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Displacements in Two Welded Monoclinic Half-Spaces due to a Non-Uniform Slip Along a Very Long Strike-Slip Fault

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Abstract

In this paper, we will obtain the closed form analytical expression for displacements in a monoclinic welded half-spaces caused by non-uniform slip on vertical strike-slip fault of infinite length and finite depth. Four slip profile are consider: Linear $b = b_0(1 - s/L)$, Parabolic $b = b_0(1 - s^2/L^2)$, Elliptic $b = b_0(1 - s^2/L^2)^{1/2}$, Cubic $b = b_0(1 - s^2/L^2)^{3/2}$, where b is the slip at distance at distance h from the surface, b_0 is the surface slip and L is the fault depth.

Keywords Monoclinic, finite width, non-uniform, welded half-space

Introduction

The elastic field in isotropic and orthotropic medium due to a strike-slip fault has been studied by various investigators. Kumar, Singh and Singh[2, 3] obtained the green function for monoclinic half-space and also for a monoclinic half-space in welded contact with another monoclinic half-space. Kumar, Singh and Singh[1, 4] used the results of Ting [6] to obtain the closed-form analytical expression for displacements in monoclinic half-space and in monoclinic welded half-spaces due to a strike-slip fault of infinite length and of finite depth L. However, these studies assumed non-uniform slip on the fault. Singh and Rani [3, 5] obtained the closed form analytical expression for displacement for an isotropic half-space and two welded isotropic half-spaces for a non-uniform slip. Further, Madan, Singh, Aggrawal and Gupta[2] obtained displacements for an orthotropic half-space for a non-uniform slip. Now, the purpose of this paper is to study the effect of non-uniform slip on the elastic field caused by a vertical strike-slip fault in a monoclinic half-space in welded contact with another monoclinic half-space. In this paper, we have obtain closed form analytical expressions for the displacements caused by a non-uniform slip on long, vertical strike-slip fault. We consider four slip-profiles: Linear, Parabolic Elliptic and Cubic. In this paper, we consider that the slip b decreases from a value b_0 at the surface to zero at the depth L.

Monoclinic Welded Half-Spaces

Consider two homogeneous, monoclinic half-spaces that are welded along the plane $x_2 = 0$. The lower half space $x_2 > 0$ is called medium I and the upper half space $x_2 < 0$ is called medium II with stiffnesses $c_{ij}^{(1)}$ and $c_{ij}^{(2)}$ respectively. A vertical strike slip fault of infinite length and finite width occupies the region $-\infty \le x_3 \le \infty$, $x_1 = 0$, $0 \le x_2 \le L$.

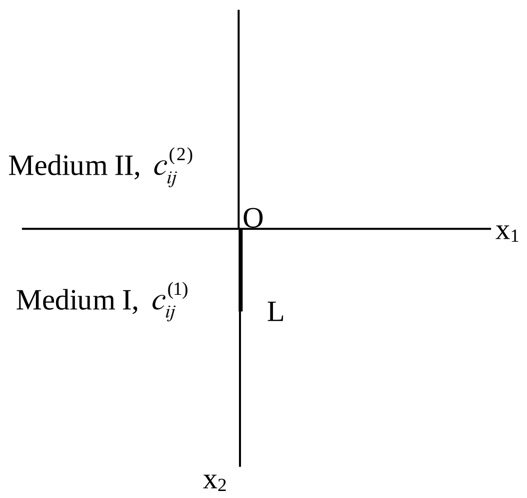

Figure 1

In the following, the superscript (1) denotes displacement in medium I and the superscript (2) denotes there in medium II. Following Kumar, Singh and Singh, the displacement parallel to the fault due to the slip b on the fault can be expressed in the form

$$u^{(i)} = \int_0^L b(s)G^{(i)}(x_1, x_2, s)ds \quad (i = 1, 2) \tag{1}$$

The Green's functions appearing in equation (1) are given by

$$G^{(1)} = \frac{\alpha_1}{2\pi}\left[\frac{x_1}{S_1^2} - \frac{K(x_1 + 2\varepsilon x_2)}{S_2^2}\right] \tag{2}$$

