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H4.SMR/1150 - 5

Fifth Workshop on Non-Linear Dynamics
and Earthquake Prediction

4 - 22 October 1999

Spherical Model of Block Structure Dynamics

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Abstract

The lecture is devoted to the problem of numerical simulation of dynamics of a system of global tectonic plates, which are considered on sphere. The approach under consideration exploits the block models and assumes that the block structure is a part of spherical layer between two con-centric spheres, one of them (outer sphere) representing Earth's surface. The system of blocks moves as a consequence of prescribed motion of the boundaries and the underlying medium. Displacements of the blocks are determined so that the system is in quasistatic equilibrium state. Block interaction along the faults is viscous-elastic while the ratio of the stress to the pressure is below a certain strength level. When the level is exceeded for a part of some fault a stress-drop (a failure) occurs in accordance with the dry friction model. The failures represent earthquakes. As a result of numerical simulation a synthetic earthquake catalog is produced. Some preliminary results of simulation of a simple enough system of tectonic plates are presented. In particular, directions of blocks movement are indicated and character of their interaction are studied. Some features of obtained synthetic catalog inherent in real ones are noted.

1 Introduction

Mathematical models of lithosphere dynamics are important tools for study of the earthquake preparation process. An adequate model should reproduce premonitory patterns determined empirically before large events and can be used to suggest and to investigate new patterns that might exist in real catalogs. It should also be noted that studying seismicity by means of statistic analysis of real catalogs is quite difficult since available data cover relatively short time interval. In contrast, a synthetic catalog resulting from numerical simulation may contain information on a seismic flow for a pretty long time interval. This allows to hope for obtaining more precise estimates of characteristics of the seismic flow.

This work deals with modelling of lithosphere dynamics by means of block models, main principles of which were formulated in [1, 2], detailed description being given, for instance, in [3]. In existing block models, a seismically active region is represented as a system of absolutely rigid blocks forming a layer with a fixed thickness between two horizontal planes. Lateral boundaries of blocks consist of segments of tectonic faults intersecting the layer with arbitrary dip angles. The system of blocks moves as a consequence of action of outside forces applied to it. The motion may be described by three parameters (so called two-dimensional model) as well as by six ones (three-dimensional model). The system is supposed to be in quasistatic equilibrium state. As the blocks are absolutely rigid, all deformations take place in the fault zones and at the block bottoms. The interaction between the blocks is viscous-elastic ("normal state") while the ratio of the stress to the pressure is below a certain strength level. When this level is exceeded in some part of a fault plane a stress-drop ("a failure") occurs in accordance with the dry friction model. The failures represent earthquakes. Immediately after the earthquake and for some time, the corresponding parts of the faults are in "creep state". This state differs from the normal one because of the faster growing of inelastic displacements and lasts until the stress falls below a given level. As a result of the numerical modelling a synthetic earthquake catalog may be produced.

It should be noted that the two-dimensional model is developed in details. Models approximating dynamics of lithosphere blocks of real seismoactive regions were built on its basis [3, 4]. It was used for studying dependence of properties of seismic flow on geometry of faults and given motions [5, 6]. Three-dimensional model [7, 8, 9] is a generalization of two-dimensional model, which admits displacements of blocks only along the plane between them, and it is intended for accounting vertical component of displacements. Three additional degrees of freedom were introduced for this purpose. Therewith, the three-dimensional model being at the moment under development keeps a number of constraints inherent in the two-dimensional one. Particularly, in both models, a block structure is located between two horizontal planes. Besides, while trying to simulate motion of a system of global plates with flat block models, it turned out that significant distortions take place, which evidences advisability of consideration of the block structure on a sphere. It obviously makes sense to introduce the spherical model for modeling motion of a system of namely global tectonic plates, while the impact of sphericity is negligible in case of a separate seismoactive region due to its relative smallness.

In this work, some first results of simulation of dynamics of a small subsystem of tectonic plates are represented.

2 Brief model description

Let us describe basic constructions and ideas of the approach used for creating the spherical modification of the block model.

2.1 Block structure geometry, block movement

A spherical layer of a depth H bounded by two concentric spheres is considered. The outer sphere is treated as the Earth's surface and the inner one is treated as the boundary between the lithosphere and the mantle. A block structure is a limited and simply connected part of this layer. Partition of the structure into blocks is defined by faults intersecting the layer. Each fault is a conic surface characterized by the following two properties. First, the line of the fault on Earth's surface is an oriented arc of a big circle. And second, the plane tangent to fault surface in a point of this line has a dip angle of α with Earth's surface. In case of such a definition of a fault, angle α (measured to the left of fault line) has the same value in all points of the fault on Earth's surface. Then geometry of a block structure is described by a system of lines of intersection of faults with outer sphere embounding the layer, and by the dip angles. Common points of faults on outer and inner spheres are called vertices. Fragments of faults limited by corresponding pairs of adjacent vertices are called segments. Intersections of blocks with limiting spheres are spherical rectangles, those on the inner sphere are called bottoms. It is supposed that the block structure is bordered by boundary blocks which are adjacent to boundary segments.

