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A Nonplanar Surface Breaking Strike Slip Fault in a Viscoelastic Half Space Model of the Lithosphere

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Abstract: *Modeling of the stress accumulation process during quasi-static aseismic period in the presence of non planar strike-slip fault in seismically active regions has been considered. A viscoelastic half space was taken to represent the lithosphere-asthenosphere system and forces arising out some tectonic processes e.g. mantle convection and the resulting driving forces, were considered to be the main reason for the accumulation of stress in the lithosphere near the earthquake faults. When the accumulated stresses exceed the frictional and cohesive forces across the fault, a sudden and/or creeping movement across the fault occurs. In this paper the pattern of stress accumulation near the faults and the surface shear strain during the aseismic period have been considered using suitable mathematical techniques including integral transforms and Green's functions. A detail study may lead to an estimation of the time-span between two consecutive seismic events. It is expected that such studies may be useful in earthquake prediction.*
Key Words- *Aseismic, Earthquake prediction, Stress Accumulation, Strike-slip faults, Viscoelastic.*

I. Introduction

Earthquakes are generated due to various types of movements across seismic faults having different geometrical features. Two major seismic events are usually separated by long quasi-static aseismic periods which may extend up to several years. Stresses accumulate near the faults during this aseismic period due to various tectonic reasons including mantle convection. When the accumulated stress exceeds some thresholds value, movement across the fault occurs leading in to an earthquake. Longtime observations indicate that in many cases the faults are not geometrically simple planar but have some non planar features. In view of this we consider a simple model of a non planar strike slip fault consisting of two plane surfaces with a common boundary inclined at different angles with horizontal.

The mechanics of quasi-statical deformation in the presence of earthquake faults of arbitrary shape and size in elastic medium were considered by many authors-Steketee [1], Maruyama [2,3], Rybicki [4], Lisowski [5], Sato[6-8], Chinnery [9-18], Sarvojit Singh, Sunita Rani [19,20], Mukhopadhyay et.al.[21-27]. The studies of dynamic ruptures in the presence of earthquakes faults of complex geometrical features was studied by Uri S.ten Brink, Rafael Katzmanl, Jian Lin [28], J. Ramon Arrowsmith and Elizabeth Stone [29], Sato, H.,et.al.[30], F. Lorenzo-Martin, R. Wang and F. Roth [31], David D. Oglesby [32], George E. Hillery, Satosi Ide , Hideo Aochi [33], Michiharu Ikeda, Dapeng Zhao, Yuki Ohno [34].

II. Formulation

We consider a simple theoretical model of the lithosphere-asthenosphere system represented by a viscoelastic half space with a creeping, surface breaking long, non-planar strike-slip fault consisting of two planar parts F_1 and F_2. The first part of the fault F_1 inclined at an angle θ_1 and second part of the fault F_2 inclined at an angle θ_2 to the horizontal respectively. Both the parts of the fault situated in a linearly viscoelastic half-space with its material of Maxwell type. The upper and the lower edge of the fault are horizontal. We, however, consider a long fault, whose length is assumed to be much greater than the width of the both parts of the fault. Let the width of the first part F_1 and second part F_2 of fault are l_1 and l_2 respectively.

We note here that some authors, such as Rybicki [4] considered layered model for the lithosphere-asthenosphere system. But, intensive numerical computations show that the presence of an elastic layer does not significantly change the characteristic behaviour of the rate of accumulation of surface shear strain and the rate of stress accumulation in the model. It only results in small quantitative changes in the stress and strain pattern due to fault movement. It is found that in upper part of the model (within a depth of 50 km) this quantitative change is well within 10% and for the region below it, it is only 1%. With these observations, it is quite reasonable to represent the lithosphere-asthenosphere system by means of a single viscoelastic half space. It is expected that of the essential features of aseismic ground deformations and the effect of fault movement and interacting effects among neighbouring faults can be well understood with the help of such half space model.

We introduce a rectangular Cartesian coordinate system (y_1, y_2, y_3) with the plane free surface of the viscoelastic half-space as the plane $y_3 = 0$ and y_3 –axis pointing into the half-space. The upper edge of the fault is taken as y_1 -axis. For convenience of the analysis we introduce another two rectangular systems of Cartesian coordinates (y'_1, y'_2, y'_3) and (y''_1, y''_2, y''_3) associated with the parts F_1 and F_2 of the fault respectively with origin O of first system and with origin $O'(0, l_1 \sin\theta_1 , l_1 \cos\theta_2)$ for second system.

The plane of first part F_1 of the fault is given by the plane $y'_2 = 0$ and the plane of second part F_2 of the fault is given by the plane $y''_2 = 0$. With this choice of axes the half space occupies the region $y_3 \geq 0$. While the fault is given by (F_1: $y'_2 = 0$, $0 \leq y'_3 \leq l_1$ and F_2: $y''_2 = 0$, $0 \leq y''_3 \leq l_2$). The relations between (y_1, y_2, y_3), (y'_1, y'_2, y'_3) and (y''_1, y''_2, y''_3) are given by:

$$y_1 = y'_1$$
$$y_2 = y'_2 \sin\theta_1 + y'_3 \cos\theta_1$$
$$y_3 = -y'_2 \cos\theta_1 + y'_3 \sin\theta_1$$

and

$$y_1 = y''_1$$
$$y_2 = l_1\cos\theta_1 + y''_2 \sin\theta_2 + y''_3 \cos\theta_2$$
$$y_3 = l_1\sin\theta_1 - y''_2 \cos\theta_2 + y''_3 \sin\theta_2$$

A section of the theoretical model by the plane $y_1 = 0$ has been shown in the Fig. (1) in which the coordinate axes (y_2, y_3), (y'_2 , y'_3), and (y''_2 , y''_3) have also been identified.

Let (u_1, u_2, u_3) be the components of the displacement **u** in the half space $y_3 \geq 0$ in the directions (y_1, y_2, y_3) axes respectively and let τ_{ij} (i, j = 1, 2, 3) the stress components while e_{ij} (i, j = 1, 2, 3) are the components of strain. For a long fault, all these quantities are taken to be independent of y_1 and are functions of y_2, y_3 and t. These components separate out into two distinct and independent groups (Maruyama, [3]) - one group containing u_1, τ_{12}, τ_{13} and e_{12}, e_{13} is associated with strike-slip movement, while the other group consisting of u_2, u_3, τ_{22}, τ_{33}, τ_{23} and e_{22}, e_{33}, e_{23} is associated with a possible dip-slip movement of the fault. Here we consider only the strike-slip movement of the fault.

II.1 Constitutive equations (stress - strain relations)

The stress-strain relations for the viscoelastic half space (Budiansky and Amazigo [35])

$$\left.\begin{aligned} \left(\frac{1}{\eta}+\frac{1}{\mu}\frac{\partial}{\partial t}\right)\tau_{12} &= \frac{\partial^2 u_1}{\partial t \partial y_2} \\ \left(\frac{1}{\eta}+\frac{1}{\mu}\frac{\partial}{\partial t}\right)\tau_{13} &= \frac{\partial^2 u_1}{\partial t \partial y_3} \end{aligned}\right\} \qquad (1)$$

$$(-\infty < y_2 < \infty), (y_3 \geq 0, t \geq 0)$$

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

II.2 Stress equation of motion

For the slow aseismic quasi-static deformation of the system, inertial forces are very small and are neglected; the relevant stress would satisfy the following relations

$$\frac{\partial}{\partial y_2}(\tau_{12}) + \frac{\partial}{\partial y_3}(\tau_{13}) = 0 \qquad (2)$$

$$(-\infty < y_2 < \infty), (y_3 \geq 0, t \geq 0)$$

From equation (1) and (2),

$$\frac{\partial}{\partial t}(\nabla^2 u_1) = 0$$

which is satisfied if

$$\nabla^2 u_1 = 0, \ (-\infty < y_2 < \infty, \ y_3 \geq 0, \ t \geq 0) \qquad (3)$$

II.3 Boundary conditions

$$\tau_{13} = 0 \text{ on } y_3 = 0 \qquad (4)$$
$$(-\infty < y_2 < \infty, \ t \geq 0)$$
$$\tau_{13} \to 0 \text{ as } y_3 \to \infty \qquad (5)$$

$(-\infty < y_2 < \infty,\ t \geq 0)$

$\tau_{12} \rightarrow \tau_\infty$ as $|y_2| \rightarrow \infty$ (6)

$(y_3 \geq 0,\ t \geq 0)$

where τ_∞ is the constant shear stress maintained by the tectonic forces far away from the fault.

