

TECHNICAL UNIVERSITY OF CIVIL ENGINEERING  
BUCHAREST  
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# RESEARCH REPORT NO.3

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DISPLACEMENTS AND DEFORMATIONS  
ANALYSIS OF CONSTRUCTIONS AND LAND

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## Chapter 1 – General aspects

### 1.1. Introduction

In order to ensure the protection and safety of dams, we must take into account the action that water exerts on these hydrotechnical constructions.

By creating water storage lakes, the dams produce a multitude of environmental effects such as: changing the climate regime, modifying the biological regime, modifying the groundwater regime from the slopes on which dams rest on etc.

In order to avoid natural hazards such as breaking the dams, overturning them, landslides, sinking downstream water etc. It is necessary to monitor the behavior of these hydrotechnical constructions over time, starting with the construction period, during loading and during operation.

The aspect of tracking the behavior in time and ensuring the safety of dams is regulated by Law no. 466 from July 18, 2001, for the approval of Government Emergency Ordinance no. 244/2000.

### 1.2. Displacements and deformations

For any objective subjected for monitoring it is necessary to know in detail the modification of geometric shapes and spatial position of the studied objective.

In order to achieve this goal we can define the notions:

- *Displacement (Fig.1.1. a)* – consists in modifying the spatial position of a point located on the objective (land or construction).
- *Deformation (Fig.1.1. b)* – consists in changing the shape of an object by altering the distances between the characteristic points located on the studied objective.

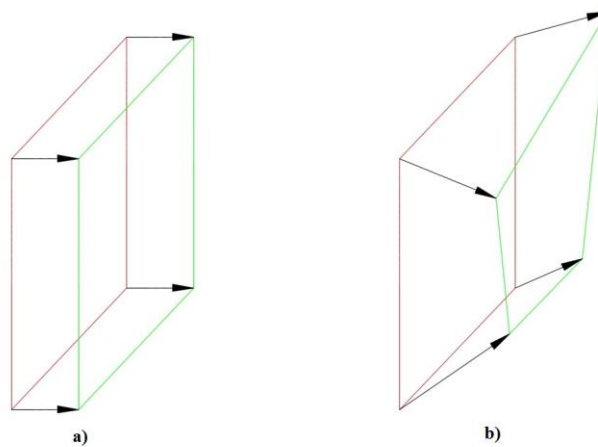


Fig. 1.1. Displacements (a) and deformations (b)

The character of the displacements and deformations identified based on measurements may be:

- *relative* - determined by measuring the distance between two or more tracking points;
- *absolute* - determined by measuring the tracking points in relation with the fixed points located outside the influence area of the objective;
- *partial* – determined on the basis of the results of only two successive measuring epochs;
- *total* - determined on the basis of the results of all measurement epochs.

Displacements and deformations may be linear, angular and specific. Linear displacements and deformations are divided into: *compactions* (vertical displacements suffered by foundations or foundation ground, in particular due to building load, water infiltration or defective design); *arrows* (mainly occurring on beams, pillars or plates that bend as a result of horizontal or vertical stresses); *linear inclinations* (are the result of unevenly distributed loads, but which do not affect the structural strength of the construction); *cracks and fissures* (represent ruptures resulting from uneven movements and deformations); *horizontal displacements* (occurring as a result of landslide, undergroundwater and groundwater action, or alteration of the foundation ground characteristics, by changing the position in the horizontal plane, which may affect the entire construction).

Angular displacements and deformations (Fig. 1.2) represent horizontal and vertical rotations, due in particular to stresses, infiltrations and landslides.

Horizontal rotations of the monitored objective are also called twistings, and vertical spins are also called angular inclinations, and represent the angles of the construction edge, which are determined by measurements at the base epoch and the current epoch.

Specific deformations occur due to compressions or tensions occurring mainly due to the action of external forces, characterized by shortcuts or elongations of the construction elements.

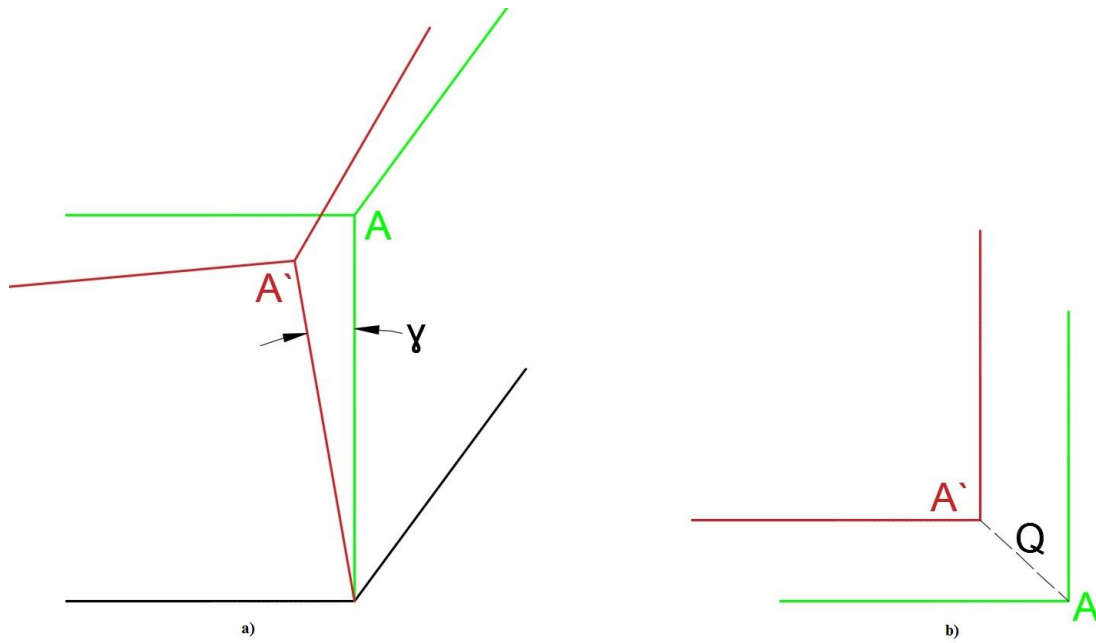


Fig. 1.2. Angular inclination (a) and linear inclination (b)

## Chapter 2 – Cumpăna Dam

### 2.1. Localization

Cumpăna Dam is located on the Cumpăna River, about 2 km from the confluence of the Cumpăna River with Vidraru Lake and 25 km upstream of the Vidraru Dam. (Fig. 2.1)



Fig.2.1. Localization Cumpăna Dam  
(source: capture <http://www.geo-spatial.org/harti/>)

## 2.2. Technical characteristics

Cumpăna dam is an arched concrete dam.

The technical characteristics of Cumpăna dam are:

- The height measured above the foundation: 33 m.
- Crown length: 110 m.
- Crown width: 2 m.
- Width at the base of the dam: 8 m.

Cumpăna Dam allows the capture of the Cumpăna and Topolog rivers (through a 7 km underground gallery) and their lead in Vidraru Lake through the Cumpăna power plant (located about 2 km downstream of the dam, with a 5 MW installed capacity). The dam was put into operation in 1968. (Fig. 2.2)



Fig.2.2. Cumpăna Dam

## 2.3. The geodetic tracking network

The microtriangulation network pilasters were built on the dam (2 pilasters) and downstream of the dam (5 pilasters). The type of pilasters is tronconic, with forced Wild type centering devices, not protected by thermal insulation. The sight marks, made by metal and enamel, are appropriate except for those that have broken and rusted.

The geodetic tracking network for monitoring the construction behavior (UCC) was designed in 1967 and is satisfactorily materialized except for the S1 pilaster, which due to the slippage of the slope had to be reconfigured.

This network (Fig. 2.3) is composed of:

- 7 pilasters (D1, D2, D3, DB, S1, S2, SB1);
- 10 tracking marks (R1, R2, R3, R4, R5, R6, R7, R8, R9, R10).