The blocks are assumed to be absolutely rigid. All block displacements are supposed to be infinitely small, compared with block sizes. Therefore, the geometry of the block structure does not change during the simulation, and the structure does not move as a whole. The gravitation forces are not essentially changed because of the blocks displacements and, since the block structure is in quasi-static equilibrium state at the initial time moment, it is correct to assume that the gravity does not cause movements of the blocks.

All vertices on the outer sphere are defined by geographic coordinates (latitude φ, and longitude ψ) in a spherical coordinate system linked to Earth's center (we will call it "System-O"). In spherical modification based on the 3D model, all blocks (including boundary blocks) have six degrees of freedom.

The displacement of each block consists of the translation and the rotation components. The progressive component is determined by translation vector $(x,\ y,\ z)$. The rotation component is described by means of three special angles γ, β, λ to immovable rectangular coordinate system, $(X,\ Y,\ Z)$, with origin at the mass center of the block, point C, which has coordinates $(\varphi_C,\ \psi_C,\ R_C)$. The X axis is directed along the parallel of latitude; the Y axis is directed along meridian, the Z axis is directed along Earth's radius outwards. Denote this system "System-C". Let us assume that the coordinate system with axes X_1, Y_1, Z_1 is strictly connected with the mass center of the block (it coincides under the absence of block displacements with the immovable system with axes X, Y, Z, in which we consider all movements of the block). The scheme of rotation of the block and of corresponding system $(X_1,\ Y_1,\ Z_1)$ with respect to system $(X,\ Y,\ Z)$ is presented in Fig. 1. The first angle γ is defined as the angle of rotation of axes Y and Z around axis X providing fulfillment of the following condition: if axis Z_2 is the intersection of planes XOZ_1 and YOZ, then axis Z should be mapped into axis Z_2, at that $Y \rightarrow Y_2$. The second angle β is defined as the angle of rotation of axes X and Z_2 around axis Y_2 providing transformation of axis Z_2 into axis Z_1 (it is possible since Z_1 belongs to XOZ_2), at that $X \rightarrow X_2$. And the third angle λ is defined as the angle of such rotation of axes X_2 and Y_2 around axis Z_1 that $X_2 \rightarrow X_1$, $Y_2 \rightarrow Y_1$.

According to the definition of the rotation angles, the components Δ_x, Δ_y and Δ_z of displacement at a block's point on the sphere with geographic coordinates (φ, ψ) have the following form in System-C:

$$\begin{aligned}
\Delta_x &= x - \hat{Y}\lambda + \hat{Z}\beta, \\
\Delta_y &= y + \hat{X}\lambda - \hat{Z}\gamma, \qquad (1) \\
\Delta_z &= z - \hat{X}\beta + \hat{Y}\gamma,
\end{aligned}$$

where $(x,\ y,\ z)$ is the block's shift; $(\hat{X},\ \hat{Y},\ \hat{Z})$ are coordinates in System-C of the vector, which is directed from the mass center of the block to point $(\varphi,\ \psi)$; angles $(\gamma,\ \beta,\ \varphi)$ are supposed to be small.

Note that in this modification, blocks can leave the spherical surface (as they have six degrees of freedom).

The model uses non-dimensional time. When interpreting the results, a chosen realistic value (e.g., 1 year) is given to one unit of non-dimensional time.

2.2 Viscose-elastic interaction between blocks. Quasi-static equilibrium equations

All the values of the components of translation vector and the angles of rotation are found from the condition that the sum of all forces acting on the block and of total moment of these forces have to be zero (at every moment of time the structure is supposed to be in a quasistatic equilibrium state). The interaction of the blocks with the underlying medium takes place on the inner sphere. The movements of the boundaries of the block structure (the boundary blocks) and of the underlying medium are assumed to be an external action on the structure. The rates of these movements are considered to be known. Motion is described as a rotation on the sphere, i.e. position of axis of rotation and angle velocity are given.

Since the depth of spherical layer is significantly less than block structure dimensions, we will consider only points belonging to a fault line on Earth's surface, while computing numerical characteristics of block interaction. So, it is assumed that all characteristics are described only by coordinates $(\varphi,\ \psi)$ and do not depend on R.

