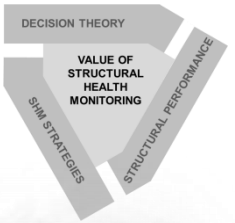
STRUCTURAL MONITORING OF ARCH DAM “PIVA” IN MONTENEGRO

Radenko Pejovic, UCG
Ivana Tesovic, UCG
Meri Cvetkovska, UKIM
Milos Knezevic, UCG
Mladen Gogic, UCG

UCG-University of Montenegro
Faculty of Civil Engineering

UKIM- Ss. Cyril and Methodius University,
Faculty of Civil Engineering, Macedonia

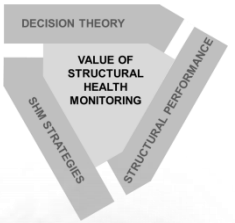


WHY WE NEED SHM OF ARCH DAMS ?

From security and safety reasons, considering that high arch dams are **objects of high risk**, permanent technical monitoring is obligatory and has to be conducted in accordance to national and international regulations.

The International Committee of large Dams (ICOLD) defines the criteria and methods of monitoring.

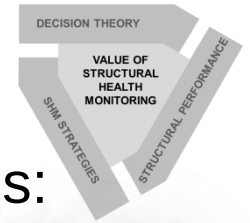
The goal of the health monitoring is to **improve safety and reliability** of the structure by predicting the possible damage or detecting the damage before it reaches a critical state.



Technical monitoring of the dam is **set of activities** that provide **precise measurements** of deformations and movements of the structure.

Technical monitoring means measurement of **any physical quantity** that could be analyzed and interpreted and, as a result of these measurements, the stress-strain condition of the structure, of the foundation and the surrounding rock mass could be defined.

These results are important from the aspect of stability and permeability and have to be conducted **during the construction**, **after the initial filling and during the operational stage**.



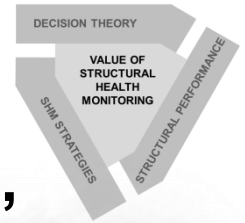
Technical monitoring of the dam is **set of activities**, such us:

- development of monitoring program,
- installation of equipment for monitoring,
- regular registration of measurements,
- evaluation of registered values in order to define stress-strain state of dam and
- dam safety evaluation.

One of the most important segments of the technical monitoring is **definition of limit values** for the parameters which are important for dam safety evaluation.

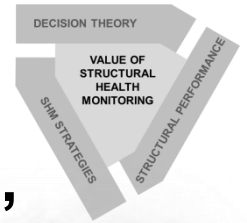
These limit values are defined **on the basis of structural analysis** in the detailed design and the measurements in the period of initial filling and during the first few years of the operational stage.

The limit values define **envelopes** which could be adopted in time.



STRUCTURAL MONITORING OF ARCH DAM "PIVA"

- Dam „Piva" is concrete, asymmetric high (large) arch dam, built on river Piva in 1976
- **Structural height** of the dam is 220 m.
- **Arch length** at the crown is 268,65 m, and at the river bed is 40,00 m.
- **Crown thickness** is 4,51 m and base thickness is 45,00 m.
- Dam is constructed of **18 cantilevers** and has **five revision galleries** at following levels: 642,602, 562, 522 i 482
- Level of the dam crown is 678,00 m.

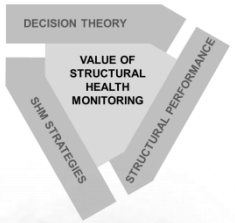


STRUCTURAL MONITORING OF ARCH DAM "PIVA"

Technical monitoring of dam „Piva" consists of:

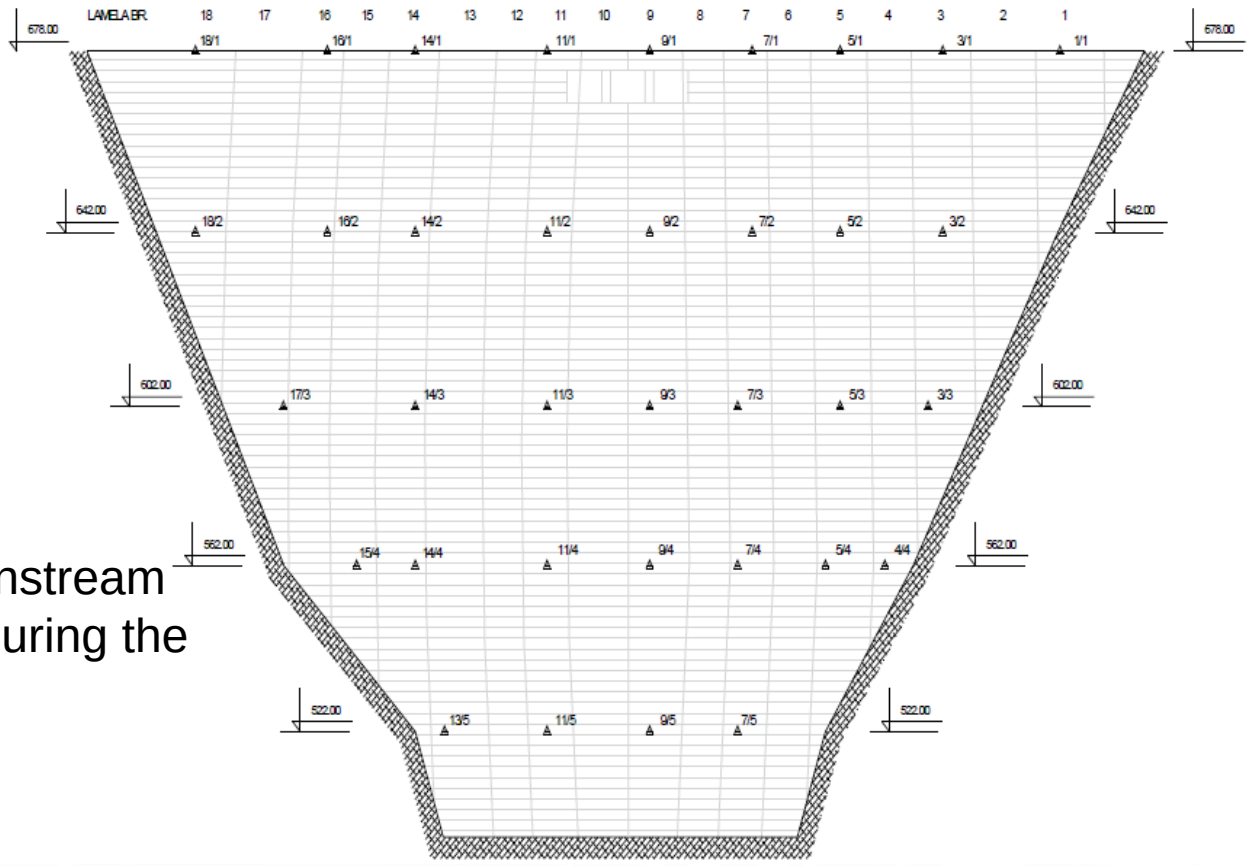
- Geodetic monitoring;
- Mechanical and telemetric monitoring;
- Hydrological and meteorological monitoring;
- Seismic monitoring.

Monitoring is carried out at about 1000 measuring points. One part of measuring points are destroyed during exploitation and they do not work at the moment.



Geodetic monitoring:

