2009 SCEC Annual Report

TITLE: What about the Bends? Renewal of SCEC Support

PIs: David D. Oglesby[1]
Steven G. Wesnousky[2]

Institutes: [1]Dept of Earth Sciences
University of California
Riverside, California 92521

[2]Center for Neotectonic Studies
Mail Stop 169
1664 N. Virginia Ave
University of Nevada, Reno 89557

Category: (B) Integration and Theory

Science Objectives: A9, A10

In 2009 our research has focused on further investigation of our double-bend (i.e., linked stepover) faulting scenarios. Building on last year's work, we have investigated another plausible regional stress configuration, investigated the effects of fault scale on the ability of rupture to propagate through the linked stepover, and developed a simple theoretical explanation for the modeled faulting behavior.

Our 2008 work on linked stepovers (cartoon geometry shown in Figure 1) assumed that the main fault segments were oriented parallel to the direction of maximum shear stress. Under this set of assumptions, an extensional stepover produced a wider range of stepover angles were statically (i.e., based on the resolved regional shear and normal stresses on the linking fault) favorable for rupture than did the compressional stepover case. Consequently, extensional stepovers allowed a wider range of dynamic rupture fronts to propagate through the stepover (Figure 2). In 2009, we investigated an equally plausible regional stress configuration, with the main fault segments aligned parallel to the direction that minimizes the strength excess on the fault segments (i.e., minimum of [mu_static*normal_stress – initial__shear_stress]). Under this new set of stress assumptions, the comparison between extensional and compressional stepovers is reversed, with compressional stepovers allowing through-going rupture over a wider range of stepover angles (Figure 3). The differences between these results can be understood by analyzing the value of the relative fault strength S = (mu_static*normal_stress – initial_shear_stress)/(initial_shear_stress – mu_sliding*normal_stress) as a function of stepover angle. The values of normal stress, initial shear stress, strength excess, stress drop, and S are plotted for various stepover angles in Figure 4 (for the basic case of main fault segments aligned with maximum shear) and in Figure 5 (for the rotated case of main fault segments aligned with minimum strength excess). Zero on the horizontal axis is the angle of the main fault segments, with negative angles corresponding to extensional stepovers and positive angles corresponding to compressional stepovers. As shown in Figure 4, in the basic case S becomes very large (i.e., the fault is quite unfavorable to rupture) at an extensional stepover angle of around -34 degrees, and at a compressional stepover angle of around 18 degrees. Note that these are exactly the angles at which asymptotic behavior is reached in Figure 2; for stepover angles greater than these, rupture of an infinitely long stepover segment is impossible. Similarly, Figure 5 shows S diverging at angles of -16 degrees for the extensional stepover and 30 degrees for the compressional stepover, matching the asymptotic angles in Figure 3. Thus, we see that for very long linking faults, the ability of rupture to propagate through the stepover is determined completely by the static favorability of that linking segment to dynamic rupture. For smaller linking fault lengths, though, Figures 2 and 3 show that ruptures can propagate across linking faults with sharper, more statically unfavorable angles. This effect is an indication of the ability of dynamic rupture to "tunnel" through otherwise energetically unfavorable regions, as long as they are small enough that the crack does not die out before reaching a more favorable region. The less energetically favorable the linking fault is (in the initially applied regional stress field), the shorter it must be to allow through-going rupture. This set of results is an indication of the relative contributions of static and dynamic effects to the propagation of rupture at a double bend.

Our other main effort was to scale our fault system up and down to determine the sensitivity of the results to the size of the main fault segments as well as the length of the linking fault. We find that the scaling is not trivial: larger fault systems allow rupture to propagate through stepovers with longer linking segments and with larger stepover angles. In particular, the maximum length of the linking fault that allows through-going rupture does not scale in a simple linear way with the size of the overall fault system. A manuscript based on these results is currently under review at BSSA, and forms one chapter of graduate student Julian Lozos's Master's Thesis.

