Experience on the field of seismic hazard zonation – SHARE Project

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The 2013 European Seismic Hazard Map

BUILDING CAPACITIES FOR ELABORATION OF NDPs AND NAs OF THE EUROCODES IN THE BALKAN REGION
4-5 November 2014, Skopje
The 2013 European Seismic Hazard Map is not an European Seismic Zonation

- Seismic Zones have to be defined at the country level by: legislators, engineers, practitioners
- National Annexes
- Zonation is country specific
Outline

• Overview of the SHARE Project

• The new European Seismic Hazard Model (the 2013 ESHM) elements:
  • Datasets
  • Seismic sources
  • Ground Motion
  • Output

• The 2013 ESH feedback to EC8
SHARE Project: Overview
European Seismic Hazard Models – The Evolution

GSHAP [1996]

SESAME

SHARE [2013]

BUILDING CAPACITIES FOR ELABORATION OF NDPs AND NAs OF THE EUROCODES IN THE BALKAN REGION

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SHARE Project: 2009 to 2013

- Collaborative Effort
- Harmonize hazard assessment across national borders
- On data level, modelling level and procedural level
- Create a community-based time-independent (rock) reference hazard model for the Euro-Mediterranean region
- Keep close connection to engineering requirements of *EC8* and its future revision
Engineering Requirements

- **Seismic Hazard Maps for six mean return periods:**
  - 50 – 100 – 475 – 975 – 2475 – 5000
- **Hazard curves and Uniform Hazard Spectra**
- **Disaggregation**
- **Mean, Median and Quantile**
  - (5%, 15%, 85%, 95%)
Collaborative Framework
Regional Integration and Cooperation

• Regional Harmonization and Integration:
  • Earthquake Hazard Model for Middle East - EMME
  • Earthquake Hazard Model for Central Asia – EMCA
Transparency

- All steps of the seismic hazard assessment have to be:
  - Validated
  - Benchmarked
  - Reproducible

“Easy Review” Box
- Assumptions
- Data
- Interpretations

“Black Box”
- INPUT
  - Hazard Software
- OUTPUT
European Facility for Earthquake Hazard and Risk:
www.efeehr.org

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Target

PoEs in 50Yrs vs PGA(g)

- 475y
- 5000y
- 1Milion y
Stability

1. Provide assurance that the numerical hazard results will be stable for the next years (5-10 years)
2. Unless significant new seismic information, which could occur at any time, calls for a major revision
The 2013 - European Seismic Hazard Model - ESHM13: Datasets
Datasets Harmonization

Map of Major Tectonic features

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Datasets Harmonization

Homogeneous Earthquake Catalogue

Stucchi et al., 2012
Grünthal et al., 2012
Datasets Harmonization

Map of Seismogenic Faults

SHARE task 3.2
The European Database of Seismogenic Faults

Sfault top trace
depth (km)

SHARE

Composite Seismogenic Source
Subduction

fault depth plane

Basili et al (2013)

Datasets Harmonization

Map of Seismogenic Faults

SHARE task 3.2
The European Database of Seismogenic Faults

Composite Seismogenic Source
Subduction

fault depth plane

Basili et al (2013)
Datasets Harmonization

Map of Seismogenic Faults In Balkans

More than 68,000 kilometers representing about 1200 mapped active faults were compiled in the new European Database of Seismogenic Faults.

Basili et al (2013)
Datasets Harmonization

A) AS-model: Smallest $M_{\text{max}}$

B) AS-model: Largest $M_{\text{max}}$

C) SEIFA-model $M_{\text{max}}$

D) Fault Sources: $M_{\text{max}}$

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Maximum Magnitude
Datasets Harmonization

Design of superzones [geometry and type]

SCR

Non-extend. crust

Extend. crust

Active regions

Minimum Mobs = 6.5

Oc. crust
Mid-At. Ridge
Azor-Gibr.

