Loading a subduction fault in earthquake cycles

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Coseismic deformation of the earth is well described by elastic dislocation models. Stress relaxation after an earthquake is reasonably well described by models of faulting in a Maxwell viscoelastic earth. However, the seemingly simple problem of how to load a fault to accumulate strain energy for earthquakes is still poorly understood, especially for subduction zones.

The most popular two-dimensional model for loading a subduction fault involves completely or partially locking a shallow segment of the fault while requiring the fault to slip at the plate convergence rate below a certain depth. This is equivalent to applying a force along the fault at that depth to drive plate convergence. Consequently, the portion of the upper plate on top of the transition between the locked and slipping segments of the fault is laterally squeezed, resulting in uplift and horizontal shortening at the ground surface. In this model, it is the near-field loading that localizes strain accumulation near the trench. The simplest model of this type is the inter-seismic elastic dislocation model.

This driving mechanism to localize strain accumulation has not found a physical explanation. We may continue to search for a mechanism for near-field loading or, alternatively, consider far-field loading and face the following consequences.

(1) In an elastic model, if the plates are pushed from the far field and if the fault below the locked segment is allowed to slip freely, the surface uplift pattern is completely different from the prediction of the inter-seismic dislocation model. Maximum horizontal surface shortening occurs near the locked zone of the fault, similar to the dislocation model, but significant surface shortening also occurs in the rest of the upper plate. In a viscoelastic model, the relaxation of the asthenosphere causes strain accumulation to be even less localized. This points to problems in relating geodetically constrained inter-seismic deformation to fault locking parameters. Localized inter-seismic crustal shortening can indeed be achieved with far-field loading in earthquake cycle models that involve dynamic interaction of the upper plate, the slab, and the mantle (Wang et al., 1994[2]), but in these models, high shortening rates are related mainly to the "recovery" of the crust from the previous earthquake, not much to subsequent fault loading.

(2) If parts of the system, such as the mantle wedge (or fault zone), has a Maxwell viscoelastic behavior (or velocity strengthening behavior), inter-seismic strain accumulation and coseismic strain release take place at different spatial scales (Wang, 1995[1]). With far-field loading, inter-seismic strain accumulation occurs over a wide region, but coseismic deformation occurs in a smaller area comparable to the size of the fault rupture. Viscous response causes delayed deformation and dissipates part of the strain energy. Therefore, seismic rupture releases only a fraction of the

strain energy accumulated during the inter-seismic period. In order not to have rapid permanent plate shortening, significant amount of plate convergence must be in the form of aseismic slip, implying a very small seismic coupling ratio.

References

[1] Wang, K., 1995, *Coupling of tectonic loading and earthquake fault slips at subduction zone,* Pure Appl. Geophys. **145**, 537-559.

[2] Wang, K., Dragert, H. and Melosh, H. J., 1994, *Finite element study of uplift and strain across Vancouver Island,* Can. J. Earth Sci. **31**, 1510-1522.