Let us consider a point with coordinates $(\varphi,\ \psi)$ belonging to some fault separating blocks with numbers i and j, block i being leftward, and block j being rightward. Denote $\vec{e}_t$ unit vector tangent to the fault line at this point and directed along the fault. Let it have coordinates $\vec{e}_t = (e_1, e_2, 0)$ in rectangular coordinate system with origin at point $(\varphi,\ \psi)$ and axes introduced analogously to those of system-C (we call this system "system-P"). Let us define vector $\vec{e}_l = (-e_2 \cos\alpha, e_1 \cos\alpha, -\sin\alpha)$, which lies on the plane tangent to the fault's surface at the given point and is perpendicular to vector $\vec{e}_t$ (here α is the dip angle of the fault). Introduce also vector $\vec{e}_n = (-e_2 \sin\alpha, e_1 \sin\alpha, -\cos\alpha)$, which is perpendicular to the mentioned plane. Let right triple $(\vec{e}_t, \vec{e}_l, \vec{e}_n)$ define a rectangular coordinate system with origin at point $(\varphi,\ \psi)$, "system-T". Let $(\Delta_x,\ \Delta_y,\ \Delta_z)$ be the vector of relative displacement of blocks at point $(\varphi,\ \psi)$ in system-P. Components of the displacement on the plane tangent to the fault's surface at this point in system-T are correlated with Δ_x, Δ_y and Δ_z by the following:

$$\Delta_t = \Delta_x e_1 + \Delta_y e_2, \quad \Delta_l = -\Delta_x e_2 \cos\alpha + \Delta_y e_1 \cos\alpha - \Delta_z \sin\alpha,$$

$$\Delta_n = -\Delta_x e_2 \sin\alpha + \Delta_y e_1 \sin\alpha + \Delta_z \cos\alpha.$$

The elastic force per unit area (f_t, f_l, f_n) applied to the point of the fault is defined by

$$f_t = K_t(\Delta_t - \delta_t), \quad f_l = K_l(\Delta_l - \delta_l), \quad f_n = K_n(\Delta_n - \delta_n). \tag{2}$$

Here, δ_t, δ_l, δ_n are corresponding inelastic displacements, evolution of which is described by the equations

$$\frac{d\delta_t}{dt} = W_t f_t, \quad \frac{d\delta_l}{dt} = W_l f_l, \quad \frac{d\delta_n}{dt} = W_n f_n. \tag{3}$$

The coefficients K_t, K_l, K_n, W_t, W_l, and W_n in (2) and (3) may be different for different faults.

Now, let us calculate components of relative displacement, Δ_x, Δ_y и Δ_z by use of formulas (1). We obtain

$$\Delta_x = \Delta_x^i - \Delta_x^j, \quad \Delta_y = \Delta_y^i - \Delta_y^j, \quad \Delta_z = \Delta_z^i - \Delta_z^j, \tag{4}$$

where (Δ_x^i, Δ_y^i, Δ_z^i) and (Δ_x^j, Δ_y^j, Δ_z^j) are vectors of displacement (in system-P) of point (φ, ψ) as a point of blocks i and j respectively. Now, in order to obtain components of these vectors, one should multiply the displacements in system-C (defined by (4)) by matrix of transformation from system-C, corresponding to the block, to system-P. Due to unwieldiness of these computations, they are omitted here. Let us note only that in such a way, one can find displacements both for points on any fault and on the block bottom.

In system-P connected with point (φ, ψ) of the block bottom, the elastic force per unit area, (f_x^u, f_y^u, f_z^u), has the form:

$$f_x^u = K_u(\Delta_x^u - \delta_x^u), \quad f_y^u = K_u(\Delta_y^u - \delta_y^u), \quad f_z^u = K_u^n \Delta_z^u, \tag{5}$$

where δ_x^u, δ_y^u are corresponding inelastic displacements, evolution of which is described by the equations:

$$\frac{d\delta_x^u}{dt} = W_u f_x^u, \quad \frac{d\delta_y^u}{dt} = W_u f_y^u. \tag{6}$$

It is assumed that there is no inelastic displacement in vertical direction (along z-axis). The coefficients K_u, K_u^n and W_u in (5) and (6) may be different for different blocks. Vector ($\Delta_x^u, \Delta_y^u, \Delta_z^u$) of relative displacement of the block and the underlying medium at point (φ, ψ) considered in system-P is defined by (1) and (4) analogously to the case of finding displacement of a fault point.

As mentioned above, components of translation vectors of the blocks and angles of their rotation around the mass centers of the blocks are found from the condition that the total force and the total moment of forces acting on each block (written in system-C corresponding to the block) are equal to zero. This is the condition of quasistatic equilibrium of the system and at the same time the condition of minimum energy.