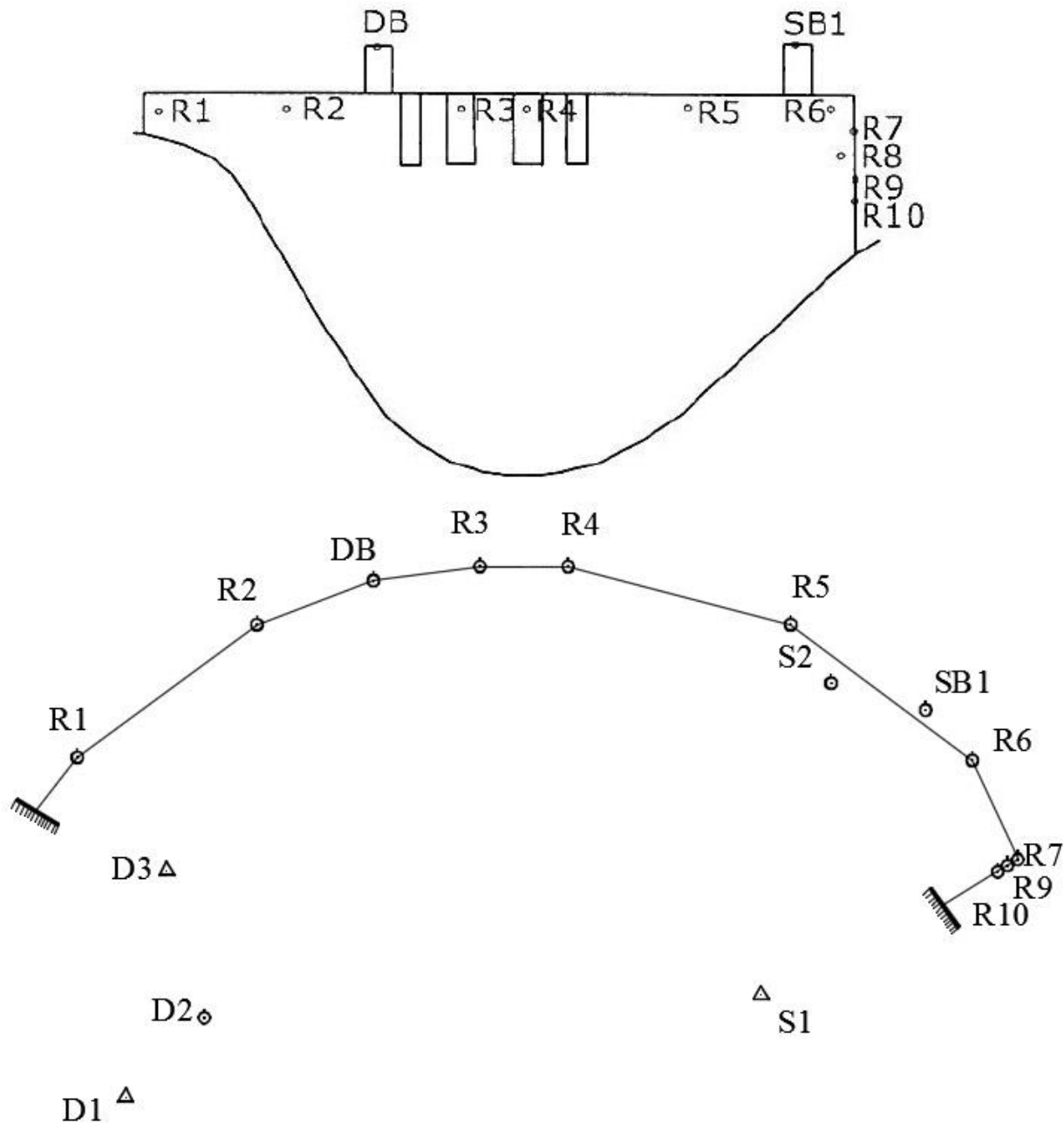


Fig. 2.3. Tracking network

## Chapter 3 – Microtriangulation network compensation

### 3.1. Equipment used

For the microtriangulation stage, respectively for measuring directions and distances, the total station Leica TM30 (Fig. 3.1) was used. This type of total station provides an angular accuracy of 0.5" or 1" and a precision for measuring distances of 0.6 mm + 1 ppm on the prism, respectively 2 mm + 2 ppm on any surface.



Fig. 3.1. Leica TM30 total station

### 3.2. Measurement and compensation methods used

In the microtriangulation network realised to track the behavior of Cumpăna dam, angular and linear observations were made. The measurement method used for the microtriangulation was the horizons method, from each pilaster in which was stationed with the apparatus were made 3 series of measurements.

The microtriangulation network compensation was done in block using the least squares method, being considered as fixed points: D1, D3 and S1. (Fig. 3.2)

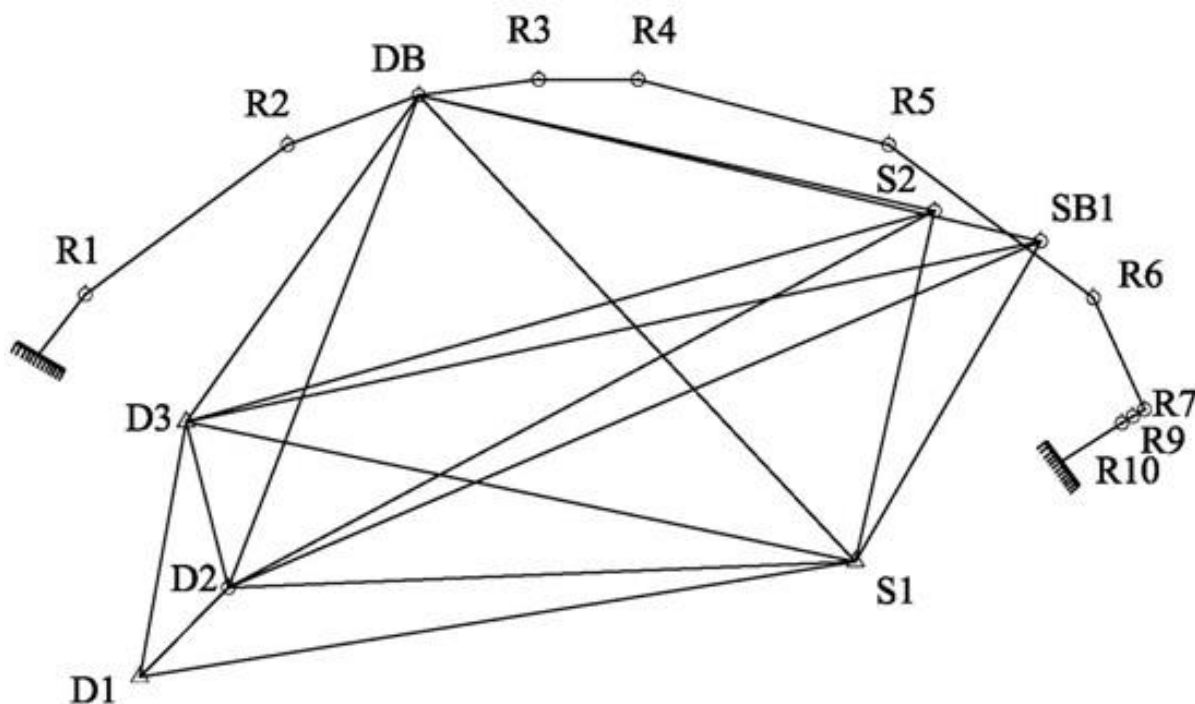


Fig. 3.2. Sketch of the Cumpăna dam tracking network

The local coordinates of pilasters and landmarks for the zero epoch are shown in Table 3.1, and the coordinate inventory with the geodetic support network points (epoch 2016) are shown in Table 3.2.

Table 3.1. Local coordinates of pilasters and landmarks – zero epoch

| POINT NAME       | X (m)    | Y (m)     |
|------------------|----------|-----------|
| <b>PILASTERS</b> |          |           |
| D3               | 946.0991 | 996.0471  |
| D1               | 965.4544 | 969.5523  |
| S1               | 954.8455 | 1020.2946 |
| D2               | 952.8683 | 972.7380  |
| DB               | 990.2022 | 987.1735  |
| S2               | 981.4304 | 1026.2654 |
| SB1              | 979.1353 | 1034.3352 |
| <b>LANDMARKS</b> |          |           |
| R1               | 975.1041 | 961.8975  |
| R2               | 986.4352 | 977.2300  |
| R3               | 991.3991 | 996.2729  |
| R4               | 991.3862 | 1003.8018 |
| R5               | 986.4351 | 1022.8078 |

|     |          |           |
|-----|----------|-----------|
| R6  | 974.8727 | 1038.3249 |
| R7  | 966.3920 | 1042.1744 |
| R8  | 966.1069 | 1041.8860 |
| R9  | 965.8737 | 1041.3242 |
| R10 | 965.3476 | 1040.4777 |

Tabel 3.2. Local coordinates of pilasters and landmarks –2016 epoch

| Point no.  | Point name | X (m)    | Y (m)     |
|------------|------------|----------|-----------|
| Old points |            |          |           |
| 1          | D1         | 946.0990 | 966.0470  |
| 2          | S1         | 954.8460 | 1020.2950 |
| 3          | D3         | 965.4544 | 969.5552  |
| New points |            |          |           |
| 4          | D2         | 952.8719 | 972.7452  |
| 5          | R1         | 975.1031 | 961.9056  |
| 6          | R2         | 986.4325 | 977.2371  |
| 7          | DB         | 990.1954 | 987.1797  |
| 8          | R3         | 991.3936 | 996.2800  |
| 9          | R4         | 991.3793 | 1003.8085 |
| 10         | R5         | 986.4265 | 1022.8120 |
| 11         | S2         | 981.4245 | 1026.2645 |
| 12         | SB1        | 979.1290 | 1034.3304 |
| 13         | R6         | 974.8602 | 1038.3191 |
| 14         | R7         | 966.3812 | 1042.1722 |
| 15         | R9         | 965.8639 | 1041.3223 |
| 16         | R10        | 965.3394 | 1040.4750 |

### 3.3. Results for the network compensation

Compensation method:

- method of weighted indirect observations;
- block compensation for triangulation and trilateration;
- block compensation for coordinate differences  $\Delta x$  and  $\Delta y$ ;
- constrained network on old points.

|                                       |      |
|---------------------------------------|------|
| Total number of points in the network | 16   |
| - old points                          | 3    |
| - new points                          | 13   |
| Average length of one side            | 32 m |

### 3.3.1. Compensation of directions

The compensation of the measured directions is presented in table 3.3.

Table 3.3. Compensation of directions

| Station point | Sight point | Measured direction [G. c. cc] | Correction [cc] | Compensated direction [G. c. cc] | Orientation [G. c. cc] |
|---------------|-------------|-------------------------------|-----------------|----------------------------------|------------------------|
| D1            | D3          | 321.5838                      | 56              | 321.5894                         | 11.4150                |
|               | D2          | 359.8234                      | -19             | 359.8215                         | 49.6471                |
|               | R2          | 327.4004                      | 30              | 327.4034                         | 17.2289                |
|               | DB          | 338.6249                      | 1               | 338.6250                         | 28.4506                |
|               | R3          | 347.6428                      | 6               | 347.6434                         | 37.4689                |
|               | R4          | 354.4252                      | 8               | 354.4260                         | 44.2516                |
|               | R5          | 370.8492                      | 18              | 370.8510                         | 60.6766                |
|               | S2          | 376.4008                      | -11             | 376.3997                         | 66.2253                |
|               | SB1         | 381.4942                      | -19             | 381.4923                         | 71.3178                |
|               | R6          | 386.0652                      | -23             | 386.0629                         | 75.8884                |
| S1            | D1          | 0.0034                        | 22              | 0.0056                           | 289.8227               |
|               | D3          | 23.2984                       | 56              | 23.3040                          | 313.1211               |
|               | D2          | 7.5396                        | 18              | 7.5414                           | 297.3585               |
|               | R1          | 31.4433                       | -13             | 31.4420                          | 321.2591               |
|               | R2          | 50.4778                       | -26             | 50.4752                          | 340.2924               |
|               | DB          | 62.2593                       | 2               | 62.2595                          | 352.0766               |
|               | R3          | 73.1754                       | -19             | 73.1735                          | 362.9906               |
|               | R4          | 83.1992                       | -34             | 83.1958                          | 373.0129               |
|               | R5          | 115.2482                      | -20             | 115.2462                         | 5.0633                 |
|               | S2          | 124.2478                      | 1               | 124.2479                         | 14.0650                |
|               | SB1         | 143.5454                      | 15              | 143.5469                         | 33.3640                |
| D3            | D1          | 0.0011                        | 67              | 0.0078                           | 211.4150               |
|               | S1          | 301.7201                      | -62             | 301.7139                         | 113.1211               |
|               | D2          | 372.7871                      | -11             | 372.7860                         | 184.1932               |
|               | R1          | 145.9166                      | 7               | 145.9173                         | 357.3245               |
|               | R2          | 210.9378                      | 15              | 210.9393                         | 22.3465                |
|               | DB          | 227.9988                      | -11             | 227.9977                         | 39.4050                |
|               | R3          | 239.5421                      | 1               | 239.5422                         | 50.9495                |
|               | R4          | 247.3463                      | 14              | 247.3477                         | 58.7549                |
|               | R5          | 264.7090                      | 14              | 264.7104                         | 76.1176                |
|               | S2          | 271.1160                      | 13              | 271.1173                         | 82.5246                |
|               | SB1         | 275.3498                      | -22             | 275.3476                         | 86.7549                |
|               | R6          | 279.9395                      | -10             | 279.9385                         | 91.3458                |
|               | R7          | 287.7817                      | -14             | 287.7803                         | 99.1875                |
| D2            | D1          | 0.0019                        | 23              | 0.0042                           | 249.6471               |
|               | S1          | 247.7207                      | -51             | 247.7156                         | 97.3585                |
|               | D3          | 134.5514                      | -11             | 134.5503                         | 384.1932               |
|               | R2          | 158.8297                      | -22             | 158.8275                         | 8.4704                 |