$$G^{(2)} = \frac{1-K}{2\pi}\left[\frac{\alpha x_1 + (\alpha_1\varepsilon_2 - \alpha_2\varepsilon_1)x_2}{S_3^2}\right] \tag{3}$$

where

$$\left.\begin{aligned} S_1^2 &= \left[s - \varepsilon_1 x_1 - \gamma_1 x_2\right]^2 + \alpha_1^2 x_1^2 \\ S_2^2 &= \left[s - \varepsilon_1(x_1 + 2\varepsilon x_2) + \gamma_1 x_2\right]^2 + \alpha_1^2 x_1^2 \\ S_3^2 &= \left[s - \varepsilon_1 x_1 - (\varepsilon_1\varepsilon_2 + \alpha_1\alpha_2)x_2\right]^2 + \left[-\alpha_1 x_1 - (\alpha_1\varepsilon_2 - \alpha_2\varepsilon_1)x_2\right]^2 \end{aligned}\right\} \tag{4}$$

$$\left.\begin{aligned} \varepsilon_i &= -\frac{C_{45}^{(i)}}{C_{44}^{(i)}} \\ \gamma_i &= \frac{C_{55}^{(i)}}{C_{44}^{(i)}} \\ \alpha_i &= (\gamma_i - \varepsilon_i^2)^{\frac{1}{2}} \end{aligned}\right\}$$

and $\quad K = \dfrac{\mu_2 - \mu_1}{\mu_1 + \mu_2}$

$$\mu_i = \sqrt{C_{44}^i C_{55}^i - (C_{45}^2)^i}, \; i=1, 2 \tag{5}$$

The expressions of the displacements for various slip profiles have been obtained from equation (1) by integrating analytically

(i) Linear

For linear slip profile, the expressions for the displacements are

$$\begin{aligned} u^{(1)} = \frac{b_0}{2\pi}\Bigg[& (1 - \varepsilon_1 X_1 - \gamma_1 X_2)\left\{\tan^{-1}\left(\frac{1 - \varepsilon_1 X_1 - \gamma_1 X_2}{\alpha_1 X_1}\right) + \tan^{-1}\left(\frac{\varepsilon_1 X_1 + \gamma_1 X_2}{\alpha_1 X_1}\right)\right\} \\ & -\alpha_1 X_1 \log\left\{\frac{(1 - \varepsilon_1 X_1 - \gamma_1 X_2)^2 + \alpha_1^2 X_1^2}{(\varepsilon_1 X_1 + \gamma_1 X_2)^2 + \alpha_1^2 X_1^2}\right\}^{\frac{1}{2}}\Bigg] - \frac{Kb_0}{2\pi}\Bigg[\frac{(X_1 + 2\varepsilon_1 X_2)}{X_1}(1 - \varepsilon_1(X_1 + 2\varepsilon_1 X_2) \\ & +\gamma_1 X_2)\left\{\tan^{-1}\left(\frac{1 - \varepsilon_1(X_1 + 2\varepsilon_1 X_2) + \gamma_1 X_2}{\alpha_1 X_1}\right) - \tan^{-1}\left(\frac{-\varepsilon_1(X_1 + 2\varepsilon X_2) + \gamma_1 X_2}{\alpha_1 X_1}\right)\right\} \\ & -(\alpha_1 X_1 + 2\alpha_1\varepsilon_1 X_2)\log\left\{\frac{(1 - \varepsilon_1(X_1 + 2\varepsilon_1 X_2) + \gamma_1 X_2)^2 + \alpha_1^2 X_1^2}{(-\varepsilon_1(X_1 + 2\varepsilon_1 X_2) + \gamma_1 X_2)^2 + \alpha_1^2 X_1^2}\right\} \end{aligned} \tag{6}$$

$$u^{(2)} = \left(\frac{1-K}{2\pi}\right) b_0 \left[(1-\varepsilon_1 X_1 - (\varepsilon_1\varepsilon_2 + \alpha_1\alpha_2) X_2) \left\{ \tan^{-1}\left(\frac{1-\varepsilon_1 X_1 - (\varepsilon_1\varepsilon_2 + \alpha_1\alpha_2)X_2}{\alpha_1 X_1 + (\alpha_1\varepsilon_2 - \alpha_2\varepsilon_1)X_2}\right) \right.\right.$$