II.4 Initial conditions

Let $(u_1)_0$, $(\tau_{12})_0$, $(\tau_{13})_0$, $(e_{12})_0$, $(e_{13})_0$ are the values of u_1, τ_{12}, τ_{13}, e_{12}, e_{13} respectively at time $t = 0$. They are functions of (y_2, y_3) and satisfy the relations (1) to (6) where time t is measured from a suitable instant when there is no seismic activity in the system.

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

In this case the displacements, stresses and strains are all continuous throughout the system and the time t is measured from a suitable instant for which conditions (1) to (6) are satisfied for $t \geq 0$. The solutions can be obtained by taking Laplace transformation of equations (1) to (6) with respect to time t which give rise to a boundary value problem for $\bar{u}_1, \bar{\tau}_{12}, \bar{\tau}_{13}$ the Laplace transformation of u_1, τ_{12}, τ_{13} with respect to time t. On taking inverse of the Laplace transforms, we get the following expression (Mukhopadhyay,et.al.[23]) in the absence of fault movement valid throughout the model for $t \geq 0$

$$\left.\begin{aligned}
u_1(y_2,y_3,t) &= (u_1)_0 + \frac{\tau_\infty t y_2}{\eta} \\
\tau_{12}(y_2,y_3,t) &= (\tau_{12})_0 e^{(-\frac{\mu t}{\eta})} + \tau_\infty[1-e^{(-\frac{\mu t}{\eta})}] \\
\tau_{13}(y_2,y_3,t) &= (\tau_{13})_0 e^{(-\frac{\mu t}{\eta})} \\
e_{12}(y_2,y_3,t) &= \frac{\partial u_1}{\partial y_2} = (e_{12})_0 + \frac{\tau_\infty t}{\eta}
\end{aligned}\right\} \quad (7)$$

$$\left.\begin{aligned}
\tau_{1'2'} &= \tau_{12}\sin\theta_1 - \tau_{13}\cos\theta_1 \\
&= (\tau_{1'2'})_0 e^{(-\frac{\mu t}{\eta})} + \tau_\infty \sin\theta_1[1-e^{(-\frac{\mu t}{\eta})}] \\
\tau_{1''2''} &= (\tau_{1''2''})_0 e^{(-\frac{\mu t}{\eta})} + \tau_\infty \sin\theta_2[1-e^{(-\frac{\mu t}{\eta})}]
\end{aligned}\right\} \quad (8)$$

where $(\tau_{1'2'})_0$, $(\tau_{1''2''})_0$ are values of $\tau_{1'2'}$ and $\tau_{1''2''}$ at $t = 0$ respectively and are given by

$$(\tau_{1'2'})_0 = (\tau_{12})_0 \sin\theta_1 - (\tau_{13})_0 \cos\theta_1$$
$$(\tau_{1''2''})_0 = (\tau_{12})_0 \sin\theta_2 - (\tau_{13})_0 \cos\theta_2$$

Thus if the shear stress $\tau_{1'2'} < \tau_\infty \sin\theta_1$ near F_1 and $\tau_{1''2''} < \tau_\infty \sin\theta_2$ at $t = 0$ then there will be a continuous accumulation of shear stress $\tau_{1'2'}$ near F_1 and $\tau_{1''2''}$ near F_2 for $t > 0$ and ultimately as $t \rightarrow \infty$, $\tau_{1'2'} \rightarrow \tau_\infty \sin\theta_1$ and $\tau_{1''2''} \rightarrow \tau_\infty \sin\theta_2$ in the neighborhood of F_1 and F_2 respectively.

It may further be noted that the rate of accumulation of shear stress $\tau_{1'2'}$ and $\tau_{1''2''}$ as well as the maximum limiting values of shear stress $\tau_{1'2'}$ (which is = $\tau_\infty \sin\theta_1$) and $\tau_{1''2''}$ (which is = $\tau_\infty \sin\theta_2$) both increase as θ_1, θ_2 increase and attain the maximum values when the fault is vertical ($\theta_1 = \pi/2, \theta_2 = \pi/2$).Thus the accumulation of shear stress $\tau_{1'2'}$, $\tau_{1''2''}$ tending to cause strike-slip movement can reach comparatively greater values if the fault is vertical or nearly vertical; so that the possibility of a major strike slip movement is relatively greater for nearly vertical fault compared to those which are inclined at relatively smaller angles to the horizontal. This result is consistent with the general observations. If the characteristic of the fault be such that it starts creeping or a sudden seismic movement occurs across it when $\tau_{1'2'}$ and $\tau_{1''2''}$ in the neighborhood of the fault reaches some critical value, say τ_c ($\tau_c < \tau_\infty \sin\theta_1$ for F_1 and $\tau_c < \tau_\infty \sin\theta_2$ for F_2) then there will be a creeping or sudden seismic movement across F_1 and F_2 after a finite length of time T (say) and then the solutions given by (7),(8) do not hold good and require some modifications.

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

We consider a slow, aseismic creep movement across the fault commencing at time $t = T$ .Then the accumulated stress is released at least to some extent and the fault becomes locked again. The time period of creeping fault is considered as a very short period compare to the aseismic period. All the relations (1) to (6) are valid for $t \geq T$. In addition we have the following conditions which characterize the creeping movements across F_1 and F_2

$[u_1]_{F_1} = U(t_1) f(y'_3) H(t_1)$ (9a)
across F_1 ($y'_2 = 0,\ 0 \le y'_3 \le l_1$)

$[u_1]_{F_2} = V(t_1) g(y''_3) H(t_1)$ (9b)
across F_2 ($y''_2 = 0,\ 0 \le y''_3 \le l_2$)

where $t_1 = t - T$ and $H(t_1)$ is heaviside unit step function. $f(y'_3)$ and $g(y''_3)$ give the spatial dependence of the creep movement along the widths of F_1 and F_2 respectively and the relative creep displacements are given by

$$[u_1]_{F_1} = \lim_{y'_2 \to 0^+} u_1 - \lim_{y'_2 \to 0^-} u_1$$

$$[u_1]_{F_2} = \lim_{y''_2 \to 0^+} u_1 - \lim_{y''_2 \to 0^-} u_1$$

Here $U(t_1)$, $V(t_1)$ are assumed to be continuous function of t_1 and $f(y'_3)$ and $g(y''_3)$ are continuous function of y'_3 and y''_3 respectively. $U(t_1) = 0$, $V(t_1) = 0$ for $t_1 \le 0$. The creep velocity across F_1, F_2 are given by

$$\frac{\partial}{\partial t}\left\{[u_1]_{F_1}\right\} = W_1(t_1) f(y'_3)$$

$$\frac{\partial}{\partial t}\left\{[u_1]_{F_2}\right\} = W_2(t_1) g(y''_3)$$

where $W_1(t_1) = \frac{d}{dt}U(t_1)$ and $W_2(t_1) = \frac{d}{dt}V(t_1)$ which is assumed to be finite for all $t_1 \ge 0$.

To solve the initial boundary value problem involving (u_1, τ_{12}, τ_{13}) for $t \ge T$, we try to obtain u_1, τ_{12}, τ_{13} in the following form

$$\left.\begin{aligned} u &= (u_1)_1 + (u_1)_2 + (u_1)_3 \\ \tau_{12} &= (\tau_{12})_1 + (\tau_{12})_2 + (\tau_{12})_3 \\ \tau_{13} &= (\tau_{13})_1 + (\tau_{13})_2 + (\tau_{13})_3 \end{aligned}\right\} \quad (10)$$

where $(u_1)_1$, $(\tau_{12})_1$, $(\tau_{13})_1$ are continuous everywhere except at the bending point O' in the model satisfying equations (1) to (6) and assumed the values $(u_1)_0$, $(\tau_{12})_0$, $(\tau_{13})_0$ at $t = 0$. The solutions for $(u_1)_1$, $(\tau_{12})_1$, $(\tau_{13})_1$ will be similar to equation (7) and (8)

$$\left.\begin{aligned} (u_1)_1 &= (u_1)_0 + \frac{\tau_\infty y_2 t}{\eta} \\ (\tau_{12})_1 &= (\tau_{12})_0 e^{(-\frac{\mu t}{\eta})} + \tau_\infty[1 - e^{(-\frac{\mu t}{\eta})}] \\ (\tau_{13})_1 &= (\tau_{13})_0 e^{(-\frac{\mu t}{\eta})} \end{aligned}\right\} \quad (11)$$

which satisfy equations (1), (2), (3) and boundary conditions (4), (5) and the following boundary condition

$(\tau_{12}) \to \tau_\infty$ as $|y_2| \to 0$ (12a)

while $(u_1)_i$, $(\tau_{12})_i$, $(\tau_{13})_i$, ($i = 2, 3$) satisfy the equation (1), (2), (3) and the boundary condition

