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Assessment of strain effect of strong-motion (focus) zones of earthquakes on earth's surface displacement

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ABSTRACT

Strain effect of focal zones on fore-seismic displacements of earth's surface is studied in the paper for real conditions of focus zones of the earthquakes. The width of the interval of maximum displacements is determined by the conditions of potential focus of tectonic earthquake. The solution of elastic problem for half-space with soft inclusion is used. Calculations are conducted also by empirical formulas, obtained for similar stress states. Possible radius of the zone of maximum revelation of strain anomaly is determined on the basis of the growth of rupture scale and change in heterogeneity volume. It is shown that obtained expression covers a wider range of magnitude variations with consideration of the interval of scale change in upcoming rupture-forming zone. In the example of Tashkent (1966) and Gazli (1984) strong ground motions, an analysis of possible strains occurrence on the Earth's surface was conducted.

1. Introduction

The change of tectonic stress fields in Earth's crust is closely related to the earthquakes. In the majority of cases, they are the direct result of tectonic displacements. In the present study, geodynamic stresses in the Earth's crust are divided into two parts. The first part deals with the reconstruction of stress fields. In practice, it makes possible to construct a vector picture of internal forces distribution in the Earth's crust. The second part deals with a necessity to define the process of stress concentration in tectonic structures. It has not yet reached the mathematical level at which it would be possible to build its quantitative distribution with necessary convergence. It is known that high horizontal stresses are unstable in the upper layers of the crust. They essentially depend on tectonic structural features, especially in the presence of seismic dislocations, inclusions, cracks, faults. It is shown that in in-situ measurements, the deformed state is fixed in local areas of the upper crust. To distribute it to wider horizons is not always right. It would be different local strains and stresses related probably to one regional field. Years of experience in geomagnetic and geodynamic studies in seismically active regions show the complexity of the change in internal forces in the crust of Western Tien Shan [1–3]. With statistics for the past 10–15 years, in the late 1970s and early 1980s, the correlations of the assessment of radii in anomalous effects occurrence of geological and geophysical parameters have been offered [1–5]. This gave a possibility to evaluate in the first approximation the effect of strains in strong-motion zones of potential earthquakes on Earth's surface displacements.

At present, in our view, I.P. Dobrovolsky's model is a unique mathematical model of tectonic strong-motion zone preparation. A detailed analysis of this model is given in his monograph [4]. Based on his ideas [6,7], quantitative models to calculate the strains on the Earth's crust are developed. As a zone of stress accumulation the zone is selected, where a derivative of any components of displacement tensor at the point of force application in selected direction changes non-monotonically [6]. This corresponds approximately to the radius equal to 2/3 of the size of a large length

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of the upcoming focus zone from its center. The area beyond these limits is considered as an external zone. In this case, the derivatives monotonically vary till an asymptotic minimum [8]. In Ref. [4], the superposition of these zones is estimated by the radius $R = e^M$ (where M is a magnitude of tectonic earthquake). For cylindrical displacement cracks, due to area compression, a zone is marked out with intense changes of displacements corresponding to intense changes in geomagnetic field. The width of this zone (as shown by comparing, for example, to Karzhantaus flexure – rupture zone) over large areas coincide with the width of seismo-genic zone [9]. So a zone of intense deformation could be considered as a close one to the width of seismo-genic zone.

At fixed values of the depth of upcoming strong-motion focus and coordinates in the vicinity of central zone, at a distance of no more than 2/3 of dimensionless unit from the center of the upcoming rupture source, the displacements and strains do not change monotonically. Since the main object is the zone of upcoming motion, the concept of the zone of local strain presents the surface under upcoming focus of the earthquake. One should bear in mind that a half of the least depth of focus rupture is taken as a unit of dimensionless length of reduction factor according to reference [6]. For example, in Tashkent earthquake (1966), in calculations this distance is about 2 km from the simulated center. Studies have shown that in every seismically active region there must be defined the dependences typical to this place only.

