IOSR Journal of Mathematics (IOSR-JM)
e-ISSN: 2278-5728, p-ISSN: 2319-765X. Volume 11, Issue 3 Ver. I (May - Jun. 2015), PP 105-114
www.iosrjournals.org

A Vertical Creeping Strike Slip Fault in a Viscoelastic Half Space under the Action of Tectonic Forces Varying with Time

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Abstract: *A long surface breaking vertical strike slip fault is consider situated in a viscoelastic half space of Maxwell type. Tectonic forces due to mantle convection and other associated phenomena are acting on the system. The magnitude of the tectonic forces has been assume to be slowly increasing with time. When the stresses near the fault exceeds the frictional force across the fault it starts creeping. Expressions for displacement, stresses and strain are obtained using suitable numerical techniques involving integral transform, Green's function techniques and Correspondence principle for both before and after the fault movement. It is expected that such expression will give us more information on the mechanism of stress accumulation in the system during the aseismic period.*

Keywords: *Aseismic period; Creeping movement; Mantle convection; Strike slip fault; Viscoelastic half space*

I. Introduction

A long strike slip fault is taken to be situated in a viscoelastic half space. Following plate tectonic theory it is expected that the tectonic forces generated due to the mantle convection play important roles in introducing movement across the faults leading to earthquakes. The nature of the tectonic forces have been investigated by many authors such as [1], [2], [3] and [4].

From these investigation it may be assumed that the magnitude of such tectonic forces are likely to be slowly increasing with time. In view of this we have developed a model where the tectonic forces are taken to be $\tau_\infty(t) = \tau_\infty(0)(1 + kt)$, where k is a parameter depend on the nature of the mantle convection.

Stresses are accumulated in the model due to this tectonic forces. When the accumulated stress exceeds the frictional and local cohesive forces across the fault, the fault starts moving. Depending upon the geological nature of the model material the movement across the fault may be sudden in nature leading to a earthquake or alternatively a creeping movement across the fault releasing the accumulated stress near it.

II. Formulation

We consider a long surface breaking strike-slip fault F situated in a viscoelastic half space of Maxwell type of width D.

We introduce a system of rectangular Cartesian coordinate axes (y_1, y_2, y_3) such that the free surface is the plane $y_3 = 0$ and the fault is in the plane $y_2 = 0$.

For long fault the displacement, stresses and strain are in assumed to be independent of y_1 and dependent on y_2, y_3 and time t. This separates out the displacements, stresses and strains into two independent groups: one group containing u, τ_{12}, τ_{13}, e_{12} and e_{13} associated with strike slip movement. The remaining components are associated with a possible dip slip movement of the fault. We consider here the strike slip movement across the fault.

We measure the time t from an instant when the model is in the aseismic state, and there is no movement, seismic or aseismic, across any fault. Then for $t \geq 0$, the displacement, stresses and strains satisfy the following relations:

2.1 Constitutive equations (stress-strain relations)

For viscoelastic material of the Maxwell type, the displacement component u and the stress components τ_{12}, τ_{13} associated with strike slip movements, are connected by the constitutive equations

$$\left.\begin{aligned}\left(\frac{1}{\eta} + \frac{1}{\mu}\frac{\partial}{\partial t}\right)\tau_{12} &= \frac{\partial}{\partial t}(e_{12}) = \frac{\partial^2 u}{\partial t\,\partial y_2}\\ \left(\frac{1}{\eta} + \frac{1}{\mu}\frac{\partial}{\partial t}\right)\tau_{13} &= \frac{\partial}{\partial t}(e_{13}) = \frac{\partial^2 u}{\partial t\,\partial y_3}\end{aligned}\right\} \quad (1)$$

where η is the effective viscosity and μ is the effective rigidity of the material.

2.2 Stress equation of motion

We consider the aseismic state of model when the medium is in a quasi-static state, and choose our time origin t=0 suitably.

For slow, aseismic, quasi-static displacement we consider, the inertial forces are very small, and can be neglected. Hence the stress equation of motion with relevant stress components τ_{12}, τ_{13} reduces to

$$\left.\begin{array}{c}\frac{\partial}{\partial y_2}(\tau_{12}) + \frac{\partial}{\partial y_3}(\tau_{13}) = 0 \\ (-\infty < y_2 < \infty, \ \ y_3 \geq 0, \ \ t \geq 0)\end{array}\right\} \quad (2)$$

neglecting the inertial term.

