AN AFTERSHOCK MECHANISM ORIGINATED FROM FLUID FLOW

by

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SUMMARY

A two-dimensional model of fluid pressure migration through porous medium is employed to investigate the frequency of occurrence of aftershocks. The model permits a complete description of the aftershock time sequence of the 1966 Parkfield - Cholame, California earthquake. The study suggests the need of developing analytical models for phenomenalogical descriptions of aftershock events and the associated source mechanisms.

INTRODUCTION

In recent years, much effort and advances have been made for understanding the mechanism of earthquakes. This involves three major phases of earthquake mechanisms: the preparatory process, the rupture of the earth's crust and the post failure adjustments (1). For the study of preparatory processes, analyses of existing earthquake precursor data have indicated that there exists the possibility of using premonitory precursors for predicting the occurrence of large earthquakes (2). For the rupture of the earth's crust, significant progresses have been made, for instance, in establishing appropriate mathematical framework to relate the observed seismograms to a few source parameters (3). As for the post failure adjustment, physical phenomena associated with aftershocks are usually monitored for seismological study in numerous events.

Aftershock data have been used to determine seismic gaps (4) and to help in identifying focal mechanisms of main shocks. Indeed, because the data are relatively more abundant, research findings in this area have been accumulated to the point as to provide reasonable correlation between the analytical and observed results. However, for the purpose of earthquake hazard mitigation and, ultimately, earthquake prediction, more rigorous analytical models which will lead to both qualitative and quantitative interpretation of earthquake mechanism are urgently needed.

Numerous reports on the aftershock measurements indicate that there exists some general patterns for the aftershock distribution (5, 6, 7). In an attempt to interpret the observed data, Nur and Brooker (8) employ a pore pressure diffusion model with a dislocation-induced initial condition; the initial decay rate of the aftershocks of the Parkfield-Cholame, California earthquake (9) is adequately predicted. In an equally stimulating but totally different mechanism, Melosh (10) shows that the theory of nonlinear stress propagation in the upper mantle can be helpful. In this case, analytical results are used to correlate the seaward migration pattern of aftershocks from the February 4, 1965 Rat Island earthquake. Apparently, a variety of physical processes and the

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combinations thereof can be responsible for the same observed "apparent" events. In view of this, in this paper, the model by Nur and Brooker is modified for its initial and boundary conditions for the purpose of improving the quantitative correlation between the computed and observed Parkfield-Cholame aftershock sequence. A complete correlation for the rate of decay is achieved as a result of this modification. Since the better results are apparently due to the modified initial and boundary conditions associated with the model, the study has served to demonstrate the need of developing various classes of models, which can be used to delineate the phenomenalogical aspects of aftershock mechanisms.

ANALYTICAL MODEL

For a certain class of shallow earthquakes in which groundwater may be present, experimental data have suggested that the rupture of the earth's crust or earthquakes can be triggered by the increase of fluid pore pressure (6, 11).

Following the same argument as was used previously by Nur and Brooker, rupture of rocks or an aftershock is considered to occur when the shearing stress in a rock exceeds its shearing resistance; an increase of fluid pore pressure is assumed to be responsible for a decrease of the strength of rocks. Furthermore, in the preparatory phase of a large shallow earthquake, owing to the possible dilatancy, cracks filled with groundwater are assumed to have developed in rocks for a region embodying the focal zone for the current model. A main shock is hypothesized to create an abrupt buildup of pore pressure along a vertical line connecting the hypocenter and the epicenter. This line source pore pressure, modeled by a Dirac Delta function, is to diffuse, which in turn is to cause a change of rock strength resulting in the delayed fracture of rocks known as aftershocks.

Hence, for the state of pore pressure field p(r,t), the following two-dimensional problem in X-Y plane is to be solved:

$$\frac{\partial}{\partial t} p(r,t) = C\nabla^2 p(r,t) \text{ and}$$
$$p(r,0) = \delta(r) \tag{1}$$

in which r is the position vector of a point (x,y), C is the average coefficient of diffusion of pore pressure for rocks with cracks. The well known solution of this problem takes the form

$$p(r,t) = \frac{1}{4\pi Ct} \exp\left(-|r|^2/4Ct\right) \tag{2}$$

Assuming that rocks in the causative region are uniform in strength and are under the same stress state immediately after a large shallow earthquake and considering further the number of possible aftershocks in a unit rock volume to be proportional to the local time rate of change of pore pressure in a given region, the frequency of all aftershocks within this region is then proportional to the integral of the time derivative of the pore pressure over the entire domain of interest. In this region, the pore pressure originated from groundwater migration is changing in an average sense. Thus,

$$\frac{dN}{dt} = \frac{1}{\alpha} \int_V \frac{\partial p}{\partial t} \, dV \qquad (3)$$

where α is a proportionality constant determined by the physical properties of the rocks and $\frac{dN}{dt}$ is the frequency of occurrence of aftershocks.