Figures

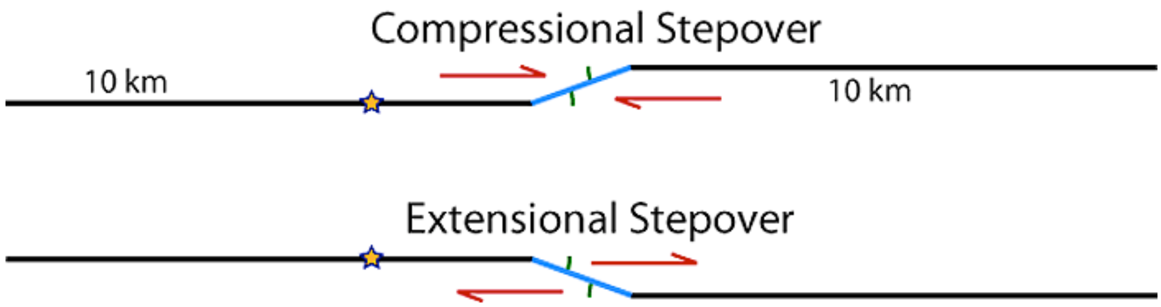
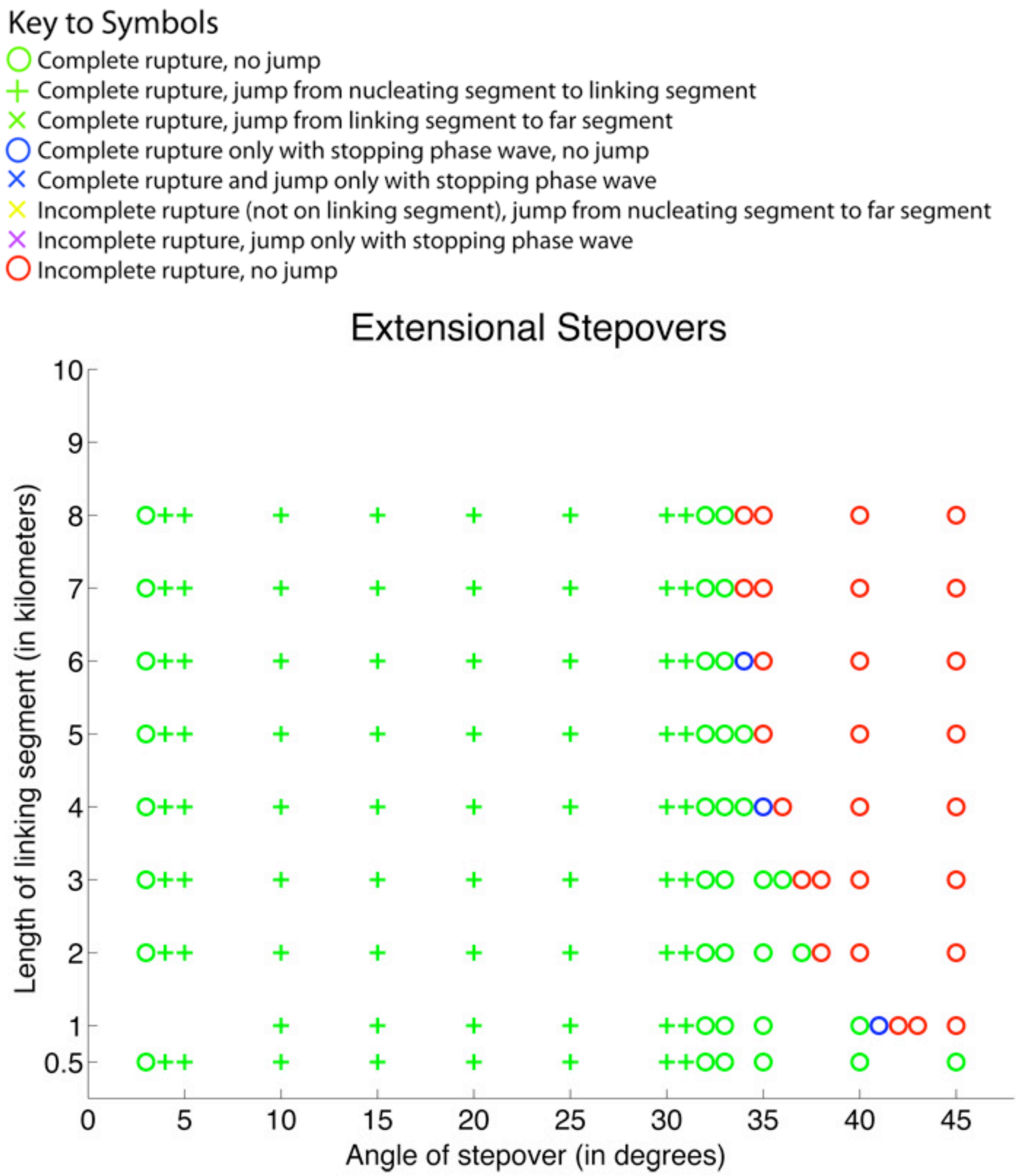
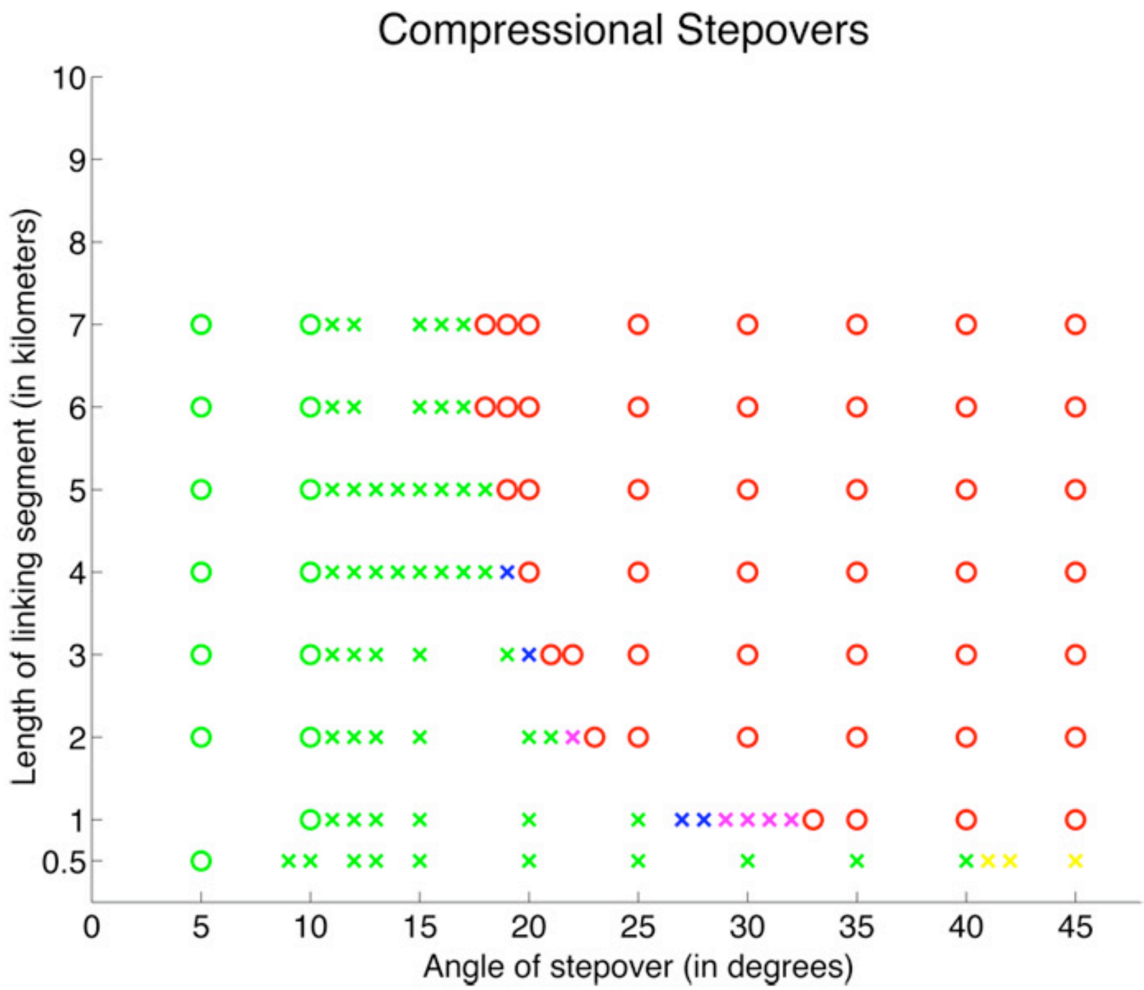