$(\tau_{12})_2$ and $(\tau_{13})_3 \to 0$ as $|y_2| \to \infty$ (12b)
($y_3 \ge 0$, $t_1 \ge 0$)

together with the creeping condition

$$\left.\begin{aligned} &[(u_1)_2] = U(t_1) f(y''_3)\ across\ F_1, \\ &t \ge T \text{ with } \mathrm{U}(t_1) = 0, \text{ for } t_1 \le 0 \end{aligned}\right\} \quad (13a)$$

and

$$\left.\begin{aligned} &[(u_1)_3] = V(t_1) g(y''_3)\ across\ F_2, \\ &t \ge T \text{ with } \mathrm{V}(t_1) = 0, \text{ for } t_1 \le 0 \end{aligned}\right\} \quad (13b)$$

Also, $(u_1)_2$, $(\tau_{12})_2$, $(\tau_{13})_2 = 0$ for $t_1 \le 0$ (14a)
$(u_1)_3$, $(\tau_{12})_3$, $(\tau_{13})_3 = 0$ for $t_1 \le 0$ (14b)

To obtain the solutions for $(u_1)_2$, $(\tau_{12})_2$, $(\tau_{13})_2$ for $t_1 \ge 0$, we take Laplace transforms of equations (1) to (6) and equations (12a), (13a), (14a) with respect to t_1, the resulting boundary value problem involve

$(\bar{u}_1)_2, (\bar{\tau}_{12})_2, (\bar{\tau}_{13})_2$ the Laplace transforms of $(u_1)_2$, $(\tau_{12})_2$ and $(\tau_{13})_2$ with respect to time t_1. The transformed equations can be solve by using modified Green's function technique developed by Maruyama [3] as explained in the Appendix. On inverting these Laplace transforms the solutions for $(u_1)_2$, $(\tau_{12})_2$, $(\tau_{13})_2$ for $t_1 \geq 0$ and $y'_2 \neq 0$ with constant creep velocity W_1 of F_1 are obtained as follows

$$\left.\begin{aligned}
(u_1)_2(y_2, y_3, t) &= H(t-T)\frac{U(t_1)}{2\pi}\phi_1(y_2, y_3) \\
(\tau_{12})_2(y_2, y_3, t) &= H(t-T)\frac{W_1\eta}{2\pi}[1-e^{\{-\frac{\mu(t-T)}{\eta}\}}]\psi_1(y_2, y_3) \\
(\tau_{13})_2(y_2, y_3, t) &= H(t-T)\frac{W_1\eta}{2\pi}[1-e^{\{-\frac{\mu(t-T)}{\eta}\}}]\chi_1(y_2, y_3)
\end{aligned}\right\} \quad (15)$$

where ϕ_1, ψ_1, χ_1 are given the appendix.

Similarly solutions for $(u_1)_3$, $(\tau_{12})_3$ and $(\tau_{13})_3$ can similar be obtained as follows

$$\left.\begin{aligned}
(u_1)_3(y_2, y_3, t) &= H(t-T)\frac{V(t_1)}{2\pi}\phi_2(y_2, y_3) \\
(\tau_{12})_3(y_2, y_3, t) &= H(t-T)\frac{W_2\eta}{2\pi}[1-e^{\{-\frac{\mu(t-T)}{\eta}\}}]\psi_2(y_2, y_3) \\
(\tau_{13})_3(y_2, y_3, t) &= H(t-T)\frac{W_2\eta}{2\pi}[1-e^{\{-\frac{\mu(t-T)}{\eta}\}}]\chi_2(y_2, y_3)
\end{aligned}\right\} \quad (16)$$

where $U_1(t_1) = W_1.t_1$, $V_1(t_1) = W_2.t_1$, W_1, W_2 are constants.

The expressions of ϕ_2, ψ_2, χ_2 are given in the appendix.

Thus the final solutions for displacements, stresses and strains for $t_1 \geq 0$ are given by

$$\left.\begin{aligned}
u_1(y_2, y_3, t) &= (u_1)_0 + \frac{\tau_\infty t y_2}{\eta} + H(t-T)\frac{t_1}{2\pi}\{W_1\phi_1(y_2, y_3) + W_2\phi_2(y_2, y_3)\} \\
\tau_{1'2'} &= \tau_{12}\sin\theta_1 - \tau_{13}\cos\theta_1 \\
&= (\tau_{1'2'})_0 e^{(-\frac{\mu t}{\eta})} + \tau_\infty \sin\theta_1[1-e^{\{-\frac{\mu t}{\eta}\}}] + H(t-T)\frac{\eta}{2\pi}[1-e^{\{-\frac{\mu(t-T)}{\eta}\}}]\times \\
&\quad \{W_1(\psi_1\sin\theta_1 - \chi_1\cos\theta_1) + W_2(\psi_2\sin\theta_1 - \chi_2\cos\theta_1)\} \\
\tau_{1''2''} &= \tau_{12}\sin\theta_2 - \tau_{13}\cos\theta_2 \\
&= (\tau_{1''2''})_0 e^{(-\frac{\mu t}{\eta})} + \tau_\infty \sin\theta_2[1-e^{\{-\frac{\mu t}{\eta}\}}] + H(t-T)\frac{\eta}{2\pi}[1-e^{\{-\frac{\mu(t-T)}{\eta}\}}]\times \\
&\quad \{W_1(\psi_1\sin\theta_2 - \chi_1\cos\theta_2) + W_2(\psi_2\sin\theta_2 - \chi_2\cos\theta_2)\} \\
e_{12} &= \frac{\partial u_1}{\partial y_2} \\
&= (e_{12})_0 + \frac{\tau_\infty t}{\eta} + \frac{H(t-T)}{2\pi}t_1\{W_1\psi_1 + W_2\psi_2\}
\end{aligned}\right\} \quad (17)$$

It is found that the displacements, stresses and strains will be finite and single valued everywhere in the model, if the following conditions are satisfied

For f(y'$_3$)

(i) $f(y'_3)$, $f'(y'_3)$ are continuous function of y'_3 for $0 \leq y'_3 \leq l_1$.

(ii) $f'(0) = 0$.

(iii) $f''(y'_3)$ is continuous in $0 \leq y'_3 \leq l_1$ except for a finite number of points of finite discontinuity in $0 \leq y'_3 \leq l_1$, or, $f''(y'_3)$ is continuous in $0 < y'_3 < l_1$ and there exist real constant m, n < 1 such that $(y'_3)^m f''(y'_3) \to 0$ or to a finite limit as $y'_3 \to 0^+$ and that $(l_1 - y'_3)^n f''(y'_3) \to 0$ or to a finite limit as $y'_3 \to l_1^{-0}$.

For g(y''$_3$)

(i) $g(y''_3)$, $g'(y''_3)$ are continuous function of y''_3 for $0 \leq y''_3 \leq l_2$.

(ii) $g(l_2) = 0$ and $g'(0) = g'(l_2) = 0$.

(iii) Either $g''(y''_3)$ is continuous in $0 \leq y''_3 \leq l_2$ or, $g''(y''_3)$ is continuous in $0 \leq y''_3 \leq l_2$ except for a finite number of points of finite discontinuity in $0 \leq y''_3 \leq l_2$ or $g''(y''_3)$ is continuous in $0 < y''_3 < l_2$ and there exist real constant m,n < 1 such that $(l_2 - y''_3)^m g''(y''_3) \to 0$ or to a finite limit as $y''_3 \to l_2^{-0}$ and $(y''_3)^n g''(y''_3) \to 0$ or to a finite limit as $y''_3 \to 0^+$

V. Numerical Computations

We compute the following quantities assigning suitable values to the model parameters (Cathles, [36], Peter Chift, Jain Lin, Udo Barcktiausen [37], Shun-ichiro Karato [38])

$\mu = 3.78 \times 10^{11}$ dyne/sq.cm

$$\eta = 3 \times 10^{21} \text{ poise}$$

for the lithosphere and upper asthenosphere (for depth not more than 200 km).

$$l_1 = 10 \text{ km}$$
$$l_2 = 12 \text{ km}$$

(i) The rate of change of surface displacement per year due to fault creep

$$R_d = \frac{\partial}{\partial t}[u_1 - (u_1)_0 - \frac{\tau_\infty t y_2}{\eta}]_{y_3=0}$$

(ii) Change in surface shear strain due to fault creep

$$E_{12} = e_{12} - (e_{12})_0 - \frac{\tau_\infty t}{\eta}$$

(iii) The rate of release (per year) of the surface shear strain due to creep

$$R_s = -\frac{\partial}{\partial t}[e_{12} - (e_{12})_0 - \frac{\tau_\infty t}{\eta}]_{y_3=0}$$

(iii) The shear stress $\left(\tau_{1'2'}\right)_{mid\ F_1}$ $(i.e.\ \text{at}\ y_2' = 0, y_3' = \frac{l_1}{2})$.

