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Computer Exercises

User's Guide for Programs EARTH and EARTH-3

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These are preliminary lecture notes, intended only for distribution to participants

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EARTH and EARTH-3**

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Programs EARTH and EARTH-3: destination and possibilities

Programs EARTH and EARTH-3 are destined for the numerical simulation of block structure dynamics and seismicity with two-dimensional and three-dimensional movements of blocks, respectively. A block structure is a part of lithosphere's layer between two horizontal planes consisting of absolutely rigid blocks. The blocks are separated by infinitely thin plane faults and interact between themselves along the faults 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 exceeds a certain level during simulation then a stress-drop ("a failure") occurs. The failures are considered as earthquakes. A synthetic earthquake catalog is produced as a result of the numerical simulation.

The input data for simulation are the following: a block structure geometry, values of parameters that define features of interaction between elements of the structure, equations describing movements of the underlying medium and the boundaries. The output data are different visual representations of sequences of model earthquakes.

Both programs are based on the same ideas and principles. They have the same structure, 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 programs are DOS applications, the programming language is Borland Pascal 7.0. IBM PC compatible with EGA/VGA monitor and not less than 8M (12M) of free memory are required for the successful work of program EARTH (EARTH-3). The following files should be placed in the same directory:

- earth.exe* – program EARTH;
- earth-3.exe* – program EARTH-3;
- rtm.exe*, *dpml6bi.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 the emphasis on additional possibilities of program EARTH-3 (3D block model) which are marked by special notes.

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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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 system of faults. 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) is a vertex which is an end point of a fault and at the same time an initial point of another one;

E (end vertex) is 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) is 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 Fig. 1.

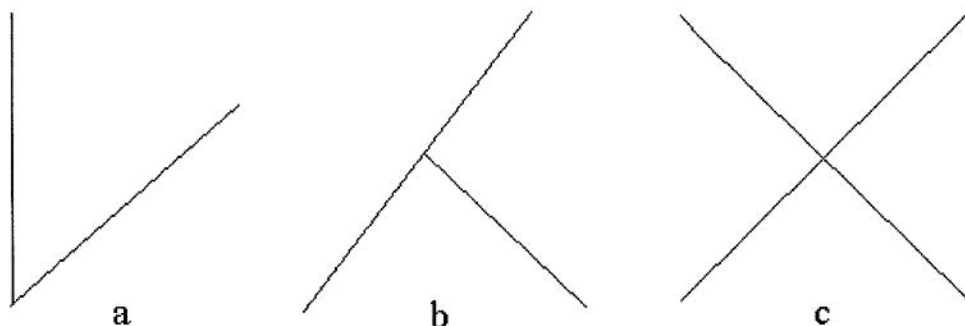


Fig. 1. Types of vertices: a – corner (C); b – end (E); c – intersection (I)

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 that connect positions on the upper and lower planes of two consecutive vertices of the fault. It is a trapezium.

The example of the block structure on the upper plane is presented in Fig. 2.