Figure 1. Cartoon of fault geometry. The blue line represents the linking segment, which is variable in length. The green arcs show the stepover angle, taken relative to the strike of the parallel end segments; this angle is also variable. The red arrows represent the direction of slip. The star marks the nucleation point, 7 km along the nucleating segment of the fault. The lengths of the nucleating and far segments, in black, are constant at 10 km each.

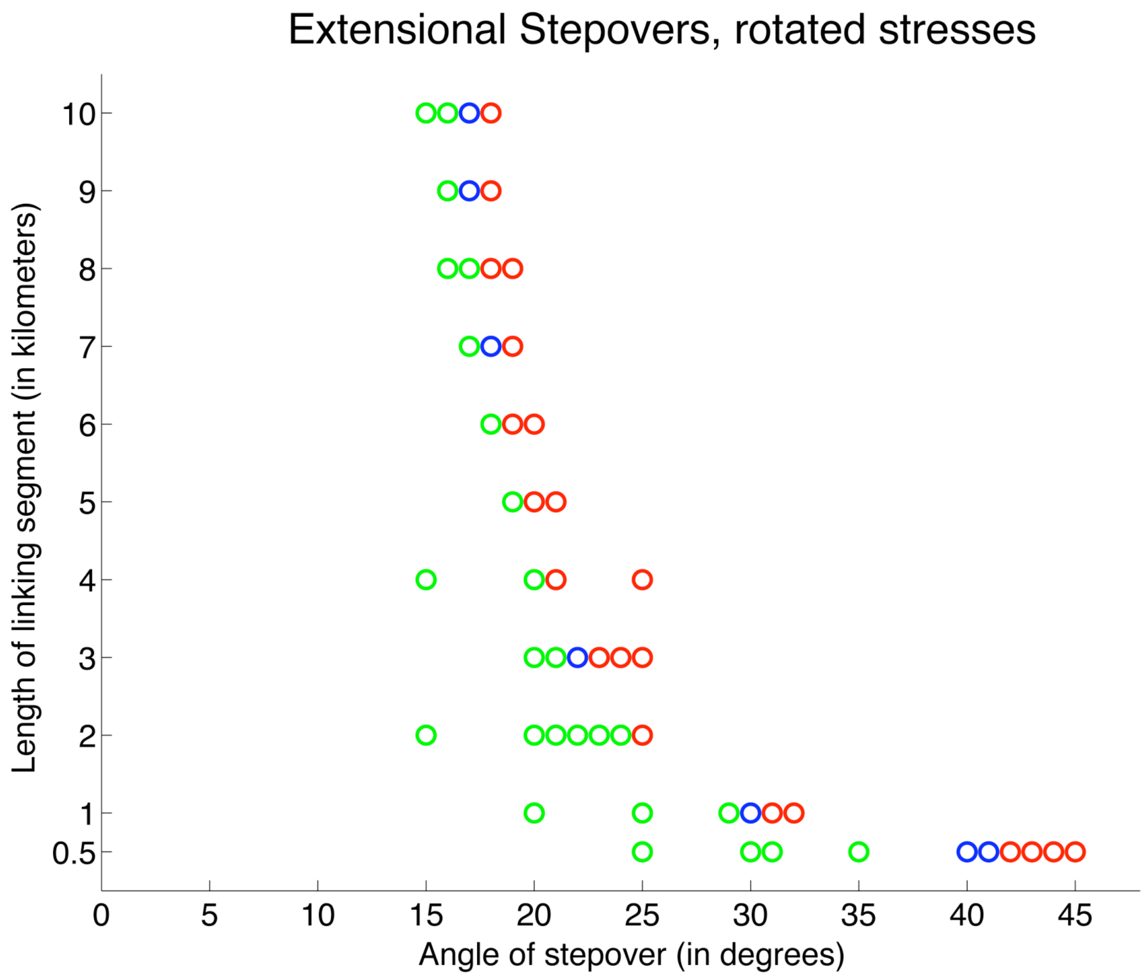

Key to Symbols
Complete rupture, no jump
Complete rupture, jump from nucleating segment to linking segment
Complete rupture, jump from linking segment to far segment
Complete rupture only with stopping phase wave, no jump
Complete rupture and jump only with stopping phase wave
Incomplete rupture (not on linking segment), jump from nucleating segment to far segment
Incomplete rupture, jump only with stopping phase wave
Incomplete rupture, no jump
Extensional Stepovers
Length of linking segment (in kilometers)
Angle of stepover (in degrees)
0
5
10
15
20
25
30
35
40
45
0.5
1
2
3
4
5
6
7
8
9
10

a)



