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Dynamic Finite Element Modeling of Fault Slip; Stress Drop and Overshoot

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OBJECTIVES

The objective of this study is to use a numerical approach to examine behaviour of stress drop and slip on a fault. We use a dynamic approach for finite element modeling. According to this model we are able to calculate, overshoot on stress drop and surface deformation, which both are important for seismic hazard assessments.

FAULT MODEL

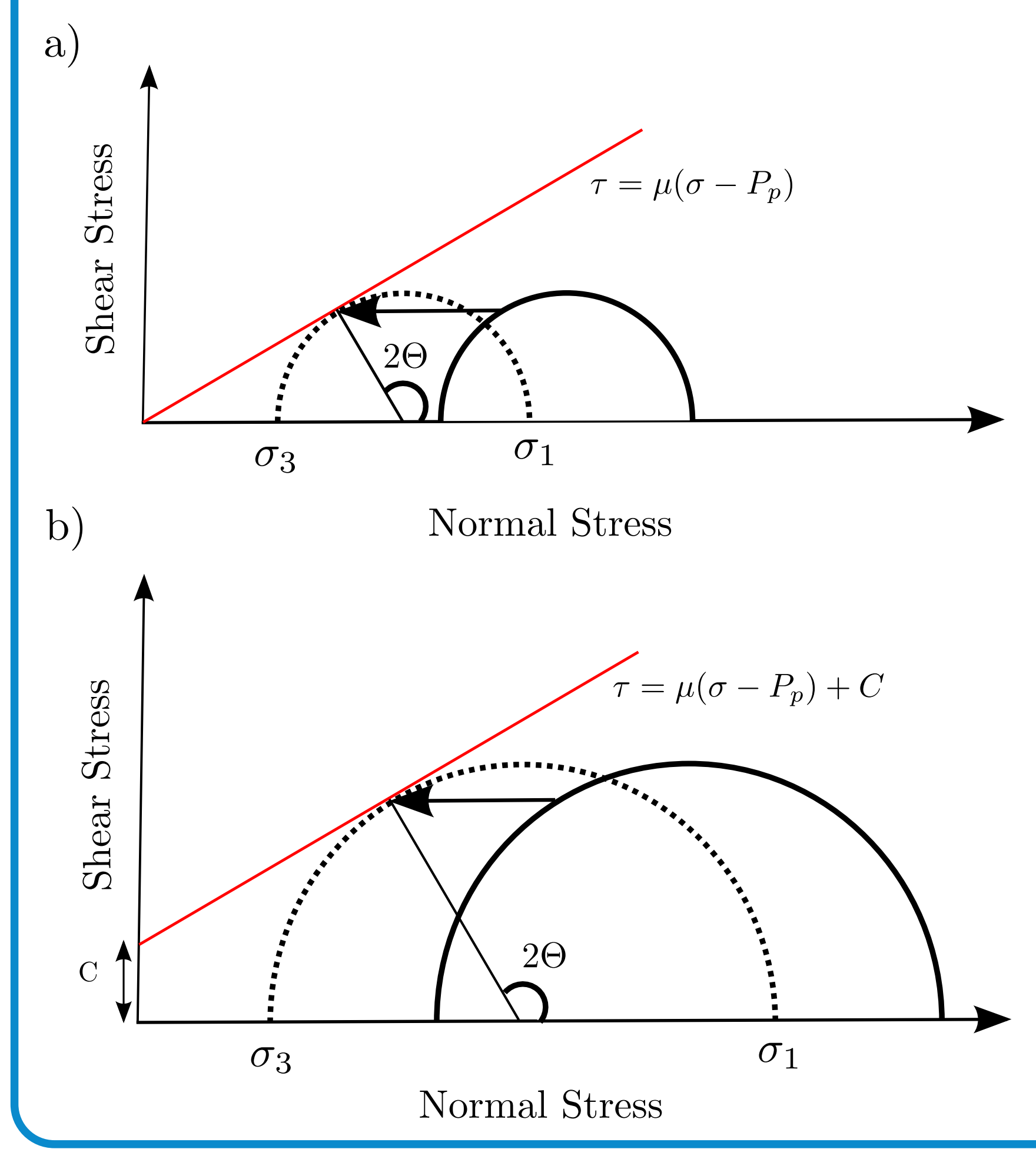

Figure 1: Mohr diagrams showing the effect of cohesion on critical stress state. a) Dashed circle shows the state of stress immediately before slip on a cohesionless fault. Black arrow shows the change in stress stage caused by an increase in pore pressure, neglecting poroelastic effects. Red line indicates the Mohr-Coulomb failure criterion, wherein slip is assumed to occur at the tangent point with the Mohr circle. The fault angle relative to the maximum principal stress direction is Θ. b) As above but in the case of non-zero cohesion. Given the same coefficient of friction, this leads to a higher state of stress at failure.