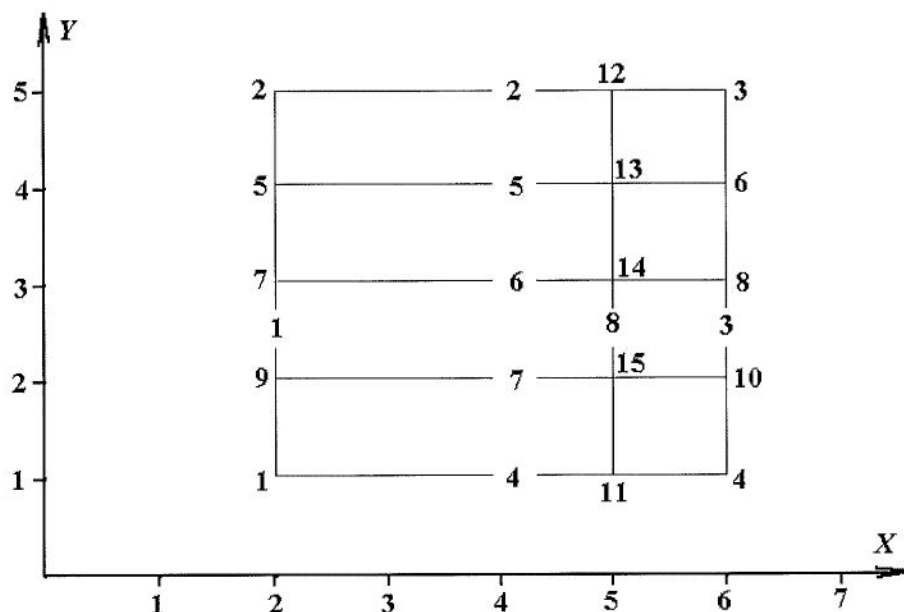


Fig. 2. The vertices and the faults on the upper plane

This structure has 4 corner vertices with coordinates (2,1), (2,5), (6,5), (6,1); 8 end vertices with coordinates (2,2), (2,3), (2,4), (5,1), (5,5), (6,2), (6,3), (6,4); 3 intersections with 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 positions shown in Fig. 3.

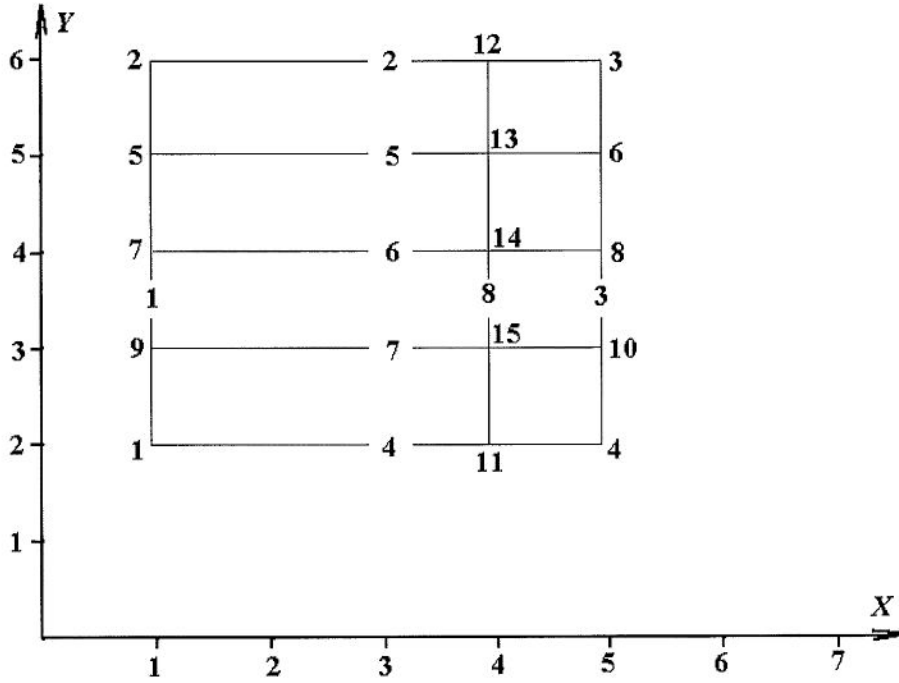


Fig. 3. The vertices and the faults on the lower plane

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

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

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

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

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

that 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

$$\mathbf{f}_u^n = K_u^n \Delta z, \quad (3)$$

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 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

$$\frac{d\Delta w}{dt} = W\mathbf{f}, \quad (4)$$

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

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

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 that characterize interaction between the blocks in the fault plane. In 3D model, the additional inelastic displacement δ_n and elastic force f_n that are normal to the fault plane are introduced. The equation describing the evolution of δ_n is the following:

$$\frac{d\delta_n}{dt} = W^n f_n. \quad (6)$$

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

$$f_n = K^n (\Delta_n - \delta_n), \quad (7)$$

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 coefficients may be different for different faults.

Another group of fault parameters define a failure rise. Denote

$$\kappa = \frac{|\mathbf{f}|}{P - p_0}, \quad (8)$$

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 that 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 , a 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 occurred are in the 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). The creep continues while the value of κ is higher than the level H_s ($H_s < H_f$). When $\kappa \leq H_s$ the cell returns to the normal state and henceforth the parameter W (and W^n) is used in equation (4) (and (6)) for this cell. Values of 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.

