Monitoring of the suffusion process development using thermal analysis performed with IRFTA model

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Introduction

DIFFUSION-ADVECTION EQUATION

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

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

⇨ **LINEAR - PARABOLIC PROBLEME**

SYSTEM NONDIMENTIONAL

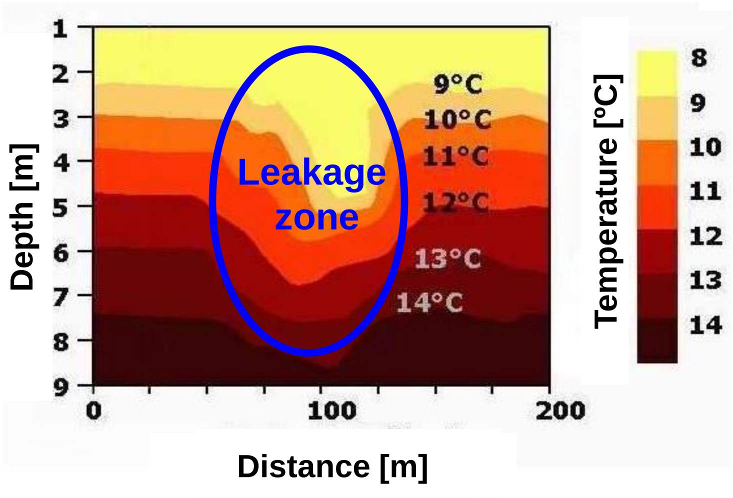
$$\vec{q} = const.$$

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

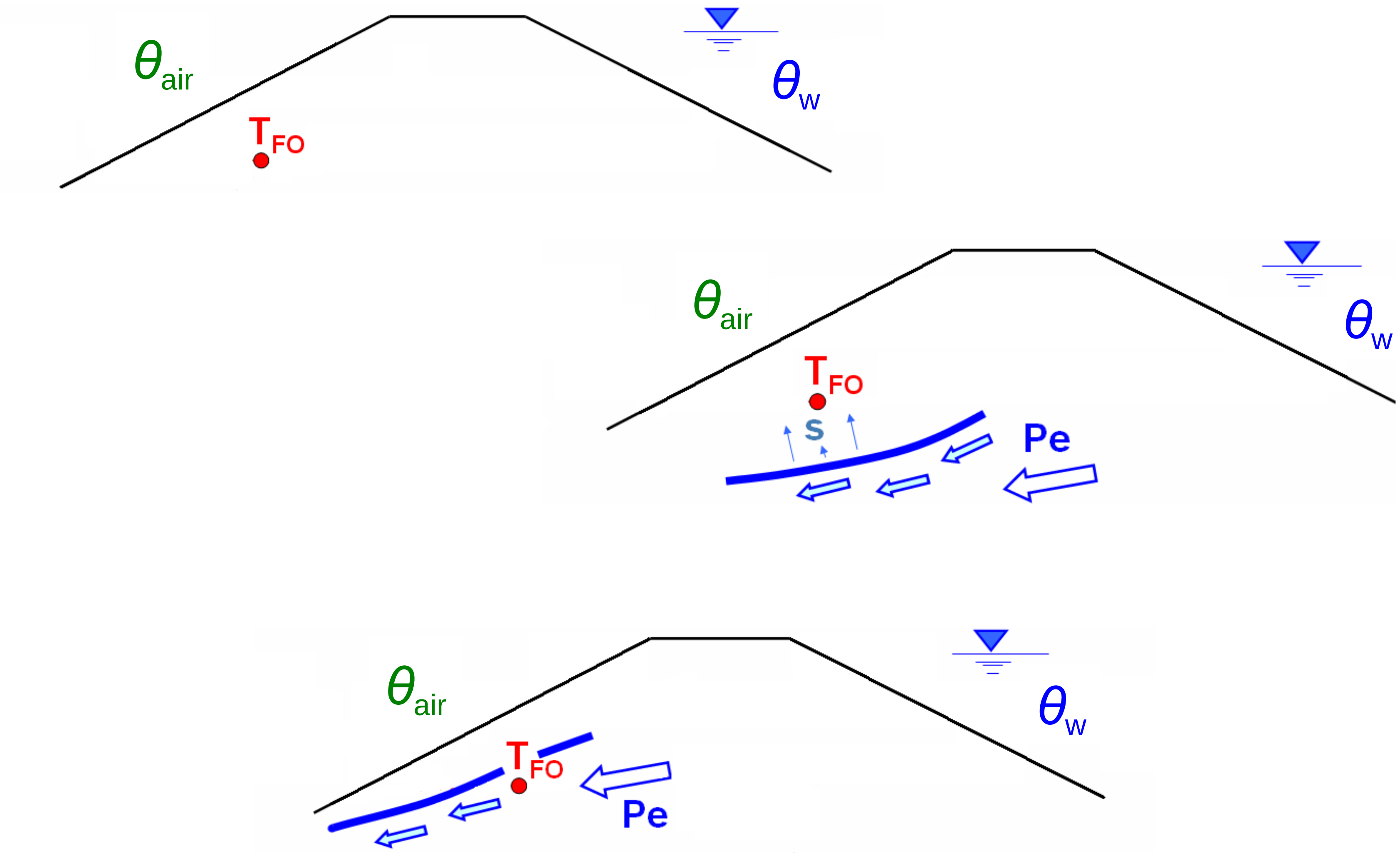
$$\frac{\partial T}{\partial \overline{t}} + Pe\frac{\partial T}{\partial \overline{x}} - \frac{\partial T}{\partial \overline{x}^2} = 0$$

Peklet number

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



Fibre optic cable location in landside toe of the structure



Model IRFTA

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

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

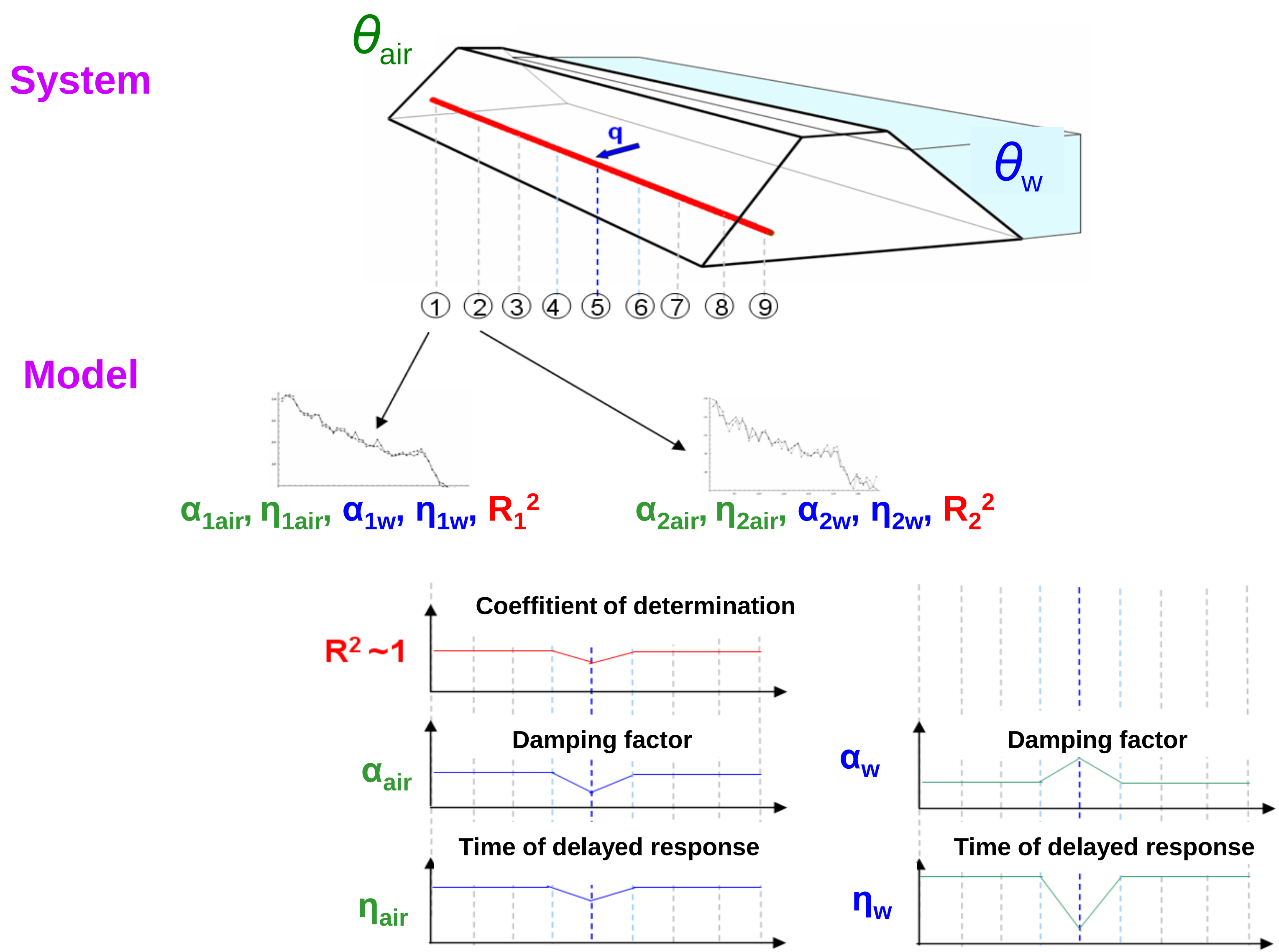
α_i - damping factor

η_i - characteristic time of the delayed system response

MODEL IRFTA (Impulse response function thermal analysis)

