

**Advanced School on Non-Linear Dynamics
and Earthquake Prediction**

28 September – 10 October 2009

**Exercises on
Numerical Simulation of Block Structure Dynamics
(2D Model)**

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2009

WRITTEN EXERCISES

I. BLOCK STRUCTURE GEOMETRY

A layer with a 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". Lines of intersection of faults with the upper plane are also called "faults".

Three or more faults cannot have a common point on the upper plane. A common point of two faults is called "vertex". 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 each of them.

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

For the structure, "boundary blocks" are defined. A boundary block is a continuous part of the structure boundary between two vertices. It is defined by 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 by lines connecting positions on the upper and lower planes of two consecutive vertices of the fault.

EXERCISE 1: An example of fault lines on the Earth surface is presented in Figure 1.

Indicate corner vertices, end vertices, and intersections for the structure in Figure 1.

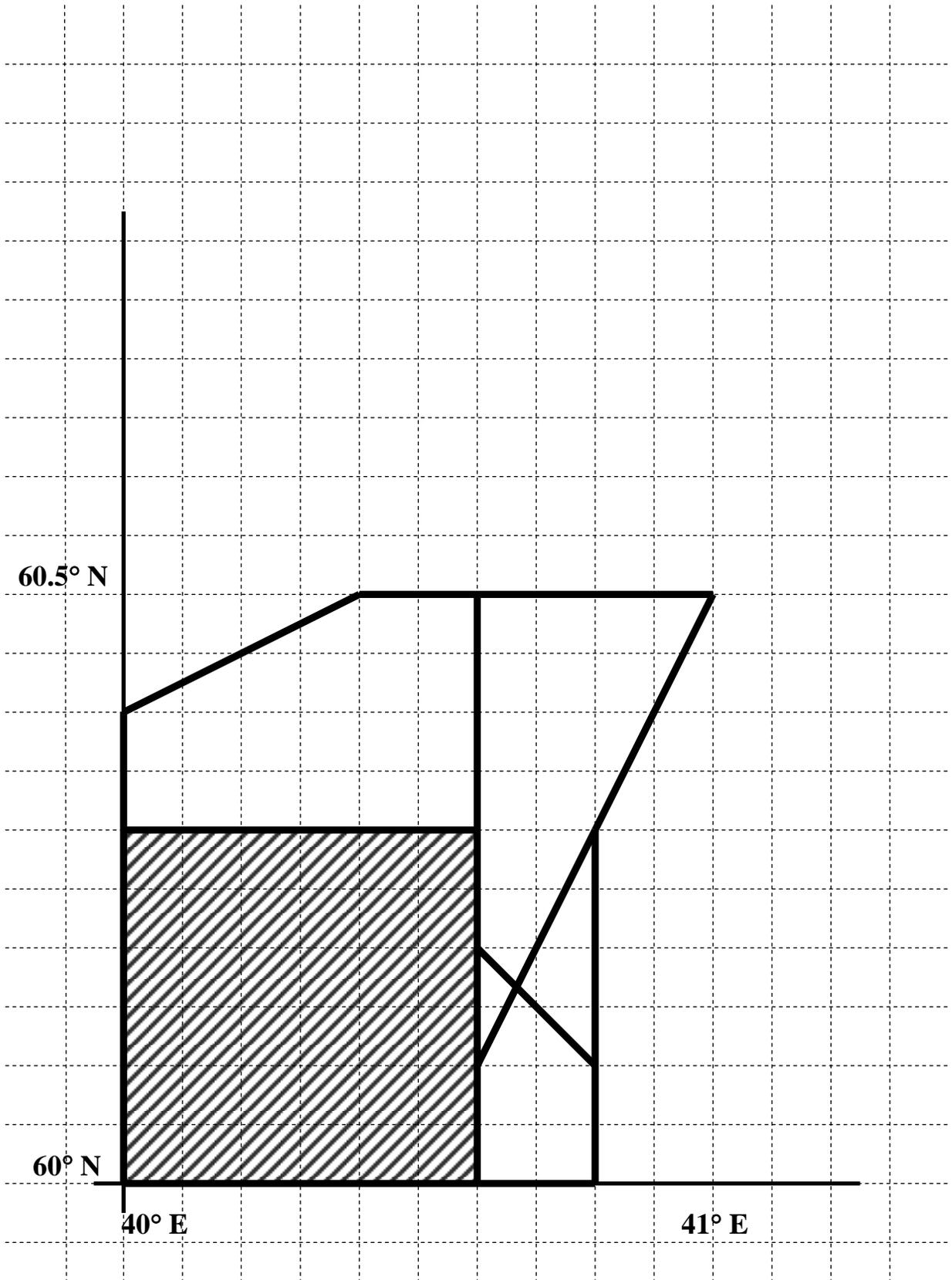


FIGURE 1

EXERCISE 2: Find co-ordinates of the corner vertices in Figure 1. Use the point with the geographic co-ordinates 60°N and 40°E as the co-ordinate origin, the east-directed parallel as the axis X , and the north-directed meridian as the axis Y . Let us remind you that 1° of the Earth meridian is equal to $40000\text{km}/360 \approx 111\text{km}$ by definition. Use as the length of 1° of the Earth parallel its length for the 60° parallel. Present the co-ordinates obtained in the units of 10 km.

EXERCISE 3: List the faults for the structure in Figure 1. Indicate for each fault the vertices belonging to it. Indicate also for end vertices and intersections another fault to which these vertices belong too.

EXERCISE 4: Find the co-ordinates and relative positions of the end vertices in the faults (the relative position is the ratio of the distance between an initial point of a fault and a vertex to the fault length) for which these vertices are not initial (or end) points.

EXERCISE 5: List the blocks for the structure in Figure 1. Indicate for each block its vertices.

EXERCISE 6: List the boundary blocks for the structure in Figure 1 by following the condition that there is one-to-one correspondence between the boundary blocks and inner blocks being contiguous with the boundaries. Let boundary block 1 be contiguous with inner block 1, and let the boundary blocks be listed in the anticlockwise direction.

EXERCISE 7: List the fault segments for the structure in Figure 1. Indicate for each fault segment the fault to which it belongs, the vertices bounding it, and the blocks being contiguous with it.

II. MOVEMENT OF BOUNDARY BLOCKS AND UNDERLYING MEDIUM

A boundary block is supposed to move progressively in the horizontal plane with a constant velocity and to rotate around the co-ordinate origin with a constant angle velocity. Values of the velocity components V_x , V_y , and the angle velocity U can be different for different boundary blocks.

The medium underlying a block is supposed to move progressively in the horizontal plane with a constant velocity and to rotate around the geometrical center of the block bottom with a constant angle velocity. Values of the velocity components V_x , V_y , and the angle velocity U can be different for different blocks.

The displacements being due to these movements are supposed to be infinitely small relative to the geometrical sizes of the blocks and are defined by the formulas

$$x = V_x t - YUt, \quad y = V_y t + XU t$$

for boundary blocks or by the formulas

$$x = V_x t - (Y - Y_c)Ut, \quad y = V_y t + (X - X_c)Ut$$

for the underlying medium. Here X and Y are the co-ordinates of the point, x and y are its displacements with respect to its position at the moment $t = 0$, X_c and Y_c are the co-ordinates of the geometrical center of the block bottom.

EXERCISE 8: The point of the boundary block with the co-ordinates (in the units of 10 km): $X = 10$, $Y = 1$ had the displacement (in cm): $x = -1$, $y = 0.5$ during one unit of the time. The point with the co-ordinates: $X = 15$, $Y = 2$ of the same boundary block had during the same time the displacement with the ratio of the components $y/x = -1$. Find for this boundary block the values of V_x , V_y , (in cm), and U (in 10^{-6} of a radian) which correspond to these displacements.

EXERCISE 9: During one unit of time the medium underlying the block shaded in Figure 1 had the following displacements: $x = 0.2$, $y = 0.5$ for the point with the co-ordinates $X = 2$, $Y = 1$ and $x = -0.2$ for the point with the co-ordinates $X = 3$, $Y = 3$. Let the angles of dip for all fault planes bounding the block be equal (the angles are measured on the block side). Find for the medium underlying the block the values of V_x , V_y , and U which correspond to these displacements.

III. SPACE DISCRETIZATION

Space discretization is defined by the parameter ε . Discretization is made for the surfaces of the fault segments and the block bottoms.