MODEL SETUP

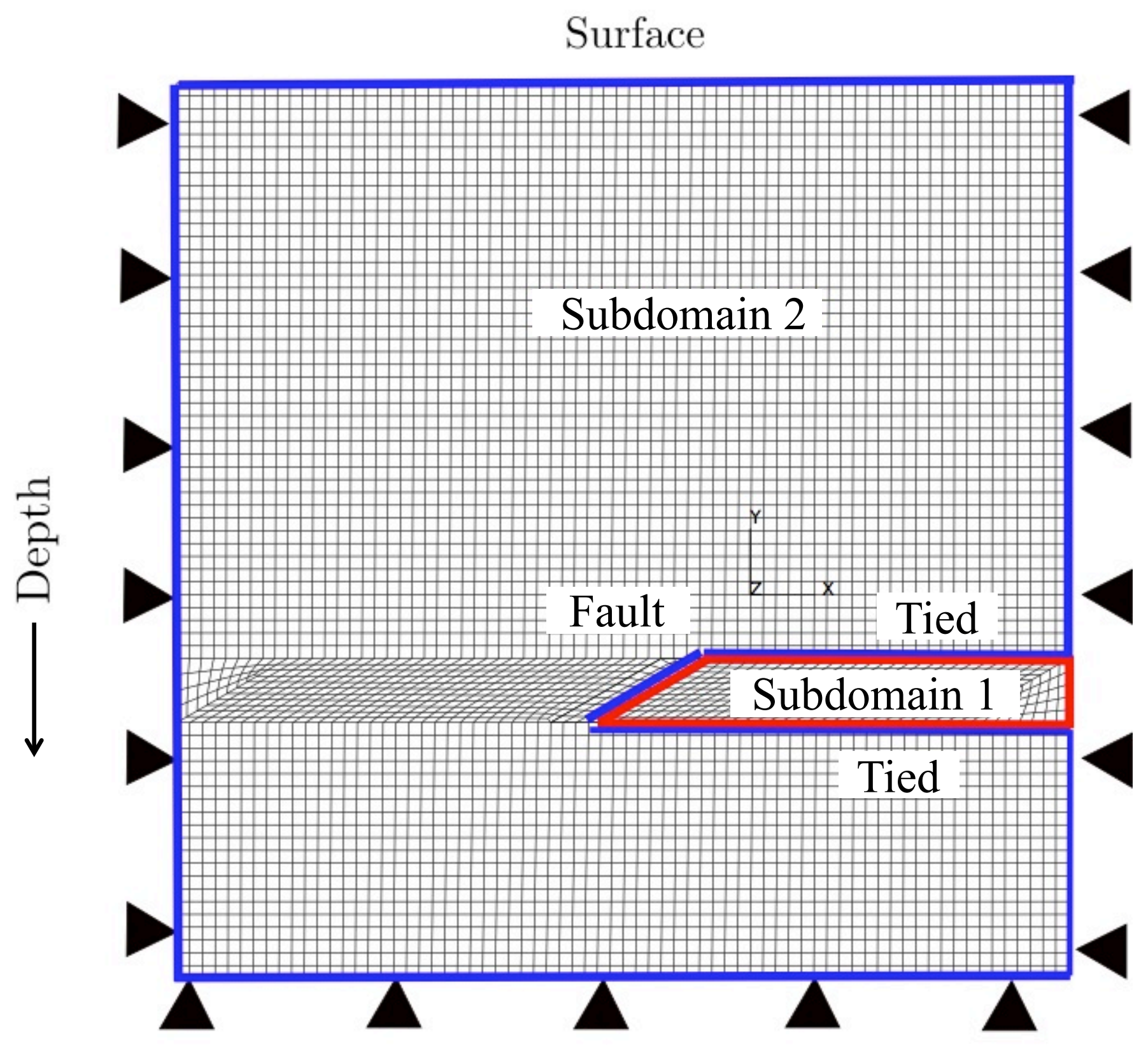

Figure 2: Example of 2D model setup showing the finite-element mesh. Here, a 1 km fault dipping at 30 degrees is embedded in a homogeneous medium, with the top of the fault at 4.5 km depth. Subdomain 1 is outlined in blue, while subdomain 2 is outlined in red. Boundaries are tied (no slip) along the horizontal top and bottom of subdomain 1, while slip is permitted along the dipping fault boundary. Sides of the model, indicated by the triangles, are fixed with no degree of freedom. A free slip boundary condition is applied along the top of the model.

