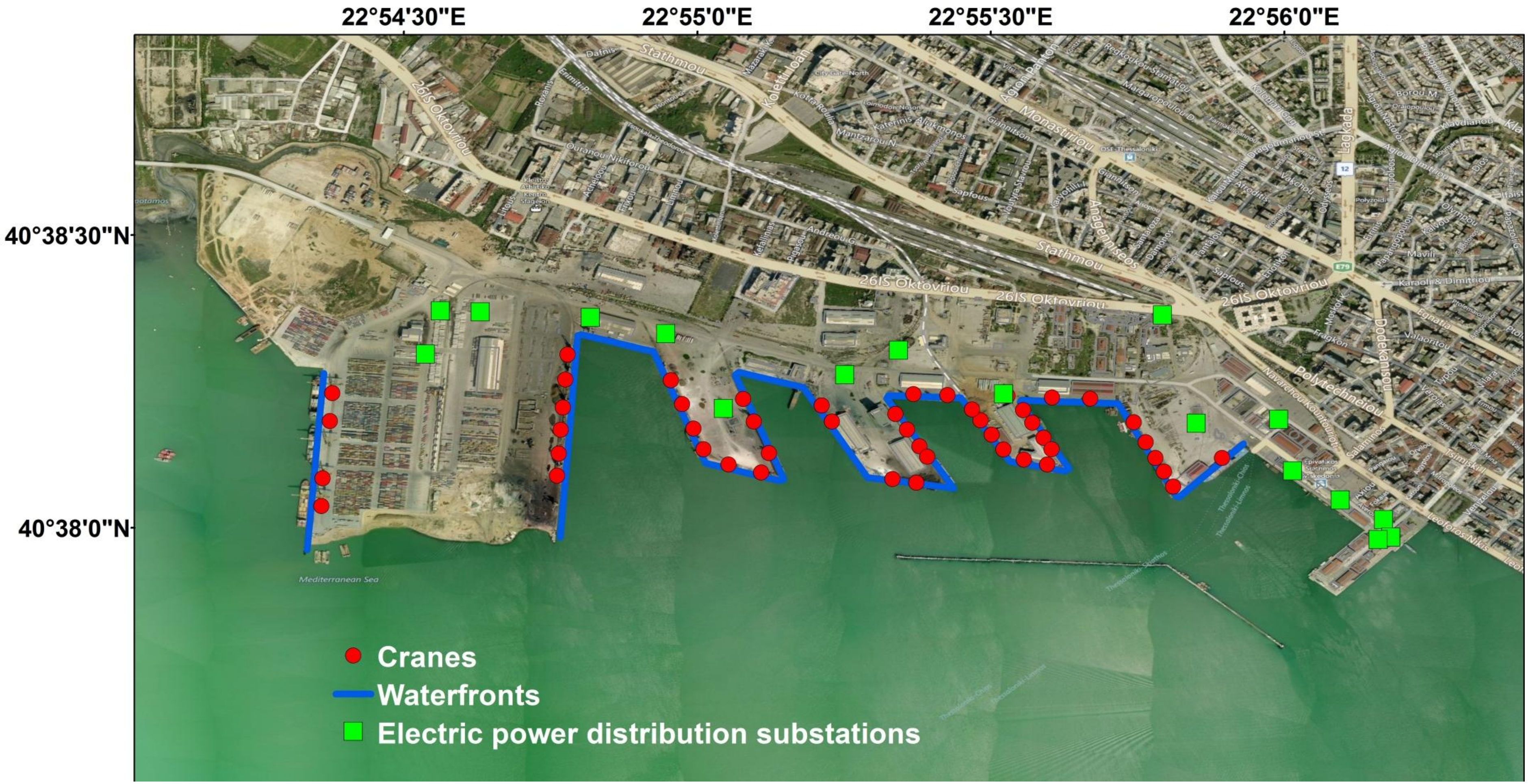
- **Terminal: total number of TEU (TCoH)**
- **Gate: movements (TCoM)**

➢ **Bulk cargo terminals**

Cargo handled (loaded and unloaded) per day, in tones

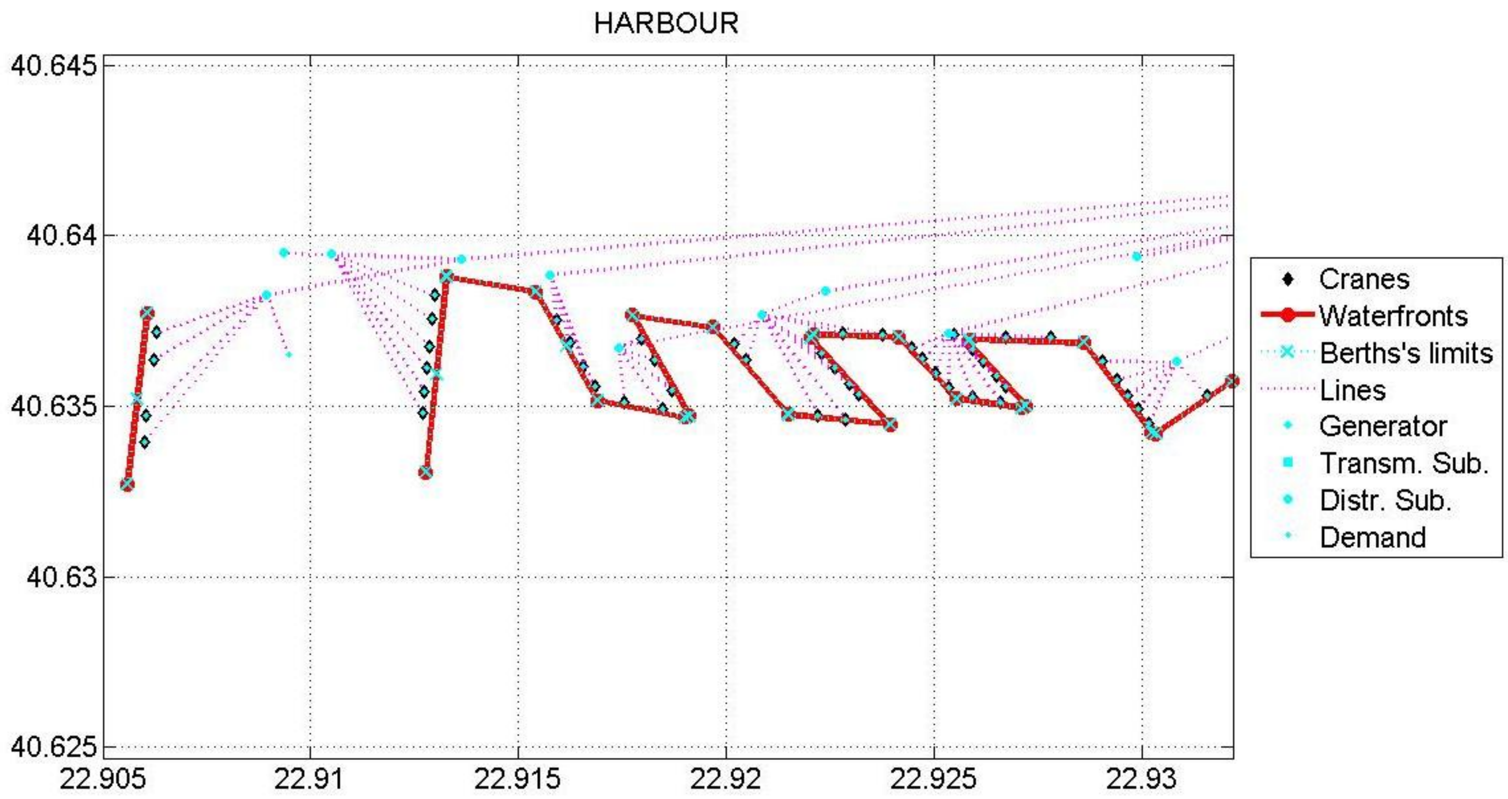
- **Terminal: total cargo (TCaH)**
- **Gate: movements (TCaM)**

Application to Thessaloniki port



Elements:

- *48 cranes*
- *17 distribution substations*
- *8 transmission substations*



Structures:

- *2 terminal (container and cargo)*
- *5 piers*
- *17 berths*

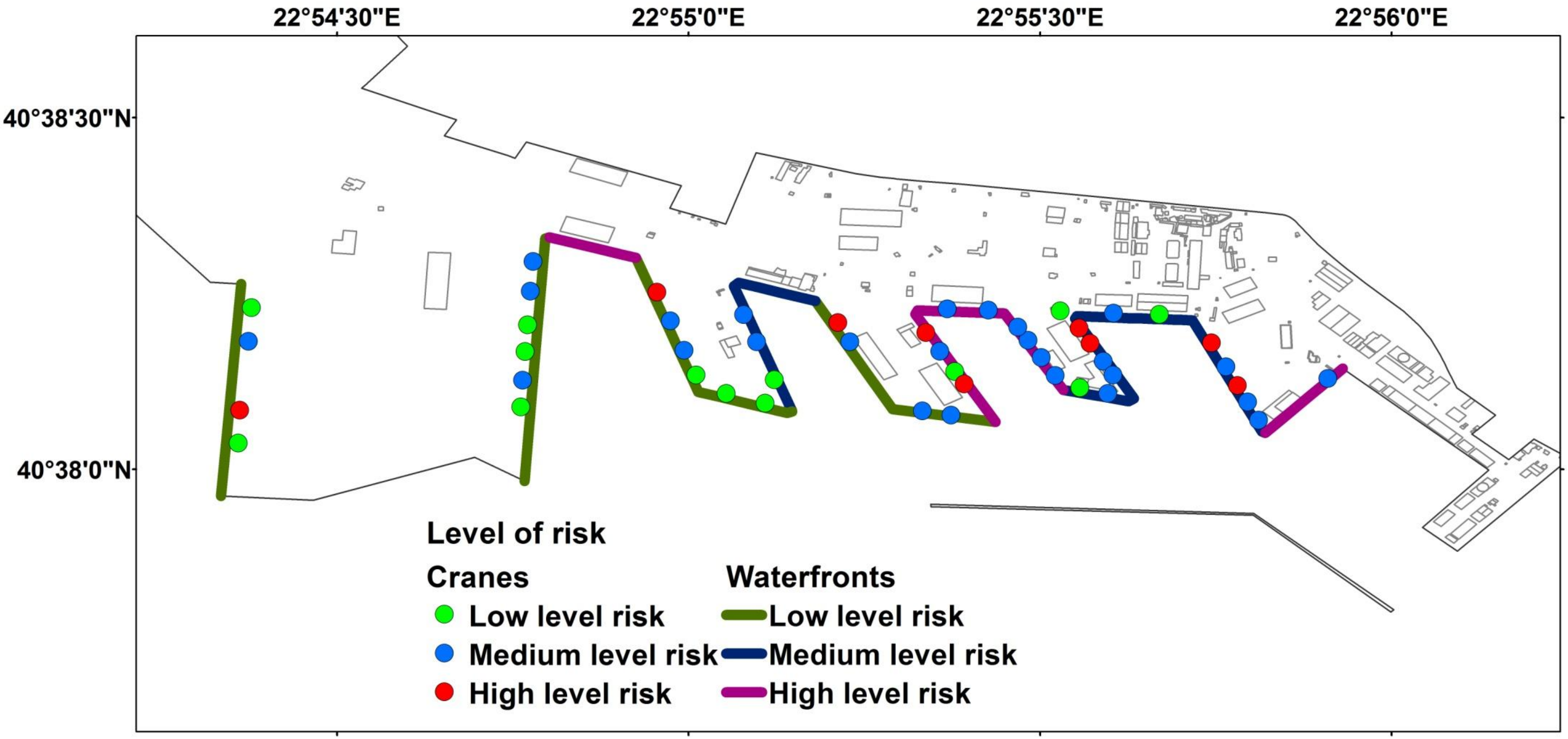
PI s (max)

(max capacity for non-seismic conditions):

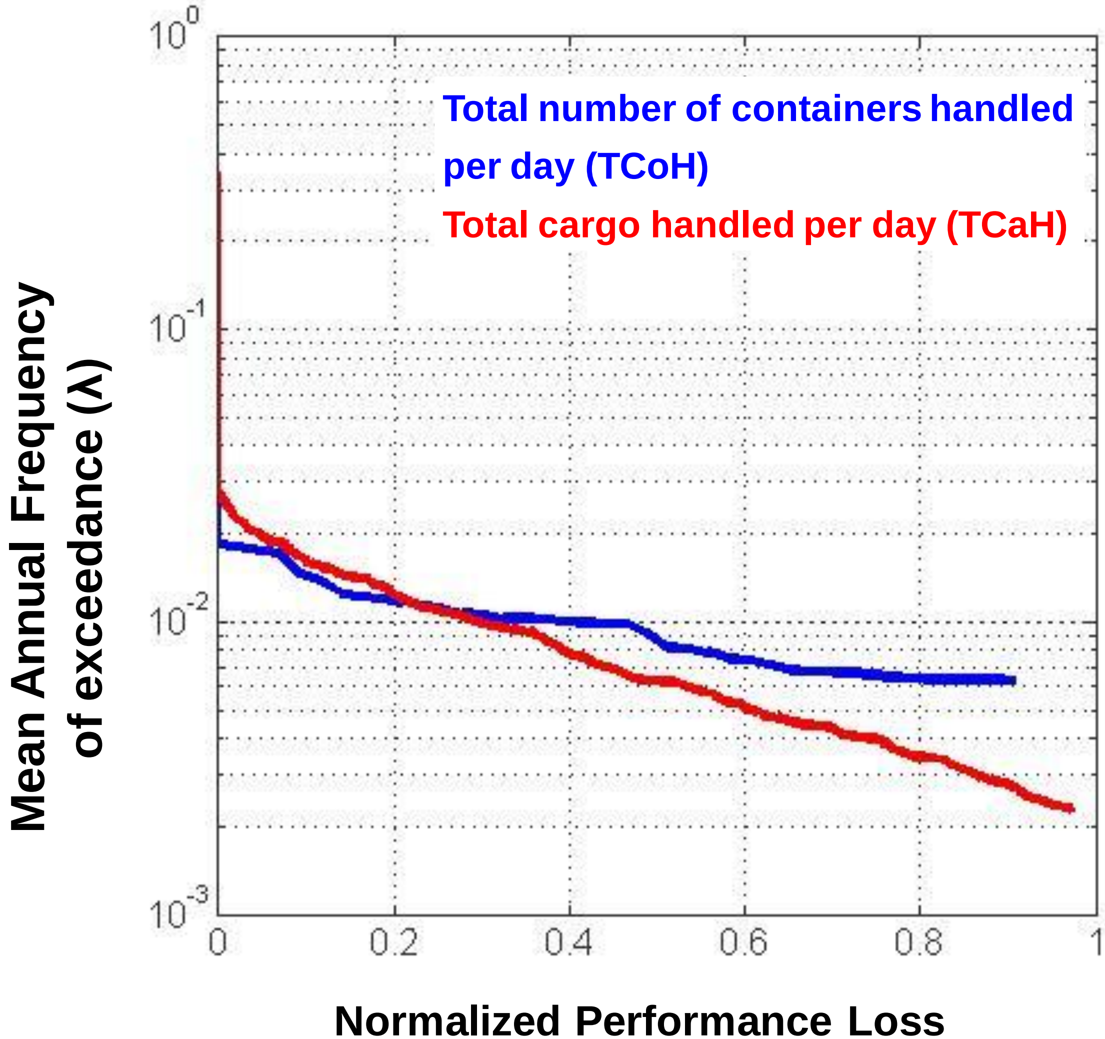
-TCoH = 1032 TEU/day

-TCaH =43512 tons/day

Average losses (MCS, 10,000 runs)



Application results, MCS simulation (10,000 runs)