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

Model IRFTA



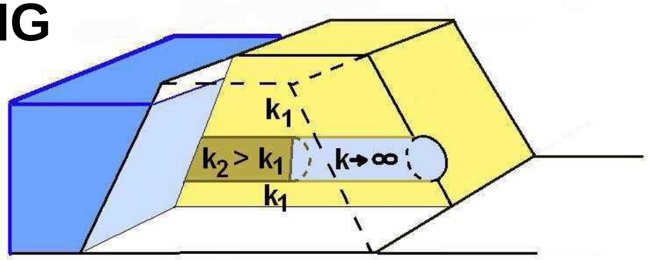
System
θair
q
θw
1 2 3 4 5 6 7 8 9
Model
α1air, η1air, α1w, η1w, R1 2
α2air, η2air, α2w, η2w, R2 2
Coeffitient of determination
R2 ~1
Damping factor
αair
αw
Damping factor
Time of delayed response
ηair
ηw
Time of delayed response

Leakage detection with IRFTA model in real French dikes

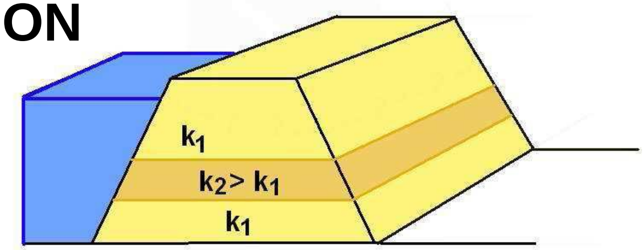
Very successful
application
of IRFTA model
for thermal
leakage detection
and
analysis of
seepage process
in real French dams

Erosion process thermal-detection and quantification

PIPING



SUFFOSION



Description of the principal thermal characteristics of the process development

In depth parametrical analysis and description of principal characteristics
Radzicki PhD, 2009; Radzicki, Bonelli, 2010

Real size test with DTFO monitoring, IjkDijk 2009, Artiere et all., 2010

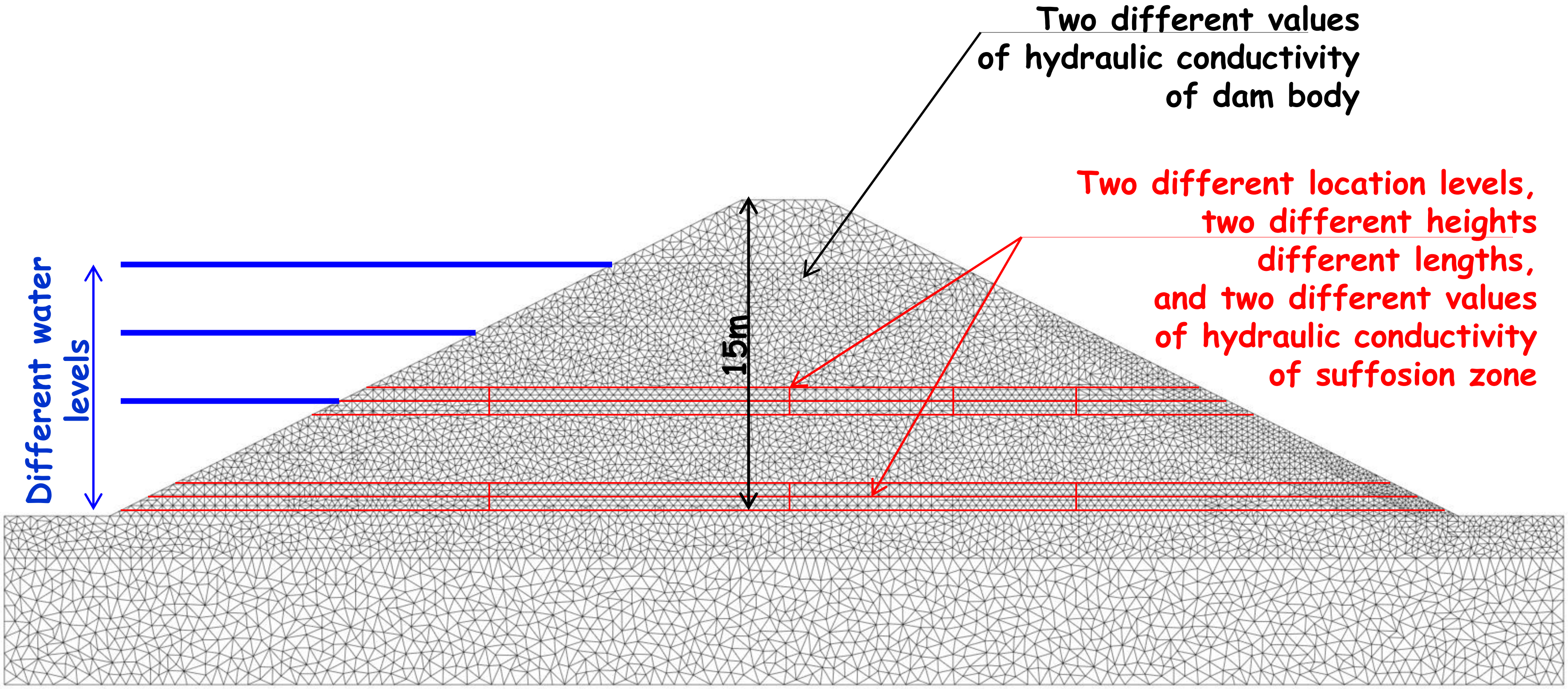
Researches in progress funded by Polish Ministry of Science Research Project No. N N506 266339 Some results is presented in the present paper

Thermal analysis with IRFTA model

Radzicki PhD, 2009
Only particulare examples
Researchers must continue

Researches in progress funded by Polish Ministry of Science Research Project No. N N506 266339 Some results is presented in the present paper

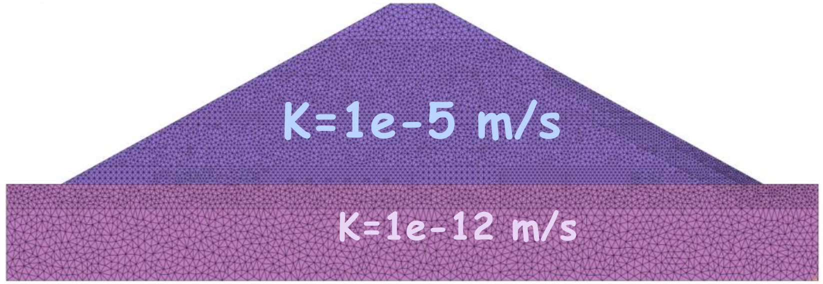
Numerical model of the homogeneous dam

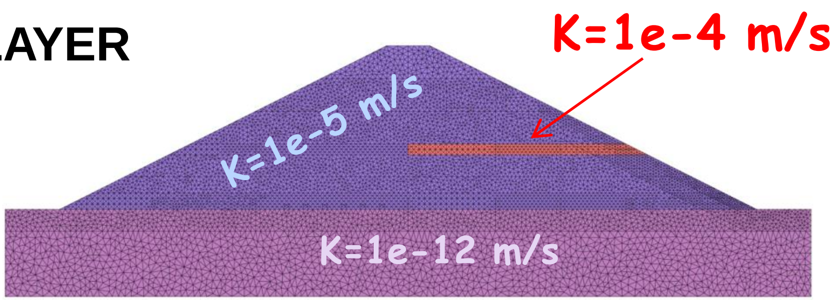


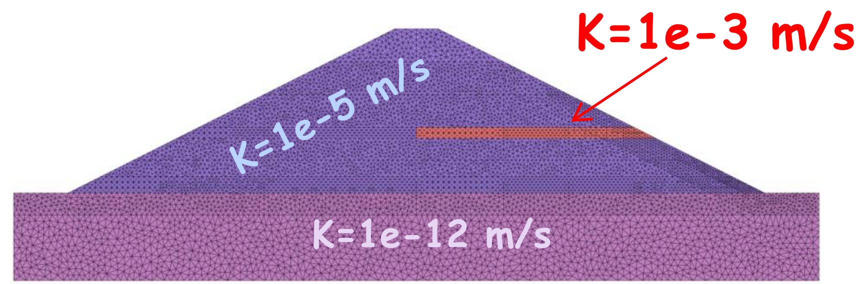
A lot of modelisations of the different cases ……