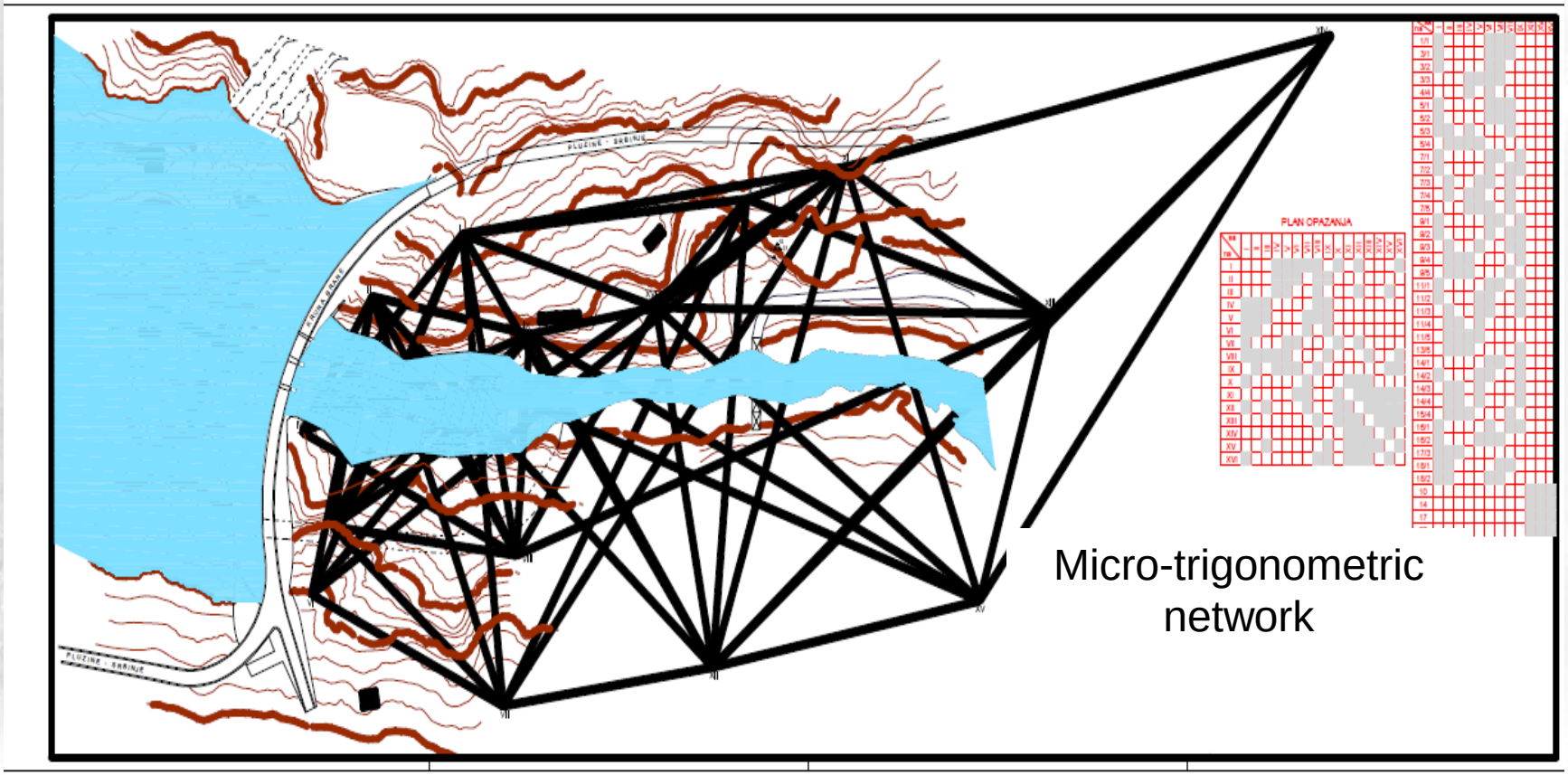
Measurement of **horizontal displacements** in radial and transversal direction on downstream side.



Position of points on downstream side of the dam, for measuring the horizontal displacements

Geodetic monitoring:

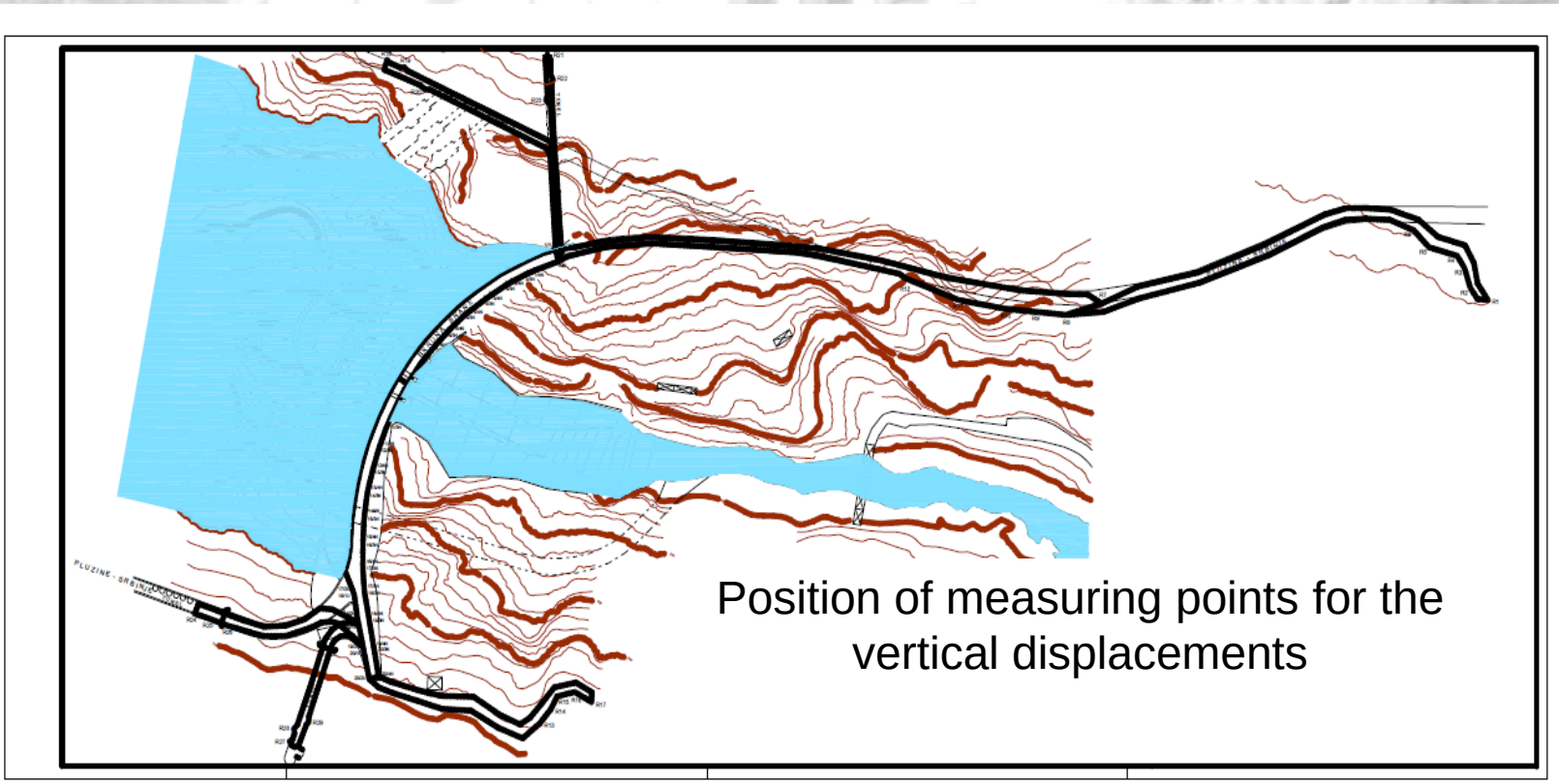
Measurement of **horizontal displacements** in radial and transversal direction on downstream side.



Micro-trigonometric network

Geodetic monitoring:

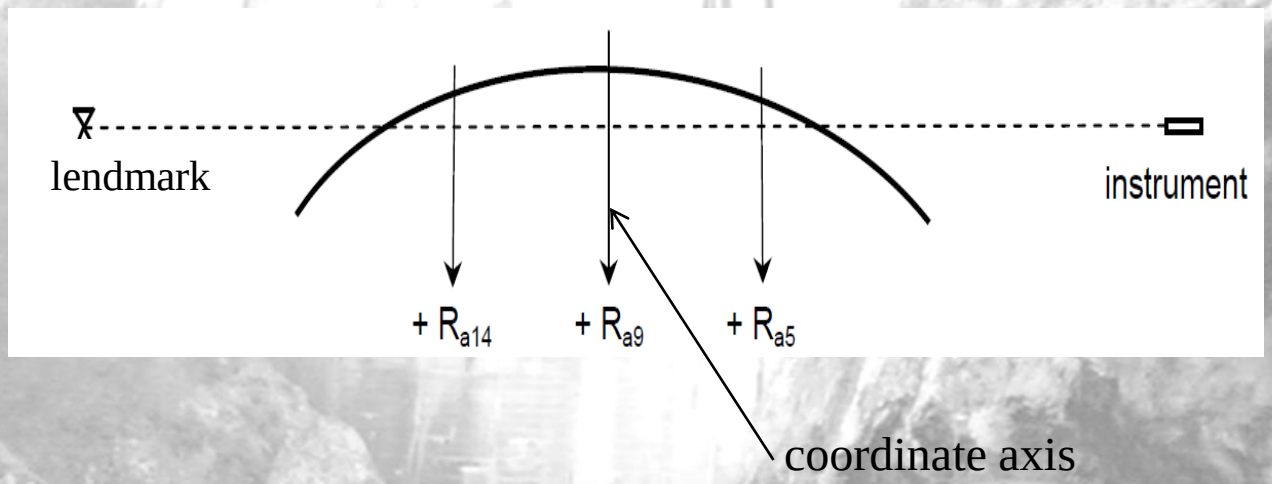
Vertical surface displacements are measured by conventional **differential leveling survey**. Measuring points are established on the crown of the dam.

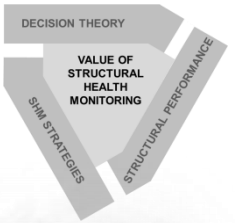


Position of measuring points for the vertical displacements

Geodetic monitoring:

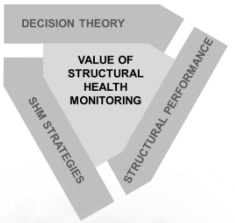
Tiltmeter– for measuring the vertical rotation of cantilevers 5, 9 and 14





Mechanical and telemetric monitoring include measurement of:

- lateral deformations,
- dilatation of radial joints,
- dam inclination (tilt),
- rock deformation,
- ground pressure,
- buoyancy (uplift) on base joint,
- pore pressure and
- concrete temperature.