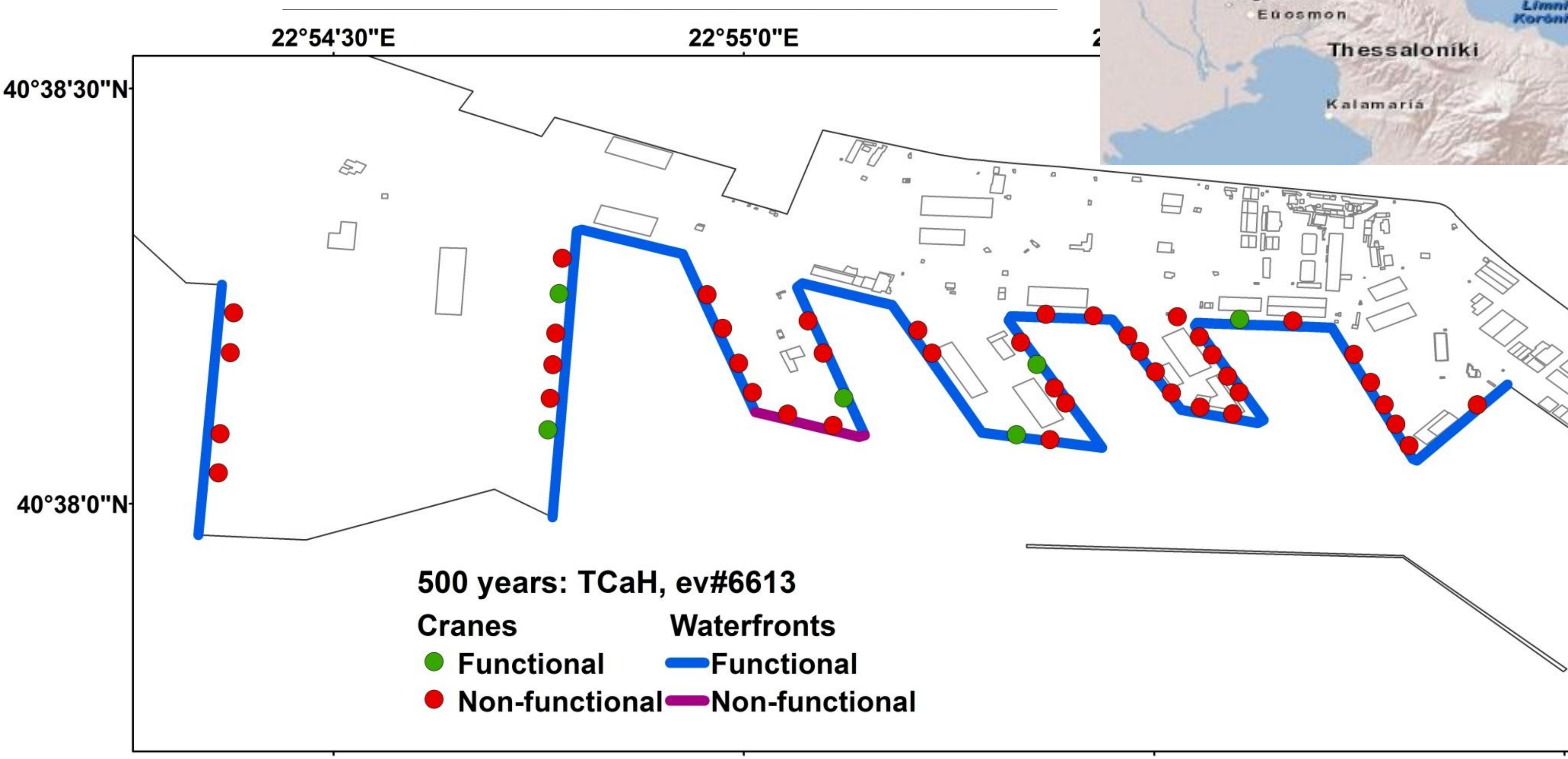


Losses for Tm=500 years of TCaH

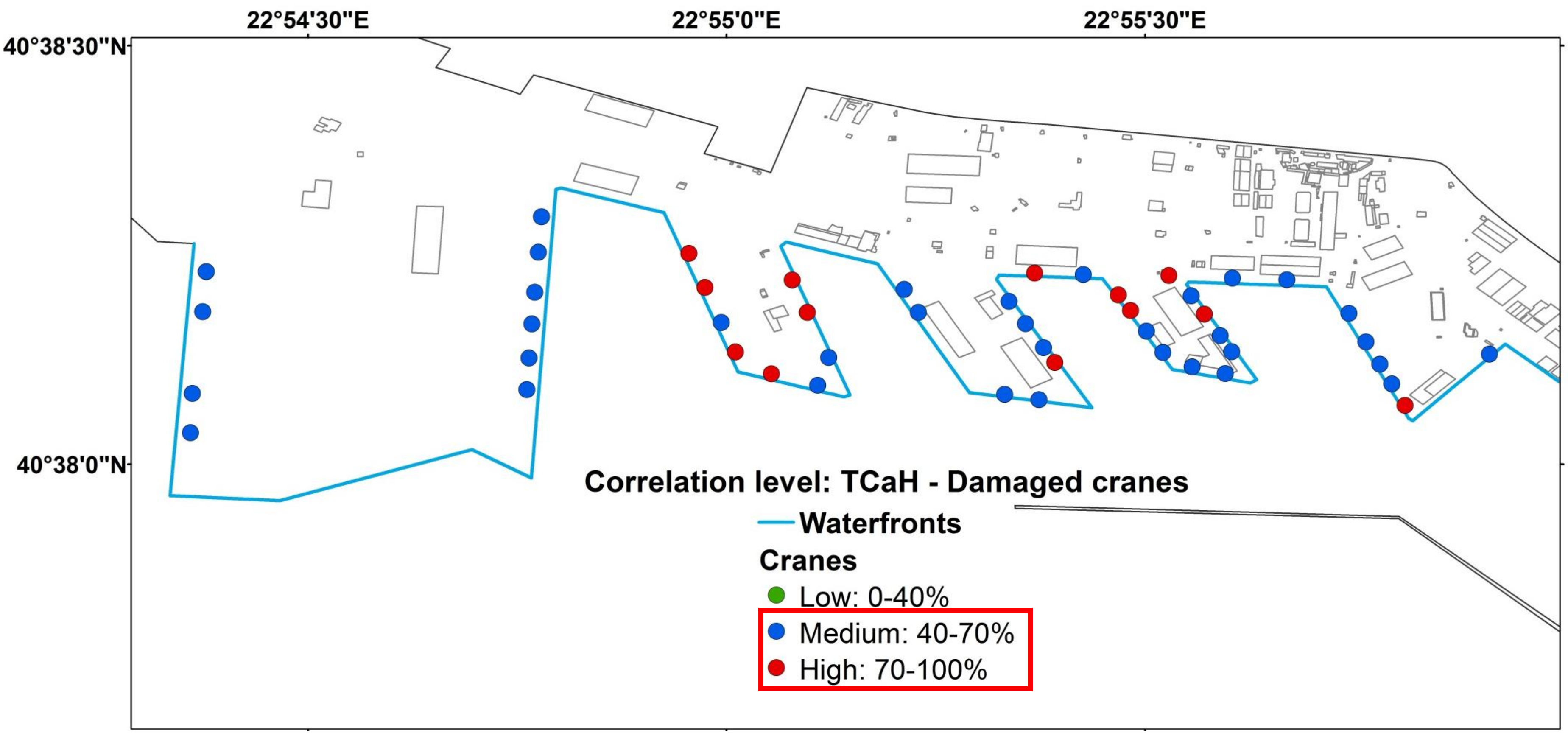
Port functionality loss

60% TCoH

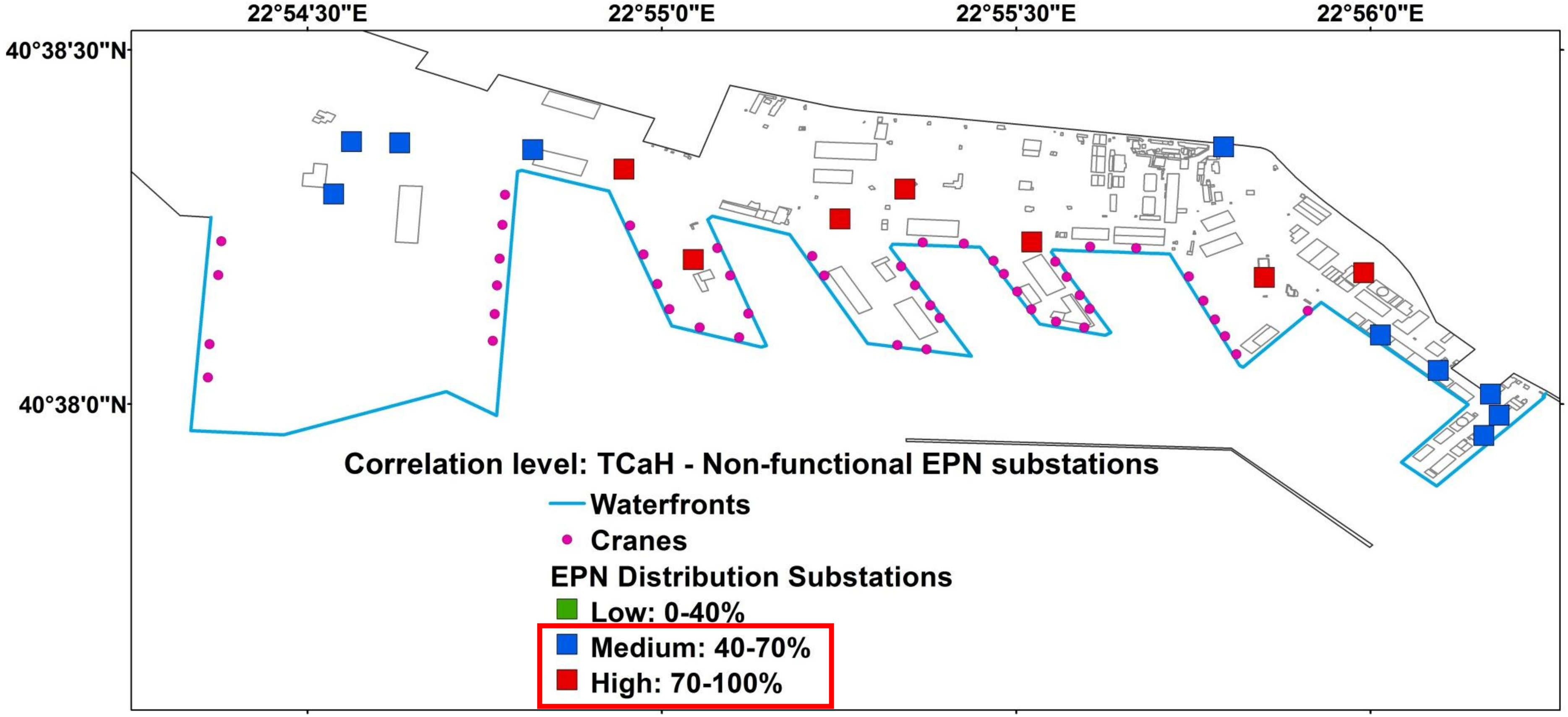
97% TCaH



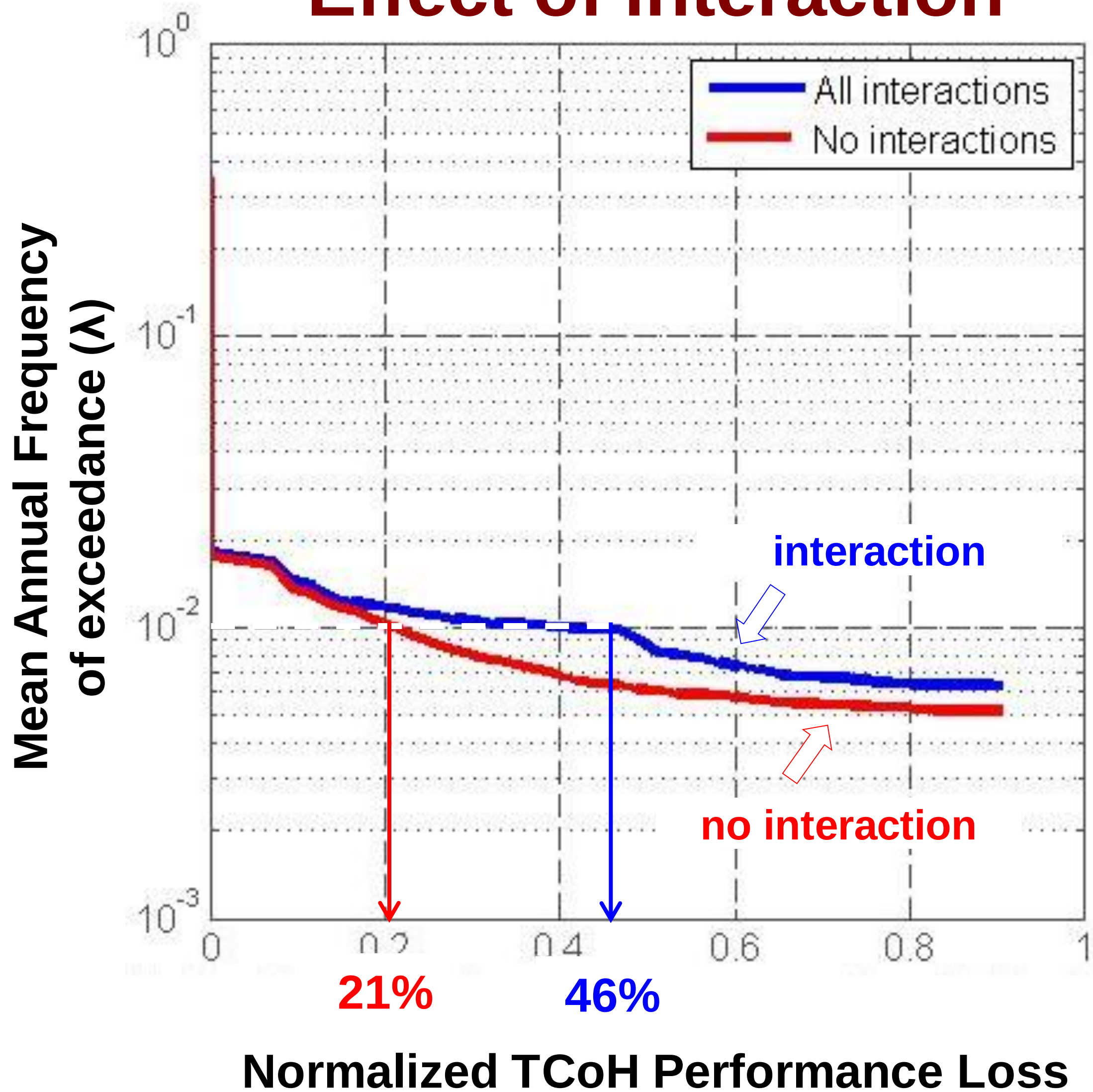
Correlation of damaged cranes to port functionality (cargo handled)

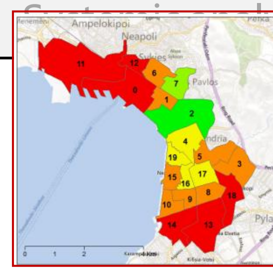


Correlation of not-functional distr. substations to port functionality (cargo handled)



