Zoning surface rupture hazard along normal faults: insight from the 2009 $M_w$ 6.3 L’Aquila, central Italy, earthquake and other global earthquakes

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L'Aquila quake: Scientists see convictions overturned

A group of Italian scientists convicted of manslaughter for failing to predict a deadly earthquake have had the verdict quashed.
Chelungpu Fault

Earthquake fault zone (EFZ):

- Hanging wall: 200m
- Foot wall: 100m
Introduction
News about L’Aquila earthquake
Surface fault-rupture hazard (SFRH)

Seismotectonic setting

Coseismic ground ruptures
4 main types of the rupture

Discussion
WRZ data from normal-faulting earthquakes globally
Delineating EFZs and Ss for Apennine-type normal faults

Conclusions
Width of earthquake fault zone (EFZ)
Width of setback (S)

Future work
Surface fault-rupture hazard (SFRH)
SFRH can be considered a localized seismic hazard due to the breaching of the ground surface from slip along a fault during a large earthquake.

Earthquake fault zone (EFZ)
EFZ is a regulatory zone around the surface traces of active faults within which fault-rupture hazard may occur.

Fault setbacks (S)
Fault setback is defined by the distance from the active fault trace within. Critical facilities and structures for human occupancy cannot be built within the zone.
Fault setbacks (S)

Earthquake fault zone (EFZ)
Seismotectonic setting

- The system extends along the axial part of the Italian Apennines, from northern Tuscany to Calabria.

http://en.wikipedia.org/wiki/Apennine_Mountains
The 6 April 2009 $M_w$ 6.3 L’Aquila earthquake is a normal-faulting earthquake that reactivated the Mount Stabia-Paganica-San Demetrio (SPD) fault system.

- **6 April mainshock $M_w$ 6.3**
  Strikes 130°-135°, dips 50°-55° southwest
  Depth: ~9.5km

- **7 April aftershock $M_w$ 5.6**
  Depth: 15km
  9km southeast of the mainshock

- **9 April aftershock $M_w$ 5.4**
  Strikes 130°, dips 50°, southwest
  Depth: 10-11km
  18km north of the mainshock Laga Mountains faults
Seismotectonic setting

- Map of the epicentral area with traces of the SPD system.

**Figure 1.** (a) Map of the 2009 L’Aquila earthquake epicentral area with traces of the SPD normal fault system. (b) Five-meter-resolution digital elevation model of the Paganica–San Gregorio populated areas showing the locations of active faults and traces of the 2009 coseismic ground ruptures.
Coseismic ground ruptures

- Ground ruptures in the form of:

  1. **En echelon or linear fractures** with centimeter-size apertures and normal dip-slip motion of a few centimeter down to the southwest.

  2. **Linear fissures** with centimeter-size openings without vertical slip.

  3. **En echelon cracks**.
Group the ground deformation into 4 main types:

1. **Type 1 deformation is coseismic surface faulting.**
The seismic rupture propagated upward along the main fault.

2. **Type 2 deformation is also coseismic surface faulting.**
The seismic slip breached the surface along synthetic splays.

3. **Type 3 open fissures** along the trace of the main fault, where fault is covered.
   Appear in the interface of the stiff bedrock and the soft alluvial covers.
4. **Type 4 typical deformation** of the San Gregorio area.

**Linear fissure and en echelon cracks**, located on the hanging wall of the seismogenic fault.
Coseismic ground ruptures

1. Type 1
Breaching of the ground surface along the main fault.
Coseismic ground ruptures

2. Type 2
Breaching of the ground surface along a synthetic splay of the main fault.

Figure 4. Orthophoto map of Paganica south (see Fig. 1) with examples of coseismic surface faulting along a synthetic splay of the main fault (Type 2 coseismic deformation) located far from the main fault trace (120–140 m). The color version of this figure is available only in the electronic edition.
3. Type 3
Open fissures along the trace of the main where fault is covered by colluvium or alluvium.
Coseismic ground ruptures

4. Type 4
Open fissures, **without appreciable vertical displacement.**
Observation of the pipe trench

- The fault zone is 40-50m wide and is formed by at least 5 steeply-dipping synthetic normal faults.
- F2 fits with the main Paganica normal fault.
- F3 to F5 are hanging wall synthesis splays of the main fault.
- The 2009 fault throw was ~10cm, F5 splay (type 2 deformation).
**Discussion**

- **Ruptures of 18 earthquakes (1912-2009)**
  - Plot shows the WRZ versus magnitude.
  - WRZ > 150m mostly come from broad deformation zones.
  - A positive relation between WRZ and magnitude is not evident.