$$+ \tan^{-1}\left(\frac{\varepsilon_1 X_1 + (\varepsilon_1\varepsilon_2 + \alpha_1\alpha_2)X_2}{\alpha_1 X_1 + (\alpha_1\varepsilon_2 + \alpha_2\varepsilon_1)X_2}\right) - (\alpha_1 X_1 - (\alpha_1\varepsilon_2 - \alpha_2\varepsilon_1)X_2)$$

$$\log\left\{\frac{(1-\varepsilon_1 X_1 - (\varepsilon_1\varepsilon_2 + \alpha_1\alpha_2)X_2)^2 + (\alpha_1 X_1 + (\alpha_1\varepsilon_2 - \alpha_2\varepsilon_1)X_2)^2}{(\varepsilon_1 X_1 + (\varepsilon_1\varepsilon_2 + \alpha_1\alpha_2)X_2)^2 + (\alpha_1 X_1 + (\alpha_1\varepsilon_2 - \alpha_2\varepsilon_1)X_2)^2}\right\} \tag{7}$$

For Orthotropic Medium

$$u^{(1)} = \frac{b_0}{2\pi}\left[(1-\gamma_1 X_2)\left\{\tan^{-1}\left(\frac{1-\gamma_1 X_2}{\alpha_1 X_1}\right) + \tan^{-1}\left(\frac{\gamma_1 X_2}{\alpha_1 X_1}\right)\right\}\right.$$

$$\left. -\alpha_1 X_1 \log\left\{\frac{(1-\gamma_1 X_2)^2 + \alpha_1^2 X_1^2}{\gamma_1^2 X_2^2 + \alpha_1^2 X_1^2}\right\}^{\frac{1}{2}} \right] + \left(\frac{1-\beta}{1+\beta}\right)\frac{b_0}{2\pi}\left[(1+\gamma_1 X_2)\left\{\tan^{-1}\left(\frac{1+\gamma_1 X_2}{\alpha_1 X_1}\right)\right.\right.$$

$$\left.\left. -\tan^{-1}\left(\frac{\gamma_1 X_2}{\alpha_1 X_1}\right)\right\} - \alpha_1 X_1 \log\left\{\frac{(1+\gamma_1 X_2)^2 + \alpha_1^2 X_1^2}{\gamma_1^2 X_2^2 + \alpha_1^2 X_1^2}\right\}\right] \tag{8}$$

where

$$\beta = \frac{\mu_2}{\mu_1} \tag{9}$$

$$u^{(2)} = \frac{b_0}{\pi(1+\beta)}\left[(1-\alpha_1\alpha_2 X_2)\left\{\tan^{-1}\left(\frac{1-\alpha_1\alpha_2}{\alpha_1 X_1}\right) + \tan^{-1}\frac{\alpha_1\alpha_2 X_2}{\alpha_1 X_1}\right\}\right.$$

$$\left. -(\alpha_1 X_1)\log\left\{\frac{(1-\alpha_1\alpha_2 X_2)^2 + \alpha_1^2 X_1^2}{\alpha_1^2\alpha_2^2 X_2^2 + \alpha_1^2 X_1^2}\right\}^{\frac{1}{2}}\right] \tag{10}$$

For Isotropic Medium

$$u^{(1)} = \frac{b_0}{2\pi}\left[(1-X_2)\left\{\tan^{-1}\left(\frac{1-X_2}{X_1}\right) + \tan^{-1}\left(\frac{X_2}{X_1}\right)\right\}\right.$$

$$\left. -X_1 \log\frac{(1-X_2)^2 + X_1^2}{X_2^2 + X_1^2}\right] + \frac{1-\beta}{1+\beta}\left[(1+X_2)\left\{\tan^{-1}\left(\frac{1+X_2}{X_1}\right) - \tan^{-1}\left(\frac{X_2}{X_1}\right)\right\}\right.$$

$$\left. -X_1 \log\left\{\frac{(1+X_2)^2 + X_1^2}{X_2^2 + X_1^2}\right\}\right] \tag{11}$$