Discretization of a fault segment is performed as follows. Note that any fault segment is a trapezium. Let a and b be the bases of the trapezium. The trapezium height h is given by the formula $h = H/\sin\alpha$, where H is the depth of the layer, α is the dip angle of the fault plane. Let $n_1 = \text{ENTIRE}(h/\varepsilon) + 1$, $n_2 = \text{ENTIRE}(\max(a,b)/\varepsilon) + 1$. The trapezium is divided into n_1n_2 small trapeziums by two groups of lines inside it: n_1-1 lines parallel to the trapezium bases with the distance between them equals to h/n_1 and n_2-1 lines connecting the points spaced at intervals placed of a/n_2 and b/n_2 respectively on the bases. The small trapeziums obtained will be called cells. The co-ordinates X, Y of the center of the mean line of the cell are assigned to all its points. The block bottom is a polygon. Before discretization it is divided into trapeziums (triangles) by lines passing through its vertices and parallel to the Y axis. The discretization of these trapeziums (triangles) is performed in the same way as in the case of fault segments. The small trapeziums (triangles) are also called cells. For all points of the cell the co-ordinates X, Y are supposed to be the same.

EXERCISE 10: Two blocks are shown in Figure 2. The block bottoms are contoured dashed lines.

Let $\varepsilon = 5$ km. Make space discretization of the fault segment which is common for the both blocks in Figure 2 (the dip angle of the fault segment plane is equal to 60°). How many cells are obtained?

EXERCISE 11: Make discretization of the bottoms of the both blocks in Figure 2 with $\varepsilon = 5$ km. How many cells are obtained for each of them?

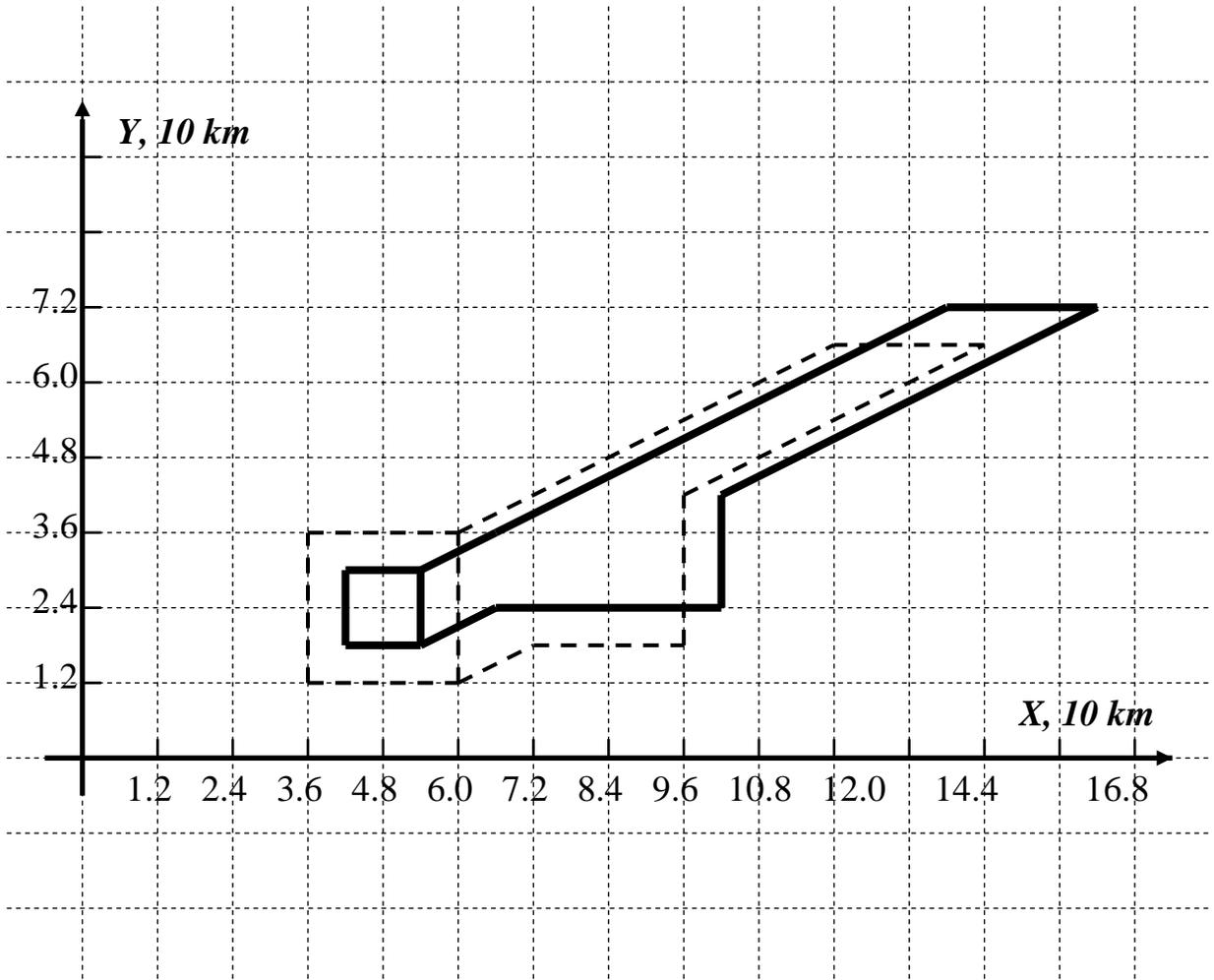


FIGURE 2

IV. ELASTIC FORCES

The elastic force which is due to the relative displacement of the block and the underlying medium at some point of the block bottom is supposed to be proportional to the difference between the total relative displacement vector and the vector of slippage (inelastic displacement) at this point.

The elastic force per unit area $\mathbf{f}^u = (f_x^u, f_y^u)$ at the point with co-ordinates X, Y at some moment t is defined by the formulas

$$f_x^u = K_u(x - x_u - (Y - Y_c)(\varphi - \varphi_u) - x_a), \quad (1)$$

$$f_y^u = K_u(y - y_u + (X - X_c)(\varphi - \varphi_u) - y_a).$$

Here X_c, Y_c are co-ordinates of the geometrical center of the block bottom; (x_u, y_u) and φ_u are the shear vector and the angle of rotation (around the geometrical center of the block bottom) of the underlying medium at the moment t ; (x, y) and φ are the translation vector of the block and the angle of its rotation around the geometrical center of the bottom at the moment t ; (x_a, y_a) is the inelastic displacement vector at the point at the moment t . The evolution of inelastic displacements at the point is described by the equations

$$\frac{dx_a}{dt} = W_u f_x^u, \quad \frac{dy_a}{dt} = W_u f_y^u. \quad (2)$$

The values of the coefficients K_u and W_u in formulas (1) and equations (2) can be different for different blocks.

At the moment t at some point of the fault plane separating the blocks numbered i and j (the block numbered i is on the left and the block numbered j is on the right of the fault) the components $\Delta x, \Delta y$ of the relative displacement of the blocks are defined by the formulas

$$\Delta x = x_i - x_j - (Y - Y_c^i)\varphi_i + (Y - Y_c^j)\varphi_j, \quad (3)$$

$$\Delta y = y_i - y_j + (X - X_c^i)\varphi_i + (X - X_c^j)\varphi_j.$$

Here $X_c^i, Y_c^i, X_c^j, Y_c^j$ are the co-ordinates of the geometrical centers of the block bottoms; $(x_i, y_i), (x_j, y_j)$ are the translation vectors of the blocks at

the moment t ; φ_i, φ_j are the angles of the block rotations around the geometrical centers of their bottoms at the moment t .

Accordingly to the assumption that in 2D model the relative displacements of blocks take place only along fault planes, the displacements along the fault plane are connected with the horizontal relative displacement by the formulas

$$\Delta_t = e_x \Delta x + e_y \Delta y, \quad \Delta_l = \frac{e_x \Delta y - e_y \Delta x}{\cos \alpha}. \quad (4)$$

Here Δ_t, Δ_l are the displacements along the fault plane parallel (Δ_t) and normal (Δ_l) to the fault line on the upper plane; (e_x, e_y) is the unit vector having direction of the fault line on the upper plane; α is the dip angle of the fault plane.

The elastic force per unit area $\mathbf{f} = (f_t, f_l)$ along the fault plane is defined by the formulas

$$f_t = K_f (\Delta_t - \delta_t), \quad f_l = K_f (\Delta_l - \delta_l). \quad (5)$$

Here δ_t, δ_l are the inelastic displacements at the point at the moment t along the fault plane parallel (δ_t) and normal (δ_l) to the fault line on the upper plane.