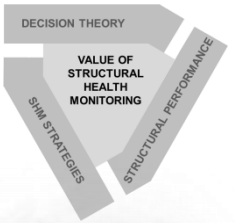
- **Lateral deformations**

  Direct and inverted pendulums as simple, and very reliable and accurate systems, were used to monitor internal lateral deformations of the dam.

  Direct pendulums are placed in cantilevers 5, 9 and 14.

  Inverted pendulums are placed under the base joint, on depth of 30m, where the rock deformation is negligible.

  From 1991 till now, the results obtained by geodetic surveying and by measuring with the pendulum are perfectly matched.



- **<u>Dilatation of radial joints</u>**

  A total number of **54 deformeters** are placed at 5 levels: 482, 522,562, 602 and 642m, in revision galleries and at the cantilever joints.

  The water level and the concrete temperature have dominant influence on the dilatation of joints.

  The effect is extreme in autumn, when the water level is decreased and the cooling of concrete starts and in spring, for opposite case.

- **Dam inclination**

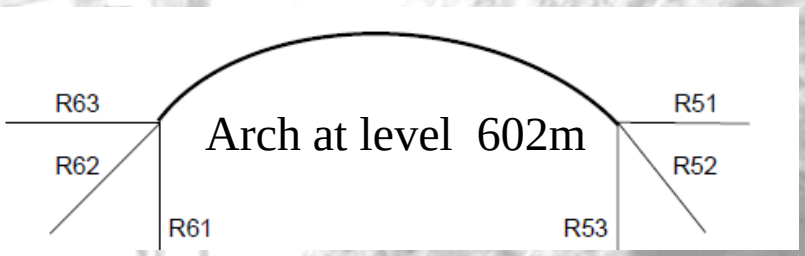
  A total number of **35 inclinometers** are placed at 6 levels of the cantilevers 3,5,7,9, 14 and 17.

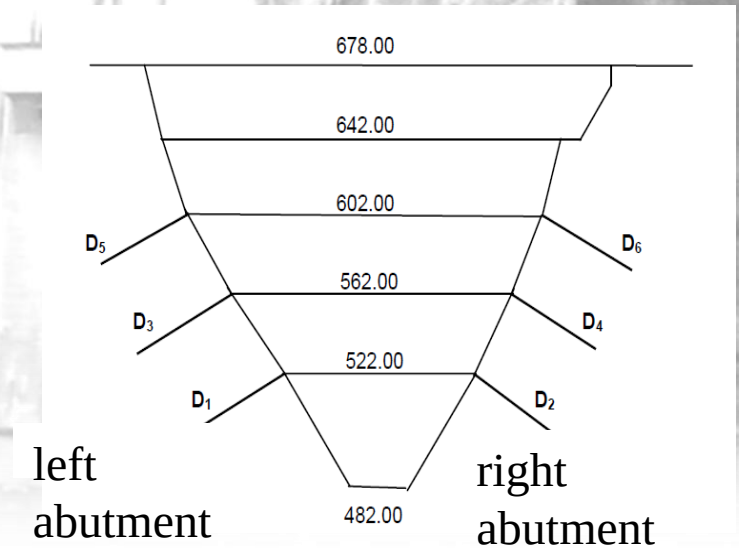
- **Rock deformation**

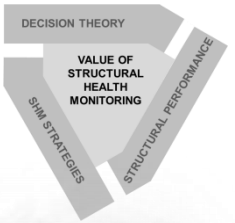
  Rock extensometers are set at 3 levels

  and

  Deflectometers are set at 3 levels







Hydrological monitoring

Groundwater level is measured by 53 piezometers
(18 in the left abutment and 35 in the right abutment).

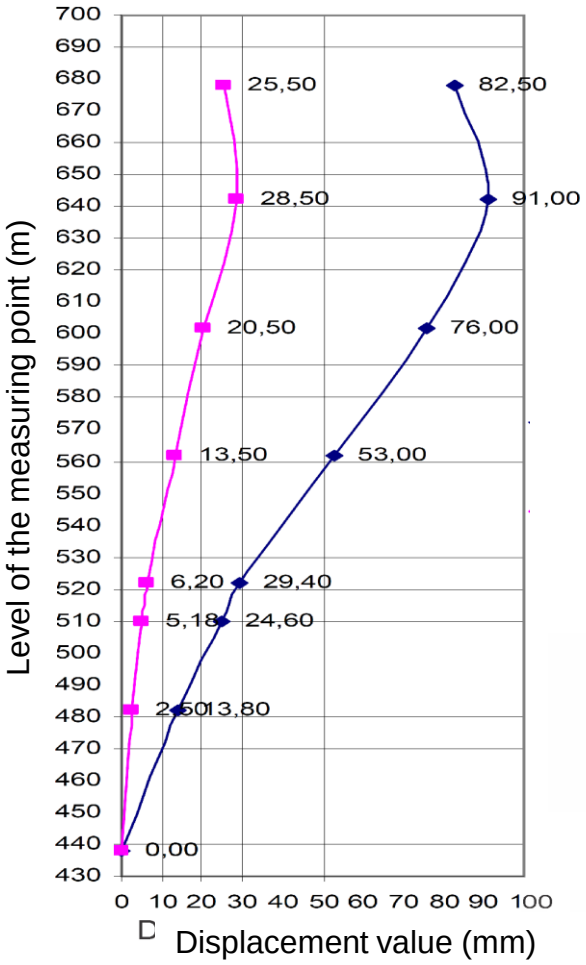
Hydrological and meteorological monitoring

Measurements of accumulation level, air and water temperature, drainage, precipitation and relative humidity.

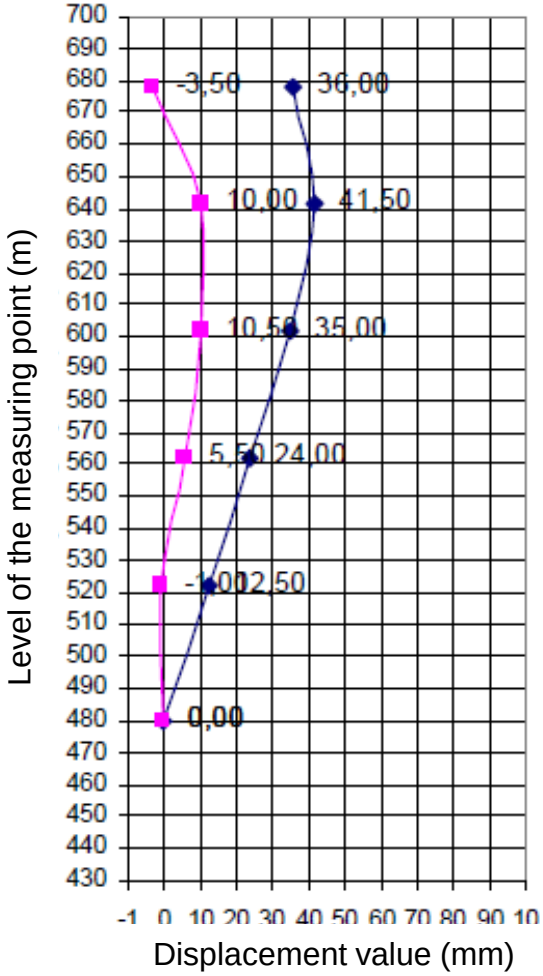
Seismic monitoring done by accelerograph type SMA-1.

Location of the dam is in a **seismic zone VII**.
(**Results will be presented at the next workshop**).

