Cracow University
of Technology

Development of innovative methods and technologies of destruction process detection and monitoring for dams, levees and geotechnical engineering application

PRESENTATION OF RESEARCH RESULTS SUMMARY

Krzysztof RADZICKI
Scientific Director of
Institute of Water Engineering and Water Management
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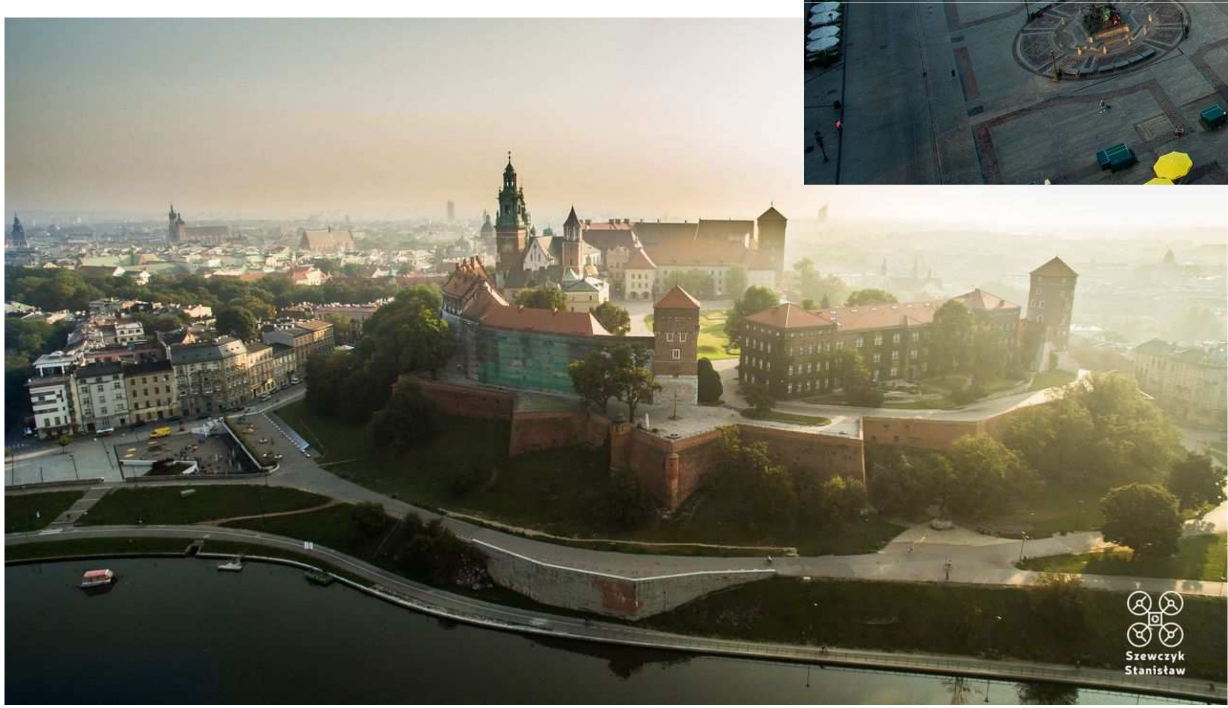
PIZA meeting, june 2017

CRACOW, POLAND



Tadeusz Kosciuszko
Cracow University of Technology

About 14 500 of students

About 1 200 of academic researches

- **FACULTY OF CIVIL ENGINEERING**
- **FACULTY OF ENVIRONMENTAL ENGINEERING**
- **FACULTY OF CHEMICAL ENGINEERING AND TECHNOLOGY**
- **FACULTY OF ELECTRICAL AND COMPUTER ENGINEERING**
- **FACULTY OF ARCHITECTURE**
- **FACULTY OF PHYSICS, MATHEMATICS AND COMPUTER SCIENCE**
- **FACULTY OF FACULTY OF MECHANICAL ENGINEERING**

Cracow University of Technology

FACULTY OF ENVIRONMENTAL ENGINEERING

About 2 000 of students

Faculty structure

- **Institute of Water Engineering and Water Management**
- **Institute of Geotechnical Engineering**
- **Institute of Water Supply and Environmental Protection**
- **Institute of Thermal Engineering and Air Protection**

IWEWM – ACTUAL RESEARCH TOPICS

I. DEVELOPMENT OF WATER MANAGEMENT METHODS, FLOOD RISK ASSESSMENT AND FLOOD PROTECTION METHODS

1. Methods for the evaluation of the economic efficiency of the flood protection investments
2. Application of the DPSIR analysis for estimation of state and forecasts of changes of river-bed and flow dynamics of the Vistula river and its tributaries in the Cracow agglomeration area
3. Assessment of the balance of hydrodynamic river within the catchments of different land use
4. The evaluation of river flow variability in the Raba catchment
5. Probabilistic approach to describe water dynamics in retention reservoir working under normal conditions.
6. Modern ways of increasing micro and small retention capability of a catchment area
7. Identification of the conditions for the development of flood protection system in the areas of different land

IWEWM – ACTUAL RESEARCH TOPICS

II. ANALYSIS OF INFLUENCE OF ANTHROPOGENIC FACTORS ON QUANTITATIVE AND QUALITATIVE PROPERTIES OF HYDROLOGICAL PROCESSES IN THE CATCHMENT

1. Identification and estimation of parameters for mathematical models of basic hydrological processes considering water quality changes.
2. Analysis of low flow characteristics in the Carpathian area of the Upper Vistula River
3. Application of natural sorbents in reduction of area pollutions from agricultural sources with particular emphasis on ameliorative drains.

IWEWM – ACTUAL RESEARCH TOPICS

III. DAMS AND LEEVES SAFETY

1. Development of innovative methods and technologies of destruction process detection and monitoring for dams, levees and geotechnical engineering application
2. Application of fuzzy inference system and artificial intelligence (AAN+FIS) in the assessment of flood risk control
3. Safety evaluation of embankment and concrete dams during passage of extreme floods

SOME OF BACKGROUND INFORMATIONS

WHY INTERNAL EROSION DETECTION AND MONITORING ARE IMPORTANT?

Statistics of dams and levees collapses due to internal erosion

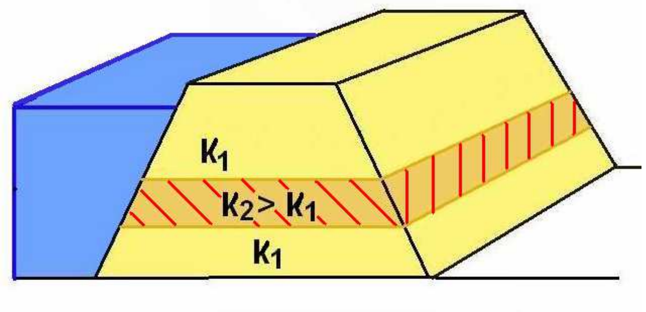
Earth dams (World , of several years) Foster, 2000	**46%**
Flood protection dikes / levees (Poland, flood 2010r) Kledyński et all. 2012	**30%**

Collapse of dike in Cracow during flood of Vistula river in 2010

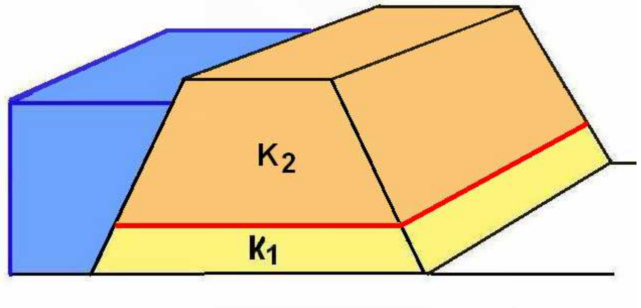
- The failure occurred at night
- No recent signs of danger

WHY INTERNAL EROSION DETECTION AND MONITORING ARE IMPORTANT?

SUFFUSION

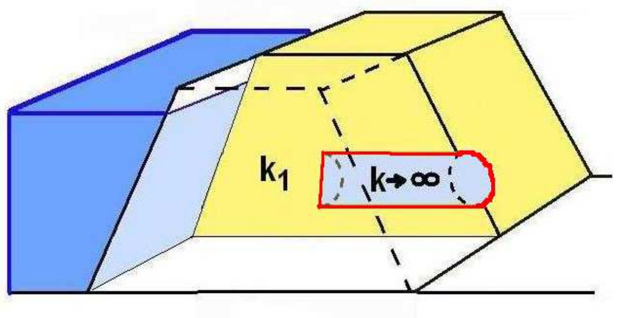


CONTACT EROSION

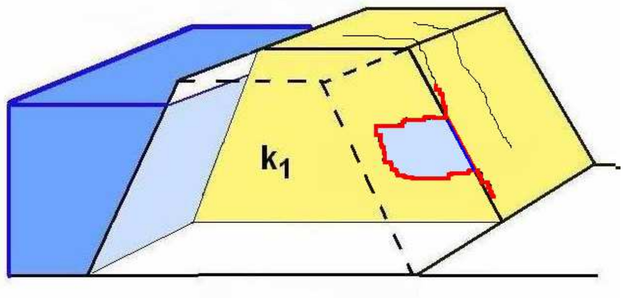


Risk of piping

BACKWARD EROSION



CONCENTRATED LEAKS



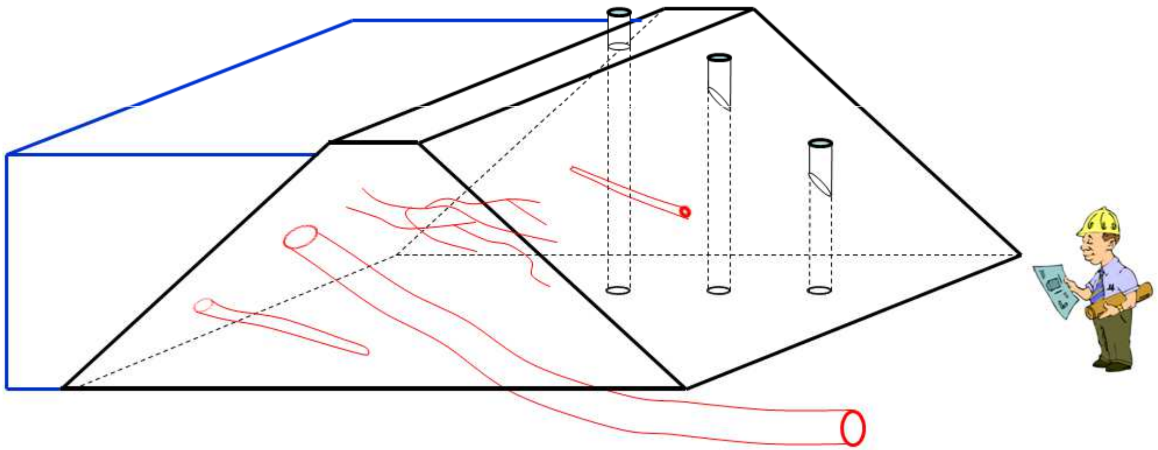
High risk of piping

1976, 100m high Teton dam collapse

WHY INTERNAL EROSION DETECTION AND MONITORING ARE IMPORTANT?

Visual inspections, spot geotechnical studies, classical geophysical surveys, spot sensor monitoring (if it exists),

- ✓ **are not sufficient to reliably detect and assess the development of erosion processes**
- ✓ **especially in the early stages of their development,**
- ✓ **and especially during the floods to keep levees safe!**



„The frequency of piping failures is significantly higher on first filling and early in the life of the dam."

FOSTER et al. (2000) <The statistics of embankment dam failures and accidents>

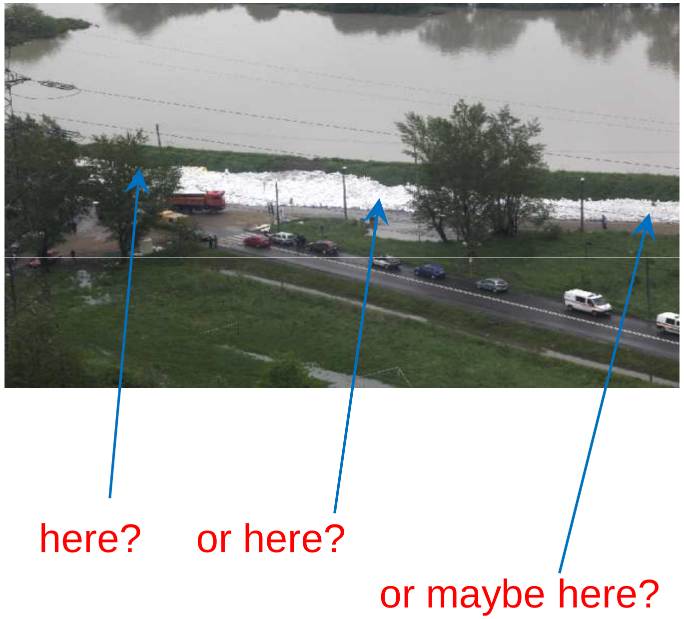
„In the majority of failures, breaching of the dam occurred within 12 h from initial visual indication of piping developing, and in many cases this took less than 6 h".

FOSTER et al. (2000 - A method for assessing the relative likelihood of failure of embankment dams by piping.)

THE PROBLEM OF RELIABLE CONDITION ASSESSMENTS AND MONITORING OF LEVEES

- The necessity to minimize the probability of disaster of dikes protecting valuable areas particularly urban and industrial ones
- Often poor condition of existing levees
- Shortage of methods for identification of vulnerable sections, especially in the early stages of development of erosion processes, especially the piping
- Shortage of diagnostic tools enabling monitoring and automatic detection of internal erosion threats during flood defence
- Shortage of methods to assess the most vulnerable sections of levees among all the sections where leakages were detected
- Shortage of decision support tools for identification of critical sections of levee after the flood that require immediate repair

Where is the most dangeour, vurneable cross section?