The evolution of the inelastic displacements at the point is described by the equations

$$\frac{d\delta_t}{dt} = W_f f_t, \quad \frac{d\delta_l}{dt} = W_f f_l. \quad (6)$$

The values of the coefficients K_f and W_f in formulas (5) and equations (6) can be different for different faults.

The reaction force per unit area which is normal to the fault plane is equal to

$$p_0 = f_l \operatorname{tg} \alpha. \quad (7)$$

The horizontal components of the vector (f_x, f_y) of the elastic force per unit area at the point are defined by the formulas

$$f_x = e_x f_t - \frac{e_y f_l}{\cos \alpha}, \quad f_y = e_y f_t - \frac{e_x f_l}{\cos \alpha}, \quad (8)$$

where f_t and f_l are defined by formulas (5).

The formulas given above are also valid for the boundary faults. In this case one of the blocks separated by the fault is the boundary block. The movement of these blocks is described by their translation vectors and rotations around the co-ordinate origin. For the boundary block, the co-ordinates of the geometrical center of the block bottom in formulas (3) are equal to zeros. For example, if the block with the number j is the boundary block then in formulas (3) $X_c^j = Y_c^j = 0$.

Note that after space discretization the cells are considered instead of points. The inelastic displacements x_a and y_a or δ_t and δ_l are supposed to be the same for all points of the same cell.

EXERCISE 12: The discretization of the bottom of the left block in Figure 2 was made in Exercise 11. Consider the central cell of the left column and calculate the components f_x^u and f_y^u of the elastic force per unit area for this cell by formulas (1). Take $t = 2$; for the medium underlying the block: the velocity components $V_x = 0.5$ cm, $V_y = -0.75$ cm, and the angle velocity $U = 0.25 \cdot 10^{-6}$; for the block: $K_u = 0.1$ bars/cm, $x = 1.5$ cm, $y = -1$ cm, and $\varphi = 0.3 \cdot 10^{-6}$; for the cell: $x_a = 0.01$ cm and $y_a = 0.02$ cm. Calculate also for this cell the new values of the inelastic displacements x_a and y_a at $t + \Delta t = 2.01$. Use the finite differences instead of the derivatives and $W_u = 0.5$ cm/bars in equations (2).

EXERCISE 13: Using the result of Exercise 10, consider the central cell of the fault segment which is common for the both blocks in Figure 2 (the dip angle of the fault segment plane is equal to 60°). Calculate the components $f_t, f_l, f_x,$ and f_y of the elastic force per unit area and the reaction force per unit area p_0 for this cell by formulas (3)-(5), (7), and (8). Take $K_f = 0.1$ bars/cm; for the right block in Figure 2: $x_1 = 1$ cm, $y_1 = 1$ cm, and $\varphi_1 = -0.2 \cdot 10^{-6}$; for the left block in Figure 2: $x_2 = 1.2$ cm, $y_2 = -1$ cm, and $\varphi_2 = 0.5 \cdot 10^{-6}$; for the cell: $\delta_t = -0.02$ cm and $\delta_l = -0.01$ cm. Use the approximate value 1.7 for $\text{tg}60^\circ$. Calculate also for this cell the new values of the inelastic displacements δ_t and δ_l in $\Delta t = 0.01$. Use the finite differences instead of the derivatives and $W_f = 0.5$ cm/bars in equations (6).

EXERCISE 14: Make the space discretization of the fault segment being adjacent to the left side of the left block in Figure 2 (the dip angle of the fault segment plane is equal to 60°) with $\varepsilon = 5$ km and consider the central cell. Calculate the components $f_t, f_b, f_x,$ and f_y of the elastic force per unit area and the reaction force per unit area p_0 for this cell by formulas (3)-(5), (7), and (8). Take $t = 2$; $K_f = 0.1$ bars/cm; for the left block in Figure 2: $x_1 = 1.5$ cm, $y_1 = -1$ cm, and $\varphi_1 = 0.5 \cdot 10^{-6}$; for the boundary block being adjacent to the fault segment: the velocity components $V_x = 1$ cm, $V_y = 2$ cm, and the angle velocity $U = -0.2 \cdot 10^{-6}$; for the cell: $\delta_t = 0.01$ cm and $\delta_l = 0.03$ cm. Calculate also for this cell the new values of the inelastic displacements δ_t and δ_l at $t + \Delta t = 2.01$. Use the finite differences instead of the derivatives and $W_f = 0.5$ cm/bars in equations (6).

V. EARTHQUAKE AND CREEP

Denote

$$\kappa = \frac{|\mathbf{f}|}{P - p_0}, \quad (9)$$

where $\mathbf{f} = (f_t, f_l)$ is the vector of the elastic force per unit area defined by formulas (5), P is the parameter which may be interpreted as the difference between lithostatic and hydrostatic pressure (P has the same value for all faults), p_0 is the reaction force per unit area which is defined by formula (7).

For each fault the values of the following three levels are specified:

$$B > H_f \geq H_s.$$

Initial conditions for numerical simulation of the block structure dynamics are supposed to satisfy the inequality $\kappa < B$ for all cells of the fault segments. If at some moment t_i the value of κ in any cell of a fault segment reaches the level B , a failure (“earthquake”) occurs. A failure means a slippage during which the inelastic displacements δ_t, δ_l in the cell changes abruptly to reduce the value of κ to the level H_f .

The new values of the inelastic displacements are calculated by the formulas

$$\delta_t^e = \delta_t + \gamma f_t, \quad \delta_l^e = \delta_l + \gamma f_l, \quad (10)$$

where $\delta_t, \delta_l, f_t,$ and f_l are the values of inelastic displacements and the components of the vector of the elastic force per unit area just before the failure. The value of the coefficient γ is defined by the formula

$$\gamma = \frac{1}{K_f} - \frac{PH_f}{|\mathbf{f}| + H_f f_l \operatorname{tg} \alpha} \frac{1}{K_f}. \quad (11)$$

It follows from formulas (5), (7), (9)-(12) that just after the failure the value of κ equals to the value of the level H_f .

The cells in which the failures occurred are considered to be in the creep state. It means that for these cells the parameter W_s ($W_s \geq W_f$) is used instead of the parameter W_f in equations (6) which describe the evolution of the inelastic displacements. The values of the parameter W_s can be different for the different faults. The cell is in the creep state until $\kappa > H_s$ for it. When $\kappa \leq H_s$, the cell returns to the ordinary state and for this cell the parameter W_f is used in equations (6) after that.

The parameters of the earthquake are defined by the following way: the time moment is t_i ; the co-ordinates and the depth are the weighted sums of the co-ordinates and the depths of the cells in which failures occurred (the weights of the cells are their squares divided on the sum of squares of those cells); the magnitude is calculated by the formula

$$M = 0.98 \log_{10} S + 3.93, \quad (12)$$

where S is the sum of the squares of the cells (in km^2) in which failures occurred during the earthquake.

EXERCISE 15: Table 1 contains the values of δ_t , δ_l , f_t , and f_l for the cells of the fault segment which is common for the both blocks in Figure 2. These cells were obtained as the result of Exercise 10. Numbering of the rows proceeds from the upper plane to the lower one. The dip angle of the fault segment plane is equal to 60° .

Take $P = 2$ Kbars and calculate the values of κ for the cells from Table 1. Use formulas (7), (9), and the approximate value 1.7 for $\text{tg}60^\circ$.

TABLE 1

Rows	Cells	δ_t , cm	δ_l , cm	f_t , bars	f_l , bars
1	1	300	200	40	30
	2	500	400	80	60
	3	800	420	120	50
	4	850	600	150	80
	5	950	700	160	120
2	6	250	75	36	15
	7	350	120	60	25
	8	650	550	112	84
	9	800	350	144	60
	10	1000	800	200	150
3	11	320	170	45	24
	12	350	200	56	42
	13	400	180	72	30
	14	450	300	75	40
	15	500	600	84	112

EXERCISE 16: Using the result of Exercise 15, list the numbers of cells (accordingly to Table 1) for which failures occur. Calculate the new values of δ_t and δ_l for these cells by formulas (10), (11). Assuming that failures have occurred only in these cells, calculate the sum of their squares and the co-ordinates, the depth, and the magnitude of the earthquake.

Take $B = 0.1$, $K_f = 0.1$ bars/cm, $H_f = 0.085$, and the approximate value 1.7 for $\text{tg}60^\circ$.

EXERCISE 17: Using the result of Exercise 15, list the numbers of cells for which the creep state is possible. Take $H_s = 0.07$.

ANSWERS FOR WRITTEN EXERCISES

1. See Figure 3:

Corner vertices: 1, 2, 3, 4, 5.