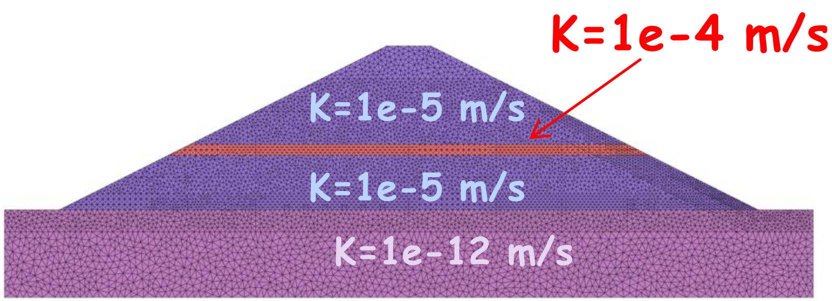
One example

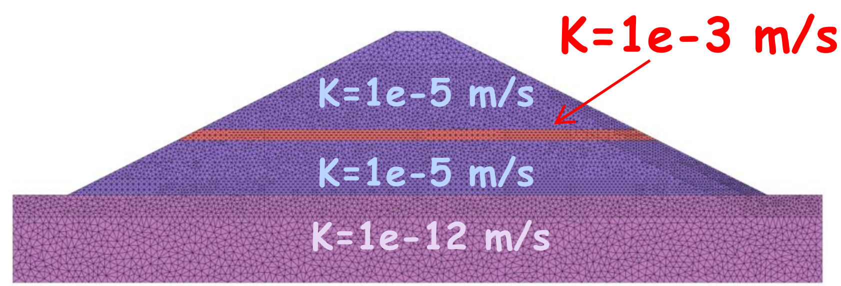
DIFFERENT LENGTH and VALUE OF HYDRAULIC CONDUCTIVITY OF SUFFOSION LAYER