In both models the system of equations that describes the movement of some block structure is a linear one and has the following form

$$A\mathbf{z} = \mathbf{b}, \quad (9)$$

where the components of the unknown vector $\mathbf{z} = (z_1, z_2, \dots, z_k)$ are the components of the translation vectors of the blocks and the angles of their

rotation around the geometrical centers of the bottoms ($k = 3n$ and $k = 6n$ for 2D model and 3D model, respectively; n is the number of blocks). It should be noted that the matrix A does not depend on time and may be calculated a priori.

DISCRETIZATION

Time discretization is defined by a time step Δt and the states of the structure are calculated for the discrete time moments $t_i = t_0 + i\Delta t$ ($i = 1, 2, \dots$), 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. It 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 . The 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 space discretization cells are considered instead of points. A failure occurs for a whole cell.

The parameters of the earthquake are defined by the following way: the origin time is t_i (failure occurrence time); the epicentral coordinates and the source depth are the weighted sums of the coordinates and depths of the failed 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 the formula

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

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

MODES OF WORK

Both programs EARTH and EARTH-3 have the following main modes of work.

I. Dynamics of block structure. This is the base mode. 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 process interruption) state will be written can be indicated. Besides, it is possible to create a file for catalog preparation. Below the description of operations with files is presented in detail.

II. Calculation of maximum stress. If this mode is selected then the programs calculate the maximum (for segment cells) value of κ (8) in percents of the value of level B . This operation is carried out for the current time moment or for some intermediate state saved in a disk file of the special structure. The information about the maximum value of the stress is screened for all segments or for a 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 file with the information for earthquake catalog preparation. The catalog may be produced by two ways: with unification of all segments of the same fault, and with distinguishing of such segments. After creating the catalog, 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 screened.

In all modes it is possible to save the information on the process parameters and calculation results in a text file of the special structure.

CATALOG

Programs EARTH and EARTH-3 create an earthquake catalog stored as a binary file in the standard "20 bytes format". The specification of the records in a file of catalog is the following. The first record consists of 20 bytes; at that 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 have the following structure:

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)	

In addition, the following information has to be specified: 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) to be assigned to the unit of time used in the equations describing dynamics of the block structure. The magnitude is calculated by formula (10).

DIALOG

The programs use the window interface represented in the form of hierarchical menus allowing us to specify different parameters and to choose different options. The first (main) menu replacing 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 the 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 seismoactive regions as rectangle zones on the model map of the world (see Fig. 4). The aim of this specification is in using some real parameters connected with the region in the simulation process (the scheme of lineaments, real geographical coordinates, different coefficients and velocities and so on). These parameters may be stored in special database files. If some region is chosen, the data from corresponding file are used. For example, the scheme of lineaments may be useful during specification of the block structure elements. It is stored in the file, 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 latitude and longitude for the coordinate origin.