End vertices: 6, 7, 8, 9, 10, 11, 12, 13.

Intersection: 14.

2.

Corner vertex	1	2	3	4	5
X, in 10 km	0	0	2.22	5.55	4.44
Y, in 10 km	0	4.44	5.55	5.55	0

1° of the 60° parallel is equal to 55.5 km

3, 4. See Figure 3:

Fault	Vertices
1	1, 8 (6, 0.75), 2
2	2, 3
3	3, 7 (5, 1/3), 4
4	5, 6 (5, 0.25), 1
5	6 (4), 10 (7, 0.2), 12 (9, 0.4), 9 (6, 0.6), 7 (3)
6	8 (1), 9 (5)
7	4, 11 (8, 0.5), 14 (9), 10 (5)
8	5, 13 (9, 1/3), 11 (7)
9	12 (5), 14 (7), 13 (8)

For end vertices and intersections, the numbers of another faults to which these vertices belong too are indicated in brackets. For end vertices, their relative positions in the faults are also indicated in brackets.

End vertex	6	7	8	9	10	11	12	13
X, in 10 km	3.33	3.33	0	3.33	3.33	4.44	3.33	4.44
Y, in 10 km	0	5.55	3.33	3.33	1.11	3.33	2.22	1.11

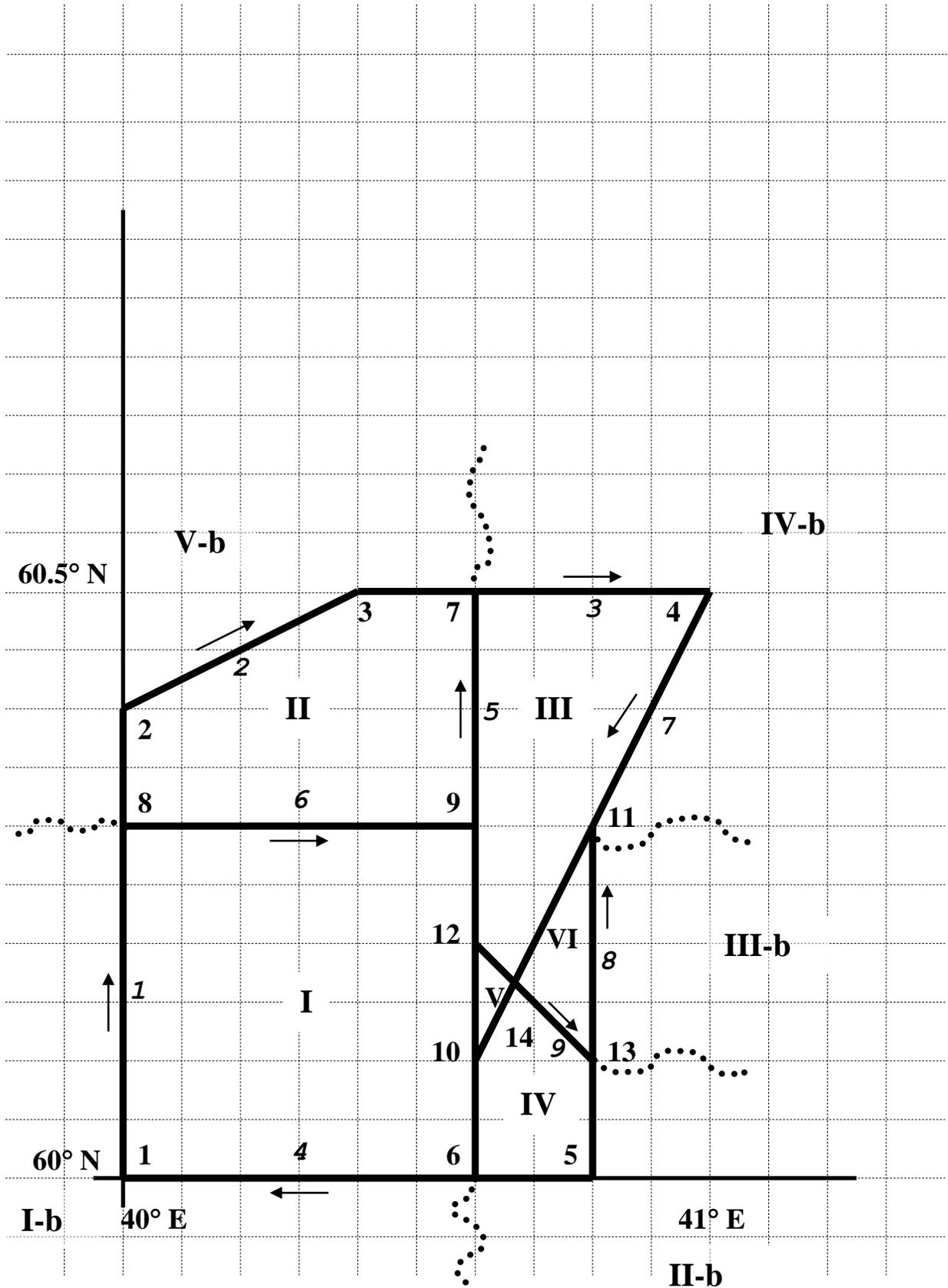


FIGURE 3

5. See Figure 3:

Block	Vertices
I	1, 6, 10, 12, 9, 8
II	8, 9, 7, 3, 2
III	12, 14, 11, 4, 7, 9
IV	6, 5, 13, 14, 10
V	12, 10, 14
VI	14, 13, 11

6. See Figure 3:

Boundary block	Vertices
I-b	6, 1, 8
II-b	13, 5, 6
III-b	11, 13
IV-b	7, 4, 11
V-b	8, 2, 3, 7

7.

Segment	Fault	Vertices	Blocks
1	1	1, 8	I-b, I
2	4	6, 1	I-b, I
3	1	8, 2	V-b, II
4	2	2, 3	V-b, II
5	3	3, 7	V-b, II
6	3	7, 4	IV-b, III
7	7	4, 11	IV-b, III
8	4	5, 6	II-b, IV
9	8	5, 13	IV, II-b
10	5	6, 10	I, IV
11	5	9, 7	II, III
12	6	8, 9	II, I
13	5	12, 9	I, III
14	7	14, 10	IV, V
15	5	10, 12	I, V
16	8	13, 11	VI, III-b
17	7	11, 14	VI, III
18	9	12, 14	III, V
19	9	14, 13	VI, IV

8. $V_x = -0.875$ cm, $V_y = -0.75$ cm, $U = 0.125 \cdot 10^{-6}$ of a radian
9. $V_x = 0.067$ cm, $V_y = 0.433$ cm, $U = 0.2 \cdot 10^{-6}$ of a radian
10. See Figure 4, 15 cells.
11. See Figure 5, 25 cells for the left block and 85 cells for the right block.
12. $f_x^u = 0.049$ bars, $f_y^u = 0.0672$ bars;
 at $t+\Delta t = 2.01$: $x_a = 0.010245$ cm, $y_a = 0.020336$ cm.
13. $f_t = -0.219$ bars, $f_l = -0.099$ bars,
 $f_x = -0.198$ bars, $f_y = 0.219$ bars,
 $p_0 = -0.1683$ bars;
 at $\Delta t = 0.01$: $\delta_t = -0.021095$ cm, $\delta_l = -0.010495$ cm.
14. $f_t = 0.388$ bars, $f_l = -0.295$ bars,
 $f_x = 0.59$ bars, $f_y = 0.388$ bars,
 $p_0 = -0.5015$ bars;
 at $t+\Delta t = 2.01$: $\delta_t = 0.01194$ cm, $\delta_l = 0.028525$ cm.

