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Programs EARTH and EARTH-3

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ABSTRACT

The programs EARTH and EARTH-3 were designed for numerical simulation of dynamics of a system of lithosphere blocks with two-dimensional and three-dimensional movements of blocks respectively. A segment of the lithosphere is represented as a layer between two horizontal planes consisting of absolutely rigid blocks. The blocks are separated by infinitely thin plane faults. The blocks interact between themselves along the fault planes and with the underlying medium along the lower plane. The interaction is viscous-elastic. The movement of the blocks is a consequence of prescribed motion of boundaries of the block structure and the underlying medium. If for some part of a fault plane the stress surpasses a certain level during simulation then a stress-drop ("a failure") occurs. The failures are considered as earthquakes and a synthetic earthquake catalog is produced as a result of the numerical simulation

The programs run on an IBM PC compatible. They work in an interactive mode with a window interface and a graphic view of the output.

To users. The programs are modified from time to time according to the experience of its applications and in order to improve user's interface. Any suggestions or information on obtained simulation results will be kindly appreciated. Please send both to

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About programs EARTH and EARTH-3

The programs are used for numerical simulation of block structure dynamics (2D and 3D models respectively). The simulation includes arising of failures ("earthquakes") resulted by the interaction between blocks along fault planes separating them.

Input data for simulation are the following: the block structure geometry, the values of parameters which define features of interaction between elements of the structure, the equations describing movement of the underlying medium and the boundaries.

Both programs are based on the same ideas and principles. They have the same structure. Programs EARTH and EARTH-3 work in the interactive mode and include the similar calculation and service procedures united by the system of hierarchical menus. All data of the programs are defined by the window interface, the output is realized in the graphic form. The programs are supplied by the help information.

The programming language is Borland Pascal 7.0. For the successful work of programs EARTH and EARTH-3 it is required IBM PC AT with EGA/VGA monitor and not less than 8M and 11M of free memory respectively. The following files are necessary for the work with the programs:

earth.exe - program EARTH;
earth-3.exe - program EARTH-3;
rtm.exe, dpmi16bi.ovl - RTM loader and overlay file;
egavga.bgi - device driver file;
litt.chr, tscr.chr - font files;
glo.pcx, glo-3.pcx, map.pcx - files with graphic pictures.

The programming skill is not required from users. Some experience with computers would be helpful.

This Guide is oriented to detailed description of program EARTH (2D block model) with emphasis on additional possibilities of program EARTH-3 (3D block model) which are marked by special notes.

BLOCK STRUCTURE GEOMETRY

A layer with depth (thickness) H between two horizontal planes is considered. A block structure is a part of this layer limited and divided into blocks by planes intersecting the layer. Parts of these planes which are inside the block structure or adjoin to it are called "faults". The block structure geometry is defined by the description of intersection lines of faults (they will also be called faults below) with the upper plane and by angles of dip for the fault planes. The geometry on the lower plane is assumed to be similar to the one on the upper plane.

The notion "vertex" is used for the description of the faults' system. Three or more faults cannot have a common point on the upper plane. Vertex is a common point of two faults. There are three types of vertices:

C (corner vertex) - a vertex which is an end point of a fault and at the same time an initial point of another one;

E (end vertex) - a vertex which is an initial (or end) point of a fault and belongs to another one but is not its initial (or end) point;

I (intersection) - a point of intersection of two faults which is not an initial (or end) for both of them.

The examples of these types of vertices are shown in Figure 1.

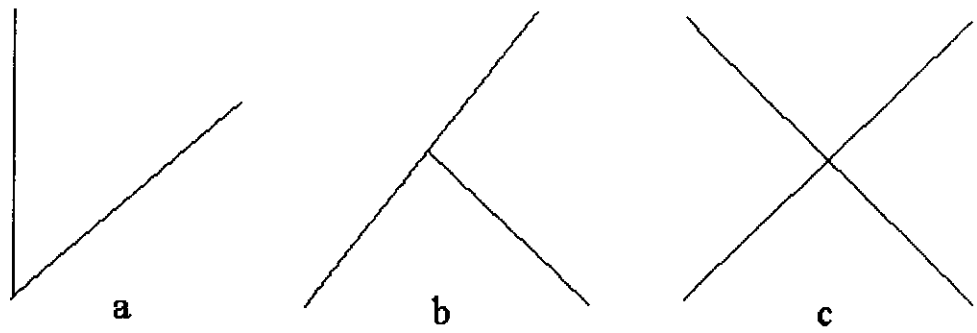

FIGURE 1 Types of vertices: a - corner (C); b - end (E); c - intersection (I).

A fault is defined by indication of its initial and end vertices. The angle of dip for the fault plane is measured to the left of the fault. The fault direction is the direction from its initial point to its end point.

The structure is separated by the faults into blocks. A common part of any block with the upper plane is a polygon.

"Boundary blocks" are defined for the structure to introduce the movement of boundaries. A boundary block is a continuous part of the

structure boundary between two vertices which consists of some sides. It is defined by the indication of its initial and end vertices.

A fault segment is a part of a fault plane limited by the upper and lower planes and lines which connect positions on the upper and lower planes of two consecutive vertices of the fault.

The example of the block structure on the upper plane is represented in Figure 2.

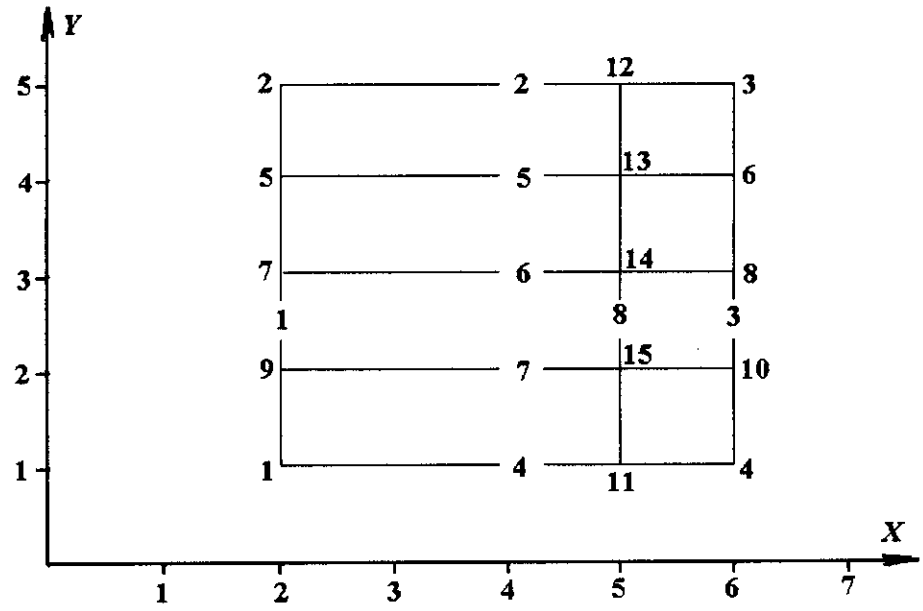

FIGURE 2 The vertices and the faults on the upper plane.

