2-D deformation of two welded half-spaces due to a blind dip-slip fault

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The solution of two-dimensional problem of an interface breaking long inclined dip-slip fault in two welded half-spaces is well known. The purpose of this note is to obtain the corresponding solution for a blind fault. The solution is valid for arbitrary values of the fault-depth and the dip angle. Graphs showing the variation of the displacement field with the distance from the fault, for different values of fault depth and dip angle are presented. Contour maps showing the stress field around a long dip-slip fault are also obtained.

1. Introduction

The sites of most earthquakes are along geological faults which are surfaces of material discontinuity in the Earth. To study the effect of faulting at a material discontinuity, the two half-space model is considered by several investigators, e.g., Rongved (1955); Dundurs and Hetényi (1965); Heaton and Heaton (1989); Kumari *et al* (1992); Singh *et al* (1993); Rani *et al* (1995); Tinti and Armigliato (1998a, b); Singh *et al* (2000), etc. for the three-dimensional case. For the two-dimensional case, Ben-Zion (1989) calculated the response of two quarter half-spaces to an SH line dislocation at the material interface and found that the resulting wavefield differs from the corresponding wavefield in a homogeneous half-space. Singh and Rani (1991) obtained analytical expressions for the displacements and the stresses at any point of a two-phase medium consisting of a homogeneous, elastic, isotropic half-space in welded contact with a homogeneous, elastic, orthotropic half-space due to two-dimensional seismic sources located in the isotropic half-space. Singh *et al* (1992) considered both the half-spaces to be isotropic. Integrating the results of Singh *et al* (1992), Rani and Singh (1992) obtained analytic expressions for the residual field due to an inclined dip-slip fault of finite

width. Recently, Kumar *et al* (2005) obtained the corresponding problem for a long inclined tensile fault of finite width.

In the model used by Rani and Singh (1992), the depth d of the upper edge of the fault does not occur explicitly in the solution. Moreover, as the dip angle tends to zero, the fault approaches the interface of the half-spaces. Therefore, their results cannot be used to study the deformation of two half-spaces caused by deep dip-slip faults of small dip angles. The purpose of the present paper is to obtain an analytical solution for the problem of a long blind dip-slip fault located in the lower half-space welded with another half-space. The depth d occurs explicitly in the solution. Therefore, the effect of the variation in the depth for a fixed dip and *vice versa* can be studied directly. Figures showing the effect of variation in the depth d on the displacement and stress field are presented.

2. Theory

Let the Cartesian coordinates be denoted by (x_1, x_2, x_3) with the x_3 -axis vertically downwards. We consider two homogeneous, isotropic, perfectly elastic half-spaces that are welded along the plane $x_3 = 0$. The upper half-space ($x_3 < 0$) is called

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Figure 1. Two half-spaces in welded contact with a long dip-slip fault of width L situated in the lower half space. d is the depth of upper edge A of the fault, δ is the dip angle and s is the distance from the upper edge of the fault measured in the down-dip direction. Half arrow denotes the slip direction indicating a reverse fault.

medium I and the lower half-space ($x_3 > 0$) is called medium II, with Lamé constants λ_1, μ_1 and λ_2, μ_2 respectively. In the following, the superscript (1) denotes the quantities related to medium I and the superscript (2) those related to medium II. A long inclined dip-slip fault parallel to x_1 -axis is situated in the medium II. The upper edge of the fault is taken to be at depth d (figure 1).