| Station point | Sight point | Measured direction [G. c. cc] | Correction [cc] | Compensated direction [G. c. cc] | Orientation [G. c. cc] |
|---------------|-------------|-------------------------------|-----------------|----------------------------------|------------------------|
|               | DB          | 173.8475                      | 23              | 173.8498                         | 23.4927                |
|               | R3          | 185.2696                      | 16              | 185.2712                         | 34.9141                |
|               | R4          | 193.5704                      | 7               | 193.5711                         | 43.2140                |
|               | R5          | 212.7694                      | -10             | 212.7684                         | 62.4113                |
|               | S2          | 219.1562                      | 9               | 219.1571                         | 68.8001                |
|               | SB1         | 224.7000                      | 2               | 224.7002                         | 74.3431                |
|               | R6          | 229.7586                      | 14              | 229.7600                         | 79.4029                |
| DB            | D1          | 4.9603                        | 19              | 4.9622                           | 228.4506               |
|               | S1          | 328.5975                      | -92             | 328.5883                         | 152.0766               |
|               | D3          | 15.9113                       | 53              | 15.9166                          | 239.4050               |
|               | D2          | 0.0030                        | 14              | 0.0044                           | 223.4927               |
|               | S2          | 290.5652                      | -1              | 290.5651                         | 114.0534               |
|               | SB1         | 291.1871                      | 6               | 291.1877                         | 114.6760               |
|               | R6          | 295.0571                      | 17              | 295.0588                         | 118.5471               |
|               | R7          | 302.5275                      | 5               | 302.5280                         | 126.0163               |
|               | R9          | 303.4005                      | -11             | 303.3994                         | 126.8877               |
|               | R10         | 304.2943                      | -10             | 304.2933                         | 127.7816               |
| S2            | D1          | 0.0023                        | 4               | 0.0027                           | 266.2253               |
|               | S1          | 347.8517                      | -93             | 347.8424                         | 214.0650               |
|               | D3          | 16.2972                       | 48              | 16.3020                          | 282.5246               |
|               | D2          | 2.5740                        | 35              | 2.5775                           | 268.8001               |
|               | R1          | 27.5457                       | -12             | 27.5445                          | 293.7671               |
|               | R2          | 40.2591                       | -12             | 40.2579                          | 306.4805               |
|               | DB          | 47.8292                       | 16              | 47.8308                          | 314.0534               |
|               | R3          | 54.2122                       | -6              | 54.2116                          | 320.4342               |
|               | R4          | 60.3411                       | 6               | 60.3417                          | 326.5643               |
|               | R9          | 284.8221                      | 5               | 284.8226                         | 151.0452               |
|               | R10         | 287.7104                      | 10              | 287.7114                         | 153.9340               |
| SB1           | D1          | 0.0018                        | -18             | 0.0000                           | 271.3178               |
|               | S1          | 362.0526                      | -64             | 362.0462                         | 233.3640               |
|               | D3          | 15.4329                       | 42              | 15.4371                          | 286.7549               |
|               | D2          | 3.0236                        | 17              | 3.0253                           | 274.3431               |
|               | R1          | 25.1459                       | 11              | 25.1470                          | 296.4648               |
|               | R2          | 36.7806                       | 14              | 36.7820                          | 308.0998               |
|               | DB          | 43.3579                       | 2               | 43.3581                          | 314.6760               |
|               | R7          | 293.5738                      | -3              | 293.5735                         | 164.8913               |
|               | R9          | 297.8007                      | 1               | 297.8008                         | 169.1186               |
|               | R10         | 301.9963                      | -3              | 301.9960                         | 173.3138               |

|                                                                  |                |
|------------------------------------------------------------------|----------------|
| Total number of horizontal directions                            | 77             |
| Average number of direction from one station point               | 11             |
| The precision required to measure a direction                    | 10 cc          |
| The average correction applied to one direction                  | 20 cc          |
| The maximum correction applied to one direction [pvv] directions | 93 cc<br>62448 |

### 3.3.2. Compensation of distances

The compensation of measured distances is presented in table 3.4.

Table 3.4. Compensation of distances

| Station point | Sight point | Measured distance [m] | Correction [mm] | Compensated distance [m] |
|---------------|-------------|-----------------------|-----------------|--------------------------|
| D1            | S1          | 54.932                | 17              | 54.949                   |
|               | D3          | 19.663                | 8               | 19.671                   |
|               | D2          | 9.521                 | 5               | 9.526                    |
|               | R2          | 41.849                | 8               | 41.857                   |
|               | DB          | 48.889                | 10              | 48.899                   |
|               | R3          | 54.448                | 10              | 54.458                   |
|               | R4          | 58.950                | 10              | 58.960                   |
|               | R5          | 69.620                | 12              | 69.632                   |
|               | S2          | 69.801                | 13              | 69.814                   |
|               | SB1         | 75.839                | 14              | 75.853                   |
|               | R6          | 77.779                | 6               | 77.785                   |
| S1            | D1          | 54.931                | 18              | 54.949                   |
|               | D3          | 51.823                | 14              | 51.837                   |
|               | D2          | 47.577                | 14              | 47.591                   |
|               | R1          | 61.791                | 12              | 61.803                   |
|               | R2          | 53.392                | 9               | 53.401                   |
|               | DB          | 48.430                | 8               | 48.438                   |
|               | R3          | 43.726                | 6               | 43.732                   |
|               | R4          | 40.077                | 4               | 40.081                   |
|               | R5          | 31.682                | -1              | 31.681                   |
|               | S2          | 27.243                | -2              | 27.241                   |
|               | SB1         | 28.051                | -4              | 28.047                   |
| D3            | D1          | 19.665                | 6               | 19.671                   |
|               | S1          | 51.825                | 12              | 51.837                   |
|               | D2          | 12.978                | 3               | 12.981                   |
|               | R1          | 12.315                | -2              | 12.313                   |
|               | R2          | 22.339                | 1               | 22.340                   |
|               | DB          | 30.373                | 4               | 30.377                   |
|               | R3          | 37.240                | 3               | 37.243                   |
|               | R4          | 42.954                | 4               | 42.958                   |

| Station point | Sight point | Measured distance [m] | Correction [mm] | Compensated distance [m] |
|---------------|-------------|-----------------------|-----------------|--------------------------|
|               | R5          | 57.232                | 5               | 57.237                   |
|               | S2          | 58.906                | 9               | 58.915                   |
|               | SB1         | 66.194                | 9               | 66.203                   |
|               | R6          | 69.402                | 2               | 69.404                   |
|               | R7          | 72.641                | -18             | 72.623                   |
| D2            | D1          | 9.521                 | 5               | 9.526                    |
|               | S1          | 47.579                | 12              | 47.591                   |
|               | D3          | 12.978                | 3               | 12.981                   |
|               | R2          | 33.857                | 3               | 33.860                   |
|               | DB          | 40.012                | 5               | 40.017                   |
|               | R3          | 45.138                | 4               | 45.142                   |
|               | R4          | 49.470                | 5               | 49.475                   |
|               | R5          | 60.264                | 7               | 60.271                   |
|               | S2          | 60.651                | 8               | 60.659                   |
|               | SB1         | 66.940                | 9               | 66.949                   |
|               | R6          | 69.160                | 2               | 69.162                   |
|               |             |                       |                 |                          |
| DB            | D1          | 48.888                | 11              | 48.899                   |
|               | S1          | 48.430                | 8               | 48.438                   |
|               | D3          | 30.374                | 3               | 30.377                   |
|               | D2          | 40.012                | 5               | 40.017                   |
|               | S2          | 40.050                | 7               | 40.057                   |
|               | SB1         | 48.426                | 6               | 48.432                   |
|               | R6          | 53.391                | -2              | 53.389                   |
|               | R7          | 59.920                | 7               | 59.927                   |
|               | R9          | 59.351                | 8               | 59.359                   |
|               | R10         | 58.801                | 6               | 58.807                   |
| S2            | D1          | 69.800                | 14              | 69.814                   |
|               | S1          | 27.242                | -1              | 27.241                   |
|               | D3          | 58.905                | 10              | 58.915                   |
|               | D2          | 60.649                | 10              | 60.659                   |
|               | R1          | 64.665                | 4               | 64.669                   |
|               | R2          | 49.278                | 5               | 49.283                   |
|               | DB          | 40.049                | 8               | 40.057                   |
|               | R3          | 31.594                | 4               | 31.598                   |
|               | R4          | 24.563                | 1               | 24.564                   |
|               | R9          | 21.652                | 1               | 21.653                   |
|               | R10         | 21.463                | 0               | 21.463                   |
|               |             |                       |                 |                          |
| SB1           | D1          | 75.839                | 14              | 75.853                   |
|               | S1          | 28.049                | -2              | 28.047                   |
|               | D3          | 66.194                | 9               | 66.203                   |
|               | D2          | 66.940                | 9               | 66.949                   |
|               | R1          | 72.531                | 6               | 72.537                   |
|               | R2          | 57.553                | 6               | 57.559                   |

| Station point | Sight point | Measured distance [m] | Correction [mm] | Compensated distance [m] |
|---------------|-------------|-----------------------|-----------------|--------------------------|
|               | DB          | 48.426                | 6               | 48.432                   |
|               | R7          | 14.965                | 2               | 14.967                   |
|               | R9          | 14.997                | -2              | 14.995                   |
|               | R10         | 15.098                | -1              | 15.097                   |

|                                                    |       |
|----------------------------------------------------|-------|
| Total number of horizontal distances               | 77    |
| Average number of distances from one station point | 11    |
| The precision required to measure a distance       | 15 mm |
| The average correction applied to one distance     | 7 mm  |
| The maximum correction applied to one distance     | 18 mm |
| [pvv] distances                                    | 952   |

### 3.3.3. Compensation of coordinates

The compensation of the points coordinates is presented in table 3.5.