2.3 Boundary conditions

The boundary conditions are

$$\left.\begin{array}{c}\tau_{13} = 0 \text{ on } y_3 = 0, (-\infty < y_2 < \infty, \ \ t \geq 0) \\ \tau_{13} \to 0 \text{ as } y_3 \to \infty, (-\infty < y_2 < \infty, \ \ t \geq 0)\end{array}\right\} \quad (3)$$

We assume $\tau_\infty(t)$, the stress maintained by different tectonic phenomena including mantle convection, a slowly linearly increasing function with time, as $\tau_\infty(t) = \tau_\infty(0)(1 + kt)$, where $k > 0$, is a small quantity. It is the main driving force for any possible strike-slip motion across F.

$$\left.\begin{array}{c}\tau_{12} \to \tau_\infty(t) = \tau_\infty(0)(1 + kt), (k > 0) \\ \text{as } |y_2| \to \infty, \text{for } y_3 \geq 0, t \geq 0. \\ \tau_\infty(0) = \text{The value of } \tau_\infty(t) \text{ at } t = 0. \\ \tau_{12}(0) \to \tau_\infty(0) \text{ as } |y_2| \to \infty, \text{for } t = 0.\end{array}\right\} \quad (4)$$

2.4 Initial conditions

Let $(u)_0, (\tau_{12})_0, (\tau_{13})_0$ and $(e_{12})_0$ are the values of u, u, τ_{12}, τ_{13}, and e_{12} respectively at time t=0. They are functions of y_2, y_3 and satisfy the relations (1) to (4).

Now differentiating partially equation (1) with respect to y_2 and with respect to y_3 and adding them using equation (2) we get,

$$\nabla^2 u(y_2, y_3, t) = 0 \quad (5)$$

III. Displacements, Stresses And Strains In The Absence Of Any Fault Movement

In the absence of any fault movement the displacement and stresses are continuous through out the model. In order to obtain the expressions for displacement, strain and stresses we take Laplace transform of (1) to (5) with respect to t. The resulting boundary value problem can be solved by taking integral transforms of the constitutive equations and the boundary conditions with respect to t. The solutions obtained are given below.(as shown in Appendix)

$$\left.\begin{array}{c}u = (u)_0 + y_2\tau_\infty(0)\left[\frac{kt}{\mu} + \frac{t}{\eta} + \frac{kt^2}{2\eta}\right] \\ e_{12} = (e_{12})_0 + \tau_\infty(0)\left[\frac{kt}{\mu} + \frac{t}{\eta} + \frac{kt^2}{2\eta}\right] \\ \tau_{12} = (\tau_{12})_0 e^{-\frac{\mu t}{\eta}} + \tau_\infty(0)\left(1 + kt - e^{-\frac{\mu t}{\eta}}\right) \\ \tau_{13} = (\tau_{13})_0 e^{-\frac{\mu t}{\eta}}\end{array}\right\} \quad (6)$$

From the above result we find that, the initial field for displacement, stresses and strain gradually die out. The relevant stress component τ_{12} is found to increase with time t and tends to $\tau_\infty(t)$ as $t \to \infty$. However the rheological behavior of the meterial near the fault F are assumed to be capable of withstanding stress of magnitude τ_c, called critical value of the stress where τ_c is less than $\tau_\infty(t)$. We assume that when the accumulated stress τ_{12} near the fault exceeds this critical level after a time, T, say, a creeping movement across F sets in, and thereby releasing the accumulated stress to a value less than τ_c.

If we assume $(\tau_{12})_0$=50 bar, $\tau_\infty(0)$=50 bar, $k = 10^{-9}$ and τ_c=200 bar, it is found that τ_{12} reaches the value τ_c in about 96 years (T=96 years). In our subsequent discussions we shall take T to be 96 years.

The relevant boundary value problem after commencement of the creeping movement across F , $t \geq T$ has been described in Appendix.

IV. Displacements, Stresses And Strains After The Commencement Of The Fault Creep

We assume that after a time T, the stress component τ_{12} which is the main driving force for the strike-slip motion of the fault, exceeds the critical value τ_c and the fault starts creeping characterized by a dislocation across the fault as discussed in Appendix. We solved the resulting boundary value problem by modified Green's function method following [5], [6] and correspondence principle (as shown in Appendix) and get the solution for displacement, strain and stresses as:

$$\left.\begin{aligned}
u &= (u)_0 + y_2\tau_\infty(0)\left[\frac{kt}{\mu}+\frac{t}{\eta}+\frac{kt^2}{2\eta}\right]+\frac{U(t-T)}{2\pi}H(t-T)\varphi_1(y_2,y_3)\\
e_{12} &= (e_{12})_0 + \tau_\infty(0)\left[\frac{kt}{\mu}+\frac{t}{\eta}+\frac{kt^2}{2\eta}\right]+\frac{U(t-T)}{2\pi}H(t-T)\psi_1(y_2,y_3)\\
\tau_{12} &= (\tau_{12})_0 e^{\frac{-\mu t}{\eta}} + \tau_\infty(0)\left(1+kt-e^{\frac{-\mu t}{\eta}}\right)\\
&\quad +\frac{\mu}{2\pi}H(t-T)\psi_1(y_2,y_3)\int_0^{t-T} v_1(\tau)e^{\frac{-\mu(t-T-\tau)}{\eta}}d\tau\\
\tau_{13} &= (\tau_{13})_0 e^{\frac{-\mu t}{\eta}} + \frac{\mu}{2\pi}H(t-T)\psi_2(y_2,y_3)\int_0^{t-T} v_1(\tau)e^{\frac{-\mu(t-T-\tau)}{\eta}}d\tau
\end{aligned}\right\}\quad (7)$$

where $\varphi_1(y_2,y_3)$, $\psi_1(y_2,y_3)$ and $\psi_2(y_2,y_3)$ are given in the Appendix.