SLIP

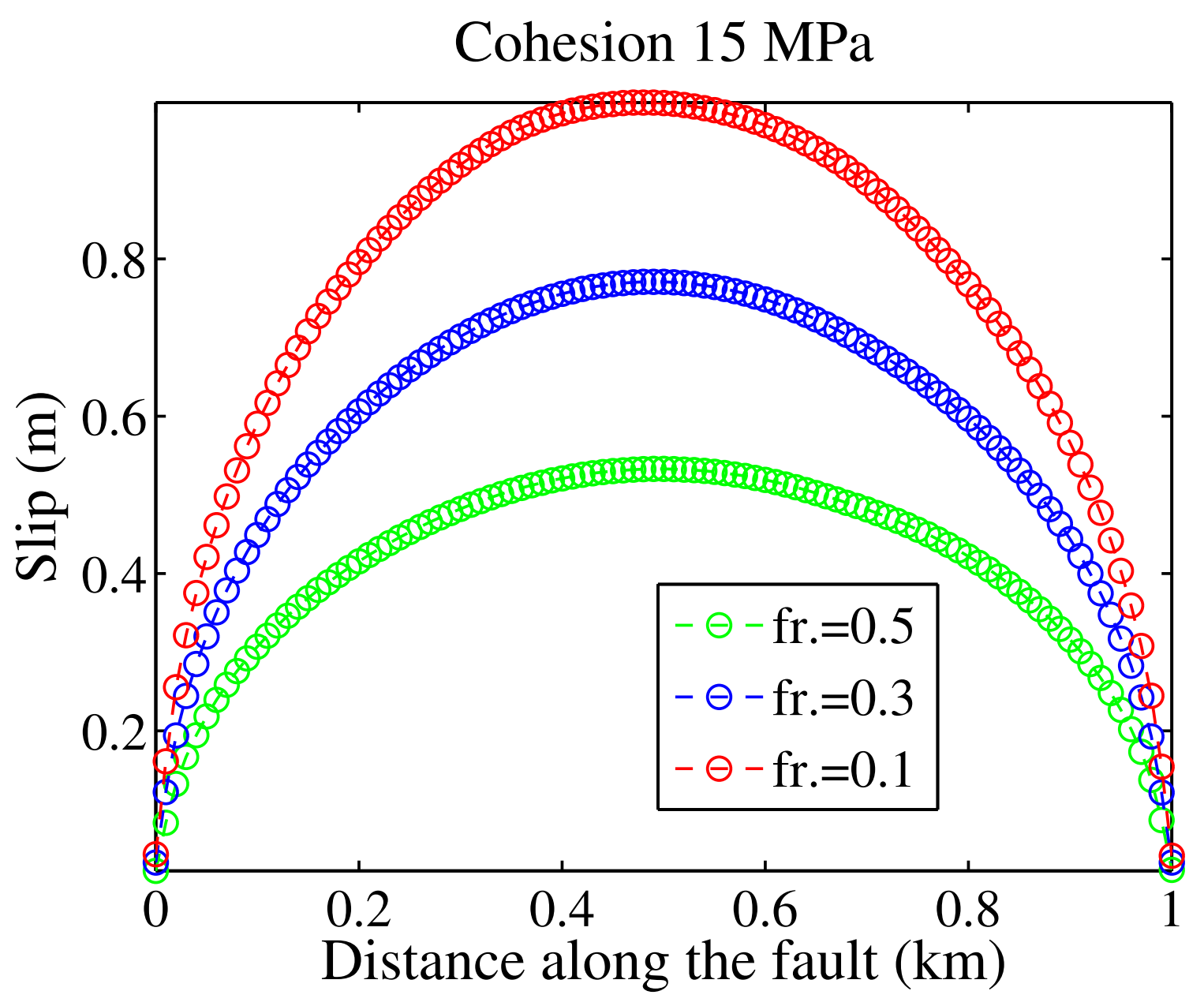

Figure 3: Normalized slip versus distance along the fault for a 1 km fault at 1 km depth with 15 MPa of cohesion. Individual curves represent various levels of slip weakening, expressed