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Shallow Dip-Slip Earthquake: Its Dynamics and Generation of Corner Waves

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It is currently widespread to invert accelerograms for obtaining fault slip distribution and rupture history for large, shallow strike-slip earthquakes. For shallow dip-slip earthquake, however, the situation is different because only few events of this type have been well recorded in the near field and the physical properties still remain unexplored due to analytical difficulties (see Madariaga, \textit{PAGEOPH}, 2003). Here, we study rupture dynamics associated with a dip-slip fault located in a two-dimensional, linear elastic half space. That fault, following a slip-weakening relation, dips either vertically or 45 degrees and is subjected to a loading static stress that increases linearly with depth. Using a finite difference technique, we investigate the seismic wave field radiated by rupture of this straight fault. The rupture propagates either spontaneously or at a constant speed. We show that in both vertical and inclined cases, when the rupture front reaches the free surface, four Rayleigh-type pulses are generated: two propagating along the free surface into the opposite directions to the far field, the other two moving back along the ruptured fault surfaces (interface) downwards into depth. If the fault is vertical, the problem is still symmetrical and the induced particle motions are symmetrical with respect to the rupturing fault, although the stopping phase of the dynamic rupture is largely controlled by the downward interface pulses. In the case the fault is inclined, the symmetry is broken: on the hanging wall, the downward-propagating interface pulse and the outward-moving Rayleigh surface pulse interact with each other, inducing a kind of shear wave (corner wave). This corner wave carries concentrated wave energy and propagates faster than the surface and interface pulses, generating extremely strong particle motions on the hanging wall before static equilibrium of the faulted medium is achieved. On the contrary, on the footwall, the ground motion is dominated simply by the weaker Rayleigh pulse propagating along the free surface and the interaction between this Rayleigh and the oppositely-moving interface pulse is also small. The generation of downward interface pulses and the corner wave has not been well recognized so far, partly because those waves are not expected for a fault that is located at depth and does not break the surface. However, the comparison of these fundamental numerical results with the seismological recordings of the 1999 Chi-Chi, Taiwan, and the 2004 Niigata-ken Chuetsu, Japan, earthquakes also suggests the need for more careful analytical treatment concerning the effects of the free surface on the strong motion near fault breakouts.

\textbf{Keywords:} Earthquake dynamics, earthquake ground motions and engineering seismology, theory in seismology, computational seismology
**OUTLINE**

- Previous Studies
- Introduction
- Problem Statement
- Surface-Breaking Fault
- Concluding Remarks

If time permits...
- Wave Simulator SWIFD

**INTRODUCTION**

Kei Aki (JGR, 1988)

1995 Parkfield, California, earthquake
→ Computation of the near field of strike-slip fault

Shallow dip-slip earthquake

Only few events of this type have been
well recorded in the near field and
the physical properties still remain unexplored
due to analytical difficulties.

**PREVIOUS STUDIES**

2D (non)linear slip-weakening

Linear case → Universal nucleation length

\[ L_n = 3.1 \times 10^{-12} \left( \frac{F}{P} \right)^{1/3} \]

for mode I and II

Nonlinear pulse-free (slip) → Instability upon slip initiation

if the power \( n = 27 \)

3D case

The aspect ratio \( h/r \) changes with time except for

\[ r = \frac{h}{r} = 1 \] (axially symmetric)

for the opening (flexural) mode

\[ r = 2 \] (slip)

\[ r = 3.5 \] (sliding mode)

\[ r = 20 \] (spherical)

These values of \( r \) minimize the area of critical rupture zone at instability (eq. 3).

**GOOD AFTERNOON**

Bonjour!
Konnichiwa!

**SHALLOW DIP-SLIP EARTHQUAKE: ITS DYNAMICS AND GENERATION OF CORNER WAVES**

**KOH UENISHI AND RAUL I. MADARIAGA**

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Laboratory de Géostatique, Département Géosciences, Ophélie, Back Normand

**CHI-CHI AND CHUETSU**

1999 Chi-Chi, Taiwan

Dip angle = 30 degrees

The hanging wall moves much more than the footwall, with the asymmetry decreasing with increasing depth on the fault (e.g., Oglesby & Day, ESSA, 2001).

2004 Niigata-ken Chuetsu, Japan

Dip angle = 50 degrees

<table>
<thead>
<tr>
<th>City</th>
<th>Damage</th>
<th>Number of Deaths</th>
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<tbody>
<tr>
<td>Tadami</td>
<td>1716.5</td>
<td>38</td>
</tr>
<tr>
<td>Nagaoka</td>
<td>1207.3</td>
<td>7</td>
</tr>
<tr>
<td>Kofu</td>
<td>878.4</td>
<td>6</td>
</tr>
<tr>
<td>Kita</td>
<td>614.4</td>
<td>9</td>
</tr>
<tr>
<td>Joetsu</td>
<td>400.4</td>
<td>3</td>
</tr>
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**Problem Statement**

Rupture dynamics of a dip-slip fault
- located in a two-dimensional, linear elastic half space;
- follows a slip-weakening relation;
- dips either vertically or at 45 degrees;
- subjected to a leading static stress that increases linearly with depth.

The rupture propagates either spontaneously or at a constant speed.

**Surface Breaking Fault**

**Vertical fault**
Four strong Rayleigh(R) type pulses
- Two propagating along the free surface into the opposite directions to the far field.
- The other two moving back along the ruptured fault surfaces (interferes) downwards into depth.

The problem is still symmetrical and the induced particle motions are symmetrical with respect to the rupturing fault, although the stopping phase of the dynamic rupture is largely controlled by the downward interface pulses.

**Surface Breaking Fault**

**Inclined fault**
The symmetry is broken: on the hanging wall, the downward-propagating interface pulse and the outward-moving Rayleigh surface pulse interact with each other, inducing a kind of shear wave (corner wave).

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**Fault at Depth**

When the fault rupture occurs (and stops) at depth, two relatively weak Rayleigh (R) pulses may be generated.

**Corner Wave**

Inclined fault
The symmetry is broken: on the hanging wall, the downward-propagating interface pulse and the outward-moving Rayleigh surface pulse interact with each other, inducing a kind of shear wave (corner wave).
**CORNER WAVE**

Inclined fault

- On the hanging wall, the corner wave carries concentrated wave energy and propagates faster than the surface and interface pulses, generating extremely strong particle motions on the hanging wall before static equilibrium of the faulted medium is achieved.

- On the contrary, on the footwall, the ground motion is dominated simply by the weaker Rayleigh pulse propagating along the free surface and the interaction between this Rayleigh and the oppositely-moving interface pulse is also small.

---

**CONCLUDING REMARKS**

- The generation of downward interface pulses and the corner wave has not been well recognized so far, partly because those waves are not expected for a fault that is located at depth and does not break the surface.

- We need more careful analytical treatment concerning the effects of the free surface on the strong motion near fault breakouts.

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