It is important that dependence of forces and moments on displacement and rotation of blocks is linear. Therefore, the system of equations for determination of these values is linear. It can be obtained in accordance with the formulas for forces:

$$A\boldsymbol{w} = \boldsymbol{b}. \tag{7}$$

Here, components of unknown vector $\boldsymbol{w} = (w_1, w_2, \ldots, w_{6n})$ are the components of translation vectors of blocks and the angles of their rotation (n is the number of blocks), i. e. $w_{6m-5} = x_m$, $w_{6m-4} = y_m$, $w_{6m-3} = z_m$, $w_{6m-2} = \gamma_m$, $w_{6m-1} = \beta_m$, $w_{6m} = \lambda_m$ ($m = 1, 2, \ldots, n$). The elements of matrix A ($6n \times 6n$) and vector $\boldsymbol{b}$ ($6n$) are determined from rather complicated formulas, which are deduced from (1)-(6) with transformation of forces and moments to system-C. For brevity sake, these formulas are omitted in this paper.

2.3 Discretization

In computational purposes, time discretization is performed by introducing a time step Δt (by full analogy with 2D model). The state of the block structure under consideration is determined at discrete time moments $t_i = t_0 + i\Delta t$ ($i = 1, 2, \ldots$), where t_0 is the initial time. The transformation from the state at t_i to the state at t_{i+1} is made as follows: (a) new values of inelastic displacements δ_x^u, δ_y^u, δ_t, δ_l, δ_n are calculated from equations (3) and (6); (b) translation vectors and the rotation angles at t_{i+1} are calculated for the boundary blocks and the underlying medium; (c) components of $\boldsymbol{b}$ in system (7) are found, and this system is used to determine the translation vectors and the rotation angles for the blocks. Since the elements of A in (7) do not depend on time, this matrix can be calculated only once, at the beginning of the process.

For calculation of various curvilinear integrals, one should discretize (split to cells) spherical surfaces of block bottoms and fault segment arcs. Therewith, values of forces and inelastic displacements are supposed to be equal in all points of a cell. Note that according to the assumption, segments are not subject to discretization by depth; we assume that in calculations for faults, one can use characteristics of cells belonging to fault lines on the Earth's surface.

2.4 Earthquake and creep

At every time t_i, we calculate (as well as in 2D model) the value of the quantity κ by the following formula

$$\kappa = \frac{\sqrt{f_t^2 + f_l^2}}{P - f_n}, \tag{8}$$

where P is the parameter which may be interpreted as the difference between the lithostatic and the hydrostatic pressure (P has the same value for all faults).

For each fault the three levels of κ are fixed

$$B > H_f \geq H_s.$$

It is assumed that the initial conditions for numerical simulation of block structure dynamics satisfy the inequality $\kappa < B$ for all cells of the fault segments. If, at some time t_i, the value of κ in some cell of a fault segment reaches the level B, a failure ("earthquake") occurs. By failure we mean slippage during which the inelastic displacements δ_t, δ_l, δ_n in the cell change abruptly to reduce the value of κ to the level H_f. Note that this procedure for 3D models essentially differs from the analogous procedure for 2D model. The new values of the inelastic displacements in the cell are calculated from

$$\delta_t^e = \delta_t + \gamma^e \xi_t f_t, \quad \delta_l^e = \delta_l + \gamma^e f_l, \quad \delta_n^e = \delta_n + \gamma^e \xi_n f_n, \tag{9}$$

where δ_t, δ_l, δ_n, f_t, f_l, f_n are the inelastic displacements and the components of elastic force vector per unit area just before the failure. The coefficients $\xi_t = K_l/K_t$ ($\xi_t = 0$ if $K_t = 0$) and $\xi_n = K_l/K_n$ ($\xi_n = 0$ if $K_n = 0$) account for inhomogeniety of displacements along the fault plane (in different directions) and normal to it (they reflect the assumption that the same value of the elastic force per unit area results in different values of rates of changing different inelastic displacements). The coefficient γ^e is given by

$$\gamma^e = \frac{\sqrt{f_t^2 + f_l^2} - H_f(P - f_n)}{K_l\sqrt{f_t^2 + f_l^2} + K_n H_f \xi_n f_n}. \tag{10}$$

It follows from (2), (8)-(10) that after calculation of the new values of the inelastic displacements and the elastic forces the value of κ in the cell is equal to H_f. Here, the following facts should be noted. After the calculation according to (2), (9), the signs of the elastic forces should be the same as just before the failure. Therefore, the case when $(1 - K_n \xi_n \gamma_e) < 0$ (and the sign of f_n changes) s to be considered in its own right as well as the case when $(1 - K_l \gamma_e) < 0$ (and the signs of f_l and f_t change). It may be proved that the second situation is possible only if $f_n < 0$. In the both cases we assume

$$\delta_n^e = \Delta_n, \quad \gamma^e = \frac{\sqrt{f_t^2 + f_l^2} - H_f P}{K_l \sqrt{f_t^2 + f_l^2}}.$$