Largest Mobs value for all the superzones

Mmax distribution anchored to the largest Mobs

Mmax model

Weights

6.0
6.2
6.4
6.6

6.5
6.7
6.9
7.1

Mobs
Mobs + 0.2
Mobs + 0.4
Mobs + 0.6

Mobs

Mobs + 0.3

Maximum Magnitude
Datasets Harmonization

Mw-Rrup scatters of ground motions in terms of EC8 site categories

- EC8-A records display a gap between 5.0<Mw<6.0.
- Mw-Rrup scatters of EC8-B and EC8-C records have similar distributions for 3.5<Mw<8.0 and Rrup>10 km
- EC8-D records are loosely distributed between 10 km<Rrup<200 km with a shift towards larger distances for large magnitude records.
ESHM13: Main Elements
Elements of Probabilistic Seismic Hazard

- *Earthquake Rate Forecasts:*
  - Area Source
  - Fault Source
  - Smoothed Seismicity

- *Ground Motion Models*
  - Expert Elicitation
  - Data Driven
Uncertainties: Logic Tree

ESHM13

- As Model
- Fs Model
- SEIFA Model

Active
- Akkar & Bommer (2010)
- Cauzzi & Faccioli (2008)
- Zhao et al. (2006)
- Chiou & Youngs (2008)

Stable
- Akkar & Bommer (2010)
- Cauzzi & Faccioli (2008)
- Chiou & Youngs (2008)

Shield

Subduction
- Interface
- Young et al 1997

Inslab
- Young et al 1997
- Lin and Lee (2008)
- Atkinson and Boore (2003)

Volcanic
- Faccoli et al (2010)

VRANCEA
- Young et al 1997
- Lin and Lee (2008)
Elements of Probabilistic Seismic Hazard

• *Earthquake Rupture Forecasts:*
  • Area Source
  • Fault Source
  • Smoothed Seismicity

[Diagram showing various seismic elements including Earthquake Rupture Forecasts, Area Source, Fault Source, and Smoothed Seismicity.]
Area Source Assumptions

- Sources depict zones of equal seismic activity that is distributed homogeneously within the zone
- Delineation can be based on
  - Large scale tectonics
  - Geology
  - Geomorphology
  - Seismicity
  - Combinations
- Critical points:
  - Zonation is generally based on expert opinion
  - Polygons usually are not characterized with an uncertainty
Area Source Model

B) Annual a-value (a(Mw=0))

C) b-value
Earthquake Rates Estimation

- Maximum Likelihood Estimate (Aki, 1965)
- Extension to time-varying completeness (Weichert, 1980, Kijko, 2012)
- Penalized Maximum Likelihood (PML) method (Johnstons, 1994; Coppersmith, 2011)
- Bayesian procedure
- Prior for b-value needed
- Considers completeness-time history
- Treat sparse data
- Developed and used in CEUS for NPPs
Activity Rates – Uncertainty Range

- **Uncertainty sources:**
- Spare earthquake data
- Completeness assessment
- **Statistics:**
- Entire catalog: more than 30000 events
- De-clustered catalog: 13919 events
- De-clustered and complete catalog: > 8600
- 45% (or 196) of areal zones with N≤10 events
Faults + Background Sources

- **Background zone:**
- *Includes an entire fault network or system*
- *Within one zone, all fault sources are completely identified!*
- *Polygons cannot cut across a fault*
- *Seismicity is generated by the mapped faults*
- *Entire accumulated moment is released seismically!*
Earthquake Rates from Geologic Info

- **Key parameters**
  - Slip rate
  - Fault source length and aspect ratio
  - Maximum magnitude

- **Assumption that fault slips entirely seismically**

\[
N(M) = \left( \frac{d}{b} \right) \left( \frac{S}{b} \right) \left[ e^{b(M_{\text{max}} - M - 1)} E^{\left((d/2)M_{\text{max}}\right)} \right]
\]

Anderson & Luco, 1983; Bungum, 2007
Faults Source Model: Uncertainty Range

ITBG068, 8 faults

Max. slip rate
Min. slip rate
Cum. FMD
Inc. FMD
Single Fault

$M_W \geq 6.5$ events locate on faults

$M_W < 6.5$ locate in background zone

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SEIFA Model

A smoothed stochastic earthquake rate forecast model considering SEIsmicity and FAult moment release for Europe

Assumptions:

1) the frequency-magnitude distribution of past earthquakes is the best estimate of the future activity

2) future earthquakes occur in the vicinity of past earthquakes,

3) larger earthquakes occur more likely on mapped faults, and more likely on fast slipping than on slow slipping faults.
(a) Annual cumulative rate forecast

