A parametric study on the effect of horizontal and vertical location parameters on surface deformation due to a buried tensile fault

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INTRODUCTION & AIM

- Continuum mechanics, in which matter is approximated as a continuously distributed medium, provides the general conceptual framework for analysing elastic deformations in a solid. The elastic dislocation theory allows to determine deformation of an elastic medium due to slip localized on a fault. The theory is widely used to model geodetic strain due to co-seismic or inter-seismic deformation. Deformations of the medium can be described by a three-dimensional, time-dependent displacement field u(x,t) and the associated infinitesimal symmetric strain tensor $e_{ij}=(u_{i,j}+u_{j,i})/2$. But for the mathematical description of the static deformation of the earth's crust, two-dimensional dislocation models have been developed by several investigators. Dislocation theories have been applied as the main tool in the mathematical and physical description of mechanics of earthquakes.

- In the present study, a detailed parametric investigation is carried out to examine the influence of the horizontal and vertical location parameters d_1 and d_2 on surface deformation caused by a long inclined tensile fault located at an arbitrary position (d_1,d_2) in a homogeneous isotropic elastic half-space, where d_1 denotes the horizontal distance of the upper edge of the fault and d_2 denotes the burial depth of the upper edge of the fault. Closed-form analytical expressions for displacement components from Singh et al., 2016, are utilized to analyse the sensitivity of horizontal and vertical surface displacements with respect to variations in fault position.

METHOD

Consider a two-dimensional plane strain problem in which the displacement components $u_i (i = 1,2,3)$ are independent of x_1 such that $\partial/\partial x_1 \equiv 0$. The stresses and displacements in terms of the Airy Stress function U are given by

$$\tau_{22} = \frac{\partial^2 U}{\partial x_3^2}, \tau_{23} = -\frac{\partial^2 U}{\partial x_2 \partial x_3}, \tau_{33} = \frac{\partial^2 U}{\partial x_2^2}, \quad (1)$$

$$\nabla^2\nabla^2 U = 0, \quad (2)$$

where τ_{ij} $(i,j = 2,3)$ are the components of stress and $\nabla^2 \equiv \frac{\partial^2}{\partial x_2^2} + \frac{\partial^2}{\partial x_3^2}$,

and

$$2\mu u_2 = -\frac{\partial U}{\partial x_2} + \frac{1}{2\alpha}\int \nabla^2 U dx_2,$$
$$2\mu u_3 = -\frac{\partial U}{\partial x_3} + \frac{1}{2\alpha}\int \nabla^2 U dx_3, \quad (3)$$

where u_i are displacement components and $\alpha = \frac{\lambda+\mu}{\lambda+2\mu} = \frac{1}{2(1-\sigma)}$, $\sigma =$ Poisson's Ratio, $\mu =$ Rigidity.