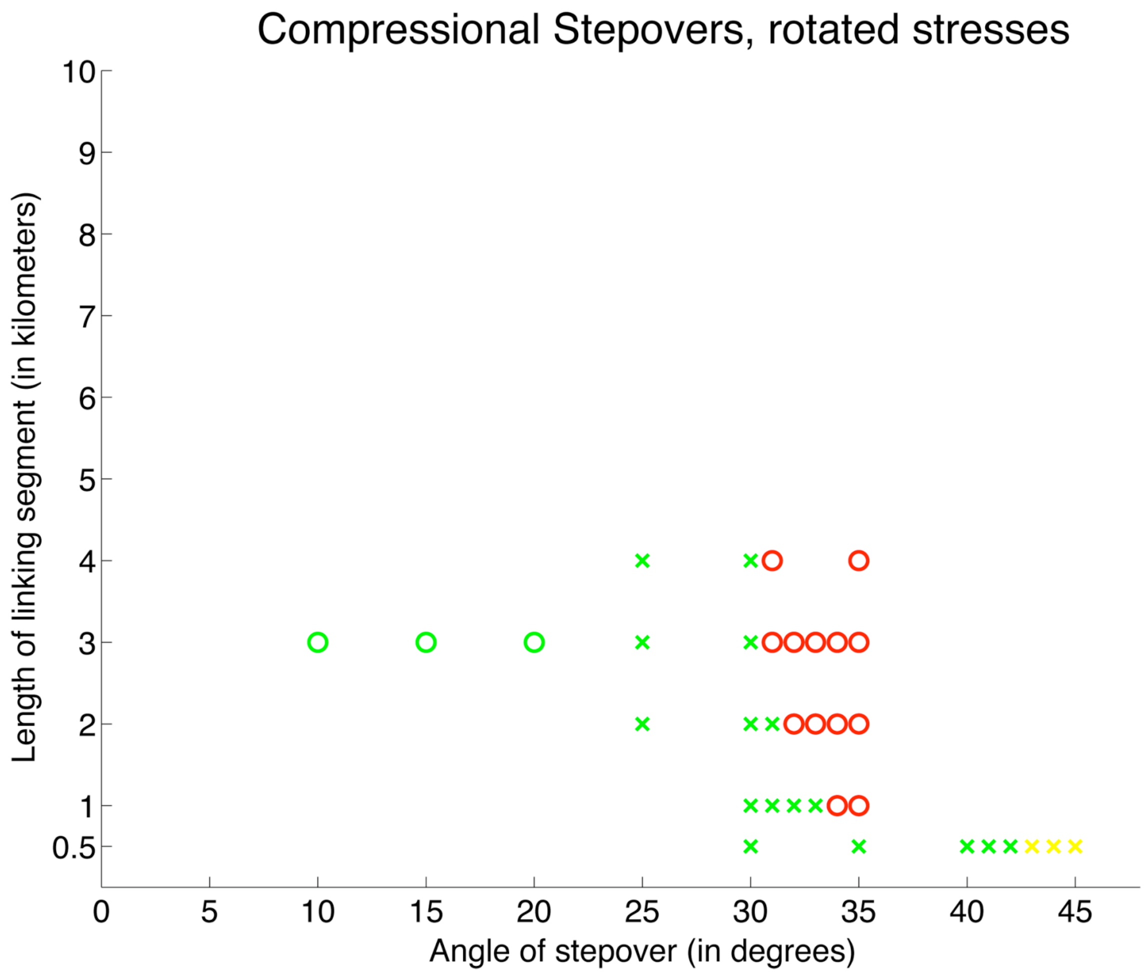
b)

Figure 2. Parameterization charts for rupture behavior in basic case extensional (a) and compressional (b) stepovers. Each symbol represents one numerical model. Note that both the angle and the width of stepover affect rupture behavior. Both small angles and short stepover lengths facilitate full propagation. Also note the asymptotic curve marking the boundary between different behaviors on both charts.



