Towards a unified and worldwide database of earthquake surface ruptures (SURE)

FDHA 2nd Meeting
December 8-9, 2016
Menlo Park, USGS

Stéphane Baize & the SURE Group

Oct 30 2016, M6.5, Castelluccio, Central Italy
Questions posed by present-day « Surface Displacement hazard » practice

- PFDHA - Probabilistic Fault Displacement Hazard estimates are based on:
  • A very limited number of data, representing a limited number of tectonic contexts
  • Covering a limited range of magnitudes ➔ need to extrapolate when confronted with M<6.5 events
  • Different datasets lead to different estimates of the probability of surface rupture:
    Japan vs USA
  • Existing databases do not account for parameters that influence rupture (surface geology, structural complexity)
  • New techniques allow the lowering of detection threshold of surface rupture during moderate earthquakes (e.g. M6 2014 Napa - USA, M6 2016 Yualara - Australia)

- Need for updated and unified database of surface rupture
- This objective also serves other approaches (deterministic A-P, scaling relationships, numerical modellers etc)
Paris, Oct 2015: the starting point of SURE dataset

- 1st Workshop: gather experts working in the topic and potentially interested to build a unified DB of surface ruptures.
- Workshop sponsored by IRSN

Objectives

- Present the available data stored in existing databases
- Propose a common database structure
- Elaborate a schedule and define actions

Framework

- INQUA Project + IAEA initiative: shared effort at international scale
- No funding; voluntary-based work
Wide range of seismotectonic contexts’ geologists

Attendees from USA; Japan; Europe; South America; New Zealand; Continental Asia; with a large attendance of INQUA community:

- Tim Dawson (CGS, USA)
- Jim McCalpin (Geo-Haz consulting, USA)
  - Makoto Takao (TEPCO, Japan)
  - Koji Okumura (U. Hiroshima, Japan)
    - Luca Guerrieri (ISPRA, Italy)
    - Francesca Cinti (INGV, Italy)
  - Pilar Villamor (GNS, New Zealand)
- Carlos Costa (U. San Juan, Argentina)
- Richard Walker (NERC-COMET, UK)
  - Yoshi Fukushima (IAEA)
  - Stéphane Baize (IRSN, France)
  - Oona Scotti (IRSN, France)
  - Hervé Jomard (IRSN, France)
  - Thomas Chartier (IRSN, France)
  - Johann Champenois (CEA, France)
- Jochen Huertgen (University Aachen, Germany)
  - Austin Elliott (NERC COMET, UK)
  - Eugénie Pérouse (ENS, France)
In 3 days, a common agreement was reached

- Existing data and databases will be implemented in a worldwide database
  - Japanese database (M. Takao) is ready;
  - USA databases (T. Dawson and J. McCalpin) need to be checked;
  - Needs to include other region datasets (Continental Asia, Middle East, New Zealand, etc)

  ➔ A structure for the new database was agreed upon
    ➔ Fault maps with primary and distributed ruptures
    ➔ 3 tables with earthquake info, fault segment description, measurement points’ table, including published references

- A statement: new technologies provide significant improvements for mapping surface ruptures
  ➔ Enlarge the magnitude range (to low M) and the distributed deformation features
  ➔ Need to anticipate the incorporation of this type of high-precision data in the DB
Modern techniques

LiDAR - SfM
- Accurate elevation model
- It may be not be available in many countries
- It may be expensive

Optical images correlation
- Only lateral component and low resolution
- Explore the historical cases

InSAR
- Continuously acquiring satellites
- ALOS2 (low resolution; good penetration in canopy)
- Sentinel1 (high resolution; low penetration)
Imaging covered regions

**InSAR - ALOS2**
- 16 pairs pre/post-quake
- Imaging densely covered regions

**Large area with distributed deformation**
- Mainly in « hanging wall » block, including Kumamoto city and Aso volcano caldera (offsets: 30 cm)

Fujiwara et al 2016
2013: InSAR analysis
Analyzing SAR data to retrieve interseismic loading on the Pallatanga fault over hundreds of km² led to…

Evidencing a shallow slip event along a 9 km long fault

Champenois et al. (submitted)
- **InSAR measurements are in the field range of checked spots**
  - Could be used to complete the slip distribution, especially in remote areas like high mountain ranges
Significant parameters to account for

- Surface geology
- Structural complexity
- ...
Surface Geology

- Stanton 2013 sandbox exp.
  - Test two lithologies
  - Test different stiffness
  - Test material state

→ Displacement at depth to product surface displacement vary

Table 8: Basal displacement required for surface rupture given material type, relative stiffness, state and shear wave velocity

<table>
<thead>
<tr>
<th>Run</th>
<th>Material Type</th>
<th>Relative Stiffness</th>
<th>Material State</th>
<th>Shear Wave Velocity (m/s)</th>
<th>Basal Displacement Required for Surface Rupture (cm)</th>
<th>h/H</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>Sand</td>
<td>Loose</td>
<td>Virgin</td>
<td>77.0</td>
<td>12.44</td>
<td>0.147</td>
</tr>
<tr>
<td>1.1</td>
<td>Sand</td>
<td>Loose</td>
<td>Disturbed</td>
<td>77.0</td>
<td>2.19</td>
<td>0.025</td>
</tr>
<tr>
<td>2.0</td>
<td>Sand</td>
<td>Dense</td>
<td>Virgin</td>
<td>101.4</td>
<td>4.01</td>
<td>0.047</td>
</tr>
<tr>
<td>2.1</td>
<td>Sand</td>
<td>Dense</td>
<td>Disturbed</td>
<td>101.4</td>
<td>0.50</td>
<td>0.0059</td>
</tr>
<tr>
<td>3.0</td>
<td>Clay</td>
<td>Stiff</td>
<td>Virgin</td>
<td>41.8</td>
<td>5.73</td>
<td>0.068</td>
</tr>
<tr>
<td>3.1</td>
<td>Clay</td>
<td>Stiff</td>
<td>Disturbed</td>
<td>41.8</td>
<td>1.15</td>
<td>0.014</td>
</tr>
<tr>
<td>4.0</td>
<td>Clay</td>
<td>Soft</td>
<td>Virgin</td>
<td>23.65</td>
<td>8.37</td>
<td>0.097</td>
</tr>
<tr>
<td>4.1</td>
<td>Clay</td>
<td>Soft</td>
<td>Disturbed</td>
<td>23.65</td>
<td>3.76</td>
<td>0.044</td>
</tr>
</tbody>
</table>
Surface Geology