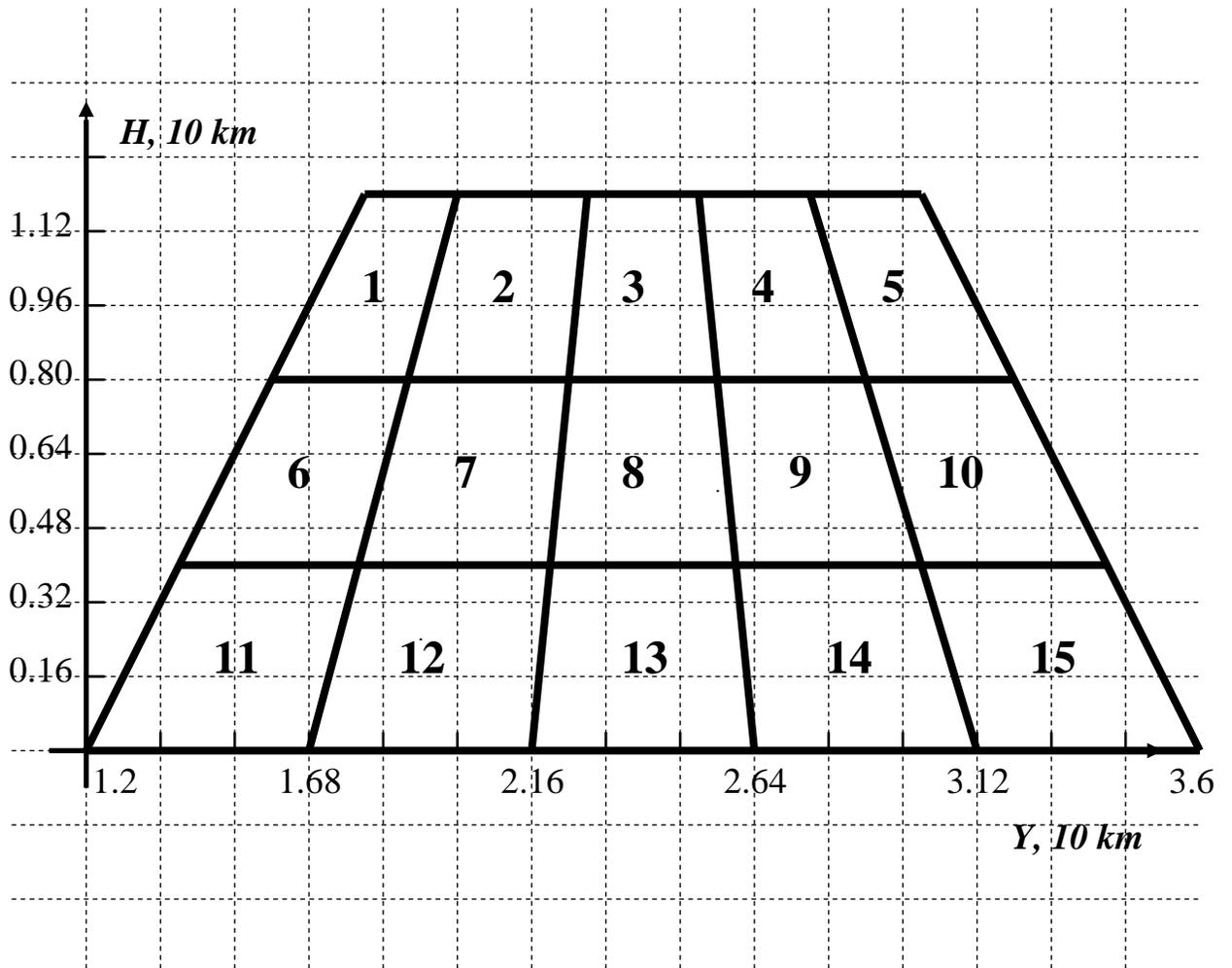


FIGURE 4

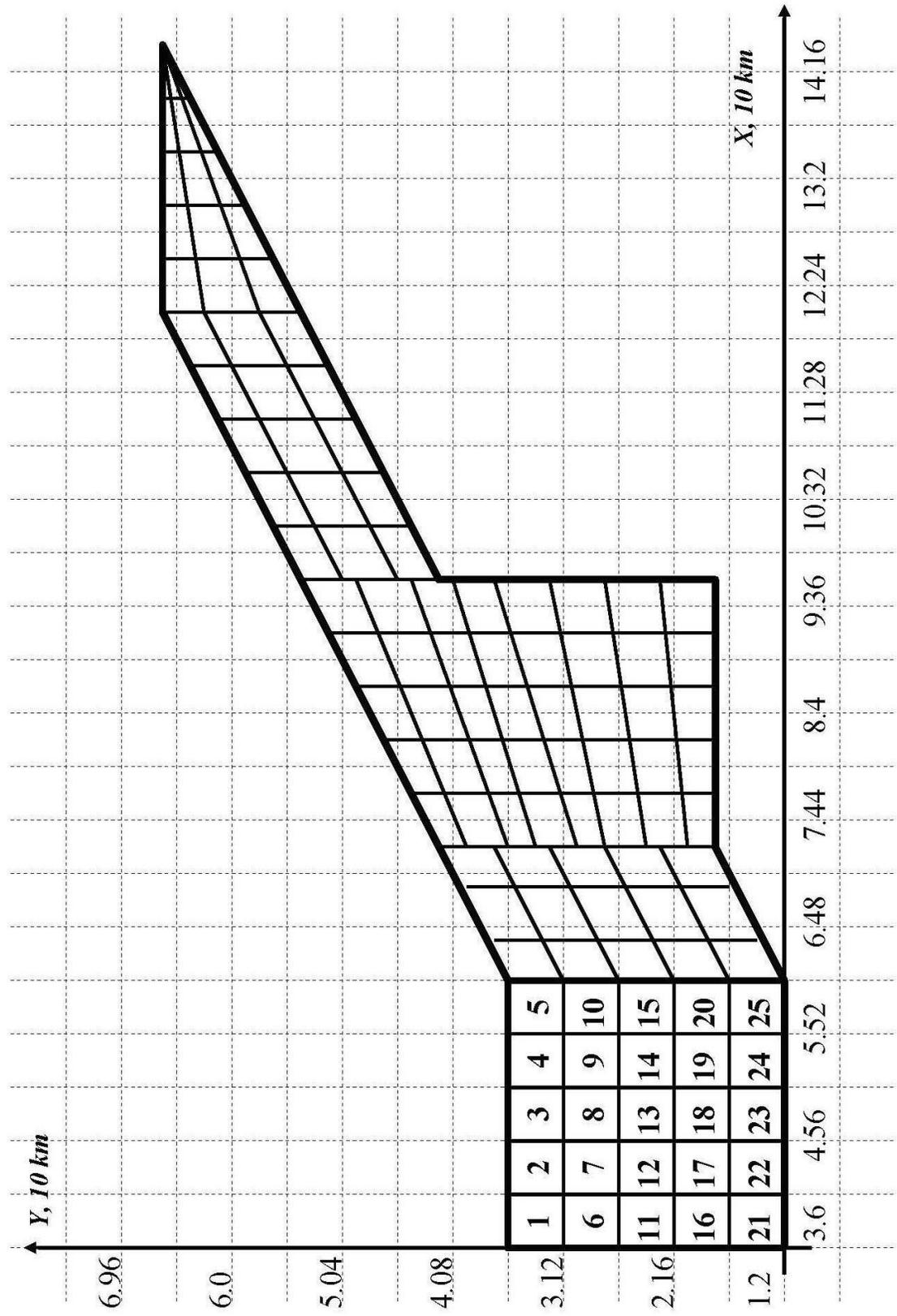


FIGURE 5

15. See Table 2.

TABLE 2

Rows	Cells	κ
1	1	0.0257
	2	0.0527
	3	0.0679
	4	0.0912
	5	0.1114
2	6	0.0198
	7	0.0332
	8	0.0754
	9	0.0822
	10	0.1433
3	11	0.0260
	12	0.0363
	13	0.0400
	14	0.0440
	15	0.0774

16. Failures occur in cells 5 and 10 (see Table 2).

The new values of δ_t and δ_l are:

$\delta_t = 1299$ cm, $\delta_l = 961$ cm for cell 5;

$\delta_t = 1749$ cm, $\delta_l = 1361$ cm for cell 10.

The sum of the squares of cells 5 and 10 is $0.256 \cdot 10^2$ km².

The parameters of the earthquake are the following:

co-ordinates $X = 5.6125 \cdot 10$ km, $Y = 3.05 \cdot 10$ km; depth 3.6125 km;

$M = 5.30$.

17. The creep state is possible for cells 4, 8, 9, and 15 (see Table 2).

EXERCISES ON THE COMPUTER TERMINAL WITH PROGRAM EARTH

EXERCISE 1

Task: To specify the block structure given in Figure 1 and to simulate its dynamics. Use the same co-ordinate system X, Y as in Exercise 2 of Section I of the written exercises, specify the lengths of the co-ordinate segments to be equal to 5.55. Compare the printout obtained with the results of Exercises 1-7 of Section I of the written exercises.

Input files: file with initial structure – no,
file with initial data – no.

