Evaluation of seismic events and earthquake faults with weak surface features

Kunihiko Shimazaki
Association for Earthquake Disaster Prevention

Earthquake Research Institute
14:50-15:15, March 16, 2010
How much information can we obtain on an underground source fault by geomorphological, geological, and geophysical surveys on active faults?

Weak earthquake feature on active faults

Weak feature of active fault

Evolutionary development of active faults
The longer an active fault is, the higher is its activity.
Major active faults in Japan

Length: 20km or longer (M7.0 or above *)

* Matsuda (1975)

Headquarters for Earthquake Research Promotion
How much information can we obtain on an underground source fault by geomorphological, geological, and geophysical surveys on active faults?

Weak earthquake feature on active faults

Weak feature of active fault

Evolutionary development of active faults
The longer an active fault is, the higher is its activity.
10cm vertical offset due to the M6.8 Chuetsu EQ of 2004 vs. 2m offset found at the trench site

Obirou site, northern Muikamachi fault

Maruyama et al (2007)
Ten earthquakes with magnitude 7.0 or above, which occurred on the major active faults during the past 200 years

Recognizable by trench excavation survey? NO for three cases

M7.4 Zenkoji earthquake of 1847
M7.4 Iga-Ueno earthquake of 1854 No earthquake fault was observed
M7.0-7.1 Hietsu earthquake of 1858
M8 Nobi earthquake of 1891
NO M7 Shonai earthquake of 1894
M7.2 Rikuu earthquake of 1896
M7.3 Kita-Tango earthquake of 1927
M7.3 Kita-Izu earthquake of 1930
NO M7.1 Fukui earthquake of 1948
NO M7.3 Kobe earthquake of 1995 (Kobe segment)
The M7 Shonai EQ of 1894

Yadarezawa fault proposed by Koto (1895) was not found to exist (Suzuki et al., 1989). The azimuth of reported rupture is not consistent with that of the Shonai-Heiya-Toen fault. The reported surface disturbance features are not on a line.
The M7.1 Fukui EQ of 1948

No clear earthquake fault was recognized on the surface.

The source fault (Sagiya, 1999) is estimated to be 4-5km west of the major fault zone.
The M7.3 Kobe earthquake of 1995

No clear earthquake fault is recognized on the Kobe segment, which is consistent with the distribution of co-seismic slip.

Horikawa et al. (1996)
1995 surface rupture on the Nojima fault

Photo taken by Nakata
Ten earthquakes with magnitude 7.0 or above, which occurred on the major active faults during the past 200 years

Recognizable by trench excavation survey?  NO for three cases

M7.4 Zenkoji earthquake of 1847 M7.4
M71/4  Iga-Ueno earthquake of 1854 No earthquake fault was observed
M7.0-7.1 Hietsu earthquake of 1858
M8 Nobi earthquake of 1891
NO  M7  Shonai earthquake of 1894
M7.2 Rikuu earthquake of 1896
M7.3 Kita-Tango earthquake of 1927
M7.3 Kita-Izu earthquake of 1930年
NO  M7.1 Fukui earthquake of 1948
NO M7.3 Kobe earthquake of 1995 (Kobe segment)
Expected number of earthquakes with magnitude 7 or above in 30 years on the major fault zones

1.5 Past 200 year history

0.9 Long-term forecast

0.4 Earthquake with weak surface feature
Existence of an earthquake which does not leave recognizable features on the surface

Active fault & underground weak zone

Seismogenic layer

Recognizable Eq

Eq with no or weak surface features

It is necessary to evaluate an event without clear surface feature
No surface feature on a deep asperity

Horikawa et al. (1996)
Another example of shallow and deep asperities

The M7.3 Tottori earthquake of 1943

15km long surface rupture vs. 28km long source fault
How much information can we obtain on an underground source fault by geomorphological, geological, and geophysical surveys on active faults?