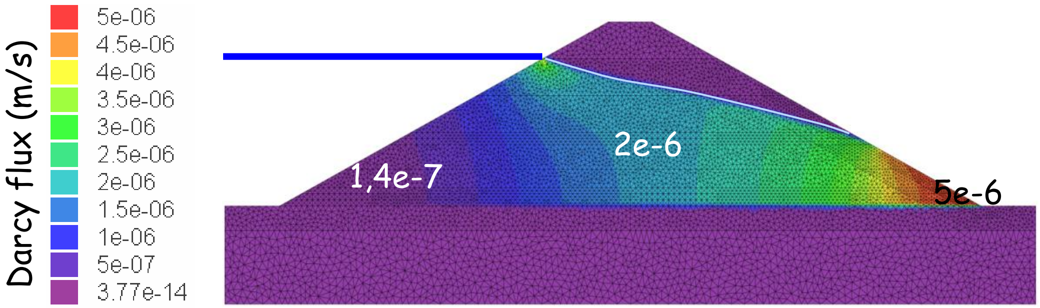


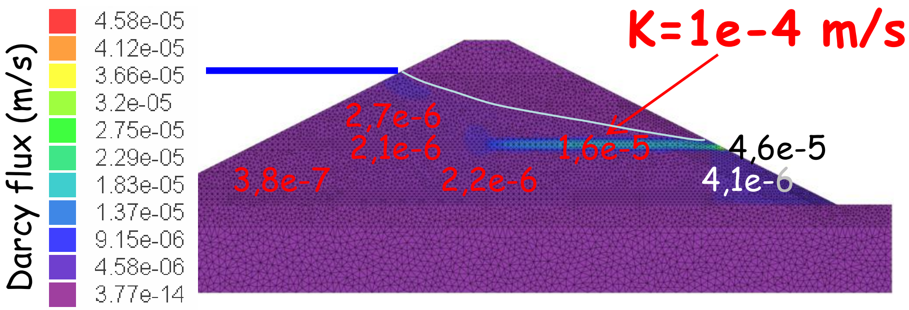


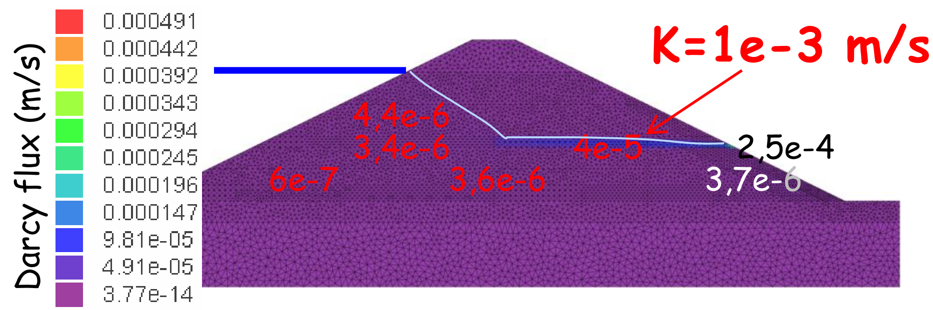


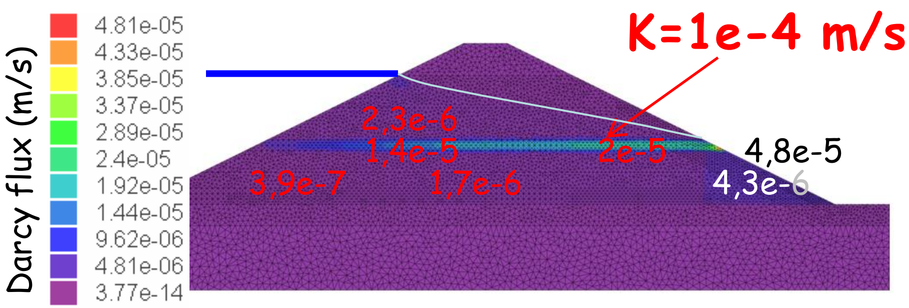


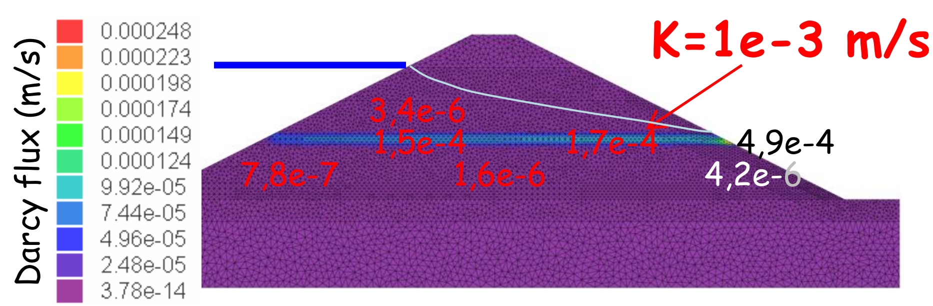
Hydraulic influence of suffosion zone



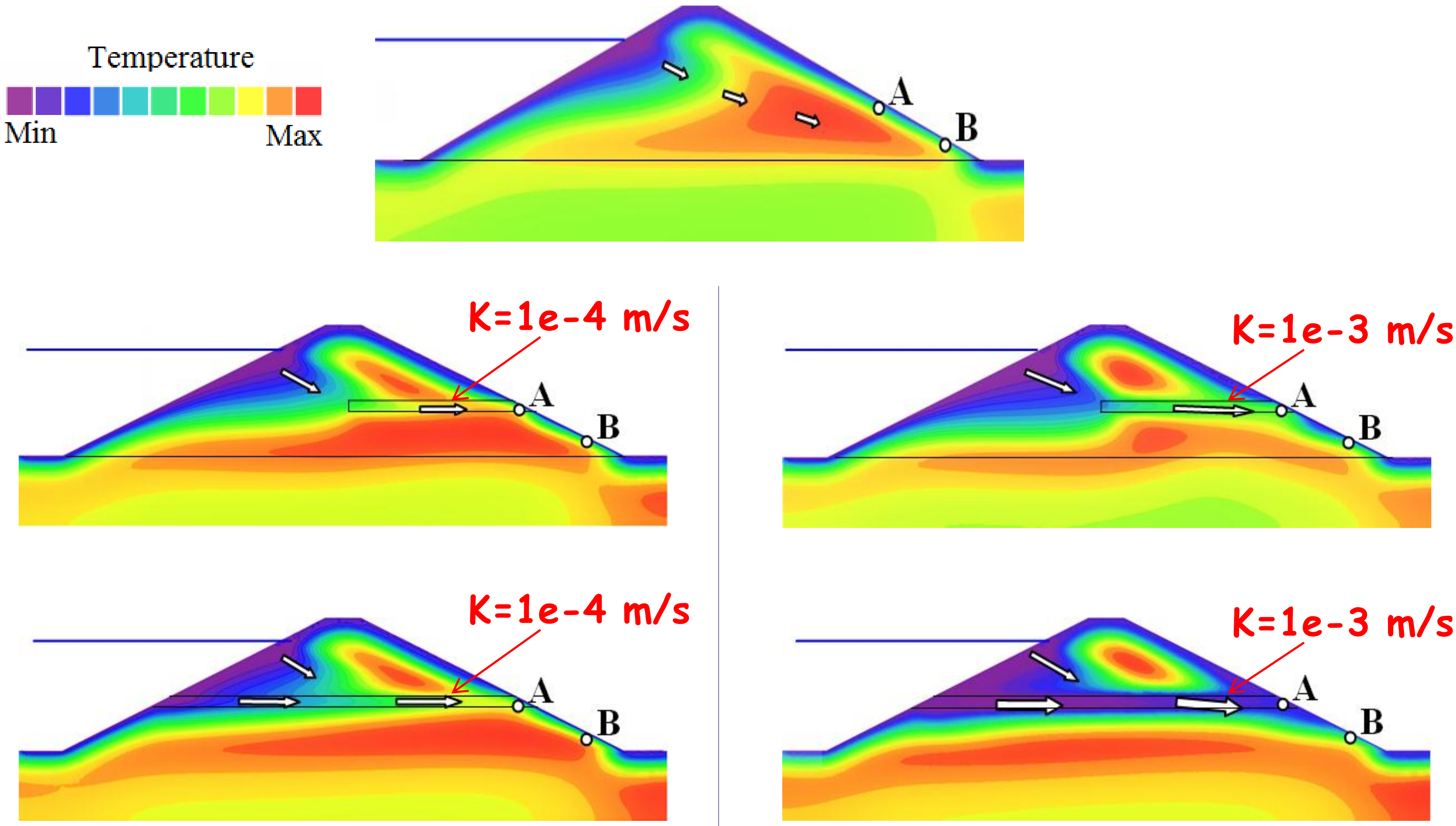




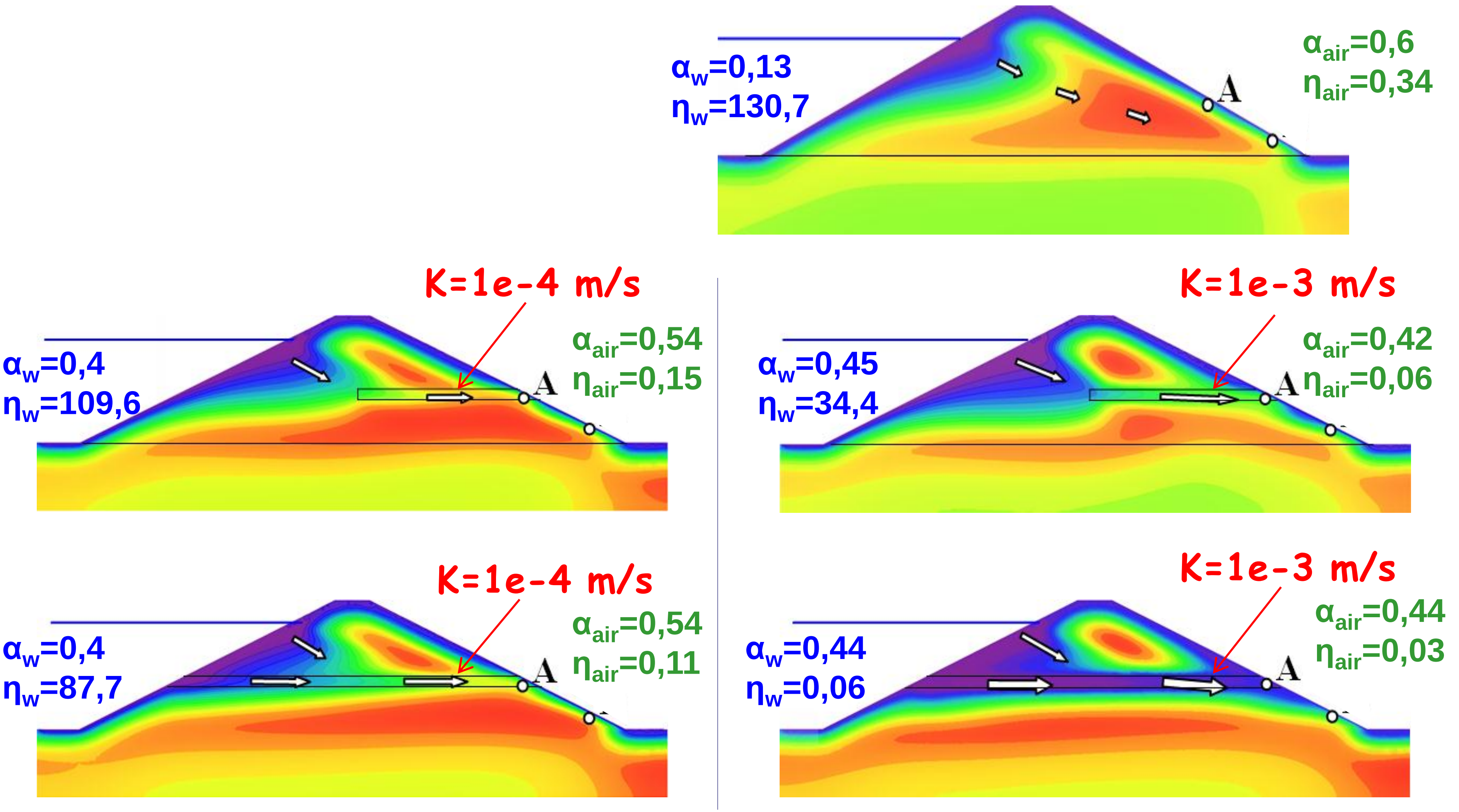




Thermal influence of suffosion zone



Thermal influence of suffosion zone – **„A” POINT**

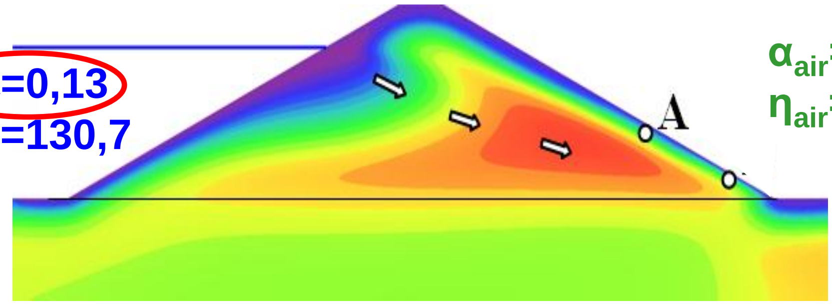


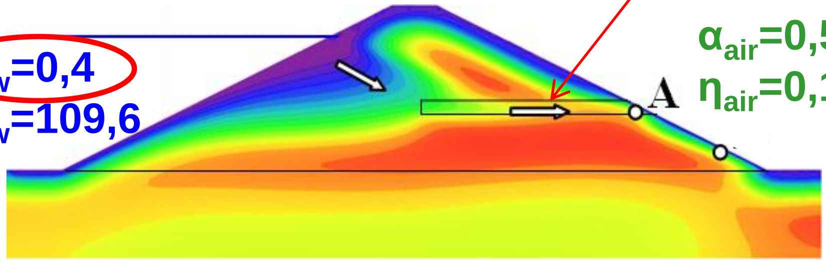
α_i - damping factor

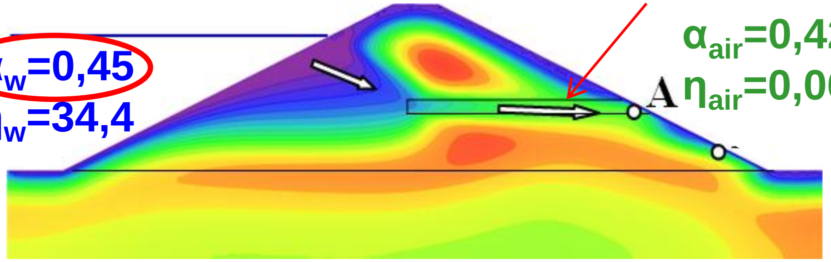
η_i - characteristic time of the delayed system response