$$u^{(2)} = \frac{b_0}{\pi(1+\beta)}\left[(1-X_2)\left\{\tan^{-1}\left(\frac{1-X_2}{X_1}\right) + \tan^{-1}\frac{X_2}{X_1}\right\}\right.$$

$$-X_2 \log \frac{(1-X_2)^2 + X_1^2}{X_2^2 + X_1^2} \Bigg] \tag{12}$$

(ii) Parabolic

The displacement expressions for parabolic slip are

$$u^{(1)} = \frac{b_0}{2\pi}\Bigg[(1-\varepsilon_1 X_1^2 - \gamma_1^2 X_2^2 + \alpha_1^2 X_1^2 - 2\varepsilon_1\gamma_1 X_1 X_2)\left\{\tan^{-1}\left(\frac{1-\varepsilon_1 X_1 - \gamma_1 X_2}{\alpha_1 X_1}\right)\right.$$

$$\left. + \tan^{-1}\left(\frac{\varepsilon_1 X_1 + \gamma_1 X_2}{\alpha_1 X_1}\right)\right\} - X_1 - 2\alpha_1(\varepsilon_1 X_1^2 + \gamma_1 X_1 X_2)\log\left\{\frac{(1-\varepsilon_1 X_1 - \gamma_1 X_2)^2 + \alpha_1^2 X_1^2}{(\varepsilon_1 X_1 + \gamma_1 X_2)^2 + \alpha_1^2 X_1^2}\right\}^{\frac{1}{2}} \Bigg]$$

$$\frac{-Kb_0}{2\pi}\Bigg[\left(\frac{X_1 + 2\varepsilon_1 X_2}{X_1}\right)\left(1 - (\varepsilon_1(X_1 + 2\varepsilon_1 X_2) + \gamma_1 X_1)^2 + \alpha_1^2 X_1^2\right)$$

$$\left\{\tan^{-1}\left(\frac{1-\varepsilon_1(X_1 + 2\varepsilon_1 X_2) + \gamma_1 X_2}{\alpha_1 X_1}\right) - \tan^{-1}\frac{-\varepsilon_1(X_1 + 2\varepsilon_1 X_2) + \gamma_1 X_2}{\alpha_1 X_1}\right\}$$

$$-(X_1 + 2\varepsilon_1 X_2) + 2\alpha_1(X_1 + \alpha\varepsilon_1 X_2)(-\varepsilon_1(X_1 + 2\varepsilon_1 X_2) + \gamma_1 X_2)$$

$$\log\left\{\frac{(1-\varepsilon_1(X_1 + 2\varepsilon_1 X_2) + \gamma_1 X_2)^2 + \alpha_1^2 X_1^2}{(-\varepsilon_1(X_1 + 2\varepsilon_1 X_2) + \gamma_1 X_2)^2 + \alpha_1^2 X_1^2}\right\}^{\frac{1}{2}}\Bigg] \tag{13}$$

$$u^{(2)} = \left(\frac{1-K}{2\pi}\right) b_0 \Big[\Big\{1 - (\varepsilon_1 X_1 + (\varepsilon_1\varepsilon_2 + \alpha_1\alpha_2)X_2)^2 + (\alpha_1 X_1 + (\alpha_1\varepsilon_2 - \alpha_2\varepsilon_1)X_2)^2\Big\}$$

$$\left\{\tan^{-1}\left(\frac{1-\varepsilon_1 X_1 - (\varepsilon_1\varepsilon_2 + \alpha_1\alpha_2)X_2}{\alpha_1 X_1 + (\alpha_1\varepsilon_2 - \alpha_2\varepsilon_1)X_2}\right) + \tan^{-1}\left(\frac{\varepsilon_1 X_1 + (\varepsilon_1\varepsilon_2 + \alpha_1\alpha_2)X_2}{\alpha_1 X_1 + (\alpha_1\varepsilon_2 - \alpha_2\varepsilon_1)X_2}\right)\right\}$$

$$-(\alpha_1 X_1 + (\alpha_1\varepsilon_2 - \alpha_2\varepsilon_1)X_2)(\varepsilon_1 X_1 - (\varepsilon_1\varepsilon_2 + \alpha_1\alpha_2)X_2)$$

$$\log\left\{\frac{(1-\varepsilon_1 X_1 - (\varepsilon_1\varepsilon_2 + \alpha_1\alpha_2)X_2)^2 + (\alpha_1 X_1 - (\alpha_1\varepsilon_2 - \alpha_2\varepsilon_1)X_2)^2}{(\varepsilon_1 X_1 + (\varepsilon_1\varepsilon_2 + \alpha_1\alpha_2)X_2)^2 + (\alpha_1 X_1 - (\alpha_1\varepsilon_2 - \alpha_2\varepsilon_1)X_2)^2}\right\}\Bigg] \tag{14}$$