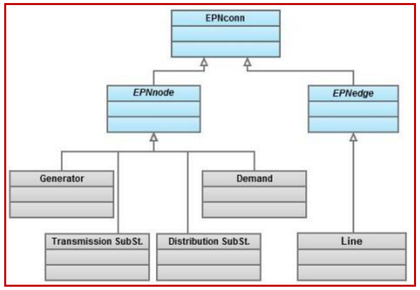
Effect of interaction



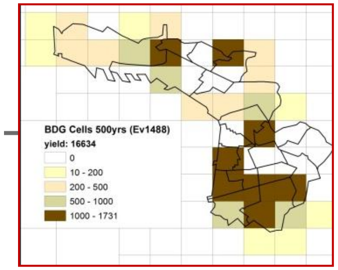


Decision Support

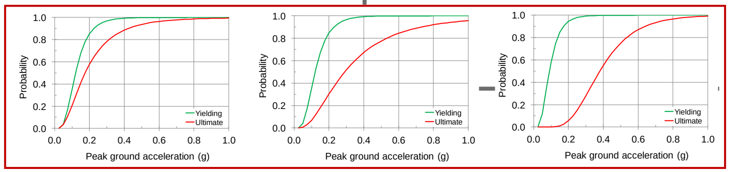
Systemic Analysis

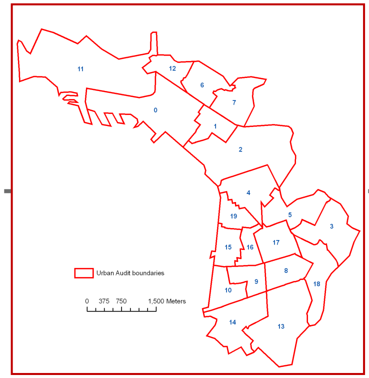


Damage & Loss Prediction



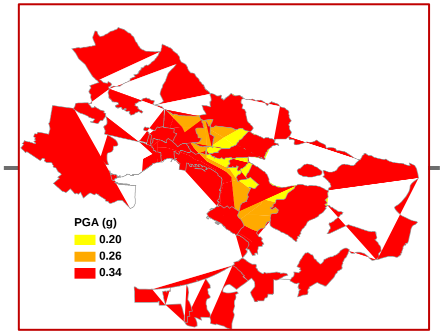
Fragility Models





Inventory Selection

Hazard Definition & Seismic Intensity Measures (IM)