This structure has 4 corner vertices with the coordinates: (2,1), (2,5), (6,5), (6,1); 8 end vertices with the coordinates: (2,2), (2,3), (2,4), (5,1), (5,5), (6,2), (6,3), (6,4); 3 intersections with the coordinates: (5,2), (5,3), (5,4). There are 8 faults. Their description is given in the table below.

number of fault	initial point	end point	dip angle
1	1	2	45°
2	2	3	45°
3	3	4	135°
4	4	1	135°
5	5	6	45°
6	7	8	45°
7	9	10	45°
8	11	12	45°

With the depth of the layer H = 1, the faults and the vertices have on the lower plane the position shown in Figure 3.

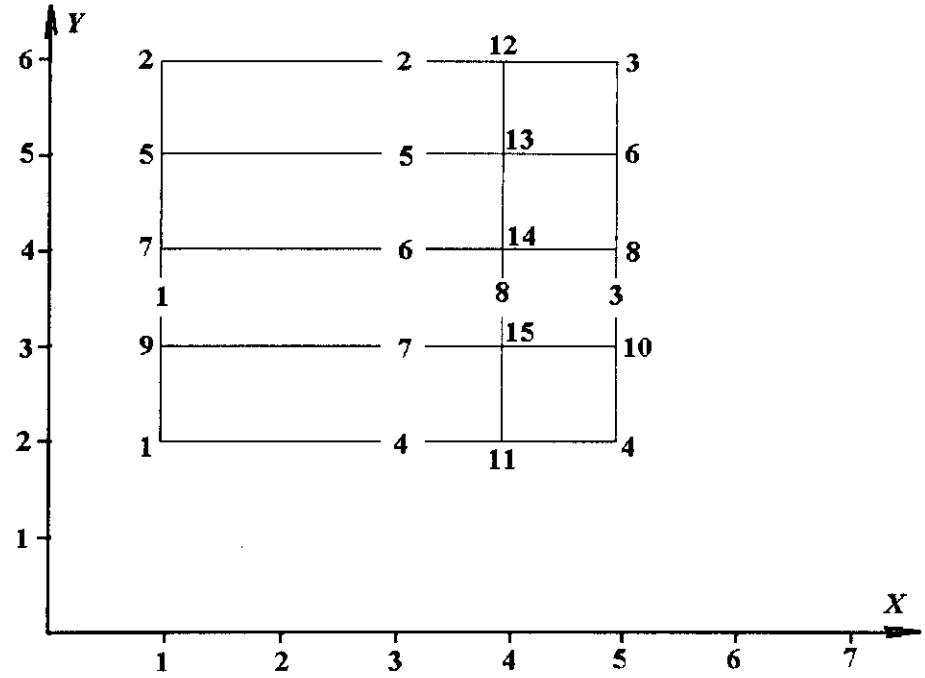

FIGURE 3 The vertices and the faults on the lower plane.

The structure has 22 segments and 8 blocks (these parts of the structure are determined by the program). The definition of the boundary blocks is left to discretion of the user. This simple block structure plays the role of the default structure both for program EARTH and for program EARTH-3.

PARAMETERS AND MOVEMENTS

Block parameters. The interaction between the block and the underlying medium at any point of the common part of the block and the lower plane (the block bottom) is described for 2D model by the equation

$$\frac{d\Delta\mathbf{u}}{dt} = W_u \mathbf{f}_u, \qquad (1)$$

where the horizontal elastic force per unit area $\mathbf{f}_u$ is defined by the formula

$$\mathbf{f}_u = K_u (\Delta\mathbf{r} - \Delta\mathbf{u}). \qquad (2)$$

Here $\Delta\mathbf{r}$ is the vector of the total horizontal displacement between the block and the underlying medium at the point, $\Delta\mathbf{u}$ is the vector of the horizontal inelastic displacement at the point. K_u and W_u are parameters which characterize the interaction between the block and the underlying medium. In 3D model the additional vertical elastic force $\mathbf{f}_u^n$ is introduced. This force per unit area is found from the formula

$$\mathbf{f}_u^n = K_u^n \Delta z\,, \tag{3}$$

where Δz is the total vertical displacement between the block and the underlying medium at the point, K_u^n is a coefficient characterizing the elastic interaction in the vertical direction. The values of all the coefficients may be different for different blocks.

Fault parameters. The interaction between two adjacent blocks at any point of the fault plane separating them is described for 2D model by the equation

$$\frac{d\Delta w}{dt} = W\mathbf{f}, \tag{4}$$

where the elastic force per unit area $\mathbf{f}$ in the fault plane is defined by the formula

$$\mathbf{f} = K\,(\Delta\mathbf{r} - \Delta\mathbf{w}). \tag{5}$$

Here $\Delta\mathbf{r}$ is the vector of the total fault plane displacement between the blocks at the point, $\Delta\mathbf{w}$ is the vector of the inelastic fault plane displacement at the point. K and W are parameters which characterize interaction between blocks in the fault plane. In 3D model the additional inelastic displacement δ_n and elastic force f_n which are normal to the fault plane are introduced. The equation describing the evolution of δ_n is the following

$$\frac{d\delta_n}{dt} = W^n f_n\,. \tag{6}$$

The elastic force per unit area f_n is found from the formula

$$f_n = K^n(\Delta_n - \delta_n)\,, \tag{7}$$

where Δ_n is the total normal displacement between the blocks at the point, W^n and K^n are coefficients. The values of all the coefficients may be different for different faults.