One of the PRINCIPAL PROBLEM is
RELIABLE LEVEE FOUNDATION MONITORING AND CONDITION ASSESSMENT

BASIC CONCLUSION FOR DESTRUCTION PROCESS DETECTION AND MONITORING FOR DAMS, LEVEES AND GEOTECHNICAL ENGINEERING APPLICATION

SOME OF THE MAIN PROCESSUS / PARAMETERS THAT SHOULD BE MONITORED

- Leakages and Seepage
- Internal Erosion
- Displacements

PRINCIPALES PROBLEMS WITH MONITORING

- Large scale of the structures limits the range of application of monitoring technologies
- Cost

NEW IDEAS FOR MONITORING METHODS AND TECHNOLOGIES AND FOR THEIRS APPLICATION METHODOLOGY

KRZYSZTOF RADZICKI TEAM RESEARCH AREAS

GENERAL OBJECTIVE: **Development of innovative methods and technologies of destruction process detection and monitoring for dams, levees and geotechnical engineering application**

FOCUSING ON:

1) DEVELOPMENT OF THERMAL METHOD OF LEAKAGES AND INTERNAL EROSION DETECTION AND ANALYSIS

   # Identification and analysis of characteristic features of thermo-hydraulic influence of internal erosion

   # Development of data analysis methods

   # Development of innovative temperature measurements instruments

   # Development of methodology of thermal method application

2) DEVELOPMENT OF INNOVATIVE TECHNOLOGIES OF DESPLACEMENT MEASUREMENTS AND IMPROVEMENT OF EXISTING ONES

3) DEVELOPMENT OF METHODOLOGY OF COMPLEX, MULTI-METHODS DESTRUCTIVE PROCESSES INVESTIGATIONS, MONITORING AND CONDITION ASSESMENT

INTRODUCTION TO THERMAL METHOD

DIFFUSION-ADVECTION EQUATION

$$C_\Theta \frac{\partial T}{\partial t} + C_f \vec{q} \frac{\partial T}{\partial x} - \lambda_\Theta \frac{\partial T}{\partial x^2} = 0$$

SYSTEM NONDIMENTIONAL

$$\vec{q} = const.$$

$$\overline{x} = \frac{x}{L} \qquad \overline{t} = t\frac{L^2}{D_\Theta} \qquad D_\Theta = \frac{\lambda_\Theta}{C_\Theta}$$

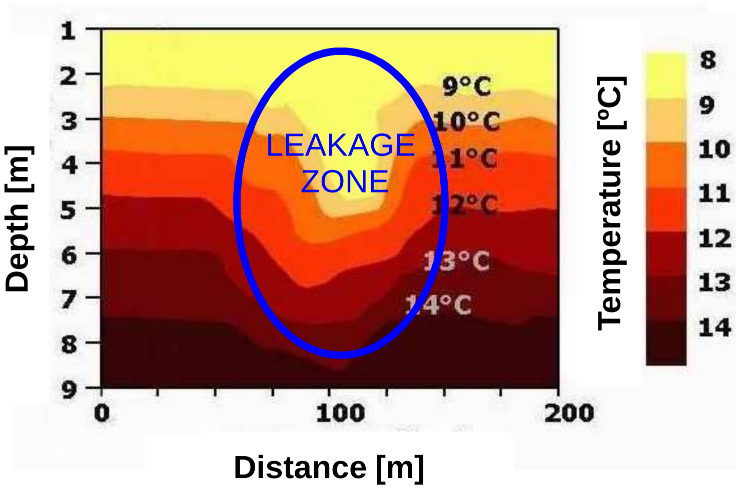
$$\frac{\partial T}{\partial \overline{t}} + Pe\frac{\partial T}{\partial \overline{x}} - \frac{\partial T}{\partial \overline{x}^2} = 0$$

Peclet number

$$Pe = \frac{advection}{conduction} = \frac{C_\Theta \vec{q} L}{\lambda_\Theta}$$

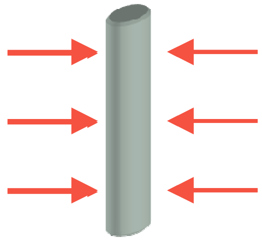
Conduction domination $Pe < 1$

Advection domination $Pe > 1$



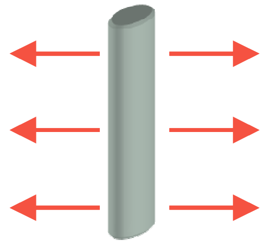
INTRODUCTION
ACTIVE AND PASSIVE THERMAL METHOD

PASSIVE METHOD



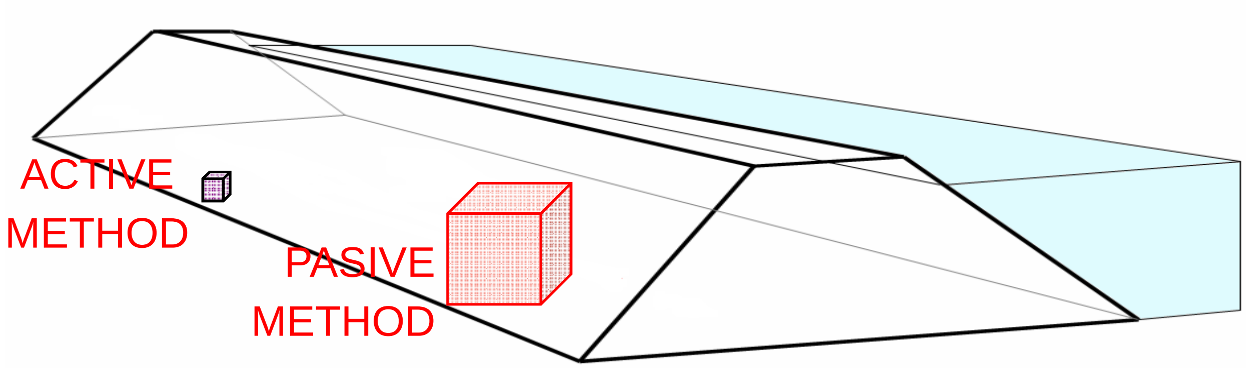
Natural temperatures
measurements

ACTIVE METHOD



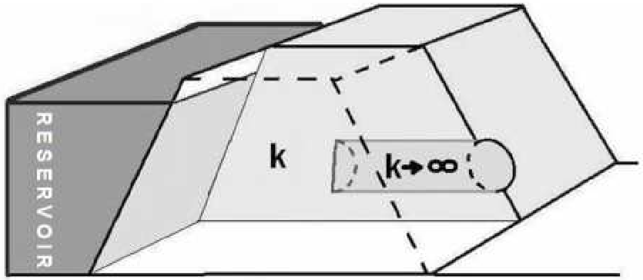
Heat emission
measurements

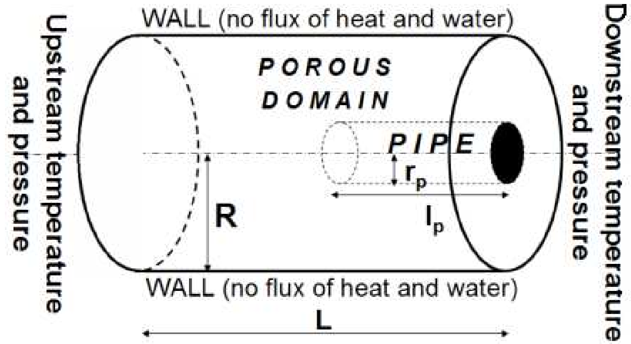
Schematic extent of the leak detection zone for spot measurements



IDENTIFICATION AND ANALYSIS OF CHARACTERISTIC FEATURES OF THERMO-HYDRAULIC INFLUENCE OF INTERNAL EROSION

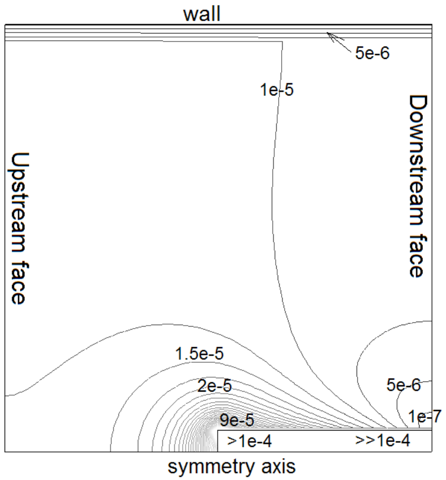
IDENTIFICATION OF RELATIONS BETWEEN DIMENTIONS OF PIPING / BACKWARD EROSION PROCESS DEVELOPMENT AND ITS INFLUENCE ON HYDRO-THERMAL FIELD OF SOIL



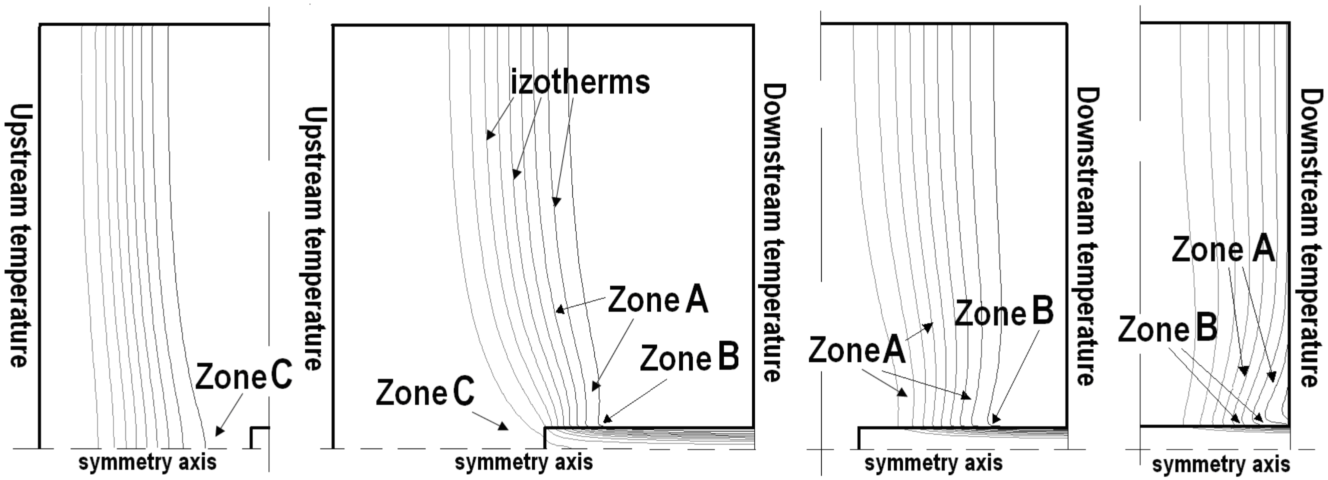


Example of pipe influence:

on water velocity field



on temperature field

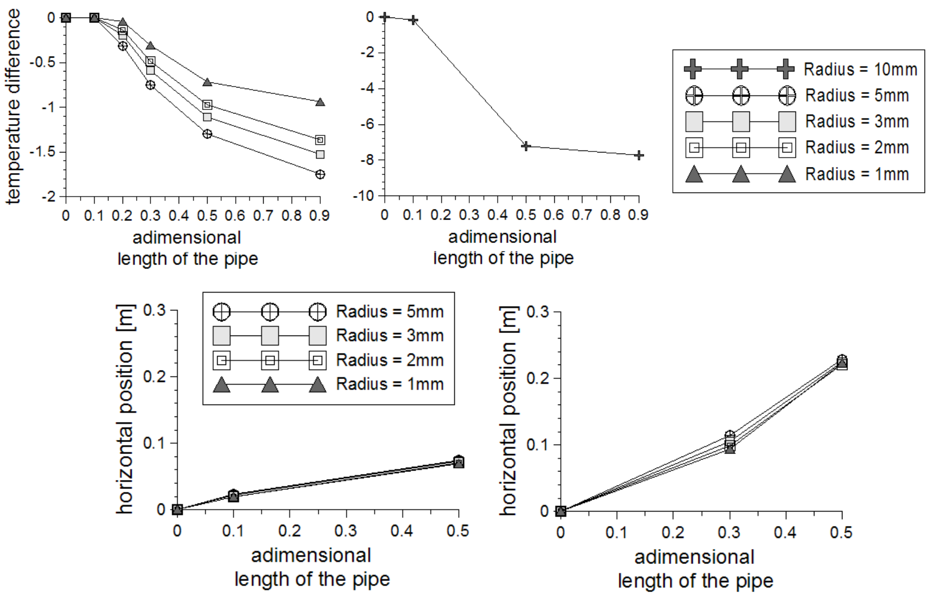


Radzicki and Bonelli (2009)

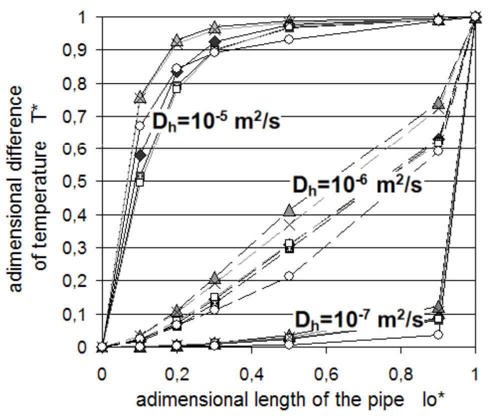
IDENTIFICATION OF RELATIONS BETWEEN DIMENTIONS OF PIPING / BACKWARD EROSION PROCESS DEVELOPMENT AND ITS INFLUENCE ON HYDRO-THERMAL FIELD OF SOIL

Examples of some results:

External thermal influence of pipe in relation to its length and radius



Adimensional temperature differences in the pipe outlet flow versus adimensional length of the pipe for different radius of the pipe



Line	Inlet temperature [°C]	Outlet temperature [°C]	Length of the system [m]	Height of the system [m]
—△—	25	5	1	1
—◆—	10	5	1	1
—⊠—	6	5	1	1
—□—	5	25	1	1
—×—	25	5	1	0,25
—○—	25	5	10	1