Tabel 3.5. Compensation of coordinates

| Point name | X [m]   | mx [mm] | Y [m]    | my [mm] | mt [mm] |
|------------|---------|---------|----------|---------|---------|
| D1         | 946.099 | 0       | 966.047  | 0       | 0       |
| S1         | 954.846 | 0       | 1020.295 | 0       | 0       |
| D3         | 965.454 | 0       | 969.555  | 0       | 0       |
| D2         | 952.872 | 1       | 972.745  | 0       | 1       |
| R1         | 975.103 | 2       | 961.906  | 2       | 3       |
| R2         | 986.433 | 2       | 977.237  | 1       | 2       |
| DB         | 990.195 | 1       | 987.180  | 1       | 2       |
| R3         | 991.394 | 2       | 996.280  | 2       | 2       |
| R4         | 991.379 | 2       | 1003.808 | 2       | 2       |
| R5         | 986.427 | 3       | 1022.812 | 2       | 3       |
| S2         | 981.424 | 1       | 1026.264 | 1       | 2       |
| SB1        | 979.129 | 2       | 1034.330 | 1       | 2       |
| R6         | 974.860 | 2       | 1038.319 | 4       | 5       |
| R7         | 966.381 | 3       | 1042.172 | 2       | 3       |
| R9         | 965.864 | 3       | 1041.322 | 2       | 3       |
| R10        | 965.339 | 3       | 1040.475 | 2       | 3       |

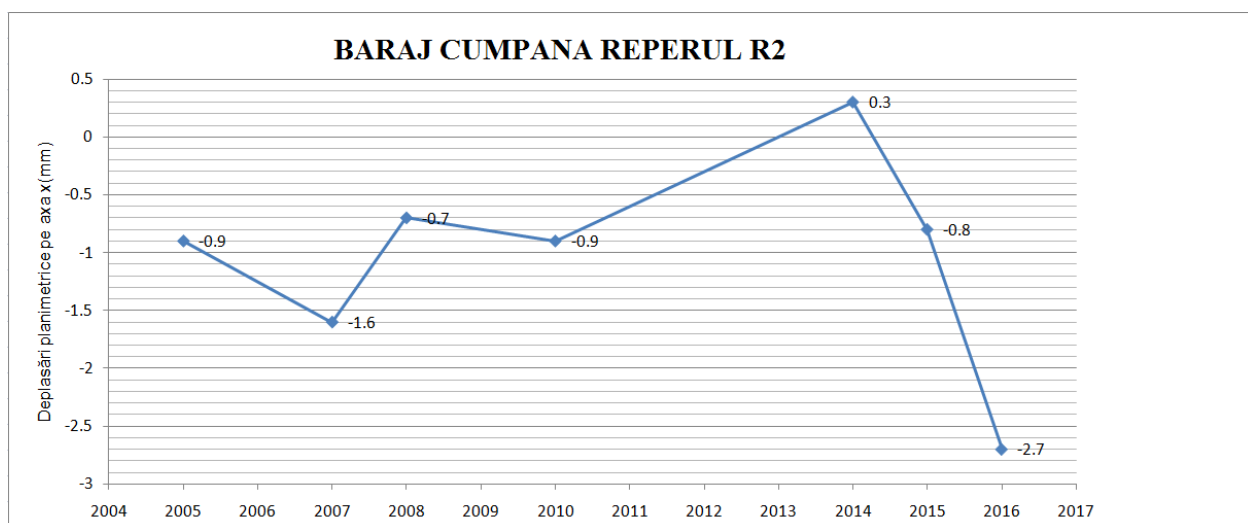
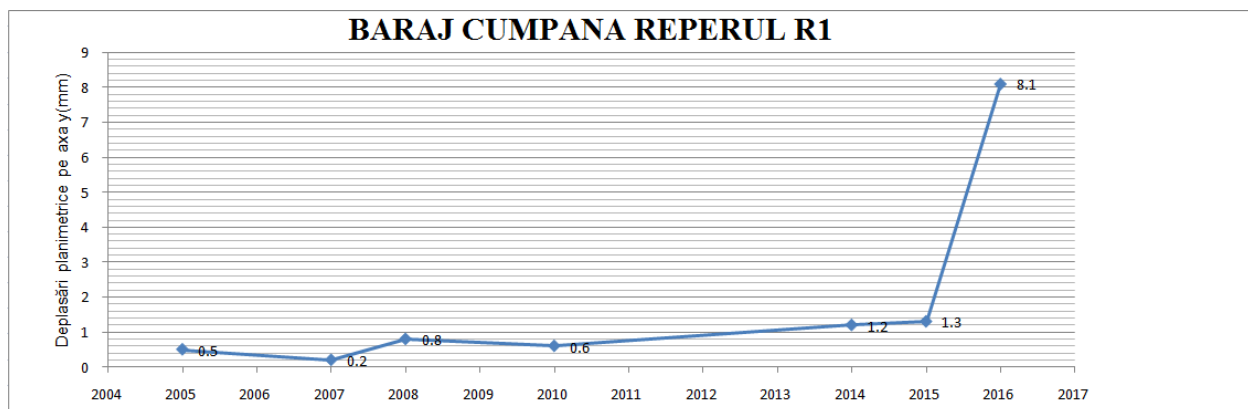
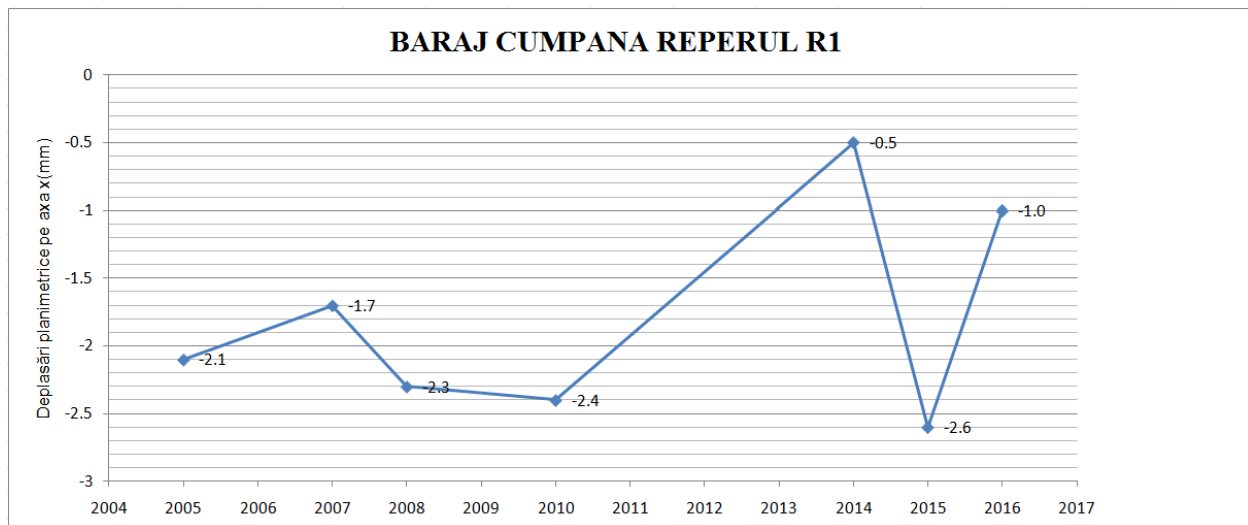
|                                             |      |
|---------------------------------------------|------|
| The weakest point determined in the network | R6   |
| - determination error on the x axis         | 2 mm |
| - determination error on the y axis         | 4 mm |
| - total error of determination              | 5 mm |
| Average error for determining a point       | 2 mm |