Another group of the fault parameters define a failure rise. Denote

$$\kappa = \frac{|\mathbf{f}|}{P - p_0} \tag{8}$$

where P is the parameter which may be interpreted as the difference between lithostatic and hydrostatic pressure, p_0 is the block reaction force per unit area which is normal to the fault plane at the point (for 3D model it is valid $p_0 = f_n$). The value of P is the same for all faults. When the value of κ in any part of a fault reaches the level B failure occurs. After that the components of the vector $\Delta\mathbf{w}$ (and δ_n for 3D model) are changed sharply to reduce the value of κ to the level H_f ($H_f < B$). Parts of the faults for which failure occured are in creep state. It means that in equation (4) (and in (6) for 3D model) the parameter W_s, $W_s \geq W$ (W_s^n , $W_s^n \geq W^n$) is used instead of W (W^n) . Creep continues while the value of κ is higher than the level H_s ($H_s < H_f$). When $k \leq H_s$ the cell returns to the ordinary state and henceforth the parameter W (and W^n) is used in equation (4) (and (6)) for this cell. Values of the parameters B, H_f , H_s , W_s , and W_s^n may be different for different faults.

Movements. The movement of the block structure is caused by the movement of its boundaries (boundary blocks) and the underlying medium.

In 2D model a boundary block is supposed to move progressively in the horizontal plane with a constant velocity (with components V_x , V_y) and to rotate around the coordinate origin with a constant angle velocity U. The medium underlying a block is supposed to move progressively in the horizontal plane with a constant velocity (with components V_x , V_y) and to rotate around the geometrical center of the block bottom with a constant angle velocity U.

In 3D model the displacement of a boundary block is determined by a constant translation velocity with three components V_x, V_y, V_z and by three angle velocities U_1, U_2, U_3 of special rotation around the coordinate origin. The displacement of the medium underlying a block is determined by a constant translation velocity with three components V_x, V_y, V_z and by three angle velocities U_1, U_2, U_3 of special rotation around the geometrical center of the block bottom.

All the characteristics may be different for different boundaries and blocks.

DISCRETIZATION

Time discretization is defined by a time step Δt and the structure state is calculated for the discrete moments of time $t_i = t_0 + i\Delta t$ (i = 1, 2, ...), where t_0 is the initial moment.

Space discretization is defined by a space step ε and applied to the surfaces of the fault segments and to the block bottoms. The discretization of a fault segment is performed as follows. Each fault segment is a trapezium which is divided into rows and then into small trapeziums (cells) within every row so that side lengths are less than ε for all cells. The bottom of a block is a polygon which is divided into trapeziums (triangles) by segments passing through its vertices and parallel to axis Y. Discretization of these figures is performed in the same way as in the case of the fault segments. The small trapeziums (triangles) are also called cells. The values of coordinates, displacements and forces are not distinguished for different points of the same cell. Thus, after the space discretization the cells are considered instead of points. Failure occurs for a whole cell. The parameters of the earthquake are defined by the following way: the origin time is t_i (failure occurence time); the epicentral coordinates and the source depth are the weighted sums of the coordinates and depths of the failured cells (the weights of the cells are given by their squares divided by the sum of squares of these cells); the magnitude is calculated from

$$M = (\log_{10} S + 4.01)/1.02, \qquad (9)$$

where S is the total area (in km^2) of cells failed in the earthquake.

MODES OF WORK

Both programs EARTH and EARTH-3 have the same four modes of work.

I. Dynamics of block structure. This is the base mode of the programs. If this mode is selected then the numerical simulation of dynamics (according to 2D or 3D model respectively) of the block structure and earthquake failure sequences caused by it is performed. The simulation can be started with zero initial conditions or from some intermediate state saved in a disk file of the special structure. If necessary the file in which the parameters of the final or the current (for the moment

of the process interruption) state will be written can be indicated. Besides, it is possible to create a file for catalog preparation. More detailed description of operations with files is stated below.

II. Calculation of maximum stress. If this mode is selected then the programs calculate for the fault segments the maximum (among the cells of the segment) value of κ (8) in percents of the value of the level B. This operation is carried out for the current time moment or for some intermediate state saved in the special file the name of which has to be indicated. The information about the maximum value of stress is imaged on the screen by two ways: (i) for all segments; (ii) for the selected segment.

III. Image of earthquake flow. If this mode is selected then the programs image on the screen the sequence of cell failures for the fault segments. In this mode the programs use the file with the information for earthquake catalog preparation. The name of this file has to be indicated in the special menu arising after the selection of the mode. There is a possibility to screen the plots of dependence of the number of earthquakes on the number of cells failed in an earthquake.

IV. Creation of catalog. If this mode is selected then the programs create an earthquake catalog using the indicated (by analogy with the previous section) file with the information for earthquake catalog preparation. The catalog may be produced by two ways: (i) with unification of all segments of the same fault; (ii) with distinguishing of such segments. After the catalog creation the plots of dependence of the number of earthquakes on the number of cells failed in an earthquake and the plot of dependence of the accumulated number of earthquakes on the magnitude are imaged on the screen.

It is possible in all modes mentioned above to save the information on the process parameters and calculation results in a text file of the special structure the name of which has to be indicated.

CATALOG

Programs EARTH and EARTH-3 create an earthquake catalog stored as a non-text file (standard "20 bytes format").

The specification of the records in the file of catalog is the following.

The first record:

20 bytes; the first 4 bytes contain an integer which is the total number of records in the file (it is the number of earthquakes plus 1).

All other records:

Positions of records	Content	Type
1-4	time of the earthquake in minutes A.D.	integer*4
5-6	latitude*100	integer*2
7-8	longitude*100	integer*2
9-10	depth (km)	integer*2
11-12	magnitude*100	integer*2
13-20	are not used (reserved)	

For catalog creation the following additional information has to be indicated: the latitude and the longitude of the coordinate origin; the initial year of the catalog (00h 00m of the 1st January of this year will be assigned to $t = 0$, it is assumed in the programs that the default initial year is 1900); the number of days (365 by default) which will be assigned to the unit of time used in the equations describing dynamics of the block structure.

The magnitude is calculated by the formula (9).

DIALOG

The programs use the window interface represented in the form of hierarchical menus.