$L^* = \frac{l_O}{L}$ $T^* = \frac{T_{out\ without\ hole} - T_{out\ with\ hole}}{T_{out\ without\ hole} - T_{in\ with\ hole}}$

Radzicki and Bonelli (2009)

Principal effects of piping hydro-thermal influence were defined

One of the most important conclusions: There is a possibility to estimate the length of pipe by analysis of temperature measurements of water at outlet of the pipe

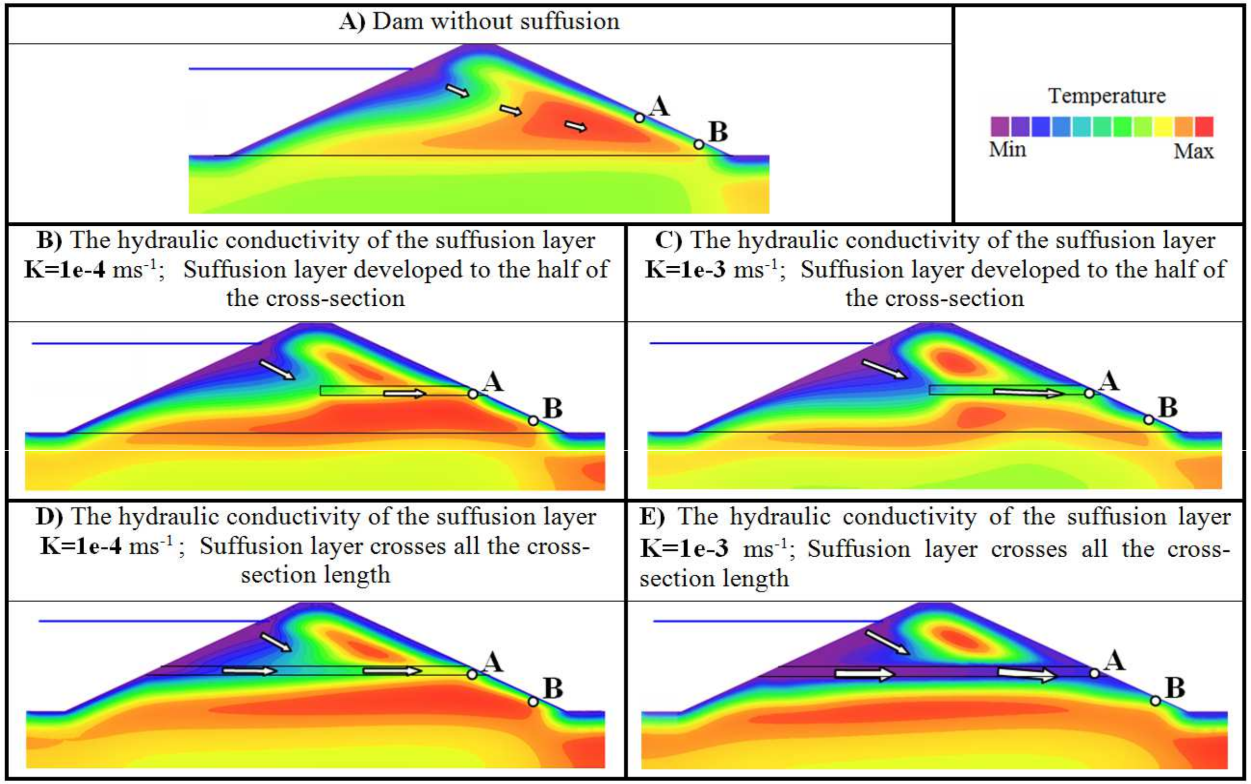
Results presented e.g in :

2009, Radzicki & Bonelli, Evaluation of piping erosion by means of temperature analysis, Studia Geotechnica et Mechanica,

2009, Radzicki, PhD rapport, Analyse retard des mesures de températures dans les digues avec application à la détection de fuite s

IDENTIFICATION OF PRINCIPAL FEATURES OF SUFFOSION PROCESS THERMO-HYDRAULIC INFLUENCE IN EARTH DAMMING STRUCTURE

Examples of some results:



Radzicki and Bonelli (2012)

Temperature fields of a dam cross-section registered at the same time instant for different lengths of suffusion layer and for different values of suffusion layer hydraulic conductivity.

Principal effects of suffosion hydro-thermal influence were defined

Some results are presented e.g in paper:

2012, Radzicki & Bonelli, Monitoring of the suffusion process development using thermal analysis performed with IRFTA model, International Conference on Scour and Erosion

ACTUAL R&D WORKS

DETAILED IDENTIFICATION AND ANALYSIS OF CHARACTERISTIC FEATURES OF THERMO-HYDRAULIC INFLUENCE OF INTERNAL EROSION IN THE CASE OF LEVEES

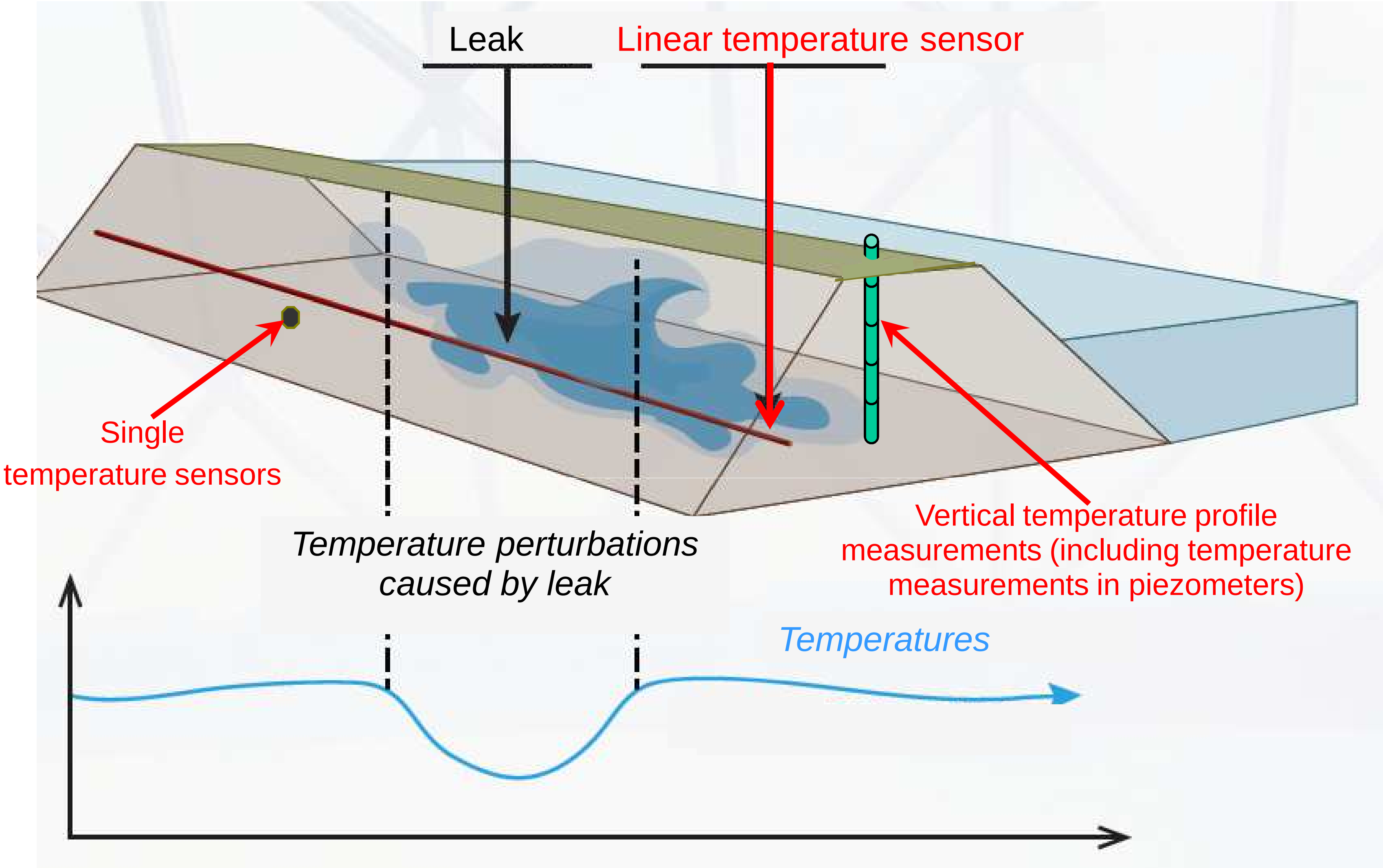
It is a one of the goals of 3 years ongoing project of development of innovative technologies of destructive processes detection and monitoring for levees and for geotechnical engineering co-founded by grant of Polish National Centre of Research and Development

Project has started in 2017

DEVELOPMENT OF INNOVATIVE MEASUREMENTS INSTRUMENTS

- quasi LINEAR TEMPERATURE SENSOR MPointS

INTRODUCTION - METHODS OF TEMPERATURE MEASUREMENTS



Linear temperature measurements sensors are crutial for thermal monitoring methods.

Continuous measurements all along the structure brought about a quality change in the monitoring of seepage, leakages and erosion processes compared with the point monitoring carried out only at selected places of the structure

INTRODUCTION - SOME REFERENCE TO THERMAL METHOD

European Working Group on Internal Erosion of ICOLD

ICOLD’s Bulletin no 164 (2013): „INTERNAL EROSION OF EXISTING DAMS, LEVEES AND DIKES, AND THEIR FOUNDATIONS”

VOL.1 INTERNAL EROSION PROCESSES AND ENGINEERING ASSESSMENT

<Many less direct means of detecting seepage are now available. The most promising is temperature measurement which can be used to infer localized flow. >

<Fiber optic cables facilitate data collection and make it possible to cover large parts of the dam. Remote sensing options also offer great potential in detecting whether the seepage has caused erosion.>

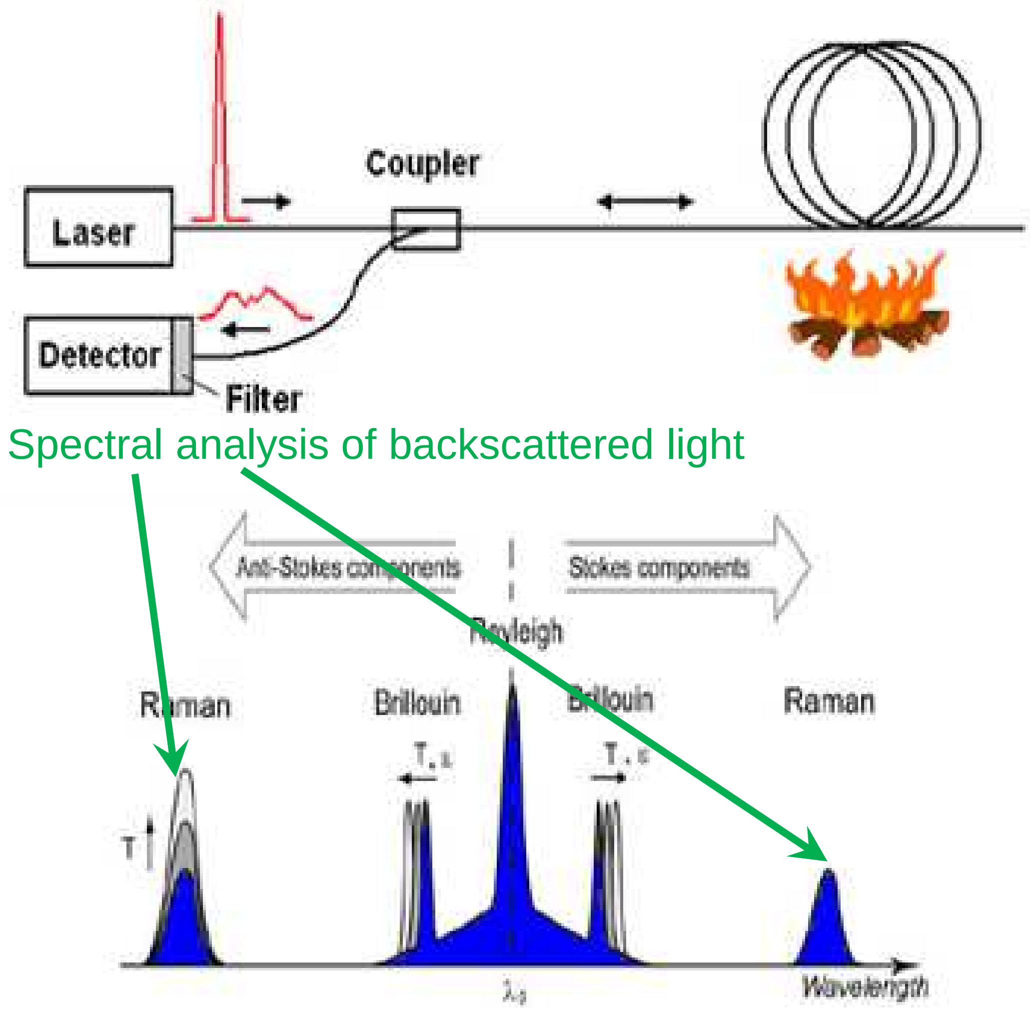
Jean-Jacques FRY (2012), the chairman of ICOLD European Working Group on Internal Erosion - 80th ICOLD annual meeting in Kioto

PAPER : „HOW TO PREVENT EMBANKMENTS FROM INTERNAL EROSION FAILURE?”