Following Rani and Singh (1992), we obtain the following expressions for the Airy stress functions due to an inclined dip-slip fault of finite width L and infinite length under the assumption of plane-strain problem:

$$\begin{aligned}
 U^{(1)} = & \frac{\alpha_2 \mu_2 b}{2\pi} \left[\{(C_1 - D_1)(X' \cos \delta - x_2 \sin \delta) \right. \\
 & + (C_1 + D_1)s \sin 2\delta + 4dD_1 \cos \delta\} \ln R \\
 & - C_1 s \sin 2\delta + (C_1 + D_1)(x_2 \cos \delta + X' \sin \delta) \\
 & \times \tan^{-1} \left(\frac{s - x_2 \cos \delta - X \sin \delta}{x_2 \sin \delta - X \cos \delta} \right) \\
 & \left. - (C_1 + D_1)s \cos 2\delta \tan^{-1} \left(\frac{x_2 - s \cos \delta}{X - s \sin \delta} \right) \right] \Bigg|_0^L, \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 U^{(2)} = & \frac{\alpha_2 \mu_2 b}{\pi} \left[(x_2 \sin \delta - X \cos \delta) \ln R \right. \\
 & + \{(C_2 + D_2)(x_2 \sin \delta - X \cos \delta) \\
 & - 2D_2 \cos \delta(d + s \sin \delta)\} \ln S \\
 & + (D_1 + 2D_2)s \sin \delta \cos \delta \\
 & - D_2 s \cos 2\delta \tan^{-1} \left(\frac{x_2 - s \cos \delta}{X' + s \sin \delta} \right) \\
 & - D_2(x_2 \cos \delta + X' \sin \delta) \\
 & \times \tan^{-1} \left(\frac{s + X' \sin \delta - x_2 \cos \delta}{x_2 \sin \delta + X' \cos \delta} \right) \\
 & \left. - 2C_2 x_3(x_2 \sin \delta + X' \cos \delta) \left(\frac{d + s \sin \delta}{S^2} \right) \right] \Bigg|_0^L, \quad (2)
 \end{aligned}$$

where

b = displacement discontinuity (slip),

δ = dip angle,

$$X = x_3 - d, \quad X' = x_3 + d,$$

$$R^2 = (x_2 - s \cos \delta)^2 + (X - s \sin \delta)^2,$$

$$S^2 = (x_2 - s \cos \delta)^2 + (X' + s \sin \delta)^2,$$

$$\beta = \frac{\mu_1}{\mu_2},$$

$$\alpha_1 = \frac{(\lambda_1 + \mu_1)}{(\lambda_1 + 2\mu_1)},$$

$$\alpha_2 = \frac{(\lambda_2 + \mu_2)}{(\lambda_2 + 2\mu_2)},$$

$$C_1 = 2\beta[\alpha_2(1 - \beta - 2/\alpha_1)]^{-1},$$

$$C_2 = (\beta - 1)(1 - \beta + 2\beta/\alpha_2)^{-1},$$

$$D_1 = 1 + C_2,$$

$$D_2 = -\frac{(C_1 + D_1)}{2},$$

$$f(s) \Big|_0^L = f(L) - f(0). \quad (3)$$

3. Stresses and displacements

The stresses and displacements at any point of two half-spaces in term of Airy stress function are given by (Rani *et al* 1991)

$$\begin{aligned}
 p_{22}^{(i)} = & \frac{\partial^2 U^{(i)}}{\partial x_3^2}, \quad p_{23}^{(i)} = -\frac{\partial^2 U^{(i)}}{\partial x_2 \partial x_3}, \quad p_{33}^{(i)} = \frac{\partial^2 U^{(i)}}{\partial x_2^2}, \quad (4)
 \end{aligned}$$

$$2\mu_i u_2^{(i)} = -\frac{\partial U^{(i)}}{\partial x_2} + \frac{1}{2\alpha_i} \int (p_{22}^{(i)} + p_{33}^{(i)}) dx_2,$$

$$2\mu_i u_3^{(i)} = -\frac{\partial U^{(i)}}{\partial x_3} + \frac{1}{2\alpha_i} \int (p_{22}^{(i)} + p_{33}^{(i)}) dx_3, \quad (5)$$

(no summation over $i, i = 1, 2$).