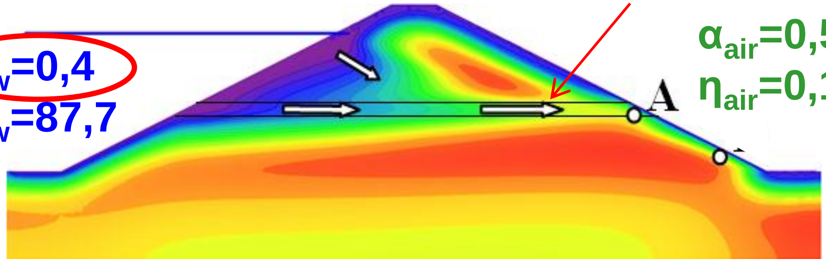
Thermal influence of suffosion zone – „A” **POINT**

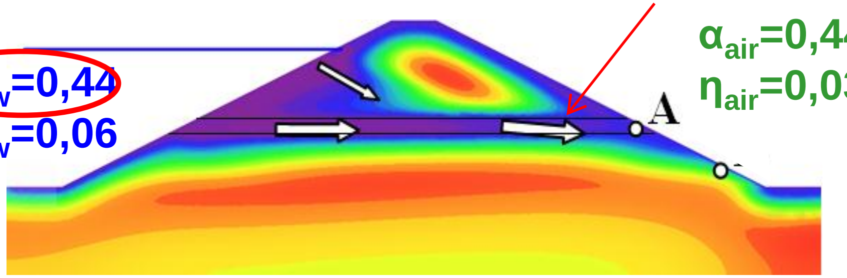
Significant increasing the value of α_w (damping decreasing) comparing the case „no suffosion” with the cases „with suffosion”









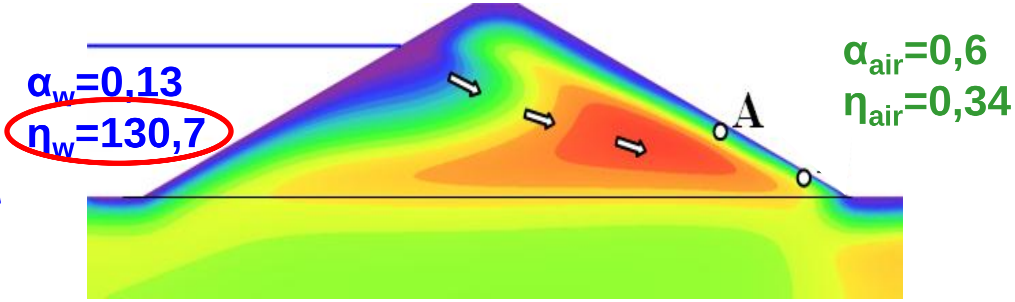


α_i - damping factor

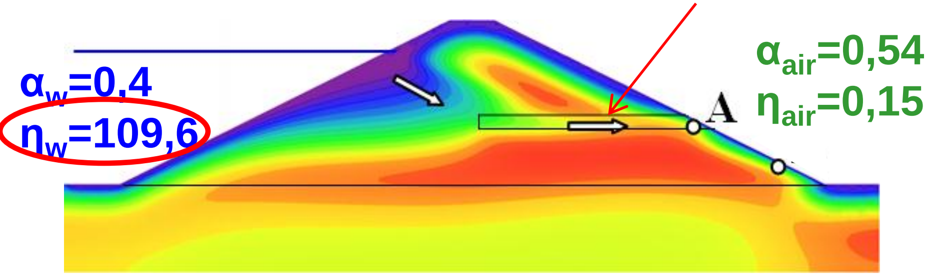
η_i - characteristic time of the delayed system response

Thermal influence of suffosion zone – **„A” POINT**

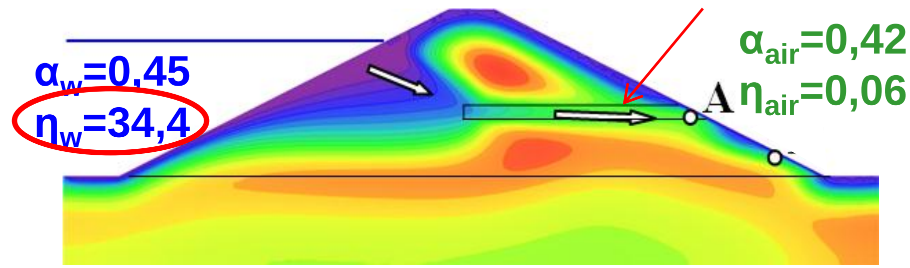
Very significant decreasing the value of η_w (increasing the signal velocity) with
- Increasing the suffosion layer length
- Increasing the value of hydraulic conductivity of suffosion zone



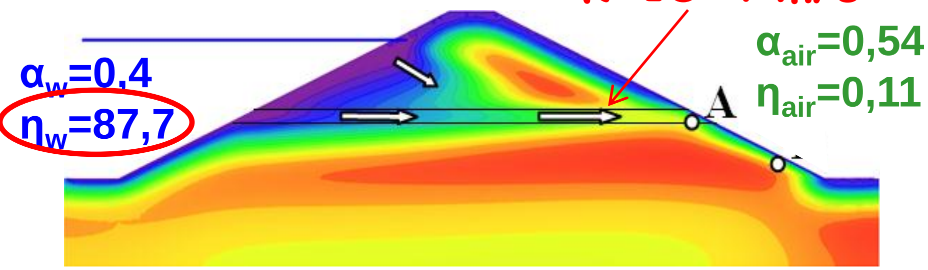
K=1e-4 m/s



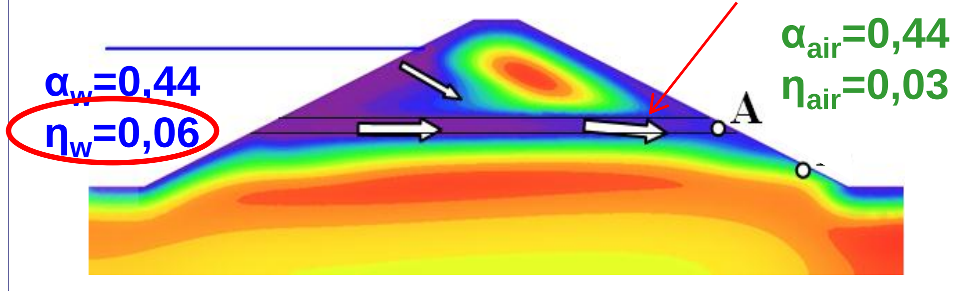
K=1e-3 m/s



K=1e-4 m/s



K=1e-3 m/s

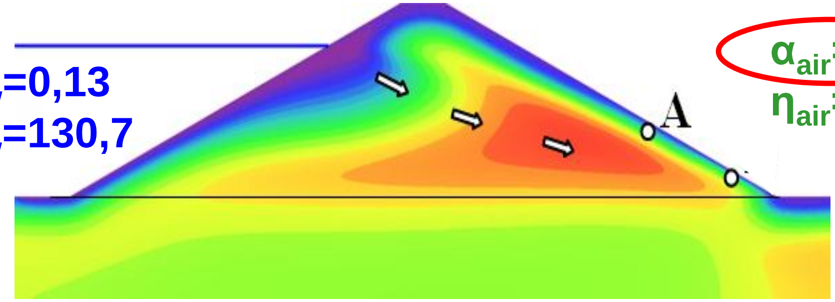


α_i - damping factor

η_i - characteristic time of the delayed system response

Thermal influence of suffosion zone – „A" POINT

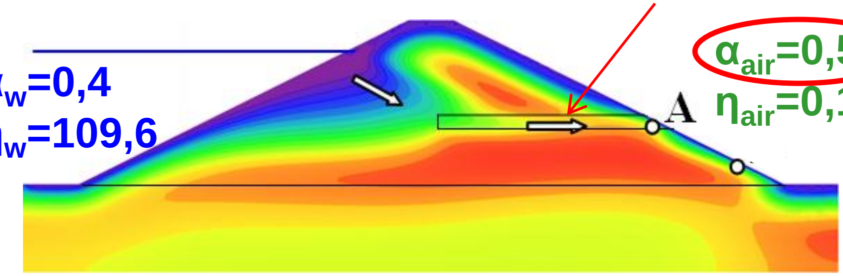
Decreasing the value of α_{air}
- comparing the case „no suffosion" with the cases „with suffosion"
- with increasing the value of hydraulic conductivity of suffosion zone