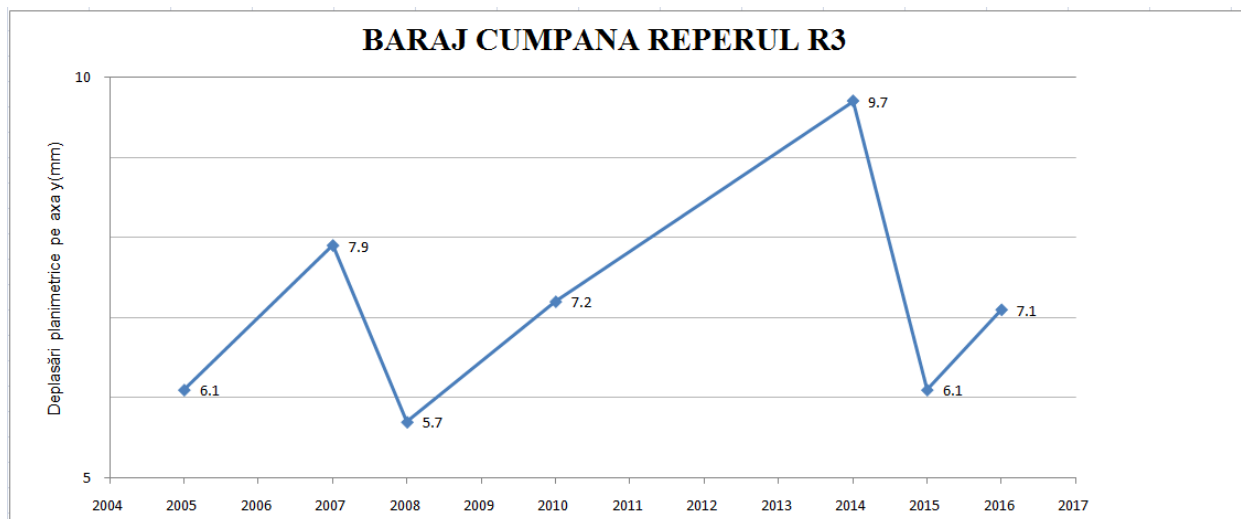
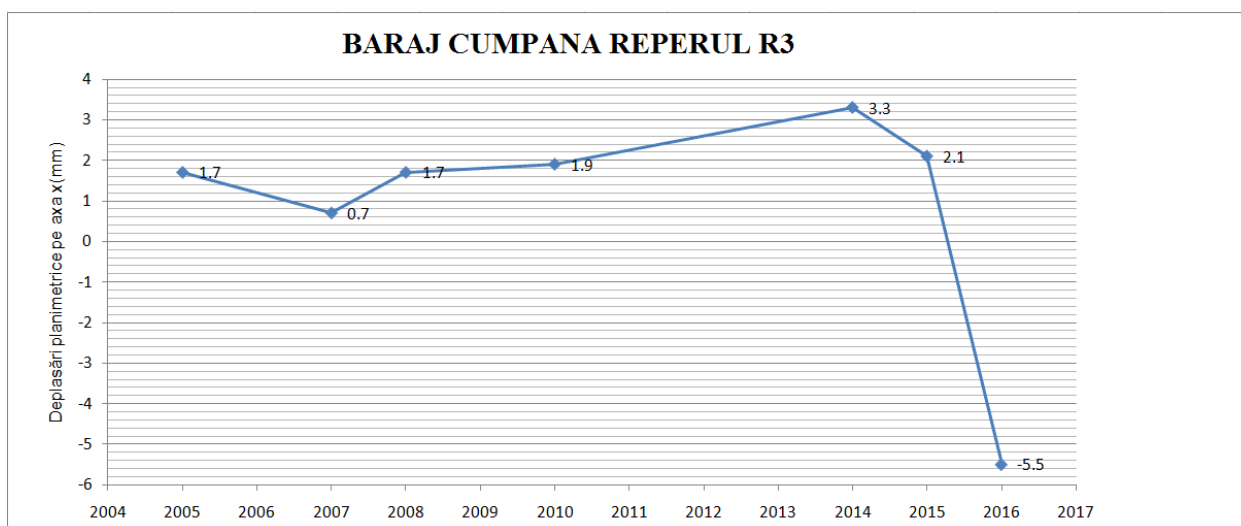
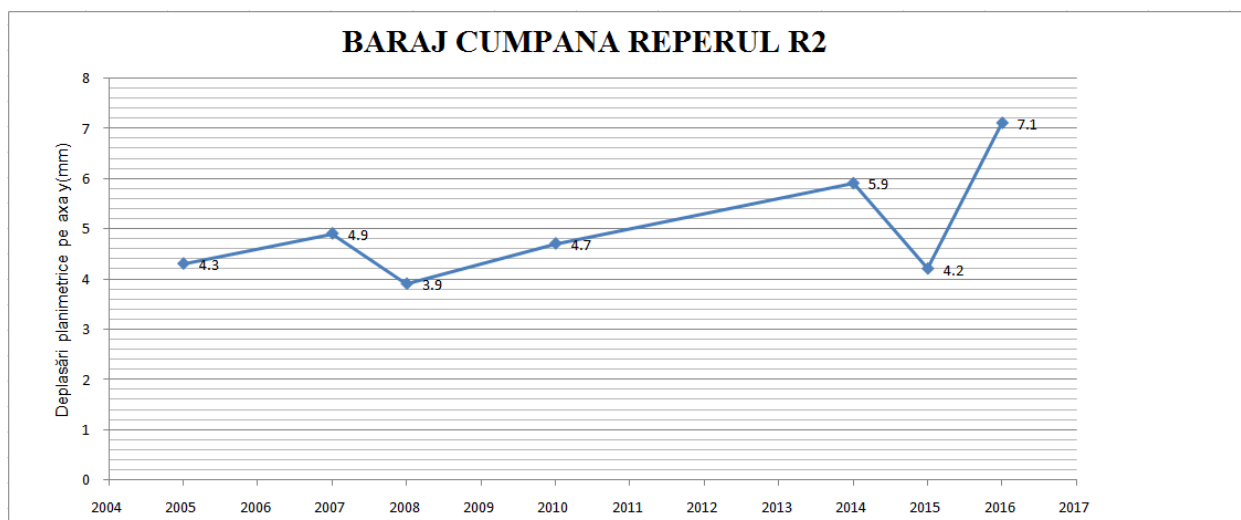
The planimetric displacements related to the base epoch are shown in Table 3.6 for each epoch.

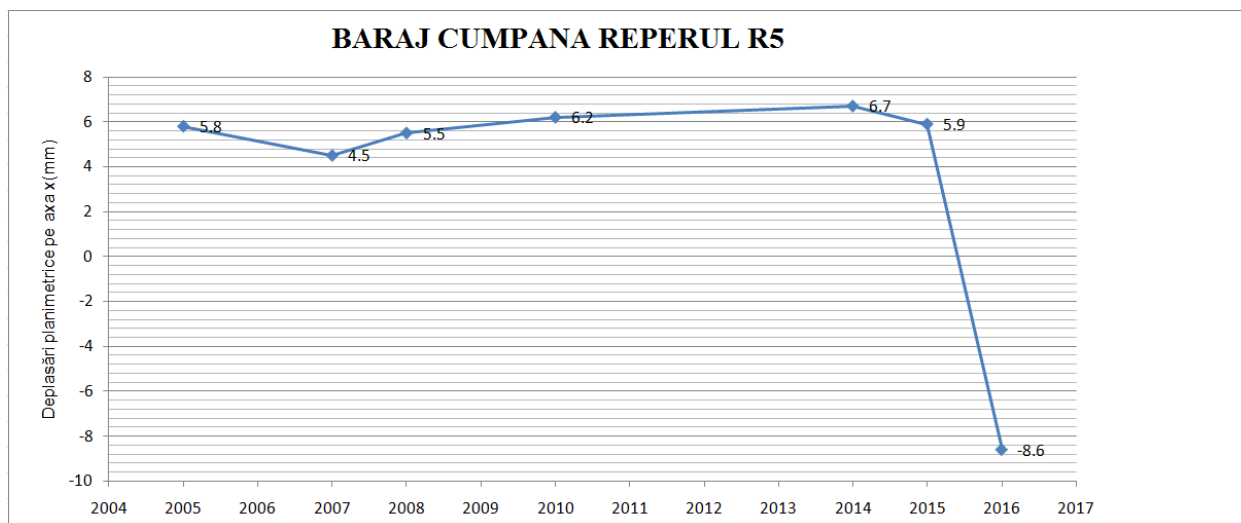
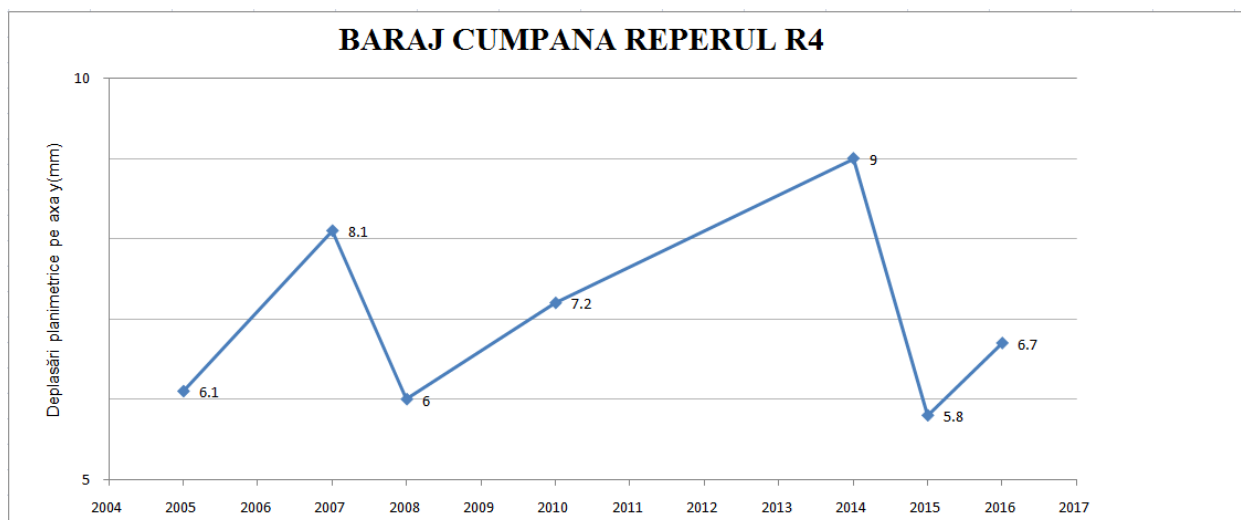
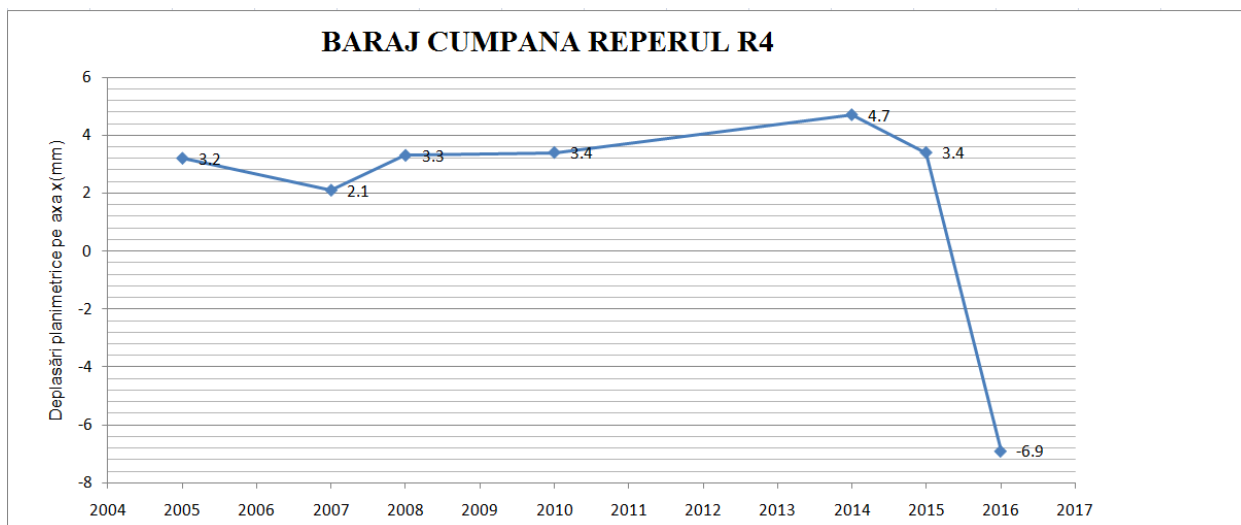
Table 3.6. Comparative table of planimetric displacements related to the base epoch