by the difference between initial and residual friction, $\mu_0 - \mu_r$.

DISPLACEMENT

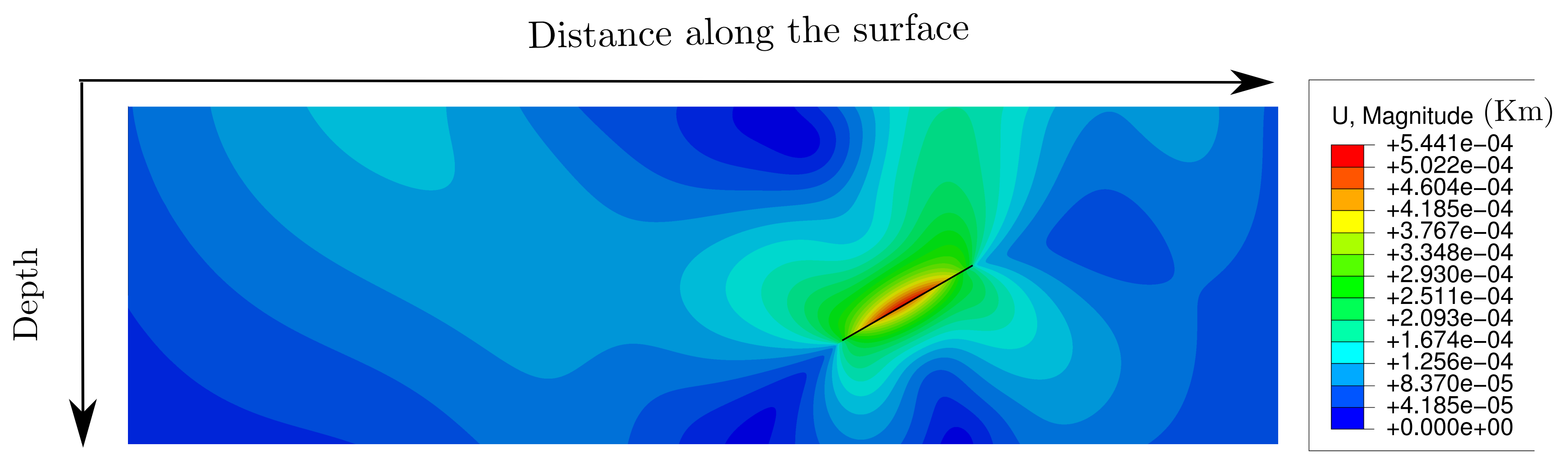

Figure 4: Displacement magnitude of the medium due to 15 MPa drop in cohesion and $\mu_r = 0.1$.