$\alpha_w=0,13$
$\eta_w=130,7$

$\alpha_{air}=0,6$
$\eta_{air}=0,34$

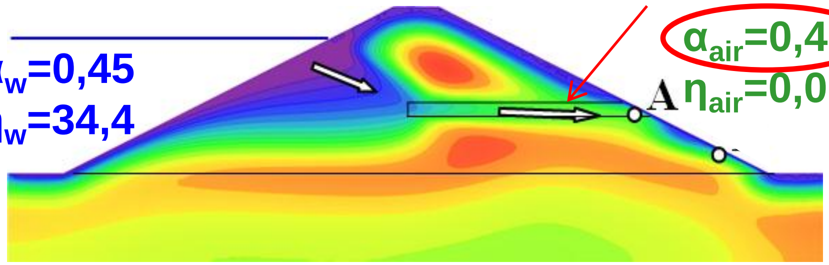
K=1e-4 m/s



$\alpha_w=0,4$
$\eta_w=109,6$

$\alpha_{air}=0,54$
$\eta_{air}=0,15$

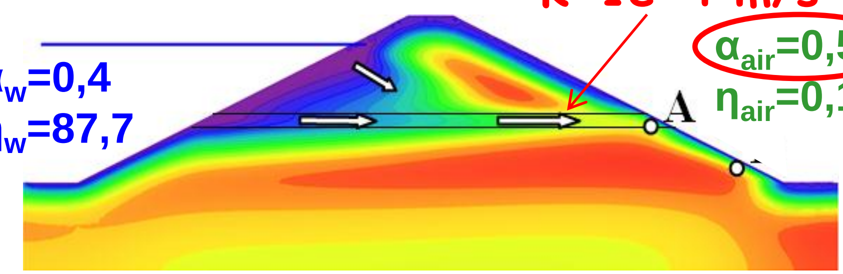
K=1e-3 m/s



$\alpha_w=0,45$
$\eta_w=34,4$

$\alpha_{air}=0,42$
$\eta_{air}=0,06$

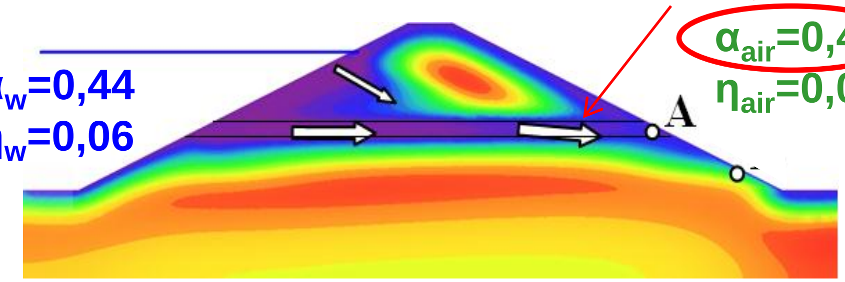
K=1e-4 m/s



$\alpha_w=0,4$
$\eta_w=87,7$

$\alpha_{air}=0,54$
$\eta_{air}=0,11$

K=1e-3 m/s



$\alpha_w=0,44$
$\eta_w=0,06$

$\alpha_{air}=0,44$
$\eta_{air}=0,03$

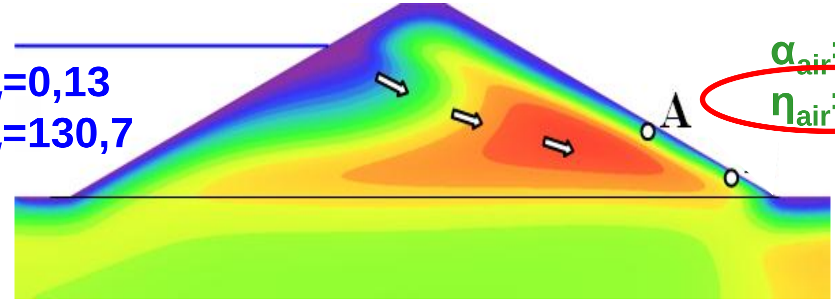
α_i - damping factor

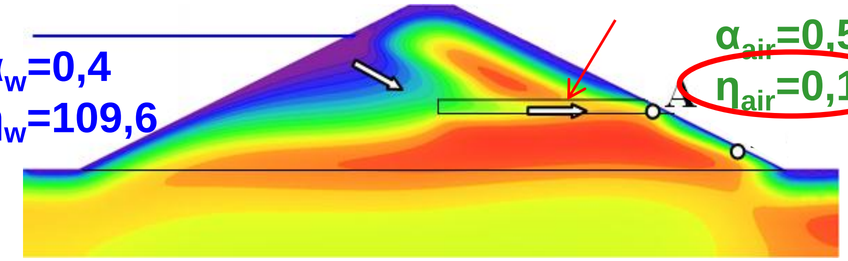
η_i - characteristic time of the delayed system response

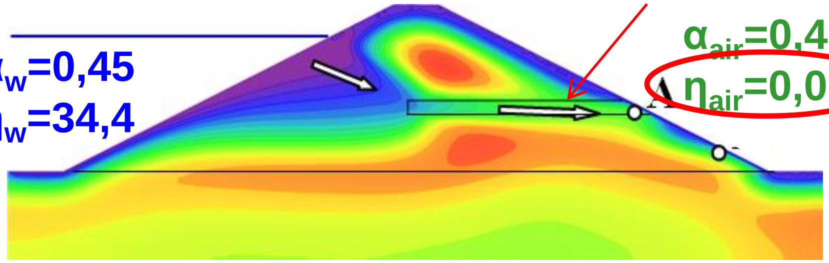
Thermal influence of suffosion zone – „A” **POINT**

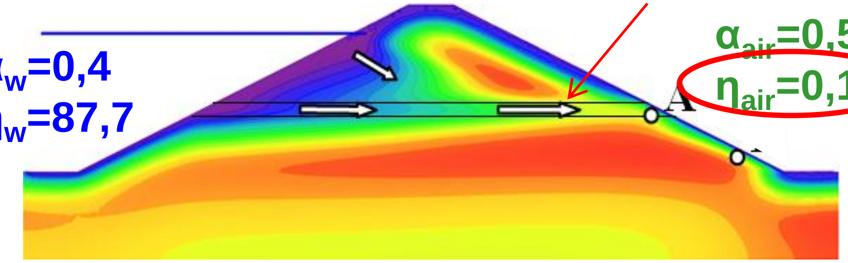
Significant decreasing the value of η_{air} (increasing of signal velocity) with

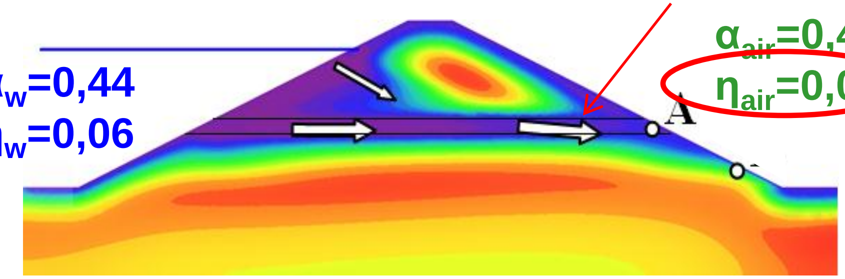
- Increasing the suffosion layer length
- Increasing the value of hydraulic conductivity of suffosion zone









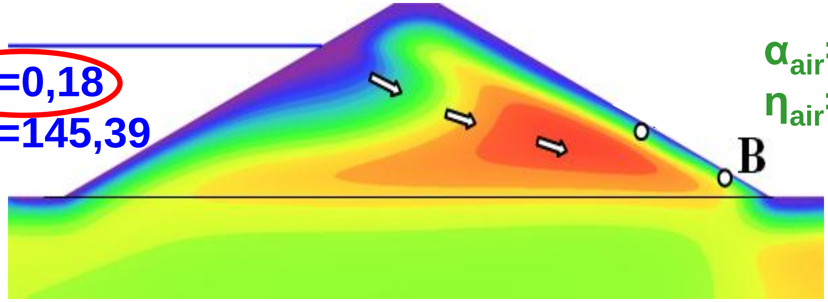


α_i - damping factor

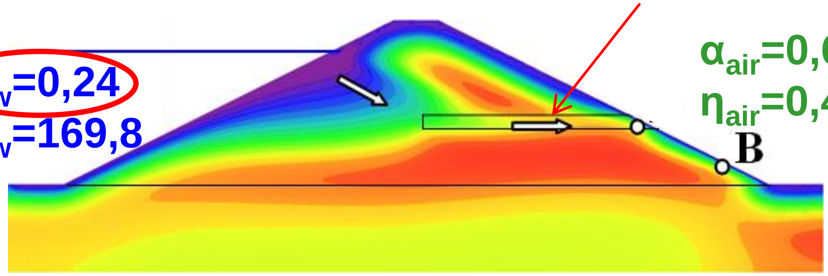
η_i - characteristic time of the delayed system response