It has been observed, as in [7] that the strains and the stresses will be bounded everywhere in the model including the lower edge of the fault, the depth dependence of the creep function $f(x_3)$ should satisfy the certain sufficient conditions:

I. $f(y_3)$, $f'(y_3)$ are continuous in $0\leq y_3 \leq D$, II) Either (a) $f''(y_3)$ is continuous in $0\leq y_3 \leq D$, or (b) $f''(y_3)$ is continuous in $0\leq y_3 \leq D$, except for a finite number of points of finite discontinuity in $0\leq y_3 \leq D$, or (c) $f''(y_3)$ is continuous in $0\leq y_3 \leq D$,except possibly for a finite number of points of finite discontinuity and for the ends points of (0,D), there exist real constants m<1 and n<1 such that ${y_3}^m f''(y_3) \to 0$ or to a finite limit as $y_3 \to 0+0$ and $(D-y_3)^n f''(y_3) \to 0$ or to a finite limit as $y_3 \to D-0$ and

II. (III) $f(D) = 0 = f'(D)$, $f'(0) = 0$,

These are sufficient conditions which ensure finite displacements, stresses and strains for all finite (y_2, y_3, t) including the points at the lower edge of the fault.

We can evaluate the integrals in (A), (B) and (C) in closed form if $f(y_3)$ is any polynomial satisfying (I),(II) and (III). One such function is

$$f(y_3) = 1 - \frac{3{y_3}^2}{D^2} + \frac{2{y_3}^3}{D^3}$$

III. Numerical Computations

We consider $f(x_3)$ to be

$$f(x_3) = 1 - \frac{3{x_3}^2}{D^2} + \frac{2{x_3}^3}{D^3}$$

which satisfies all the conditions for bounded strain and stresses stated above.

Following [8], [9] and the recent studies on rheological behaviour of crust and upper mantle by [10], [11] , the values to the model parameters are taken as:

$\mu = 3.5x10^{11}\, dyne/sq.cm.$

$\eta = 5x10^{20}\ poise$

D=Depth of the fault = 10 km. [noting that the depth of the major earthquake faults are in between 10-15 km.]

$t_1 = t - T$

$\tau_\infty(t) = \tau_\infty(0)(1+kt)$

$\tau_\infty(0) = 50$ bar

$(\tau_{12})_0 = 50\ bar$

$(\tau_{13})_0 = 50$ bar

$k = 10^{-9}$

IV. Discussion Of The Results

We compute the following quantities:

$$U = u - (u)_0 = y_2\tau_\infty(0)\left[\frac{kt}{\mu} + \frac{t}{\eta} + \frac{kt^2}{2\eta}\right] + \frac{U(t-T)}{2\pi}H(t-T)\,\varphi_1(y_2,y_3)$$

$$E_{12} = e_{12} - (e_{12})_0 = \tau_\infty(0)\left[\frac{kt}{\mu} + \frac{t}{\eta} + \frac{kt^2}{2\eta}\right] + \frac{U(t-T)}{2\pi}H(t-T)\,\psi_1(y_2,y_3)$$

$$\tau_{12} = (\tau_{12})_0 e^{\frac{-\mu t}{\eta}} + \tau_\infty(0)\left(1 + kt - e^{\frac{-\mu t}{\eta}}\right)$$

$$+\frac{\mu}{2\pi}H(t-T)\,\psi_1(y_2,y_3)\int_0^{t-T} v_1(\tau)e^{\frac{-\mu(t-T-\tau)}{\eta}}d\tau$$

$$\tau_{13} = (\tau_{13})_0 e^{\frac{-\mu t}{\eta}} + \frac{\mu}{2\pi}H(t-T)\,\psi_2(y_2,y_3)\int_0^{t-T} v_1(\tau)e^{\frac{-\mu(t-T-\tau)}{\eta}}d\tau$$

where the expression for u, τ_{12}, e_{12} are given in expression (7).

6.1. Strain against year

Fig. 2 shows Surface share strain before the commencement of the fault movement. It is observed from the figure that the share strain increases slowly with time under the action of $\tau_\infty(t)$ but its magnitude is found to be of the order of 10^{-3} which is in conformity with the observational facts.

6.2. Displacement against y_2

Fig. 3 shows surface displacement against y_2, the distance from the fault, just before and after commencement of the fault movement.

It is observed from the figure that the displacement increases at a constant rate as expected for t=95 years (just before the commencement of the fault movement). The curve in the red colour shows the displacement against y_2 for t=98 years just after commencement of the fault movement. Comparing this two curve it is found that the magnitude of the displacement is always greater in the latter case. The displacement increases but with a gradually decreasing rate.

6.3. Stress near the midpoint on the fault (y_2=0.5 km. and y_3= 5.0 km.) against time for different creep velocities

From Fig. 4 and Fig. 5, we compare the result obtained here for stress accumulation near the mid point of the fault with the case when τ_∞ is suppose to be constant. Fig. 5 shows the accumulation of stress near the mid point of the fault as obtained by [12]. Although the numerical values of the parameters are slightly different (near the mid point of the fault) there are some qualitative and quantitative difference. After the commencement of the creep the rate of increase of stresses get released initially for a few years and start increasing after a few years due to the increasing value of $\tau_\infty(t)$. The velocity of the creep also found to be much higher in the present case. On the other hand, when $\tau_\infty(t)$ is constant, the stress τ_{12} is found to get released when $v \geq 2.0$ cm/year.