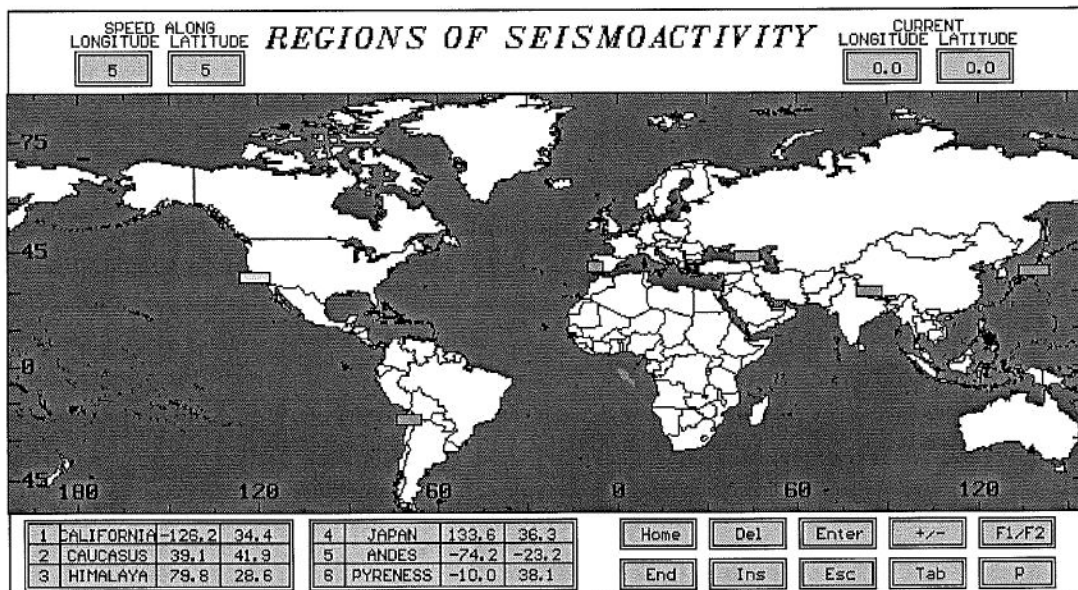


Fig. 4. The regions of seismoactivity by default

The picture contains the following help information:

- a) the speed of cursor moving (in pixels) along the latitude and longitude directions (at the upper left corner of the screen);
- b) the real geographic coordinates (the latitude and longitude) of the cursor (at the upper right corner of the screen);
- c) the number of specified zones, their names and coordinates of their upper left corners (at the lower left corner of the screen);
- d) the programmed keys (at 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, a zone area is limited by 1000 "squared degrees", zones can not be intersected by each other.

There are the following functional keys.

Key	Function and Comments
<→>, <←>, <↓>, <↑>	To find a 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 specification of zones. 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 that 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 informative name is specified (the name by default is "region" plus ordering number of the zone). The coordinates and name are placed into the special table on the screen.
	To fulfil some deleting operations. If is pressed

	under the mode "Draw zone" it switches off this mode and cancels the current specification. 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 the standard (default) configuration. You may do it by pressing this key if your picture is empty. The 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 a zone name without any other changes. The cursor must indicate to the desired zone.
<TAB>	To switch an active zone. We call an active one the zone lineaments of which may be taken for specification 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 latitude and 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 which 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 vertices are defined directly on the coordinate plane with real geographical coordinates. The dip angles and other numerical parameters are defined in the special menu system.

There are the following restrictions on the geometric parameters of a block structure (the maximum values are listed):

	2D model, EARTH	3D model, EARTH-3
Vertices	100	90
Faults	75	50
Segments	150	120

Blocks	30	30
Boundary blocks	20	20
Cells per a segment row	250	450
Rows per a segment	40	50
Cells per a bottom trapezium	1100	1500
Trapeziums per a block bottom	7	8

When specification of the block structure geometry is finished, the verification procedure is performed. It should be noted that the block structure is inadmissible in the following cases:

- there is an intersection of more than two faults at one vertex;
- there is a vertex belonging to only one fault or not belonging to any fault;
- there is a multiply connected block structure;
- there is a segment which does not occur in any block;
- there is a segment which has intersection of its sides.

If the structure is recognized as an admissible one (otherwise the procedure marks the illegal part of the structure), its blocks and segments are determined automatically. After this action the boundary blocks, dip angles, and other numerical parameters of faults, blocks, and boundary blocks are defined in the special menu system. Thus, the process of passing from geometric parameters of a real seismic region to its program approximation is rather difficult. The example of model structure is presented in Fig. 5.