From equations (1)–(2) and (4)–(5), we get the following expressions for the stresses and the displacements. For the medium I,

$$p_{22}^{(1)} = \frac{\alpha_2 \mu_2 b}{2\pi} \left[\{C_1(5X \cos \delta - 3x_2 \sin \delta + 2d \cos \delta) - D_1(x_2 \sin \delta + X \cos \delta - 2d \cos \delta - 2s \sin 2\delta)\} \right. \\ \left. \times \frac{1}{R^2} + 4(X - s \sin \delta)(x_2 \sin \delta - X \cos \delta) \right. \\ \left. \times \{C_1 x_3 + D_1(d + s \sin \delta)\} \frac{1}{R^4} \right] \Bigg|_0^L, \quad (6)$$

$$p_{23}^{(1)} = \frac{\alpha_2 \mu_2 b}{2\pi} \left[\{(D_1 - C_1)(x_2 \cos \delta - X' \sin \delta - s) - 4C_1 x_3 \sin \delta\} \frac{1}{R^2} + 4(X - s \sin \delta) \right. \\ \left. \times (x_2 \cos \delta + X \sin \delta - s) \right. \\ \left. \times \{C_1 x_3 + D_1(d + s \sin \delta)\} \frac{1}{R^4} \right] \Bigg|_0^L, \quad (7)$$

$$p_{33}^{(1)} = \frac{\alpha_2 \mu_2 b}{2\pi} \left[\{(D_1 - C_1)(x_2 \sin \delta + X' \cos \delta) - 4D_1 \cos \delta(d + s \sin \delta)\} \frac{1}{R^2} \right. \\ \left. + 4(X - s \sin \delta)(X \cos \delta - x_2 \sin \delta) \right. \\ \left. \times \{C_1 x_3 + D_1(d + s \sin \delta)\} \frac{1}{R^4} \right] \Bigg|_0^L, \quad (8)$$

$$2\mu_1 u_2^{(1)} = \frac{\alpha_2 \mu_2 b}{2\pi} \left[\left(C_1 - D_1 - \frac{2C_1}{\alpha_1} \right) \sin \delta \ln R \right. \\ \left. - (C_1 + D_1) \cos \delta \right. \\ \left. \times \tan^{-1} \left(\frac{s - x_2 \cos \delta - X \sin \delta}{x_2 \sin \delta - X \cos \delta} \right) \right. \\ \left. + \left(\frac{2C_1}{\alpha_1} \right) \cos \delta \tan^{-1} \left(\frac{x_2 - s \cos \delta}{X - s \sin \delta} \right) \right. \\ \left. + 2\{C_1 x_3 + D_1(d + s \sin \delta)\} \right. \\ \left. \times \left(\frac{s - x_2 \cos \delta - X \sin \delta}{R^2} \right) \right] \Bigg|_0^L, \quad (9)$$

$$2\mu_1 u_3^{(1)} = \frac{\alpha_2 \mu_2 b}{2\pi} \left[\left(D_1 - C_1 + \frac{2C_1}{\alpha_1} \right) \cos \delta \ln R \right. \\ \left. - (C_1 + D_1) \sin \delta \right. \\ \left. \times \tan^{-1} \left(\frac{s - x_2 \cos \delta - X \sin \delta}{x_2 \sin \delta - X \cos \delta} \right) \right. \\ \left. - \left(\frac{2C_1}{\alpha_1} \right) \sin \delta \tan^{-1} \left(\frac{X - s \sin \delta}{x_2 - s \cos \delta} \right) \right. \\ \left. + 2(x_2 \sin \delta - X \cos \delta) \right. \\ \left. \times \{C_1 x_3 + D_1(d + s \sin \delta)\} \frac{1}{R^2} \right] \Bigg|_0^L. \quad (10)$$