6.4. Stress against depth

In Fig. 6 the stress T_{12} along the fault due to the movement across F where,

$$T_{12} = \frac{\mu}{2\pi}H(t-T)\psi_1(y_2,y_3)\int_0^{t-T} v_1(\tau)e^{\frac{-\mu(t-T-\tau)}{\eta}}d\tau$$

The magnitude of T_{12} has been computed very close to the fault line with y_2=0.5 km. and $y_3$varies from 0 to 50 km. The figure shows that initially the stress is negative and its magnitude increases up to a depth of 2 km. from the upper edge of the fault. Thereafter its magnitude decreases up to the lower edge of the fault, where its attends its maximum positive value at y_3=10 km.. As we move downwards the accumulated stress gradually die out and tends to zero.

6.5. Stress against depth and y_2

Fig. 7 shows Identification of the region of stress accumulation and stress reduction due to the creeping movement across F.

We computed T_{12} for a set of values of y_2 from -50 km. to 50 km. and for a set of values of y_3 ranging from 0 km. to 50 km..It is found that, there is a clear demarcation of the zones where stress is increased due to the fault movement marked by (A: Blue in the graph) and a stress reduction zone (R: Red in the graph). This implies that if a second fault be situated in region A the rate of accumulation of stress near it will be increased due to the fault movement across F and thereby enhance the time of possible movement across the second fault. On the other hand if a second fault be situated in the region R the rate of stress accumulation near it will be reduced due to the fault movement across F and thereby delayed any possible movement across the second fault. This will give some idea about the interaction among neighbouring faults in a seismic fault system. The interacting effects depends upon the relative positions of the faults. Similar results are obtained by [13].

6.6. Contour map

Fig. 8 shows contour map for stress accumulation/release in the medium due to the fault creep across F (with fault F is shown in black colour).

V. Appendix

7.1. Displacements, stresses, and strains before the commencement of the fault creep

We take Laplace Transform of all constitutive equations and boundary conditions

$$\left.\overline{\tau_{12}} = \frac{p}{\left(\frac{p}{\mu}+\frac{1}{\eta}\right)}\frac{\partial\bar{u}}{\partial y_2} + \frac{\frac{(\tau_{12})_0}{\mu} - \left(\frac{\partial u}{\partial y_2}\right)_0}{\left(\frac{p}{\mu}+\frac{1}{\eta}\right)}\right\} \tag{8}$$

where $\overline{\tau_{12}} = \int_0^\infty \tau_{12} e^{-pt}\, dt$, p being the Laplace transform variable.

Also the stress equation of motion in Laplace transform domain as:

$$\left.\frac{\partial}{\partial y_2}(\overline{\tau_{12}}) + \frac{\partial}{\partial y_3}(\overline{\tau_{13}}) = 0\right\} \tag{9}$$

and the boundary conditions are (after transformation)

$$\left.\begin{array}{l}\overline{\tau_{13}} = 0\ on\ y_3 = 0\,, (-\infty < y_2 < \infty, \quad t \geq 0) \\ \overline{\tau_{13}} \to 0\ as\ y_3 \to \infty\,, (-\infty < y_2 < \infty, \quad t \geq 0)\end{array}\right\} \tag{10}$$

$$\left.\begin{array}{l}\overline{\tau_{12}} \to \overline{\tau_\infty}(p) = \tau_\infty(0)(1+kt), (k > 0) \\ as\ |y_2| \to \infty, for\ y_3 \geq 0, \qquad t \geq 0.\end{array}\right\} \tag{11}$$

Using (8) and other similar equation assuming the initial fields to be zero, we get from (9)

$$\nabla^2\bar{u} = 0$$

(12)

Thus we are to solve the boundary value problem (12) with the boundary conditions (10) and (11)

Let,

$$\bar{u} = \frac{(u)_0}{p} + Ay_2 + By_3$$

be the solution of (12)

Using the boundary conditions (10) and (11) and the initial conditions we get,

$$A = \tau_\infty(0)\left[\frac{k}{p^2\mu} + \frac{1}{\eta p^2} + \frac{k}{\eta p^3}\right]$$
$$B = 0$$

On taking inverse Laplace transform, we get

$$u = (u)_0 + y_2\tau_\infty(0)\left[\frac{kt}{\mu} + \frac{t}{\eta} + \frac{kt^2}{2\eta}\right]$$

$$e_{12} = (e_{12})_0 + \tau_\infty(0)\left[\frac{kt}{\mu} + \frac{t}{\eta} + \frac{kt^2}{2\eta}\right]$$

$$\tau_{12} = (\tau_{12})_0 e^{-\frac{\mu t}{\eta}} + \tau_\infty(0)\left(1 + kt - e^{-\frac{\mu t}{\eta}}\right)$$

$$\tau_{13} = (\tau_{13})_0 e^{-\frac{\mu t}{\eta}}$$

7.2. Displacements, stresses and strains after the commencement of the fault creep

We assume that after a time T the stress component τ_{12}, which is the main driving force for the strike-slip motion of the fault, exceeds the critical value τ_c, the fault F starts creeping then (8) to (11) are satisfied with the following conditions of creep across F:

$[u] = U(t_1)f(y_3)H(t_1)$
(13)

where $[u]$ is the discontinuity in u across F, and $H(t_1)$ is Heaviside unit step function.
That is

$[u] = lim_{y_2 \to 0+0}\, u - lim_{y_2 \to 0-0}\, u\,,$
$0 \le y_3 \le D$ (14)

The creep velocity

$$\frac{\partial}{\partial t}[u] = v(t_1)f(y_3)H(t_1)$$

where

$$v(t_1) = \frac{\partial}{\partial t}U(t_1) = \frac{\partial}{\partial t_1}U(t_1)$$

and $v(t_1), U(t_1)$ vanish for $t_1 \le 0$.
Taking Laplace transform in (13) with respect to t_1, we get

$[\bar{u}] = \bar{U}(p_1)f(y_3)$
(15)

The fault creep commence across F after time T, we take
$U(t_1) = 0$ for $t_1 \le 0$ that is $t \le T$
So that $[u] = 0$ for $t \le T$.
We try to find the solution as:

$$\left.\begin{aligned} u &= (u)_1 + (u)_2 \\ e_{12} &= (e_{12})_1 + (e_{12})_2 \\ \tau_{12} &= (\tau_{12})_1 + (\tau_{12})_2 \\ \tau_{13} &= (\tau_{13})_1 + (\tau_{13})_2 \end{aligned}\right\} \quad (16)$$

where $(u)_1,\ (e_{12})_1, (\tau_{12})_1\ and\ (\tau_{13})_1$ are continuous everywhere in the model satisfying equations (1) to (5). The solution for $(u)_1,\ (e_{12})_1, (\tau_{12})_1\ and\ (\tau_{13})_1$are similar to equation (6).
For the second part $(u)_2,\ (e_{12})_2, (\tau_{12})_2\ and\ (\tau_{13})_2$ boundary value problem can be stated as:

$\nabla^2(\bar{u})_2 = 0$
(17)

where $(\bar{u})_2$ is the Laplace transformation of $(u)_2$ with respect to t, give

$$(\bar{u})_2 = \int_0^\infty e^{-pt}u(t)dt$$

The modified boundary condition:
$\overline{(\tau_{12})_2} \to 0$ as $|y_2| \to \infty$,
for $y_3 \ge 0,\ t_1 \ge 0.$ (18)

and the other boundary conditions are same as (10) and (11).

Now we solve the boundary value problem by using a modified Green's function technique developed by [1], [2] and the Correspondence Principle.

Let, $Q(y_1, y_2, y_3)$ is any point in the medium and $P(x_1, x_2, x_3)$ is any point on the fault, then we have

$$(\bar{u})_2(Q) = \int [(\bar{u})_2(P)]G(P,Q)dx_3$$

Therefore , $[(\bar{u})_2(P)] = \overline{U_1}(P)f(x)_3$

where G is the Green's function satisfying the above boundary value problem and

$$G(P,Q) = \mu\frac{\partial}{\partial x_2}G_1(P,Q)$$

where

$$G_1(P,Q) = -\frac{1}{4\pi\mu}[log\{(x_2 - y_2)^2 + (x_3 - y_3)^2\} + log\{(x_2 - y_2)^2 + (x_3 + y_3)^2\}]$$

$$(\bar{u})_2(Q) = \int_0^D f(x_3)\frac{\bar{U}\,(P)}{2\pi}\left[\frac{y_2}{(x_3 + y_3)^2 + {y_2}^2} + \frac{y_2}{(x_3 - y_3)^2 + {y_2}^2}\right]dx_3$$

Now,

$$(\overline{\tau_{12}})_2 = \bar{\mu}\frac{\partial(\bar{u})_2}{\partial y_2}$$

where

$$\bar{\mu} = \frac{p}{\left(\frac{p}{\mu}+\frac{1}{\eta}\right)}$$

We assume that $f(y_3)$ is continuous everywhere on the fault $0 \leq y_3 \leq D$.
Now, taking inverse Laplace transformation

$$(u)_2(Q) = \frac{1}{2\pi}U(t-T)H(t-T)\varphi_1(y_2,y_3)$$

where $H(t-T)$ is Heaviside unit step function, and

$$\varphi_1(y_2,y_3) = \int_0^D f(x_3)\left[\frac{y_2}{(x_3+y_3)^2+{y_2}^2}+\frac{y_3}{(x_3-y_3)^2+{y_2}^2}\right]dx_3$$

where $f(x_3)$ is the depth-dependence of the creeping function across F.
We also have,

$$(\overline{\tau_{12}})_2 = \frac{p}{\left(\frac{p}{\mu}+\frac{1}{\eta}\right)}\ \frac{\partial(\bar{u})_2}{\partial y_2}$$

and similar other equations.
Now, taking inverse Laplace transformation we get

$$(\tau_{12})_2 = \frac{\mu}{2\pi}H(t-T)\psi_1(y_2,y_3)\int_0^{t-T} v_1(\tau)e^{\frac{-\mu(t-T-\tau)}{\eta}}d\tau$$

where

$$\psi_1(y_2,y_3) = \frac{\partial}{\partial y_2}\{\varphi_1(y_2,y_3)\}$$

$$= \int_0^D f(x_3)\left[\frac{(x_3+y_3)^2-{y_2}^2}{((x_3+y_3)^2+{y_2}^2)^2}+\frac{(x_3-y_3)^2-{y_2}^2}{((x_3-y_3)^2+{y_2}^2)^2}\right]dx_3$$

