NEAR FIELD STOCHASTIC MODELLING

by

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SYNOPSIS

A stochastic model is suggested for seismic dislocations. The model gives an insight into generalised seismic sources and a guide to a-seismic design accounting for surface rupture.

INTRODUCTION

One of the seismic hazards encountered in the near field of shallow earthquakes is surface rupture. A-seismic design considers the possibility of surface earthquake dislocations either as a crucial factor in siting a facility or as input to the design of the facility, e.g., the probability of surface fracture is minimised in siting nuclear power plants whereas in planning networks it is difficult to exclude this possibility from the design.

In contrast to the dynamic effects of an earthquake, seismic dislocations constitute frozen evidence of the occurrence of earthquakes and as such are related to long term observations like rates of crustal deformation. On the other hand, seismic dislocations being the prerequisite for setting up ground vibrations are related to dynamic effects through source mechanism models. Therefore, seismic dislocation studies in general are interesting as a link between slow crustal deformation rates and dynamic effects.

This contribution formulates a simple stochastic model for surface rupture. The model follows from simple assumptions on the occurrence of seismic events and a two parameter dislocation mechanism. The objective of the stochastic analysis was set to evaluate the occurrence of surface rupture at a site located on the fault. As a side product the analysis gives an insight to the long term behaviour of seismic sources.

THE MODEL

The model is formulated for an idealised vertical earthquake fault. The fault is of a limited extent ($L < L_{lim}$) has a limited capacity to produce large earthquakes ($M < M_{lim}$) and is assigned an activity v in terms of events per year.

The basic statistical input is given in terms of magnitude since most of earthquake statistics are based on this parameter. The statistical distribution of events associated with the earthquake fault is assumed to be a Guttenberg-Richter relation (Cornell and Vanmarcke, 1969):

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(1) $$P = (1 - K) + K\ 10^{-b\,(M - M_{min})}$$

where M_{min} = the minimum magnitude in the population

b = the Richter coefficient

and k = factor accounting for the truncated magnitude distribution. Furthermore, it is assumed that earthquakes are Poisson events deprived of memory. Then, for rare events the average annual rate of occurrence is:

(2) $$p = vP$$

where v = activity rate of events exceeding M_{min}.
The earthquake population is assumed to occur at an average depth $\bar{h}$.

A simple two parameter dislocation model (Brune, 1972) is selected to represent the seismic source. The model intercorrelates source parameters like seismic moment, stress drop, dislocation area and average dislocation. The two parameters necessary to define the model are chosen to be the seismic moment M_o, and the stress drop $\Delta\sigma$. The distribution (1) is translated to moments through the general relation (Wyss, 1974).

(3) $$\log M_o = c + dM$$

The stochastic analysis branches off in order to compute recurrence curves for single and cumulative dislocations respectively.

i - Single dislocations. To a given value of seismic moment (for a fixed stress drop $\Delta\sigma$) correspond a dislocation area and an average dislocation. The dislocation will break at the surface if the dislocation radius exceeds the average focal depth and will propagate to the site if the latter lies within the dislocation area (Fig.1.) Therefore, the dislocation will be manifested at the site with an average annual rate obtained from (2) for the corresponding seismic moment and an activity rate reduced to the corresponding dislocation area. The dislocation area is not allowed to exceed the limited fault dimensions.

ii - Cumulative dislocation. Based on the original assumption that earthquakes are Poisson events we can express, following Wyss, 1974, the total moment $M_{o,\ tot}$ in terms of the seismic moment M_o.