For Orthotropic Medium

$$u^{(1)} = \frac{b_0}{2\pi}\Bigg[(1 + \alpha_1^2 X_1^2 - \gamma_1^2 X_1^2)\left\{\tan^{-1}\left(\frac{1-\gamma_1 X_2}{\alpha_1 X_1}\right) + \tan^{-1}\left(\frac{\gamma_1 X_2}{\alpha_1 X_1}\right)\right\}$$

$$-X_1 - 2\alpha_1\gamma_1 X_1 X_2 \log\left\{\frac{(1-\gamma_1 X_2)^2 + \alpha_1^2 X_1^2}{\gamma_1^2 X_2^2 + \alpha_1^2 X_1^2}\right\}^{\frac{1}{2}}\Bigg] + \left(\frac{1-\beta}{1+\beta}\right)\left(\frac{b_0}{2\pi}\right)\Big[(1 - \gamma_1^2 X_1^2 + \alpha_1^2 X_1^2)$$

$$\left\{\tan^{-1}\left(\frac{1+\gamma_1 X_2}{\alpha_1 X_1}\right) - \tan^{-1}\left(\frac{\gamma_1 X_2}{\alpha_1 X_1}\right)\right\} - X_1 + 2\alpha_1\gamma_1 X_1 X_2 \log\left\{\frac{(1+\gamma_1 X_2)^2 + \alpha_1^2 X_1^2}{\gamma_1^2 X_2^2 + +\alpha_1^2 X_1^2}\right\}\Bigg] \tag{15}$$

$$u^{(2)} = \frac{b_0}{\pi(1+\beta)}\left[(1-\alpha_1^2\alpha_2^2X_2^2+\alpha_1^2X_1^2)\left\{\tan^{-1}\frac{1-\alpha_1\alpha_2X_2}{\alpha_1X_1}+\tan^{-1}\frac{\alpha_1\alpha_2X_2}{\alpha_1X_1}\right\}\right.$$

$$\left.-\alpha_1\lambda_1-\alpha_1^2\alpha_2X_1X_2\log\frac{(1-\alpha_1^2\alpha_2^2X_2^2)+\alpha_1^2X_1^2}{\alpha_1^2\alpha_2^2X_2^2+\alpha_1^2X_1^2}\right] \quad (16)$$

For Isotropic Medium

$$u^{(1)} = \frac{b_0}{2\pi}\left[(1+X_1^2-X_2^2)\left\{\tan^{-1}\left(\frac{1-X_2}{X_1}\right)+\tan^{-1}\frac{X_2}{X_1}\right\}-X_1-2X_1X_2\log\frac{(1-X_2)^2+X_1^2}{X_2^2+X_1^2}\right.$$

$$+\left(\frac{1-\beta}{1+\beta}\right)\left[(1+X_1^2-X_2^2)\left\{\tan^{-1}\left(\frac{1+X_2}{X_1}\right)-\tan^{-1}\frac{X_2}{X_1}\right\}-X_1\right.$$

$$\left.\left.+2X_1X_2\log\frac{(1+X_2)^2+X_1^2}{X_2^2+X_1^2}\right]\right] \quad (17)$$

$$u^{(2)} = \frac{b_0}{\pi(1+\beta)}\left[(1+X_1^2-X_2^2)\left\{\tan^{-1}\left(\frac{1-X_2}{X_1}\right)+\tan^{-1}\frac{X_2}{X_1}\right\}\right.$$