Thermal influence of suffosion zone – „B" POINT

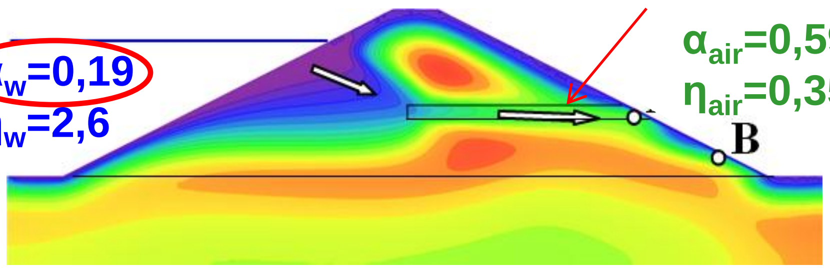
Increasing the value of α_w (damping decreasing) with increasing the suffosion layer length



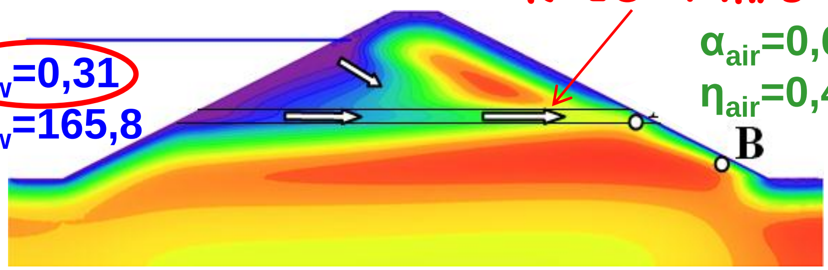
K=1e-4 m/s



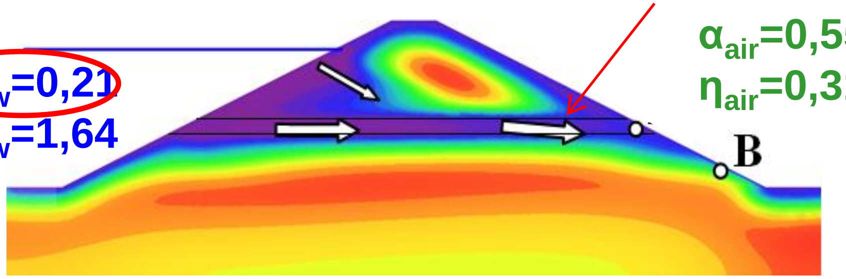
K=1e-3 m/s



K=1e-4 m/s



K=1e-3 m/s



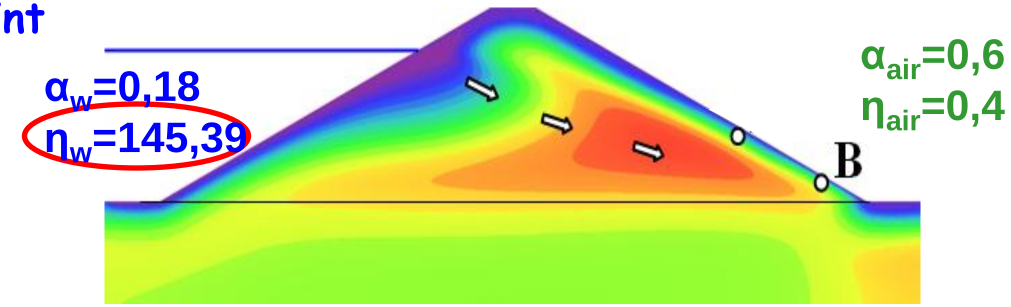
α_i - damping factor

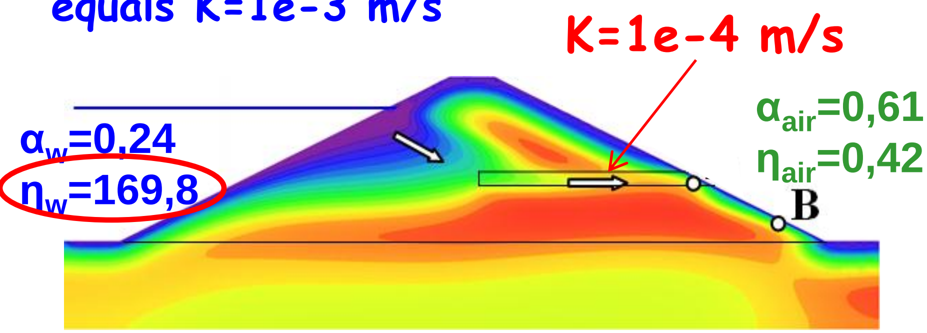
η_i - characteristic time of the delayed system response

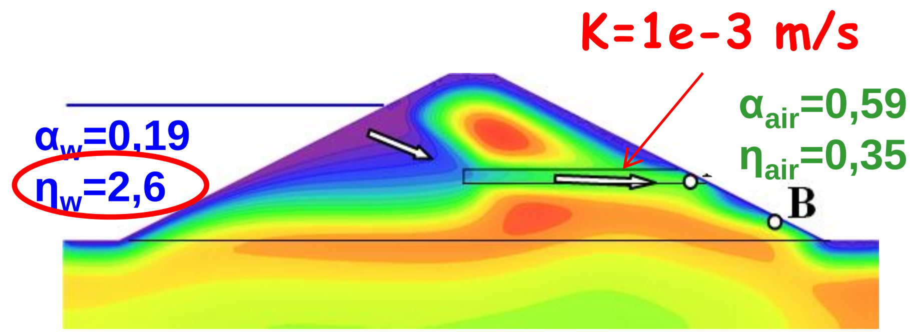
Thermal influence of suffosion zone – **„B” POINT**

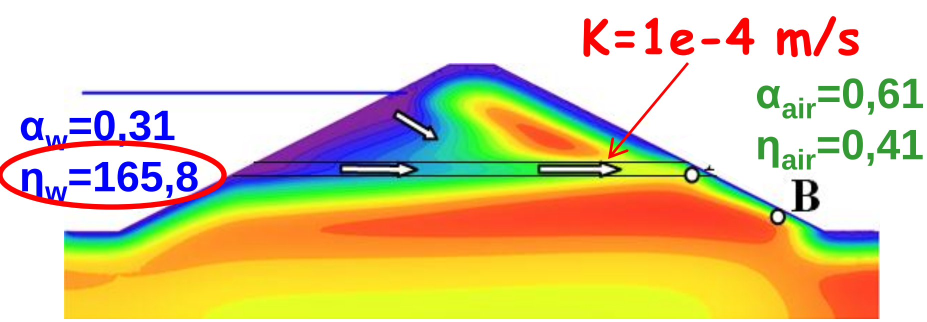
Different response of system in B point for η_w value for different value of hydraulic conductivity

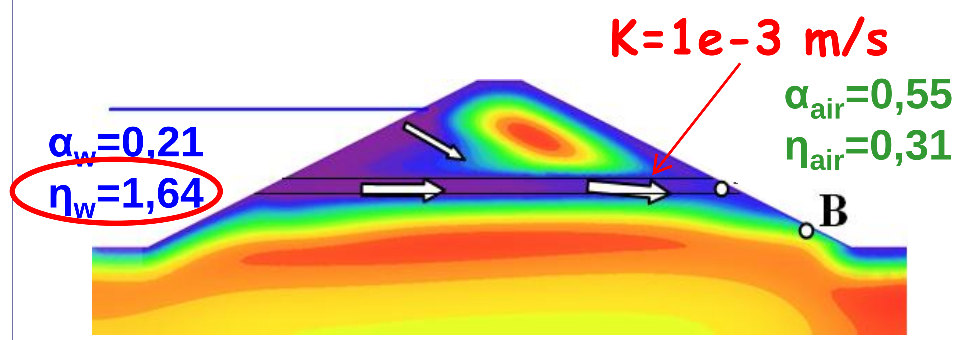
Very significant decreasing the value of η_w for the value of hydraulic conductivity of suffosion zone equals K=1e-3 m/s