The first (main) menu arising after the initial picture consists of the following six items:

I. Dynamics of Block Structure
II. Calculation of Maximum Stress
III. Image of Earthquake Flow
IV. Creation of Catalog
V. File Operations
VI. Exit

To select necessary mode you have to move the cursor to the proper item and press <ENTER>. It is possible to terminate the programs and to return to DOS by selecting the special item "Exit" and pressing <Y> as the answer to the confirmation question. It should be noted that this is the only legal exit from the programs.

I. Dynamics of Block Structure

If this item of the main menu is selected then the menu of the following five items appears:

1. Regions of Seismoactivity
2. Geometry of Block Structure
3. Numerical Parameters
4. Simulation of Block Dynamics
5. Viewing of Current Variables

You may press <ESC> to return to the main menu.
Below there is the detailed description of the items listed above.

1. Regions of Seismoactivity

This mode gives an opportunity to specify the rectangle zones in seismoactive regions on the model map of the world (see Figure 4). If the scheme of lineaments was specified for the region it may be useful during the inputing of the block structure elements. The scheme of lineaments is stored in the file of the special structure which may be created by program LINEAM described at the end of this Guide. The geographic coordinates of the upper left corner of the zone may be used as the values of the latitude and the longitude for the coordinate origin.

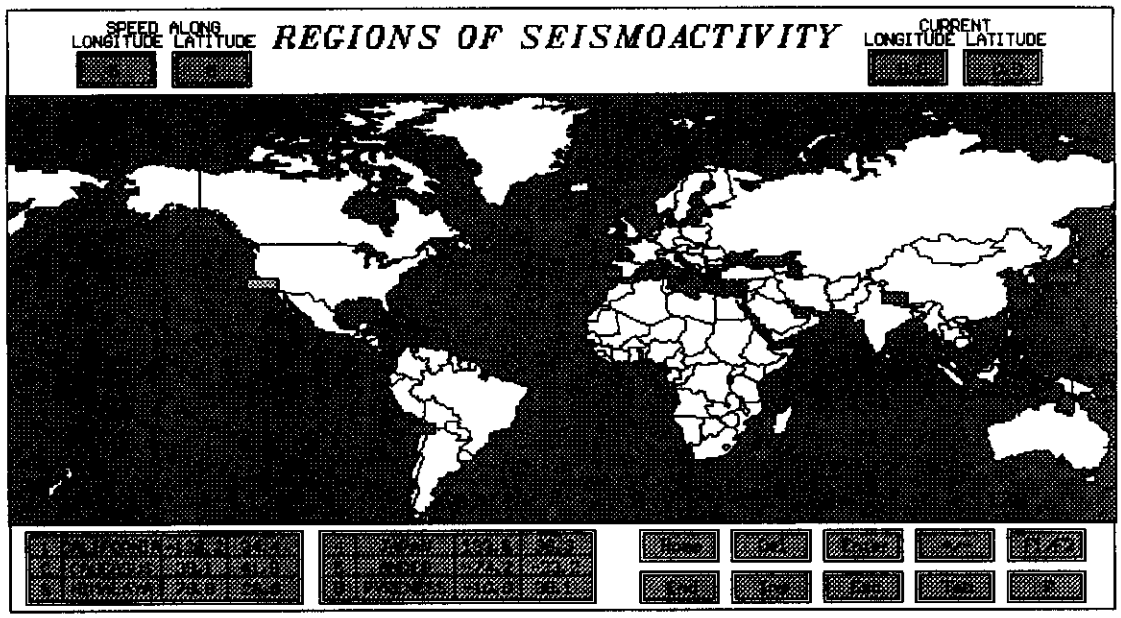

FIGURE 4 The model map of the world.

The picture contains the following help information:

a) the speed of cursor moving along the latitude and the longitude directions (the upper left corner of the screen);

b) the real geographic coordinates (the latitude and the longitude) of the cursor (the upper right corner of the screen);

c) the number of zones inputed, their names and coordinates of their upper left corners (the lower left corner of the screen);

d) the programmed keys (the lower right corner of the screen).

It should be noted that in programs EARTH and EARTH-3 Northern latitude and Eastern longitude are supposed to be positive and Southern latitude and Western longitude - negative. There are the following restrictions adopted in the program: the maximum number of zones is equal to 6, the zone area is limited by 1000 "squared degrees", the zones can not be intersected by each other.

There are the following functional keys.

Key	Function and Comments
<→>, <←>, <↓>, <↑>	To find the desired point on the model map. The direction of cursor moving coincides with the direction of the corresponding arrow.
<+>, <->	To regulate the speed of cursor moving. You may increase (decrease) the number of pixels which define the step of cursor moving. The maximum step is equal to 10 pixels, the minimum step is equal to 1 pixel.
<HOME>, <END>	To place the cursor at the upper left corner and the lower right corner of the model map of the world respectively.
<ENTER>	To realize the process of zone inputing. You may fix the upper left corner of the zone (it means to define its geographic coordinates) by pressing <ENTER> at the first time. The program switches on the mode "Draw zone". After it cursor movements only downwards and to the right are possible. If the key <ENTER> is pressed at the second time the lower right corner of the zone is fixed and exit from the mode "Draw zone" is fulfilled. Then the interior part of the zone is colored red, the specific name is inputed (the name by default is "region" plus ordering number of the zone). The coordinates and the name are placed into the informational table on the screen.
<DEL>	To fulfil some deleting operations. If <DEL> is pressed under

	the mode "Draw zone" it switches off this mode and cancels the current inputing. Otherwise if you press this key at the point belonging to some zone then this zone will be deleted after the confirmation. If the key is pressed at the point out of any zone then all zones will be deleted after the confirmation.
<INS>	To load standard (default) configuration. You may do it by pressing this key if your picture is empty. Standard configuration consists of 6 zones: CALIFORNIA (-126.2, 34.4), CAUCASUS (39.1, 41.9), HIMALAYA (79.8, 28.6), JAPAN (133.6, 36.3), ANDES (-74.2, -23.2), PYRENESS (-10.0, 38.1).
<F1>	To output help information on hot keys.
<F2>	To change the zone name without any other changes. The cursor must indicate to the desired zone.
<TAB>	To switch active zone (we call an active one the zone lineaments of which may be taken for inputing of a block structure on the coordinate plane. In this case the geographic coordinates of its upper left corner will be used as the values of the latitude and the longitude for the coordinate origin). The active zone is marked by lightblue color. It is CALIFORNIA that active in the default configuration.
<ESC>	To return to the menu of "Dynamics of Block Structure"

2. Geometry of Block Structure

This mode gives an opportunity to specify the geometry of a block structure. As mentioned above, the geometry is defined by the description of intersection lines of the faults with the upper plane and by angles of dip for the fault planes. The faults and the vertices are inputed in the graphic mode on the coordinate plane (see Figure 5). The dip angles and other numerical parameters are defined in the special menu system. When inputing of the block structure geometry is finished verification procedure has to be performed.

