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Shear strain energy level as sign of seismic hazards

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ABSTRACT: A method for finding areas where the strong earthquake are possible is given. It is based on the study of the distribution of shear strain energy in the earth crust. The problem is reduced to examination of the equilibrium of elastic plate that damaged by the tectonic faults. For quantative description of the earth crust damage is used the tectonic map. Numerical results for South California and Northern Tien-Shan show that the earthquake epicenters are occurred in the areas with high level of potential energy.

1 INTRODUCTION

Earthquake prediction is beginning from finding the places where in future are possible the strong seismic hazards. Usually approach are based on the complex analysis of geological and geophysical information in all sorts of maps. At the same time the solution of stress distribution problem enable to diminish the number of the analysis geological and geophysical information because the big part of its should be included into suitable model.

The distributions of stresses are depended from many causes but particularly we must to distinguish the fault structure of earth crust as it are connected with plate tectonic. Fault zones are strong sources of stress and strain field excitation. With excited of stresses are connected the high level of potential elastic energy. This can be an indication of the places where the strong earthquake are possible (Sadovsky *et al*, 1987). Moreover the fracture kinetics is closely connected with the reverse of energy in system and first of all with the part that depends on the shape alteration. If the reserve of the shear strain energy are big then it is flowed to the fracture zone and accelerate the process of strain localization (Garagash and Nicolaevsky, 1989). Otherwise the fracture is sluggish and process can be slow down.

The faults places in the upper part of the crust behaves as a brittle elastic medium. Within the faults rocks are crushed and have high fissured. The rigid of the fault zones are less than the rigid of the earth crust block. At the depth near 15-20 km for high temperatures and pressures the crust behaves as a ductile material follows a power law (Kirby, 1985) and faults disappears.

In this paper for calculation of the distribution of anomaly energy zones in the earth crust is solved the problem about stress state of the elastic plate damaged by faults and loaded by the regional tectonic forces. The plate with faults is replaced by the layer with effective non-homogeneous mechanical properties which are accepted as continuous functions of coordinates in the layer plane. These functions are modeled the idea about the faults as damage cracked zones. The analyzes of the appropriate equilibrium equations come to the solution of recurrent problems of the theory of elasticity.

2 NON-HOMOGENEOUS ELASTIC MODEL

From the position of the mechanics of fractured body we can to consider the earth crust as effective medium with non-homogeneous physical properties and average strain ε_{ij}.

Then the stress tensor σ_{ij} have the form

$$\sigma_{ij}=\tau_{ij}-\kappa\tau_{kl}g_{ijkl}\ ,\ \tau_{ij}=E_{ijkl}\varepsilon_{kl}\ , \qquad (1)$$

where $0\le g_{ijkl}\le 1$ is the tensor of the function of non-homogeneity, $\kappa\le 1$ - parameter.

Here τ_{ij} is a stress tensor in the homogeneous non-damaged body with moduli E_{ijkl}

Stresses σ_{ij} must to satisfy to the differential equations of equilibrium and boundary conditions

$$\sigma_{ij,j}=X_i\,,\quad P_m=n_i\sigma_{im}\,, \tag{2}$$

where P_m and X_i are the projections on the co-ordinate axes of the surface and mass loads.

For the solution of the equations (2) use the method of perturbations. Input the power series

$$\sigma_{ij}=\sum_{n=0}^{\infty}\kappa^n\sigma_{ij}{}^{(n)}\,,\quad \varepsilon_{ij}=\sum_{n=0}^{\infty}\kappa^n\varepsilon_{ij}{}^{(n)}\,. \tag{3}$$

and substituting this in equations (2) obtain the problem for zero approximation

$$\sigma^{0}_{ij,j}=X_i\,,\quad P_m=n_i\sigma^{0}_{im}\,,\quad \sigma^{0}_{ij}=E_{ijkl}\varepsilon^{0}_{kl} \tag{4}$$

and the following successive of the problems

$$\sigma^{(k)}_{ij,j}=0\,,\quad n_i\sigma^{(k)}_{im}=0\,, \tag{5}$$

$$\sigma^{(k)}_{ij}=\tau^{(k)}_{ij}-\tau_{kl}{}^{(k-1)}g_{ijkl}\,,\quad \tau^{(k)}_{ij}=E_{ijkl}\varepsilon_{kl}\,.$$

Thus for every step we must to solve the equations for homogeneous body with fictive mass and surface loads.

