Prototyping Korean PSHA Model

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OYORMS Corporation
2016 Gyeongju Earthquake (M5.8, Mw5.4)

Main Shock  M5.8  2016/09/12 20:32

Foreshock  M5.1  2016/09/12 19:44

KTX was brought to an emergency stop

The production lines of Samsung and LG were stopped temporarily

Urban Railway stopped several minutes

LNG combined power plant stopped

by KMA & Yonhap News
Background and Outline of the Study

- After the Gyeongju Earthquake, we tried collecting information to understand how much is the seismic risk in the Korean Peninsula.
- We tried developing PSHA model of Korea based on the collected data.
- The model consists of three components:
  - **Seismic Source Model**: Crustal background earthquake model & Active fault model.
  - **Seismic Propagation Model**: GMPEs.
  - **Subsurface Amplification Model**: Subsurface ground model & Amplification equation.
- Introduce Results: PSHA Map and Response Spectra.
- Challenges for the future.
Procedure of PSHA Modeling in this Study

- Tectonics Data
- Observed EQ Catalog
- Historical EQ Catalog
- Active Fault Data
- Topographic Data

- Tectonic Zone
- Major Event List
- G-R Law
- Background EQ Model
- Strain Rate Stress Field
- Fault Model
- GMPEs
- Vs30 Model (USGS)
- Amp. Equation

- Data & Information
- Analysis & Modeling

- Source Model
- GMPE Model
- Subsurface Ground Model
- PSHA Model
### Earthquake Catalogs

<table>
<thead>
<tr>
<th>Type</th>
<th>Author</th>
<th>Year</th>
<th>Title</th>
<th>Reference/Organization</th>
<th>Time Span</th>
<th># of EQs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Historical</td>
<td>Wada, Y.</td>
<td>1912</td>
<td>A survey of Korean ancient and recent earthquakes, Report of the study of Korean ancient observations</td>
<td>Meteorological Observatory of the Government General of Korea</td>
<td></td>
<td>1,644</td>
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<tr>
<td>Historical</td>
<td>Lee et al.</td>
<td>1982</td>
<td>Seismic risk map of Korea</td>
<td>KAERI*3/RR-380/82</td>
<td>27 A.D. - 1833</td>
<td>309</td>
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<tr>
<td>Historical</td>
<td>Lee*1 et al.</td>
<td>1999</td>
<td>Evaluation and Cataloging of Korean Historical Earthquakes</td>
<td>KINS*4/HR-261</td>
<td>2 A.D. - 1904</td>
<td>1,965</td>
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<tr>
<td>Historical</td>
<td>Lee*1 and Yang</td>
<td>2006</td>
<td>Historical Seismicity of Korea</td>
<td>Bulletin of the Seismological Society of America (BSSA)</td>
<td>2 A.D. - 1904</td>
<td>2,186</td>
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<tr>
<td>Historical</td>
<td>Hahm et al.</td>
<td>2014</td>
<td>Historical Earthquake Records in Korea</td>
<td>Korean Meteorological Archives*5</td>
<td>2 A.D. - 1888</td>
<td>2,123</td>
</tr>
<tr>
<td>Observed</td>
<td>Jun<em>2 and Jeon</em>2</td>
<td>2001</td>
<td>Early Instrumental Earthquake Data (1905-1942) in Korea</td>
<td>Economic and Environmental Geology</td>
<td>1905-1942</td>
<td>533</td>
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<td>Observed</td>
<td>-</td>
<td>2016</td>
<td>Observed Earthquake Catalog</td>
<td>National Earthquake Comprehensive Information System (NECIS)</td>
<td>1978 - 2016</td>
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</table>

*1 Seoul National University  
*2 Korea Institute of Geoscience and Mineral Resources (KIGAM)  
*3 Korea Advanced Energy Research Institute  
*4 Korea Institute of Nuclear Safety  
*5 Korea Meteorological Administration
### Major Historical Earthquakes in the Korean Peninsula