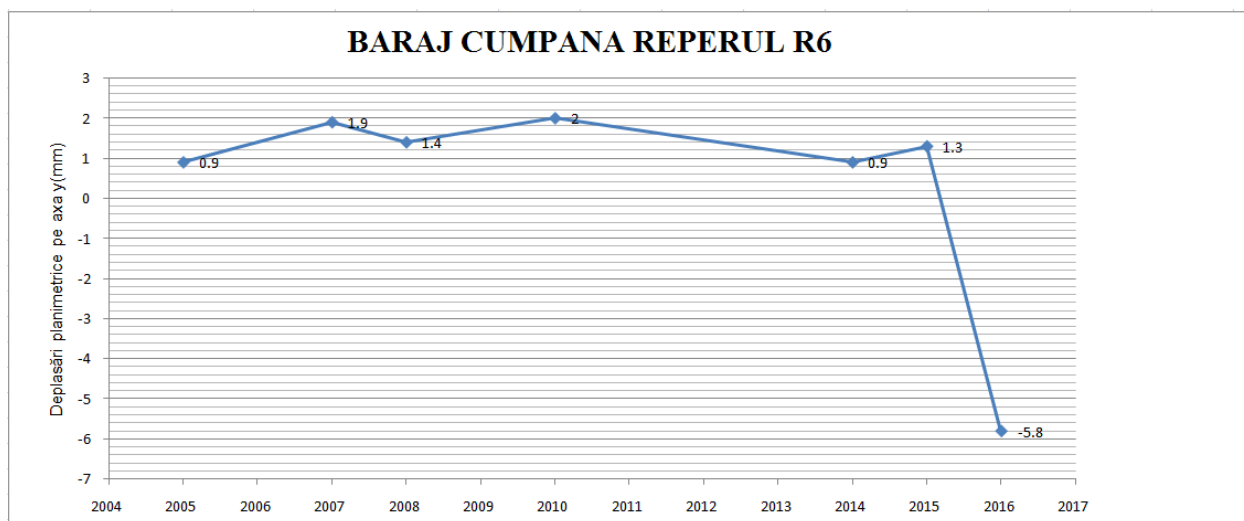
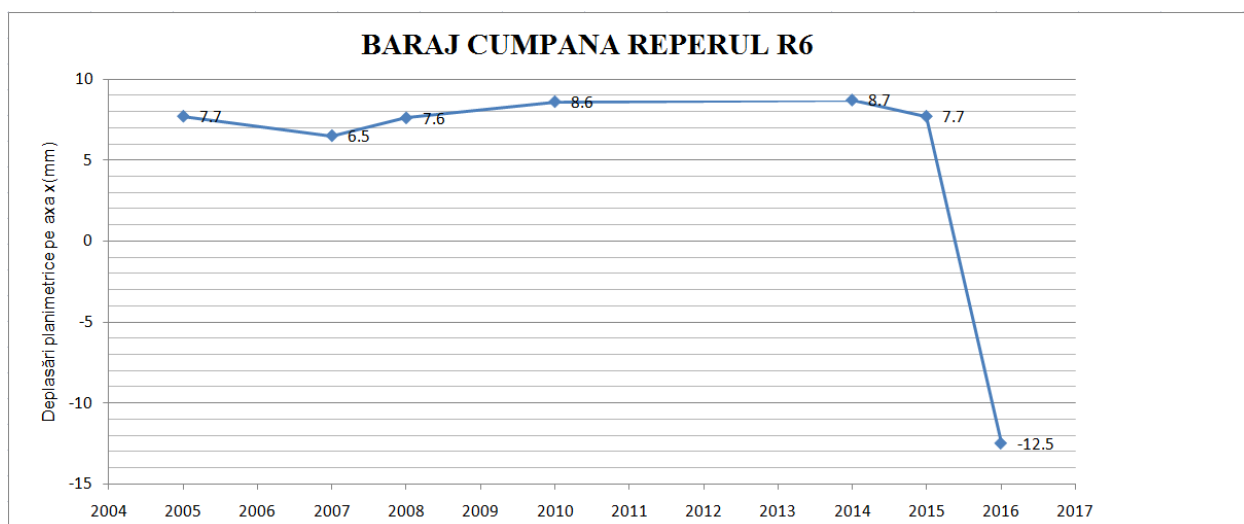
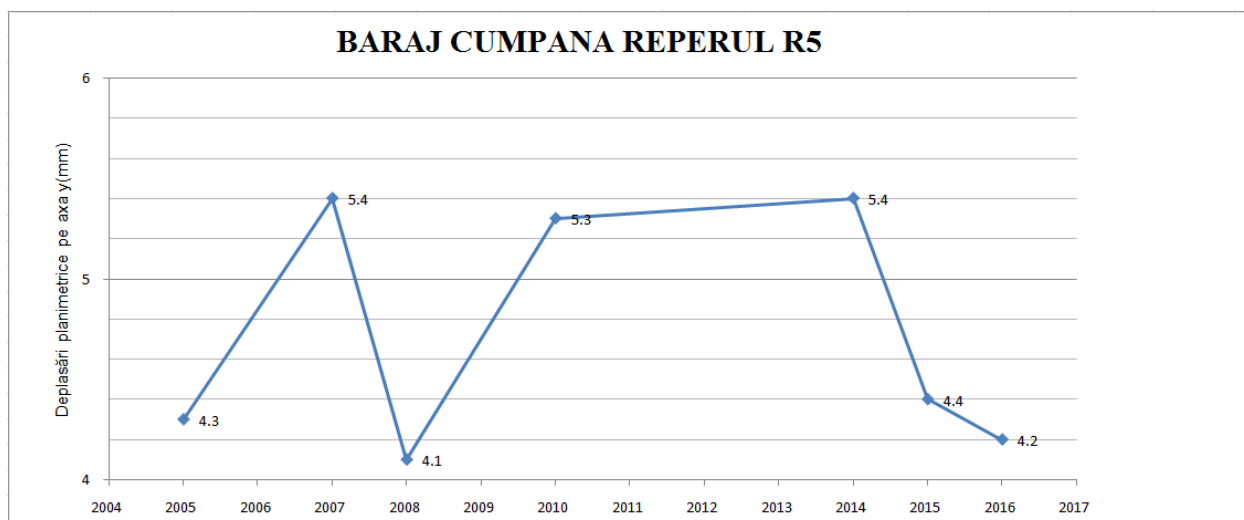
| CUMPĂNA DAM                                         |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
|-----------------------------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| PLANIMETRIC DISPLACEMENTS RELATED TO THE BASE EPOCH |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Landmark No.                                        | June 2005       |                 | September 2007  |                 | June 2008       |                 | May 2010        |                 | June 2014       |                 | May 2015        |                 | November 2016   |                 |
|                                                     | $\Delta x$ (mm) | $\Delta y$ (mm) | $\Delta x$ (mm) | $\Delta y$ (mm) | $\Delta x$ (mm) | $\Delta y$ (mm) | $\Delta x$ (mm) | $\Delta y$ (mm) | $\Delta x$ (mm) | $\Delta y$ (mm) | $\Delta x$ (mm) | $\Delta y$ (mm) | $\Delta x$ (mm) | $\Delta y$ (mm) |
| LANDMARK DEVIATIONS                                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| $\Delta D3$                                         | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | -0.1            | -0.1            |
| $\Delta D1$                                         | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 2.9             |
| $\Delta S1$                                         | 20.5            | 4.3             | 19.2            | 4.7             | 20.5            | 4.3             | 20.5            | 4.3             | 20.5            | 4.3             | 20.5            | 4.3             | 0.5             | 0.4             |
| $\Delta D2$                                         | 4.2             | 1               | 4.3             | 1.2             | 4.5             | 1.2             | 5.1             | 1.5             | 4.8             | 1.4             | 4.9             | 1.4             | 3.6             | 7.2             |
| $\Delta DB$                                         | -0.2            | 4.2             | -1.3            | 5.9             | -0.4            | 3.5             | -0.3            | 4.6             | 1               | 7.6             | 0.2             | 4.4             | -6.8            | 6.2             |
| $\Delta S2$                                         | 1.1             | 2.6             | -0.4            | 1.2             | 0.7             | 2.7             | 1.9             | 5               | 2.2             | 3.4             | 1.2             | 3.7             | -5.9            | -0.9            |
| $\Delta SB1$                                        | 3               | 5.7             | 1.7             | 6.1             | 2.4             | 5.4             | 4.2             | 6.3             | 2.9             | 6.1             | 2.8             | 5.4             | -6.3            | -4.8            |
|                                                     |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| R1                                                  | -2.1            | 0.5             | -1.7            | 0.2             | -2.3            | 0.8             | -2.4            | 0.6             | -0.5            | 1.2             | -2.6            | 1.3             | -1              | 8.1             |
| R2                                                  | -0.9            | 4.3             | -1.6            | 4.9             | -0.7            | 3.9             | -0.9            | 4.7             | 0.3             | 5.9             | -0.8            | 4.2             | -2.7            | 7.1             |
| R3                                                  | 1.7             | 6.1             | 0.7             | 7.9             | 1.7             | 5.7             | 1.9             | 7.2             | 3.3             | 9.7             | 2.1             | 6.1             | -5.5            | 7.1             |
| R4                                                  | 3.2             | 6.1             | 2.1             | 8.1             | 3.3             | 6               | 3.4             | 7.2             | 4.7             | 9               | 3.4             | 5.8             | -6.9            | 6.7             |
| R5                                                  | 5.8             | 4.3             | 4.5             | 5.4             | 5.5             | 4.1             | 6.2             | 5.3             | 6.7             | 5.4             | 5.9             | 4.4             | -8.6            | 4.2             |
| R6                                                  | 7.7             | 0.9             | 6.5             | 1.9             | 7.6             | 1.4             | 8.6             | 2               | 8.7             | 0.9             | 7.7             | 1.3             | -12.5           | -5.8            |
| R7                                                  | 7               | 0.2             | 5.2             | 0.5             | 6.2             | 0.5             | 8.8             | 0.4             | 6.8             | -0.9            | 7.1             | 0.2             | -10.8           | -2.2            |
| R8                                                  | 6.5             | 0.8             | 4.7             | 1.2             | 5.9             | 0.8             | 8.5             | 0.7             | 6.9             | -1.2            | 7               | 0.4             | -               | -               |
| R9                                                  | 6.9             | 0.3             | 4.8             | 1.1             | 6.3             | 0.3             | 8.9             | 0.2             | 6.7             | -1.2            | 7.5             | -0.3            | -9.8            | -1.9            |
| R10                                                 | 6.9             | -0.1            | 5.1             | 0.2             | 6.5             | -0.1            | 8.6             | 0.2             | 6.6             | -1.2            | 7.4             | -0.5            | -8.2            | -2.7            |