(v) The shear stress $\left(\tau_{1''2''}\right)_{mid\ F_2}$ $(i.e.\ \text{at}\ y_2'' = 0, y_3'' = \frac{l_2}{2})$.

for different values of θ_1 and θ_2 in ($0< \theta_1, \theta_2 \leq \pi/2$) and W_1, W_2 in the range of (0-7) cm/year. All the computations have been done at time $t_1 = t - T = 1$ year, i.e. one year after the commencement of fault creep. We take τ_∞ =300 bar which is in conformity with most of the estimations made in this direction (Mukhapadhyay, et.al. [21-27]). The threshold level τ_c of the shear stress that can be balanced by the frictional and cohesive forces across the fault depends upon the inclination of the fault. For example, we consider the upper part F_1 of the fault which is inclined to the horizontal at an angle θ_1. Let us assume $\tau_c \approx \frac{1}{2}\tau_\infty \sin\theta_1$ for F_1, noting that $\tau_\infty \sin\theta_1$ is the maximum value of the shear stress $\tau_{1'2'}$ that can be accumulated near F_1 under the action of τ_∞. Further let the creeping movement across F_1 releases (stress-drop) two-third of τ_c and one-third of τ_c remains when aseismic state re-established, so that at $t = 0$, $(\tau_{1'2'})_0 \approx \frac{1}{6}\tau_\infty \sin\theta_1$. It is found that it takes about 129 years to reach accumulated stress near F_1 to the threshold level τ_c under the action of τ_∞, so that $T \sim 129$ years.

We carried out the numerical computations with the following choice of $f(y')$ and $g(y'')$

$$f(y_3') = 1 - (\frac{y_3'}{l_1})^2 + \frac{1}{2}(\frac{y_3'}{l_1})^3$$

$$g(y_3'') = \frac{1}{2}\frac{(y_3''^2 - l_2^2)^2}{l_2^4}$$

The depth-dependence of f and g are chosen in a way that the continuity at the common edge be maintained, i.e. f (at $y'_3 = l_1$) = g (at $y''_3 = 0$) = k (here k has been chosen as 1/2, may be taken otherwise). This continuity condition however violated the conditions stated earlier for bounded stress even at the common edge. However, stress very close to this common edge are found to be bounded.

VI. Discussion Of The Result

Fig. 2(a), 2(b), 2(c) and 2(d) show the regions of stress accumulation (A) and stress release (R) due to fault creep across F_1 and F_2. It is found that if a second fault be situated in the region A, the rate of stress accumulation near it will be enhanced due to the creeping movement across F_1 and F_2, and thereby expedite a possible movement across the second fault. The reverse will be the case if the second fault be situated in the region R.

VI.1 Rate of change of surface displacement per year due fault creep

Fig. 3(a)-3(c) show the rate of change of surface displacement for different y_2 one year (t-T=1 year) after the commencement of the fault creep on F_1 and F_2. It is found that R_d depends upon various factors such that

(i) the inclination of F_1 and F_2 with the horizontal

ii) the velocity of creep W_1 and W_2 on F_1 and F_2 respectively.

R_d undergoes two discontinuities- one at $y_2 = 0$, i.e. along the strike of the fault and another at a point vertically above F_2. The magnitudes of these discontinuities depend upon W_1 and W_2, more the values of W_1 and / or W_2 more the discontinuities. The effect of W_1 is more pronounced on R_d and on its discontinuities, as expected. The position of the second point of discontinuity of R_d essentially depends upon the inclination of the fault. The second point of discontinuity shifted away from the strike of the fault in the positive direction of y_2 as the inclination of F_1 / F_2 with the horizontal decreases. Fig. 3(b) and 3(c) indicates that effect of F_1 on the character of R_d is more pronounced than that of F_2.

VI.2 Change of surface shear strain with time near the strike of the fault

The creeping movements of the fault F_1 and F_2 introduce a change in the surface shear strain E_{12} as shown in figure 4(a) and 4(b). Before the creep, E_{12} changes at a gradually increasing rate with time till the creeping movement commences. The rate of change of surface strain falls of with time after the commencement of fault creep. The magnitude of the surface shear strain E_{12} is found to decrease with time. The rate of release of surface shear strain essentially depends upon the creep velocities W_1, W_2 and also of the inclination of the faults. Here also the effect of W_1 is more pronounced compared to that of W_2. Fig. 5(a), 5(b) and 5(c) shows the rate of release of surface shear strain (R_s) due to fault creep on F_1, F_2 against y_2, the distance from the strike of the fault. It is found that R_s has the maximum value mostly in the region $0 \leq y_2 \leq 10$ and its magnitude is found to be of the order of 10^{-7} per year which is totally in conformity with observations.

VI.3 Accumulation of shear stress near the mid point of the fault

We note that the maximum possible value of accumulated shear stress near the mid points of F_1 and F_2 under the action of τ_∞ would be around $\tau_\infty \sin \theta_1$ and and $\tau_\infty \sin \theta_2$ respectively. Fig. 6(a)-6(d) show the total stress accumulation $\tau_{1'2'}$ and $\tau_{1''2''}$ with time t near the mid-points of F_1 and F_2 for various inclinations with horizontal. We observe that

(i) In each case the rate of change of shear stress near the fault falls off suddenly after $t = T$.
(ii) In general, more the values of W_1 and W_2 , more are the decreases in the rate.
(iii) The change in $\tau_{1'2'}$ near F_1 is more prominent with the changes in W_1 but changes in W_2 have little effect on it.
(iv) Similar results are obtained for stresses near F_2. The rate of total stress accumulation get a sudden fall at $t = T$. The effect of W_2 is more prominent in this case (fig.6(c)).
(v) One interesting result has been observed in fig. 6(d), the rate of stress accumulation near F_2 is found to be higher compared to smaller values of W_1. A close observation of fig. 6(b): B, C, D also indicate similar results for $\tau_{1'2'}$ near F_1.

VII. Numerical Computation For Earthquake Prediction

From the result shown in fig. 6(a)-6(d), it is possible to have an estimates of the time to the next possible movement of the fault. For example, let us consider a single case with $\theta_1 = \pi/3$, $\theta_2 = \pi/4$ and creep velocities W_2 = 1.0 cm/year across F_2, W_1 = 0.5 cm/year and W_1 = 1.0 cm/year across F_1. Fig. 7(a) shows the total stress accumulation ($\tau_{1'2'}$) with time t near the mid-point of F_1. Assuming that at $t = 0$ initial stress $(\tau_{1'2'})_0 \sim 1/6\ (\tau_\infty \sin \theta_1) \approx 43.30$ bar. At $T \sim 129$ years the accumulated near F_1 reaches the threshold level $\tau_c \sim 130$ bar, and a creeping movement of the fault starts. We assume that the stress is released by the same amount due to this movement and came down to its critical value 43.30 bar. After the fault creep, stresses will built up again at a reduced rate. It is computed from the graph that $\tau_{1'2'}$ near F_1 will again reach the threshold level τ_c at $t \approx 495$ years if $W_1 \sim 0.5$ cm/year and at $t \approx 713$ years if $W_1 \sim 1.0$ cm/year. Thus there would be a possible second movement after 365 and 584 years if $W_1 \sim 0.5$ cm/year, ~ 1.0 cm/year respectively. On the other hand if the stress drop is at $t = T$ is only 50% of τ_c then a possible second movement may takes place after a gap of 217 years and 288 years for W_1 = 0.5 cm/year and W_1 = 1.0 cm/y ear respectively (Fig. 7(b)), with W_2 = 1.0 cm/year.

VIII. Appendix

A1.Displacements, stresses, and strains for t > T after commencement of the fault creep- the method of solution

The displacements and stresses after commencement of the fault creep have been found in the form given in equation (10). Taking Laplace transforms of equations (1) to (5), (12a), (12b), (13a), (13b) and (14a), (14b) with respect to time t_1, a boundary value problem involving $\left(\bar{u}_1\right)_2, \left(\bar{\tau}_{12}\right)_2, \left(\bar{\tau}_{13}\right)_2$ and $\left(\bar{u}_1\right)_3, \left(\bar{\tau}_{12}\right)_3, \left(\bar{\tau}_{13}\right)_3$ which are Laplace transforms of $(u_1)_2$, $(\tau_{12})_2$, $(\tau_{13})_2$ and $(u_1)_3$, $(\tau_{12})_3$, $(\tau_{13})_3$ respectively with respect to t_1.