<table>
<thead>
<tr>
<th>No.</th>
<th>Year</th>
<th>Lon</th>
<th>Lat</th>
<th>KIER 1982 MMI</th>
<th>Lee &amp; Yang 2006 MMI</th>
<th>M</th>
<th>Seo 2010 M &gt;=5.0</th>
<th>Chu, Baag &amp; Tsuji 2005 M</th>
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<td>IX</td>
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<td>VIII-IX</td>
<td>6.7</td>
<td>≧ 6.2</td>
<td>6.5</td>
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<td>VIII</td>
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<td>VIII</td>
<td>VIII-IX</td>
<td>6.7</td>
<td>≧ 6.0</td>
<td>6.5</td>
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<td>VIII</td>
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<td>36.6</td>
<td>VI</td>
<td>VIII</td>
<td>6.4</td>
<td>(4.0-4.5)</td>
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<td>VIII</td>
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<td>Gyeongsang-do</td>
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<td>&gt;6.5</td>
<td>7.5</td>
<td>Gangwon-do</td>
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<td>6.7</td>
<td>&gt;6.5</td>
<td>6.5</td>
<td>Hamgyong-do</td>
</tr>
</tbody>
</table>

**Reference**

Epicenter Map in and around the Korean Peninsula

Major Historical EQ (27 A.D.-1833)

- 1681 M6.5<
  - Largest Earthquake

Observed EQ (1978 – 2016)

- 2016/9/12 20:32
  - M5.8
Gutenberg-Richter Law

\[ y = -0.98x + 6.63 \]

\[ y = -0.87x + 3.58 \]

\[ y = -0.72x + 1.50 \]

\[ y = -0.53x + 0.76 \]

\[ y = -0.65x + 1.26 \]
Major tectonic features and stratigraphy of the Korean Peninsula

Maps showing tectonic divisions and Mesozoic igneous rocks of the Korean Peninsula

After Paek et al. (1996) and KIGAM (1995)

1) Kwon et al. (2009): Evidence for Perm–Triassic collision in Far East Asia: The Korean coalitional orogen
2) USGS (2010): Porphyry Copper Assessment of East and Southeast Asia—Philippines, Taiwan, Republic of Korea, and Japan
3) Chough (2013): Geology and Sedimentology of the Korean Peninsula
## Tectonic Zone for Background Earthquake Model

### Tectonic Zoning of the Korean Peninsula

<table>
<thead>
<tr>
<th>Tectonic Unit</th>
<th>Tectonic Province</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dumangang Fold Zone</td>
<td>1 Dumangang Fold Zone</td>
</tr>
<tr>
<td>Hambug Massif</td>
<td>2 Hambug Massif</td>
</tr>
<tr>
<td>Macheongryeong Massif</td>
<td>3-a Peaktusan Volcanic Zone</td>
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<tr>
<td></td>
<td>3-b Tanchon Fold Zone</td>
</tr>
<tr>
<td>Nangrim Massif</td>
<td>4 Chnjingang Fold Zone</td>
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<tr>
<td></td>
<td>5 Nangrim Massif</td>
</tr>
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<td></td>
<td>6 Sakju-Kusong Fold Zone</td>
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<tr>
<td>Pyeongan Basin</td>
<td>7-a Pyeongan Basin</td>
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<tr>
<td></td>
<td>7-b Haeju Zone</td>
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<tr>
<td></td>
<td>8 Rimjingang Rift Valley</td>
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<td>9 Yonbaek Zone</td>
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<td>Gyonggi Massif</td>
<td>10 Gyonggi Massif</td>
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<td>11 Chungnam Basin</td>
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<td>Ogcheon Basin</td>
<td>12 Samcheok Basin</td>
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<td>13 Ogcheon Fold Zone</td>
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<td>14 Youngdong - Gwangju Zone</td>
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<tr>
<td>Yeungnam Massif</td>
<td>15 Yeungnam Massif - Taebaegsan Area</td>
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<td>16 Sobaegsan Massif</td>
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<td>Gyeongsang Basin</td>
<td>17 Gyeongsang Basin</td>
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<tr>
<td></td>
<td>18 Pohang - Ulsan Tertiary Basin</td>
</tr>
<tr>
<td></td>
<td>0 Jeju Island</td>
</tr>
</tbody>
</table>

*Fundamental Analysis of Geological Structure for DPRK (2001), Metal Mining Agency of Japan*
\[ f_t = \frac{f_z + f_m}{2} = \frac{F_{z,obs}/N_z + F_{m,obs}}{P}/2 \]

