Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

SSS28-02 会場:201A 時間:5 月 24 日 14:15-14:30

媒質境界を伝播する定常的パルス破壊の非特異的解の数理解析
Mathematical analysis of the non-singular solution for steady state dynamic slip pulse problem on a bimaterial interface

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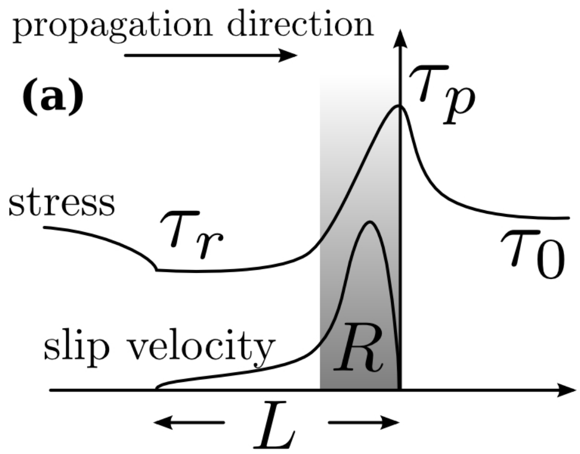
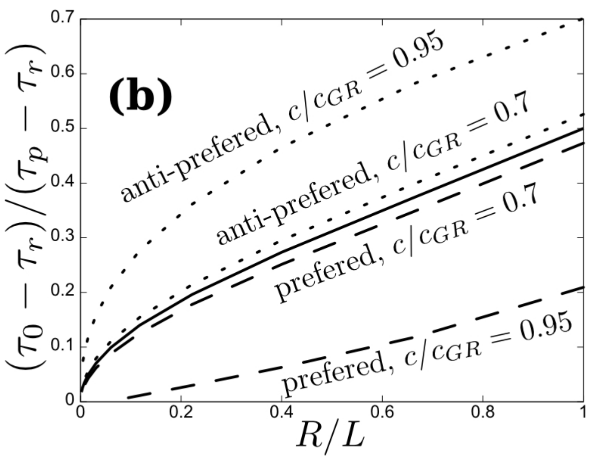
Some major faults as represented by inter-plate faults and tectonic lines are known to be located on material interfaces whose origins are different each other. As an elasticity problem, earthquake occurring on such faults can be modelled by dynamic rupture propagation along an interface of welded two different elastic materials, which is referred to as ”bimaterial”. In fact, up to 30% difference in seismic wave velocities have been reported across the San Andreas and some major faults, and many researchers have investigated behaviour of such faults in many ways. Weertman (1980, JGR) analytically showed that in-plane rupture propagation along a material interface with a constant velocity changes normal stress on its slip plane in proportion to slip velocity unlike in homogeneous medium. Then, rupture propagating towards slip direction of more compliant material, which is referred to as ”preferred direction”, reduces normal stress and rupture towards another direction increases normal stress. This result suggests a possibility that some different phenomena may be observed depending on the propagation direction of rupture along material interface. After his work, many numerical simulations have been done. Such simulations have revealed that rupture towards preferred direction significantly increases slip velocity (Rubin & Ampuero 2007, JGR), or tends to propagate not as crack-like but as pulse-like rupture (Ampuero & Ben-Zion 2008, GJI).

On the other hand, analytical study in this field have not shown many major progresses after Weertman (1980) mainly because the analysis is highly complicated if we assume friction law dependent on normal stress change: note that the normal stress change depends on slip velocity if bimaterial is assumed. Significant results have been provided only by a few researches including Adams (2001, J. App. Mech.), and Adda-Bedia & Ben Amar (2003, J. Mech. Phys. Solids). They concluded that, as long as constant dynamic friction coefficient is assumed, only a singular solution is obtained, which represents divergence of normal stress. In general, however, analytical study plays a complementary role to numerical studies, so that progress in analytical study may be required in order to interpret results obtained by numerical studies.

In this study, we treat steady state slip pulse propagating on a bimaterial interface, construct an singular integral equation for this problem, and analyse its solution. First, we show that the singular solution obtained by previous studies yields finite energy release rate even though its singularity is, if rupture propagates towards the preferred direction, larger than the square root singularity appearing in the solution for homogeneous problem. Next, we analytically derive the condition to remove the singularity, namely the condition that the shear stress drops continuously from the peak value tau_p to the residual value tau_r at the pulse tip as illustrated in fig.(a); tau_0 is the background stress level. This condition is found to be a function of the stress ratio (tau_0 - tau_r) / (tau_p - tau_r), ratio R/L, propagation velocity of pulse c and propagation direction of pulse as shown in fig.(b), where L is a length of the pulse and R is a characteristic length of process zone. For a homogeneous medium, this condition have been derived by Rice et al. (2005, BSSA), which, however, does not depend on rupture velocity (solid line in fig. (b)). This result suggests that rupture towards the preferred direction requires small stress drop relative to rupture towards opposite direction if the same size of process zone is considered. That is to say, in a different point of view, rupture towards the preferred direction may generate larger process zone if the same value is assumes for the stress drop. We mention some physical implications and applicabilities of this result.

キーワード: 断層, 動的破壊, 媒質境界, スリップパルス, 解析解
Keywords: fault, dynamic rupture, bimaterial interface, slip pulse, analytical solution


propagation direction
(a)
τ_p
stress
τ_r
τ_0
slip velocity
R
L


(b)
anti-prefered, $c/c_{GR} = 0.95$
anti-prefered, $c/c_{GR} = 0.7$
prefered, $c/c_{GR} = 0.7$
prefered, $c/c_{GR} = 0.95$
$(\tau_0 - \tau_r)/(\tau_p - \tau_r)$
R/L
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
1