Input data: mode of work – dynamics of block structure;
depth of the layer: 20 km;
space step: 5 km;
difference between lithostatic and hydrostatic pressure: 2 Kbars;
time step: 0.01;
time interval of simulation: 1.5;
co-ordinates of vertices, faults, and blocks – accordingly to Figure 1;
dip angles for faults: 1 – 95°, 2 – 100°, 3 – 95°, 4 – 95°, 5 – 85°,
6 – 95°, 7 – 95°, 8 – 80°, 9 – 85°.
(according to numbering of faults from the answer for Exercises 3, 4 of the written exercises);
the same values of constants for all faults:
 $K_f = 1$ bars/cm, $W_f = 0.75$ cm/bars, $W_s = 20$ cm/bars,
 $B = 0.1$, $H_f = 0.085$, $H_s = 0.07$;
the same values of constants for all blocks:
 $K_u = 0.1$ bars/cm, $W_u = 0.5$ cm/bars;
the same values of velocities of the underlying medium for all blocks: $V_x = -1$ cm, $V_y = 1$ cm, $U = 0$;
boundary blocks – the same definition as in Exercise 6 of Section I of the written exercises (only after specification of the depth of the layer);
velocities for boundary blocks:
for block I-b: $V_x = -5$ cm, $V_y = -10$ cm, $U = 10^{-6}$ rad;
for blocks II-b, III-b: $V_x = 5$ cm, $V_y = -5$ cm, $U = 10^{-6}$ rad;
for block IV-b: $V_x = -5$ cm, $V_y = 5$ cm, $U = 0$;
for block V-b: $V_x = -5$ cm, $V_y = 10$ cm, $U = 0$

(according to numbering of blocks from the answer for Exercise 6 of the written exercises);

Create files: for output data with name EXE1.DDT;
for catalog preparation with name EXE1.DPT;
for output structure with name EXE1.BLK;
for text information with name EXE1.PRI.

EXERCISE 2

Task: To calculate the maximum values of κ for fault segments of the block structure given in Figure 1 after simulation of its dynamics executed in the previous exercise.

Input file: with initial data – EXE1.DDT (created in Exercise 1).

Input data: mode of work – calculation of maximum stress.

Create file for text information with name EXE2.PRI.

EXERCISE 3

Task: To continue the numerical simulation of the block structure dynamics which was started in Exercise 1.

Input file: with initial data – EXE1.DDT (created in Exercise 1).

Input data: mode of work – dynamics of block structure;

time step: 0.01;

time interval of simulation: 1.

Create files: for output data with name EXE3.DDT;

for catalog preparation with name EXE3.DPT;

for text information with name EXE3.PRI.

EXERCISE 4

Task: To repeat Exercise 3 with another value of the time step.
Input file: with initial data – EXE1.DDT (created in Exercise 1).
Input data: mode of work – dynamics of block structure;
 time step: 0.001;
 time interval of simulation: 1.
Create files: for output data with name EXE4.DDT;
 for catalog preparation with name EXE4.DPT;
 for text information with name EXE4.PRI.

EXERCISE 5

Task: To look at the failure sequence obtained in Exercise 3.
Input file: with initial structure – EXE1.BLK (created in Exercise 1).
Input data: mode of work – image of earthquake flow;
 file for catalog preparation – EXE3.DPT (created in Exercise 3).
Create file for text information with name EXE5.PRI.

EXERCISE 6

Task: To look at the failure sequence obtained in Exercise 4. Compare the result with the result obtained in Exercise 5.
Input file: with initial structure – EXE1.BLK (created in Exercise 1).
Input data: mode of work – image of earthquake flow;
 file for catalog preparation – EXE4.DPT (created in Exercise 4).
Create file with text information with name EXE6.PRI.

EXERCISE 7

Task: To create the synthetic earthquake catalog from the failure sequence obtained in Exercise 3. Type the catalog by means of **CompiCat** program (mode File/Import).

Input file: with initial structure – EXE1.BLK (created in Exercise 1).

Input data: mode of work – creation of catalog (with distinguishing);
file for catalog preparation – EXE3.DPT (created in Exercise 3);
initial magnitude: 4.70;
magnitude step: 0.1.

Create files: for output catalog with name EXE7.DAT;
for text information with name EXE7.PRI.

EXERCISE 8

Task: To create the synthetic earthquake catalog from the failure sequence obtained in Exercise 4. Type the catalog by means of **CompiCat** program (mode File/Import). Compare the result with the result obtained in Exercise 7.

Input file: with initial structure – EXE1.BLK (created in Exercise 1).

Input data: mode of work – creation of catalog (with distinguishing);
file for catalog preparation – EXE4.DPT (created in Exercise 4);
initial magnitude: 4.70;
magnitude step: 0.1.

Create files: for output catalog with name EXE8.DAT;
for text information with name EXE8.PRI.

RESULTING PRINTOUTS FOR EXERCISES

Exercise 1

MODE: DYNAMICS OF BLOCK STRUCTURE

Depth of layer = 2.00, Space step = 0.5000

Difference between lithostatic and hydrostatic pressure = 2000.00

Time step = 0.01000, Time interval = 0.00000..1.50000

File for output data: exe1.ddt

File for catalog preparation: exe1.dpt

Output Profile: exe1.blk

14 VERTICES

#	Top co-ordinates		Bottom co-ordinates		Position in fault
	X	Y	X	Y	
1	0.0000	0.0000	0.1750	0.1750	
2	0.0000	4.4400	0.1750	4.1332	
3	2.2200	5.5500	2.6586	5.3750	
4	5.5500	5.5500	5.2669	5.3750	
5	4.4400	0.0000	4.0873	0.1750	
6	3.3300	-0.0000	3.1550	0.1750	0.2500
7	3.3300	5.5500	3.1550	5.3750	0.3333
8	0.0000	3.3300	0.1750	3.1550	0.7500
9	3.3300	3.3300	3.1550	3.1550	0.6000
10	3.3300	1.1100	3.1550	1.1513	0.2000
11	4.4400	3.3300	4.0873	3.0160	0.5000
12	3.3300	2.2200	3.1550	2.6424	0.4000
13	4.4400	1.1100	4.0873	1.7101	0.3333
14	3.7000	1.8500	3.6521	2.1454	

9 FAULTS

#	Angle	Kf	Wf	Ws	B	Hf	Hs	Vertices
1	95.00	1.0000	0.7500	20.0000	0.1000	0.0850	0.0700	1 8 2
2	100.00	1.0000	0.7500	20.0000	0.1000	0.0850	0.0700	2 3
3	95.00	1.0000	0.7500	20.0000	0.1000	0.0850	0.0700	3 7 4
4	95.00	1.0000	0.7500	20.0000	0.1000	0.0850	0.0700	5 6 1
5	85.00	1.0000	0.7500	20.0000	0.1000	0.0850	0.0700	6 10 12 9 7
6	95.00	1.0000	0.7500	20.0000	0.1000	0.0850	0.0700	8 9
7	95.00	1.0000	0.7500	20.0000	0.1000	0.0850	0.0700	4 11 14 10
8	80.00	1.0000	0.7500	20.0000	0.1000	0.0850	0.0700	5 13 11
9	85.00	1.0000	0.7500	20.0000	0.1000	0.0850	0.0700	12 14 13

6 BLOCKS

#	Ku	Wu	Vx	Vy	U	Vertices
1	0.1000	0.5000	-1.0000	1.0000	0.0000	1 8 9 12 10 6
2	0.1000	0.5000	-1.0000	1.0000	0.0000	2 3 7 9 8
3	0.1000	0.5000	-1.0000	1.0000	0.0000	4 11 14 12 9 7
4	0.1000	0.5000	-1.0000	1.0000	0.0000	5 6 10 14 13
5	0.1000	0.5000	-1.0000	1.0000	0.0000	10 12 14
6	0.1000	0.5000	-1.0000	1.0000	0.0000	13 11 14

5 BOUNDARY BLOCKS

#	Vx	Vy	U	Vertices
1	-5.0000	-10.0000	1.0000	8 1 6
2	5.0000	-5.0000	1.0000	6 5 13
3	5.0000	-5.0000	1.0000	13 11
4	-5.0000	5.0000	0.0000	11 4 7
5	-5.0000	10.0000	0.0000	7 3 2 8

19 SEGMENTS

#	Vertices:		Fault	Blocks:	
	first	final		left	right
1	1	8	1	1-boundary	1
2	6	1	4	1-boundary	1
3	8	2	1	5-boundary	2
4	2	3	2	5-boundary	2
5	3	7	3	5-boundary	2
6	7	4	3	4-boundary	3
7	4	11	7	4-boundary	3
8	5	6	4	2-boundary	4
9	5	13	8		2-boundary
10	6	10	5	1	4
11	9	7	5	2	3
12	8	9	6	2	1
13	12	9	5	1	3
14	14	10	7	4	5
15	10	12	5	1	5
16	13	11	8	6	3-boundary
17	11	14	7	6	3
18	12	14	9	3	5
19	14	13	9	6	4