Numerically achieved results for the **envelopes of the limit displacements** (as function of the water level, air temperature and deformation of the foundation, caused by dam's weight and the accumulation)



Cantilever L9 (central)



Cantilever L5

Max. limit value of radial displacement Ec=18000N/mm^2

Min. limit value of radial displacement, Ec=40000N/mm^2

MONITORING RESULTS

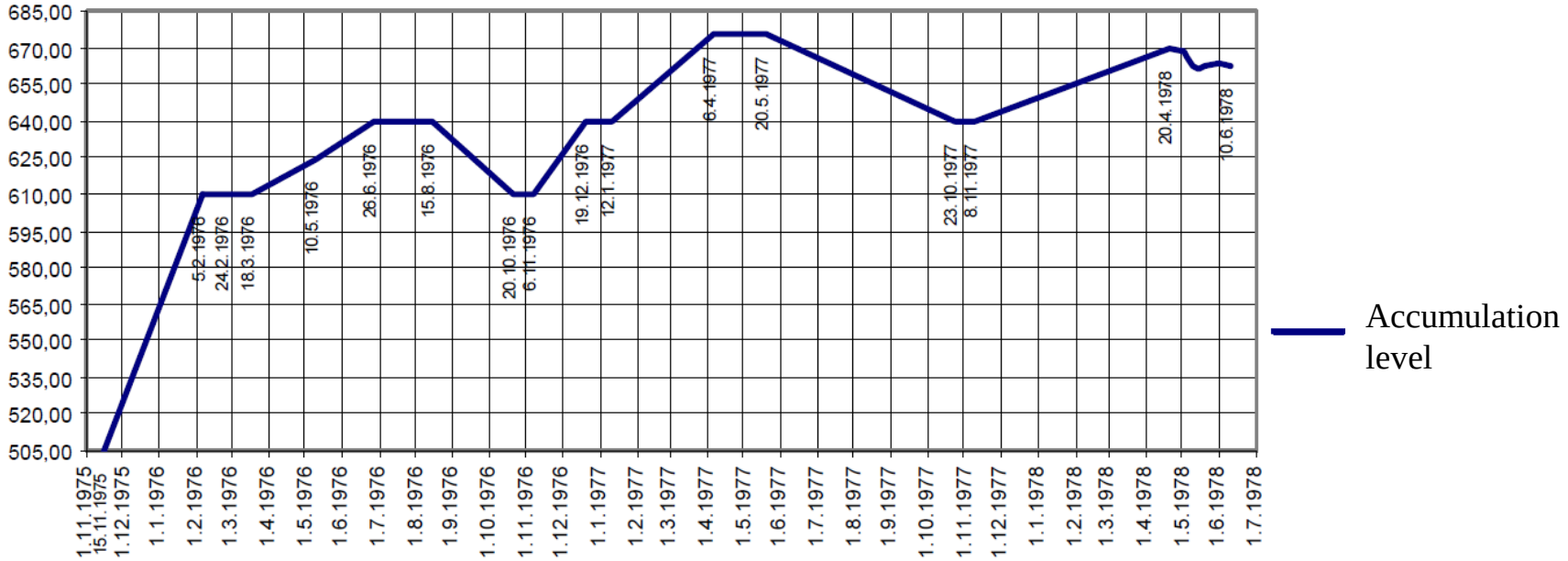
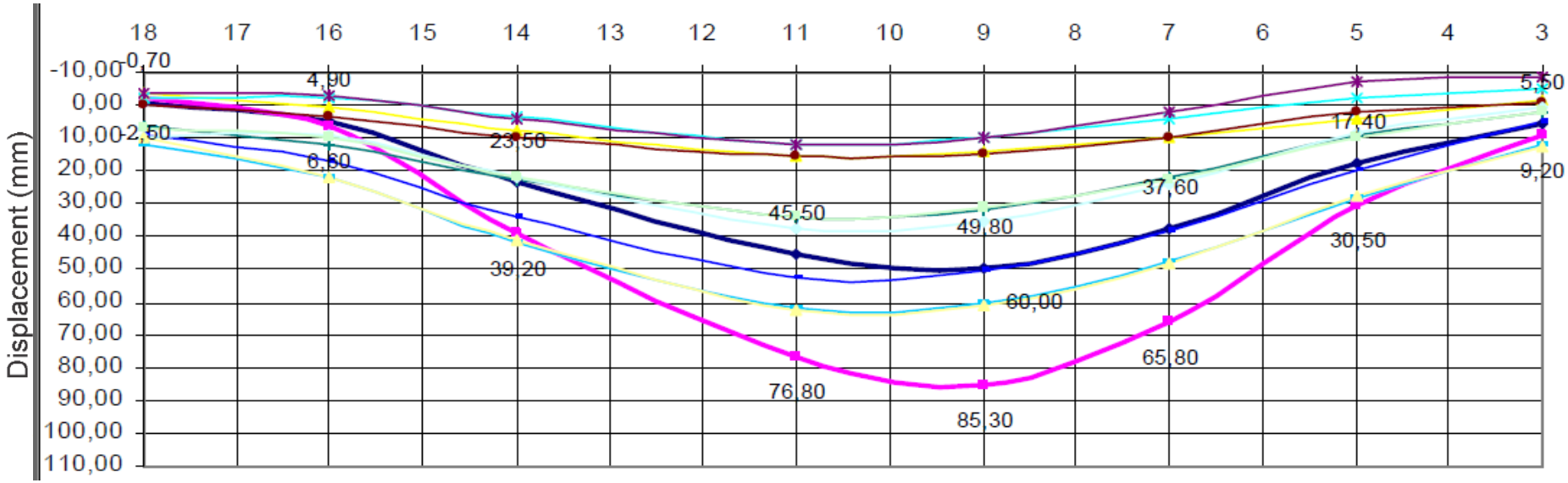


Diagram of water level during the initial filling of the dam ‘PIVA’

Diagram of radial displacements at level 678 m, during the initial filling, 1976-1978



Radial displacement (mm) za Eb=40000 Nmm^2

Radial displacement (mm) za Eb=18000 Nmm^2

I control geodetic measurement 19.2.1976 (accumulation level 610 m.el.) t_{air}=-2^{o}C

II control geodetic measurement 07.5.1976 (accumulation level 622.5 m.el.) t_{air}=12.1^{o}C

III control geodetic measurement 11.7.1976 (accumulation level 640 m.el.) t_{air}=16.5^{o}C

IV control geodetic measurement 28.10.1976 (accumulation level 610 m.el.) t_{air}=7.0^{o}C

V control geodetic measurement 24.12.1976 (accumulation level 640 m.el.) t_{air}=-6.0^{o}C

VI control geodetic measurement 09.3.1977 (accumulation level 666.5 m.el.) t_{air}=4.3^{o}C

VII control geodetic measurement 17.4.1977 (accumulation level 675 m.el.) t_{air}=5.1^{o}C

VIII control geodetic measurement 10.9.1977 (accumulation level 658 m.el.) t_{air}=9.8^{o}C

IX control geodetic measurement 30.10.1977 (accumulation level 640 m.el.) t_{air}=3.7^{o}C

X control geodetic measurement 22.4.1978 (accumulation level 669 m.el.) t_{air}=5.9^{o}C