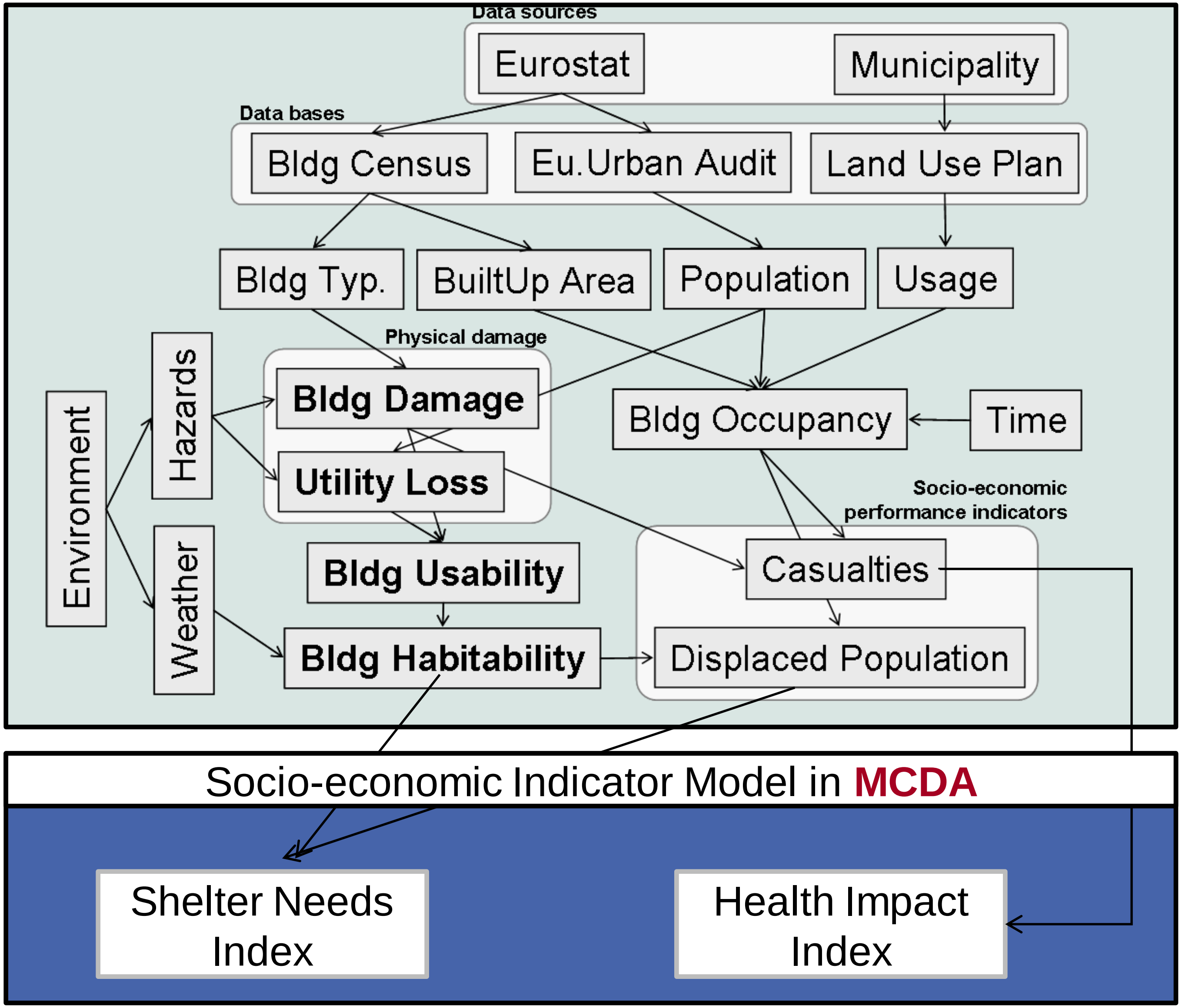


SDGEE

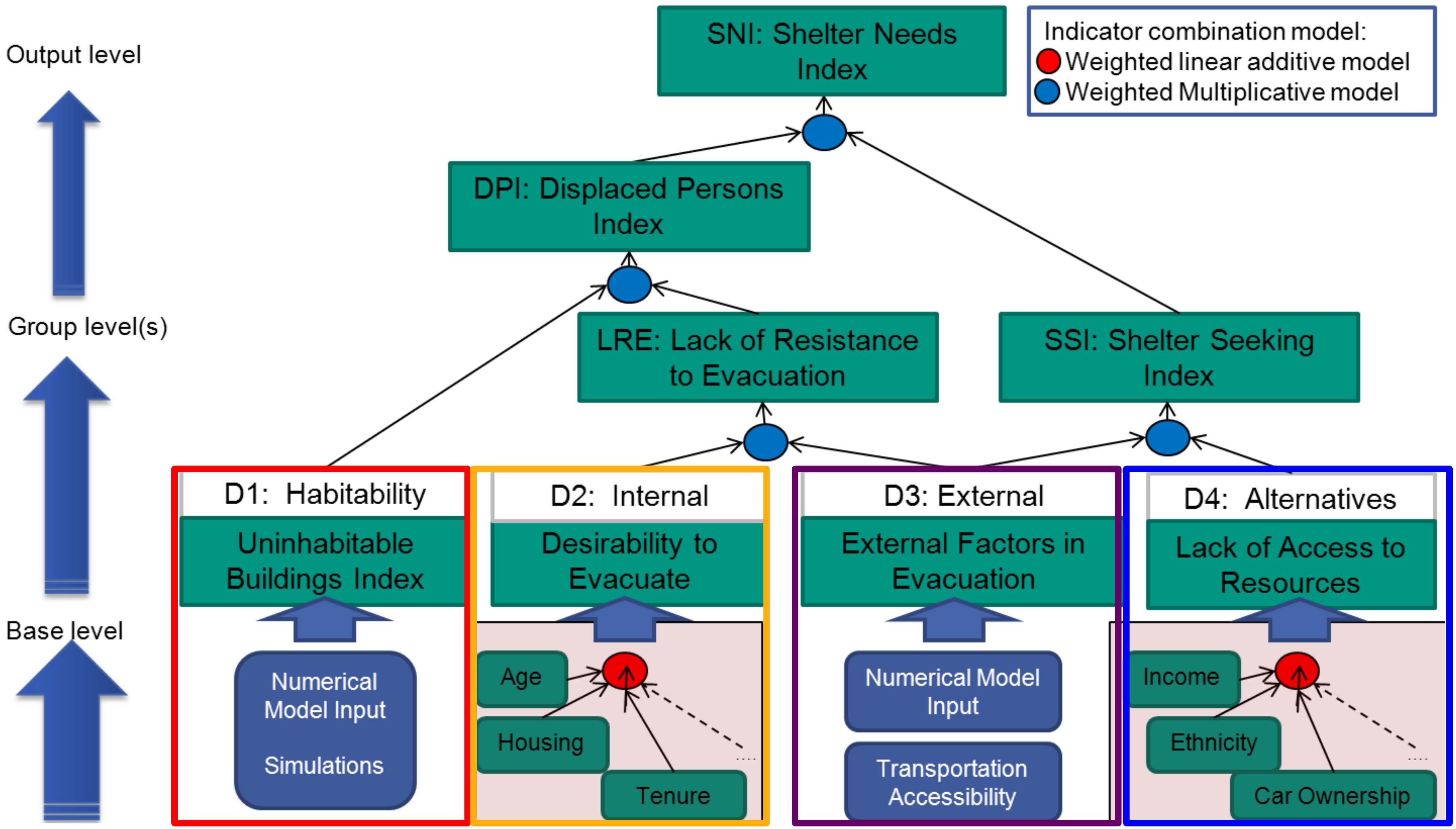
Physical and Social Model Interactions in SYNER-G