Magnitude >= 4.5

(b) Annual incremental rates

Hiemer et al., 2014, GJI
Hiemer et al., 2013, BSSA (Application to California)
Subduction and Vrancea

a) Smallest maximum magnitude

b) Largest maximum magnitude
Elements of Probabilistic Seismic Hazard

- **Ground Motion Models**
- **Expert Elicitation**
- **Data Driven**
Ground Motion Models Selection

Selection of candidate GMPEs
- Identification of worldwide GMPEs
- Application of the exclusion criteria of Cotton et al. (2006)
- Review of the GMPEs applicability range
- Adjustment for parameter compatibility
- Evaluation of the GMPEs using the criteria of Bommer et al. (2010)

Expert judgment
- Logic trees from 6 experts

Testing using data
- Rankings of GMPEs based on Scherbaum et al. (2009)

Proposition of logic trees: WP4 consensus
- Selection of the final GMPEs
- Proposition of different sets of weights

Sensitivity analysis of the proposed weights on the seismic hazard

Final logic tree

Active shallow crustal regions
Ranking based on PSA at 5 periods (0.1s, 0.2s, 0.5s, 1s, 2s)
For all magnitudes and distances ~ 6911 observations

<table>
<thead>
<tr>
<th>rank</th>
<th>LLH</th>
<th>weight</th>
<th>ratio(*)</th>
<th>name</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>2.378</td>
<td>0.120</td>
<td>1.00</td>
<td>Bindi et al. (2009)</td>
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<tr>
<td>2</td>
<td>2.396</td>
<td>0.119</td>
<td>1.01</td>
<td>Cauzzi and Facioli (2008)</td>
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<tr>
<td>3</td>
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<td>0.116</td>
<td>1.03</td>
<td>Cotton et al. (2008)</td>
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<tr>
<td>4</td>
<td>2.588</td>
<td>0.104</td>
<td>1.16</td>
<td>Akkar and Bommer (2010)</td>
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<tr>
<td>5</td>
<td>2.680</td>
<td>0.097</td>
<td>1.23</td>
<td>Douglas et al. (2006)</td>
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<tr>
<td>6</td>
<td>2.800</td>
<td>0.090</td>
<td>1.34</td>
<td>Zhao et al. (2006)</td>
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<tr>
<td>7</td>
<td>2.938</td>
<td>0.082</td>
<td>1.47</td>
<td>Chiou and Youngs (2008)</td>
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<tr>
<td>8</td>
<td>3.158</td>
<td>0.070</td>
<td>1.72</td>
<td>Ambraseys et al. (2005)</td>
</tr>
<tr>
<td>9</td>
<td>3.271</td>
<td>0.065</td>
<td>1.86</td>
<td>Danciu and Tselenitis (2007)</td>
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<tr>
<td>10</td>
<td>3.869</td>
<td>0.043</td>
<td>2.81</td>
<td>Abrahamson and Silva (2008)</td>
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<tr>
<td>11</td>
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<td>0.036</td>
<td>3.30</td>
<td>Boone and Atkinson (2008)</td>
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<tr>
<td>12</td>
<td>4.785</td>
<td>0.023</td>
<td>5.30</td>
<td>Campbell and Bozorgnia (2008)</td>
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<tr>
<td>13</td>
<td>4.921</td>
<td>0.021</td>
<td>5.80</td>
<td>Kalkan and Gulkan (2004)</td>
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<tr>
<td>14</td>
<td>5.332</td>
<td>0.016</td>
<td>7.70</td>
<td>Massa et al. (2008)</td>
</tr>
</tbody>
</table>

(*) ratio between the larger weight and the weight of each model.
Ground Motion Models

BUILDING CAPACITIES FOR ELABORATION OF NDPs AND NAs OF THE EUROCODES IN THE BALKAN REGION

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GMPEs comparison

Rjb = 10.0, Dip = 90.0 (strike-slip), Rake = 0.0

GMPEs
- AkkarBommer2010 - Median
- CauzziFaccioli2008 - Median
- ChiouYoungs2008 - Median
- ZhaoEtAl2006Asc - Median
ESHM13: OUTPUT
Reference PGA map, RP=475Yrs, Vs30 =800m/s
Quantiles PGA Maps RP 475yrs

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Hazard Curves
Uniform Hazard Spectra

L'Aquila, Lon=13.38, Lat=42.3
Rhodes, Lon=27.98, Lat=36.2
Cologne, Lon=6.88, Lat=50.9
Lisbon, Lon=-9.22, Lat=38.7