Similarly,

$$(\tau_{13})_2 = \frac{\mu}{2\pi}H(t-T)\psi_2(y_2,y_3)\int_0^{t-T} v_1(\tau)e^{\frac{-\mu(t-T-\tau)}{\eta}}d\tau$$

where

$$\psi_2(y_2,y_3) = \frac{\partial}{\partial y_3}\{\varphi_1(y_2,y_3)\}$$

$$= \int_0^D 2f(x_3)\left[\frac{(x_3-y_3)y_2}{((x_3-y_3)^2+{y_2}^2)^2}-\frac{(x_3+y_3)y_2}{((x_3+y_3)^2+{y_2}^2)^2}\right]dx_3$$

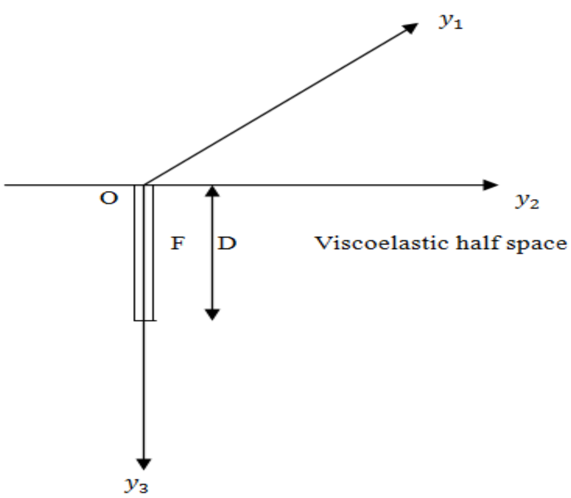

Figure 1. The section of the model by the plane $y_1 = 0$.

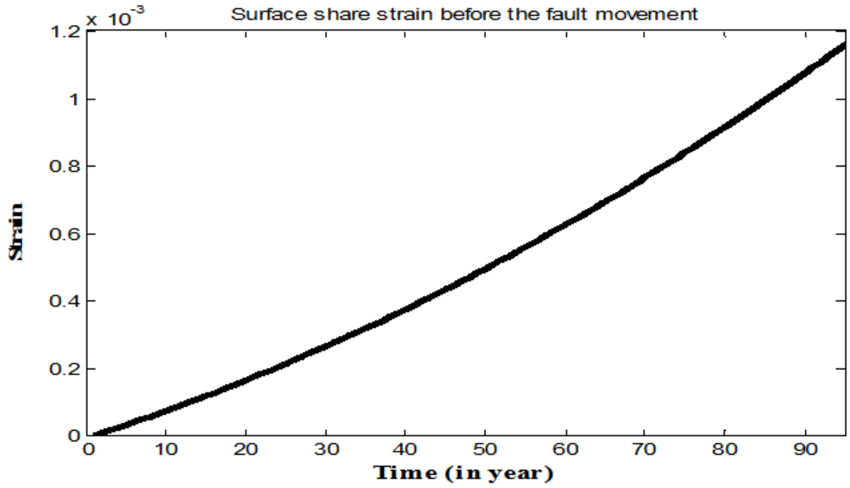

Figure 2. Surface share strain before the fault movement.