Weak earthquake feature on active faults

Weak feature of active fault

Evolutionary development of active faults

The longer an active fault is, the higher is its activity.
Empirical relationship

M: magnitude
L: fault length \( \log L (\text{km}) = 0.6M - 2.9 \)
D: co-seismic slip \( \log D (\text{m}) = 0.6M - 4.0 \)

(Matsuda, 1975)

Seismic moment \( Mo (\text{Nm}) = 3.8 \times 10^{16} L^2 \)
Average repeat time \( T (\text{y}) \sim 80L / \text{s} \)

\( s (\text{mm/y}): \) average slip rate
Recent earthquakes with magnitude 7.0 or larger, which took place on a short active fault

M7.2 Iwate-Miyagi EQ of 2008
M7.0 Fukuoka-Seihouoki EQ of 2005
M7.3 Western Tottori EQ of 2000
The M7.2 Iwate-Miyagi earthquake of 2008

Source fault 40km
Active fault 3-4km
Suzuki et al. (2008)
The M7.0 Fukuoka-Seiho-Oki EQ of 2005

Hydrographic and Oceanographic Dept., Japan Coast Guard (2005)
M7.3 Western Tottori EQ of 2000
20km long source fault

3km long estimated active fault on the aftershock zone (Tsutsumi et al., 2000)
The M7.3 Western Tottori EQ of 2000

Linear zone of large gradient of gravity anomaly along the after-shock zone (Sato, 2007)

3km long active fault

The length of 25km corresponds to M7.2
How much information can we obtain on an underground source fault by geomorphological, geological, and geophysical surveys on active faults?

Weak earthquake feature on active faults

Weak feature of active fault

Evolutionary development of active faults

The longer an active fault is, the higher is its activity.
Shimazaki (1986)

Scaling relations for Japanese shallow crustal earthquakes

Proportional to $L^2$

Proportional to $L^3$

$Mo = 7.5 \times 10^{25} \text{dyn}\cdot\text{cm}$
Brittle rupture starts from the bottom of seismogenic layer.

Exception near a volcano

Unidentifiable source
A part of source fault reaches to the surface when magnitude is M6.9 or larger

Shimazaki (1986)
Cumulative frequency

Major active faults in Japan

Assumed power law for source faults

Short active fault: max M7.4

Unidentifiable source?
Surface active fault and underground source fault

Larger than M6.8 and smaller than M7.5

Perhaps smaller than 7.1-7.2

Active fault length = Source length
Short active fault: max M7.4

Cumulative frequency

Fault length, km

Major active faults in Japan

Unidentifiable source?
Major active faults in Japan

$b=1$ for G-R relationship

Cumulative frequency

Long recurrence for short fault

Short recurrence for long fault

M = 7.0, 7.5, 8.0
The longer an active fault is, the shorter is the recurrence interval.
Ishibe and Shimazaki (2009)
Conclusions

There exist an earthquake leaving no clear feature on the surface, and an active fault whose source fault is much longer than surface features.

The longer an active fault is, the higher is its activity.
活断層セグメント長の頻度分布

沖野・隈元 (2007, 活断層研究)

M7.2

活断層詳細デジタルマップデータ (中田・今泉, 2002)

M7.5
マグニチュードの範囲

<table>
<thead>
<tr>
<th></th>
<th>最小</th>
<th>最大</th>
</tr>
</thead>
<tbody>
<tr>
<td>予め震源が特定しにくい地震</td>
<td>-</td>
<td>7.0-7.1</td>
</tr>
<tr>
<td>地表で活動が認めにくい地震</td>
<td>-</td>
<td>?</td>
</tr>
<tr>
<td>短い活断層の地震</td>
<td>6.9</td>
<td>7.4程度</td>
</tr>
</tbody>
</table>
Main part of Ishikari-Heiya-Tohen fault zone M7.9

160cm/s
既存の断層（餅転-細倉構造線）からM7.0
北上低地西縁断層帯から分岐M7.3
2008年岩手・宮城内陸地震
佐藤他, 2008