Therefore,

$$\left\{(\bar{u}_1)_2,(\bar{u}_1)_3,(\bar{\tau}_{12})_2,(\bar{\tau}_{12})_3,(\bar{\tau}_{13})_2,(\bar{\tau}_{13})_3\right\}=\int_0^\infty\left\{(u_1)_2,(u_1)_3,(\tau_{12})_2,(\tau_{12})_3,(\tau_{13})_2,(\tau_{13})_3\right\}e^{-pt_1}dt_1$$

where p is the Laplace transform variable. We have the following relations in transformed domain

$$\left.\begin{aligned}(\bar{\tau}_{12})_2&=\frac{p}{\left(\frac{1}{\eta}+\frac{p}{\mu}\right)}\frac{\partial}{\partial y_2}(\bar{u}_1)_2\\(\bar{\tau}_{13})_2&=\frac{p}{\left(\frac{1}{\eta}+\frac{p}{\mu}\right)}\frac{\partial}{\partial y_3}(\bar{u}_1)_2\end{aligned}\right\}\qquad\text{(A1)}$$

$$\frac{\partial}{\partial y_2}(\bar{\tau}_{12})_2+\frac{\partial}{\partial y_3}(\bar{\tau}_{13})_2=0\qquad\text{(A2)}$$

$$\nabla^2(\bar{u}_1)_2=0\qquad\text{(A3)}$$

$(-\infty < y_2 < \infty,\ y_3 \geq 0)$

$$(\bar{\tau}_{13})_2=0\text{ on }y_3=0\qquad\text{(A4)}$$

$(-\infty < y_2 < \infty)$

$$(\bar{\tau}_{13})_2\to 0\text{ as }y_3\to\infty\qquad\text{(A5)}$$

$(-\infty < y_2 < \infty)$

$$(\bar{\tau}_{12})_2\to 0\text{ as }|y_2|\to\infty\qquad\text{(A6)}$$

$(y_3 \geq 0)$

and

$$[(\bar{u}_1)_2]=\bar{U}(p)f(y'_3)\qquad\text{(A7)}$$

across F_1: $(y'_2 = 0,\ 0 \leq y'_3 \leq l_1)$

and

$$\left.\begin{aligned}(\bar{\tau}_{12})_3&=\frac{p}{\left(\frac{1}{\eta}+\frac{p}{\mu}\right)}\frac{\partial}{\partial y_2}(\bar{u}_1)_3\\(\bar{\tau}_{13})_3&=\frac{p}{\left(\frac{1}{\eta}+\frac{p}{\mu}\right)}\frac{\partial}{\partial y_3}(\bar{u}_1)_3\end{aligned}\right\}\qquad\text{(B1)}$$

$$\frac{\partial}{\partial y_2}(\bar{\tau}_{12})_3+\frac{\partial}{\partial y_3}(\bar{\tau}_{13})_3=0\qquad\text{(B2)}$$

$$\nabla^2(\bar{u}_1)_3=0\qquad\text{(B3)}$$

$(-\infty < y_2 < \infty,\ y_3 \geq 0)$

$$(\bar{\tau}_{13})_3=0\text{ on }y_3=0\qquad\text{(B4)}$$

$(-\infty < y_2 < \infty)$

$$(\bar{\tau}_{13})_3\to 0\text{ as }y_3\to\infty\qquad\text{(B5)}$$

$(-\infty < y_2 < \infty)$

$$(\bar{\tau}_{12})_3\to 0\text{ as }|y_2|\to\infty\qquad\text{(B6)}$$

$(y_3 \geq 0)$

and

$$[(\bar{u}_1)_3]=\bar{V}(p)g(y''_3)\qquad\text{(B7)}$$

across F_2: $(y''_2 = 0,\ 0 \leq y''_3 \leq l_2)$

Here,

$$\bar{U}(p)=\int_0^\infty U(t_1)e^{-pt_1}dt_1$$

$$\bar{V}(p)=\int_0^\infty V(t_1)e^{-pt_1}dt_1$$

To solve the above boundary value problems, a suitably modified form of Green's function technique, developed by Maruyama [3] and Rybicki [4] is used

$$(\bar{u}_1)_2(Q)=\int_{F_1}[(\bar{u}_1)_2(P)]\{G'_{12}(Q,P)d\xi_2-G'_{13}(Q,P)d\xi_3\} \quad \text{(A8)}$$

$$(\bar{u}_1)_3(Q)=\int_{F_2}[(\bar{u}_1)_3(P')]\{G'_{12}(Q,P')d\eta_2-G'_{13}(Q,P')d\eta_3\} \quad \text{(B8)}$$

where $Q(y_1, y_2, y_3)$ is the field point in the half space and $P(\xi_1, \xi_2, \xi_3)$ is any point on the fault F_1 and $P'(\eta_1, \eta_2, \eta_3)$ is any point on the fault F_2. $[(\bar{u}_1)_2(P)]$ is the discontinuity in $(\bar{u}_1)_2$ across F_1 at P and $[(\bar{u}_1)_3(P')]$ is the discontinuity in $(\bar{u}_1)_3$ across F_2 at P'. The Green's function $G'_{12}(Q, P)$, $G'_{13}(Q, P)$, $G'_{12}(Q, P')$, $G'_{13}(Q, P')$ are given by

$$G'_{13}(Q,P)=\frac{1}{2\pi}\left[\frac{(y_3-\xi_3)}{L^2}-\frac{(y_3+\xi_3)}{M^2}\right]$$

$$G'_{12}(Q,P)=\frac{1}{2\pi}\left[\frac{(y_2-\xi_2)}{L^2}+\frac{(y_2-\xi_2)}{M^2}\right]$$

$$G'_{13}(Q,P')=\frac{1}{2\pi}\left[\frac{(y_3-\eta_3)}{L'^2}-\frac{(y_3+\eta_3)}{M'^2}\right]$$

$$G'_{12}(Q,P')=\frac{1}{2\pi}\left[\frac{(y_2-\eta_2)}{L'^2}+\frac{(y_2-\eta_2)}{M'^2}\right]$$

$$\text{where, } L^2=(y_2-\xi_2)^2+(y_3-\xi_3)^2$$

$$M^2=(y_2-\xi_2)^2+(y_3+\xi_3)^2$$

$$L'^2=(y_2-\eta_2)^2+(y_3-\eta_3)^2$$

$$M'^2=(y_2-\eta_2)^2+(y_3+\eta_3)^2$$

Now $P(\xi_1, \xi_2, \xi_3)$ being a point on F_1, $0 \le \xi_2 \le l_1\cos\theta_1$, $0 \le \xi_3 \le l_1\sin\theta_1$ and $\xi_2 = \xi_3\cot\theta_1$ we introduce a change of coordinate axes from (ξ_1, ξ_2, ξ_3) to (ξ'_1, ξ'_2, ξ'_3) connected by the relations $\xi_1 = \xi'_1$, $\xi_2 = \xi'_2\sin\theta_1 + \xi'_3\cos\theta_1$, $\xi_3 = -\xi'_2\cos\theta_1 + \xi'_3\sin\theta_1$).

So on F_1: $\xi'_2 = 0$, $0 \le \xi'_3 \le l_1$.

Then from (A8) using (A7) we have

$$\left(\bar{u}_1\right)_2(Q)=\frac{\bar{U}(p)}{2\pi}\int_0^{l_1} f(\xi'_3)\left[\frac{y_2\sin\theta_1-y_3\cos\theta_1}{\xi'^2_3-2\xi'_3(y_2\cos\theta_1+y_3\sin\theta_1)+(y_2^2+y_3^2)}+\frac{y_2\sin\theta_1+y_3\cos\theta_1}{\xi'^2_3-2\xi'_3(y_2\cos\theta_1-y_3\sin\theta_1)+(y_2^2+y_3^2)}\right]d\xi'_3$$

or,

$$(\bar{u}_1)_2(Q)=\frac{\bar{U}(p)}{2\pi}\phi_1(y_2,y_3) \quad \text{(A9)}$$

where,

$$\phi_1(y_2,y_3)=\int_0^{l_1} f(\xi'_3)\left[\frac{y_2\sin\theta_1-y_3\cos\theta_1}{\xi'^2_3-2\xi'_3(y_2\cos\theta_1+y_3\sin\theta_1)+(y_2^2+y_3^2)}+\frac{y_2\sin\theta_1+y_3\cos\theta_1}{\xi'^2_3-2\xi'_3(y_2\cos\theta_1-y_3\sin\theta_1)+(y_2^2+y_3^2)}\right]d\xi'_3 \quad \text{(A10)}$$

Now $P'(\eta_1, \eta_2, \eta_3)$ being a point F_2, $0 \le \eta_2 \le l_2\cos\theta_2$, $0 \le \eta_3 \le l_2\sin\theta_2$ and $\eta_2 = \eta_3\cot\theta_3$. We also introduce a change of coordinate axes from (η_1, η_2, η_3) to $(\eta''_1, \eta''_2, \eta''_3)$ connected by the relations $\eta_1 = \eta''_1$, $\eta_2 = \eta''_2\sin\theta_2 + \eta''_3\cos\theta_2$, $\eta_3 = -\eta''_2\cos\theta_2 + \eta''_3\sin\theta_2$.