SHEAR STRESS

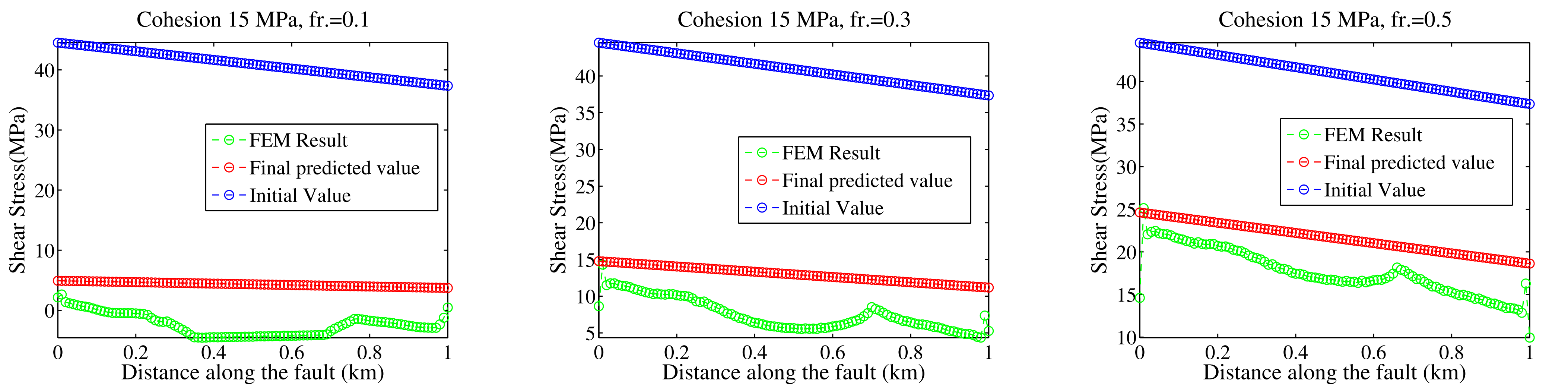

Figure 5: Calculated shear stresses along the fault, before and after slip. All cases has 15 MPa initial cohesion but different μ_r. Red circles shows the Final predicted value according to static modeling.

OVERSHOOT

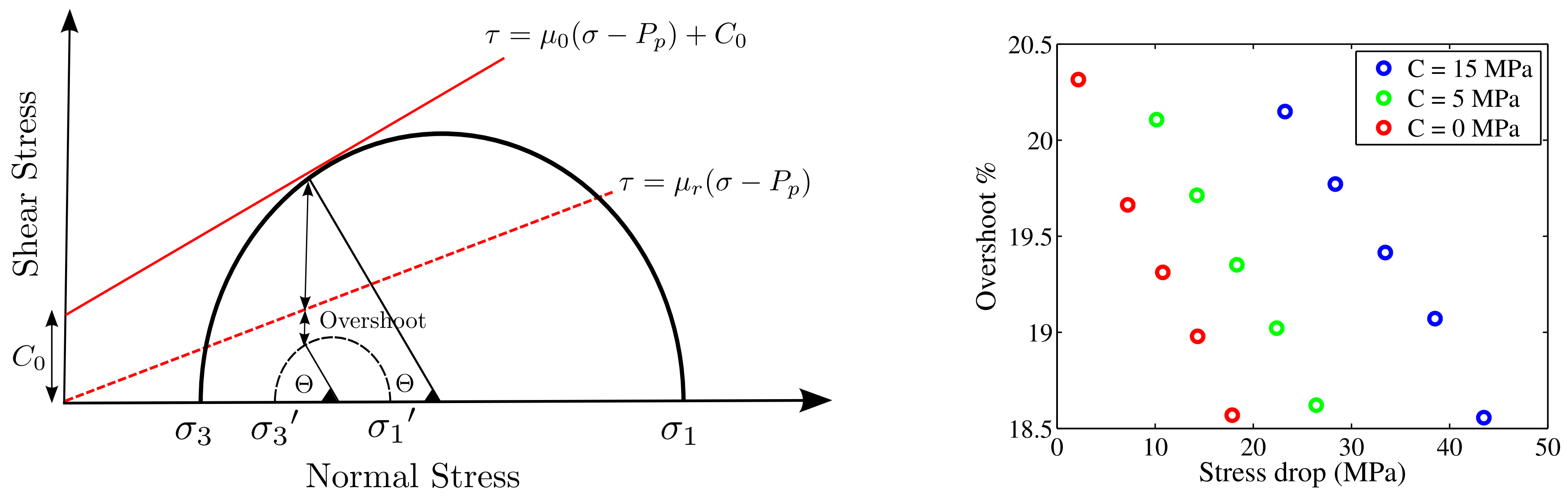

Figure 6: Left) Mohr circle representation of co-seismic stress drop according to our finite element modelling (FEM) results. The solid red line shows the initial Mohr-Coulomb failure criterion, while the dashed red line shows the fault strength after slip with reduced friction and cohesions. Similarly, the solid and dashed Mohr circles show the initial (critically stressed) and residual stress states for the fault, respectively. The black arrow shows the computed co-seismic stress drop, which is a pure reduction in shear stress with no change in normal stress. Right: Calculated overshoot for systems with different residual value of friction and cohesion.