For the medium II,

$$p_{22}^{(2)} = \frac{\alpha_2 \mu_2 b}{\pi} \left[(x_2 \sin \delta - 3X \cos \delta + s \sin 2\delta) \right. \\ \left. \times \left(\frac{1}{R^2} + \frac{C_2}{S^2} \right) - \{8C_2(d + s \sin \delta) \cos \delta \right. \\ \left. + D_2(x_2 \sin \delta + X' \cos \delta)\} \frac{1}{S^2} \right. \\ \left. - 2(x_2 \sin \delta - X \cos \delta) \right. \\ \left. \times \left\{ \frac{(X - s \sin \delta)^2}{R^4} + \frac{C_2(X' + s \sin \delta)^2}{S^4} \right\} \right. \\ \left. + 4C_2(d + s \sin \delta) \{(x_2 \sin \delta + X' \cos \delta \right. \\ \left. + x_3 \cos \delta)(3x_3 + 2d + 2s \sin \delta) - x_3^2 \cos \delta\} \right. \\ \left. \times \frac{1}{S^4} - 16C_2 x_3(d + s \sin \delta)(x_2 \sin \delta \right. \\ \left. + X' \cos \delta)(X' + s \sin \delta)^2 \frac{1}{S^6} \right] \Bigg|_0^L, \quad (11)$$

$$p_{23}^{(2)} = \frac{\alpha_2 \mu_2 b}{\pi} \left[(x_2 \cos \delta + X \sin \delta - s) \right. \\ \left. \times \left(\frac{1}{R^2} + \frac{C_2 + D_2}{S^2} \right) - \frac{2D_2 x_3 \sin \delta}{S^2} \right. \\ \left. + 2(s - x_2 \cos \delta - X \sin \delta) \right. \\ \left. \times \left\{ \frac{(X - s \sin \delta)^2}{R^4} + \frac{C_2(X' + s \sin \delta)^2}{S^4} \right\} \right. \\ \left. + 4C_2 x_3(d + s \sin \delta) \right. \\ \left. \times (s - x_2 \cos \delta + 3X' \sin \delta + 2s \sin^2 \delta) \frac{1}{S^4} \right. \\ \left. + 16C_2 x_3(x_2 \cos \delta - X' \sin \delta - s) \right. \\ \left. \times (d + s \sin \delta)(X' + s \sin \delta)^2 \frac{1}{S^6} \right] \Bigg|_0^L, \quad (12)$$

$$\begin{aligned}
p_{33}^{(2)} = & \frac{\alpha_2 \mu_2 b}{\pi} \left[(x_2 \sin \delta + X \cos \delta - s \sin 2\delta) \right. \\
& \left(\frac{1}{R^2} + \frac{C_2}{S^2} \right) + D_2 (x_2 \sin \delta + X' \cos \delta) \frac{1}{S^2} \\
& + 2(x_2 \sin \delta - X \cos \delta) \\
& \times \left\{ \frac{(X - s \sin \delta)^2}{R^4} + \frac{C_2 (X' + s \sin \delta)^2}{S^4} \right\} \\
& - 4C_2 x_3 (d + s \sin \delta) \\
& \times (x_2 \sin \delta + 3X' \cos \delta + s \sin 2\delta) \frac{1}{S^4} \\
& + 16C_2 x_3 (d + s \sin \delta) (X' + s \sin \delta)^2 \\
& \times (x_2 \sin \delta + X' \cos \delta) \frac{1}{S^6} \left. \right] \Bigg|_0^L, \quad (13)
\end{aligned}$$