<In our opinion, Distributed Fibre Optic Temperature measurement is the best method …. Remote control monitoring of temperature by fibre optic is the only method available for practical application, which has been used successfully during the last 10 years during the last 10 years in Germany, Sweden and France>

<The IJkdijk-piping tests clearly demonstrate the reliability and the capabilities of the fiber optic system to detect the early stage of a piping process.>

INTRODUCTION
DFOT (Distributed Fibre Optic Temperature) SENSING



Fiber optic temperature sensing:

- Spatial resolution 1m
- Resolution ± 0,1°C
- Measurement distance
  - up to 30km with one fiber optic cable

PROBLEMS WITH INSTALLATION OF DFOT SYSTEMS

COST OF APPLICATION

- Cost of fiber optic cable installation (particularly if earth works are required)
- Costly technology for short distances of measurements
  due to relatively high cost of sensing unit (DTS unit)

SAFETY PROBLEMS

- Earthworks affect body or foundation of the structure. They must be carried out very carefully. There is a risk of creation of preferential seepage paths by these works
- In the case of high water level in the body of earth damming structure the risk of piping appearance due to affection the soil by installation of fiber optic cable can be very high

OTHER PROBLEMS

- Permission of earthworks usually is necessary
- There must be an access for vehicle along the structure (problem particularly for levees)
- Limited depth for foundation monitoring

IN CONSEQUENCE: DFOT is recommended to be installed on new dams or levees or during their renovations, for their long sections (more than some hundreds meters), where cost of earthworks is already included

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DFOT system is not optimal for temporal (up to several years), short distance (up to some hundreds meters) monitoring, particularly in the cases where urgent investigation is necessary or for the problem of deep (more than 2m) foundation investigation?

These are typical problems for the case of levee investigation or monitoring

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Presented problems and conclusions were described e.g in paper: 2015, Radzicki K., Siudy A., Stoliński M. , An innovative 3D system for thermal monitoring of seepage and erosion processes and an example of its use for upgrading the monitoring system at the Kozłowa Góra dam in Poland, Q. 99 – R. 7, 25th International Congress on Large Dams,

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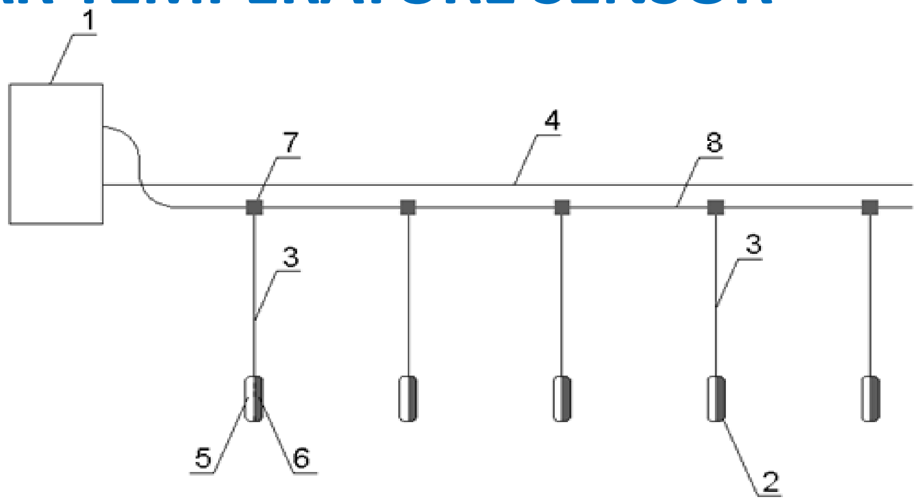
INNOVATIVE QUASI-LINEAR TEMPERATURE SENSOR

MPointS

Driving Multi Points Sensor to use for passive or/and active quasi continuous thermal monitoring



MPointS are mounted without an excavation by inserting successive sensors in a series, one after another without necessity of the earthworks from the surface of terrain (for example from the crest of the berm, etc.).

MPointS can be installed along the damming structure particularly at its downstream toe instead of fiber optic cable.

This sensors can be installed much more deeper than fiber optic cable

MPointS are particularly useful for monitoring of existing dams and levees sections up to several hundreds meters of length. This is much cheaper and easier for installation than fiber optics.
No earthwork permission is necessary.

MPointS could be immediately installed to investigate leakages and internal erosion processes in order to optimize decisions about necessity of renovation and/or about its range.

NeoStrain PK

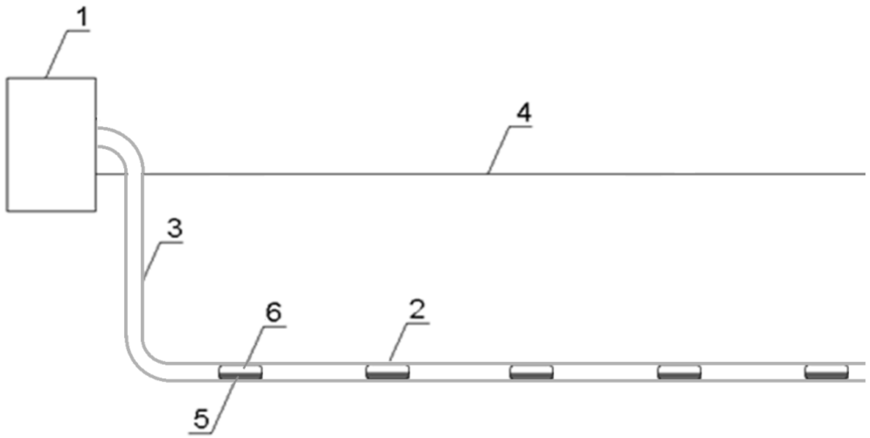
MPointS technology was described e.g. in papers: 2015, Radzicki K., Siudy A., Stoliński M., An innovative 3D system for thermal monitoring of seepage and erosion processes and an example of its use for upgrading the monitoring system at the Kozłowa Góra dam in Poland, Q. 99 – R. 7, 25th International Congress on Large Dams,

2015, Radzicki K., The concept of quasi-3d monitoring of seepage and erosion processes and deformations in dams and dikes, considering in particular linear measurement sensors, Technical Transactions

INNOVATIVE QUASI-LINEAR TEMPERATURE SENSOR

MCableS

Multipoint Cable Sensor to use for passive or/and active quasi continuous thermal monitoring



MCableS is a cable inside which single temperature sensors and communication and supply cables have been placed and integrated.

The main advantage of this solution for short measurement sections of up to several hundred meters is its cost which is even several times lower than that of a fibre optic-based thermal monitoring system.

MCables can be applied in water temperature measurements in piezometers. Given its small diameter, a “multi sensor cable” does not prevent manual periodic measurements in a piezometer, which are more often than not required for dams in order to verify automatic pressure measurements.

NeoStrain PK

MPointS technology was described e.g. in papers: 2015, Radzicki K., Siudy A., Stoliński M., An innovative 3D system for thermal monitoring of seepage and erosion processes and an example of its use for upgrading the monitoring system at the Kozłowa Góra dam in Poland, Q. 99 – R. 7, 25th International Congress on Large Dams,

2015, Radzicki K., The concept of quasi-3d monitoring of seepage and erosion processes and deformations in dams and dikes, considering in particular linear measurement sensors, Technical Transactions

ACTUAL R&D WORKS

DEVELOPMENT OF LOW-POWER CONSUMPTION MPointS SYSTEM DEDICATED FOR THERMAL PASSIVE AND ACTIVE LEVEE SYSTEM MONITORING

EXISTING LEVEES WILL BE EQUIPED WITH THIS SYSTEM:
- 2017 ONGOING INSTALLATION
- 2018 PLANNED INSTALLATION

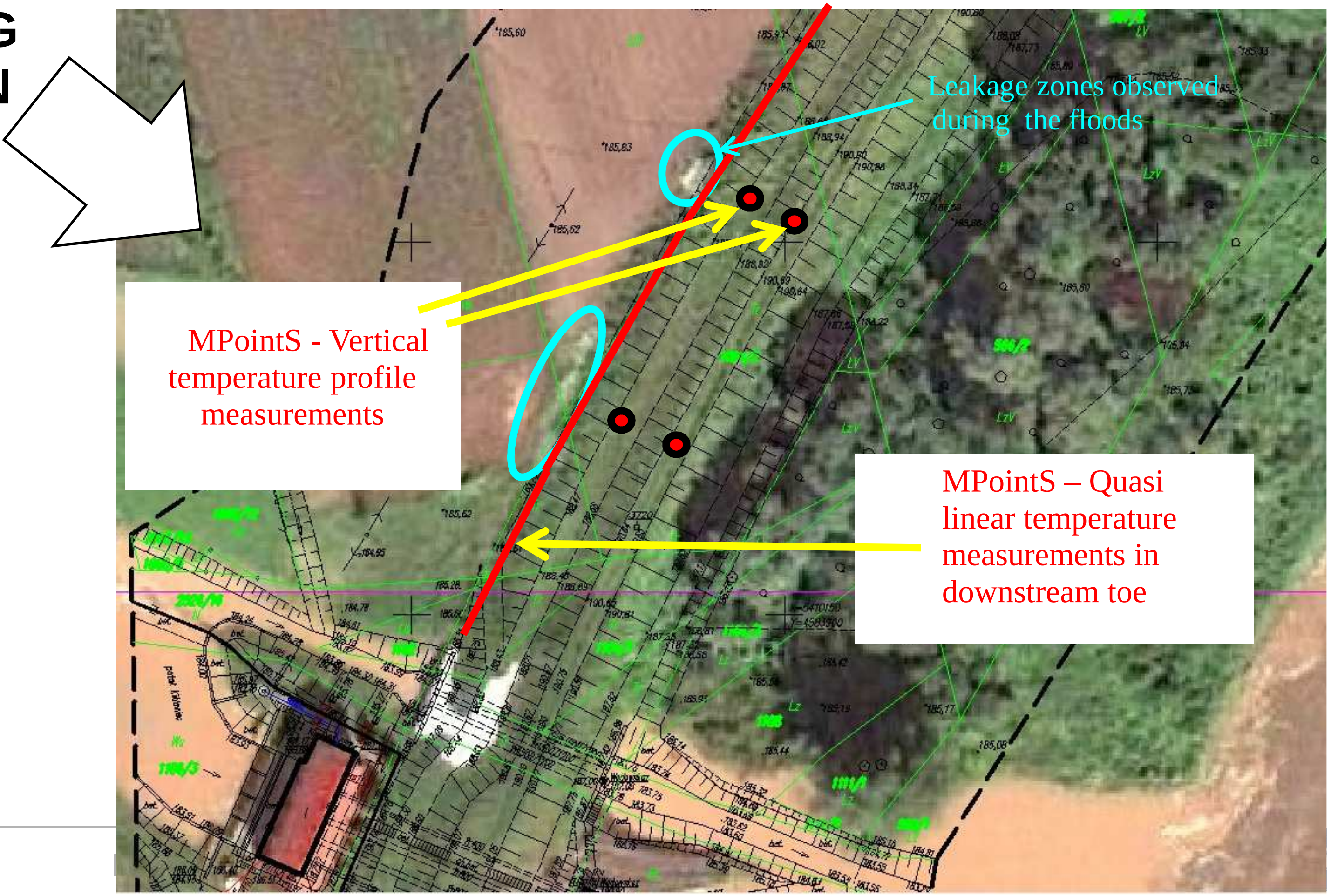
It is a one of the goals of 3 years ongoing project of development of innovative technologies of destructive processes detection and monitoring for levees and for geotechnical engineering co-founded by grant of Polish National Centre of Research and Development

Project has started in 2017

ACTUAL R&D WORKS

DEVELOPMENT OF LOW-POWER CONSUMPTION MPointS SYSTEM DEDICATED FOR THERMAL PASSIVE AND ACTIVE LEVEE SYSTEM MONITORING

EXISTING LEVEE
2017 ONGOING INSTALLATION



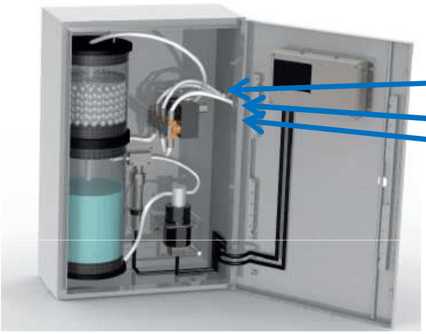
DEVELOPMENT OF INNOVATIVE MEASUREMENTS INSTRUMENTS

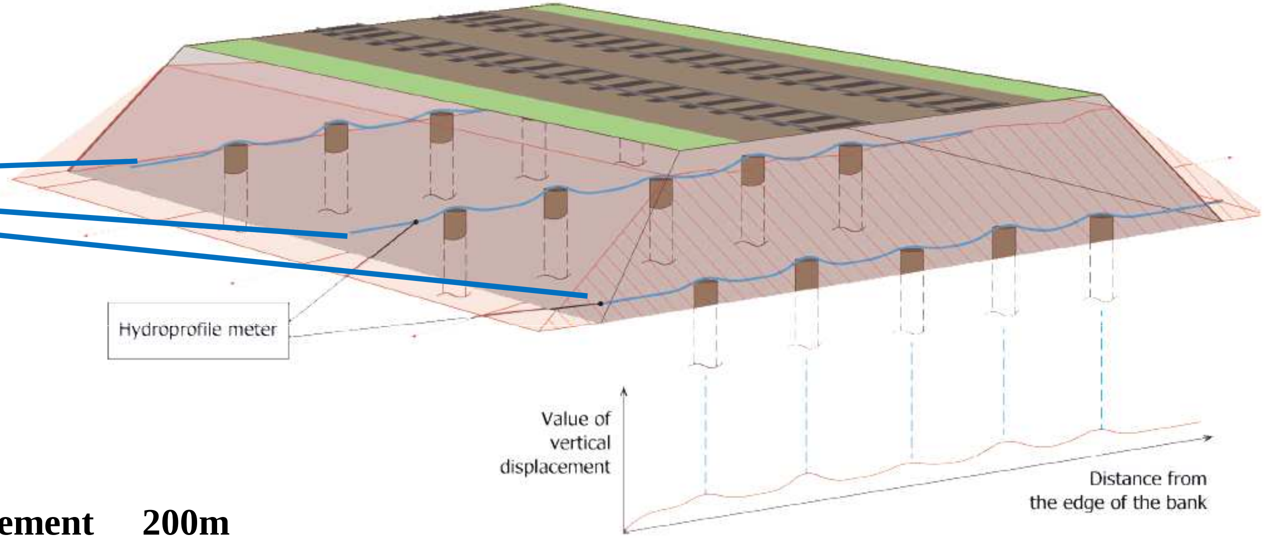
VERTICAL DISPLACEMENT LINEAR SENSOR - Hydroprofile meter

INNOVATIVE VERTICAL DISPLACEMENT LINEAR SENSOR

Hydroprofile meter

The sensor is a hose through which a liquid is pushed. The position of the hose is identified by measurements of the liquid pressure in relation to the reference level of hose inlet. An adequately dense measurement of the position points of the measuring hose allows to achieve quasi-continuous measurements.