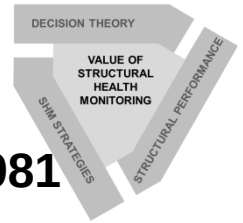
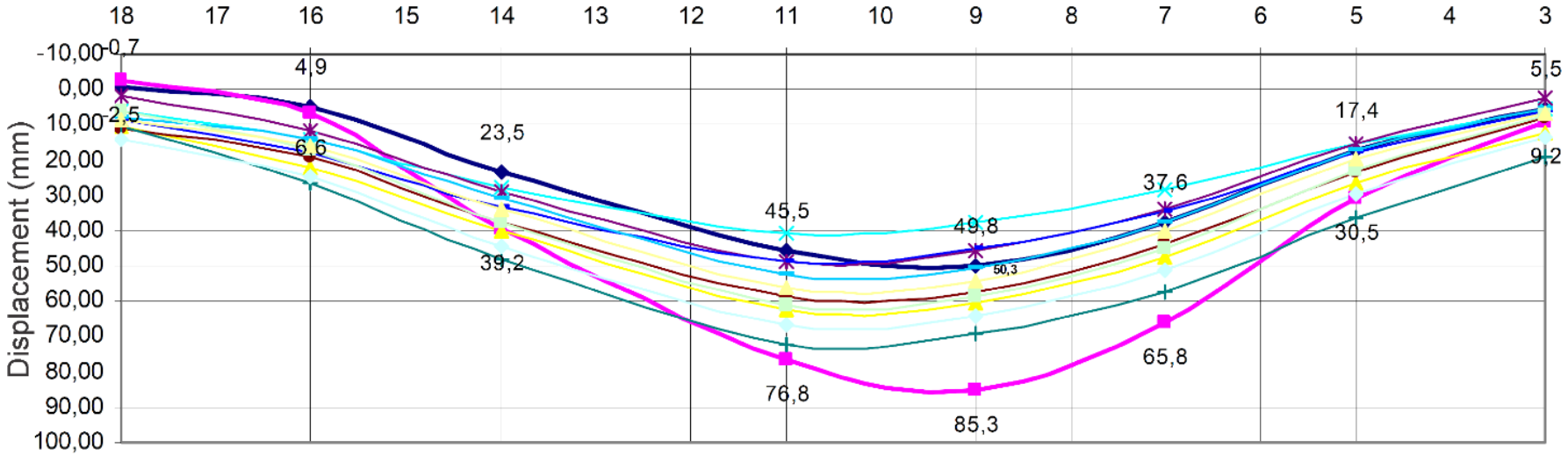
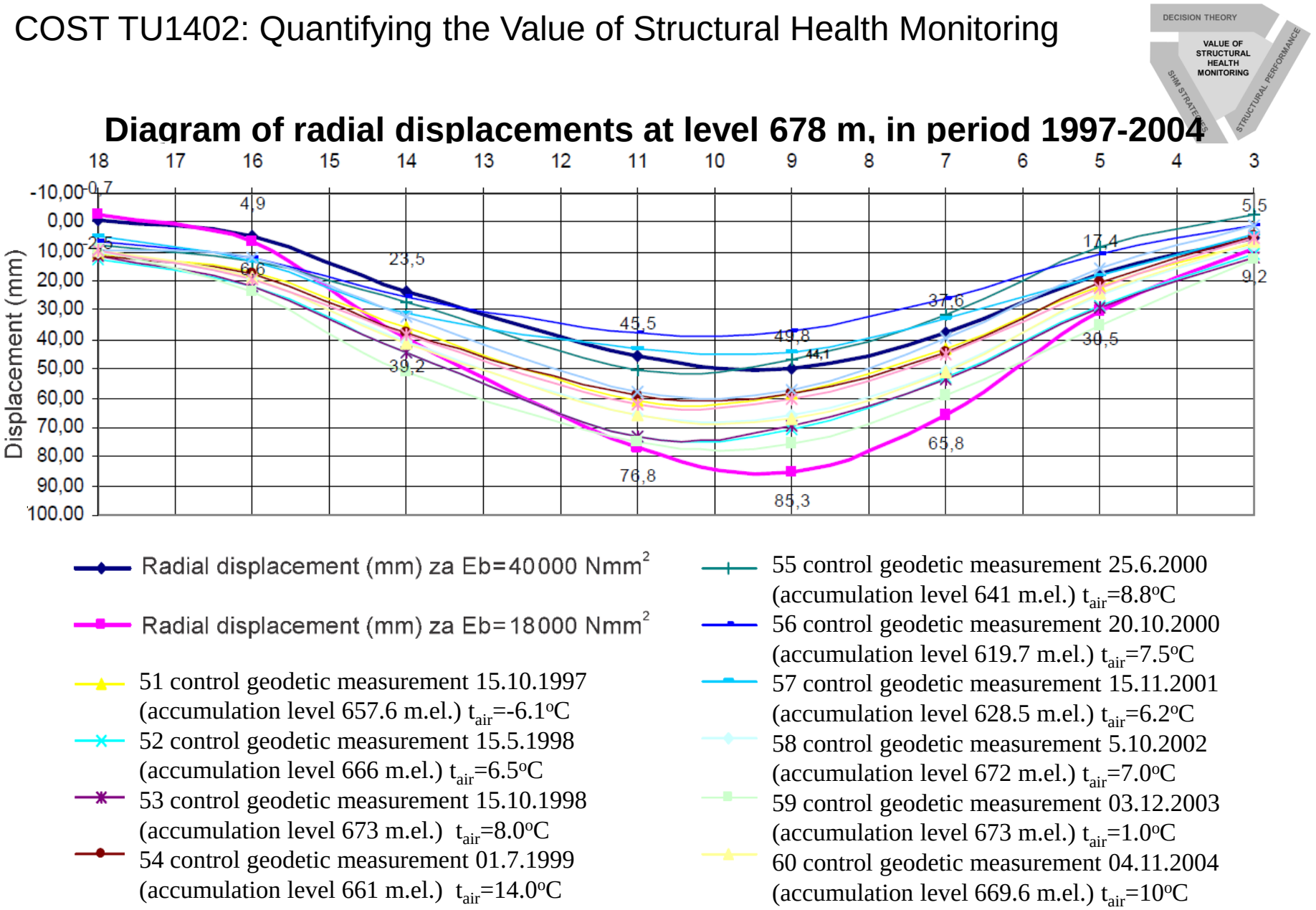
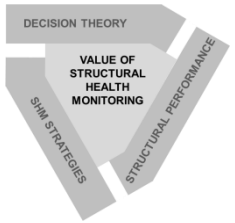


Diagram of radial displacements at level 678 m, in period 1978-1981

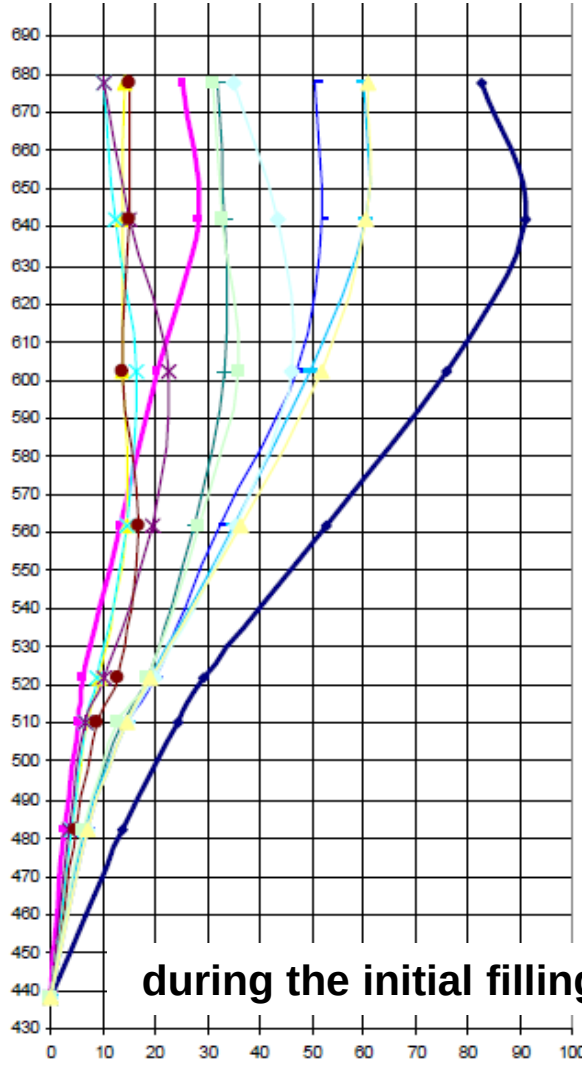


- Radial displacement (mm) za Eb=40000 Nmm^2
- Radial displacement (mm) za Eb=18000 Nmm^2
- 11. control geodetic measurement 06/06/1978 (accumulation level) 674.00 m.el. t_{air} =9.0°C
- 12. control geodetic measurement 11/12/1978 (accumulation level) 610.00 m.el. t_{air} =1.1°C
- 13. control geodetic measurement 23/04/1979 (accumulation level) 655.10 m.el. t_{air} =6.4°C
- 14. control geodetic measurement 27/07/1979 (accumulation level) 673.20 m.el. t_{air} =19.1°C
- 15. control geodetic measurement 08/12/1979 (accumulation level) 671.80 m.el. t_{air} =2.5°C
- 16. control geodetic measurement 20/04/1980 (accumulation level) 632.30 m.el. t_{air} =6.0°C
- 17. control geodetic measurement 05/09/1980 (accumulation level) 667.90 m.el. t_{air} =8.3°C
- 18. control geodetic measurement 13/11/1980 (accumulation level) 670.50 m.el. t_{air} =4.4°C
- 19. control geodetic measurement 25/04/1981 (accumulation level) 666.50 m.el. t_{air} =5.6°C
- 20. control geodetic measurement 17/07/1981 (accumulation level) 669.90 m.el. t_{air} =16.5°C


DECISION THEORY
VALUE OF STRUCTURAL HEALTH MONITORING
SHM STRATEGIES
STRUCTURAL PERFORMANCE
Diagram of radial displacements at level 678 m, in period 1997-2004
18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3
Displacement (mm)
-10,00 0,00 10,00 20,00 30,00 40,00 50,00 60,00 70,00 80,00 90,00 100,00
0,7
4,9
2,5
6,6
23,5
39,2
45,5
76,8
49,8
44,1
85,3
37,6
65,8
17,4
30,5
5,5
9,2
Radial displacement (mm) za Eb=40000 Nmm2
Radial displacement (mm) za Eb=18000 Nmm2
51 control geodetic measurement 15.10.1997 (accumulation level 657.6 m.el.) tair=-6.1oC
52 control geodetic measurement 15.5.1998 (accumulation level 666 m.el.) tair=6.5oC
53 control geodetic measurement 15.10.1998 (accumulation level 673 m.el.) tair=8.0oC
54 control geodetic measurement 01.7.1999 (accumulation level 661 m.el.) tair=14.0oC
55 control geodetic measurement 25.6.2000 (accumulation level 641 m.el.) tair=8.8oC
56 control geodetic measurement 20.10.2000 (accumulation level 619.7 m.el.) tair=7.5oC
57 control geodetic measurement 15.11.2001 (accumulation level 628.5 m.el.) tair=6.2oC
58 control geodetic measurement 5.10.2002 (accumulation level 672 m.el.) tair=7.0oC
59 control geodetic measurement 03.12.2003 (accumulation level 673 m.el.) tair=1.0oC
60 control geodetic measurement 04.11.2004 (accumulation level 669.6 m.el.) tair=10oC