After some manipulations, it can be shown that

$$\frac{dN}{dt} = - \frac{R^2}{4\alpha C t^2} \exp\left(-R^2/4Ct\right) \qquad (4)$$

where R is the radius of a cylinder considered for the affected region of interest.

With proper selection of parameters R, α, and C, the variation rate of frequency of aftershock events can be determined as a function of time.

RESULTS AND CONCLUSIONS

Figure 1 shows a comparison of the value of dN/dt computed from Eq. 4, the observed data and those obtained by Nur and Brooker. The parameters R, α and C concerning the physical properties of the affected causative region have been selected in a few trial and error parametric study. In general, they are not sensitive to alter the basic shape of the curve except for its initial asending branch. As opposed to the results by Nur and Brooker, the current model shows that the decay rate first increase until it peaks out in about half an hour or less and it decreases to about 10 or less shocks per day over a period of 100 days. Except for the very initial phase where observed data are lacking, the present results agree quite well for the complete range of observed data. It is seen that right after the peak, the rate of decay is proportional to $t^{-1/2}$. This part of the results also agrees with that of Nur and Brooker. After about half a day, however, the observed rate of decay gradually changes to t^{-1} as was predicted by current model.

Because of the good correlation obtained, the model seems to reinforce further a direct link between the mechanism of pore pressure migration and the occurrence of the time-dependent aftershock sequence. In view of this, the following conclusions are noteworthy:

1. In this study, the linear diffusion equation with cylindrical symmetry was solved for the pore pressure distribution. The time rate of change was integrated over the same region to give the rate of change of occurrence of aftershocks. The resulting model is seen insensitive to either the change of the diffusion coefficient nor the size of the domain of integration.

2. The linear diffusion with point source apparently yields better agreement with the observed data than the results by Nur and Brooker. However, this alone cannot be construed as a justification for its validity. To this end, there is a further need to take a closer look at this model for its implied

source mechanism. In particular, its relationship to the well established dislocation theory as well as the fault plane solution should be studied. It should be pointed out here that the dislocation-induced initial condition employed by Nur and Brooker also requires a singularity at the source.

3. From a phenomenalogical point of view, additional check of the validity of this model can be provided by comparing the predicted temporal and spatial distrubutions of the well documented aftershock activities. The temporal distribution can be obtained by making appropriate changes in the initial condition and/or the boundary conditions. For example, one can change the initial condition from a line source to a plane source along the fault plane. The integration limits can also be modified to account for the actual banded focal zones, say.

4. To further validate the models, analytical model development should be emphasized for the spatial distribution part of the problem. Since the physical processes, thus, the governing equations for the spatial distribution of the aftershock events are not readily available, a phenomenalogical approach again is most helpful. In this connection, kinematic wave formulation may provide the keys to the solution.

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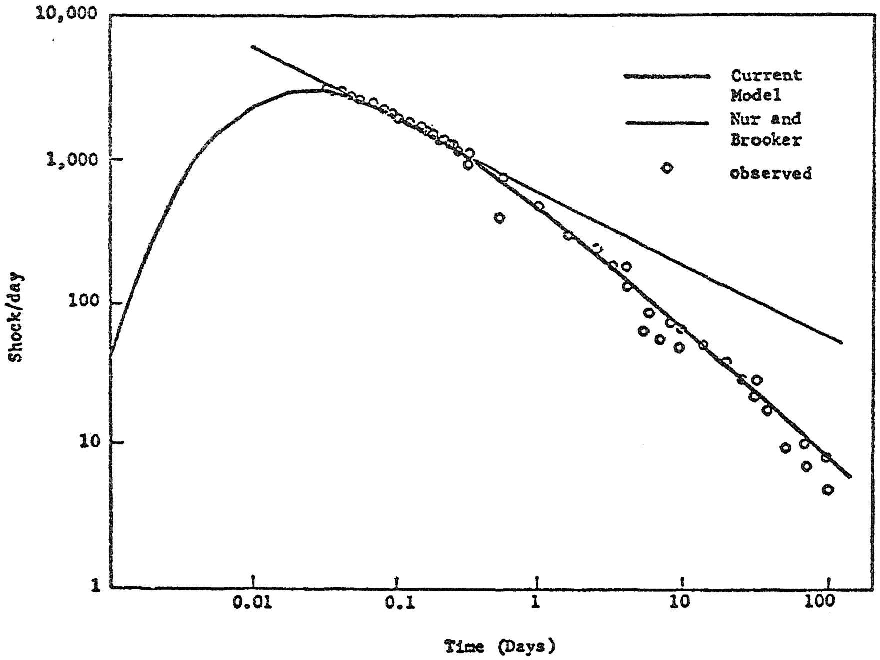

Fig. 1 Correlation of Aftershock Sequence for the Parkfield-Cholame Earthquake