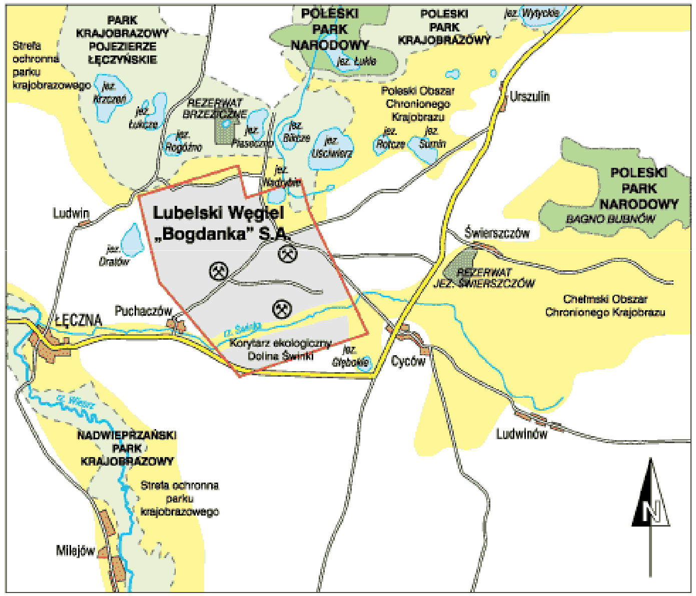
Length of single measurement element	**200m**
The measurement range of vertical displacement	**up to 10m**
Precision of measurement	**0,2 % of vertical displacement range**
Resolution of measurement	**0,01 %**
Outer diameter of hydraulic hose	**15mm**

NeoStrain

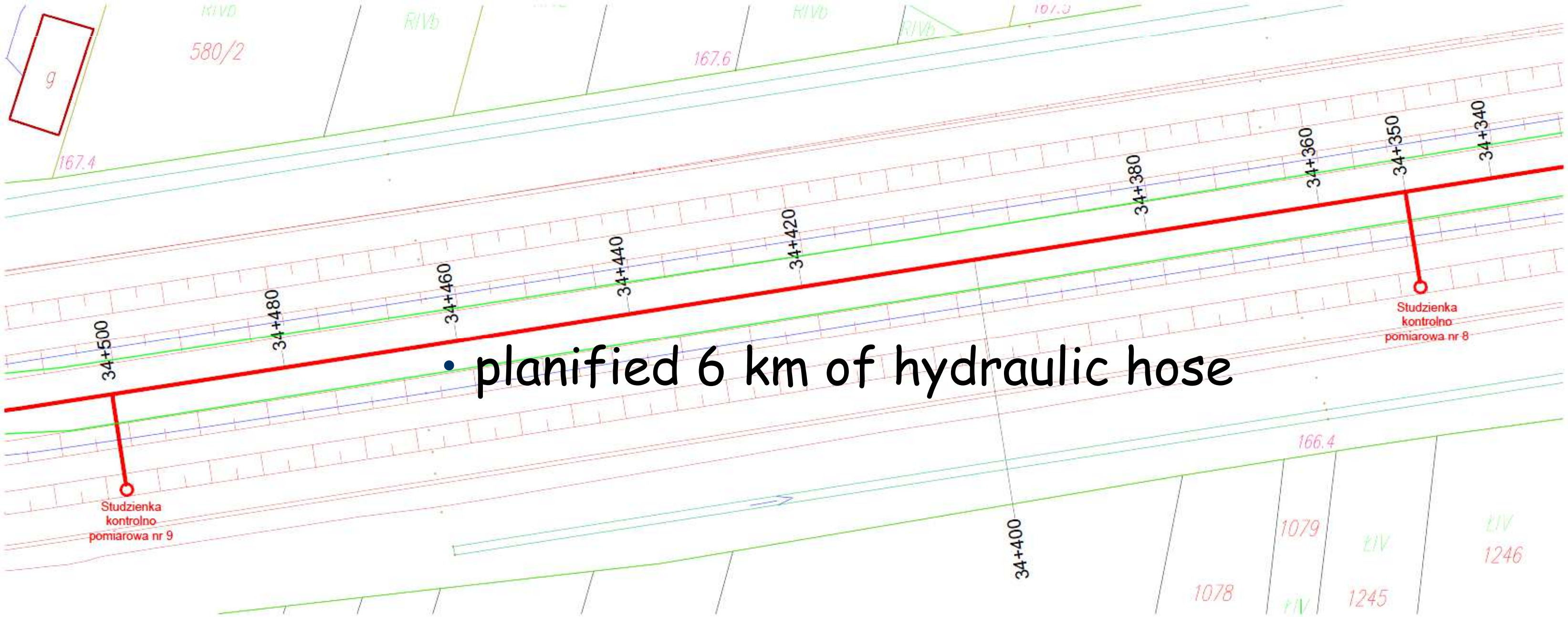
Technology was described e.g. n paper: 2015, Radzicki K., The concept of quasi-3d monitoring of seepage and erosion processes and deformations in dams and dikes, considering in particular linear measurement sensors, Technical Transactions

PLANNED APPLICATION OF Hydroprofile meter FOR INVESTIGATIONS OF WIEPRZ-KRZNA CANAL

Lokalizacja terenów chronionych w sąsiedztwie kopalni „Bogdanka"



PLANNED APPLICATION OF Hydroprofile meter FOR INVESTIGATIONS OF WIEPRZ-KRZNA CANAL



- planified 6 km of hydraulic hose

ACTUAL R&D WORKS

DEVELOPMENT OF HYDROPROFILE METER FOR APPLICATION IN GEOTECHNICAL MONITORING INCLUDING LEVEE MONITORING,

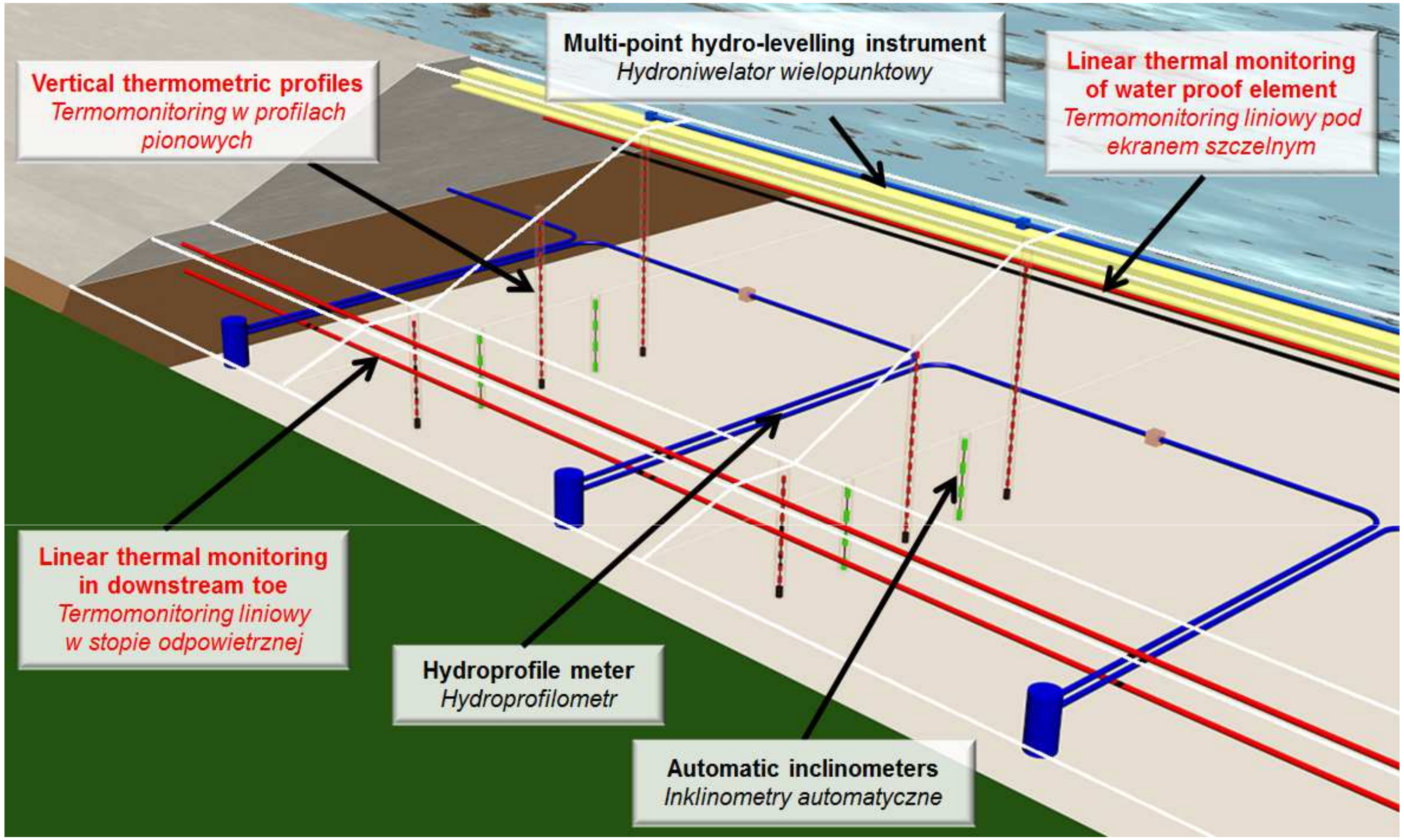
TWO EXISTING LEVEES WILL BE EQUIPED WITH THIS SYSTEM IN 2017 AND IN 2018

It is a one of the goals of 3 years ongoing project of development of innovative technologies of destructive processes detection and monitoring for levees and for geotechnical engineering co-founded by grant of Polish National Centre of Research and Development

Project has started in 2017

DEVELOPMENT OF
QUASI 3D MONITORING DEFINITION AND METHODOLOGY INCLUDING LINEAR OR QUASI LINEAR SENSORS

DEVELOPMENT OF QUASI 3D MONITORING DEFINITION AND METHODOLOGY



Conception of quasi 3D thermal monitoring and displacement monitoring proposed e.g. for the largest, planned Polish dam, Racibórz dam

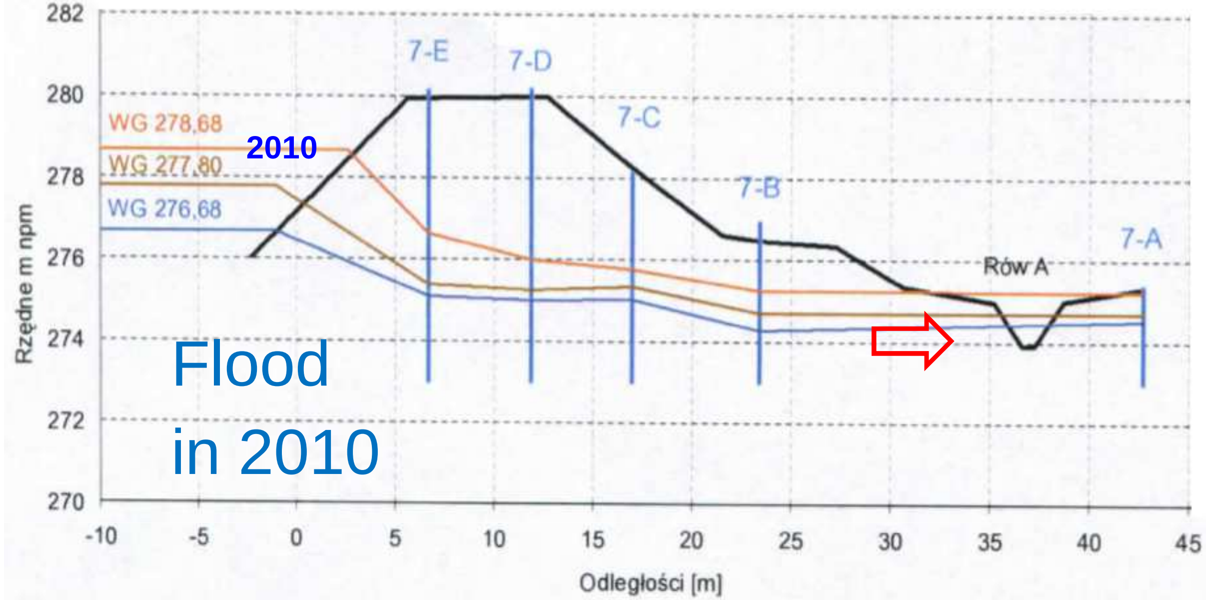
Conception presented e.g. in: 2015, Radzicki K., The concept of quasi-3d monitoring of seepage and erosion processes and deformations in dams and dikes, considering in particular linear measurement sensors, Technical Transactions of earth dams and leeves"