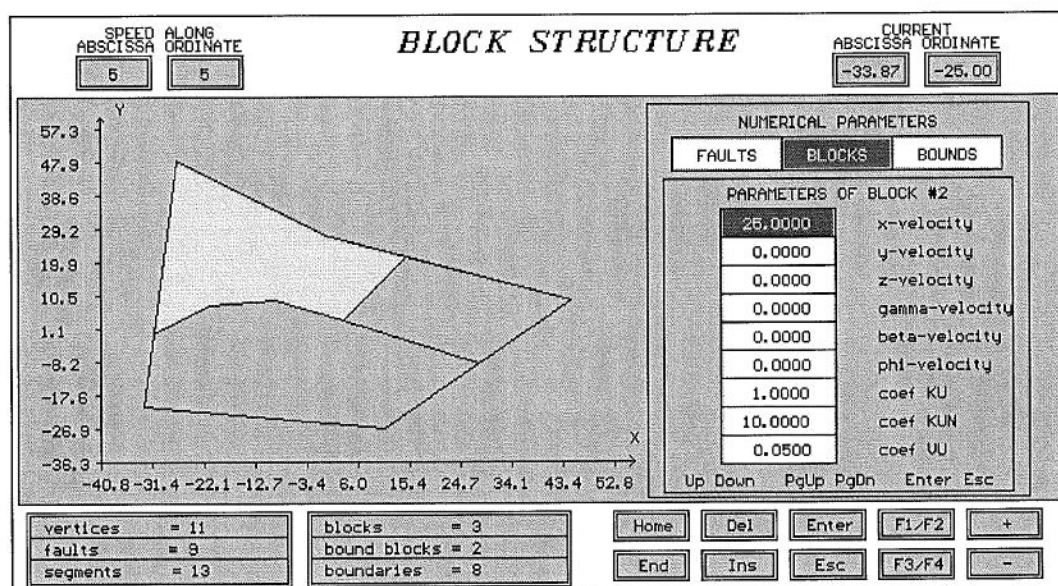


Fig. 5. The program approximation of the real seismic region

The picture contains the following help information:

a) the speed of cursor moving (in pixels, at the upper left corner of the screen);

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

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

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

There are the following functional keys.

Key	Function and Comments
<→>, <←>, <↓>, <↑>	To find a 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 specification of a structure. You may fix a corner vertex (define its coordinates in the units of 10 km) by pressing <ENTER> at a screen point without inputted vertex (mode "Draw vertex", the blue cursor). If you press <ENTER> at a screen point with existing vertex the program switches on another mode ("Draw fault", the red cursor). This vertex is assumed to be the initial point of a fault. Next pressing <ENTER> allows to fix the end point of the fault and, consequently, the fault itself. A vertex may be placed on the existing fault (it is the end vertex), 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.
	To fulfil some deleting operations. If is pressed under mode "Draw fault" it switches off this mode. If you use this key under 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 a screen point without any 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 the standard (default) structure. You may do it by pressing this key if your picture is empty. The standard structure consists of 15 vertices, 8 faults, 22 segments, 8 blocks and 2 boundary blocks (see Fig. 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 geometry specification.
<F4>	To perform verification procedure, to input boundary blocks and numerical parameters of the structure. The description of this possibility 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 screened and the illegal part of the structure is marked by lightblue color. Otherwise the block structure is imaged 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 us to specify boundary blocks for the structure. There are three opportunities to do it.

1. WHOLE – this choice defines the only boundary block consisting of all boundary segments.

2. SINGLE – this choice defines each boundary segment as a separate 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.

3. USER – this choice remains definition of boundary blocks to the user. You can do it 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 definition of a next one by analogy. Press <ESC> to pass to specification of numerical parameters if the configuration of boundary blocks is acceptable.

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

1. 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 fault parameters contains the following windows.

Dip angle	To specify the value (in degrees) of a dip angle 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 parameter K in (5). The range of changing is [0, 100].
Coef WF	To specify for the fault the value (in cm/bars) of parameter W in (4). The range of changing is [0, 500].

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

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

2. 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 block parameters contains the following windows.

Coef KU	To specify for the block bottom the value (in bars/cm) of parameter K_u in (2). The range of changing is $[0, 100]$.
Coef WU	To specify for the block bottom the value (in cm/bars) of parameter W_u in (1). The range of changing is $[0, 500]$.
X-velocity	To specify for the block the value (in cm) of the velocity of 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 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.

3. 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 boundary block parameters 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 (4)–(7). Item F_LEVEL is destined for specification of the values of a dip angle for the fault plane and of levels B , H_f , H_s . Item BLOCKS is destined for specification of the values of all coefficients in (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 equal to 10 km) and the lengths of segments along axes OX and OY (they determine the scale of graphic picture). The ranges of changing are $[-500, 500]$ for the coordinates of the origin and $[0.1, 800]$ for the lengths of segments.