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Disaggregation (ongoing)
ESHM13 to Eurocode 8
Defining The Ec 8 Spectrum


\[ S_a(T) = \text{constant acceleration} \]

\[ S_a(T) \propto 1/T \text{ (constant velocity)} \]

\[ S_a(T) \propto 1/T^2 \text{ (constant displacement)} \]

\[ S_d(T) = \text{constant displacement} \]

\[ S_d(T) \propto T \text{ (constant velocity)} \]

\[
0 \leq T \leq T_B: S_e(T) = a_g \cdot S \cdot \left[ 1 + \frac{T}{T_B} \cdot (\eta \cdot F_0 - 1) \right], \quad T_B \leq T \leq T_C: S_e(T) = a_g \cdot S \cdot \eta \cdot F_0 \]

\[
T_C \leq T \leq T_D: S_e(T) = a_g \cdot S \cdot \eta \cdot F_0 \cdot \left[ \frac{T_C}{T} \right], \quad T_D \leq T \leq 4.0 \text{ s}: S_e(T) = a_g \cdot S \cdot \eta \cdot F_0 \cdot \left[ \frac{T_C T_D}{T^2} \right] \]
Regional Variation in Spectral Shape

Amplification Factor $F_0$
(Current EC8 = 2.5)
Regional Variation in Spectral Shape

Constant Acceleration Corner Period ($T_B$)
(Current EC8: 0.15s – Type 1, 0.05 – Type 2)
Regional Variation in Spectral Shape

Constant Velocity Corner Period ($T_C$) (Current EC8 = 0.4 s – Type 1 0.25 – Type 2)
Regional Variation in Spectral Shape

Constant Displacement Corner Period ($T_D$)
(Currently EC8: 2.0 s – Type 1, 1.2 s – Type 2)
SHARE Design Spectra – General Trends

$S_a(T) = \text{constant acceleration}$

General narrowing of constant acceleration part of the spectrum

$S_a(T) \propto 1/T$ (constant velocity)

$S_a(T) \propto 1/T^2$

(constant displacement)

Slight flattening of spectrum (reduction in $F_0$) in more active regions

$T_D$ shifting toward longer periods

$F_0$

$S_a$

$T_s$

$T_B$, $T_C$, $T_D$, $T (s)$
“k-value”: Usage and Implications

“At most sites the annual rate of exceedance, $H(a_{gR})$, of the reference peak ground acceleration $a_{gR}$ may be taken to vary with $a_{gR}$ as:

$$H(a_{gR}) \sim k_0 a_{gR}^{-k},$$

with the value of the exponent $k$ depending on seismicity, but being generally of the order of 3”

• Allows for scaling to different performance levels and adjustment of the importance factor

• Why 3?

• Over what return periods is this approximation valid?
“$k$-value”: Usage and Implications

Hazard Curve for Bergen (5.3821, 60.4000)

Hazard Curve for Bucharest (26.1821, 44.5000)

Hazard Curve for Rhodes (28.1821, 36.4000)

Hazard Curve for Thessaloniki (22.8821, 40.6000)

BUILDING CAPACITIES FOR ELABORATION OF NDPs AND NAs OF THE EUROCODES IN THE BALKAN REGION

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$k$-value Across Europe

$K$-value fit to Peak Ground Acceleration (PGA)

$K$-value fit to 1-second Spectral Acceleration
Summary

- **SHARE Project** successfully delivered a pan-European Model
- **Compilation of harmonized databases** of all parameters required for PSHA
- Adoption of **rigorous, standardized** procedures in all steps of the process
- **Full accounting** of epistemic uncertainties for model components and hazard results
- **Full transparency and open availability** of all data, results, and methods
- **Multidisciplinary approach**, relying on input from all branches of earthquake science and engineering
- Ensured the definition of **proper output specifications** relevant for Eurocode 8
ESHM13 – Pathway to Eurocodes

- Improvement and Acceptance of ESHM13
  - Investigation of factors causing differences between ESHM13 and existing models

- Updates and improvements at local level – further contribution from local scientists

- Revision and Version Control

- Application in local/regional risk studies
  - Comparison with losses from previous models
Availability

European Facility for Earthquake Hazard and Risk:
www.efeehr.org

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Thank you!