$$\begin{aligned}
2\mu_2 u_2^{(2)} = & \frac{\alpha_2 \mu_2 b}{\pi} \left[- \left(1 - \frac{1}{\alpha_2} \right) \sin \delta \ln R \right. \\
& - \left(D_2 + C_2 - \frac{C_2}{\alpha_2} \right) \sin \delta \ln S \\
& - \frac{\cos \delta}{\alpha_2} \left\{ \tan^{-1} \left(\frac{x_2 - s \cos \delta}{X - s \sin \delta} \right) \right. \\
& + C_2 \tan^{-1} \left(\frac{x_2 - s \cos \delta}{X' + s \sin \delta} \right) \left. \right\} + D_2 \cos \delta \\
& \times \tan^{-1} \left(\frac{s - x_2 \cos \delta + X' \sin \delta}{x_2 \sin \delta + X' \cos \delta} \right) \\
& + (x_2 \cos \delta + X \sin \delta - s) \\
& \times \left\{ \frac{X - s \sin \delta}{R^2} + \frac{C_2 (X' - s \sin \delta)}{S^2} \right\} \\
& + 2C_2 (s - x_2 \cos \delta + X' \sin \delta) \\
& \times \left\{ d - \left(\frac{1}{\alpha_2} \right) (d + s \sin \delta) \right\} \frac{1}{S^2} \\
& + 2C_2 x_3 \sin \delta (s \sin \delta - d) \frac{1}{S^2} \\
& + 4C_2 x_3 (s - x_2 \cos \delta + X' \sin \delta) \\
& \times (d + s \sin \delta) (X' + s \sin \delta) \frac{1}{S^4} \left. \right] \Bigg|_0^L, \quad (14)
\end{aligned}$$

$$\begin{aligned}
2\mu_2 u_3^{(2)} = & \frac{\alpha_2 \mu_2 b}{\pi} \left[\left(1 - \frac{1}{\alpha_2} \right) \cos \delta \ln R \right. \\
& + \left(D_2 + C_2 - \frac{C_2}{\alpha_2} \right) \cos \delta \ln S \\
& + \frac{\sin \delta}{\alpha_2} \left\{ \tan^{-1} \left(\frac{X - s \sin \delta}{x_2 - s \cos \delta} \right) \right.
\end{aligned}$$

$$\begin{aligned}
& + C_2 \tan^{-1} \left(\frac{X' + s \sin \delta}{x_2 - s \cos \delta} \right) \left. \right\} \\
& + D_2 \sin \delta \tan^{-1} \left(\frac{s - x_2 \cos \delta + X' \sin \delta}{x_2 \sin \delta + X' \cos \delta} \right) \\
& - (x_2 \sin \delta - X \cos \delta) \\
& \times \left\{ \frac{X - s \sin \delta}{R^2} + \frac{C_2 (X' + s \sin \delta)}{S^2} \right\} \\
& + 2C_2 (d + s \sin \delta) \left\{ \left(1 - \frac{1}{\alpha_2} \right) \right. \\
& \times (x_2 \sin \delta + X' \cos \delta) + x_3 \cos \delta \left. \right\} \frac{1}{S^2} \\
& - 4C_2 x_3 (d + s \sin \delta) (x_2 \sin \delta + X' \cos \delta) \\
& \times (X' + s \sin \delta) \frac{1}{S^4} \left. \right] \Bigg|_0^L. \quad (15)
\end{aligned}$$

On substituting $d = 0$ in equation (6)–(15), the results coincide with the corresponding expressions for the interface breaking fault given by Rani and Singh (1992).

4. Numerical results

To examine the effect of the depth d of the upper edge of the fault in the variation of the displacement and stress field, we assume the half-spaces to be Poissonian (i.e., $\lambda_i = \mu_i$; $i = 1, 2$) so that $\alpha_1 = \alpha_2 = 2/3$, $C_1 = -3\beta/(2 + \beta)$, $D_1 = 3\beta/(1 + 2\beta)$. For numerical computations we take $\beta = 1/2$. Further, as shown in figure 1, we assume a reverse dip-slip fault of dip $\delta = 0^\circ, 5^\circ$ and 15° .