Level 1
Direct losses

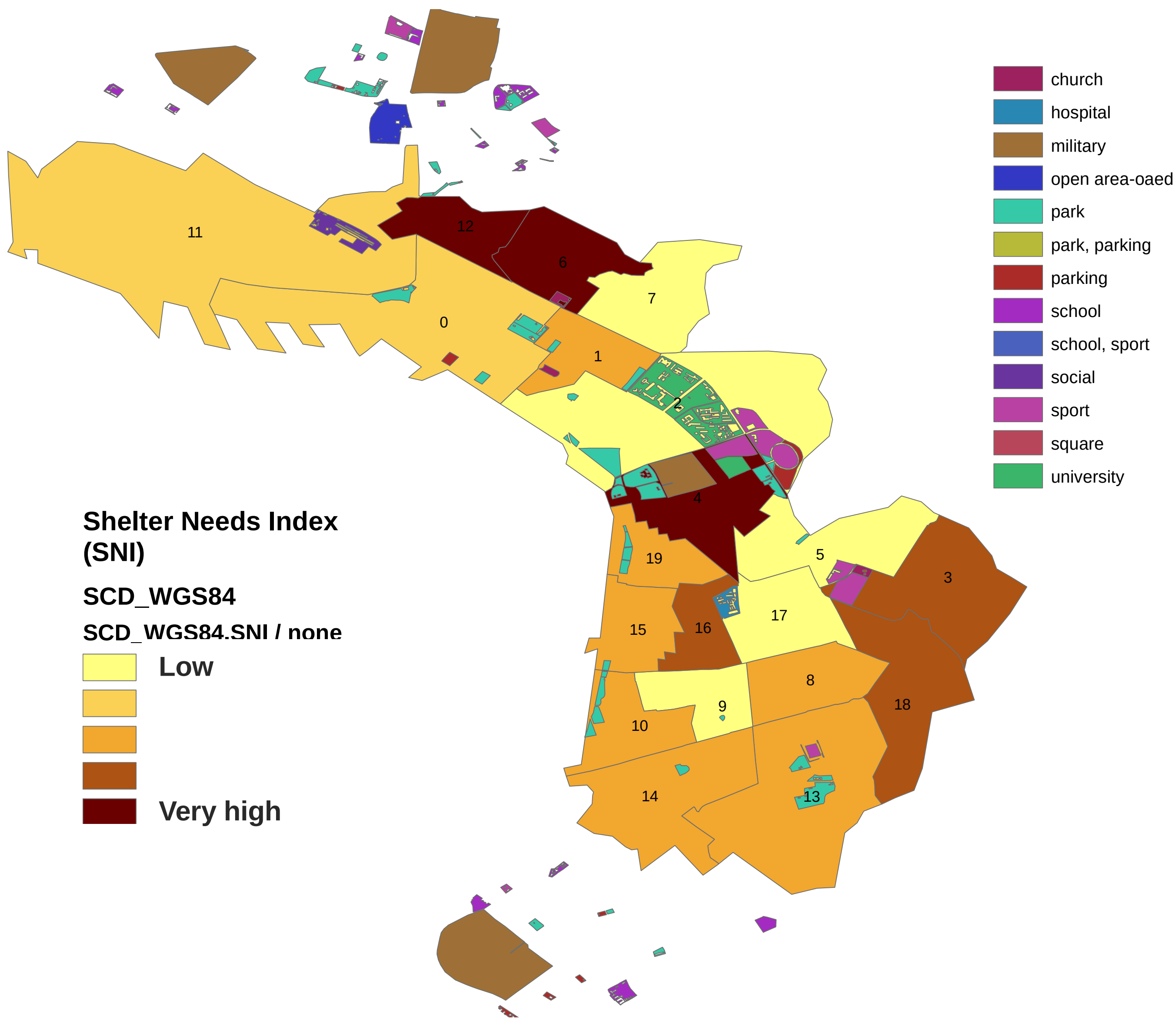
Level 2
Indirect losses



Framework for Obtaining Shelter Needs Index

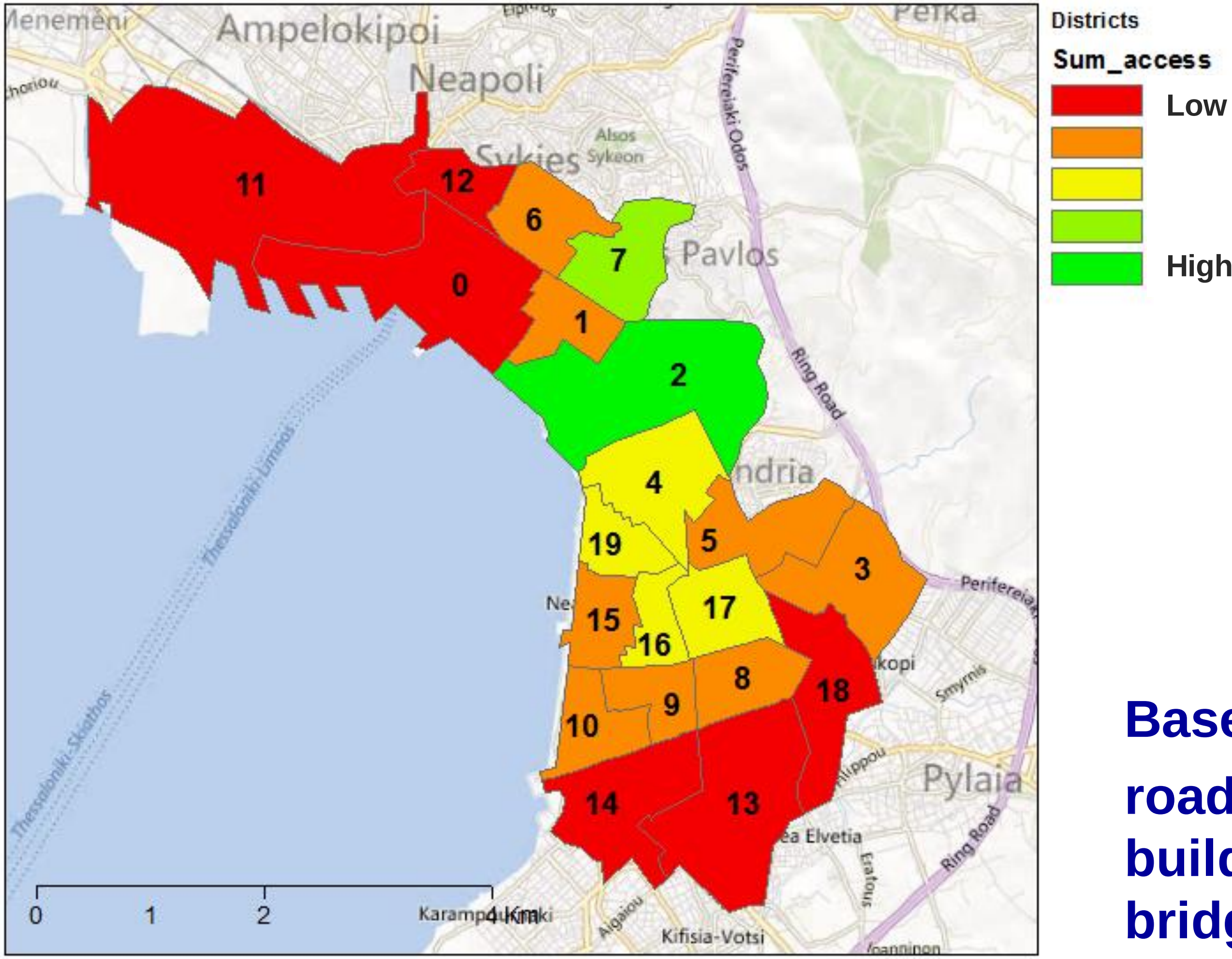


Shelter needs



SDGEE

Accessibility to hospitals

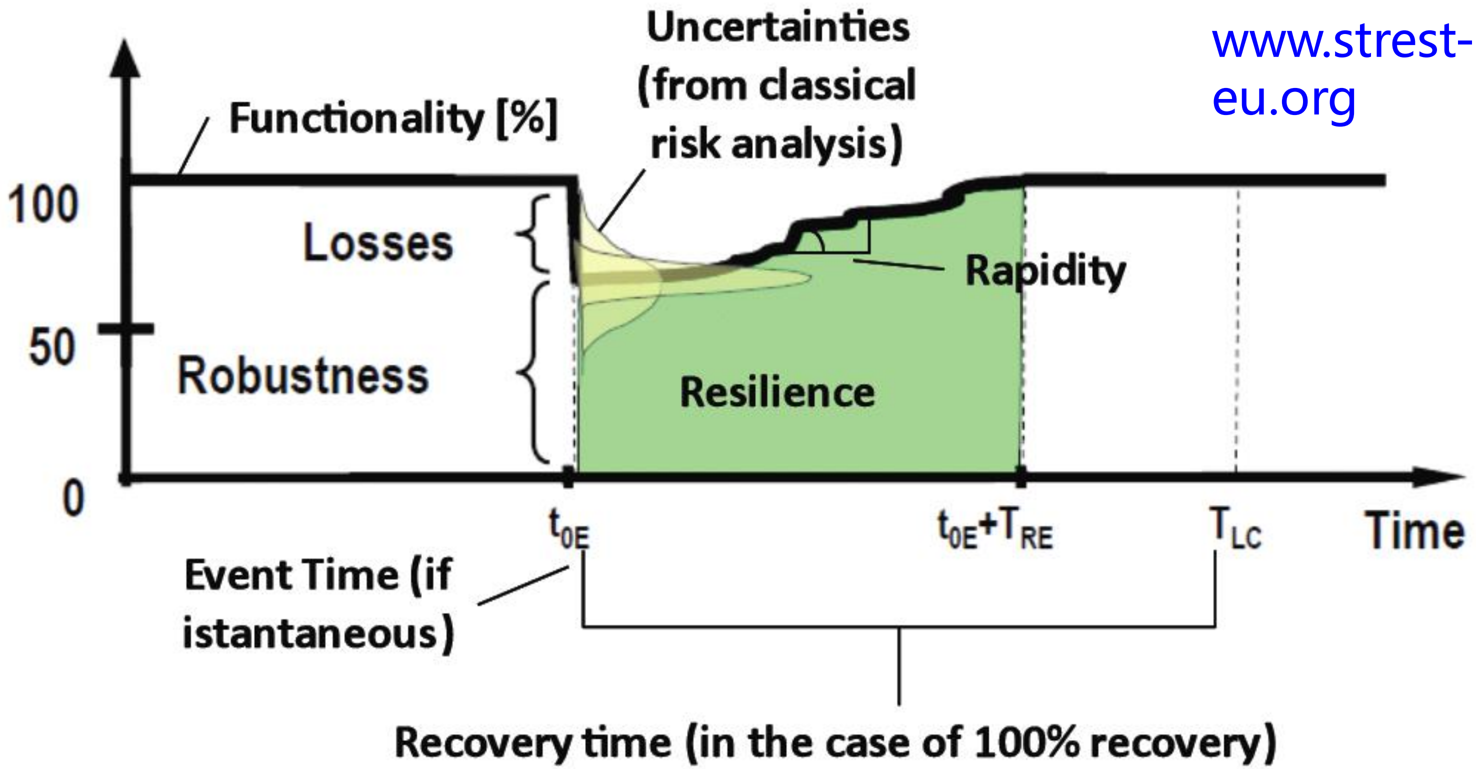


Based on:

road blockages due to building collapses and bridge/road damages

Resilience

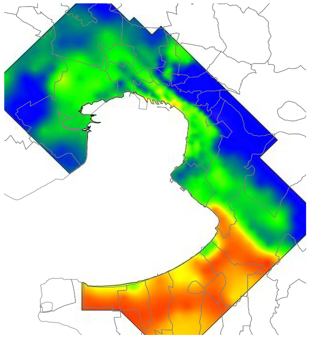
www.strest-eu.org



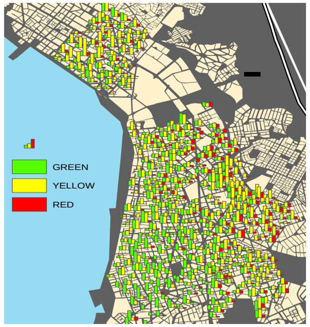
Resilience referring to a system subjected to natural and/or manmade hazards usually goes towards its capability to recover its functionality after the occurrence of a disruptive event. It is affected by attributes of the system, namely: robustness (residual