After calculations described above for all the failed cells, the new components of vector $\boldsymbol{b}$ are computed, and from the system of equations (7) the translation vectors and the angles of rotation for the blocks are found. If for some cell(s) of the fault segments, $\kappa > B$, the whole procedure is repeated. When for all cells of faults it becomes $\kappa < B$, calculation is continued by usual scheme. Immediately after the earthquake, it is assumed that the failured cells are in the creep state. It means that, for these cells, in equations (3), which describe the evolution of inelastic displacements, the parameters W_t^s $(W_t^s > W_t)$, W_l^s $(W_l^s > W_l)$, and W_n^s $(W_n^s > W_n)$ are used instead of W_t, W_l, and W_n. They may be different for different faults. The failured cells are in the creep state as long as $\kappa > H_s$, while when $\kappa \leq H_s$, the cells return to the normal state and hereinafter W_t, W_l, and W_n are used in (3).

The cells of the same fault plane in which failure occurs at the same time form a single earthquake. The parameters of the earthquake are defined as follows: (a) the origin time is t_i; (b) the epicentral coordinates and the source depth are the weighted sums of the coordinates and depths of the cells involved in the earthquake (the weight of each cell is given by its square divided by the sum of squares of all cells involved in the earthquake); (c) the magnitude is calculated by the formula [10]:

$$M = 0.98 \log_{10} S + 3.93, \tag{11}$$

where S is the sum of squares of cells included in the earthquake. Depth of earthquake in the considered modification is not defined.

3 Some numerical results

Let us consider program realization of spherical modification of 3D model of lithosphere dynamics. Taking into account that spherical geometry is reasonable to introduce for studying dynamics of a system of global plates (see, Fig. 2), one can define the following goals of modeling:

- creation of a global image of instant cinematics of the largest tectonic plates in the known system of "hot spots" [11];
- modeling of subduction and spreading belts, study of character of interaction between plates at their boundaries;
- analysis of vertical component of plate motions;
- estimation of spatial distribution of epicenters of strong earthquakes in the world scale;
- simulation of spatial and time migration of earthquakes;
- ascertainment of mechanisms of plate motion (for instance, plate's abilities to transmit stress through long distances or necessity of additional sources).

It should be noted that the tasks listed above are formulated "as a prospect".

The block models of lithosphere dynamics (especially 3D modifications) are quite time and memory consuming on sequential computers that does not allow to model dynamics of complex structures with large number of blocks and small enough step of space discretization. Considering a structure on a sphere complexifies significantly computations. However, the approach described above admits a natural parallelization of computations on multiprocessor machines. Parallelization was engaged in computational procedures. Service procedures [12] give to a user possibilities of specification of a block structure by graphic or numeric way, visualization of obtained sequence of earthquakes, creation and processing of synthetic catalogs of earthquakes in standard 20 byte format etc.

At the first stage, modeling of a small subsystem of plates was begun. The structure includes South America, Caribbean, Cocos, and Nazca plates (Fig. 2). Other, surrounding, plates (North America, Africa, Antarctica, and Pacific) are treated as boundary blocks moving by known laws [11]. This region is chosen because it includes various types of plate boundaries with quite contrast motions and high seismic activity. The structure under consideration has 4 blocks, 33 vertices, 36 faults (and segments), and 4 boundary blocks.

Dip angles of faults at boundary South America/Nazca equal 50°, other faults having dip angles of 90°.

Discretization was defined by the following values of steps: by time— 0.01, by space— 3 km. for segments and 1/3° for block bottoms. The largest block's bottom was split into 40 000 cells.

As far as parallelization is concerned, a parallel computational program was created for multiprocessor computer consisting of i860 (64 MHz) processors. For the parameters listed above, the highest rate was reached on 28 processors. Simulation of 20 units of non-dimensional time took 11.1 secs., which is 22.5 times as faster as that for one processor. The coefficient of efficiency in this case equals 0.8.

As results of computation, the program returns quantitative characteristics of block displacements, which may be treated as velocities (in cm/yr.), and relative displacements of points belonging to fault segments separating blocks (these displacements give notion on qualitative character of interaction between tectonic plates). Obtained data were compared with real ones, and behavior of boundary points showed that model zones of subduction and spreading correspond to observed ones (Fig. 2). This may be treated as a promising result. However, it seems to be early to discuss any quantitative characteristics of such processes.

A synthetic catalog of earthquakes was also obtained as a result of the experiment. The following its characteristics were studied: frequency-magnitude graphs, spatial distribution of epicenters, clustering phenomenon, and some other features.