![Graph showing WRZ versus magnitude with specific events indicated.](image)
Discussion

- WRZ data from normal-faulting earthquakes globally

- WRZ is generally less than 120-150m.
Discussion

- Delineating EFZs and Ss

**Known fault trace**

- Both the EFZ and the S should be asymmetrically shaped around the trace of the active fault.
- Wider zone on the hanging wall than on the footwall.
- An EFZ doesn’t assure the ruptures cannot occur outside the zone.
Discussion

- Delineating EFZs and Ss

**Uncertain fault trace**

- Fault trace bracketed within a zone of geological uncertainty.
- Wider zone on the hanging wall than on the footwall.
Discussion

- **Delineating EFZs and Ss**

  **Uncertain fault trace**

- Area with flat topography.

- Giving a Symmetric EFZ centered on the most likely fault trace.
Conclusions

- **Delineating setbacks**

We proposed setback on footwall is 15m account for uncertainties in the fault location, such as faults are covered by the consolidated deposits. The value of 15m is adopted in the United States (Bryant and Hart, 2007; Batatian 2002 Recommendations for fault setbacks).

The setback on the hanging wall 40m, includes the belt of coseismic faulting and fracturing plus an estimated mapping error of 5m.
Conclusions

● Delineating EFZs

EFZ should include all the reasonably inferred fault-rupture hazards, both on the main fault and the possible active branches of the main fault.

Using the history of the Paganica fault, the EFZ should include:
1. The main deformation zone
2. The reactivated synthetic splays

The edge of the EFZ on the hanging wall should be at least 150m. On the foot wall, the EFZ of 30m is probably sufficient.
Conclusions

P fault (Paganica active fault)

- An S of 15m for the footwall, on the hanging wall an S of 40m.

- We suggest that the minimum width of EFZ 30m on the footwall and the EFZ is 150m on the hanging.

- Providing a case of study that help defining basic criteria for determining EFZs and Ss.
Collecting the surface rupture data from other strike-slip-faulting earthquakes globally.

Finally, we hope that we can propose general criteria for strike-slip fault.
Thanks for your attention
<table>
<thead>
<tr>
<th>Unit</th>
<th>Description</th>
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<tbody>
<tr>
<td>U1</td>
<td>Modern soil. Filled fissure.</td>
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<tr>
<td>U2</td>
<td>Matrix supported gravelly colluvium (with ceramic artifacts). Late Holocene.</td>
</tr>
<tr>
<td>U3</td>
<td>Gravelly alluvium / colluvium. Holocene.</td>
</tr>
<tr>
<td>U4</td>
<td>Dark greyish brown scarp-derived colluvium with organic soil pieces. Holocene.</td>
</tr>
<tr>
<td>U5</td>
<td>Orange-brown scarp-derived colluvium with petrocalcic horizons. Holocene.</td>
</tr>
<tr>
<td>U6</td>
<td>Orange scarp-derived colluvium. Late Pleistocene?</td>
</tr>
<tr>
<td>U7</td>
<td>Sandy gravel scarp-derived colluvium. Late Pleistocene?</td>
</tr>
<tr>
<td>U8</td>
<td>Dark brown paleosol and colluvium with CaCO3 concretions. Late Pleistocene.</td>
</tr>
<tr>
<td>U9</td>
<td>Alluvial fan gravel in yellow sandy matrix, poorly cemented. Late Pleistocene.</td>
</tr>
<tr>
<td>U10</td>
<td>Gravelly scarp-derived colluvium (variable matrix content). Middle Pleistocene.</td>
</tr>
<tr>
<td>U12</td>
<td>Coarse/medium alluvial fan gravel (dense / cemented). Middle Pleistocene.</td>
</tr>
<tr>
<td>U13</td>
<td>Yellowish brown pedogenised sandy loam with abundant volcaniclastic material. Middle Pleistocene.</td>
</tr>
<tr>
<td>U14</td>
<td>Dark-brown/reddish paleosols with Fe/Mn and CaCO3 concretions, formed in volcaniclastic parent material. Middle Pleistocene.</td>
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**Main fault (F2)**
- Main deformation zone (30-35 m)
- Open fissures and warping
- April 6th 2009 fault throw: ~10 cm

**Legend**
- U: Unit
- F: Fault
3. Type 3
Open fissures along the trace of the main fault in unconsolidated colluvium.
These fissures are accompanied by flexure of the hanging wall with wavelength of few meters.

Figure 5. Examples of Type 3 coseismic deformation (see Fig. 3 for locations). (a) Open fissures along the trace of the main fault in unconsolidated colluvium. (b) Open fissures along the trace of the main fault in unconsolidated alluvium, accompanied by flexure of the hanging wall. The color version of this figure is available only in the electronic edition.
Figure (c)-(f) are examples of large WRZ data measured at major geometric complexities of the main fault of dip-slip.
Right-lateral, left-stepping