functionality right after the disruptive event), rapidity (recovery rate), resourcefulness and redundancy (Bruneau et al. 2003)

Before the earthquake

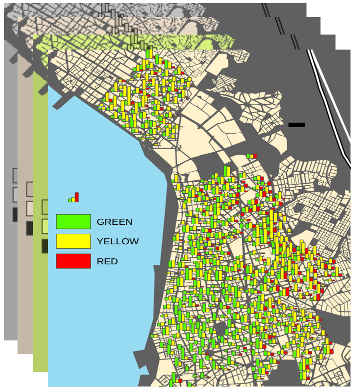
1. Time dependent seismic hazard assessment for a given site



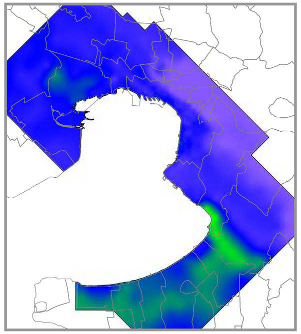
2. Time dependent vulnerability assessment of buildings and infrastructures

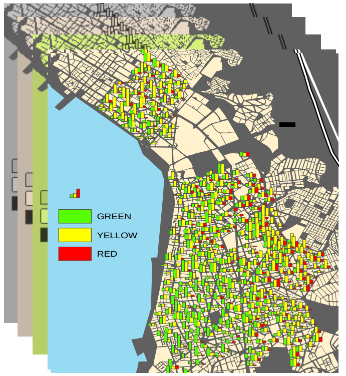


3. Develop and store multiple seismic risk scenarios (different seismic sources)



During the earthquake (Earthquake Early Warning – EEW)





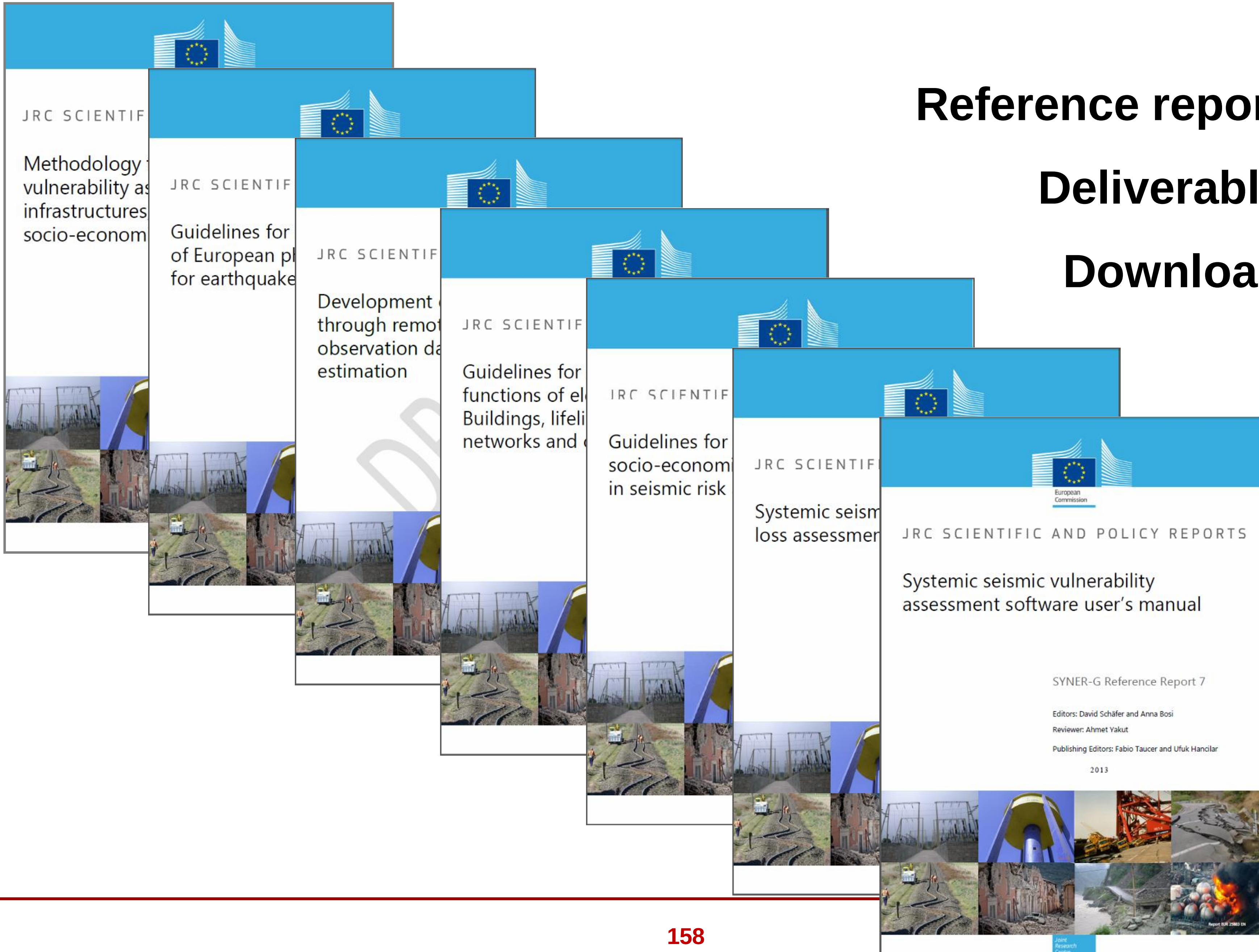
1. Selection of the "matching" seismic scenario based on the real time estimation of the earthquake Magnitude and Epicenter