3 EQUATIONS FOR THE CRUST PLATE

Let to consider the infinite isotropic elastic crust plate loaded by tectonic forces. The plate are bedded on viscous foundation. As the talk is about fields that exist long time imply that viscous reaction of foundation is relaxed. It suppose that the width of plate is small and the conditions of generalized plane stress are satisfied. Input the isotropic function of non-homogeneity

$$g_{ijkl}(x_1,x_2)=\frac{1}{2}g(x_1,x_2)\,(\delta_{ik}\delta_{jl}+\delta_{il}\delta_{jk})\,.$$

For first approximation the general solution of equilibrium equation have the form

$$\sigma^{(1)}_{11}=\Phi_{,22}\,,\quad \sigma^{(1)}_{22}=\Phi_{,11}\,,\quad \sigma^{(1)}_{12}=-\Phi_{,12}\,, \tag{6}$$

where Φ is the stress function.

Used the equations (3), (4), (5) and compatibility condition

$$8\varepsilon^{(1)}_{11,22}+\varepsilon^{(1)}_{22,11}=2\varepsilon^{(1)}_{12,12}\,, \tag{7}$$

receive the basic equation

$$\nabla^4\Phi=-(\sigma^{0}_{11}-\nu\sigma^{0}_{22})\,g_{,22}-(\sigma^{0}_{22}-\nu\sigma^{0}_{11})\,g_{,11}+ \tag{8}$$

$$+2(1+\nu)\,\sigma^{0}_{12}\,g_{,12}\,,$$

where ∇^2 is Laplacian operator and ν is Poisson's number.

The solution of equation (10) easy to write on the base of double Fourier transformation.

The stresses of zero approximation σ^{0}_{ij} correspond to the equilibrium of homogeneous plate and can to define from distribution of the tectonic forces on the infinity. We can usually judge about them using such data as recent crust movements and the mechanisms of earthquake focuses. For example we know that California is in the state of pure shear (Savage *et al*, 1986) then as for Asia situation is determined by compression of Indian plate (Villote *et al*, 1982).

For definition of the non-homogeneity function $g(x_1,x_2)$ we offer to use the density of faults. One variant consists in dividing the map of region on the square areas and for each one is calculated the total length of faults taking into account its ranks. Then this table of numbers divide by maximum value and is used as function of non-homogeneity.

For definition of the places where the strong earthquakes are possible we must to calculate the shear strain energy distribution S. Within the framework of perturbation method it can to write in form

$$S=S^{\circ}+\kappa S^{(1)}+\ldots\,, \tag{9}$$

where

$$S^{(1)}=\frac{1}{2}G\gamma^{0}(2\gamma-\gamma^{0}g)\,, \tag{10}$$

$$\gamma=[2(\varepsilon_{kl}-\frac{\varepsilon_{pp}}{3})(\varepsilon_{kl}-\frac{\varepsilon_{pp}}{3})]^{1/2}\,.$$

For conclusion about the distribution of shear energy in the earth crust in comparison with average level S° rather to observe the value $S^{(1)}$