So on F_2: $\eta''_2 = 0$, $0 \le \eta''_3 \le l_2$.

Then from (B7) using (B8)

$$\left(\bar{u}_1\right)_3(Q)=\frac{\bar{V}(p)}{2\pi}\int_0^{l_2} g(\eta''_3)\left[\frac{y_2\sin\theta_2-y_3\cos\theta_2}{\eta''^2_3-2\eta''_3(y_2\cos\theta_2+y_3\sin\theta_2)+(y_2^2+y_3^2)}+\frac{y_2\sin\theta_2+y_3\cos\theta_2}{\eta''^2_3-2\eta''_3(y_2\cos\theta_2-y_3\sin\theta_2)+(y_2^2+y_3^2)}\right]d\eta''_3$$

$$(\bar{u}_1)_3(Q) = \frac{\bar{V}(p)}{2\pi}\phi_2(y_2, y_3) \quad \text{(B9)}$$

where,

$$\phi_2(y_2, y_3) = \int_0^{l_2} g(\eta_3'')\left[\begin{array}{l}\dfrac{y_2\sin\theta_2 - y_3\cos\theta_2}{\eta_3''^2 - 2\eta_3''(y_2\cos\theta_2 + y_3\sin\theta_2) + (y_2^2 + y_3^2)} + \\ \dfrac{y_2\sin\theta_2 + y_3\cos\theta_2}{\eta_3''^2 - 2\eta_3''(y_2\cos\theta_2 - y_3\sin\theta_2) + (y_2^2 + y_3^2)}\end{array}\right]d\eta_3'' \quad \text{(B10)}$$

Taking inverse Laplace transforms of (A9) and (B9) with respect to t_1 and noting that

$(u_1)_0 = 0$, $(u_1)_3 = 0$ for $t_1 \le 0$

$$(u_1)_2(y_2, y_3, t) = H(t-T)\frac{U(t_1)}{2\pi}\phi_1(y_2, y_3)$$

$$(u_1)_3(y_2, y_3, t) = H(t-T)\frac{V(t_1)}{2\pi}\phi_2(y_2, y_3)$$

where ϕ_1 and ϕ_2 are given by equation (A10) and (B10).

Again from (A1) and (B1)

$$(\bar{\tau}_{12})_2 = \frac{p}{(\frac{1}{\eta} + \frac{p}{\mu})}\frac{U(p)}{2\pi}\psi_1(y_2, y_3) \quad \text{(A11)}$$

$$(\bar{\tau}_{13})_2 = \frac{p}{(\frac{1}{\eta} + \frac{p}{\mu})}\frac{U(p)}{2\pi}\chi_1(y_2, y_3) \quad \text{(A12)}$$

$$(\bar{\tau}_{12})_3 = \frac{p}{(\frac{1}{\eta} + \frac{p}{\mu})}\frac{V(p)}{2\pi}\psi_2(y_2, y_3) \quad \text{(A13)}$$

$$(\bar{\tau}_{13})_2 = \frac{p}{(\frac{1}{\eta} + \frac{p}{\mu})}\frac{V(p)}{2\pi}\chi_2(y_2, y_3) \quad \text{(A14)}$$

where,

$$\psi_1(y_2, y_3) = \frac{\partial\phi_1}{\partial y_2}, \chi_1(y_2, y_3) = \frac{\partial\phi_1}{\partial y_3}$$

$$\psi_2(y_2, y_3) = \frac{\partial\phi_2}{\partial y_2}, \chi_2(y_2, y_3) = \frac{\partial\phi_2}{\partial y_3}$$

Now taking Laplace invers transformation with respect t_1 and noting that

$(\bar{\tau}_{12})_2 = 0$ for $t_1 \le 0$

$$(\tau_{12})_2(y_2, y_3, t) = H(t-T)\frac{\eta}{2\pi}W_1\psi_1(y_2, y_3)[1 - e^{-\frac{\mu(t-T)}{\eta}}]$$

$$(\tau_{12})_3(y_2, y_3, t) = H(t-T)\frac{\eta}{2\pi}W_2\psi_2(y_2, y_3)[1 - e^{-\frac{\mu(t-T)}{\eta}}]$$

and

$$(\tau_{13})_2(y_2, y_3, t) = H(t-T)\frac{\eta}{2\pi}W_1\chi_1(y_2, y_3)[1 - e^{-\frac{\mu(t-T)}{\eta}}]$$

$$(\tau_{13})_3(y_2, y_3, t) = H(t-T)\frac{\eta}{2\pi}W_2\chi_2(y_2, y_3)[1 - e^{-\frac{\mu(t-T)}{\eta}}]$$

where,

$$\psi_1(y_2, y_3) = \int_0^{l_1} f(\xi_3')\left[\begin{array}{l}\dfrac{\xi_3'^2\sin\theta_1 - 2\xi_3' y_3 - (y_2^2 - y_3^2)\sin\theta_1 + 2y_2y_3\cos\theta_1}{\left\{\xi_3'^2 - 2\xi_3'(y_2\cos\theta_1 + y_3\sin\theta_1) + (y_2^2 + y_3^2)\right\}^2} + \\ \dfrac{\xi_3'^2\sin\theta_1 + 2\xi_3' y_3 - (y_2^2 - y_3^2)\sin\theta_1 - 2y_2y_3\cos\theta_1}{\left\{\xi_3'^2 - 2\xi_3'(y_2\cos\theta_1 - y_3\sin\theta_1) + (y_2^2 + y_3^2)\right\}^2}\end{array}\right]d\xi_3'$$

$$\psi_2(y_2, y_3) = \int_0^{l_2} g(\eta_3'')\left[\begin{array}{l}\dfrac{\eta_3''^2\sin\theta_2 - 2\eta_3'' y_3 - (y_2^2 - y_3^2)\sin\theta_2 + 2y_2y_3\cos\theta_2}{\left\{\eta_3''^2 - 2\eta_3''(y_2\cos\theta_2 + y_3\sin\theta_2) + (y_2^2 + y_3^2)\right\}^2} + \\ \dfrac{\eta_3''^2\sin\theta_2 + 2\eta_3'' y_3 - (y_2^2 - y_3^2)\sin\theta_2 - 2y_2y_3\cos\theta_2}{\left\{\eta_3''^2 - 2\eta_3''(y_2\cos\theta_2 - y_3\sin\theta_2) + (y_2^2 + y_3^2)\right\}^2}\end{array}\right]d\eta_3''$$

Then finally, we can compute $e_{12} = \dfrac{\partial u_1}{\partial y_2}$ and $(\tau_{12})_{F_1}$ and $(\tau_{12})_{F_2}$ near mid point of F_1 and F_2 respectively.

IX. Figures

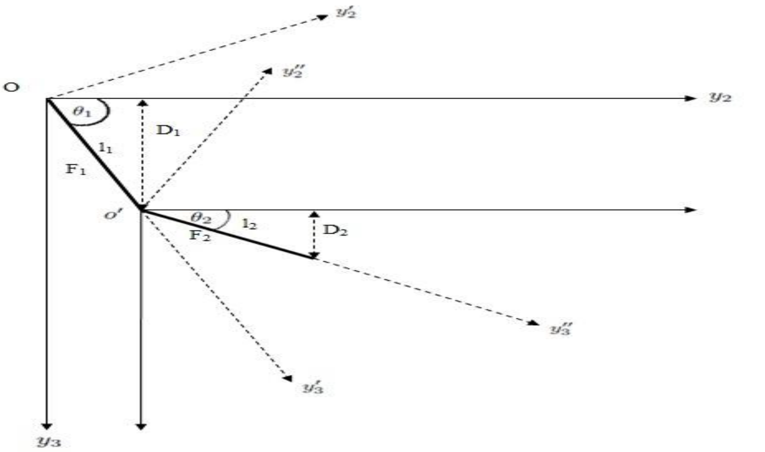

Fig.1: Section of the model by the plane y_1=0 and coordinate system

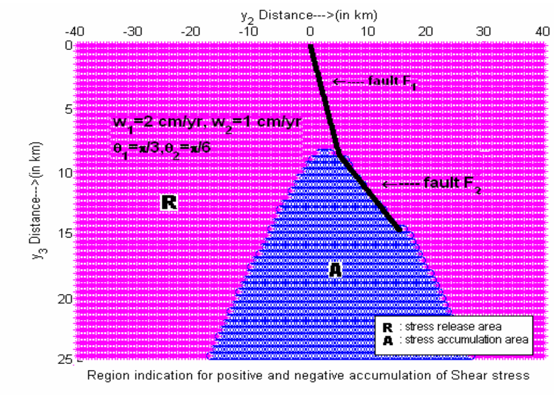

Fig 2(a): Region indication for positive and negative accumulation of Shear stress