Extensional Stepovers, rotated stresses
Length of linking segment (in kilometers)
10
9
8
7
6
5
4
3
2
1
0.5
0
5
10
15
20
25
30
35
40
45
Angle of stepover (in degrees)

a)



b)

Figure 3. Parameterization of rupture behavior for extensional and compressional stepovers with parallel end segments aligned most optimally for rupture. Note that compressional stepovers are easier to rupture than extensional ones are, opposite to the basic case. Also note that asymptotic behavior manifests itself at a much shorter linking segment length for compressional stepovers than for extensional ones. Each symbol represents one numerical model; the key to symbols is the same as in Figure 2.

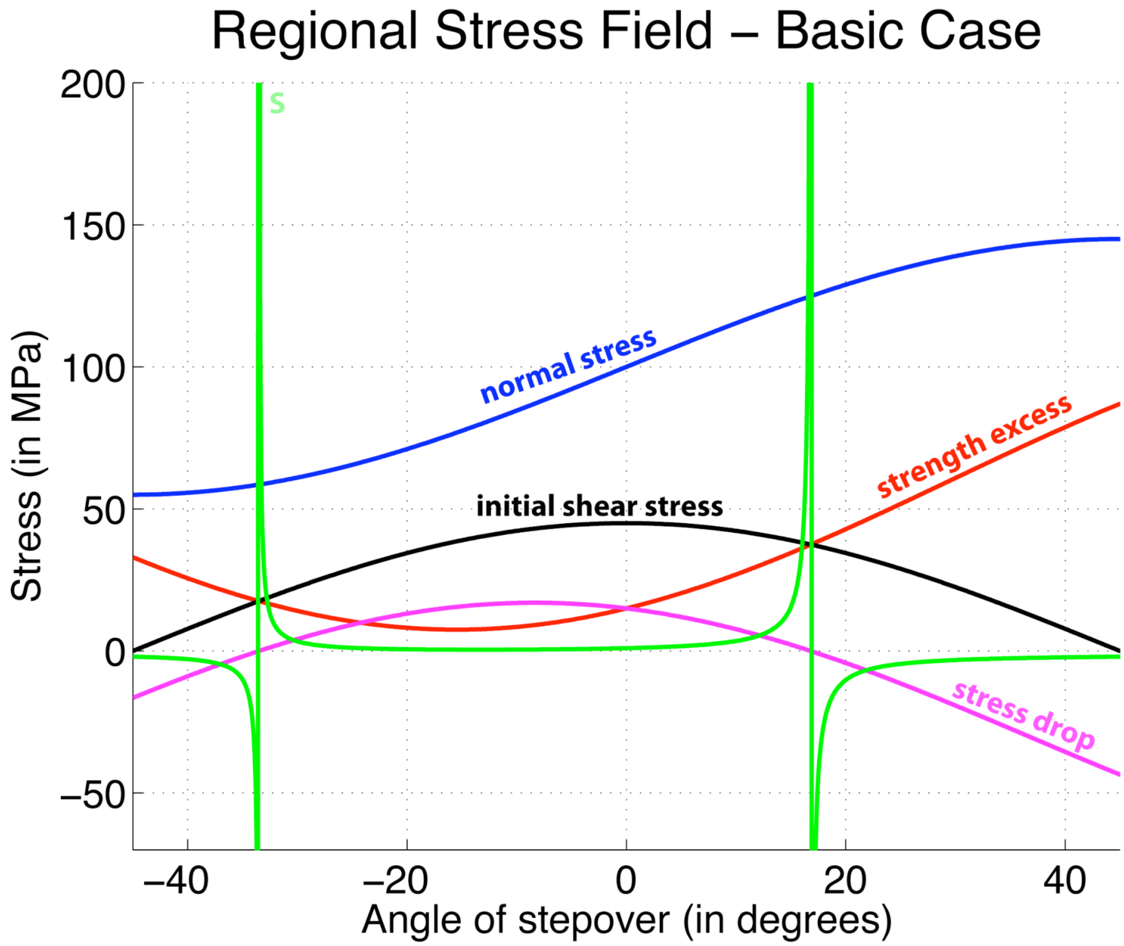


Figure 4. Regional stress field resolved onto the linking fault for the basic case, in which the parallel end segments of the fault are aligned with the direction of maximum shear. Angles above 0 represent compressional stepovers, and angles below 0 represent extensional stepovers. The blue line represents the absolute value of normal stress. The black line represents initial shear stress. The red curve represents strength excess on the fault, defined as the difference between yield stress and initial shear stress. Relative fault strength S is shown in green. Stress drop is shown in magenta. Note that the peaks in S occur at the same angles as the thresholds below which the entire fault always ruptures in figure 2.