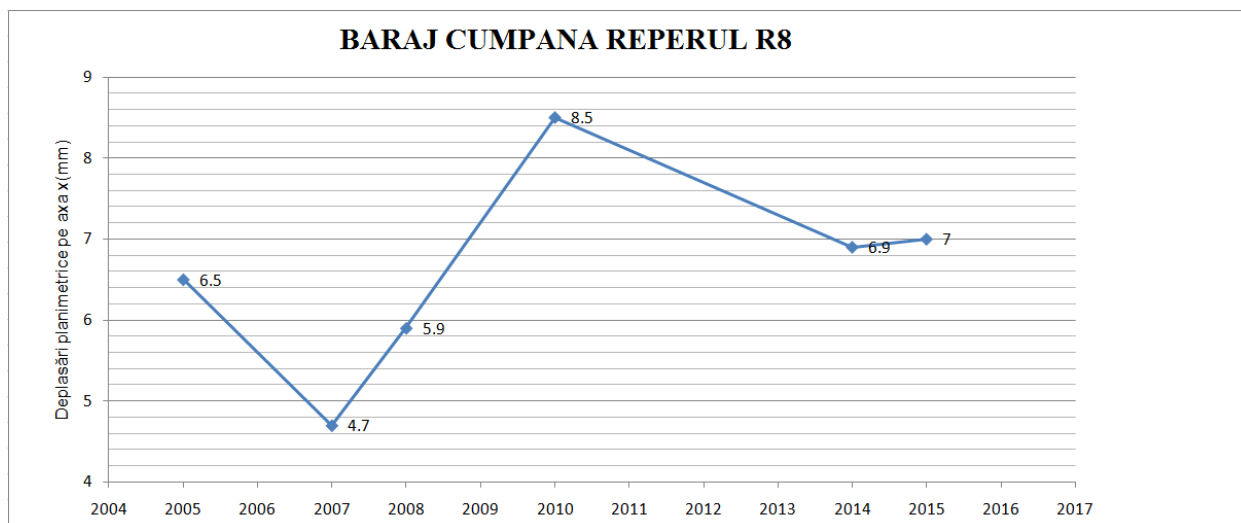
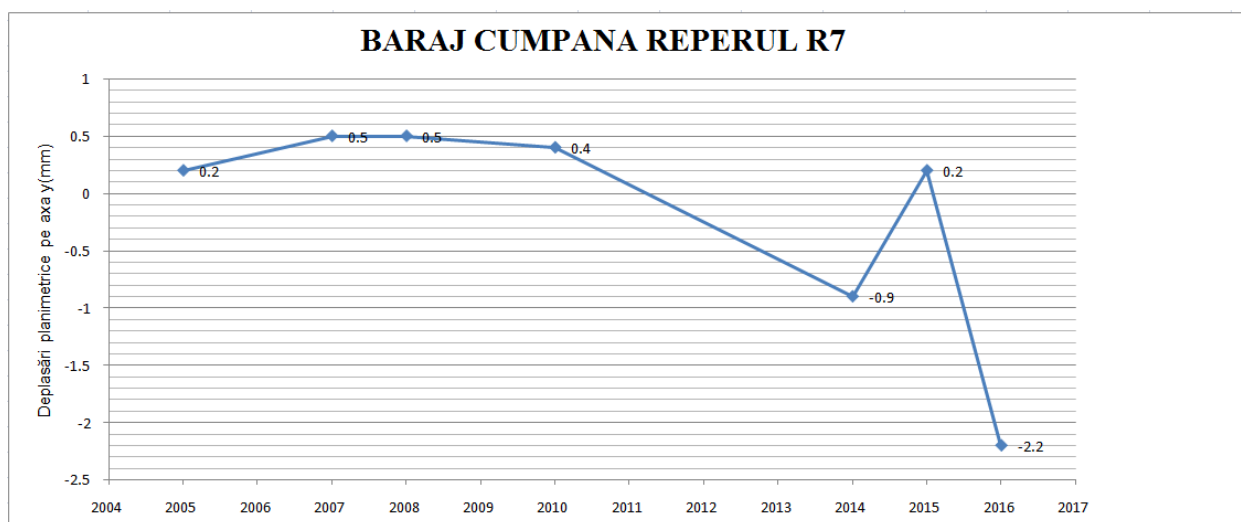
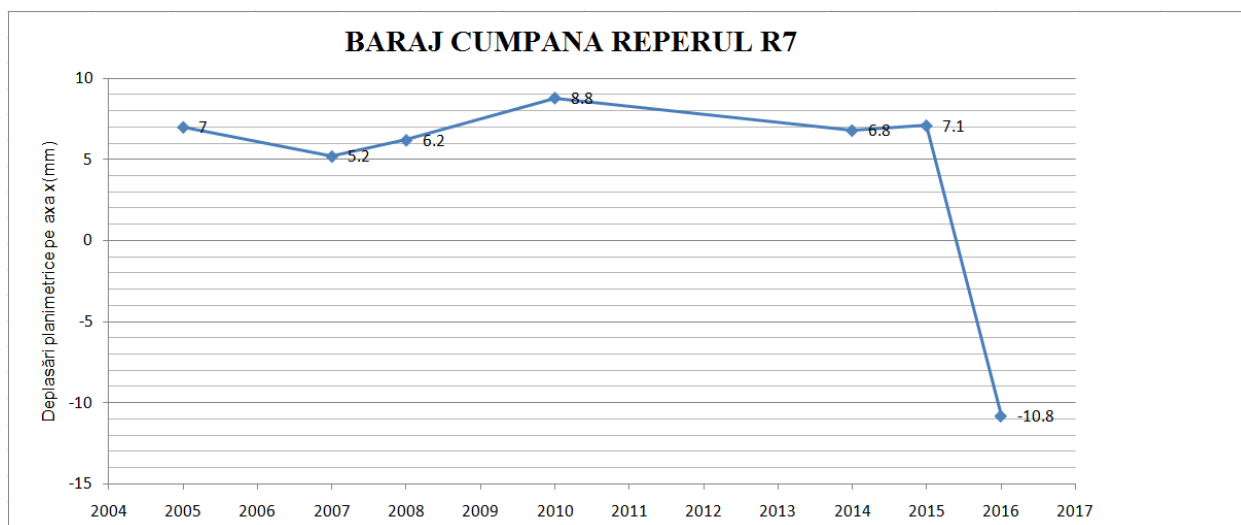
### 3.4. Graphic representation of tracking landmarks in a horizontal plane