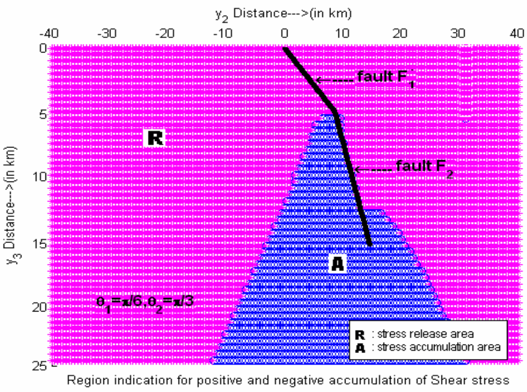

Fig 2(b): Region indication for positive and negative accumulation of Shear stress

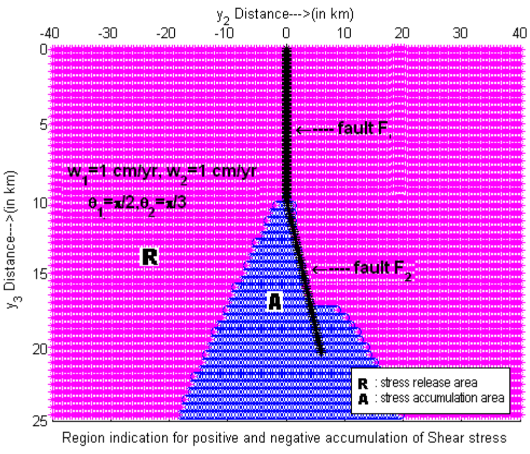

Fig 2(c): Region indication for positive and negative accumulation of Shear stress

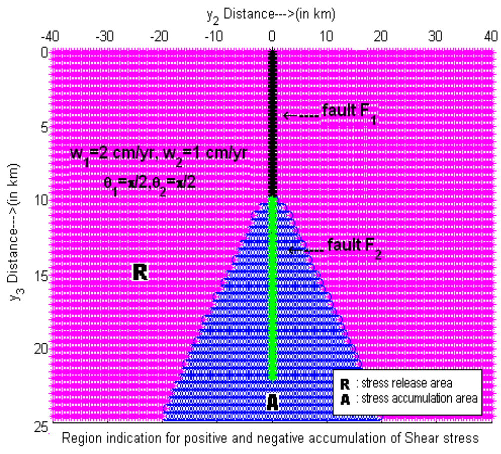

Fig 2(d): Region indication for positive and negative ccumulation of Shear stress