The traction-free boundary conditions are

$$\tau_{23} = \tau_{33} = 0 \text{ at } x_3 = 0.$$

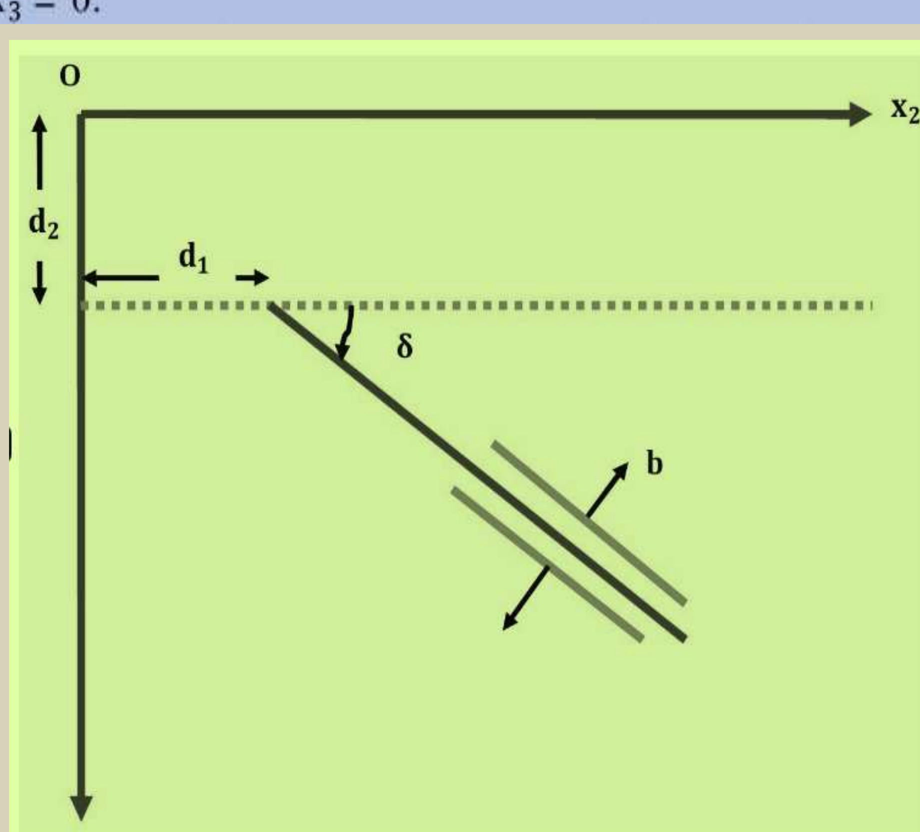


Figure 1. Geometry of a blind tensile fault of infinite length and finite depth at an arbitrary location (d_1, d_2) below the eath surface.

RESULTS & DISCUSSION

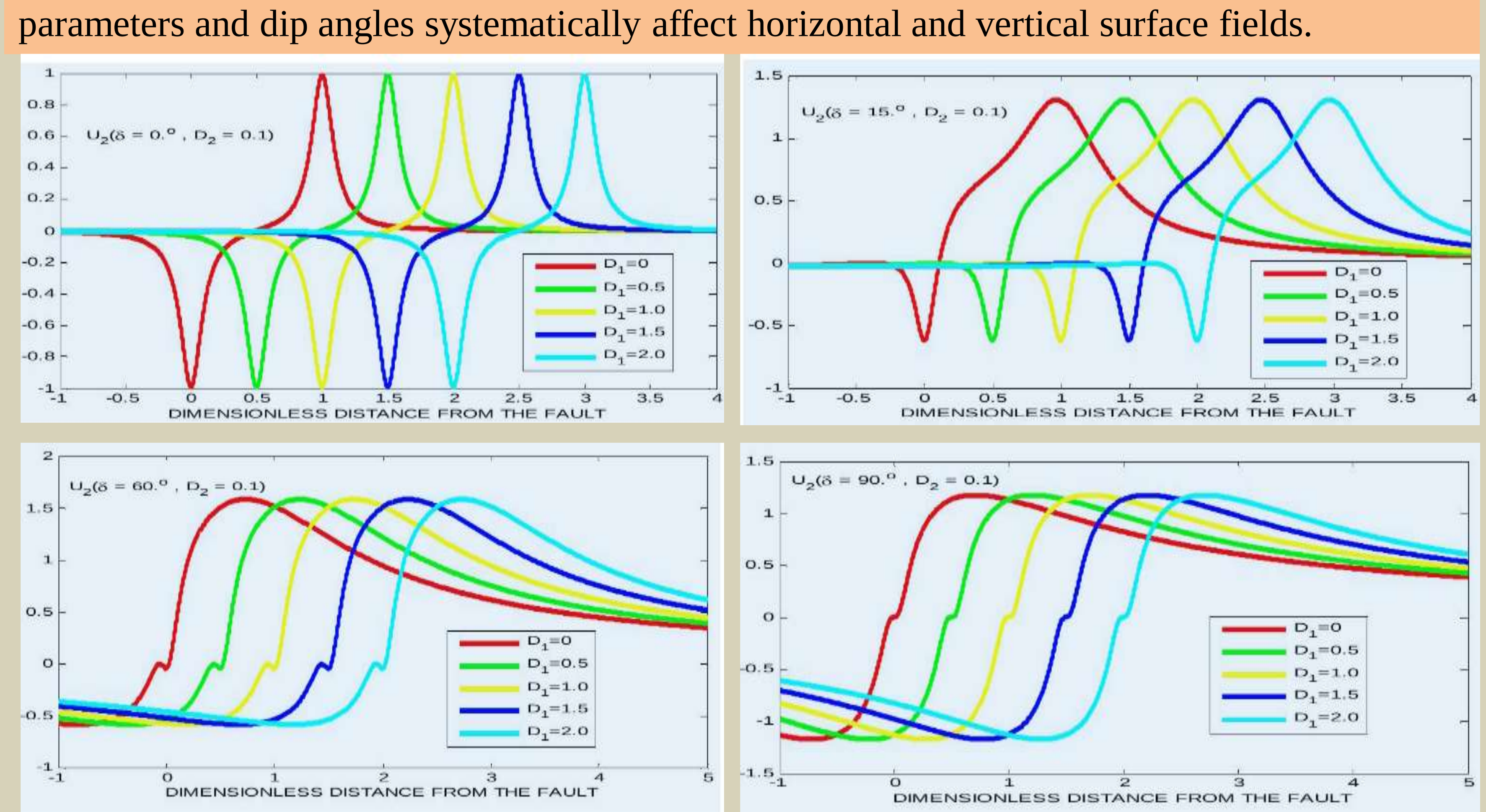
The Airy stress function for an inclined tensile fault of finite width L and infinite length placed at an arbitrary position (d_1, d_2) (where d_1 is the distance from x_3-axis and d_2 is the distance from x_2 −axis) in a uniform half-space $x_3 \geq 0$ is obtained as:

$$U = \frac{\mu b}{2\pi(1-\sigma)}\left[\{s - X_2\cos\delta - X_3\sin\delta\}\log\left(\frac{S}{R}\right) + \frac{2x_3\{X_2(X_2\sin\delta + d_2\cos\delta) + x_3X_3'\sin\delta\}}{S^2} + \frac{2sx_3\{(X_3'\sin\delta - X_2\cos\delta)\sin\delta - d_2\}}{S^2}\right]\Bigg|_{s_1}^{s_2}, \quad (4)$$

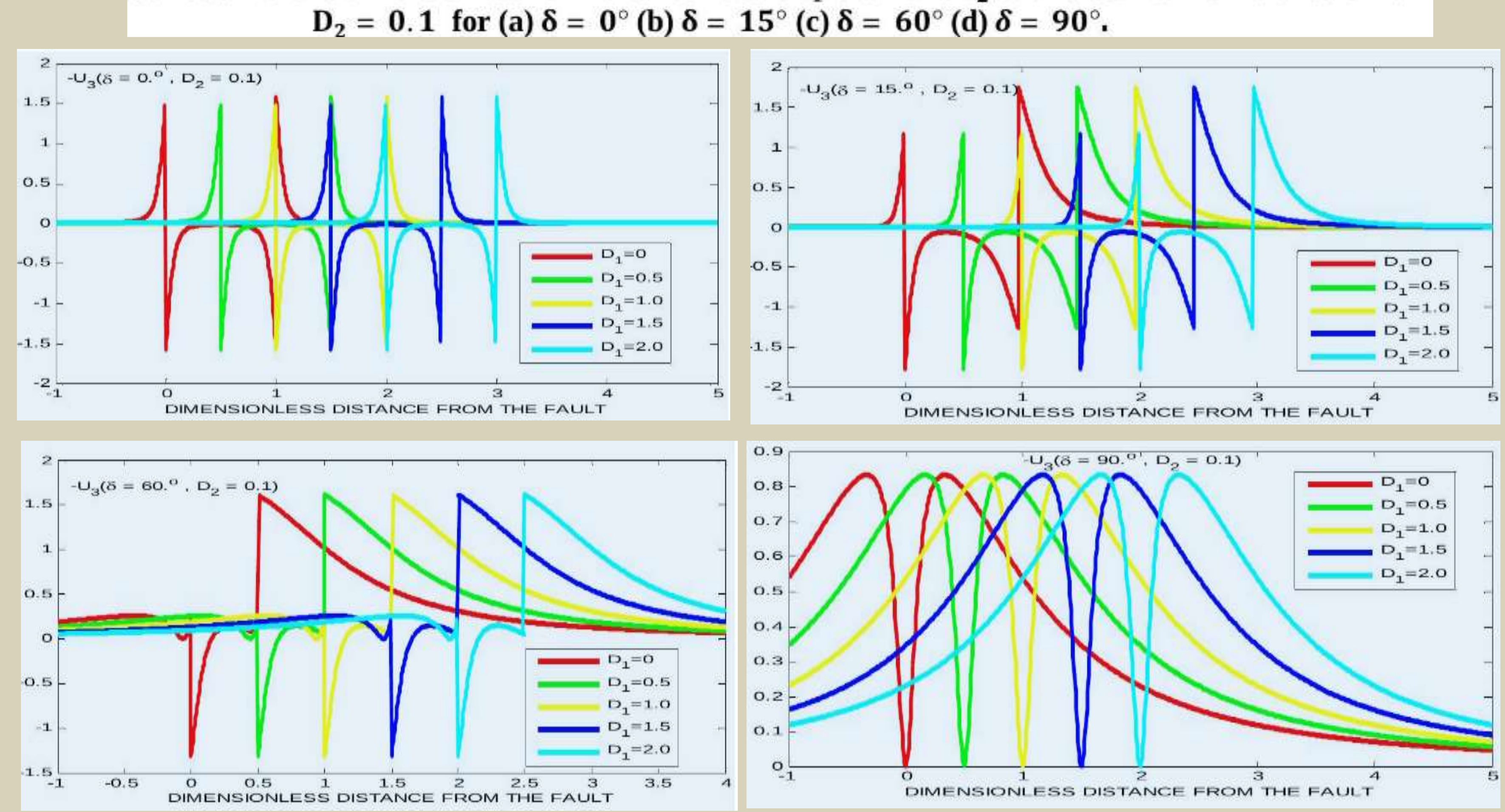
where

$$X_2 = x_2 - d_1,\ X_3 = x_3 - d_2,\ X_3' = x_3 + d_2,$$
$$R^2 = (X_2 - sco\delta)^2 + (X_3 - s\sin\delta)^2,$$
$$S^2 = (X_2 - s\cos\delta)^2 + (X_3' + s\sin\delta)^2. \quad (5)$$

The stresses and displacements are derived using equations (1) and (3). The specific parameters and dimensionless variables are used to generalize the given mathematical model. For the numerical simulations, Poisson's ratio (σ) is set to ¼, a standard value for many crustal rocks and elastic materials. The figures are drawn to map out how buried depth parameters and dip angles systematically affect horizontal and vertical surface fields.



Variation of the dimensionless horizontal surface displacement U_2 with distance from the fault for $D_2 = 0.1$ for (a) $\delta = 0°$ (b) $\delta = 15°$ (c) $\delta = 60°$ (d) $\delta = 90°$.



Variation of the dimensionless surface uplift $-U_3$ with distance from the fault for $D_2 = 0.1$ for (a) $\delta = 0°$ (b) $\delta = 15°$ (c) $\delta = 60°$ (d) $\delta = 90°$.

CONCLUSION