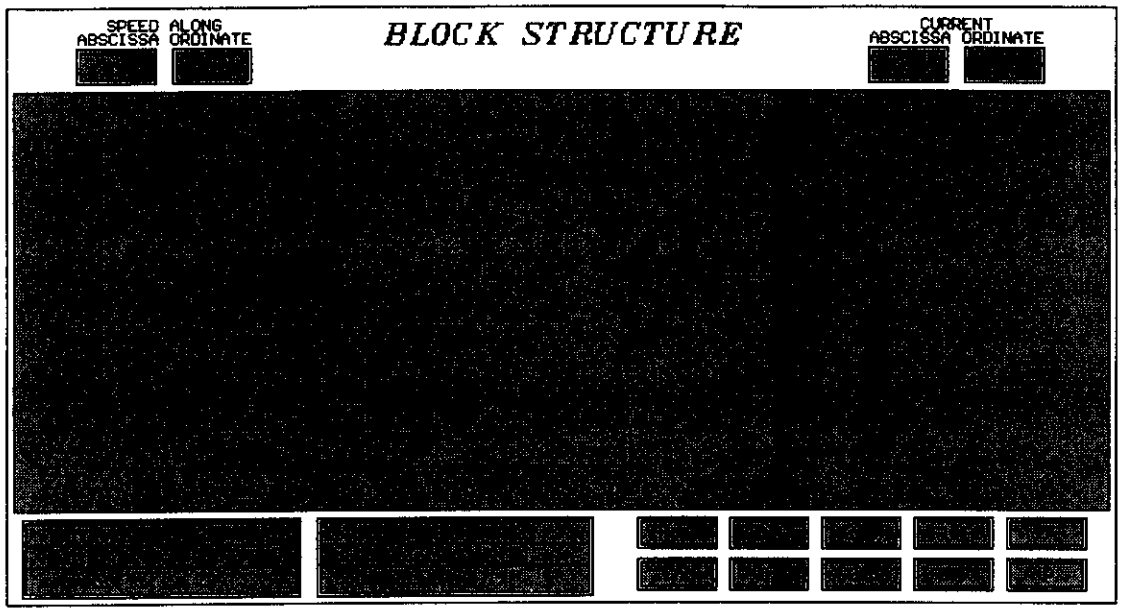

FIGURE 5 The coordinate plane.

It should be noted that the block structure is inadmissible in the following cases:

a) there is an intersection of more than two faults at one vertex;

b) there is a vertex belonging to only one fault or not belonging to any fault;

c) there is a multiply connected block structure;

d) there is a segment which does not occur in any block;

e) there is a segment which has intersection of its sides.

If the structure is admissible then its blocks and segments are determined. After this operation the boundary blocks and all numerical parameters of the blocks, faults and underlying medium are inputed (these parameters may be different for different structure elements).

There are the following restrictions on the geometric parameters of a block structure:

	2D model EARTH	3D model EARTH-3
the maximum number of vertices	100	90
the maximum number of faults	75	50
the maximum number of segments	150	120
the maximum number of blocks	30	30
the maximum number of boundary blocks	20	20
the maximum number of cells per a segment row	250	450
the maximum number of rows per a segment	39	50
the maximum number of cells per a bottom trapezium	1089	1500
the maximum number of trapeziums per a block bottom	7	8

The picture contains the following help information:

a) the speed of cursor moving (the upper left corner of the screen);

b) the real coordinates of the cursor (the upper right corner of the screen);

c) the number of inputed vertices and faults and the number of defined segments, blocks, boundary blocks and boundary segments (the lower left corner of the screen (if verification procedure has not worked yet then there is expression "UNDEFINED" instead of the number of segments, blocks and others));

d) the programmed keys (the lower right corner of the screen).

There are the following functional keys.

Key	Function and Comments
<→>, <←>, <↓>, <↑>	To find the desired point on the coordinate plane in order to enter or delete a vertex. The direction of cursor moving coincides with the direction of the corresponding arrow.
<+>, <->	To regulate the speed of cursor moving. You may increase (decrease) the number of pixels which define the step of cursor moving. The maximum step is equal to 10 pixels, the minimum step is equal to 1 pixel.
<HOME>, <END>	To place the cursor at the upper left corner and the lower right corner of the coordinate plane respectively.
<SHIFT> + <→>, <←>, <↓>, <↑>	To realize picture scrolling in the corresponding direction.
<SHIFT> + <HOME>	To return the coordinate origin to the point (0, 0)
<ENTER>	To realize the process of structure inputing. You may fix a corner vertex (define its coordinates in the units of 10 km) by pressing <ENTER> at the screen point without inputed vertex (mode "Draw vertex", blue cursor). If you press <ENTER> at the screen point with existing vertex the program switches on another mode ("Draw fault", red cursor). This vertex is assumed to be the initial point of the fault. Next pressing <ENTER> allows to fix the end point of the fault and, consequently, the fault itself. The vertex may be placed on the existing fault (it is the end vertex), the intersection

	vertices are found automatically. Remember that the situation when more than two faults begin (end) at the same vertex is inadmissible. It is possible to extend the existing fault by a natural way.
<DEL>	To fulfil some deleting operations. If <DEL> is pressed under the mode "Draw fault" it switches off this mode. If you use this key under the mode "Draw vertex" it deletes some structure elements when the cursor indicates to the existing vertex or the whole structure when the cursor indicates to the screen point without vertex. In the first case the selected vertex and the faults having it as one of the ends are deleted after the confirmation. Note that isolated vertices (we call so vertices which are not one of the end points of any fault) are deleted automatically during the work of verification procedure.
<INS>	To load standard (default) structure. You may do it by pressing this key if your picture is empty. Standard simple structure consists of 15 vertices, 8 faults, 22 segments, 8 blocks and 2 boundary blocks (see Figure 2). The values of coefficients and velocities are specified in such a way that there are earthquakes during the process simulation.
<F1>	To output help information on hot keys.
<F2>	To show the block structure on the bottom plane (the mode works only after the successful verification). Repeated pressing switches off the bottom plane.
<F3>	To image on the screen the scheme of lineaments of the seismoactive zone selected in item "Regions of Seismoactivity". Repeated pressing cancels this mode and eliminates the scheme. Lineaments may be useful in the picture drawing.
<F4>	To perform verification procedure, to input boundary blocks and numerical parameters of the structure. This description requires separate section (you find it after this table).
<ESC>	To return to the menu of "Dynamics of Block Structure"

Verification procedure.