(4) $$M_{o,\ tot} = \frac{B}{1-B}\ M_o \left[1 - \left(\frac{M_{o,min}}{M_o} \right)^{1-B} \right]$$

where $B = b/d$ is the exponential factor for the moment distribution. On the basis of (4) we can obtain through (3) and (2) mean annual rates corresponding to $M_{o,tot}$. On the other hand, $M_{o,tot}$ may be correlated with the cumulative dislocation following Brune (1968) i.e., assigning to all moments the same average dislocation area A_o:

$$(5) \quad u_{tot} = \frac{M_{o,tot}}{\mu A_o}$$

Then it follows that the recurrence curve for the cumulative dislocation will take a bilinear form (Fig.1). The second linear branch is the assymtote corresponding to the long term average annual rate of deformation:

$$(6) \quad \log \bar{\dot{u}} = \log v + f \; (B, M_{o,lim}, M_{o,min}, A_o)$$

This deformation rate is associated with earthquake dislocations only.

AN EXAMPLE

A hypothetical case is considered as an illustration. The basic input data are taken from Southern California; hence numerical values are more appropriate to the tectonic environment of western U.S.

The total length of the fault is assumed 30 Km, the average focal depth is taken at 8 Km and the average activity rate is assumed to be .01 events/Km/year. This activity rate corresponds according to equation (6) to an average regional deformation rate of .13 cm/yr. The basic statistical distribution of seismic events is described by a b value of 1.0 and a limiting magnitude of 7.

The dislocation model is defined on the basis of the analysis of South California data by Thatcher and Hanks, 1973, i.e., the stress drop range is fixed between .1 and 100 bars and M_o is correlated to magnitude through the average relation

$$\log M_o = 1.5M + 16.0.$$

The results of the analysis are shown on Fig. 1 for both the single and cumulative dislocations.

The single dislocation recurrence curves are shown as continuous or dashed lines (a dashed line indicates that the dislocation does not break at the surface) for different values of $\Delta\sigma$. The solid circles indicate the envelope curve for single dislocations and the range of stress drops considered. For comparison, a similar model was run based on empirical correlations between magnitude, surface break and surface dislocations suggested by Bonilla and Buchanan, 1970. The empirical relations selected in this application correspond to North American data. These data, with the exception of a few Alaskan events are compiled from California. The results within ± 1 sigma (on the surface dislocation correlation) are shown as a shaded band on Fig.1. The two models gave the same range of expected dislocations. However, the dislocation model gave longer return periods for small dislocations (small earthquakes) and no apparent lower bound. The former discrepancy may be attributed to the basic data used in deriving empirical correlations of magnitude vs source parameters since only events with surface deformation were considered. The latter discrepancy may underline the fact that large earthquakes are associated with stress drops in the range $10 < \Delta\sigma < 100$ bars. Analysis of strong motion data pointed to the same trend (Trifunac, 1976).

The cumulative dislocation recurrence curve is shown as open circles. It follows closely the envelope single dislocation curve up to the break point. Beyond this point it does not flatten off but changes to a gentler slope of 45° corresponding to the average deformation rate of .13 cm/yr.

DISCUSSION

Lack of data seems to impose a severe limitation in using either more sophisticated input or more elaborated source mechanisms. Even in the simple case considered here, difficulties in defining the parameters involved are obvious. For the chosen set of parameters the dislocation model, essentially defined on the basis of seismic observations, compared reasonably well with surface observations. However, the validity of the results relies heavily upon the assumptions made. The most severe of these assumptions seems to be the statistical distribution of events associated with the tectonic fracture. The assumption of a Poisson distribution seems to be more plausible for the overall behaviour (cumulative dislocation) than for the occurrence of single dislocations where strain migration plays an important role.

With regard to the structural design, the model covers only the basic principles. For the actual design details of fracture (e.g. distribution of the dislocation within a deformation zone, propagation through sedimentary cover etc.,) are very important and the careful study of surface manifestations of past earthquakes in the region is invaluable. Depending on the design philosophy, emphasis may be given to either the single or cumulative recurrence curves. The two curves differ basically in the long return periods: the single dislocation curve approaches a limiting value whereas the cumulative curve tends to the average regional rate of deformation given by equation (6). This equation correlates parameters defining generalised seismic sources to long term regional behaviour. The same parameters provide the basic input to the stochastic analysis of earthquake induced ground vibrations.