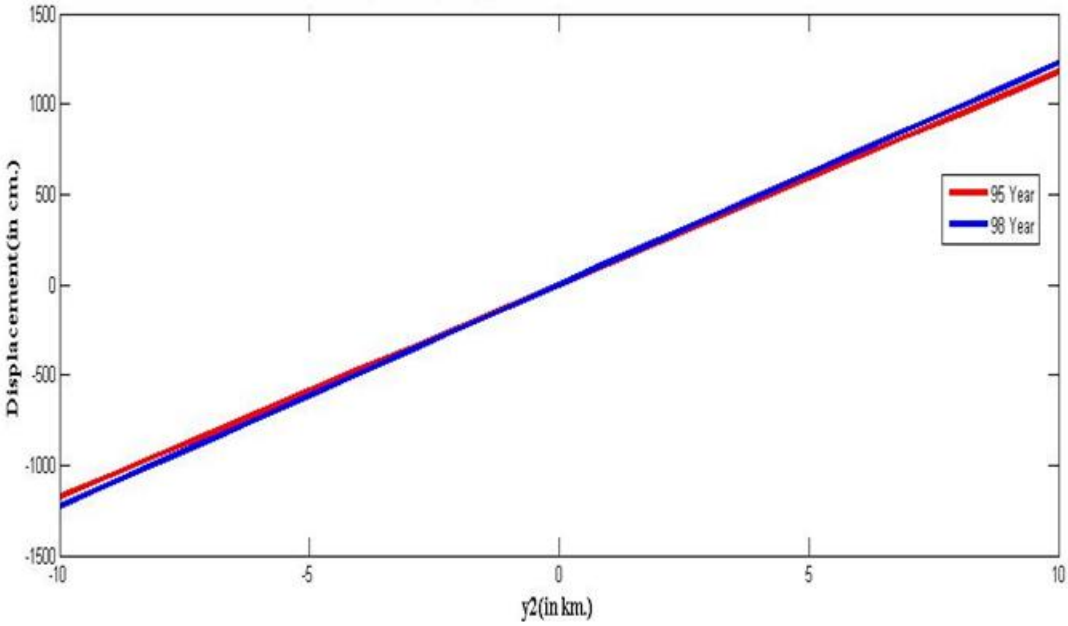

Figure 3. Surface displacement against y_2, just before and after commencement of the fault movement.

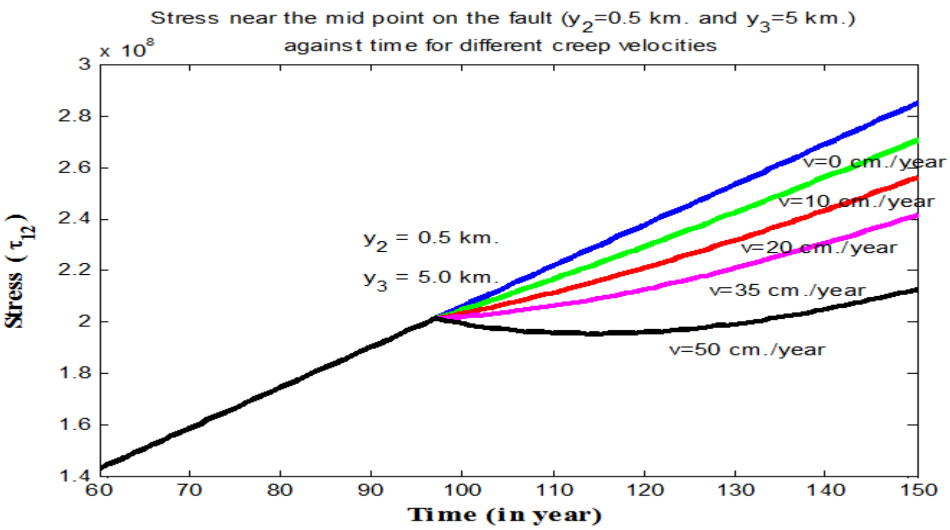

Figure 4. Stress near the mid point on the fault (y_2=0.5 km. and y_3= 5.0 km.) against time for different creep velocities (τ_∞ is slowly increasing with time)

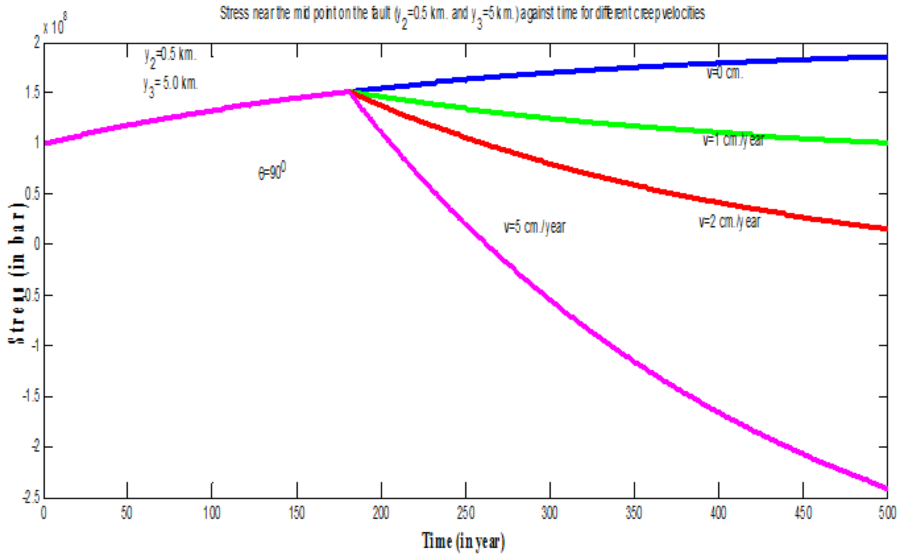

Figure 5. Stress near the mid point on the fault (y_2=0.5 km. and y_3= 5.0 km.) against time for different creep velocities (τ_∞ is suppose to be constant)