Functional key <F4> is used to switch on verification and editing modes during specification of a block structure geometry. If verification procedure defining blocks and segments is not successful then one of the messages mentioned above is imaged on the screen and the illegal part of the structure is marked by lightblue color. Otherwise the block structure is screened in the optimal scale and the mode of editing switches on. There are two menus in the mode of editing:

Boundary Blocks,

Numerical Parameters.

The first menu allows to specify boundary blocks for the structure. There are three opportunities to do this.

WHOLE - the only boundary block consists of all boundary segments.

SINGLE - each segment of the structure boundary is interpreted as a boundary block. If the number of boundary segments exceeds the maximum for the number of boundary blocks then all remaining segments are included in the last block. Both items "WHOLE" and "SINGLE" are supplied by the color mark of boundary blocks.

USER - boundary blocks are defined by user. You can define boundary blocks by the following way. Select the initial (anticlockwise) segment of the first boundary block using left and right arrows and press <ENTER>. Specify other segments of the first boundary block by use of <+> and <->. Press <ENTER> to complete definition of the block and to start a next one which is defined by analogy. Press <ESC> to pass to numerical parameters specification if you want to stop changes.

The second menu allows to specify all numerical parameters for the faults, blocks and boundary blocks. This menu has the different forms in programs EARTH and EARTH-3. There are the following three items in program EARTH.

FAULTS - to specify the values of fault parameters. You may select the desired fault by pressing <PgUp>, <PgDn>. The selected fault and its direction are marked on the screen by lightblue color. The menu for specification of the parameters for the fault contains the following windows.

Dip angle	To specify the value (in degrees) of the angle of dip for the fault plane. The range of changing is [10, 170] without [89.9, 90.1]
Coef KF	To specify for the fault the value (in bars/cm) of the parameter K in the formula (5). The range of changing is [0, 100].

Coef WF	To specify for the fault the value (in cm/bars) of the parameter W in the equation (4). The range of changing is [0, 500].
Coef WS	To specify for the fault the value (in cm/bars) of the parameter W_s which is used in the equation (4) in the creep state. The range of changing is [0, 500]. Note that $W_s \geq W$. Otherwise the new values of these parameters will be abrogated.
Level B	To specify for the fault the value of the level B. The range of changing is [0, 100].
Level HF	To specify for the fault the value of the level H_f . The range of changing is [0, 100].
Level HS	To specify for the fault the value of the level H_s. The range of changing is [0, 100]. Note that $B > H_f > H_s$. Otherwise the new values of these parameters will be abrogated.

By pressing <Esc> it is possible to return to the second menu.

BLOCKS - to specify the values of block parameters. You may select the desired block by pressing <PgUp>, <PgDn>. The selected block is filled on the screen by lightblue color. The menu for specification of the parameters for the block contains the following windows.

Coef KU	To specify for the block bottom the value (in bars/cm) of the parameter K_u in the formula (2). The range of changing is [0, 100].
Coef WU	To specify for the block bottom the value (in cm/bars) of the parameter W_u in the equation (1). The range of changing is [0, 500].
X-velocity	To specify for the block the value (in cm) of the velocity of the progressive movement of the underlying medium along axis X of the coordinate system. The range of changing is [-100, 100].
Y-velocity	To specify for the block the value (in cm) of the velocity of the progressive movement of the underlying medium along axis Y of the coordinate system. The range of changing is [-100, 100].
U-velocity	To specify for the block the value (in 10^{-6} of a radian) of the angle velocity of the underlying medium rotation around the geometrical center of the block bottom. The range of changing is [-100, 100].

By pressing <Esc> it is possible to return to the second menu.

BOUNDS - to specify the values of boundary block parameters. You may select the desired boundary block by pressing <PgUp>, <PgDn>. The selected block is marked on the screen by lightblue color. The menu for specification of the parameters for the boundary block contains the following windows.

X-velocity	To specify for the boundary block the value (in cm) of the velocity of its progressive movement along the axis X of the coordinate system. The range of changing is [-100, 100].
Y-velocity	To specify for the boundary block the value (in cm) of the velocity of its progressive movement along the axis Y of the coordinate system. The range of changing is [-100, 100].
U-velocity	To specify for the boundary block the value (in 10^{-6} of a radian) of the angle velocity of its rotation around the coordinate origin. The range of changing is [-100, 100].

By pressing <Esc> it is possible to return to the second menu.

Program EARTH-3 has the following four items in the second menu of verification procedure: F_COEFF, F_LEVEL, BLOCKS, and BOUNDS. Item F_COEFF is destined for specification of the values of all coefficients in the equations (4)-(7). Item F_LEVEL is destined for specification of the values of the dip angle for the fault plane and of the levels B, H_f , H_s. Item BLOCKS is destined for specification of the values of all coefficients in the equations (1)-(3) and of all translation and angle velocities for the underlying medium. Item BOUNDS is destined for specification of the values of all translation and angle velocities for the boundaries. The ranges of changing for all parameters in program EARTH-3 coincide with corresponding ranges in program EARTH.

3. Numerical Parameters

If this item is selected then the new menu appears. It contains three opportunities:

Local Axes Parameters,

Time Parameters,

Space Parameters.

Local axes parameters. This mode is used to input the coordinates of the origin (it is assumed that point (0,0) coincides with the upper left corner of the seismoactive zone selected and the unit is 10 km) and the lengths of the segments along axes OX and OY (they determine the scale of

the graphic picture). The ranges of changing are [-500, 500] for the coordinates of the origin and [0.1, 800] for the lengths of the segments.