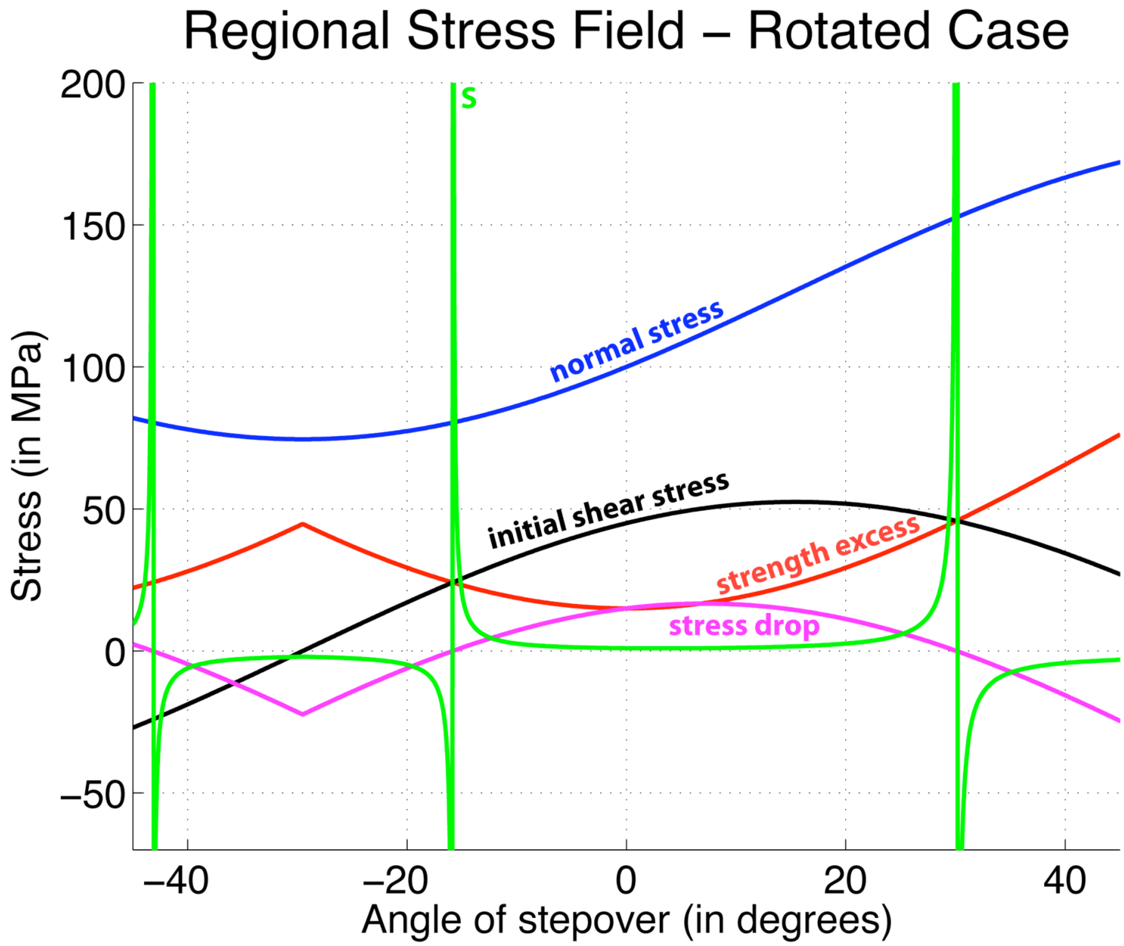


Figure 5. Regional stress field resolved onto the linking fault for the stress rotated case, in which the parallel end segments of the fault system are optimally aligned for rupture, as determined by minimization of the fault's strength excess. Angles above 0 represent compressional stepovers, and angles below 0 represent extensional stepovers. The blue line represents the absolute value of normal stress. The black line represents initial shear stress. The red curve represents strength excess on the fault, defined as the difference between yield stress and initial shear stress. Relative fault strength S is shown in green. Stress drop is shown in magenta. Note that the peaks in strength excess are shifted from the basic case (Figure 4), and that they align with the asymptotes in figure 3.