Time parameters. This mode is used to input the values of time interval and time step Δt for the 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 step has to be less than the value of interval. Otherwise new values of these parameters will be abrogated.

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

4. Simulation of Block Dynamics

This mode gives an opportunity to visualize results of the numerical simulation of dynamics of the block structure (according to 2D or 3D model in programs EARTH and EARTH-3, respectively). At every time moment the displacements and rotation angles of the blocks are recalculated, the state of the structure 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 level B (maximum stress) for the structure including the fault, segment, row and column of the cell where this value is reached, see Fig. 6. So, you can see the distribution of events in time and can compare a model earthquake flow with a real one. It should be noted that dimensionless time is used in the model, so it is necessary to set the correspondence between the model and real time units, for example, by using the seismic cycle or recurrence of strong events.

You may press <ESC> to abort the simulation and to return to the menu of "Dynamics of Block Structure". In this case all necessary information is saved in a file specified for output data and in a file for text information.

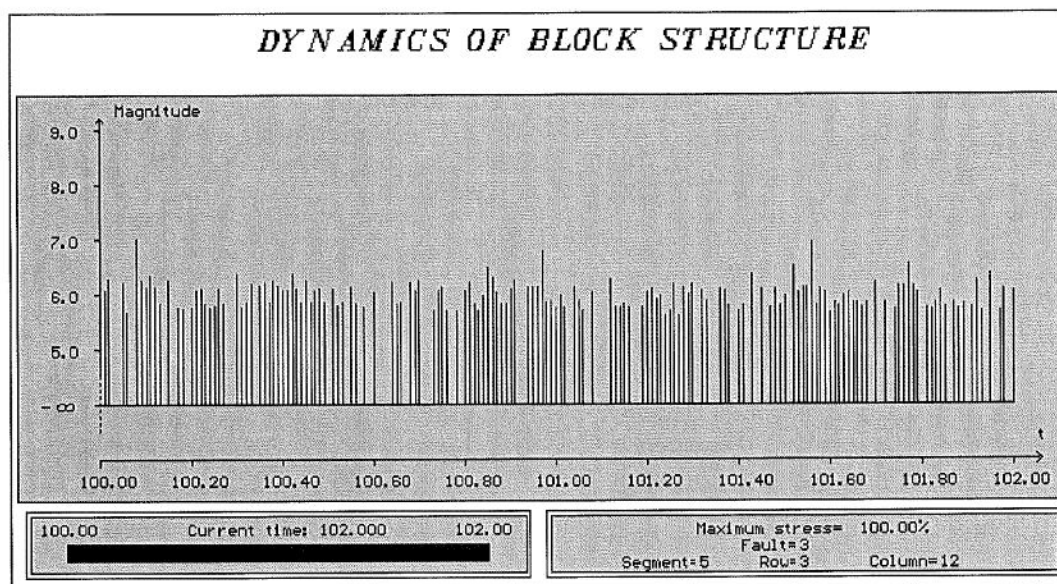


Fig. 6. Dependence of model magnitude on time for structure from Fig. 5

5. Viewing of Current Variables

Using this mode you may view the following information:

- a) the name of 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 time and space numerical parameters;
- d) the names of files specified in "File Operations".

If a parameter is not specified then the 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 the maximum (for segment cells) value of κ (8) in percents of the value of 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 a disk file of the special structure.

The information on the maximum stress is outputted by two ways: for all segments and for a 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 color. 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 the 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 outputted 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 the maximum stress for this segment, the percent and the additional remark if the stress reaches the maximum for the whole structure, see Fig. 7.