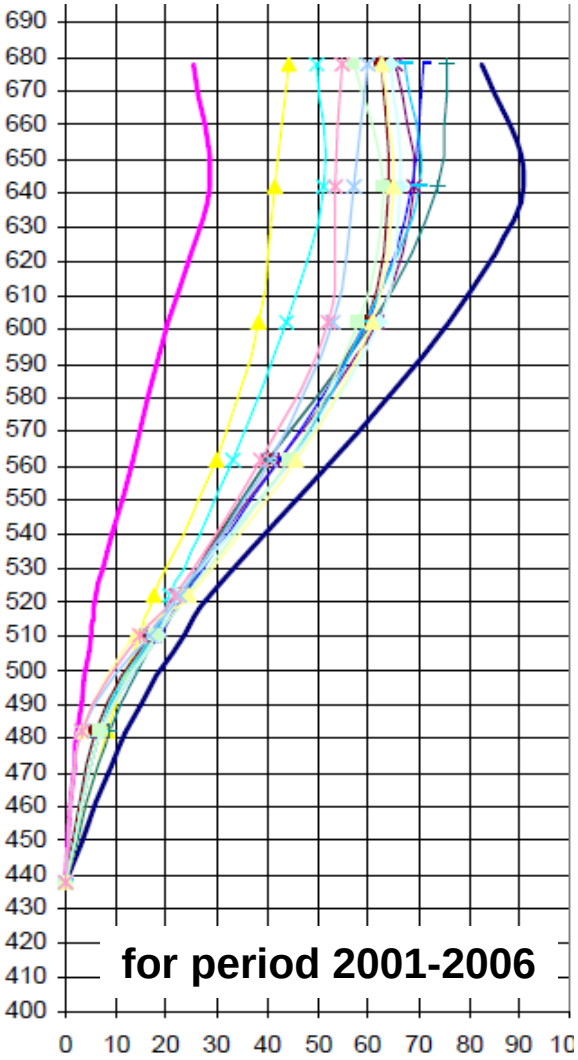
Comparison of measured and limit displacements for the cantilever L9 (central),



Max. limit value of radial displacement

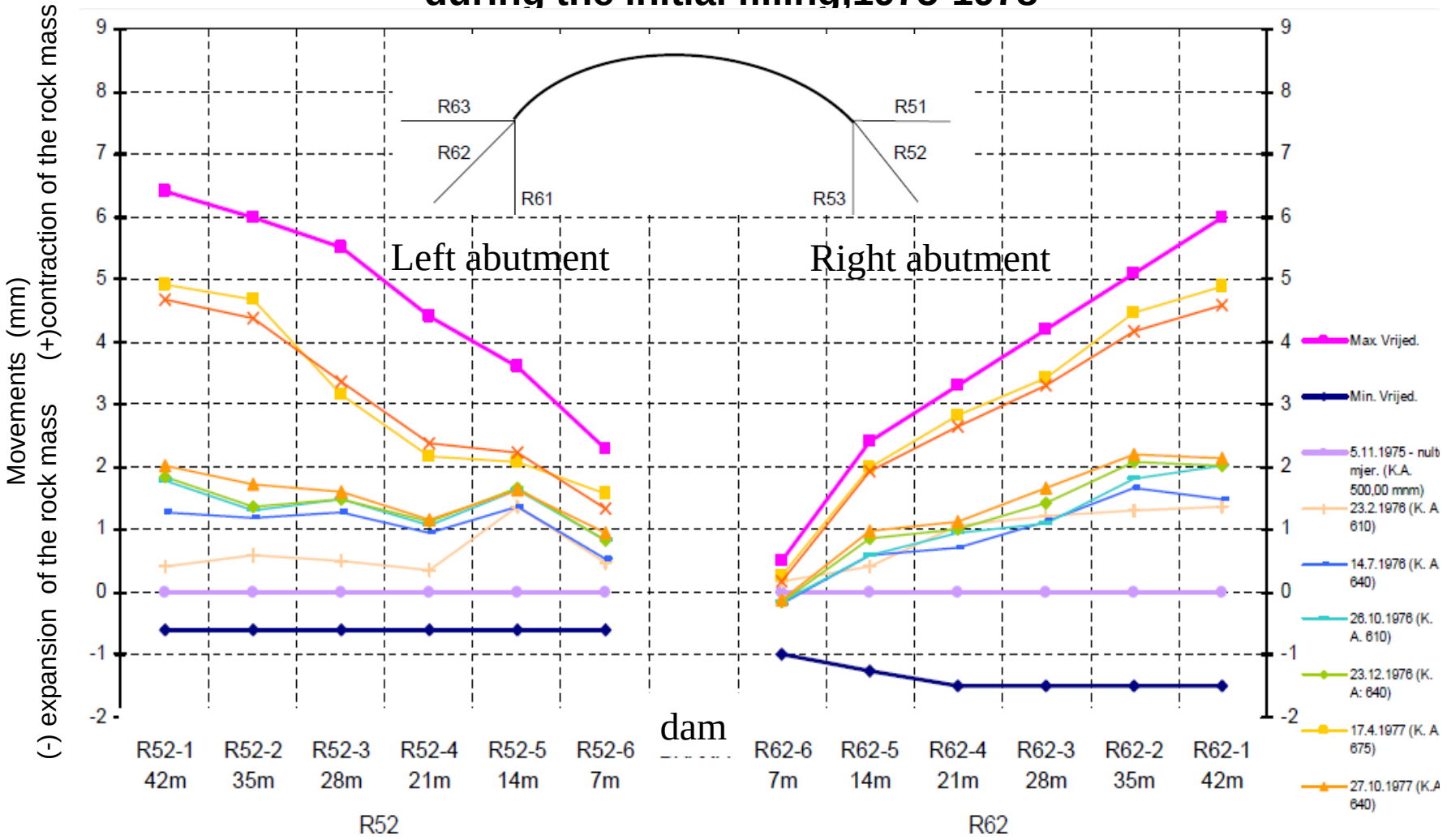
Min. limit value of radial displacement

during the initial filling (1976)