2. Theory of calculation of Earth's surface displacement

On the example of an assessment of vertical displacements variation of the surface for the case of soft aggregate, taken from Refs. [4,6,7] for different values of turning angle of rupture and magnitude, we calculate real distances to the point in Earth's surface, where the displacement reaches its maximum value. Earlier L.A. Khamidov and A. Sadikov have determined the reduction factor R for the transition to real sizes. This coefficient is derived from equality condition of the volume of upcoming focus to the volume of reduced ellipsoid, as in Ref. [4]. It is formed by the rotation of focus zone (having the form of an ellipse) around major axis of simulated inclusion. Using Yu.V. Riznichenko's empirical formulas [10] to determine the sizes of focus region, we use the formulas of ellipse rupture, which, according to Ref. [4], have the following form:

$$\mathrm{L} = 10^{0.440M-1.289}\mathrm{km} \quad (1)$$

$$l = 10^{0.401M-1.448}\mathrm{km} \quad (2)$$

where M is a magnitude of seismic moment [6,8]. In Ref. [4], heterogeneity is presented as an ellipsoid with axes (L, l, l), and its volume is then determined from (1) and (2) by formula:

$$V_{\max} = \frac{\pi}{6}Ll^2 = 10^{1.242M-4.466}\mathrm{km}^3 \quad (3)$$

On the other hand, a real volume of upcoming strong-motion zone according to reference [4] and determined with reduction factor R is:

$$V = 1.58R \times 1.58R \times 3.16R = 7.89R^3 \quad (4)$$

From relations (3) and (4), it is in round form, determined that

$$R = 0.51 \times 10^{0.41M-1.49} \quad (5)$$

Multiplying (5) by dimensionless distance from the origin of coordinates to the point (x_0,y_0), where the maximum of dimensionless vertical displacements is reached, we find a sought for distance R_w from epicenter of the zone of arranging of earthquake initiation to the point of potential maximum vertical displacement:

$$R_w = 0.51\ (x_0 + y_0)10^{0.41M-1.49}\ \ \mathrm{km} \quad (6)$$

and $\sqrt{x_0^2 + y_0^2} = H \sin\phi$, where H is a real depth of inclusion laying (of upcoming focus).

Table 1 shows calculated results of the value R_w for different angles of inclination φ of simulated inclusions as a zone of upcoming focus. They correspond to different values of the magnitude M and turning angle of simulated inclusion φ, that is to different values of the pairs (M,φ) or (H, φ) at $V/H =$ const. It should be noted that these values are given for $h = H/R = 1.8$, where h and H are dimensionless and real depth of bedding of the inclusion, respectively.

Here V is a volume of potential focus, φ an angle of inclination of the focus of long axis of ellipsoid in clockwise direction and intersecting the Earth's surface at $\varphi = 0$.

To analyze the errors of approximate formulas, we have considered the differences in displacement values calculated according to I.P. Dobrovolsky's exact formula [4] and to approximate formula [8]. The calculations have been carried out for the following values of parameters $v = 0.25$; $z = 0$; $h = 1, 2, 3, 4, 5, 6$; $V = 2 \times 2 \times 2$; and when the infinity is effected by stress system $\sigma_{xy} = \sigma_{yx}$ only. Comparison of exact and approximate values has shown that the ratio error relative to exact value of displacements near upcoming focus zone at shallow depth of inclusion may amount up to 18%.

So at small values of h and near the inclusions, the calculation of displacements and strains should be conducted only by comparison with theoretical model according to corresponding methods.

In the first approximation, an actual zone of occurrence of magnetic anomalies for geodynamic sites may be determined by the expression $\lg L = 0.46M + 0.08$ [8,11]. This expression is a generalized one for all sites of Uzbekistan.

Considering above mentioned and other data on the parameters of the effects, S.Kh. Maksudov and A.I. Tuichiev have specified and re-evaluated some reference parameters of a network of repeated site, route and stationary observations (Table 2) [5]. Reference values of the parameters of magnetic effects and corresponding characteristics of measuring grid are determined from Table 2. Rapid changes are studied with continuous measurements. Table 2 allows to select the parameters of survey, which, first of all, depend on a target problem. In our case, the survey interval is taken to an order less then linear size of the effect.

Results of the survey emphasize middle- and short-period variations of the field, conjugated by measured geodesic displacements. The former ones with the sample rate 3,4 times a year were studied in observations in a network of repeated route surveys in Tashkent, Fergana and Kyzylkum sites and in a network of prediction stations; the latter ones, by continuous measurements in a network of stationary stations. By nature, these anomalous variations are connected with the processes in the zones of upcoming earthquakes, that is, with the processes, occurring beginning from near-surface part of the Earth's crust to the boundary of Earth's crust and upper mantle. They are also connected with the operation of techno-genic objects of underground gas-holders, large water reservoirs and oil and gas deposits.

The main feature of observed anomalous variations of seismic and geodynamic origin is a possibility of their simultaneous occurrence. At one and the same point there may be local changes from the sources of different depth and nature. With detailed data about all local anomalous variations and following anomalies in