It is shown that in a uniform elastic half-space, deformation is invariant under horizontal translation, i.e., the horizontal parameter d_1 produces only a translational shift in the deformation field without altering its amplitude. In contrast, deformation is highly sensitive to burial depth, i.e., the burial depth parameter d_2 significantly affects the magnitude, decay rate, and spatial distribution of deformation. The results demonstrate that in physical interpretations, a deeper tensile fault produces weaker surface deformation and shallow tensile faults produce intense surface deformation, while moving the fault sideways only shifts the deformation zone. Further, the effect of dip angle is also considered in the analysis of this study. The scientists use satellite data (InSAR & GPS) and compare it to the theoretical curves as plotted above. If the satellite data shows a very sharp cliff-like jump in the ground surface, the mathematical model reveals that the fault parameters d_1 and d_2 are very small. If the satellite shows a wide, gentle, smooth mound, the fault is deeply buried.

FUTURE WORK / REFERENCES

The present mathematical model may be further generalized by incorporating more realistic earth properties associated with non-planar fault geometries within heterogeneous, layered and anisotropic half-spaces.

[1] Bonafede, M. & Rivalta, E., 1999. The tensile dislocation problem in a layered elastic medium, Geophys. J. Int., 136, 341-356.
[2] Singh, M. & Singh, S.J., 2000. Static deformation of a uniform half-space due to a very long tensile fault, ISET J. Earthq. Techn., 37, 27-38.