Figure 2(a) shows the variation of normalized horizontal displacement (u_2/b) at the interface with the normalized distance from the upper edge of the fault (x_2/L) for a horizontal dip-slip fault for three values of $d = L/10, L/2$ and L . In this case, the horizontal displacement is symmetric about the interface point vertically above the mid-point of the fault. Figures 2(b) and 2(c) are for $\delta = 5^\circ$ and $\delta = 15^\circ$ for four different values of fault depth $d = 0, L/10, L/2$ and L . For an interface breaking fault, the normalized horizontal displacement (u_2/b) is discontinuous at the origin (upper edge of the fault). Figures 3(a) to 3(c) show the variation of dimensionless vertical (positive downwards) displacement (u_3/b) at the interface with the dimensionless horizontal distance from the fault (x_2/L) for three dip angles $\delta = 0^\circ, 5^\circ$ and 15° . Figure 3(a) is for a horizontal dip-slip fault with dislocation in

Figure 2. Variation of the normalized horizontal displacement (u_2/b) at the interface with the normalized distance from the fault (x_2/L) assuming $\mu_1/\mu_2 = 1/2$ for various values of depth d of the upper edge of the fault for (a) $\delta = 0^\circ$, (b) $\delta = 5^\circ$ and (c) $\delta = 15^\circ$.

Figure 3. Variation of the normalized vertical displacement (u_3/b , positive downwards) at the interface with the normalized distance from the fault (x_2/L) assuming $\mu_1/\mu_2 = 1/2$ for various values of depth d of the upper edge of the fault for (a) $\delta = 0^\circ$, (b) $\delta = 5^\circ$ and (c) $\delta = 15^\circ$.

Figure 4. Contour map for the stress component $P_{22}^{(i)} [= p_{22}^{(i)} / (\mu_2 b / L)]$, $(i = 1, 2)$ for $\mu_1 / \mu_2 = 1/2$ for $\delta = 15^\circ$ for the depth (a) $d = 0$, (b) $d = L/2$ and (c) $d = L$. Solid lines denote positive values and dashed lines denote negative values. Heavy line indicates the fault.

Figure 5. (Continued)

Figure 6. Contour map for the stress component $P_{33}^{(i)} [= p_{33}^{(i)} / (\mu_2 b / L)]$, ($i = 1, 2$) for $\mu_1 / \mu_2 = 1/2$ for $\delta = 15^\circ$ for the depth (a) $d = 0$, (b) $d = L/2$ and (c) $d = L$.

Figure 6. (Continued)

the vertical direction. In this case, the vertical displacement is asymmetric about the interface point vertically above the mid point of the fault. As the depth increases, the maximum vertical displacement decreases. Figures 3(b) and 3(c) are for $\delta = 5^\circ$ and 15° , respectively. For the interface breaking fault, the displacement is discontinuous at the origin but for the blind fault, it is continuous.

Contour maps in vertical planes perpendicular to the length of the fault for stress field are given in figures 4–6 for $\delta = 15^\circ$. The horizontal line is the distance from the fault in units of (x_2/b) and the vertical line, taken downwards is depth in units of (x_3/b) . The contour values for the isolines are indicated. Solid lines denote positive values and dashed lines denote negative values. Heavy line indicates the fault. Figures 4(a)–4(c) exhibit the plot of the stress component $P_{22}^{(i)} [= p_{22}^{(i)}/(\mu_2 b/L)]$, ($i = 1, 2$) for $d = 0, L/2$ and L respectively. The case $d = 0$ corresponds to the interface breaking fault whereas the case $d = L/2$ and L correspond to the blind fault. We observe that the maps for interface breaking fault and blind fault differ significantly. Figures 5(a)–5(c) are for the stress component $P_{23}^{(i)} [= p_{23}^{(i)}/(\mu_2 b/L)]$, ($i = 1, 2$) for $d = 0, L/2$ and L respectively. Figures 6(a)–6(c) display the stress component $P_{33}^{(i)} [= p_{33}^{(i)}/(\mu_2 b/L)]$, ($i = 1, 2$). In the results of Rani and Singh (1992), however the source location can be changed with ease but as

the dip angle decreases, the depth d decreases. For $\delta = 0^\circ$, the fault approaches the interface. Hence the depth d depends upon the dip angle. In the present paper the elastic field is obtained for arbitrary values of fault depth and the dip angle.