SURFACE VERTICAL DISPLACEMENT

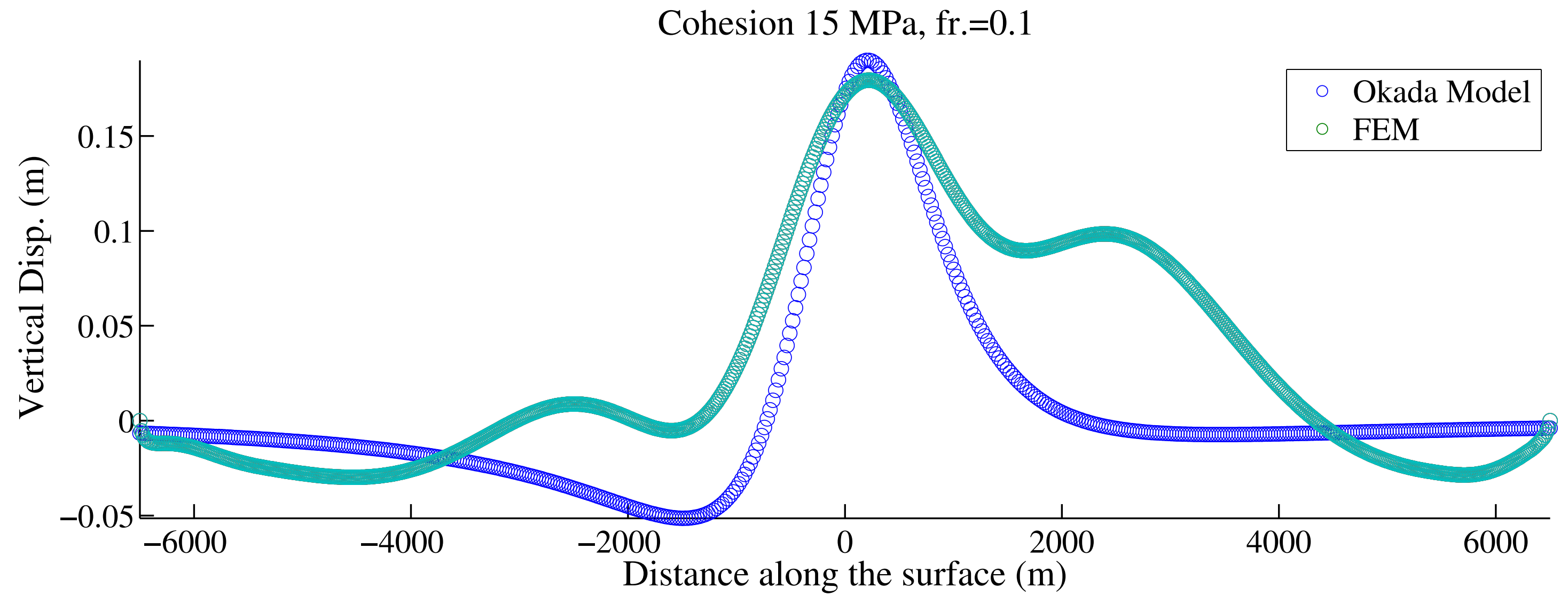

Figure 7: Blue circles show calculated surface vertical displacement using Okada model. Same slip pattern of the green FEM calculated result due to 15 MPa cohesion ,$\mu_r = 0.1$ and 1km depth, is used for Okada model.