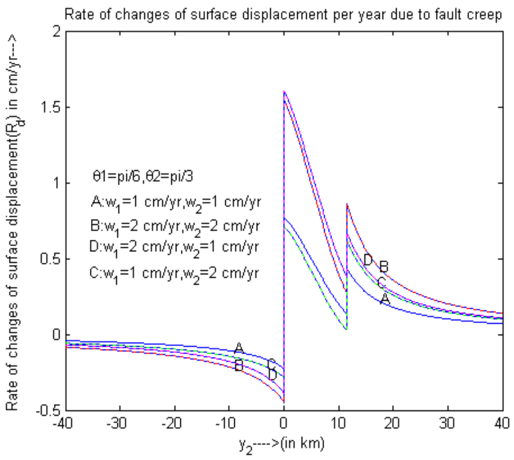

Fig-3(a) : Rate of change of surface displacement per year due to fault creep

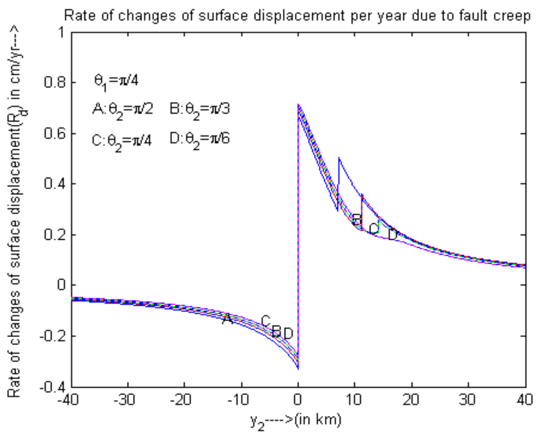

Fig-3(b) : Rate of change of surface displacement per year due to fault creep

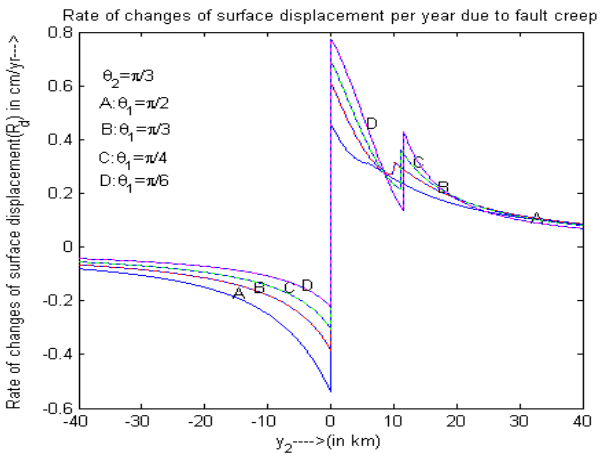

Fig-3(c) : Rate of change of surface displacement per year due to fault creep

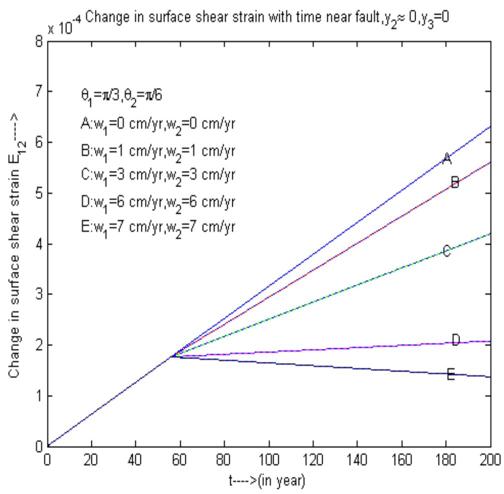

Fig-4(a): Change in surface shear strain near fault, $y_2 \sim 0$, $y_3 = 0$

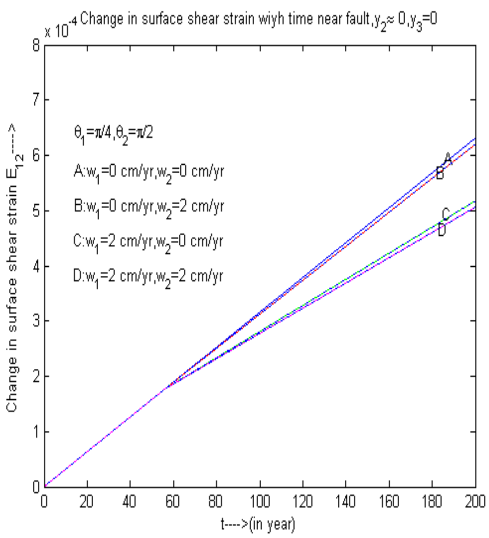

Fig-4(b): Change in surface shear strain near fault, y_2

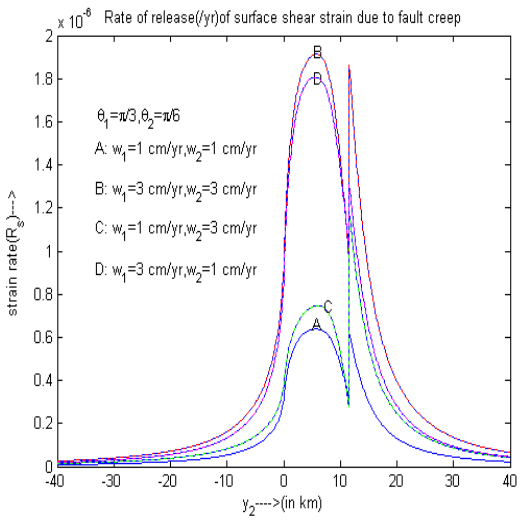

Fig-5(a): Rate of release (/year) of surface shear strain due to

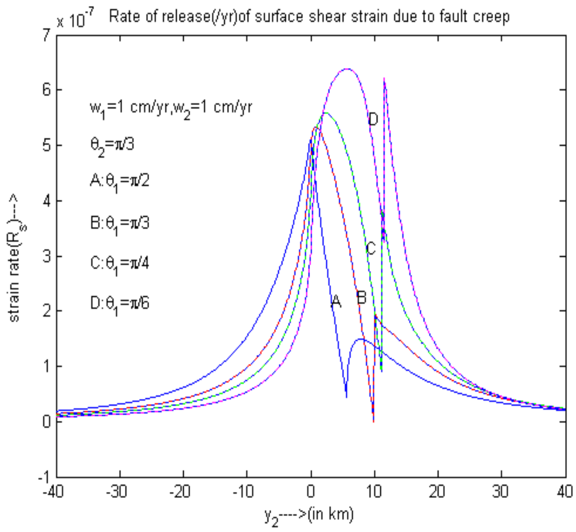

Fig-5(b): Rate of release (/year) of surface shear strain due to fault creep

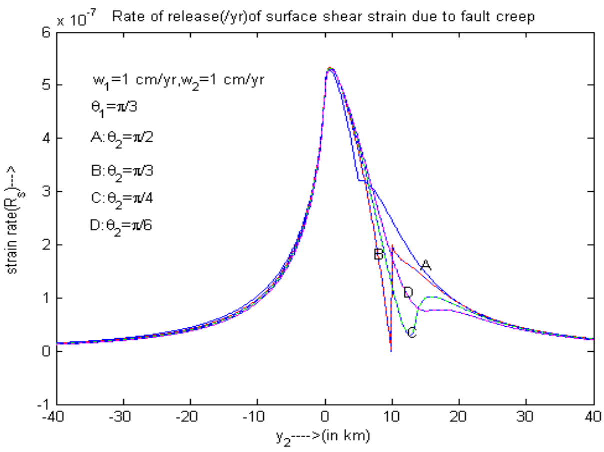

Fig-5(c): Rate of release (/year) of surface shear strain due to fault creep

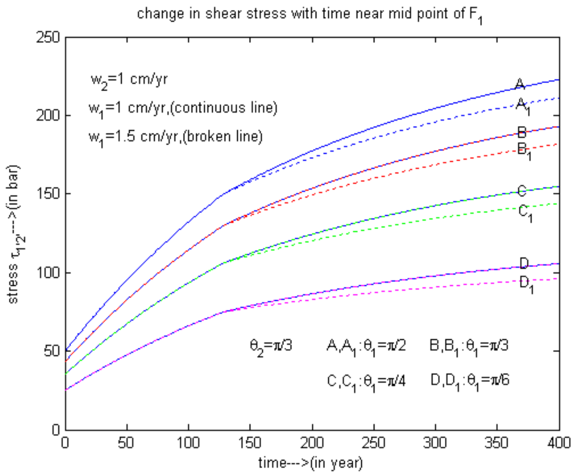

Fig-6(a): Change in shear stress with time near mid point of F_1

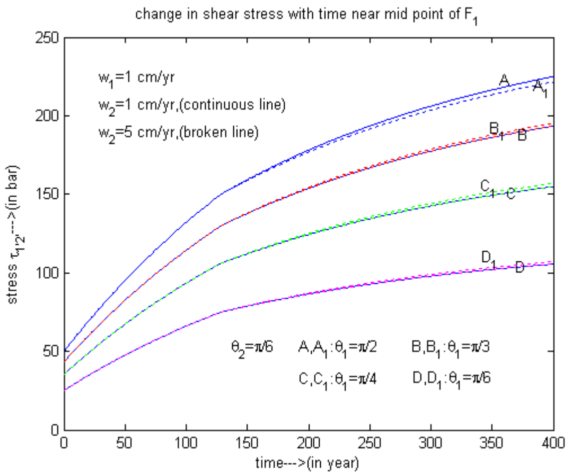

Fig-6(b): Change in shear stress with time near mid point of F_1

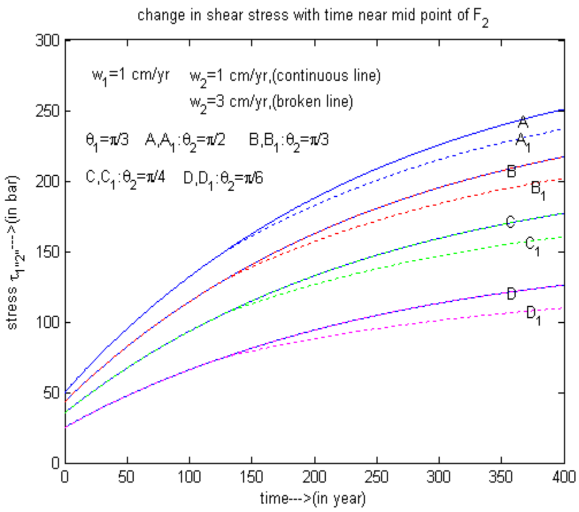

Fig-6(c): Change in shear stress with time near mid point of F_2

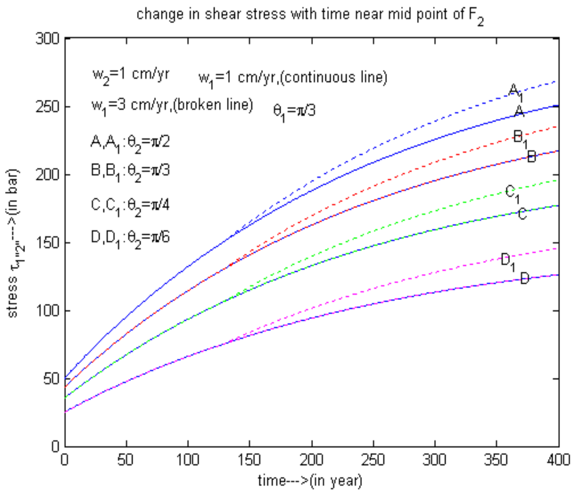

Fig-6(d): Change in shear stress with time near mid point of F_2

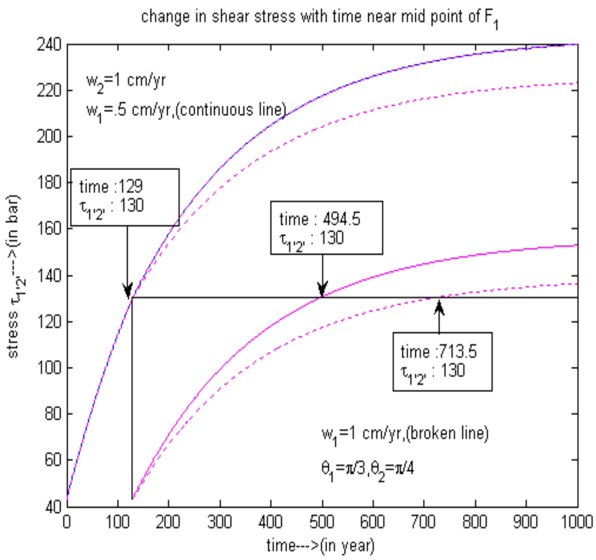

Fig-7(a): Example of time taken to the next seismic event

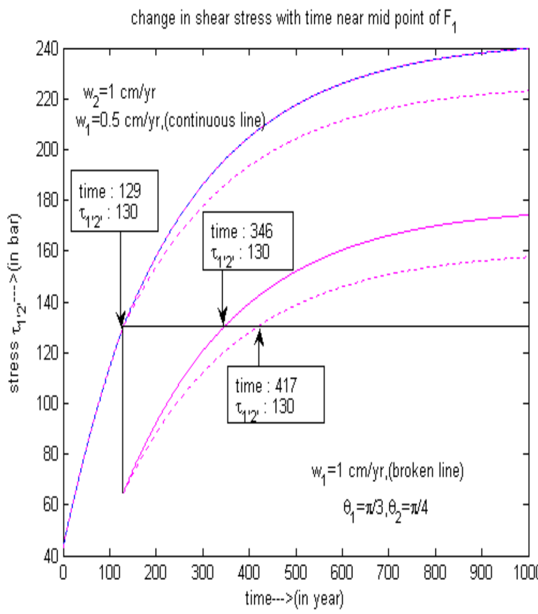

Fig-7(b): Example of time taken to the next seismic event

X. Conclusion

The non-planar structure of the strike-slip fault shows significant differences in the computations made in this paper, when compared to a long and plane strike-slip fault.

The rate of change of surface displacement for a plane fault has only one discontinuity at $y_2 = 0$, while for a non-planar fault, there exist a second line of discontinuity as discussed above, which is closely related with the inclination of the second part. Considering the rate of change (release) of surface shear strain per year, we find that in the present case the shape of the curve is much more complicated compare to a plane fault. In case of a plane fault, the curves are symmetrical about a line $y_2 = k$, $k = 0$ for $\theta = \pi/2$ and $k > 0$ for $0 < \theta < \pi/2$. For surface shear stress near the mid point of F_1 and F_2, movement on each part has some influence on the total shear stress accumulation near the other. These features are obviously not present in case of plane fault. In the present case we have considered a fault which can be represented by two planar sub-parts. In fact for a complicated geometrical structure, the number of sub-parts can be increased and the corresponding problem can be solved in a similar way.

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