- *M7.2 El Mayor Cucapah earthquake, Mexico, from Teran et al. 2015*

- Loose Quaternary sediments increase the distribution of surface faulting, in terms of distance to primary and number of scarps

Teran et al. 2015
Alluvium attenuate slip on distinctive rupture

M6.5 Norcia Earthquake, Italy
Structural complexity

- Ruptures of 1954 Dixie Valley, Nevada from Caskey et al 1996 BSSA.

- Note most distributed faults occur in fault bend ("piedmont faults"), a stationary feature that will persist. Elsewhere distributed faults are rare

- Should be included in rupture description
Significant decisions to be taken when database will be implemented

- Assignment of Primary / Distributed / Triggered character to slip observations

- Which Metrics (distances primary/distributed)

- ...
Primary vs Distributed

- Model approach (Japan)

Takao et al 2013

« Process Zone »
(Vermilye and Scholz, 1998)
Primary vs Distributed
- Empirical approach (USA)
  - Primary: segment(s) w/ major displacement & length
  - Primary segments have structural relationship (splays, step-overs)

From Youngs et al. (2003) and Dawson (2015)
How to define triggered slip?

Primary and Distributed faulting and deformation

Elastic rebound

Primary

Distributed

Triggered slip
2014 M6 Napa earthquake
Sentinel (fringe: 2.5 cm)
*Source INSARAP*
Decision on Primary vs Distributed changes Distances

1987 M6.3 Edgecumbe  
New Zealand

Data from Beanland et al 1989

Option 1 of Shortest distance to Primary

Option 2 of Shortest distance to projection of Primary

Data from Beanland et al 1989
Ground Motion Prediction Equations
Various distances are used

Which Metrics to choose?

Rupture

\[ R_{jb} = R_x = R_{rup} \]

\[ R_{rup} \]

\[ R_{jb} = 0 \]
Surface faulting

Rupture

Faults are 3D structures: Which Metrics to choose?
Which metrics are the most relevant for Surface Faulting?

Question to discuss today

Faults are 3D structures: Which Metrics to choose?
SURE status in 2016/12

- 2016 task after Paris Workshop
  - Each data holder implements case(s) according to the proposed template

- Cases to be implemented first: **we are progressing!**

  - 1944 San Juan and 1977 Caucete (Argentina), by C. Costa
  - 1987 Edgecumbe and 2010 Darfield (New Zealand), by P. Villamor
  - 1980 Irpinia, 1997 Colfiorito and 2009 L’Aquila (Italy), by F. Cinti and L. Guerrieri
  - 1968 Dasht-E-Bayaz and another case (Iran), by R. Walker and A. Elliott
  - 1995 Kobé and another case to be defined (Japon), by M. Takao
  - 2014 Nagano (Japan) and 1999 Koaceli (Turkey), by K. Okumura
  - 1959 Hebgen Lake and 1983 Borah Peak (Basin and Range), by J. McCalpin
SURE status in 2016/12

Johann Champenois started in October (IRSN-IPGP, Y. Klinger)
→ SURE implementation & optical correlation to capture deformation
Historical cases

**M6.9 1995 Kobe**
- Fault segments; >300 obs. points (P+D)

**M7.0 1944 La Laja**
- 1 observation point (D)

**M6.3 2009 L’Aquila**
- >1000 obs. points (P+D+other) and no segment information; additional info to be formatted

**M6.3 1987 Edgecumbe**
- 146 obs. points (P+D) and 2 primary segments; no additional info

**M7.1 1959 Hebgen Lake**
- 62 obs. points (P) and P+D segments; no additional info

**M6.9 1983 Borah Peak**
- 93 obs. points (P+D) and P+D segments; no additional info
Modern cases: List of post-2000 earthquakes

- To update the existing databases w/ recent events that can potentially be (have been) observed w/ modern techniques

- Jim McCalpin (2016) performed this first search in the USGS earthquake database
  - 130 shallow M6+ epicenters onshore between 2000 and 2016
  - Most occurred in China (21), Iran (13), Japan (8), Russia (8), Pakistan (7), Turkey (7), New Zealand (6), Kyrgyzstan (5), USA (5), Chile (5), Nepal (5), Myanmar (4).
  - Very few have surface rupture information reported in literature and there is a need for regional geologists’ participation.

- Solicitation of “regional geologists” is one major task of the SURE working group in the next years.
Project started as a shared effort, to rely on the entire community:

- IAEA and INQUA groups;

2016 Menlo Park Meeting is a unique opportunity

- To open to other contributors;
- To discuss the structure and other topics (metrics, primary vs distributed);

Implementing SURE will be time-consuming and might require sponsorship:

- Who? Where? How?

SURE, a free, homogenous and downloadable database,

- To date, based on published data;
- Appropriate platform for this will also have to be set up;