- **\( f_t \): Annual frequency of background earthquakes for the mesh**
- **\( f_z \): Annual freq. of obs. Eqs for the zone**
- **\( f_m \): Annual freq. of obs. Eqs for the mesh**
- **\( F_{z,obs} \): Freq. of obs. Eqs* for the zone**
- **\( F_{m,obs} \): Freq. of obs. Eqs* for the mesh**
- **\( N_z \): Number of meshes in the zone**
- **\( P \): Observing period**

*Observed Data (M>=3.0)*

- 1978 – 2016: NECIS

1) **NECIS**: national earthquake comprehensive information system, http://necis.kma.go.kr/
Background Earthquake Model (b-value & $M_{\text{max}}$)

- **Pyeongan Basin**: $M_{\text{max}} = 6.4$
- **Japan Sea (East Sea)**: $M_{\text{max}} = 7.5$
- **Gyeonggi Massif - West**: $M_{\text{max}} = 6.0$
- **Gyeongsang Basin**: $M_{\text{max}} = 6.2$
- **Ogcheon Basin**: $M_{\text{max}} = 6.0$
- **Yeungnam Massif**: $M_{\text{max}} = 6.0$
- **Jeju Island**: $M_{\text{max}} = 6.0$
- **Tsushima Trough**: $M_{\text{max}} = 6.0$
Fault Data

Lineament Map of Korea

Choi and Sato (1997): Horizontal Strain of the Crust in Korea inferred from Geodetic Data

Active Fault Database

by KIGAM?
### Fault Model

#### Yansan Fault

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<td>Northern-Part</td>
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<td>0.03-0.05 (0.04)</td>
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<td>Southern-Part1</td>
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<td>7.0</td>
<td>0.02-0.07 (0.045)</td>
<td>83</td>
<td>0.0007703</td>
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<td>Southern-Part2</td>
<td>45</td>
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<td>0.02-0.07 (0.045)</td>
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<td>110</td>
<td>7.5</td>
<td>*</td>
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<td>S1 + S2</td>
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<td>155</td>
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#### Ulsan Fault

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<td>Ulsan bay</td>
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<td>0.03-0.22</td>
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<td>46</td>
<td>7.0</td>
<td>*</td>
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</table>

*1: Matsuda et al. (1975), $M_J = (\log L + 2.9)/0.6, M_w = 0.78M_J + 1.08$
*2: Stirling et al. (2002), $M_w = 4.743 + 1.375 \log L$
*3: HERP (2009), $\log R = \log (L/S) + 1.9$

1) Kyung (2003) : Paleoseismology of the Yansan Fault, southeastern part of the Korean Peninsula  
2) Inoue and Choi (2006): The Activity of the Ulsan Fault System Based on Marine Terrace Age Study at the Southeastern Part of Korean Peninsula
Ground Motion Prediction Equations (GMPEs)

**Atkinson and Boore (2006)** \(^1\)

\[
\log(PSA) = c_1 + c_2 M_w + c_3 M_w^2 + (c_4 + c_5 M_w) f_1 + (c_6 + c_7 M_w) f_2 + (c_8 + c_9 M_w) f_0 + c_{10} R_{cd} + S
\]

\[
f_0 = \max(\log(R_0/R_{cd}), 0) \quad R_0 = 10
\]

\[
f_1 = \min(\log R_{cd}, \log R_1) \quad R_1 = 70
\]

\[
f_2 = \max(\log(R_{cd}/R_2), 0) \quad R_2 = 140
\]

**Pezeshk et al. (2011)** \(^2\)

\[
\log(PSA) = c_1 + c_2 M_w + c_3 M_w^2 + (c_4 + c_5 M_w) f_1 + (c_6 + c_7 M_w) f_2 + (c_8 + c_9 M_w) f_0 + c_{10} R
\]

\[
f_0 = \max(\log(R/R_2), 0)
\]

\[
f_1 = \min(\log R, \log R_1)
\]

\[
f_2 = \max[\min(\log(R/R_1), \log(R_2/R_1)), 0]
\]

\[
R_1 = 70 \quad R_2 = 140
\]

\[R = \sqrt{R_{cd}^2 + c_{11}^2}\]