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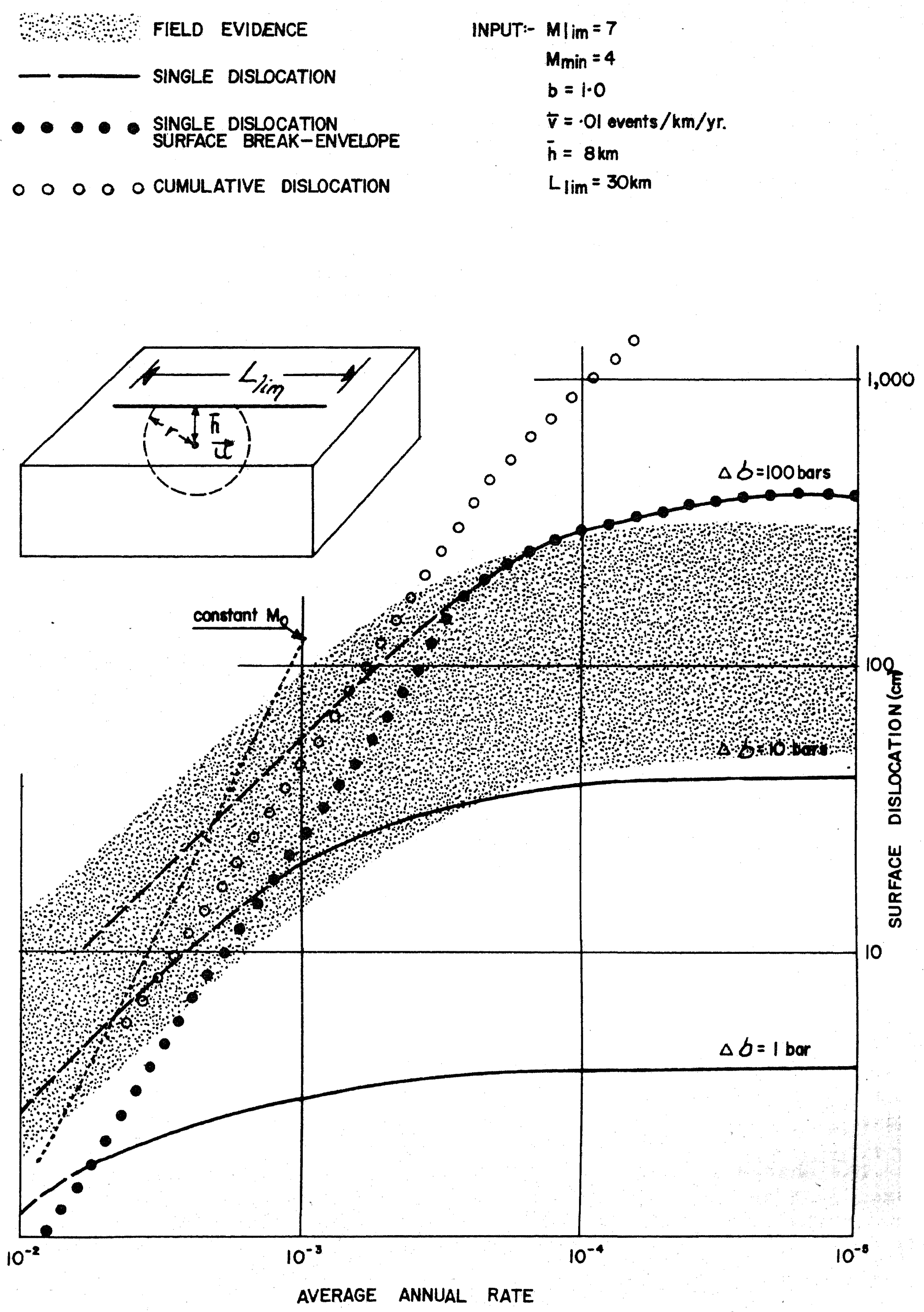

FIG I. DISLOCATION MODEL AND EXAMPLE OF RECURRENCE CURVES