Time = 0.00000

Displacements of blocks

#	dX	dY	Angle
1	0.000000	0.000000	0.000000
2	0.000000	0.000000	0.000000
3	0.000000	0.000000	0.000000
4	0.000000	0.000000	0.000000
5	0.000000	0.000000	0.000000
6	0.000000	0.000000	0.000000

Displacements of boundary blocks

#	dX	dY	Angle
1	-0.000000	-0.000000	0.000000
2	0.000000	-0.000000	0.000000
3	0.000000	-0.000000	0.000000
4	-0.000000	0.000000	0.000000
5	-0.000000	0.000000	0.000000

Displacements of block bottoms

#	dX	dY	Angle
1	-0.000000	0.000000	0.000000
2	-0.000000	0.000000	0.000000
3	-0.000000	0.000000	0.000000
4	-0.000000	0.000000	0.000000
5	-0.000000	0.000000	0.000000
6	-0.000000	0.000000	0.000000

Time = 1.50000

Displacements of blocks

#	dX	dY	Angle
1	-7.590684	-6.889700	2.339311
2	-9.660167	-0.466836	4.102465
3	-9.338010	5.177488	1.295500
4	-3.116913	0.092537	1.502843
5	-6.220536	1.198951	1.007860
6	-5.013021	3.667885	1.467732

Displacements of boundary blocks

#	dX	dY	Angle
1	-7.500000	-15.000000	1.500000
2	7.500000	-7.500000	1.500000
3	7.500000	-7.500000	1.500000
4	-7.500000	7.500000	0.000000
5	-7.500000	15.000000	0.000000

Displacements of block bottoms

#	dX	dY	Angle
1	-1.500000	1.500000	0.000000
2	-1.500000	1.500000	0.000000
3	-1.500000	1.500000	0.000000
4	-1.500000	1.500000	0.000000
5	-1.500000	1.500000	0.000000
6	-1.500000	1.500000	0.000000

Exercise 2

MODE: CALCULATION OF MAXIMUM STRESS

Depth of layer = 2.00, Space step = 0.5000

Difference between lithostatic and hydrostatic pressure = 2000.00

File with initial data: EXE1.DDT

.....
Time = 1.50000

Displacements of blocks

#	dX	dY	Angle
1	-7.590684	-6.889700	2.339311
2	-9.660167	-0.466836	4.102465
3	-9.338010	5.177488	1.295500
4	-3.116913	0.092537	1.502843

5	-6.220536	1.198951	1.007860
6	-5.013021	3.667885	1.467732

Displacements of boundary blocks

#	dX	dY	Angle
1	-7.500000	-15.000000	1.500000
2	7.500000	-7.500000	1.500000
3	7.500000	-7.500000	1.500000
4	-7.500000	7.500000	0.000000
5	-7.500000	15.000000	0.000000

Displacements of block bottoms

#	dX	dY	Angle
1	-1.500000	1.500000	0.000000
2	-1.500000	1.500000	0.000000
3	-1.500000	1.500000	0.000000
4	-1.500000	1.500000	0.000000
5	-1.500000	1.500000	0.000000
6	-1.500000	1.500000	0.000000

MAXIMUM STRESS IN SEGMENTS

Segment	Maximum stress	Percent of B	Row	Column	Fault
1	0.0145031	14.50	1	1	1
2	0.0320824	32.08	7	1	4
3	0.0108513	10.85	3	1	1
4	0.0385233	38.52	1	1	2
5	0.0939987	94.00	1	1	3
6	0.0117945	11.79	1	5	3
7	0.0111985	11.20	6	1	7
8	0.0085208	8.52	3	1	4
9	0.0173686	17.37	4	5	8
10	0.0113445	11.34	3	5	5
11	0.0162179	16.22	5	1	5
12	0.0409864	40.99	7	1	6
13	0.0120283	12.03	3	1	5
14	0.0083951	8.40	3	5	7
15	0.0085584	8.56	3	5	5
16	0.0174099	17.41	1	1	8
17	0.0094037	9.40	1	1	7
18	0.0088486	8.85	1	5	9
19	0.0085493	8.55	1	5	9

Exercise 3

MODE: DYNAMICS OF BLOCK STRUCTURE

Depth of layer = 2.00, Space step = 0.5000

Difference between lithostatic and hydrostatic pressure = 2000.00

Time step = 0.01000, Time interval = 1.50000..2.50000

File with initial data: EXE1.DDT

File for output data: exe3.ddt

File for catalog preparation: exe3.dpt

.....

Time = 1.50000

Displacements of blocks

#	dX	dY	Angle
1	-7.590684	-6.889700	2.339311
2	-9.660167	-0.466836	4.102465
3	-9.338010	5.177488	1.295500
4	-3.116913	0.092537	1.502843
5	-6.220536	1.198951	1.007860
6	-5.013021	3.667885	1.467732

Displacements of boundary blocks

#	dX	dY	Angle
1	-7.500000	-15.000000	1.500000
2	7.500000	-7.500000	1.500000
3	7.500000	-7.500000	1.500000
4	-7.500000	7.500000	0.000000
5	-7.500000	15.000000	0.000000

Displacements of block bottoms

#	dX	dY	Angle
1	-1.500000	1.500000	0.000000
2	-1.500000	1.500000	0.000000
3	-1.500000	1.500000	0.000000
4	-1.500000	1.500000	0.000000
5	-1.500000	1.500000	0.000000
6	-1.500000	1.500000	0.000000

Time = 2.50000

Displacements of blocks

#	dX	dY	Angle
1	-12.678316	-11.885104	3.744102
2	-16.167143	-1.708955	6.268617
3	-15.489396	8.677973	2.094496
4	-5.291568	0.159972	2.409432
5	-10.358415	2.001983	3.209902
6	-8.393990	6.142004	2.394955

Displacements of boundary blocks

#	dX	dY	Angle
1	-12.500000	-25.000000	2.500000
2	12.500000	-12.500000	2.500000
3	12.500000	-12.500000	2.500000
4	-12.500000	12.500000	0.000000
5	-12.500000	25.000000	0.000000

Displacements of block bottoms

#	dX	dY	Angle
1	-2.500000	2.500000	0.000000
2	-2.500000	2.500000	0.000000
3	-2.500000	2.500000	0.000000
4	-2.500000	2.500000	0.000000
5	-2.500000	2.500000	0.000000
6	-2.500000	2.500000	0.000000

Exercise 4

MODE: DYNAMICS OF BLOCK STRUCTURE

Depth of layer = 2.00, Space step = 0.5000

Difference between lithostatic and hydrostatic pressure = 2000.00

Time step = 0.00100, Time interval = 1.50000..2.50000

File with initial data: EXE1.ddt

File for output data: exe4.ddt

File for catalog preparation: exe4.dpt

.....
Time = 1.50000

Displacements of blocks

#	dX	dY	Angle
1	-7.590684	-6.889700	2.339311
2	-9.660167	-0.466836	4.102465
3	-9.338010	5.177488	1.295500
4	-3.116913	0.092537	1.502843
5	-6.220536	1.198951	1.007860
6	-5.013021	3.667885	1.467732

Displacements of boundary blocks

#	dX	dY	Angle
1	-7.500000	-15.000000	1.500000
2	7.500000	-7.500000	1.500000
3	7.500000	-7.500000	1.500000
4	-7.500000	7.500000	0.000000
5	-7.500000	15.000000	0.000000

Displacements of block bottoms

#	dX	dY	Angle
1	-1.500000	1.500000	0.000000
2	-1.500000	1.500000	0.000000
3	-1.500000	1.500000	0.000000
4	-1.500000	1.500000	0.000000
5	-1.500000	1.500000	0.000000
6	-1.500000	1.500000	0.000000

Time = 2.50000

Displacements of blocks

#	dX	dY	Angle
1	-12.671340	-11.792315	3.778173
2	-16.150486	-1.496260	6.395451
3	-15.504513	8.667147	2.109523
4	-5.270326	0.158181	2.433804
5	-10.360001	2.003784	3.240329
6	-8.384614	6.132762	2.406470

Displacements of boundary blocks

#	dX	dY	Angle
1	-12.500000	-25.000000	2.500000

2	12.500000	-12.500000	2.500000
3	12.500000	-12.500000	2.500000
4	-12.500000	12.500000	0.000000
5	-12.500000	25.000000	0.000000

Displacements of block bottoms

#	dX	dY	Angle
1	-2.500000	2.500000	0.000000
2	-2.500000	2.500000	0.000000
3	-2.500000	2.500000	0.000000
4	-2.500000	2.500000	0.000000
5	-2.500000	2.500000	0.000000
6	-2.500000	2.500000	0.000000

Exercise 5

MODE: IMAGE OF EARTHQUAKE FLOW

Depth of layer = 2.00, Space step = 0.5000

All segments

File for catalog preparation: exe3.dpt

.....