$$\left.-X_1-2X_1X_2\log\frac{(1-X_2)^2+X_1^2}{X_2^2+X_1^2}\right] \quad (18)$$

(iii) Elliptic

The displacement expressions for elliptic slip profile at the interface ($x_2 = 0$) are

$$u^{(1)} = u^{(2)} = \frac{b_0}{2\pi}\left(\frac{1-K}{4}\right)\left[\alpha_1\pi X_1 + i\sqrt{1+(\alpha_1+i\varepsilon_1)^2X_1^2}\right.$$

$$\log\left\{\frac{-2\alpha_1X_1(1-i\alpha_1X_1-\varepsilon_1X_1}{[1+(\alpha_1+i\varepsilon_1)^2X_1^2]^{\frac{3}{2}}(i+\alpha_1X_1-i\varepsilon_1X_1)}\right\}$$

$$-i\sqrt{1+(\alpha_1-i\varepsilon_1)^2X_1^2}\log\left\{\frac{-2\alpha_1X_1(1+i\alpha_1X_1-\varepsilon_1X_1}{[1+(\alpha_1+i\varepsilon_1)^2X_1^2]^{3/2}(-i+\alpha_1X_1+i\varepsilon_1X_1)}\right\}$$

$$-i\sqrt{(\alpha-i\varepsilon)^2}X_1\log\left\{\frac{-2\alpha_1X_1\sqrt{1+(\alpha_1-i\varepsilon_1)^2X_1^2}-2\alpha_1X_1}{[1+(\alpha_1+i\varepsilon_1)^2X_1^2]^{3/2}(\alpha_1X_1-i\varepsilon_1X_1)}\right\}$$

$$\left.+i\sqrt{(\alpha+i\varepsilon)^2}X_1\log\left\{\frac{-2\alpha_1X_1\sqrt{1+(\alpha+i\varepsilon)^2X_1^2}-2\alpha X_1}{[1+(\alpha_1X_1+i\varepsilon X_1)^2]^{3/2}(\alpha_1X_1+i\varepsilon_1X_1)}\right\}\right] \quad (19)$$

For Orthotropic Medium

$$u^{(1)} = u^{(2)} = \frac{b_0}{2}\frac{1}{(1+\beta)}\left[\alpha_1X_1 \pm \sqrt{1+\alpha_1^2X_1^2}\right] \quad (20)$$

For Isotropic Medium

$$u^{(1)} = u^{(2)} = \frac{b_0}{2}\frac{1}{(1+\beta)}\left[X_1 \pm \sqrt{1+X_1^2}\right] \tag{21}$$

(iv) Cubic

The expressions for the displacement at the interface ($x_2 = 0$) is

$$\begin{aligned} u^{(1)} = u^{(2)} = \frac{b_0}{2\pi}\left(\frac{1-K}{2}\right)\Bigg[& 4\alpha_1\varepsilon_1X_1^2 - \pi X_1\left(\frac{3}{2} + \alpha_1X_1^2 - 3\varepsilon_1X_1^2\right) \\ & + i(1+(\alpha_1X_1 - i\varepsilon_1X_1)^2)^{\frac{3}{2}}\log\left(\frac{-i(\alpha_1X_1 - i\varepsilon_1X_1)}{1+\sqrt{1+(\alpha_1X_1 - i\varepsilon_1X_1)^2}}\right) \\ & - i(1+(\alpha_1X_1 + i\varepsilon_1X_1)^2)^{\frac{3}{2}}\log\left(\frac{i(\alpha_1X_1 + i\varepsilon_1X_1)}{1+\sqrt{1+(\alpha_1X_1 - i\varepsilon_1X_1)^2}}\right)\Bigg] \end{aligned} \tag{22}$$

For Orthotropic Medium

$$u^{(1)} = u^{(2)} = \frac{b_0}{2(1+\beta)}\left[-X_1\left(\frac{3}{2} + \alpha_1X_1^2\right) \pm (1+\alpha_1^2X_1^2)^{\frac{3}{2}}\right] \tag{23}$$

For Isotropic Medium

$$u^{(1)} = u^{(2)} = \frac{b_0}{2}\left[-X_1\left(\frac{3}{2} + X_1^2\right) \pm (1+X_1^2)^{\frac{3}{2}}\right] \tag{24}$$

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