**Silva et al. (2002)** \(^3\)

\[
\ln(PSA) = c_1 + c_2 M_w + (c_6 + c_7 M_w) \times \ln(R_{cd} + \exp(c_4)) + c_{10} (M_w - 6)^2
\]

**Note**: PSA value by Pezeshk et al. (2011) and Silva et al. (2002) are converted from Hard-rock site to BC site by the method of USGS (2014)

**Reference**
3) Silva et al. (2002): *Development of Regional Hard Rock Attenuation Relations for Central and Eastern North America*
GMPE Model (at Vs=760m/s site)
Subsurface Ground Model

Global Vs30 Model by USGS

Topography by ALOS DSM

VS30 (m/s)
- 760 - 900
- 500 - 760
- 400 - 500
- 300 - 400
- 250 - 300
- 200 - 250
- 100 - 200

Elevation (m)
- Sea
- 0
- 20
- 200
- 500
- 1500

This map is made from 'ALOS Global Digital Surface Model ©JAXA'
Atkinson and Boore (2006)

✓ for $pgaBC \leq 60 \text{cm/sec}^2$

$$S = \log\{\exp[b_{\text{lin}}\ln(\frac{V_{30}}{V_{\text{ref}}}) + b_{n}\ln(60/100)]\}$$

✓ for $pgaBC > 60 \text{cm/sec}^2$

$$S = \log\{\exp[b_{\text{lin}}\ln(\frac{V_{30}}{V_{\text{ref}}}) + b_{n}\ln(pgaBC/100)]\}$$
Kyung et al. (2016): An Analysis of Probabilistic Seismic Hazard in the Korean Peninsula – Probabilistic Peak Ground Acceleration (PGA)

http://static.seismo.ethz.ch/GSHAP/global/
Kyung et al. (2016): An Analysis of Probabilistic Seismic Hazard in the Korean Peninsula – Probabilistic Peak Ground Acceleration (PGA)
Kyung et al. (2016): An Analysis of Probabilistic Seismic Hazard in the Korean Peninsula – Probabilistic Peak Ground Acceleration (PGA)
PSHA Map of the Korean Peninsula (10% in 50 years)

Vs=760 m/sec

Ground surface

PGA cm/sec²

- 375 -
- 350 - 375
- 325 - 350
- 300 - 325
- 275 - 300
- 260 - 275
- 226 - 260
- 200 - 225
- 175 - 200
- 150 - 175
- 125 - 150
- 100 - 125
- 75 - 100
- 50 - 75
- 25 - 50
- 0 - 25
PSHA Map of the Korean Peninsula (10% in 250 years)

Vs=760 m/sec

Ground surface

Seoul

Daejeon

Daegu

Gwangju

Busan

Seoul

Daejeon

Daegu

Gwangju

Busan

PGA cm/sec²

- 375 -
- 350 - 375
- 325 - 350
- 300 - 325
- 275 - 300
- 260 - 275
- 225 - 260
- 200 - 225
- 175 - 200
- 150 - 175
- 125 - 150
- 100 - 125
- 75 - 100
- 50 - 75
- 25 - 50
- 0 - 25

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Response Spectra at 5 Major City Sites

Seoul
- 50yr10%(surface)
- 250yr10%(surface)
- 50yr10%(Vs760)
- 250yr10%(Vs760)

Daejeon
- 50yr10%(surface)
- 250yr10%(surface)
- 50yr10%(Vs760)
- 250yr10%(Vs760)

Daegu
- 50yr10%(surface)
- 250yr10%(surface)
- 50yr10%(Vs760)
- 250yr10%(Vs760)

Gwangju
- 50yr10%(surface)
- 250yr10%(surface)
- 50yr10%(Vs760)
- 250yr10%(Vs760)

Busan
- 50yr10%(surface)
- 250yr10%(surface)
- 50yr10%(Vs760)
- 250yr10%(Vs760)
Challenges for the next step

- Enhancement of fault model
  - More information/Data

- Review of tectonic zones
  - Further understanding of tectonics

- Consistency with the surrounding area
  - China, Japan

- Effective use of the historical earthquake catalogs
  - Need review of data, M, epicenter etc.

- Update of modeling method
  - Incorporate logic tree etc.

- Toward Probabilistic Risk Model
  - Vulnerability
Thank you!