EARTHQUAKE NUMBER DEPENDENCE ON NUMBER OF CELLS FORMING THEM

	Number of	Accumulated number
cells	earthquakes	of earthquakes
1	18	21
2	1	3
3	2	2

Exercise 6

MODE: IMAGE OF EARTHQUAKE FLOW

Depth of layer = 2.00, Space step = 0.5000

All segments

File for catalog preparation: exe4.dpt

.....

EARTHQUAKE NUMBER DEPENDENCE ON NUMBER OF CELLS FORMING THEM

	Number of	Accumulated number
cells	earthquakes	of earthquakes
1	24	26
2	2	2

Exercise 7

MODE: CREATION OF CATALOG

Depth of layer = 2.00, Space step = 0.5000

Latitude and longitude of co-ordinate origin: Lat0 = 60.00, Lon0 = 40.19

Year0 = 1900, Number of days in unit of time = 365, All segments

Initial magnitude and magnitude step for graph: M0 = 4.70, dM = 0.10

File for catalog preparation: exe3.dpt

File for output catalog: exe7.dat

.....

EARTHQUAKE NUMBER DEPENDENCE ON NUMBER OF CELLS FORMING THEM

	Number of cells	earthquakes	Accumulated number of earthquakes
	1	18	21
	2	1	3
	3	2	2

EARTHQUAKE NUMBER DEPENDENCE ON MAGNITUDE

Magnitude	Accumulated number of earthquakes
4.70	21
4.80	17
4.90	14
5.00	11
5.10	3
5.20	3
5.30	2
5.40	1

PRINTOUT OF CATALOG FROM FILE EXE7.DAT

	year	mo	d	h	mi	s	lat	long	dep	mb	ms	ml	mp	in
1	1901	8	3	8	24	0	60.50	40.63	2	5.06	0.00	0.00	0.00	0
2	1901	8	17	22	48	0	60.49	40.65	6	5.00	0.00	0.00	0.00	0
3	1901	9	8	20	24	0	60.49	40.66	10	4.94	0.00	0.00	0.00	0
4	1901	9	27	2	24	0	60.49	40.67	14	4.87	0.00	0.00	0.00	0
5	1901	10	22	15	36	0	60.48	40.68	18	4.79	0.00	0.00	0.00	0
6	1901	11	28	3	36	0	60.50	40.70	2	5.06	0.00	0.00	0.00	0
7	1901	12	1	19	12	0	60.49	40.70	6	5.00	0.00	0.00	0.00	0
8	1901	12	5	10	48	0	60.49	40.71	10	4.94	0.00	0.00	0.00	0
9	1901	12	9	2	24	0	60.49	40.71	14	4.87	0.00	0.00	0.00	0
10	1901	12	12	18	0	0	60.48	40.72	18	4.79	0.00	0.00	0.00	0
11	1902	1	25	13	12	0	60.50	40.63	2	5.06	0.00	0.00	0.00	0
12	1902	2	16	10	48	0	60.49	40.65	6	5.00	0.00	0.00	0.00	0
13	1902	3	17	15	36	0	60.48	40.75	18	4.79	0.00	0.00	0.00	0
14	1902	3	21	7	12	0	60.49	40.72	11	5.39	0.00	0.00	0.00	0
15	1902	3	24	22	48	0	60.49	40.74	6	5.45	0.00	0.00	0.00	0
16	1902	4	8	13	12	0	60.48	40.68	18	4.79	0.00	0.00	0.00	0
17	1902	6	5	22	48	0	60.50	40.70	2	5.06	0.00	0.00	0.00	0
18	1902	6	9	14	24	0	60.49	40.70	6	5.00	0.00	0.00	0.00	0
19	1902	6	16	21	36	0	60.49	40.71	10	4.94	0.00	0.00	0.00	0
20	1902	6	24	4	48	0	60.49	40.71	14	4.87	0.00	0.00	0.00	0
21	1902	6	27	20	24	0	60.49	40.66	8	5.24	0.00	0.00	0.00	0

Exercise 8

MODE: CREATION OF CATALOG

Depth of layer = 2.00, Space step = 0.5000

Latitude and longitude of co-ordinate origin: Lat0 = 60.00, Lon0 = 40.19

Year0 = 1900, Number of days in unit of time = 365, All segments

Initial magnitude and magnitude step for graph: M0 = 4.70, dM = 0.10

File for catalog preparation: exe4.dpt

File for output catalog: exe8.dat

EARTHQUAKE NUMBER DEPENDENCE ON NUMBER OF CELLS FORMING THEM

	Number of cells	earthquakes	Accumulated number of earthquakes
	1	24	26
	2	2	2

EARTHQUAKE NUMBER DEPENDENCE ON MAGNITUDE

Magnitude	Accumulated number of earthquakes
4.70	26
4.80	21
4.90	16
5.00	11
5.10	2
5.20	2
5.30	1

PRINTOUT OF CATALOG FROM FILE EXE8.DAT

	year	mo	d	h	mi	s	lat	long	dep	mb	ms	ml	mp	in
1	1901	8	1	21	22	0	60.50	40.63	2	5.06	0.00	0.00	0.00	0
2	1901	8	20	20	53	0	60.49	40.65	6	5.00	0.00	0.00	0.00	0
3	1901	9	11	0	58	0	60.49	40.66	10	4.94	0.00	0.00	0.00	0
4	1901	10	4	18	22	0	60.49	40.67	14	4.87	0.00	0.00	0.00	0
5	1901	10	31	18	36	0	60.48	40.68	18	4.79	0.00	0.00	0.00	0
6	1901	12	9	2	24	0	60.50	40.70	2	5.06	0.00	0.00	0.00	0
7	1901	12	14	5	2	0	60.49	40.70	6	5.00	0.00	0.00	0.00	0
8	1901	12	19	7	41	0	60.49	40.67	5	5.30	0.00	0.00	0.00	0
9	1901	12	21	3	29	0	60.49	40.71	14	4.87	0.00	0.00	0.00	0
10	1901	12	24	10	19	0	60.48	40.72	18	4.79	0.00	0.00	0.00	0
11	1902	1	1	19	48	0	60.49	40.65	6	5.00	0.00	0.00	0.00	0
12	1902	1	31	9	22	0	60.49	40.66	10	4.94	0.00	0.00	0.00	0
13	1902	3	6	8	2	0	60.49	40.67	14	4.87	0.00	0.00	0.00	0
14	1902	4	14	18	7	0	60.48	40.68	18	4.79	0.00	0.00	0.00	0
15	1902	4	15	11	38	0	60.48	40.75	18	4.79	0.00	0.00	0.00	0
16	1902	4	16	22	41	0	60.49	40.75	14	4.87	0.00	0.00	0.00	0
17	1902	4	18	0	58	0	60.49	40.76	10	4.94	0.00	0.00	0.00	0
18	1902	4	19	3	14	0	60.49	40.76	6	5.00	0.00	0.00	0.00	0
19	1902	4	19	12	0	0	60.50	40.76	2	5.06	0.00	0.00	0.00	0
20	1902	4	26	19	12	0	60.50	40.67	2	5.35	0.00	0.00	0.00	0
21	1902	4	28	15	0	0	60.49	40.70	6	5.00	0.00	0.00	0.00	0
22	1902	4	30	10	48	0	60.49	40.65	6	5.00	0.00	0.00	0.00	0
23	1902	5	10	7	19	0	60.49	40.71	14	4.87	0.00	0.00	0.00	0
24	1902	5	11	9	36	0	60.49	40.71	10	4.94	0.00	0.00	0.00	0
25	1902	5	12	11	53	0	60.48	40.72	18	4.79	0.00	0.00	0.00	0
26	1902	5	24	4	12	0	60.49	40.66	10	4.94	0.00	0.00	0.00	0

NOTA BENE!

In all the computer exercises, some values in your resulting printouts (for example, values of displacements) can slightly differ from the corresponding values in the printouts presented here due to differences in arithmetic on different platforms.