Time parameters. This mode is used to input the values of the time interval and the time step Δt for numerical simulation of dynamics of the block structure. The ranges of changing are [0, 9999] for the interval and [0.0001, 1] for the step. Note that the value of the step has to be less then the value of the interval. Otherwise the new values of these parameters will be abrogated.

Space parameters. This mode is used to input the values of the depth H of the layer, the step of space discretization ε (these values are measured in the units of 10 km) and the parameter P in the formula (8) (the value of P is measured in bars). When you change the depth, the structure bottom and space discretization are recalculated, and boundary blocks should be defined. When you change the space step, the space discretization is recalculated. The ranges of changing are [0.5, 30] for the value of the depth, [0.01, 5] for the step and [0, 5000] for the parameter P. Note that the value of the step has to be less then the value of the depth. Otherwise the new values of these parameters will be abrogated.

4. Simulation of Block Dynamics

If this item is selected then the process of numerical simulation (according to 2D or 3D model in programs EARTH and EARTH-3 respectively) of dynamics of the block structure starts. At every time moment the displacements and rotation angles of the blocks are recalculated, the structure state is analyzed, arising failures are processed. The programs image on the screen the moments of earthquakes by vertical lines of the lengths proportional to the magnitudes and the information on the current maximum value of κ (8) in percents of the level B (maximum stress) for the structure including the fault, segment, row and column of the cell where this value is. You may press <ESC> to abort the simulation and to return to the menu of "Dynamics of Block Structure". In this case all information needed is saved in the file indicated for output data and in the file for text information.

5. Viewing of Current Variables

Using this mode you may view

a) the name of the seismoactive zone selected and the geographic coordinates of its upper left corner;

b) the number of vertices, faults, segments, blocks, boundary blocks and boundary segments;

c) the values of the time and space numerical parameters described above;

d) the names of the files specified in "File Operations" (if a file is not specified then expression "UNDEFINED" is imaged).

You may press any key to exit.

II. Calculation of Maximum Stress

If this mode is selected then the programs image on the screen for fault segments the maximum (among the cells of the segment) value of κ (8) in percents of the value of the level B. This operation is carried out for the current time moment (if the simulation has been interrupted) or for some intermediate state saved in the special file.

The information about maximum stress is outputed by two ways: for all segments and for selected segment. You may press <TAB> to switch over these modes. In the first case there are the percents written at the middle of each segment of the block structure on the coordinate plane in the optimal scale. The maximum percents are typed by red color, other values - by black. If the structure consists of too many segments the picture may be rather incomprehensible and it is recommended to apply the second mode. In this mode the fault segments with maximum stress for the whole structure are marked by red color. Using left and right arrows you may select the segment for receiving more detailed information (the selected segment is marked by lightblue color). Information on the selected segment is outputed in the special window and contains the current time moment, the parameters of the fault, which this segment belongs to, the coordinates of the cell with maximum stress for this segment, the percent and the additional remark if the stress reaches maximum for the whole structure. Pressing <ESC> cancels both modes and returns you to the main menu.

III. Image of Earthquake Flow

If this item is selected then the subdirectories and the files with extension *".dpt"* for program EARTH or *".dp3"* for program EARTH-3 (there are standard extensions for files for catalog preparation) from the current directory are screened in the special window. You may choose the file. If the file is not selected the program returns to the main menu. If the selected file corresponds with the current block structure then you have an opportunity to select some segment on the coordinate plane and to output the sequence of failures for it on the screen. Otherwise the error message is imaged.

There are the following functional keys.

Key	Function and Comments
<→>, <←>	To select the segment for viewing. The selected segment is marked by lightblue color.
<ENTER>	To image on the screen the sequence of cell failures for the selected segment. The form of imaged cell depends on its state (normal, creep or earthquake). Segments with failed cells are marked on the picture by red. There is no any information on all other segments. The segment direction from left to right is marked by letters "L" and "R". Press <ESC> to return to the base picture of the mode.
<F1>	To output help information on hot keys.
<F2>	To output on the screen the plot of dependence of the number of earthquakes on the number of cells failed in an earthquake. The plot is presented in the logarithmic scale. Press <ESC> to return to the base picture of the mode.
<F3>	To output on the screen the plot of dependence of the accumulated number of earthquakes on the number of cells failed in an earthquake. The plot is presented in the logarithmic scale. Press <ESC> to return to the base picture of the mode.
<ESC>	To return to the main menu of the programs.

IV. Creation of Catalog

If this item is selected then the new menu appears. It contains four opportunities:

Time Parameters,
Magnitude Parameters,
Creation with Unification,
Creation with Distinguishing.

Time parameters. This mode is used to input the values of the initial year and the number of days per unit of non-dimensional time for determination of "real" time of a earthquake during creation of a catalog. The ranges of changing are [-2000, 2000] for the initial year and [1, 3650] for the number of days.

Magnitude parameters. This mode is used to input the values of the initial magnitude and of the magnitude step for the plots of different dependences screened after creation of a catalog. The ranges of changing are [3, 8] for the initial magnitude and [0.01, 1] for the magnitude step.

Creation with unification. This item defines creation of a catalog with unification of all simultaneously quaked cells of the conjugated segments belonging to the same fault into one earthquake.

Creation with distinguishing. This item defines creation of a catalog with distinguishing all simultaneously quaked cells of the different segments. In this case the number of earthquakes at any time moment is equal to the number of such segments.

If one of the last two items is selected then the subdirectories and the files with extension *".dpt"* for program EARTH or *".dp3"* for program EARTH-3 (there are standard extensions for files for catalog preparation) from the current directory are screened in the special window. You may choose the file. If the file is not selected the programs return to the previous menu. If the selected file does not correspond with the current block structure then the error message is imaged. The current number of records in the catalog and the mode of creation are screened in the process. When the creation of the catalog is completed you may view (by pressing any key) the plots of dependence of the number of earthquakes on the number of quaked cells, the plot of dependence of the accumulated number of earthquakes on the magnitude and the information on the total number of earthquakes, on the minimum and maximum magnitudes, on the maximum number of cells in one earthquake. The plots are presented in the logarithmic scale. Pressing <ESC> returns you to the previous menu.