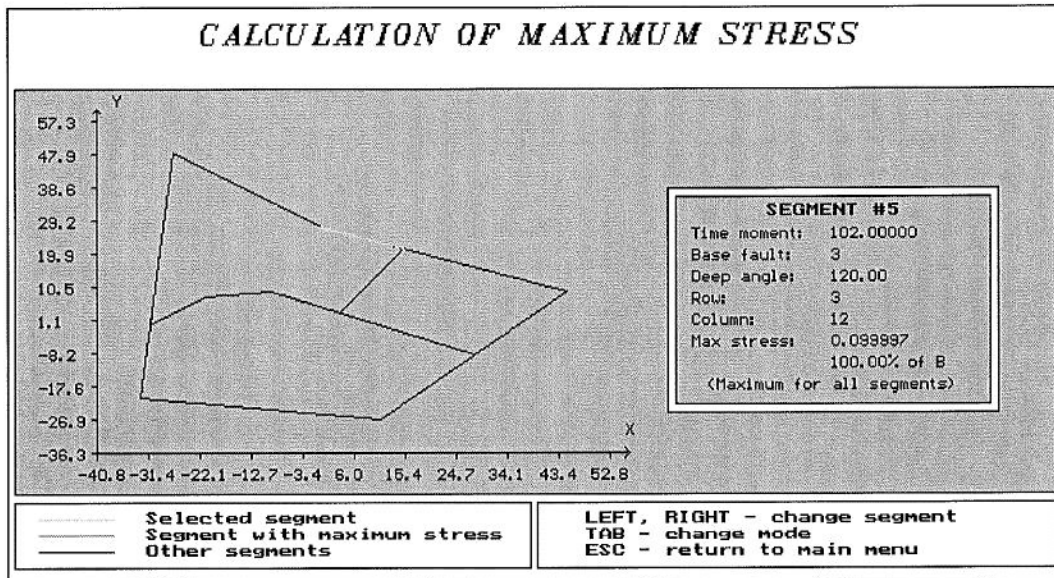


Fig. 7. Maximum stress for structure from Fig. 5

This mode helps to find the most active boundaries of the structure and to observe how the stress spreads through the structure. Pressing <ESC> cancels both informational 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 a file. If no file is selected the programs return to the main menu. If the selected file corresponds to 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, see Fig. 8. Otherwise the error message is imaged. It should be noted that the distribution of cell failures in time is the important information for studying the phenomenon

of migration of earthquakes along the faults and for investigating mechanisms of arising and spreading earthquakes.

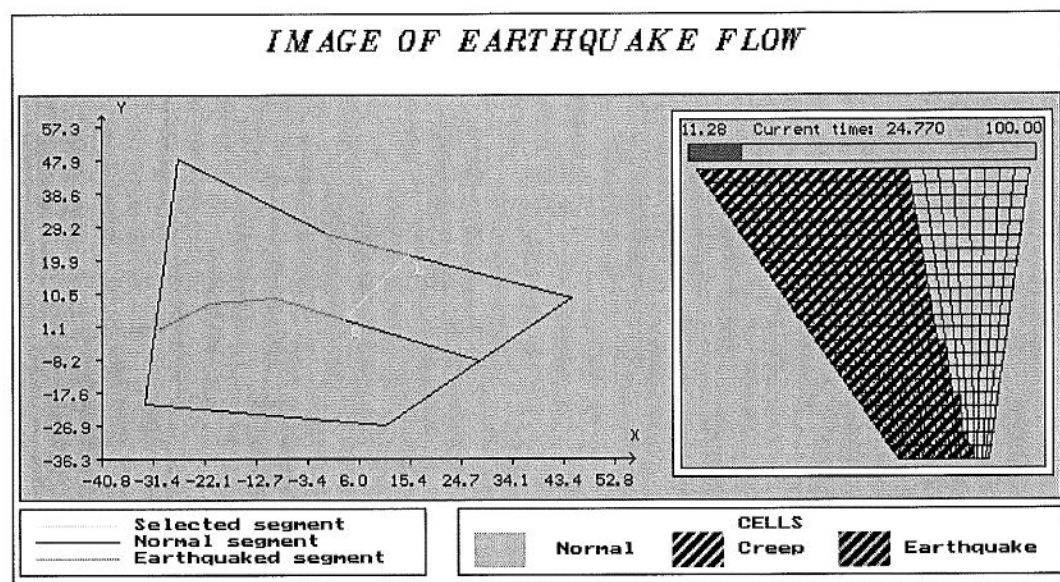


Fig. 8. Image of earthquake flow for structure from Fig. 5

There are the following functional keys.