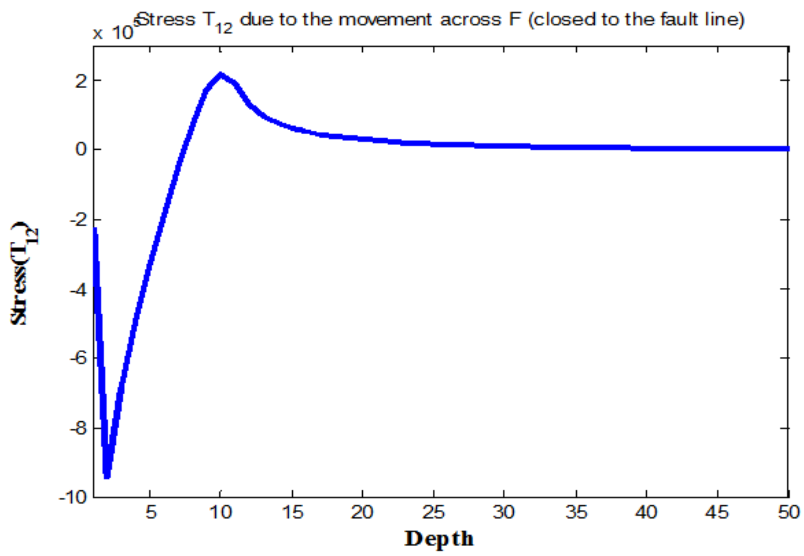

Figure 6. Stress T_{12} due to the movement across the F (closed to the fault line)

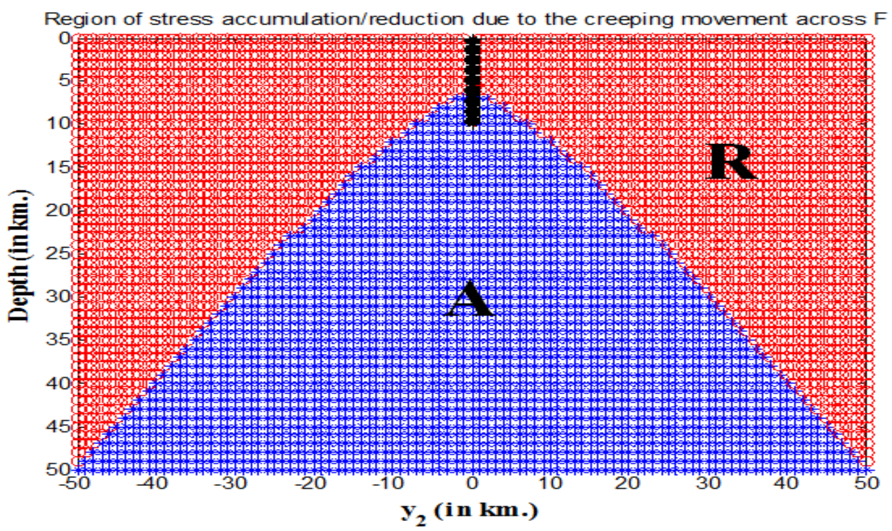

Figure 7. Region of stress accumulation/reduction due to the creeping movement across F.

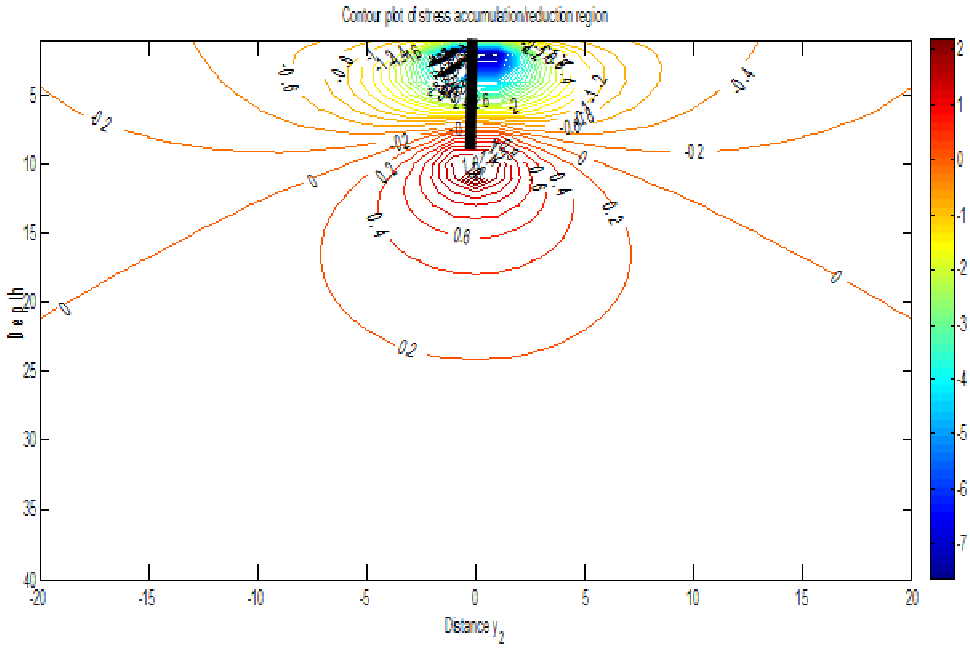

Figure. 8. Contour map for stress accumulation/release in the medium due to the fault slip across F

Acknowledgements

One of the authors (Papiya Debnath) thanks the Principal and Head of the Department of Basic Science and Humanities, Techno India College of Technology, a unit of Techno India Group (INDIA), for allowing me to pursue the research, and also thanks the Geological Survey of India; Department of Applied Mathematics, University of Calcutta for providing the library facilities.

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