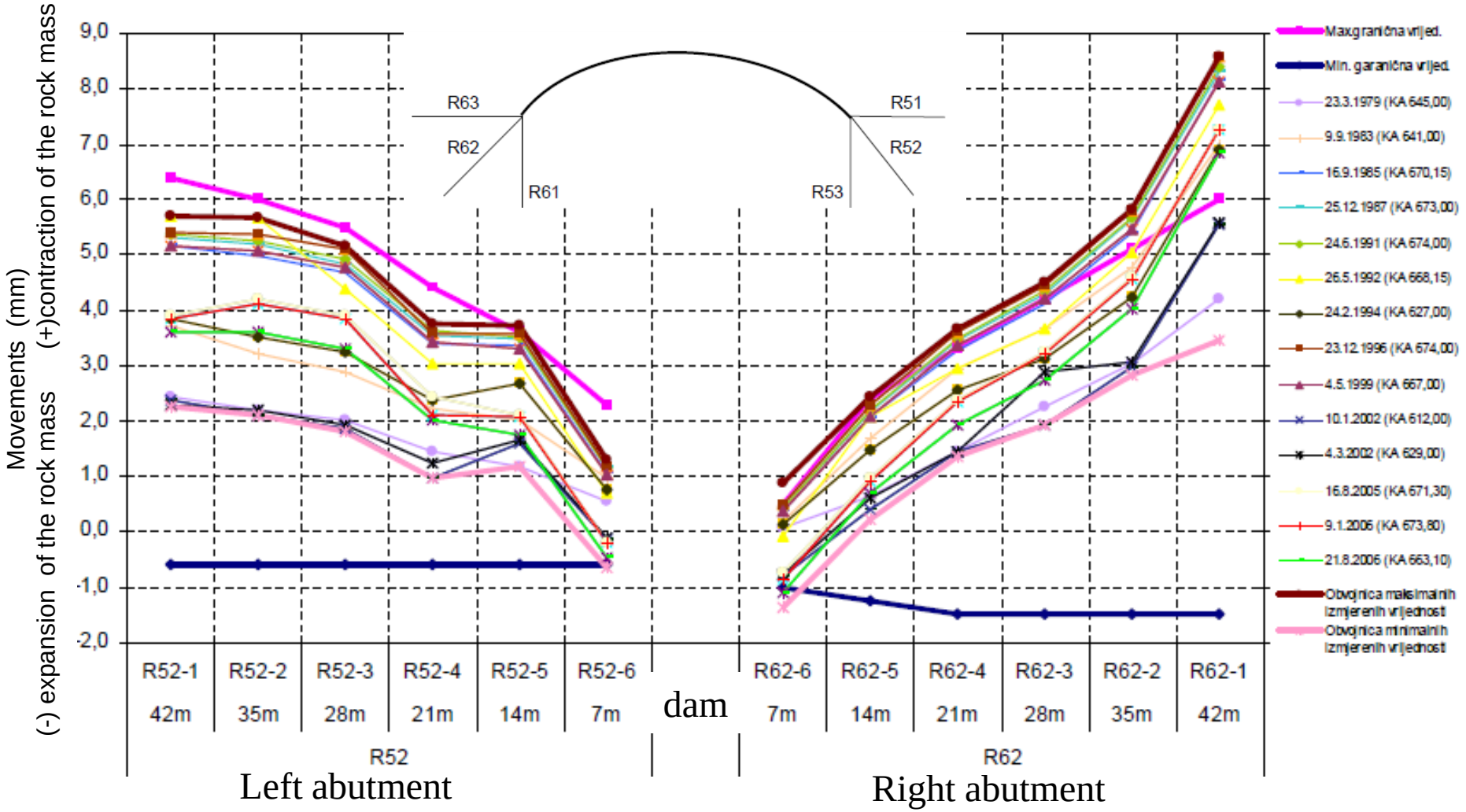


for period 2001-2006

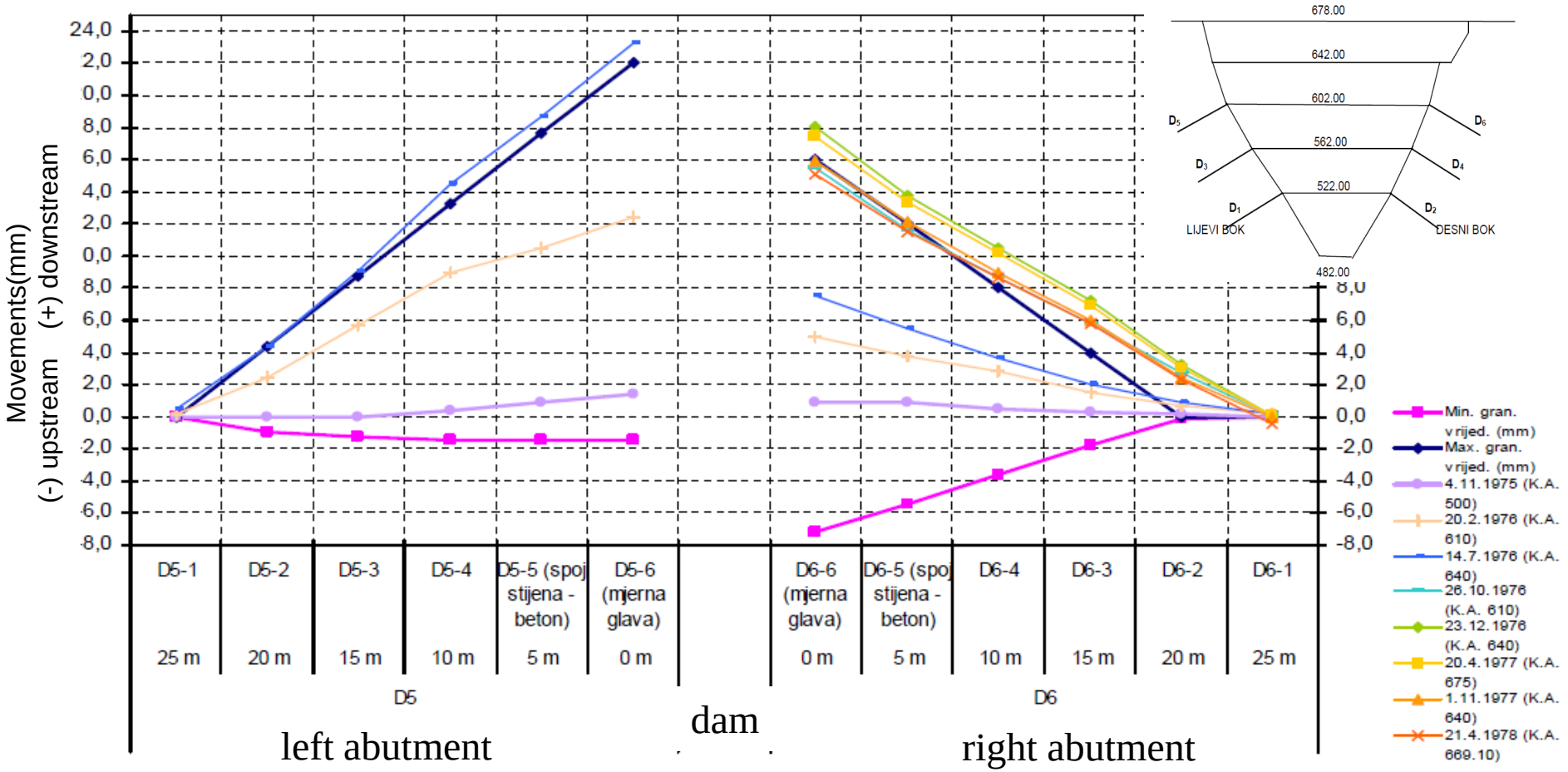
Rock extensometers results: Comparison of measured and limit values for the movements of points on the left and right abutments, at level 602 during the initial filling,1975-1978



Rock extensometers results: Comparison of measured and limit values for the movements of points on the left and right abutments, at level 602 for the period 1979-2006

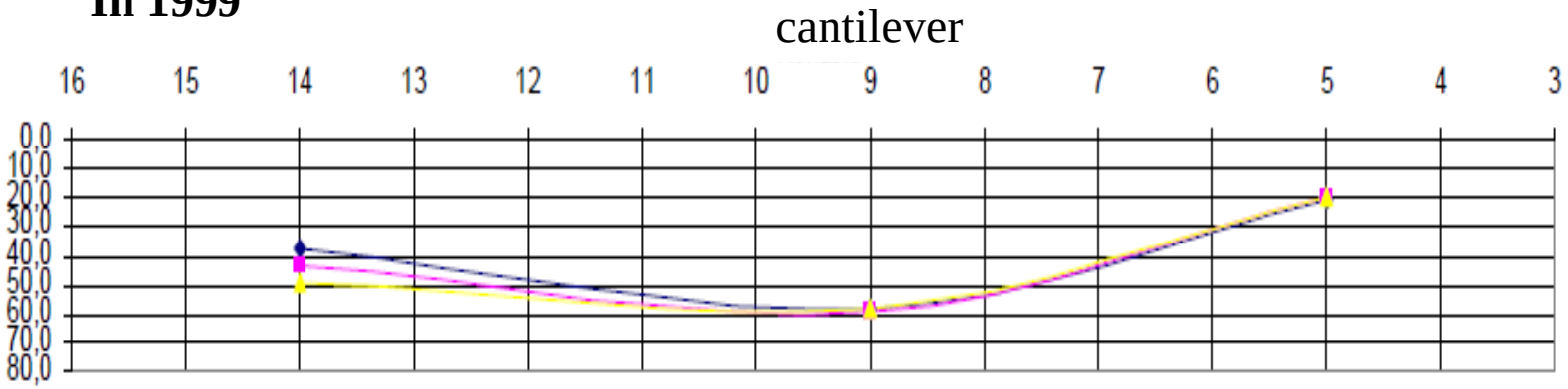


Deflectometer results: Comparison of measured and limit values for the movements of points on the left and right abutments, at level 602 during the initial filling.1975-1978

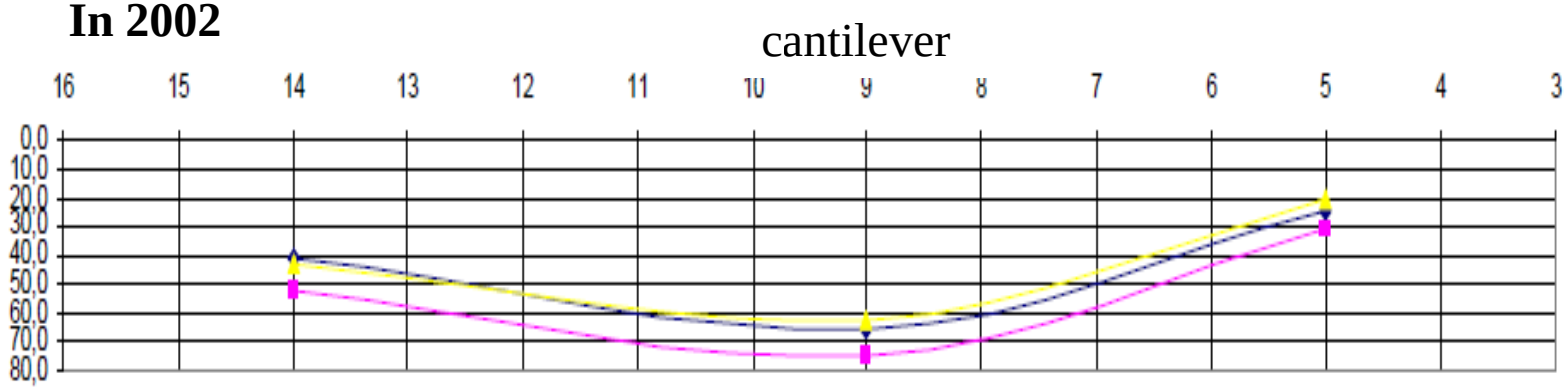


Comparison of displacements at crown level, measured by geodetic instruments, pendulum and tilt-meters