The catalog covers a period of 20 units of non-dimensional time and contains 13744 events with magnitude of 6.3 trough 8.9, calculated by formula (11). Let us briefly mention some features inherit in the synthetic catalog. Clustering (grouping) of events may be seen both for separate segments and for the whole structure (Fig. 3). foreshocks, main shocks, and aftershocks may be indicated in the graphs. The pattern of seismicity repeats qualitatively in a certain interval of non-dimensional time (which depends on fault), periods of post-seismic relaxation and stress accumulation being also seen [13]. One can observe the phenomenon of earthquake migration along faults. Spatial distribution of events shows that, although model earthquakes occur at nearly all segments of the structure, there are some faults where a significant part of all synthetic seismicity is concentrated (these spots are marked on Fig. 2). These faults correspond to main seismoactive zones (Nazca/South

America and Nazca/Pacific boundaries). Frequency-magnitude dependence graphs for the synthetic catalog are shown on Fig. 4. They have a bit smaller inclination than analogous curves built for the observed data.

An experiment was performed in order to answer the question: which external stress source (motion of which boundary blocks) has the strongest influence on synthetic seismicity occurring in the considered subsystems of plates? The following three variants were considered: 1) African plate is motionless; 2) both Africa and Pacific have non-zero velocities (taken from [11]); 3) Pacific is motionless. Three corresponding synthetic catalogs obtained for a time period of 20 units of non-dimensional time were compared. It is found that under motionless Pacific plate, seismic activity of the structure is lower than under motionless Africa plate, influence of which being relatively small. In case (1), number of events is 13567, magnitude varying from 6.3 up to 9.06; in case (2), number of events is 13744, magnitude varying from 6.3 up to 8.9; in case (3), number of events is 12084, magnitude varying from 6.3 up to 9.06.

The table below reflects levels of activity of different seismic boundaries of the plate system under study. The following notations of the plates are used: *sam*, South America; *ant*, Antarctica; *afr*, Africa; *car*, Caribbean; *nam*, North America; *coc*, Cocos; *pac*, Pacific. Length of a boundary is measured in kms., (N_1, N_2, N_3) and (D_1, D_2, D_3) are number of events and seismic moment per unit length of boundary (measured in 10^{10} N) for the three variants of motion of boundary blocks respectively. Total seismic moment for a boundary is the sum of moments of all earthquakes occurred on the boundary. The following formula was used for calculations [14]:

$$\lg M_0 = 1.5M + 9.14,$$

where M_0 is seismic moment of the earthquake; M is the magnitude.

Boundary	Length	N_1	N_2	N_3	D_1	D_2	D_3
sam-ant	6267	403	481	483	316	340	329
afr-sam	12827	1320	1288	1294	1174	851	841
car-nam	3818	462	457	443	323	335	319
car-coc	1750	1768	1794	1805	28	27	28
car-sam	2975	145	144	138	505	556	483
car-naz	850	483	490	523	2990	2772	1451
coc-pac	2821	2526	2537	1411	199	197	13
coc-naz	2700	1427	1423	1470	521	514	457
naz-sam	6083	3042	3160	3173	15023	13125	12024
naz-pac	7627	1975	1952	1326	9602	9476	5768

The characteristic under consideration (seismic moment density) is maximum (up to 15.023×10^{13} N) on the boundary South America/Nazca (in reality: an active subduction zone). Boundaries Pacific/Nazca and Caribbean/Nazca (spreading zones) are of a smaller, but quite significant, values of the ratio: up to 9.062×10^{13} N and 2.99×10^{13} N respectively. Among all cases, maximum density of seismic energy per unit length of boundary is observed under motionless Africa plate. It is slightly less under motion of both plates and minimal under motionless Pacific plate. Let us try to explain this fact on the example of considering boundary South America/Nazca by means of the following qualitative speculations.

1) Due to sphericity of the structure (see, Fig. 5), motion of Africa plate causes occurrence of force $\vec{F}_A$, which is nearly parallel to the section of the fault on boundary Nazca/South America. This force acts upon South America plate and has such components on n- and l-axes of boundary Nazca/South America (System-T) that decrease the subduction motion and increase compression on the fault, i. e. it decreases the value of κ (8).

2) Motion of Pacific plate causes occurrence of force $\vec{F}_P$, which is nearly perpendicular to the section of the fault on boundary Nazca/South America. Hence, this force has almost no impact on the subduction motion, but it increases extension on the fault along n-axis, i. e. increases value of κ (8).

Therefore, seismic activity is higher in the second variant. Let us emphasize that abovementioned explanations may be true only thanks to spherical shape of the structure.

4 Conclusion

Some preliminary results of modeling a system of large-scale blocks with spherical geometry are presented. Some qualitative characteristics of plate motion and of character of their interaction are obtained. A synthetic catalog, which has some "real" features, was created. The spherical modification of block model shows some phenomena, which may occur only due to sphericity of a structure. This allows to hope to discover new factors causing seismic activity of a region.

5 Acknowledgments

The work was supported in part by International Science and Technology Center (Moscow), project 1293-99. For the first two authors, the work was also supported by Russian Foundation for Basic Research, grant 99-07-90441.