Key	Function and Comments
<→>, <←>	To select a 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 involved 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 involved 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

This mode gives an opportunity to create an earthquake catalog in the standard "20 bytes format". 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 one unit of dimensionless time for determination of "real" time of an 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 different plots 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 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 a file. If no file is selected the programs return to the previous menu. If the selected file does not correspond to 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 plot 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, see Fig. 9.

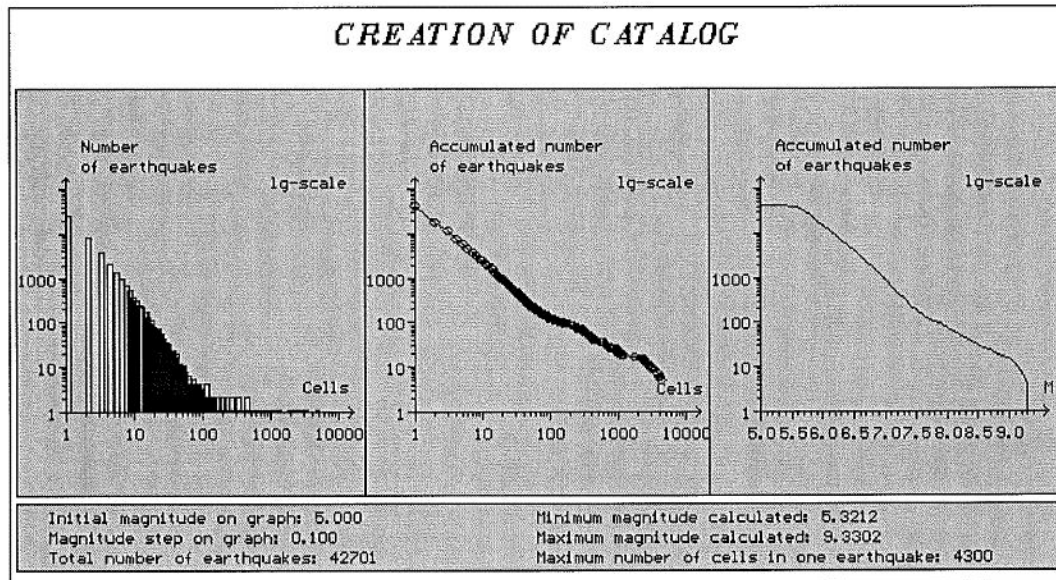


Fig. 9. Plots of dependencies for structure from Fig. 5

Pressing <ESC> returns you to the previous menu.

V. File Operations

All data may be saved in and may be loaded from disk files of the special structure at every time moment during the simulation process. 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 then 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 before 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 a 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 then 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 a 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 (interval and step) should be specified. If a file with initial data is specified then the specifications made before for a file with initial structure and a file for output structure are cancelled. The same actions are performed if you

choose mode "Simulation of Block Dynamics" with a 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 a 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 then 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 a 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")) then the request for overwriting is screened and the file is created only after the confirmation. If overwriting is prohibited then the new information will be added at the end of the file. Remember that by this reason a 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 a binary file (in the standard 20 bytes format) with an 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") then the request for overwriting is screened and the file is created only after the confirmation. If overwriting is prohibited then the new information will be added at the end of the file. Remember that by this reason a file for

catalog 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 files listed above for programs EARTH and EARTH-3 are incompatible with exception of standard catalog files.

Program LINEAM

This small program allows us to specify lineaments for a rectangle zone selected in a region for which a scheme of lineaments is available and to save data in a file. Specification 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 specification of a lineament or word "exit" to complete specification 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 specification procedure has completed the program asks for the confirmation to save the scheme in a file. It should be noted that a scheme for the zone numbered by i will be saved in the file named "*i.lnm*".

Programs DISTR and DISTR-3

These programs allow us to image on the screen the time distribution of earthquakes from a 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 visualizing data saved in ".dpt" (or ".dp3") files. The main menu contains 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 a 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 initial dimensionless time and 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 a file. If no file is selected the programs return to the main menu. If the selected file does not correspond to the current block structure then the error message is imaged. Otherwise the programs image on the screen the moments of earthquakes loaded from the selected file for catalog preparation.

Exit. This item needs no clarification.