DynEarthSol3D (DES3D) [Choi et al., 2013; Tan et al., 2013; Ta et al., 2015; Logan et al., 2017] is an explicit dynamic finite element code providing quasi-static solutions to the momentum balance equation via the dynamic relaxation [Cundall, 1989] and mass scaling [e.g. Chung et al., 1998]. The explicit formulation makes it easy to implement complex rheologies. The limit on time step size is a drawback associated with an explicit time integration but the mass scaling technique can mitigate it to some degree.

In this project, we are going to use the Mohr-Coulomb elasto-plastic rheology. This rheology is suitable for describing elastic and brittle behaviors of rocks as in `fdfault` without complications from rate-dependent creep as in viscoelastic or elasto-visco-plastic rheologies. That we can choose to exclude completely time-dependent creep behaviors from consideration not only ensures seamless coupling with `fdfault` but also must subdue the unwarrented but often-raised doubt about the legitimacy of using `DES3D` for interseismic time scales of 1-1000 years.

Recent extension of the Mohr-Coulomb rheology in `DES3D` to the rate-and-state friction [Tong and Lavier, *in prep*] further demonstrates that this code can handle the rheology perfectly relevant to earthquake cycles. In Tong and Lavier's approach, velocity magnitude is evaluated, the state variable is updated based on it and the rate-and-state friction coefficient (μ_{RS}) is computed based on the updated velocity and state variable at each quadrature point of an element. μ_{RS} is then used in the Mohr-Coulomb failure criterion as well as in the return mapping for stress update.

In an example showin in Fig. 1, a 10 km-thick layer of elastic crust is sheared to initiate and maintain earthquake cycles. A 2 km-thick pre-existing shear zone is in contact with the crustal layer and composed of the Mohr-Coulomb plastic materials with rate-and-state friction. Due to the shear loading, shear stress elastically accumulates in both layers. When plastic yielding occurs in the shear zone, the coseismic slip and release of elastic stress occurs and the rate-and-state friction governs this stress-releasing process. μ_{RS} is given as

$$\mu_{RS} = \mu_0 + a\,\ln(V/V_0) + b\,\ln(V_0\,\theta/L), \tag{1}$$

where mu_0 is the reference friction coefficient, θ is the state variable that evolves in time as $\dot{\theta} = 1 - V\theta/L$, V is the slip velocity, V_0 and L are reference velocity and characteristic length scale. In the shown example, we set $\mu_0 = 0.6$, $V_0 = 10^{-6}$ m/s and $L = 3$ mm. Also, $a = 0.015$, $b = 0.019$ for velocity-weakening patch (central 50 km-wide region in the shear zone) while $a = 0.0019$ and $b = 0.0015$ for velocity-strengthening patches. As evident in the right panel of Fig. 1, the implemented rate-and-state friction law successfully reproduces the quasi-periodic earthquake cycles.

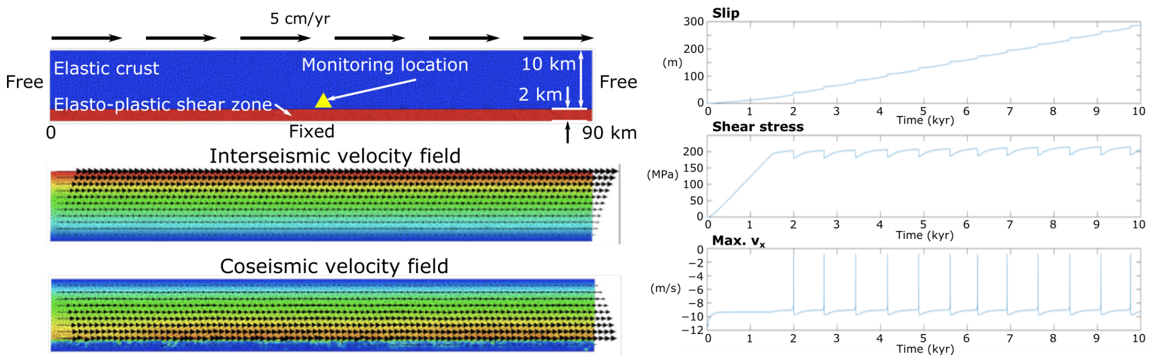

Figure 1: (left) Top: Model setup. Middle and bottom: Snapshots of velocity field during interseismic loading and coseismic slip, respectively. (right) Time history of slip, shear stress and maximum velocity magnitude, all of which consistently and clearly exhibit the main characteristics of earthquake cycles.

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