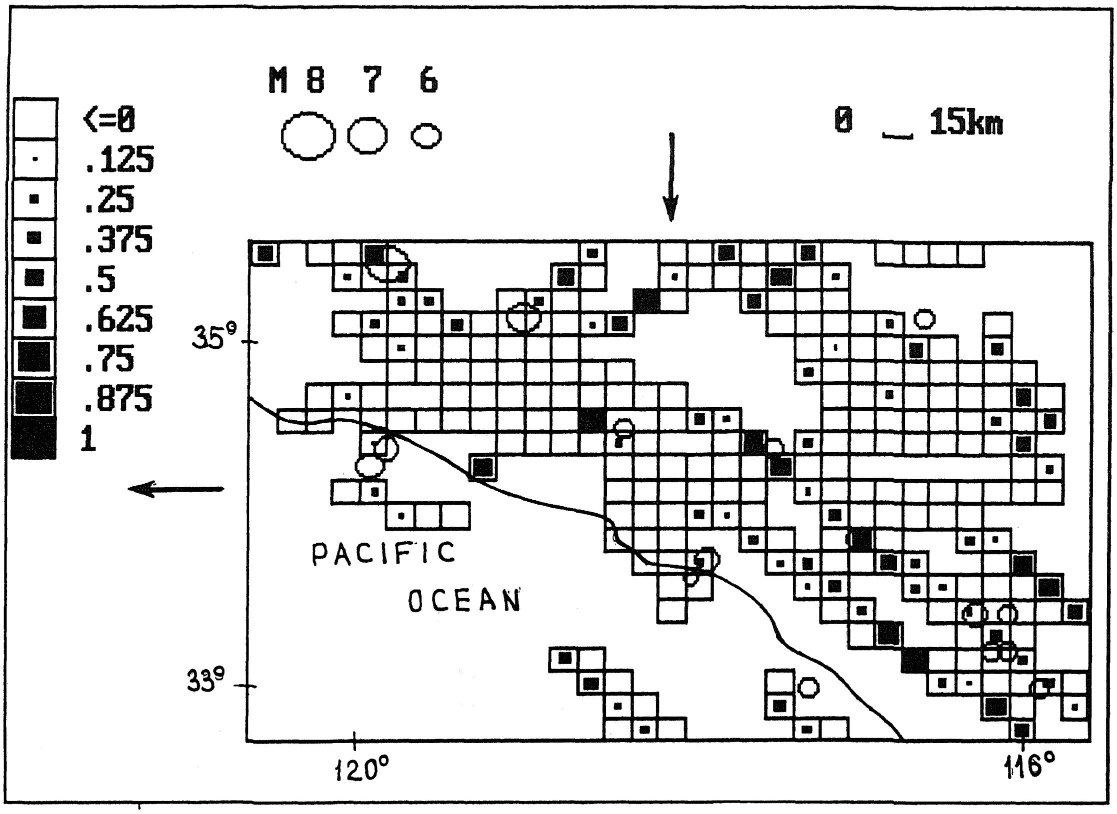

Figure 1. Sketch map of the anomal energy zones in Southern California.

4 COMPUTATION AND RESULTS

As an example let's take the region of South California that is known by high level of seismic hazard. For determination of the non-homogeneity function here is used the map of major quarternary faults with scale 1:1500000. As the deformation near San Andreas fault close to pure shear the distributions of regional tectonic stress are allotted in

form $\sigma^{0}_{11}=p$, $\sigma^{0}_{22}=-p$, $\sigma^{0}_{12}=0$.

In result the map of anomaly energy zones is drawn on the Figure 1. On it one can see the distribution of crust areas in the fault zones for which the value of shear strain energy $S^{(1)}$ exceeds the middle level S° corresponding to homogeneous layer (zero approach solution). The potential energy is related to the maximum value and alter from 0 to 1. It show by the black squares with areas are proportional to the energy. The black boxes are marked the crust areas damaged by faults. The earthquakes with magnitude from 5 to 8 occurred on this territory for the last 200 years are shown by the various size circles. One can to see that it are coincided with high energy zones.

On the Figure 2 demonstrates the distribution of energy zones in the earth crust of the Northern Tien Shan near the Issyk-Kul lake. The damage of the earth crust is taken from the tectonic map of Kazakh SSR with scale 1:1500000. The faults of the first and second ranks have been taken into account. From the analysis of the mechanisms of earthquakes focuses for the region it is in near meridian compression. Therefore the distribution of tectonic forces in zero approach is are expressed as

$\sigma^{0}_{11}=-0.5p$, $\sigma^{0}_{22}=-p$, $\sigma^{0}_{12}=0$.