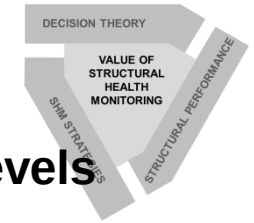
In 1999



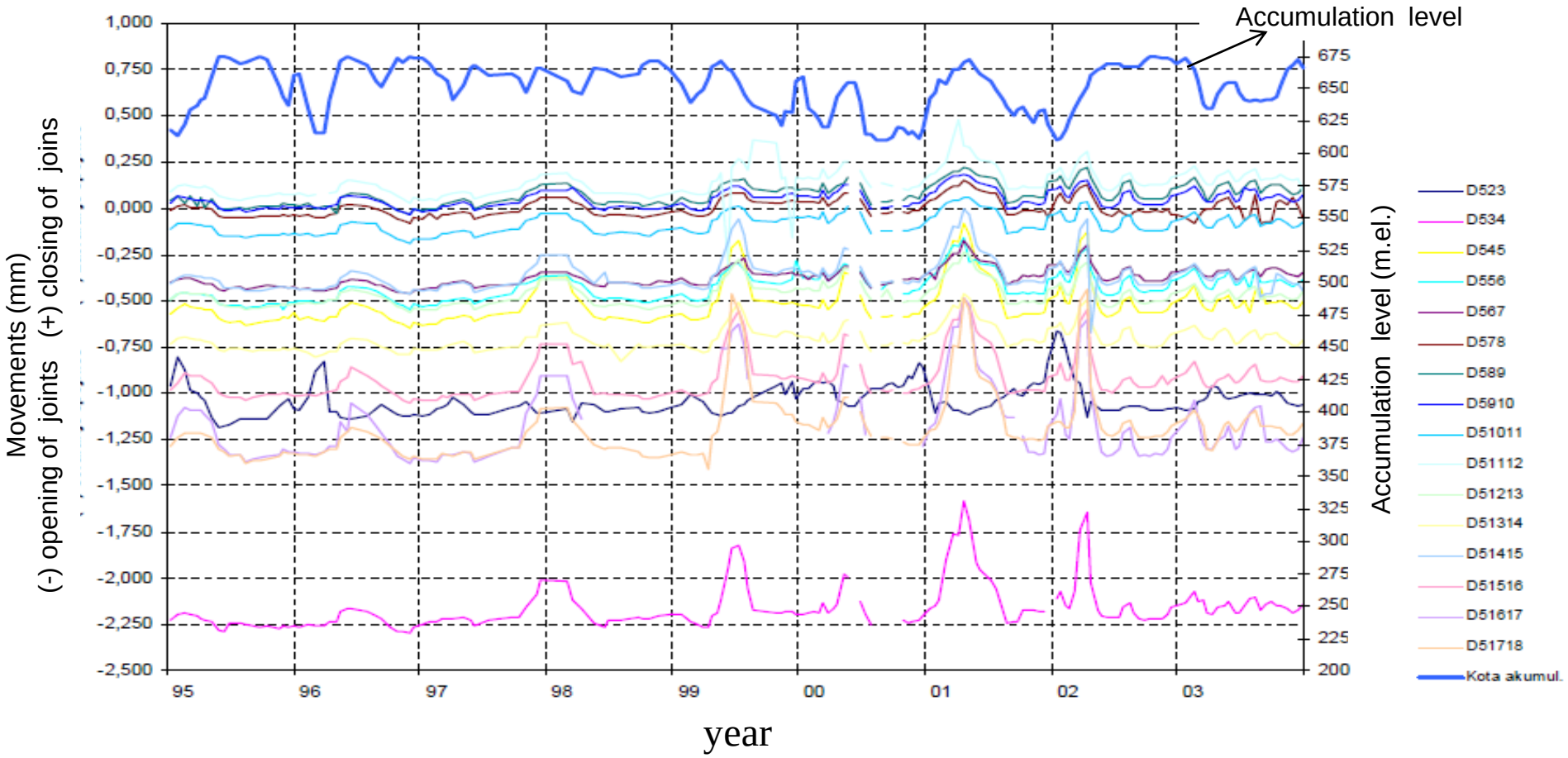
In 2002

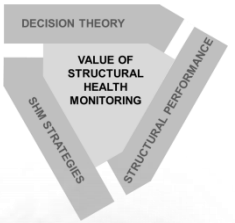


Geodetic measurements
Tilt meter
pendulum
Geodetic measurements
Tilt meter
pendulum



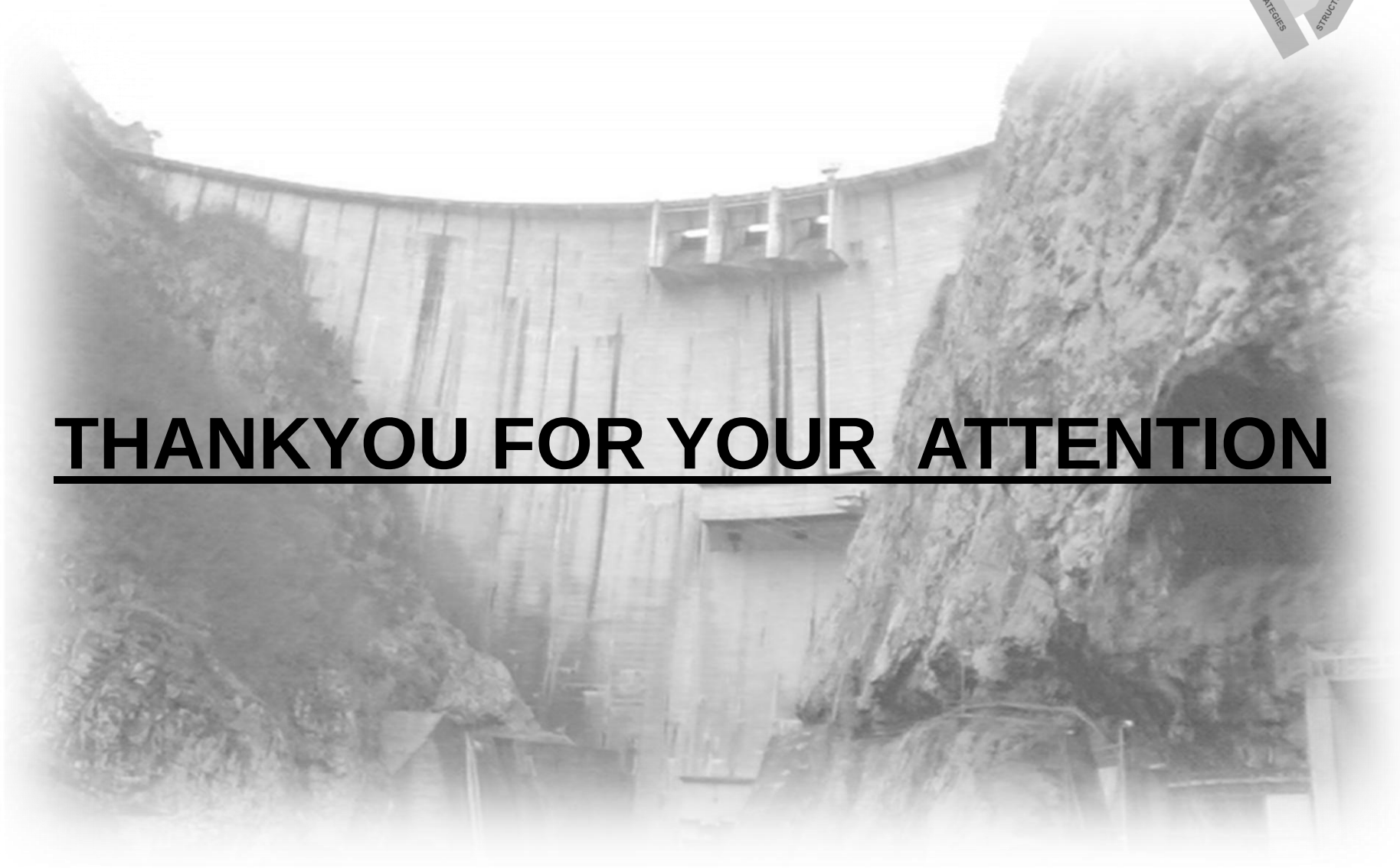
Deformeter results: Diagrams of joint movements at different levels in period 1995-2003





CONCLUSIONS

- Due to the limitations of the calculation model, used for the design of the dam (before 1976), which did not take into account the real interaction between the structure, the surrounding rock (foundation) and the water in the reservoir it was not possible to define the actual bearing capacity, security and stability of the dam "Piva".
- A new numerical model, based on the finite element method, made it possible.
- Results obtained by geodetic measurements, the pendulum and the rock extensometers represent a major element of the dam safety assessment and determine the behavior of the dam in real conditions of exploitation.
- These results give an answer to the question whether the dam behaves in accordance with the requirements and the calculation results.
- The measurement results are used for calibration of the new calculation model.



THANKYOU FOR YOUR ATTENTION