Complex scientific paper preparation is in progress

QUASI 3D MONITORING SYSTEM ON KOZŁOWA GÓRA DAM

QUASI 3D MONITORING SYSTEM ON KOZŁOWA GÓRA DAM

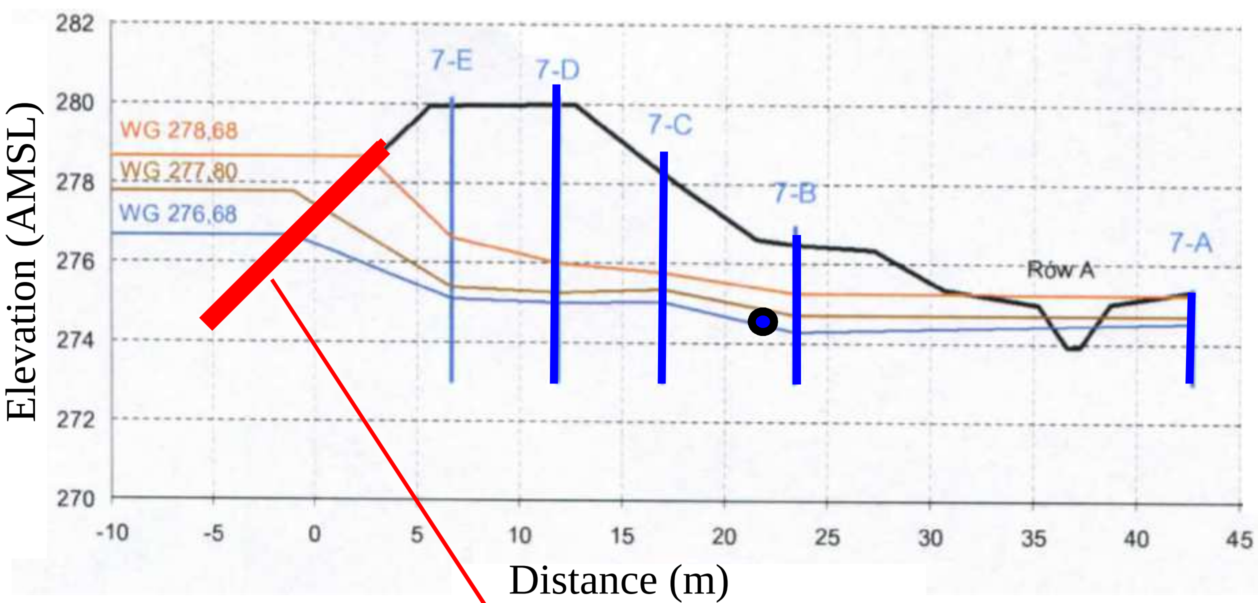
QUASI 3D MONITORING SYSTEM ON KOZŁOWA GÓRA DAM

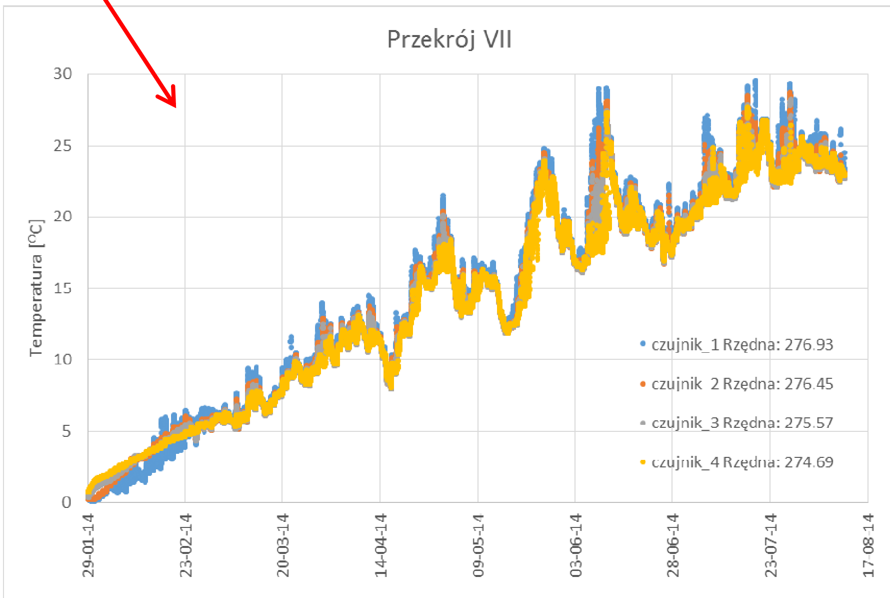


QUASI 3D MONITORING SYSTEM ON KOZŁOWA GÓRA DAM

MCableS

Measurements of vertical temperature profile in the reservoir





GÓRNOŚLĄSKIE PRZEDSIĘBIORSTWO WODOCIĄGÓW SPÓŁKA AKCYJNA

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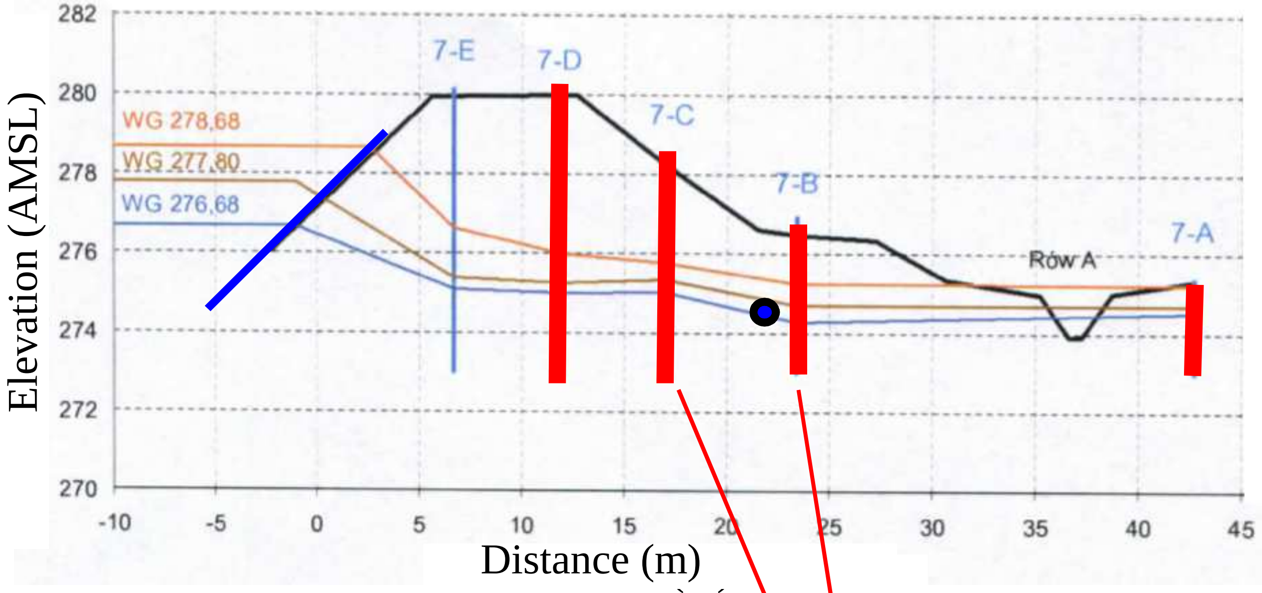
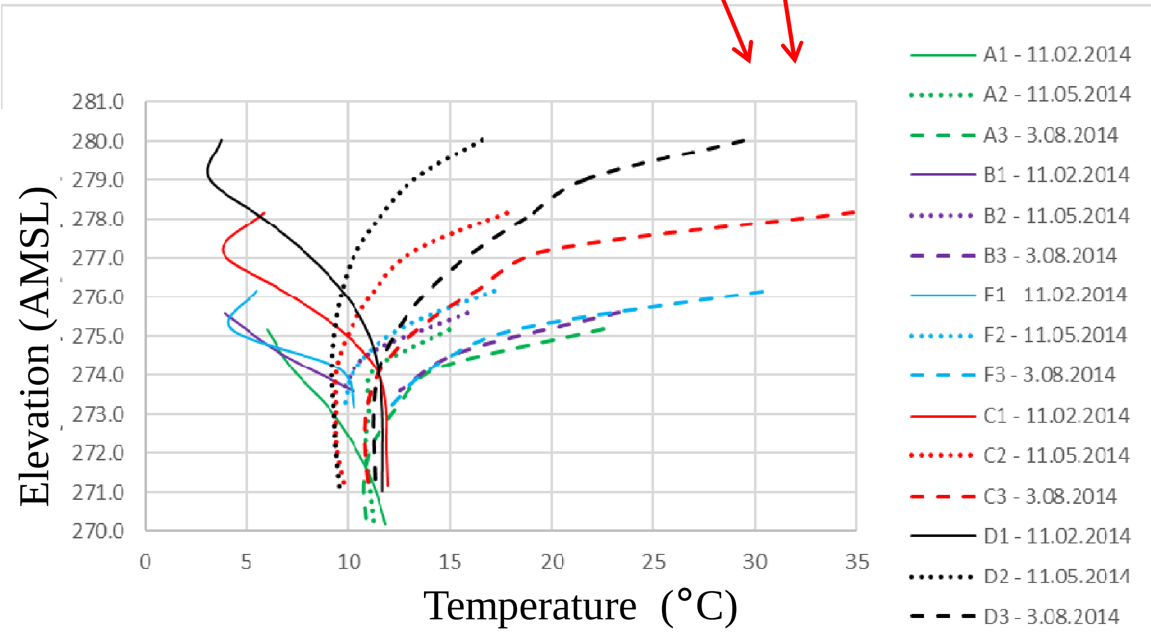
QUASI 3D MONITORING SYSTEM ON KOZŁOWA GÓRA DAM

MCableS

Measurements of vertical temperature profiles in the dam body in existing piezometers



PASSIVE THERMAL METHOD



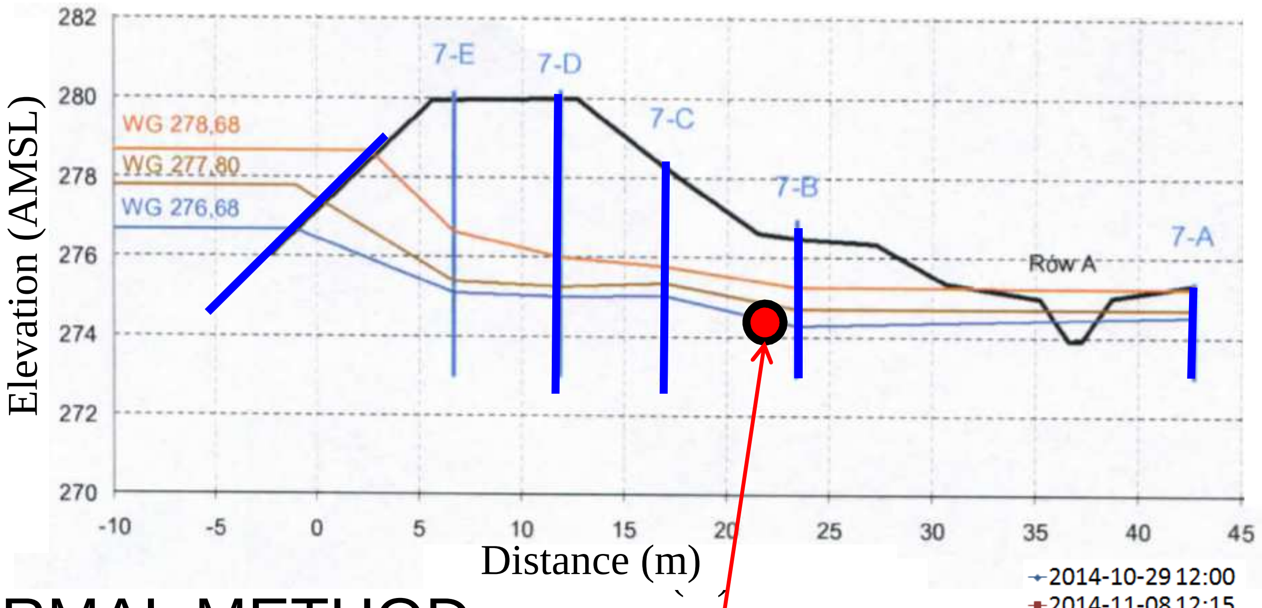
GÓRNOŚLĄSKIE PRZEDSIĘBIORSTWO WODOCIĄGÓW SPÓŁKA AKCYJNA

NeoStrain

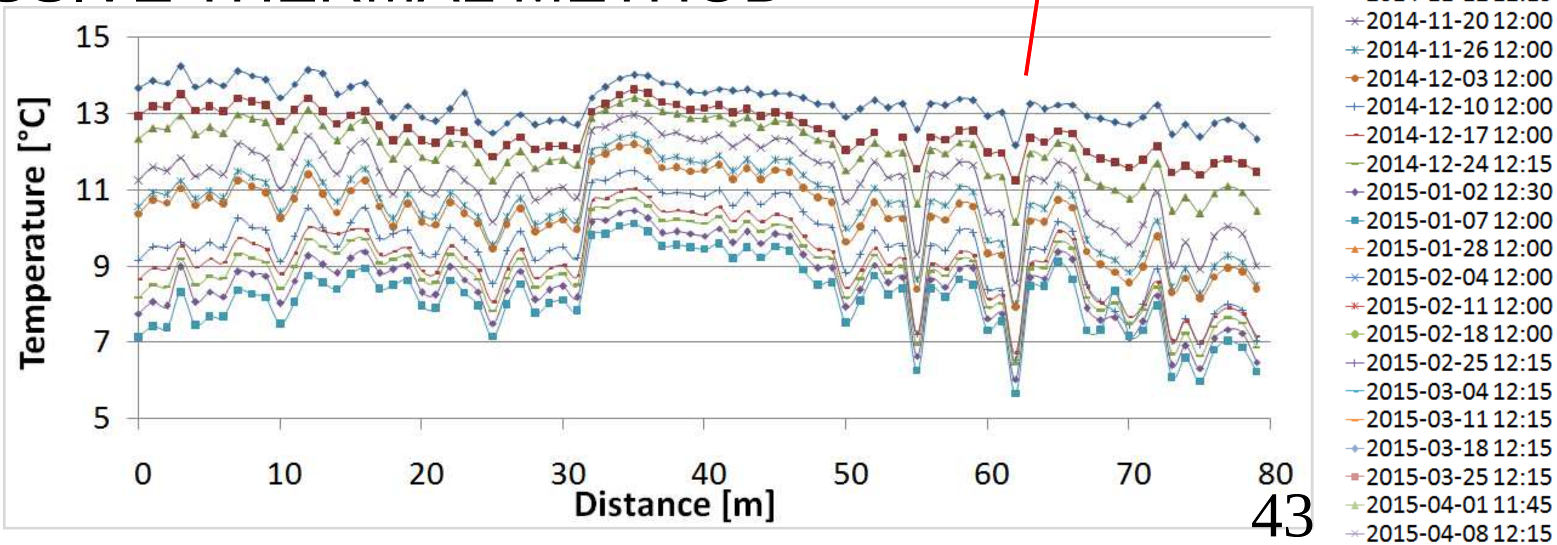
QUASI 3D MONITORING SYSTEM ON KOZŁOWA GÓRA DAM