5. Discussion

We have obtained the analytical expressions for the displacements and the stresses at any point of the two welded half-spaces caused by a long dip-slip fault of dip δ and width L located in one of the half-spaces, buried at arbitrary depth. The results for a long dip-slip fault in a uniform half-space (medium II) follow as a particular case on putting $\mu_1 = 0$ which implies $\beta = 0, C_2 = -1, C_1 = D_1 = D_2 = 0$. It has been verified that the results obtained on putting $\mu_1 = 0$ in equations (6)–(15) coincide with the corresponding results of Tomar and Dhiman (2003) for a uniform half-space.

The displacements given by equations (9)–(10) and (14)–(15) have been obtained by integrating the strains. This integrating process introduces arbitrary additive constants which are required to obtain the necessary continuity conditions. However, these constants pose no problem since the integrals are definite, so these constants get cancelled.

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References

- Ben-Zion Y 1989 The response of two joined quarter spaces to SH line sources located at the material discontinuity interface; *Geophys. J. Int.* **98** 213–222.
- Dundurs J and Hetényi M 1965 Transmission of force between two semi-infinite solids; *ASME J. Appl. Mech.* **32** 671–674.
- Heaton T H and Heaton R E 1989 Static deformation from point forces and point force couples located in welded elastic Poissonian half-spaces: Implications for seismic moment tensor; *Bull. Seismol. Soc. Am.* **79** 813–841.
- Kumar A, Singh S J and Singh J 2005 Deformation of two welded elastic half-spaces due to a long inclined tensile fault; *J. Earth Syst. Sci.* **114** 97–103.
- Kumari G, Singh S J and Singh K 1992 Static deformation of two welded elastic half-spaces caused by a point dislocation source; *Phys. Earth Planet. Int.* **73** 53–76.
- Rani S and Singh S J 1992 Static deformation of two welded half-spaces due to dip-slip faulting; *Proc. Indian Acad. Sci. (Earth Planet. Sci.)* **101** 269–282.
- Rani S, Singh S J and Garg N R 1991 Displacements and stresses at any point of a uniform half-space due to two-dimensional buried sources; *Phys. Earth Planet. Int.* **65** 276–282.
- Rani S, Singh S J and Kumari G 1995 Static deformation of two welded elastic half-spaces caused by a rectangular fault located on the interface; *Phys. Earth Planet. Int.* **92** 261–269.
- Rongved L 1955 Force interior to one of two joined semi-infinite solids; In: Proceedings of the 2nd Midwestern Conference on Solid Mechanics, Purdue University, Indiana, (ed.) Bogdanoff J L, *Res. Ser.* **129** 1–13.
- Singh S J, Kumari G and Singh K 1993 Static deformation of two welded elastic half-spaces caused by a finite rectangular fault; *Phys. Earth Planet. Int.* **79** 313–333.
- Singh S J, Kumari G, Singh K and Rani S 2000 Deformation of two welded half-spaces due to inclined shear and tensile point dislocations and a centre of dilation; *Phys. Earth Planet. Int.* **122** 251–267.
- Singh S J and Rani S 1991 Static deformation due to two-dimensional seismic sources embedded in an isotropic half-space in welded contact with an orthotropic half-space; *J. Phys. Earth* **39** 599–618.
- Singh S J, Rani S and Garg N R 1992 Displacements and stresses in two welded half-spaces due to two-dimensional sources; *Phys. Earth Planet. Int.* **70** 90–101.
- Tinti S and Armigliato A 1998a Single force point source static fields: an exact solution for two elastic half-spaces; *Geophys. J. Int.* **135** 607–626.
- Tinti S and Armigliato A 1998b Displacements and stresses induced by a point source across a plane interface separating two elastic semi-infinite spaces: an analytical solution; *J. Geophys. Res.* **103** 15,109–15,125.
- Tomar S K and Dhiman N K 2003 2-D deformation analysis of a half-space due to a long dip-slip fault at finite depth; *Proc. Indian Acad. Sci. (Earth Planet. Sci.)* **112** 587–596.