SHAPE FACTOR

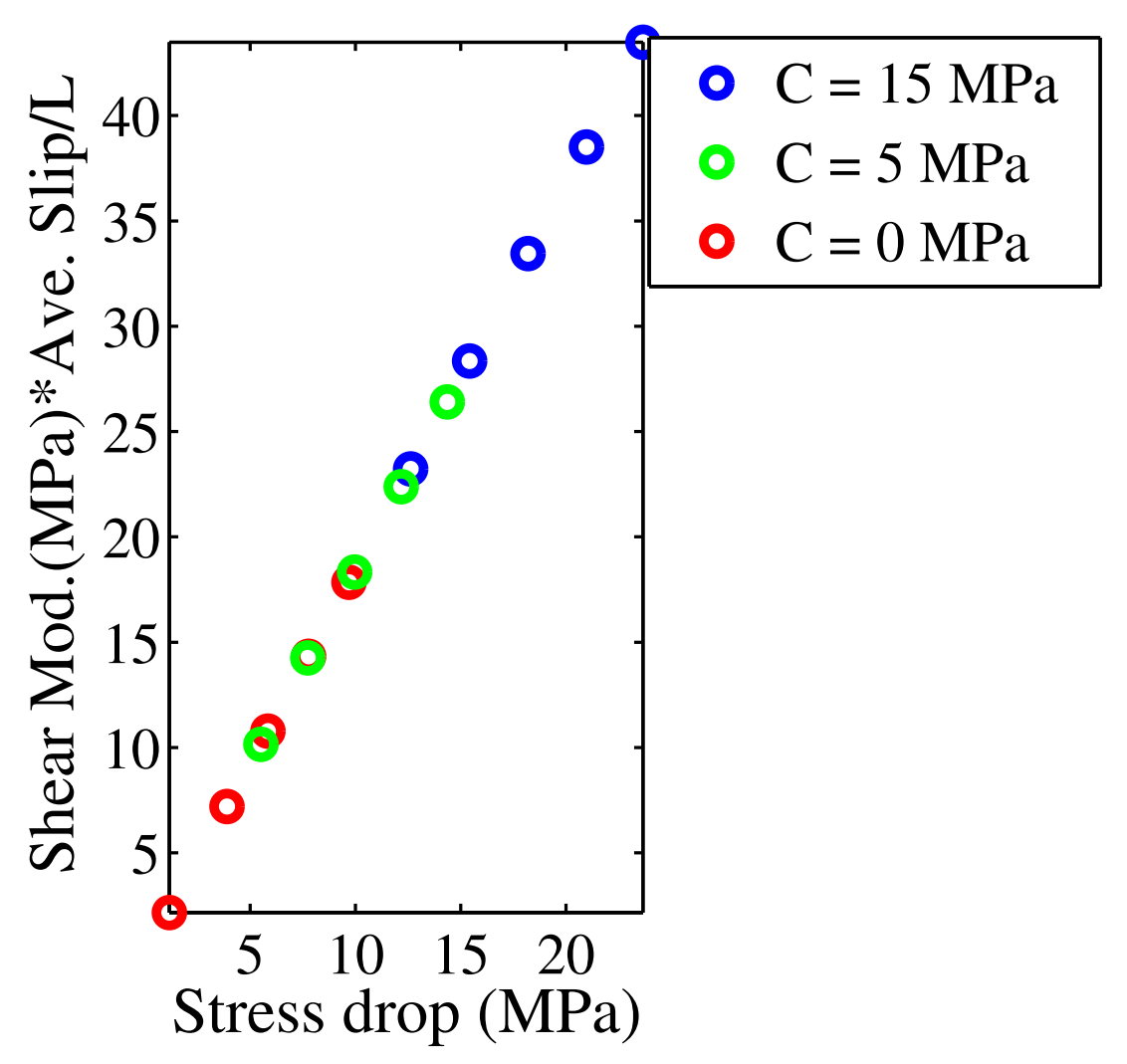

Figure 8: Linear relationship between stress drop and normalized average slip. The slope of this line is given by the product of shear modulus μ and a nondimensional fault shape factor, $C_{sp}\mu$. C_{sp} is 1.84.

CONCLUSION

- In our models, stress drop is determined by a reduction in friction and Cohesion.
- Normal stress of fault does not change due to slip.
- Slip pattern on fault is symmetric and has the maximum value in the middle. Our model has the shape factor of 1.84.
- Shear stress drop pattern on the fault shows amount of overshoot in our modeling, which is higher in the middle of the fault. An average of 19 percent of overshoot is shown. Also shear stress reversal can be observed for high stress drop.
- Asymmetric movement of particles around fault is shown which is due to broken symmetry by having a free surface.
- Dynamic modeling shows a difference for the same slip pattern on fault compare to Okada model.

ACKNOWLEDGMENTS

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