MPointS

QUASI LINEAR PASSIVE AND ACTIVE temperature measurements along the dam in the downstream toe



PASSIVE THERMAL METHOD



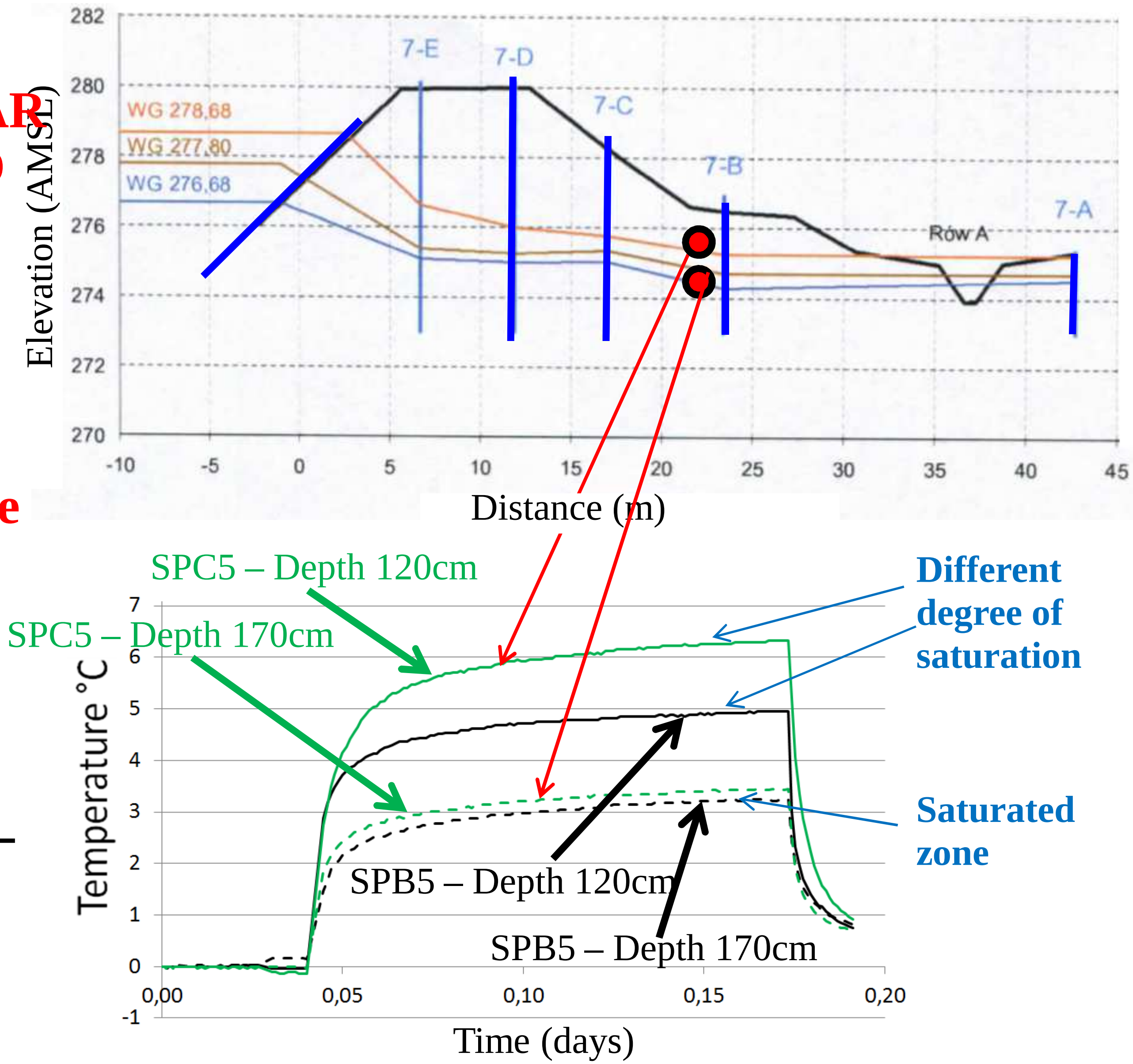
GÓRNOŚLĄSKIE PRZEDSIĘBIORSTWO WODOCIĄGÓW SPÓŁKA AKCYJNA

NeoStrain

QUASI 3D MONITORING SYSTEM ON KOZŁOWA GÓRA DAM

MPointS

QUASI LINEAR PASSIVE AND ACTIVE temperature measurements along the dam in the downstream toe



ACTIVE THERMAL METHOD

ACTUAL R&D WORKS

WE PREPARE RECOMENDATIONS FOR LEVEES CONCERNING THERMAL METHOD APPLICATION INCLUDING QUASI 3D SYSTEMS

TWO EXISTING LEVEES WILL BE EQUIPED WITH QUASI 3D SYSTEM

It is a one of the goals of 3 years ongoing project of development of innovative technologies of destructive processes detection and monitoring for levees and for geotechnical engineering co-founded by grant of Polish National Centre of Research and Development

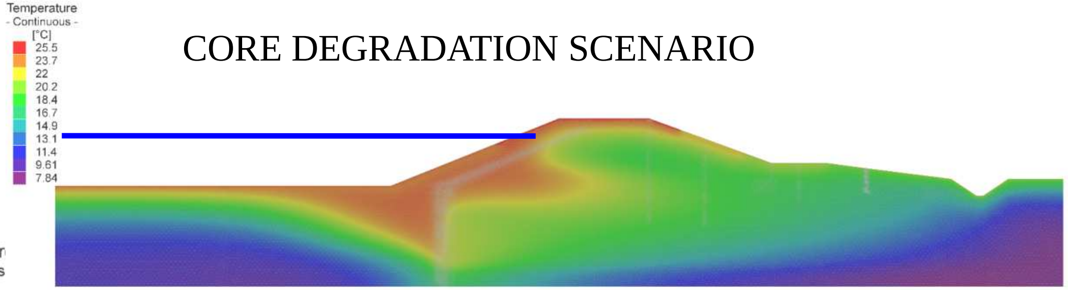
Project has started in 2017

VERIFICATION AND DEVELOPMENT OF NEW OR EXISTING METHODS OF DATA ANALYSIS

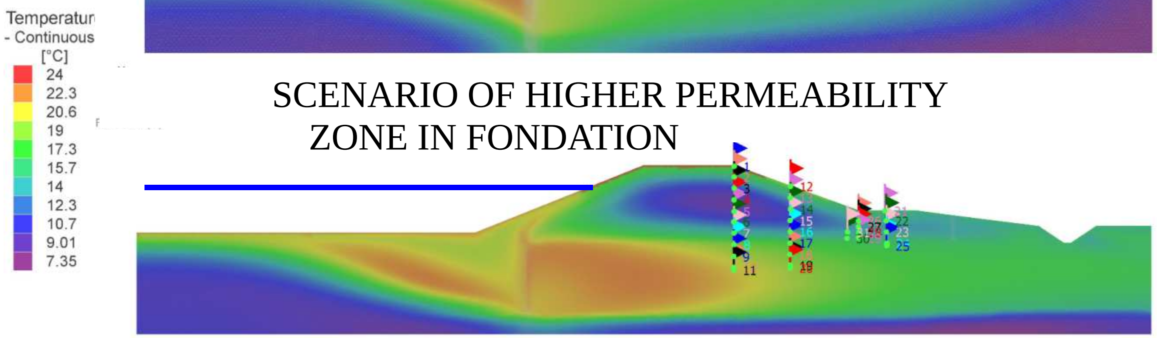
NUMERICAL MODELLING OF DATA FROM KOZŁOWA GÓRA

High value of information, low cost of the solution

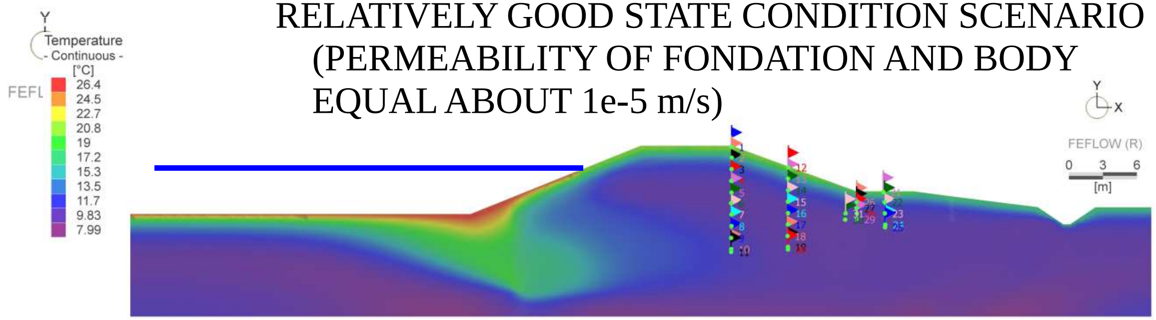
CORE DEGRADATION SCENARIO



SCENARIO OF HIGHER PERMEABILITY ZONE IN FONDATION



RELATIVELY GOOD STATE CONDITION SCENARIO (PERMEABILITY OF FONDATION AND BODY EQUAL ABOUT 1e-5 m/s)



This scenario reproduce with a good accuracy the real temperature measurements carried out in the body and the foundation of dam

We proved that thermal method allows for very precise investigation of seepage and internal erosion. Only thermal method allowed in cost-effective way to investigate a foundation of Kozłowa Góra dam

Results are presented e.g in:

2017, Radzicki K., Termomonitoring procesów filtracyjno-erozyjnych w zaporach i wałach przeciwpowodziowych

2018, Radzicki K., Opaliński P, Bonelli S., Investigation of leakages and internal erosion at Kozłowa Góra dam using thermal method and HST model, ICOLD congress, accepted paper

DEVELOPMENT OF IRFTA (Impulse Response Function Thermal Analysis) MODEL

SOLUTION OF LINEAR PROBLEM WITH THE GREEN'S FONCTION

Impulse response function to the air temperature influence

Impulse response function to the water temperature influence

$$T(x,t) = \theta_0(x) + h_{air}(x,t) * \theta_{air}(t) + h_w(x,t) * \theta_w(t)$$

Air temperature

Water temperature

Convolution product $h(x,t) * \theta(t) = \int_0^t h(t-t')\theta(t')dt' = \int_0^t h(t')\theta(t-t')dt'$

Simplest exponential approximation of the impulse response function

$$h_i(t) = F_i(a_i, h_i, t)$$

α_i - damping factor

η_i - characteristic time of the delayed system response

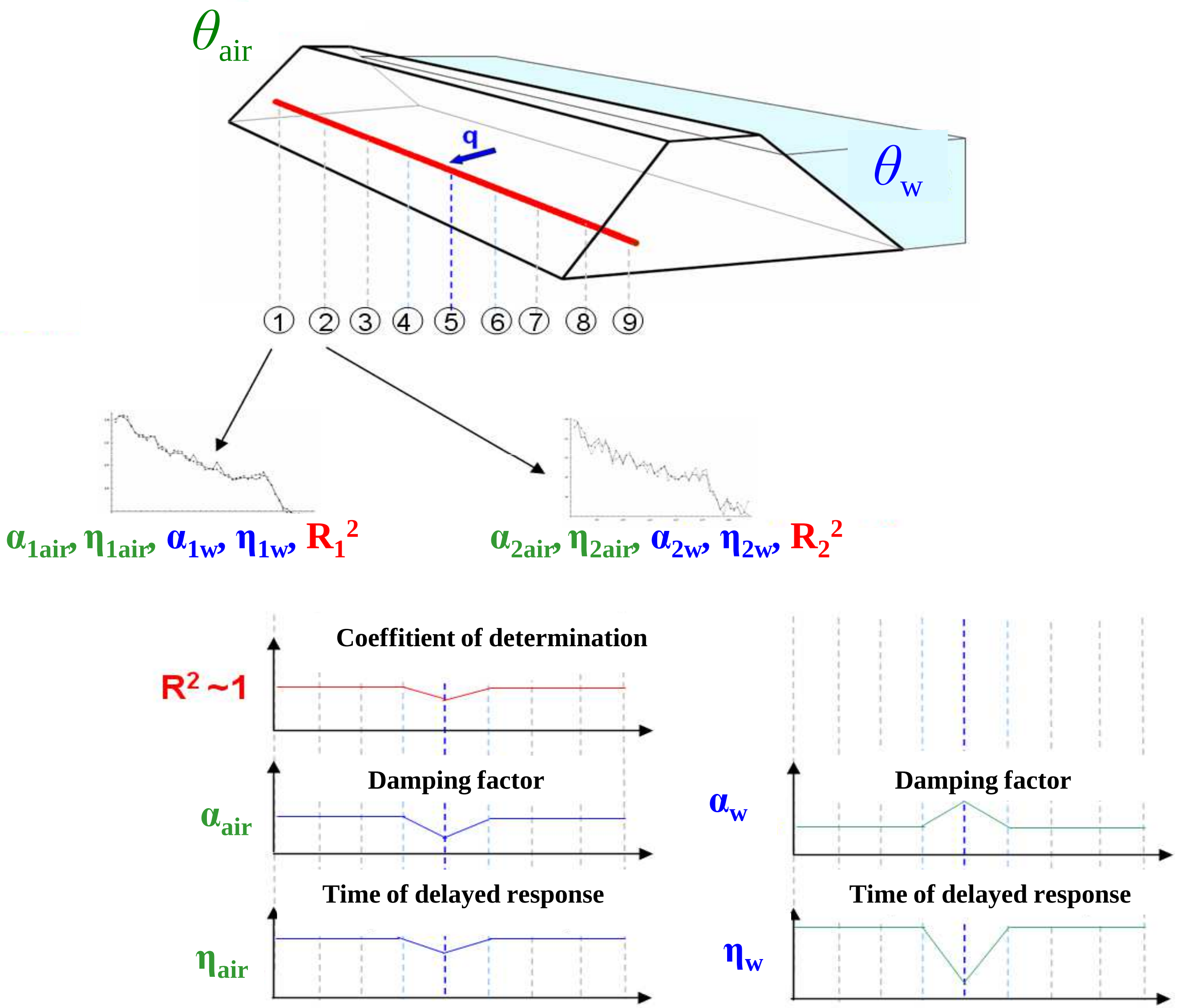
MODEL IRFTA (Impulse response function thermal analysis)

$$\hat{T}(x,t) = \theta_0(x) + F_{air}(\alpha_{air}, \eta_{air}, t) * \theta_{air}(t) + F_w(\alpha_w, \eta_w, t) * \theta_w(t)$$