2. Retrieve in "real time" the stored maps with estimated damages and losses to support the crisis management

Real Time Assessment

3. Real time measurements (e.g. gas system, railways, elevators, chemical industries, nuclear power facilities, hospitals)

SYNER-G web portal http://www.syner-g.eu

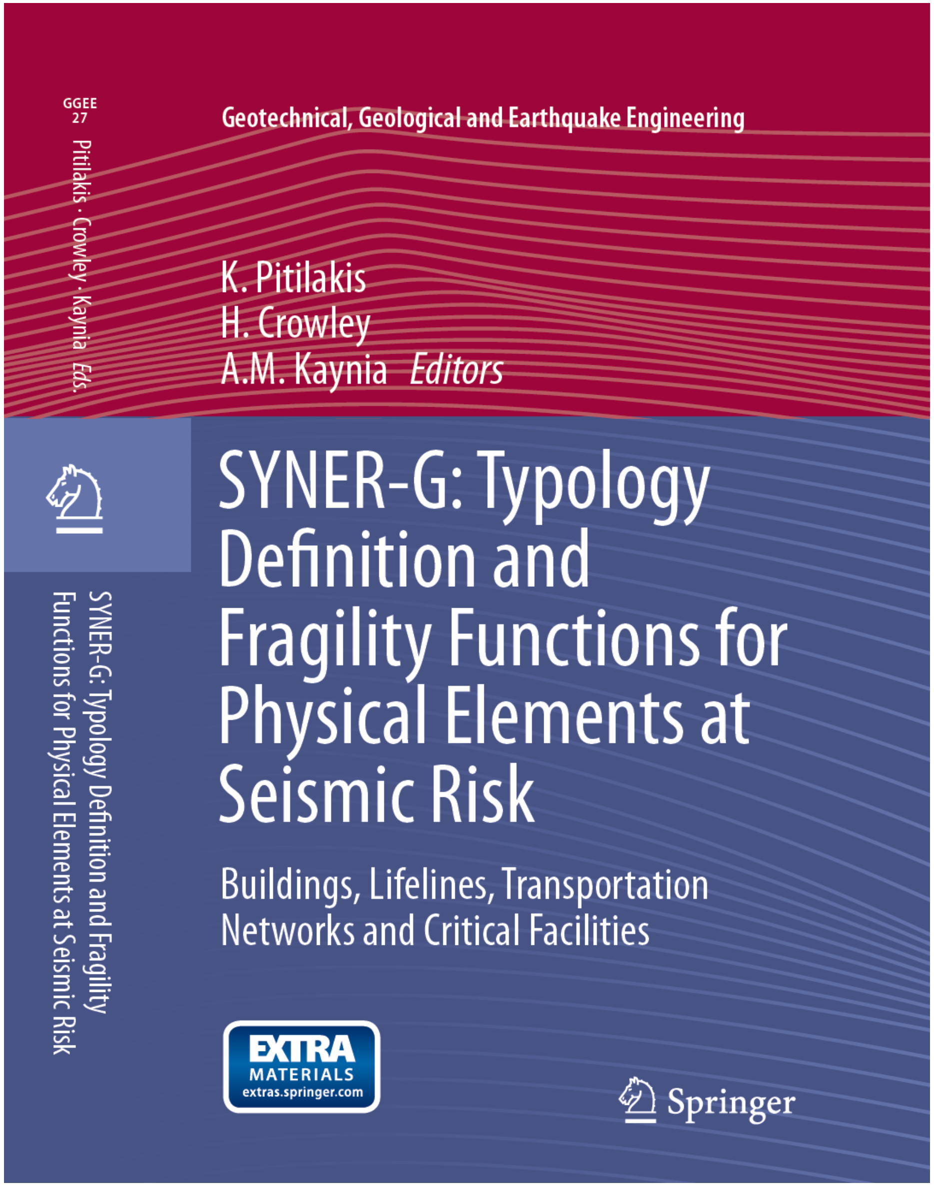


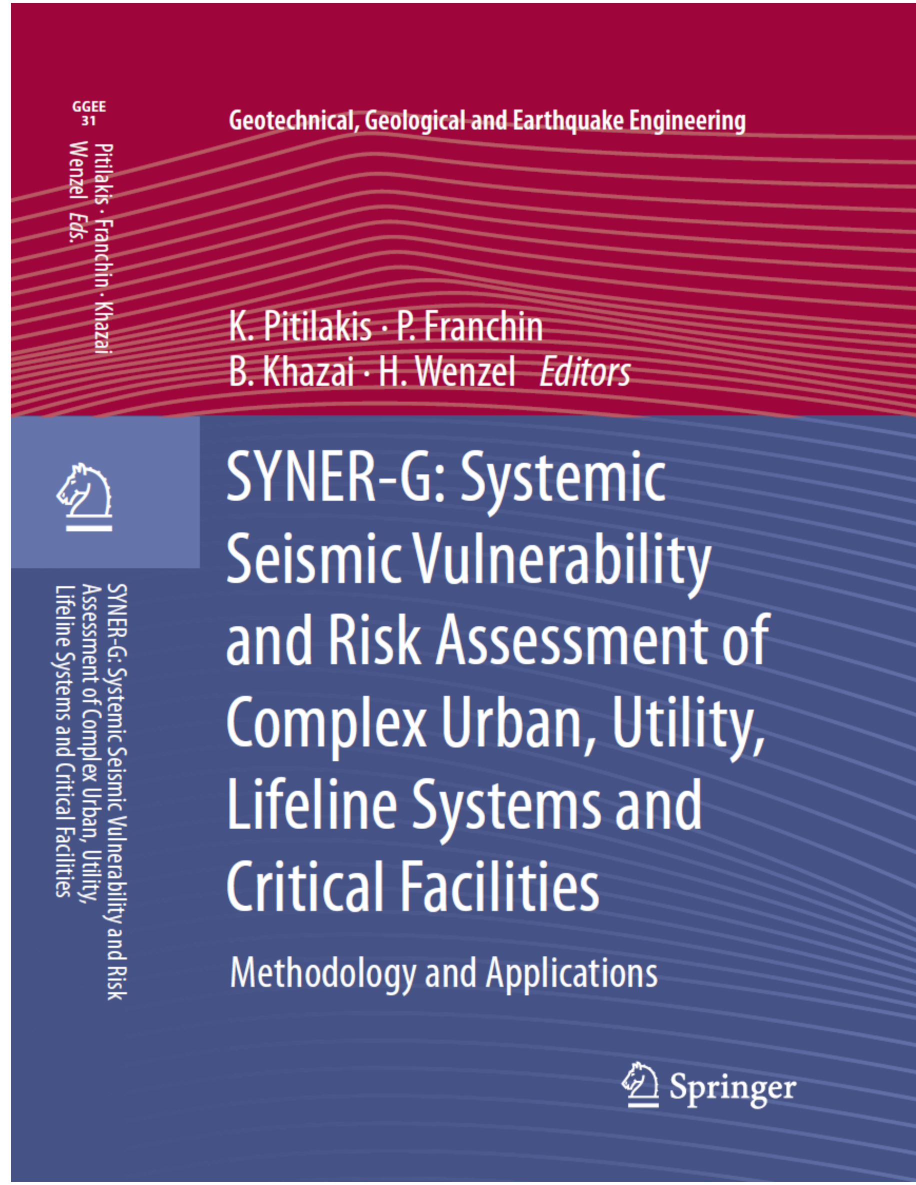
Reference reports

Deliverables

Downloads

SYNER-G Books





Thank you

谢谢

謝謝

Ευχαριστώ