From Figure 2 one can see that earthquakes with magnitude M>4 after 1929 coincided with high energy areas. Particularly one should distinguish three disastrous earthquakes with M>7 (are shown by big hexagons) which have occurred in more energy saturation places near Issyk-Kul lake.

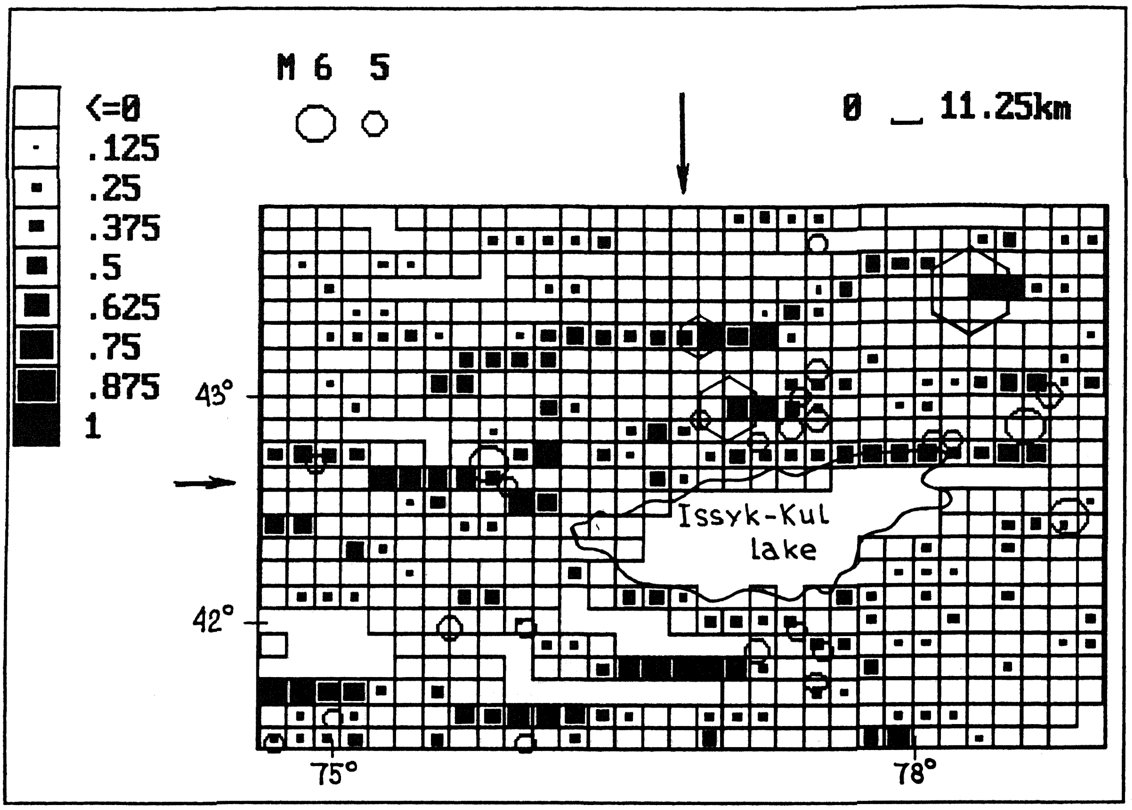

Figure 2. Scetch map of the anomal energy zones in Northern Tien-Shan.

5 CONCLUSIONS

The analysis show that not all faults and throughout its extent are dangerous. So for South California the length of fault pieces with anomaly energy saturation put about one third from total length of faults. This relation is also suitable for Northern Tien Shan. Moreover the total potential energy in the earth crust to the north of Issyk-Kul lake more than one third exceeds the same value for the southern part, that is reflected in the seismicity of these two regions.

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