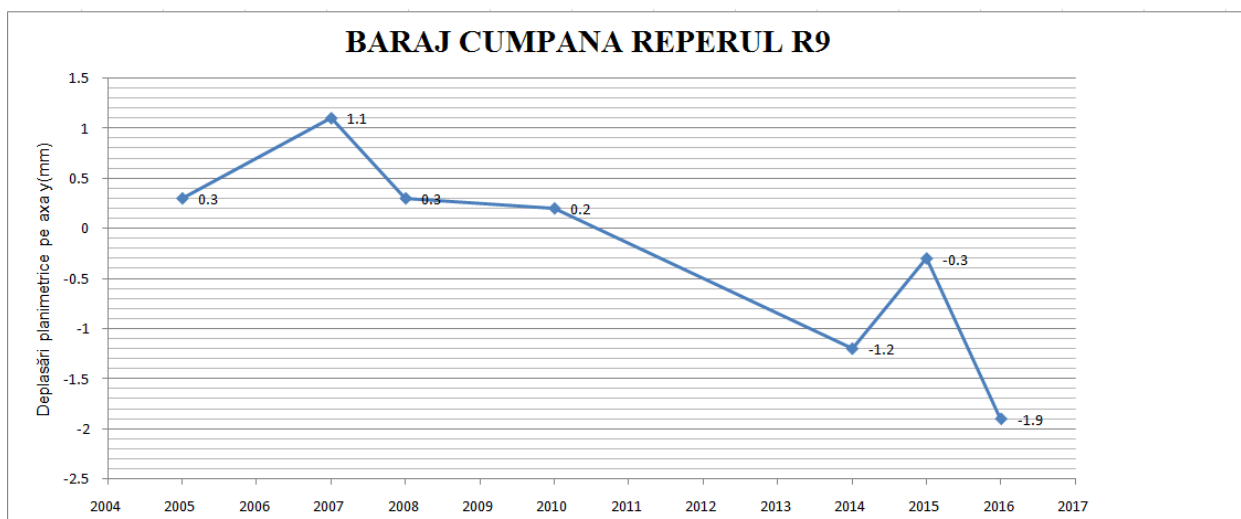
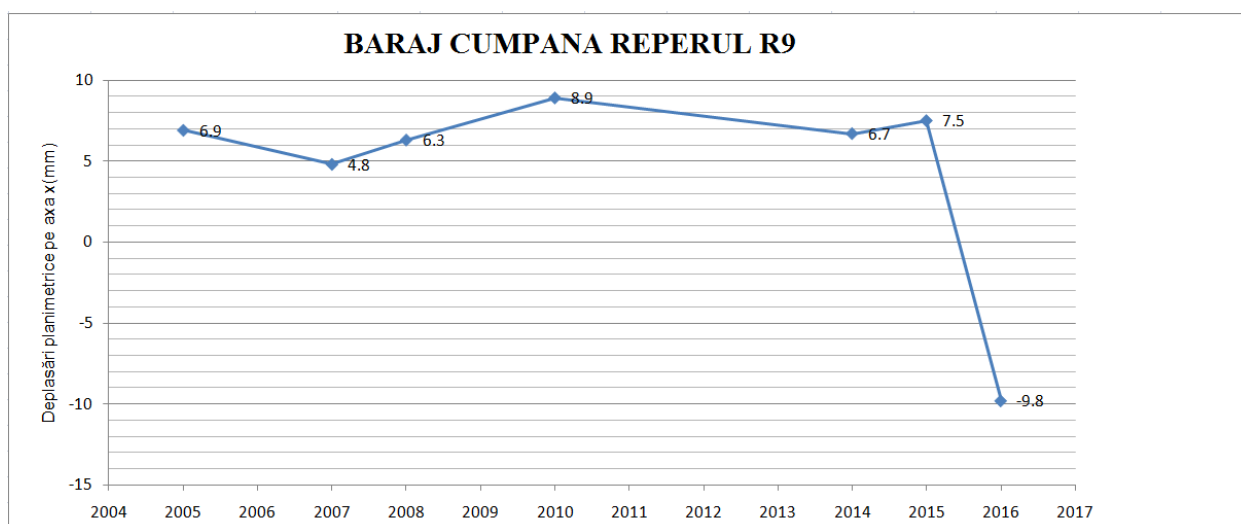
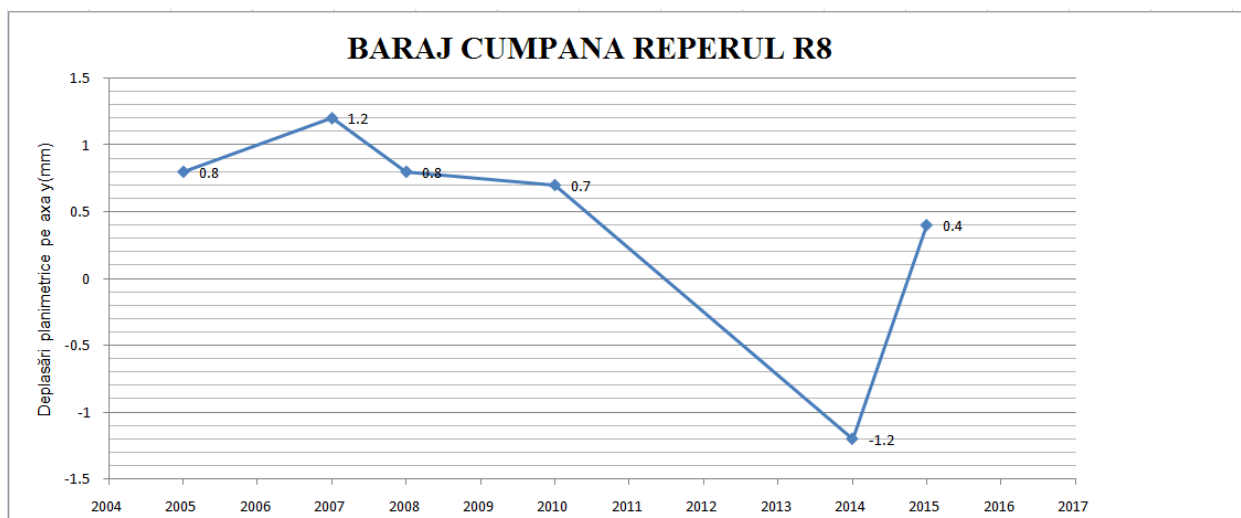


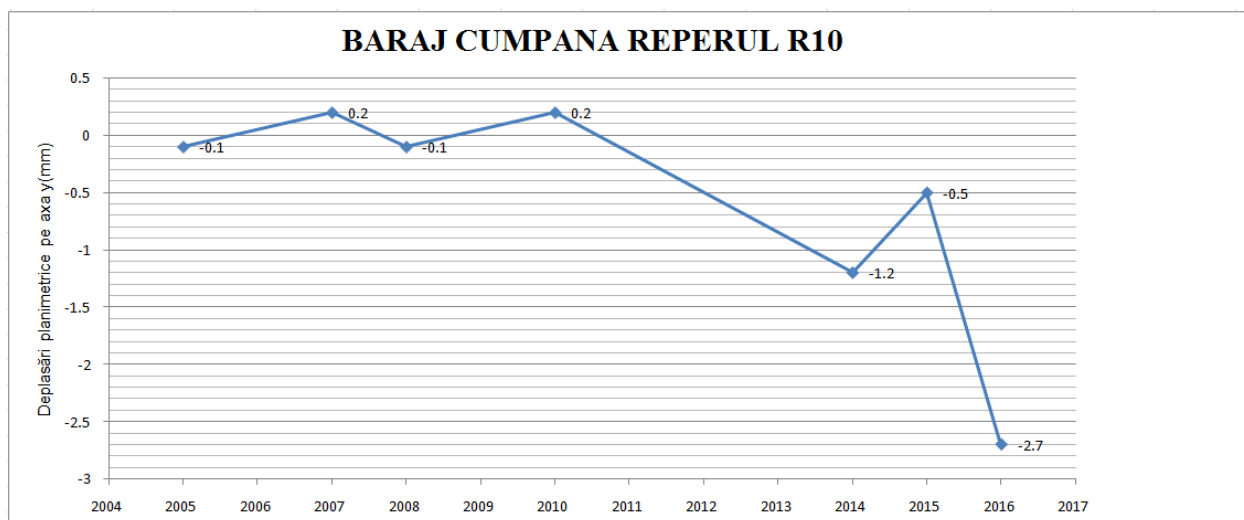
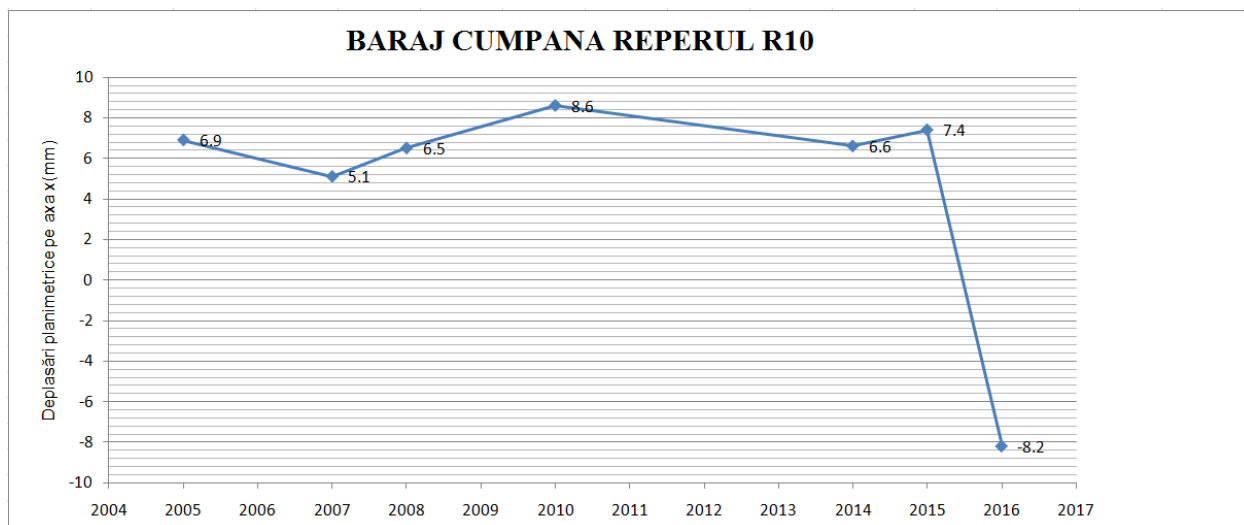












## Chapter 4 – Conclusions

### 4.1. Observations and recommendations

When performing the topo-geodetic measurements, it was found that the DB and SB1 pilasters were damaged at the top because of lack of protective caps. In this regard, it is necessary to protect them with protective caps, to prevent their degradation over time.

In order to carry out in good conditions the following microtriangulation tranches, the visibility gaps between the microtriangulation pilasters and the landmarks embedded in the dam must be widened. It is also advisable to notify the Forestry authorities about the need for these deforestations from the S.H. Curtea de Argeș patrimony..

#### **4.1. Research Perspectives**

A 3D model of Cumpăna dam and the nearby area will be made using terrestrial laser scanning and UAV technology.

Based on this 3D model, it is possible to perform mathematical analyzes and modeling related to different risk situations (floods, landslides, dam breakage, etc.).

The results obtained will be valued by attending various conferences and publishing scientific papers in various ISI quoted journals such as AgroLife, SGEM etc.

Also, an article will be published at the GeoPreVi Conference to be held in September 2017 at the Faculty of Geodesy of the Technical University of Civil Engineering in Bucharest.