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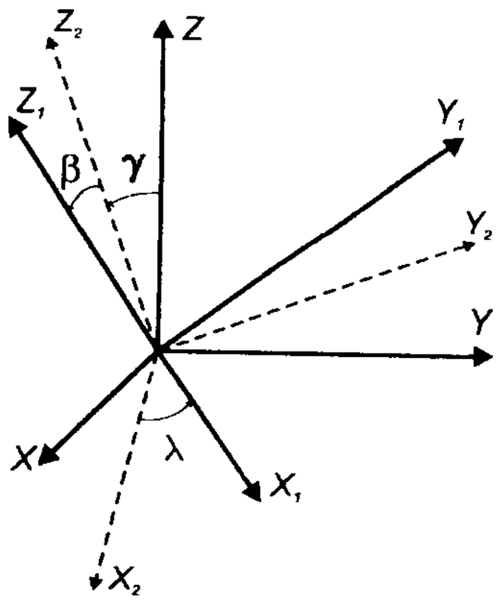

Fig. 1. Definition of rotation angles γ, β, and λ

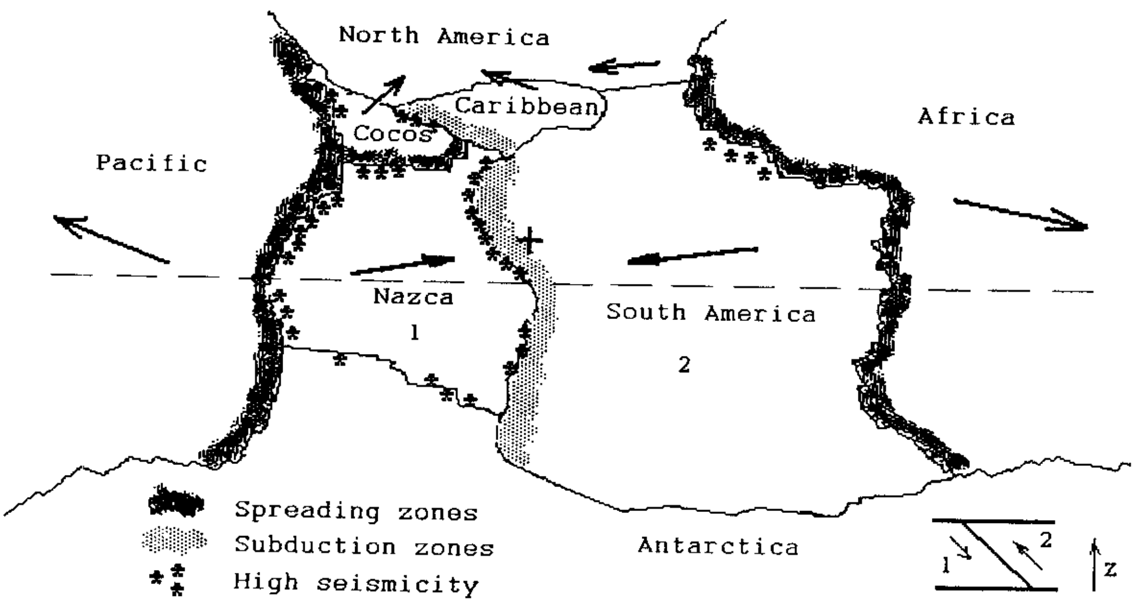

Fig. 2. Results of simulation of plate motion and spatial distribution of strong earthquakes. (Vertical component of relative motion at the boundary South America/Nazca is shown.)