DEVELOPMENT OF
IRFTA (Impulse Response Function Thermal Analysis) MODEL

System

Model



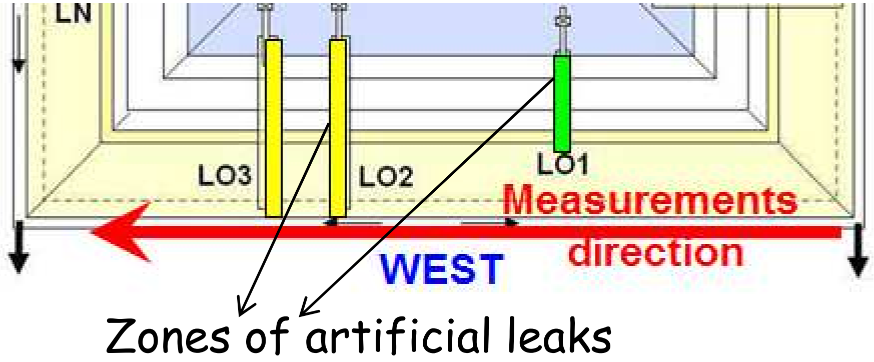
DEVELOPMENT OF
IRFTA (Impulse Response Function Thermal Analysis) MODEL

Very successful application of IRFTA model for thermal leakage detection and analysis of seepage process on French damming structures

e.g we proved e.g. that even, only changes of moisture of soil (without water flow) is enough to detect a leakage by IRFTA model using sensors located in downstream toe of structure

PEERINE experimental basin

dike of canal of EDF



Results presented e.g. in:

2012, Radzicki & Bonelli (2012). Physical and parametric monitoring of leakages in earth dams using analysis of fibre optic distributed temperature measurements with IRFTA model, 24thICOLD Congress,

2009, Radzicki, PhD rapport, Analyse retard des mesures de températures dans les digues avec application à la détection de fuites

ACTUAL R&D WORKS

NEW MODELS FOR THERMAL METHOD ARE BEING DEVELOPPED

It is a one of the goals of 3 years ongoing project of development of innovative technologies of destructive processes detection and monitoring for levees and for geotechnical engineering co-founded by grant of Polish National Centre of Research and Development

Project has started in 2017

DEVELOPMENT OF THERMAL METHOD APPLICATION METHODOLOGY

AND MULTI-METHODS APPLICATIONS METHODOLOGY

COMPLEX METHODOLOGY OF THERMAL MONITORING METHOD APPLICATION FOR EARTH DAMS AND LEVEES INCLUDING INNOVATIVE MEASUREMENTS TECHNOLOGIES

SINCE 2015
PARTICIPATION IN
Cost Action TU1402:
"Quantifying the Value
of Structural Health Monitoring"

Strategies of thermal method application

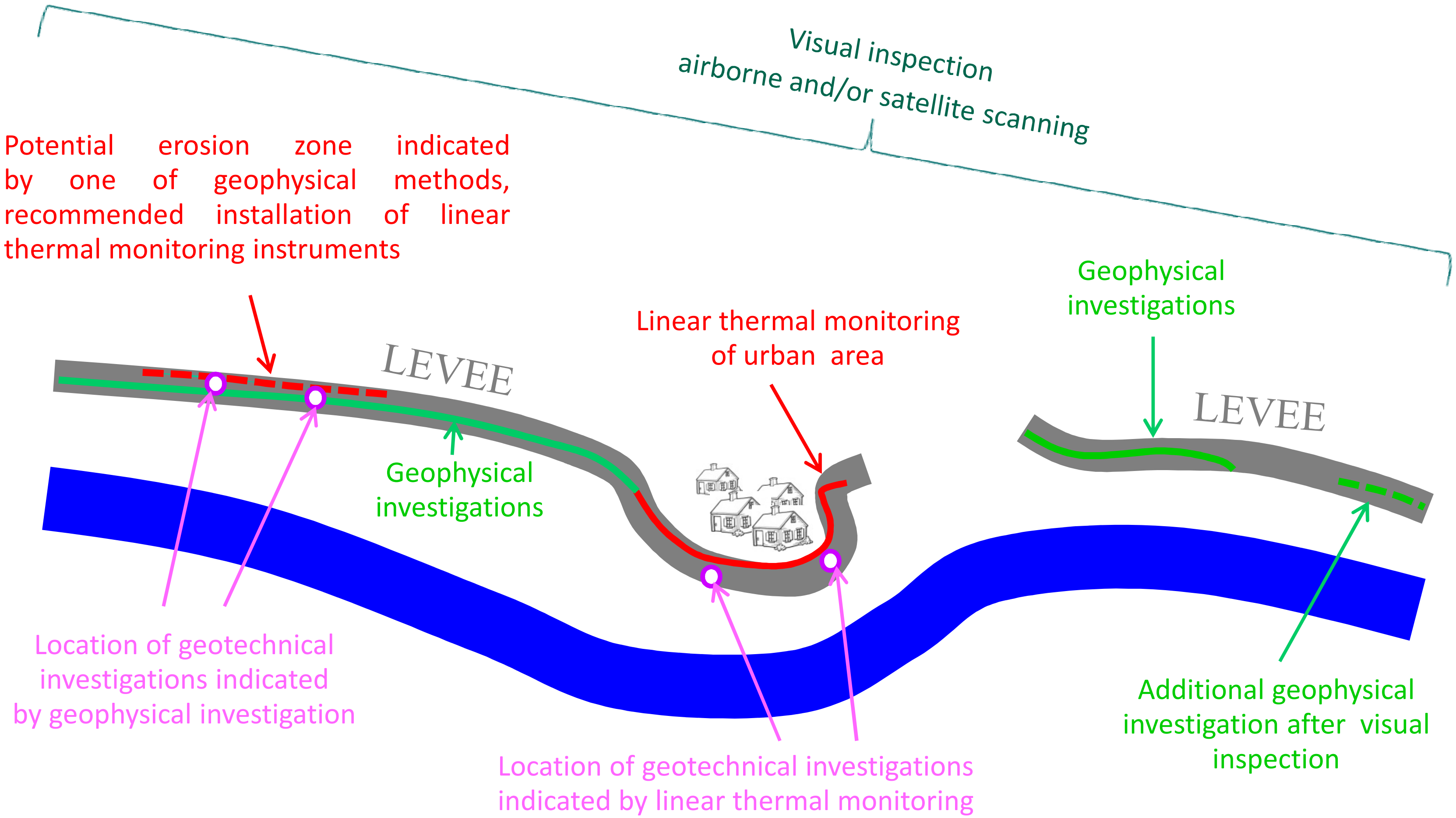
- A) vary in terms of the feasibility of SHM
  - A.1) SHM and SCA
  - A.2) Solely SCA
- B) vary in terms of duration of the measurements
  - B.1) Permanent measurements system
  - B.2) Temporary measurements system
- C) related to spatial dimensions of temperature measuring systems
  - C.1) Single point sensors
  - C.2) Single temperature vertical profile measurements
  - C.3) Temperature vertical multi profiles measurements in cross section(s) of structure
  - C.4) Linear (1D) system or quasi 2D system
  - C.5) Quasi-3D system
- D) vary in terms of type of temperature measurements sensor
  - D.1) No linear sensors
  - D.2) Linear continous (distributed) – DFOT (distributed fiber optic temperature) sensors
  - D.3) Linear quasi-continous – multipoint sensors
- D) related to type of thermal method and periodicity of its use
  - E.1) Permanent temperature measurements and frequent periodic active method application
  - E.2) Permanent temperature measurements and occasional active method application
  - E.3) Solely permanent temperature measurements without active method application
  - E.4) Occasional passive and/or active method application

Results are presented in:

2016, Complex report :
Strategies of structural health thermal monitoring and condition assessment with thermal monitoring of earth dams and leeves"

Scientific paper preparation is in progress

COMPLEX METHODOLOGY OF MULTI-METHODS APPLICATIONS FOR LEVEES INVESTIGATIONS, MONITORING AND CONDITION ASSSESMENT



Concept is presented e.g in paper:

2014, Radzicki K., (2014). The important issues of levees monitoring with special attention to thermal-monitoring method application, South Baltic Conference on New Technologies and Recent Developments in Flood Protection.

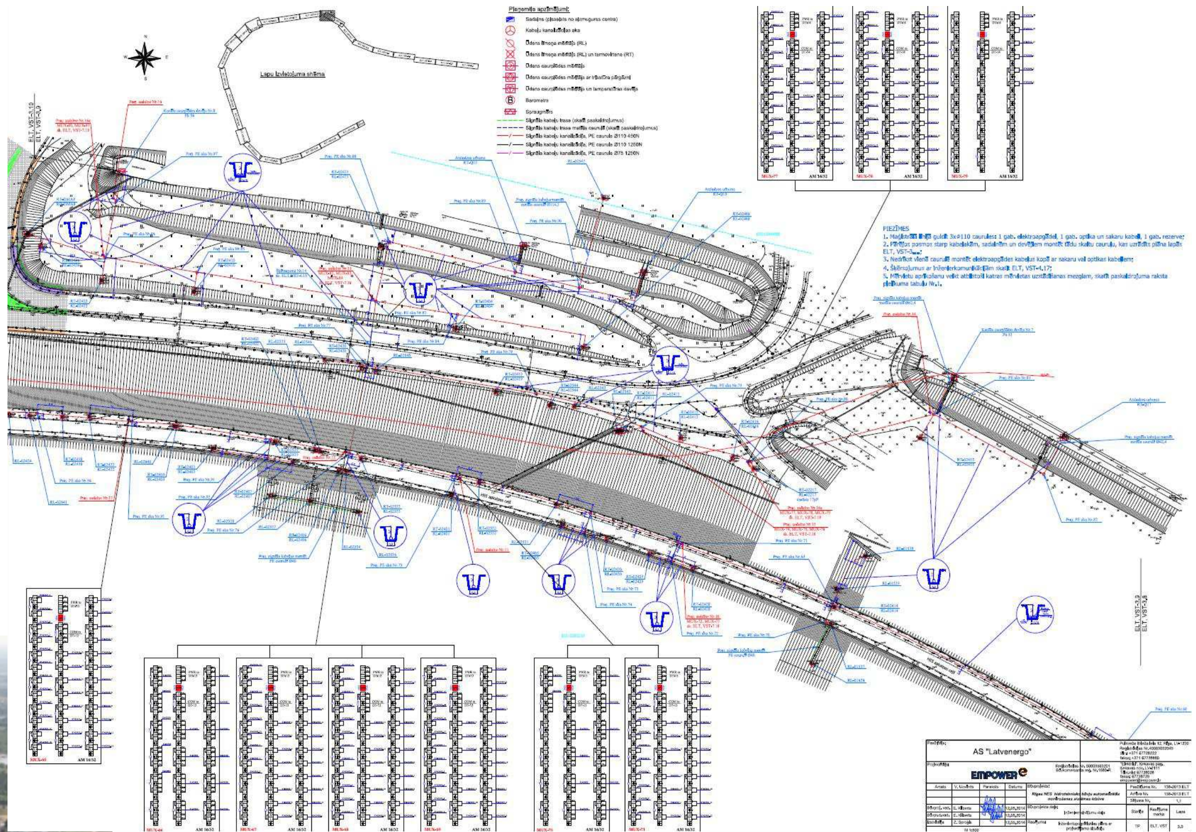
ACTUAL R&D WORKS

COMPLEX METHODOLOGY OF THERMAL METHOD AND MULTI-METHODS APPLICATIONS FOR LEVEES INVESTIGATIONS, MONITORING AND STATE ASSSESMENT ARE BEING DEVELOPPED

It is a one of the goals of 3 years ongoing project of development of innovative technologies of destructive processes detection and monitoring for levees and for geotechnical engineering co-founded by grant of Polish National Centre of Research and Development

Project has started in 2017

INSTALATION OF ABOUT 2000 OF TEMPERATURE SENSORS TO INVESTIGATE CROSS SECTIONS OF RYGA EARTH DAMS



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MORE INFORMATIONS ABOUT PRESENTED SUBJECTS ARE AVAILABLE IN ELECTRONIC VERSION

ON RESEARCH GATE **write in Google <RESEARCH GATE RADZICKI>**

OR ON **http://suw.biblos.pk.edu.pl** **(*write RADZICKI)***

Thank you for your attention

Krzysztof Radzicki Ph.D Eng

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