V. File Operations

If this item is selected then the menu of the following seven items appears:

1. *File for Output Structure*
2. *File with Initial Structure*
3. *File for Output Data*
4. *File with Initial Data*
5. *File for Text Information*
6. *File for Catalog Preparation*
7. *File for Catalog*

You may press <ESC> to return to the main menu. Below there is the detailed description of the items listed above.

1. File for Output Structure

You select this item if you want to save the block structure and all numerical parameters of the process in a text file. The name of this file has to be specified in the special window. The name must be without extension (standard extension for data files *".blk"* for program EARTH (or *".bl3"* for program EARTH-3) will be added automatically). If the name is illegal the corresponding message is imaged. If a file with the name specified already exists the request for overwriting is screened and the data are saved only after the confirmation. Pressing <ESC> means that this file will not be created. Note that data are saved twice. The first operation is performed immediately after specification of the file name, the second one - before exit from the program to save the last version. Successful execution of verification procedure is required preliminary for saving in both cases.

2. File with Initial Structure

The subdirectories and the files with extension *".blk"* for program EARTH (or *".bl3"* for program EARTH-3) from the current directory are screened in the special window. You may choose the file. Program EARTH (EARTH-3) loads the block structure from the selected file. You may edit it or run the simulation process.

3. File for Output Data

You select this item if you want to save the conditions and parameters of the final or any intermediate state of the process in a file of the special structure. The name of this file has to be specified in the special window. The name must be without extension (standard extension for such files *".ddt"* for program EARTH (or *".dd3"* for program EARTH-3) will be added automatically). If the name is illegal the corresponding message is imaged. If a file with the name specified already exists the request for overwriting is screened and the data are saved only after the confirmation. Pressing <ESC> means that this file will not be created. It should be noted that file for output data includes also the information on the block structure geometry and all numerical parameters of the process for data consistency.

4. File with Initial Data

The subdirectories and the files with extension *".ddt"* for program EARTH (or *".dd3"* for program EARTH-3) from the current directory are screened in the special window. You may choose the data file. Program EARTH (or EARTH-3) loads the block structure from the selected file. You may continue the simulation process for this structure from the state recorded in the selected file. The time parameters (the interval and the step) have to be specified. If file with initial data is specified then the

specifications made before for file with initial structure and file for output structure are cancelled. The same takes place if you choose mode "Simulation of Block Dynamics" with file with initial data specified. If this file is not selected then calculations will be performed with zero initial conditions.

5. File for Text Information

You select this item if you want to create text file with the structure parameters and calculation results. This file may be created in all main modes of the programs. The name of the file has to be specified in the special window. The name must be without extension (standard extension for these files *".pri"* for program EARTH (or *".pr3"* for program EARTH-3) will be added automatically). If the name is illegal the corresponding message is imaged. If a file with the name specified already exists the request for overwriting is screened and the data are saved only after the confirmation. Pressing <ESC> means that this file will not be created.

6. File for Catalog Preparation

You select this item if you want to create file which can be used for earthquake catalog preparation. The name of this file has to be specified in the special window. The name must be without extension (standard extension for files for catalog preparation *".dpt"* for program EARTH (or *".dp3"* for program EARTH-3) will be added automatically). If the name is illegal the corresponding message is imaged. If a file with the name specified already exists (or it is the default file *"tmp.dpt"* (or *"tmp.dp3"*)) the request for overwriting is screened and the file is created only after the confirmation. If overwriting is not allowed then new information will be added at the end of the file. Remember that by this reason file for catalog preparation may include data written during previous executions of the program in mode "Simulation of Block Dynamics". Pressing <ENTER> confirms your choice, <ESC> means that the default file will be used.

7. File for Catalog

You select this item if you want to create the binary file in 20 bytes format described above with the earthquake catalog. The name of the file has to be specified in the special window. The name must be without extension (standard extension for catalog files *".dat"* for programs EARTH and EARTH-3 will be added automatically). If the name is illegal the corresponding message is imaged. If a file with the name specified already exists (or it is the default file *"tmp.dat"*) the request for overwriting is screened and the file is created only after the confirmation. If overwriting is not allowed then new information will be added at the end of the file.

Remember that by this reason catalog file may include data written during previous executions of the program in mode "Creation of Catalog". Pressing <ENTER> confirms your choice, <ESC> means that the default file will be used.

It should be noted that all the files listed above for programs EARTH and EARTH-3 are incompatible with exception of standard catalog files.

Program LINEAM

This small program allows to input the lineaments for a rectangle zone selected in a region for which a scheme of morthostructural lineaments is available and to save the data in a file. Inputing of lineaments' vertices (their local coordinates x and y) is realized by means of the simplest dialog. You type and enter word "end" to complete the inputing of a lineament or word "exit" to complete the inputing of a scheme. The maximum number of lineaments is equal to 20, the maximum number of vertices in a lineament is equal to 10. When the inputing procedure has completed the program asks for the confirmation to save the scheme in the file. It should be noted that a scheme for zone number *i* will be saved in the file named *"i.lnm"*.

Programs DISTR and DISTR-3

These programs allow to image on the screen time distribution of earthquakes from some file for catalog preparation. As in mode "Simulation of Block Dynamics" of program EARTH (EARTH-3) the moments of earthquakes are pictured by vertical lines of the lengths proportional to the magnitudes. Programs DISTR and DISTR-3 are the simple tools for visualization of the data saved in *".dpt"* (or *".dp3"*) files. The main menu of the programs contain five items:

File with Block Structure,
View of Block Structure,
Numerical Parameters,
DP_-reading & Visualization,
Exit.

File with block structure. The subdirectories and the files with extension *".blk"* for program DISTR (or *".bl3"* for program DISTR-3) from the current directory are screened in the special window. You may choose the file. Program DISTR (DISTR-3) loads the block structure from the selected file.

View of block structure. This mode is used to look over the current block structure in the graphic mode on the coordinate plane.

Numerical parameters. This mode is used to input the values of the initial non-dimensional time and the time interval for data visualization.

DP_-reading & visualization. If this item is selected then the subdirectories and the files with extension *".dpt"* for program DISTR (or *".dp3"* for program DISTR-3) from the current directory are screened in the special window. You may choose the file. If the file is not selected the programs return to the main menu. If the selected file does not correspond with the current block structure then the error message is imaged. Otherwise the programs image on the screen the moments of earthquakes red from the selected file for catalog preparation.

Exit. This item needs no clarification.