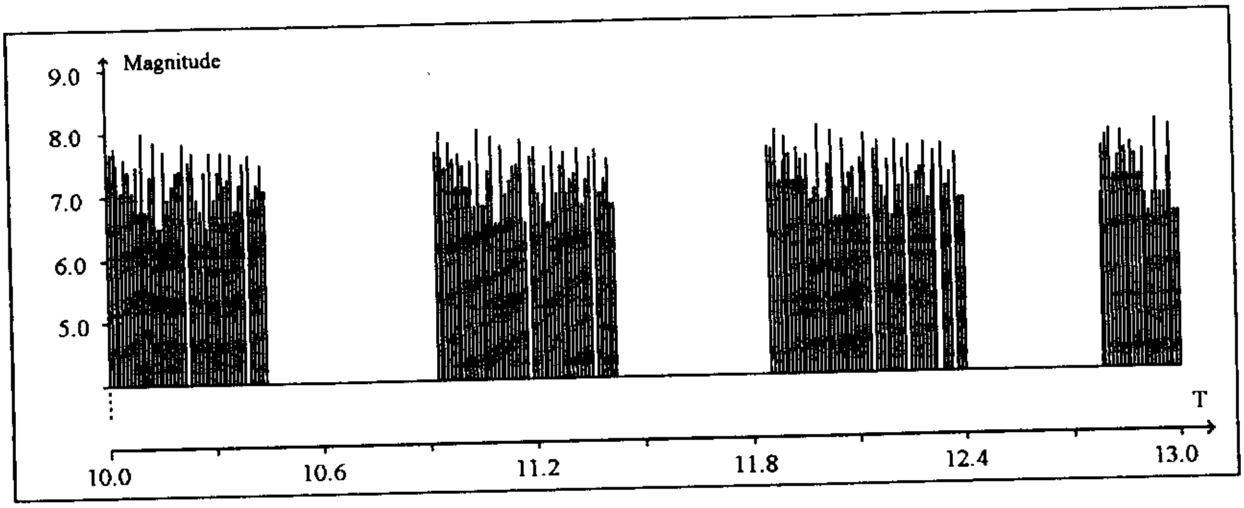

Fig. 3. Moments of earthquakes occurrence (vertical lines) for the segment (marked with "+" on Fig. 2) for a period of 3 units of non-dimensional time.

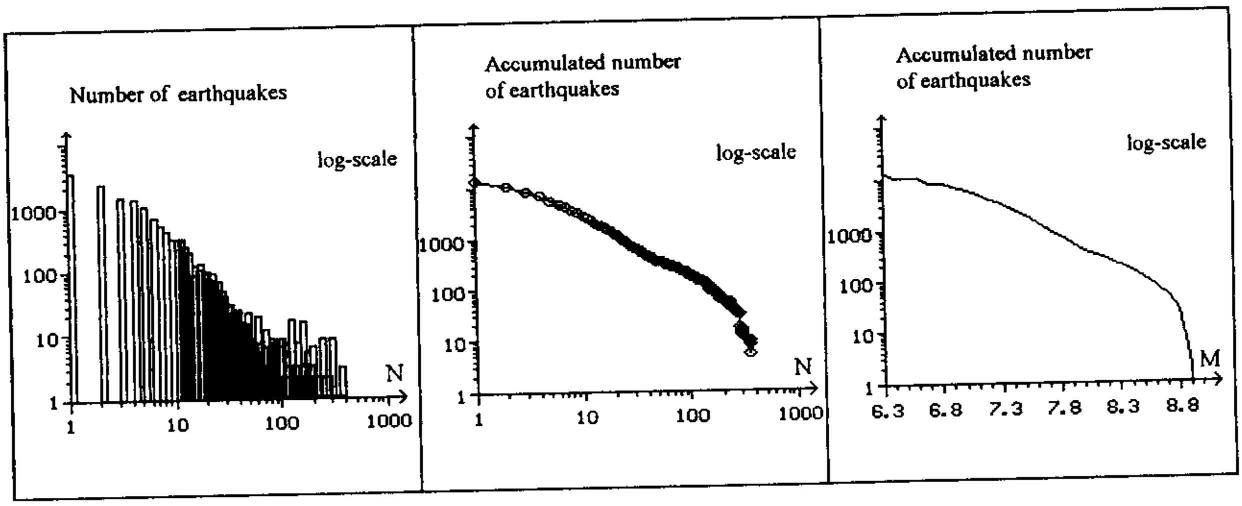

Fig. 4. Frequency-magnitude graphs for the synthetic catalog obtained under motion of Africa and Pacific plates. (N is number of cells, M is the magnitude.)

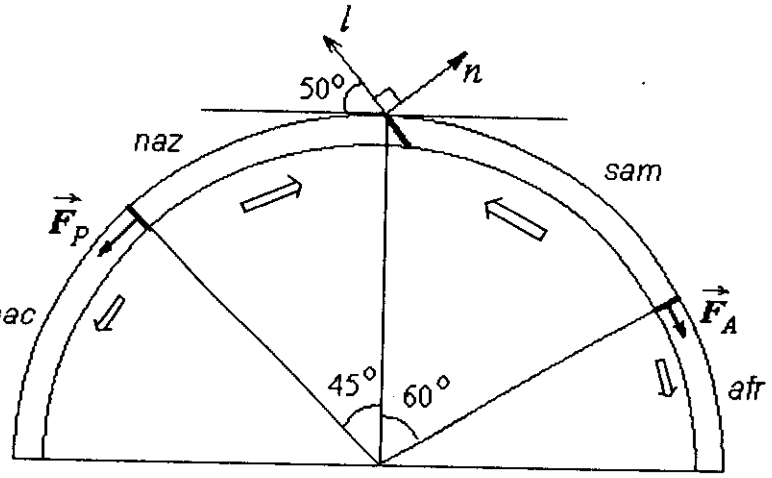

Fig. 5. Scheme of the impact of motion of Pacific and Africa plates on seismicity at the fault Nazca/South America. The section by the horizontal plane, which is marked with the dashed line on Fig. 2, is shown.