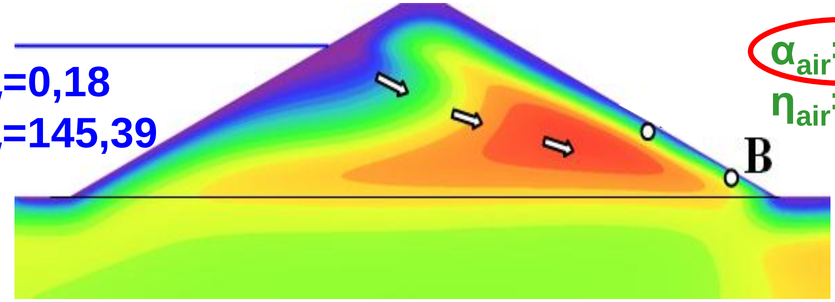
α_i - damping factor

η_i - characteristic time of the delayed system response

Thermal influence of suffosion zone – „B" POINT

Insignificant changes in value of α_{air}

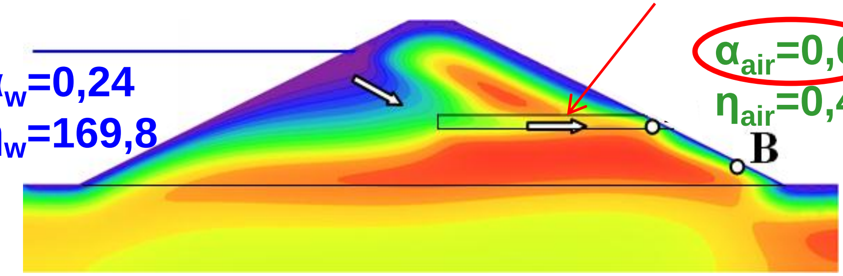
$\alpha_w=0,18$
$\eta_w=145,39$



$\alpha_{air}=0,6$
$\eta_{air}=0,4$

K=1e-4 m/s

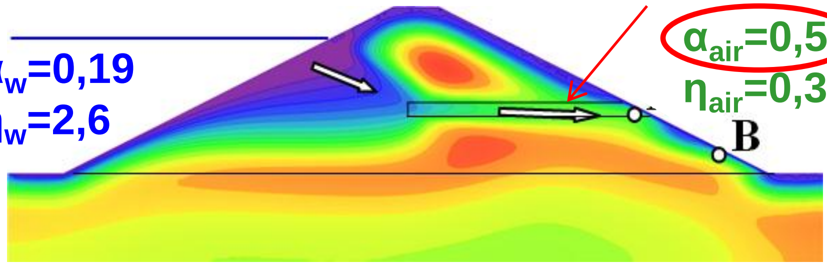
$\alpha_w=0,24$
$\eta_w=169,8$



$\alpha_{air}=0,61$
$\eta_{air}=0,42$

K=1e-3 m/s

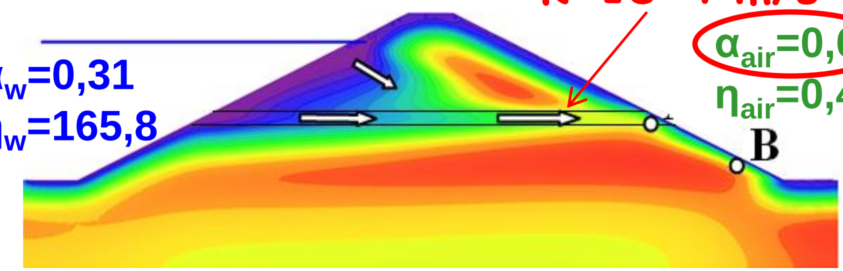
$\alpha_w=0,19$
$\eta_w=2,6$



$\alpha_{air}=0,59$
$\eta_{air}=0,35$

K=1e-4 m/s

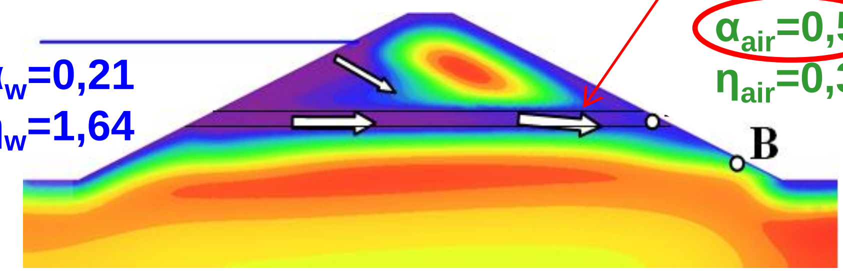
$\alpha_w=0,31$
$\eta_w=165,8$



$\alpha_{air}=0,61$
$\eta_{air}=0,41$

K=1e-3 m/s

$\alpha_w=0,21$
$\eta_w=1,64$



$\alpha_{air}=0,55$
$\eta_{air}=0,31$

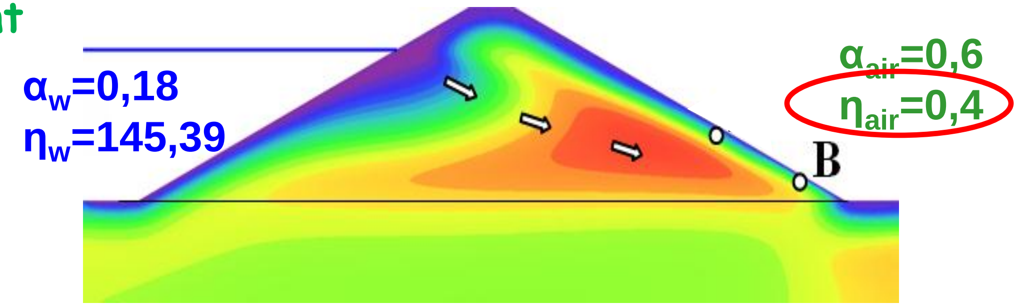
α_i - damping factor

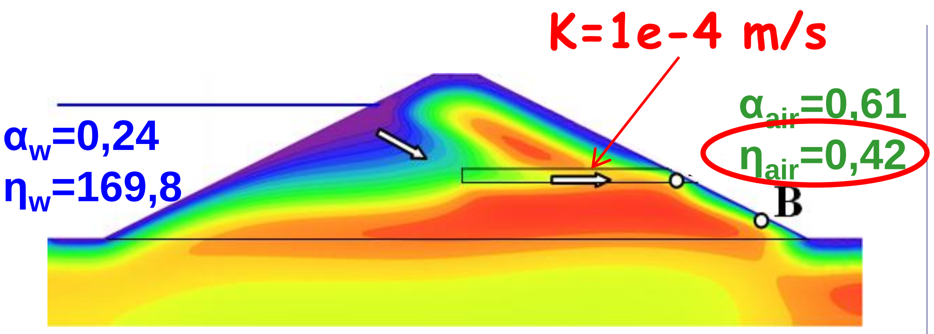
η_i - characteristic time of the delayed system response

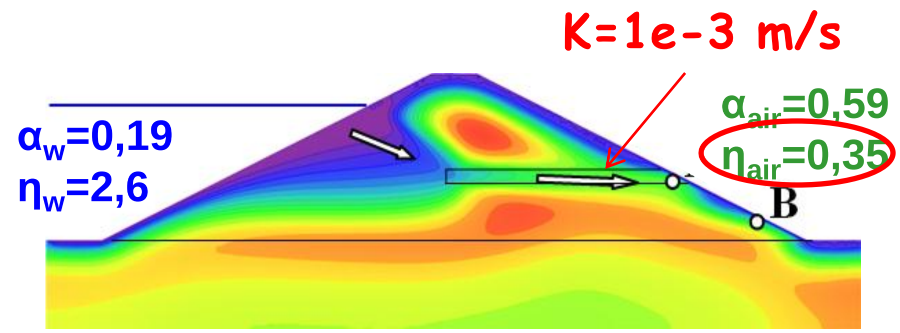
Thermal influence of suffosion zone – „B” POINT

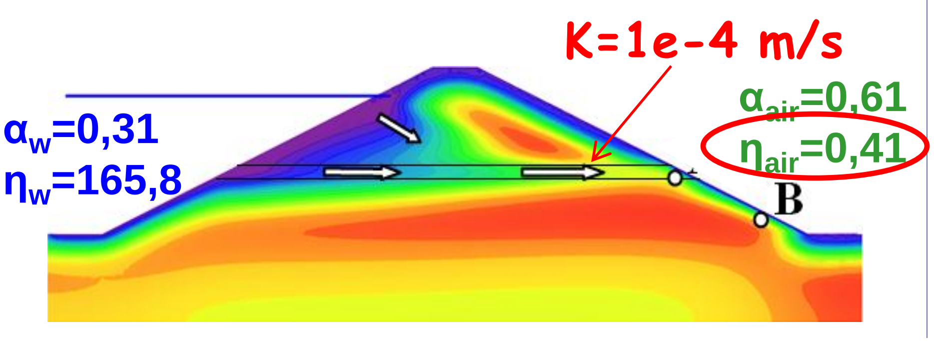
Different response of system in B point for η_{air} value for different value of hydraulic conductivity

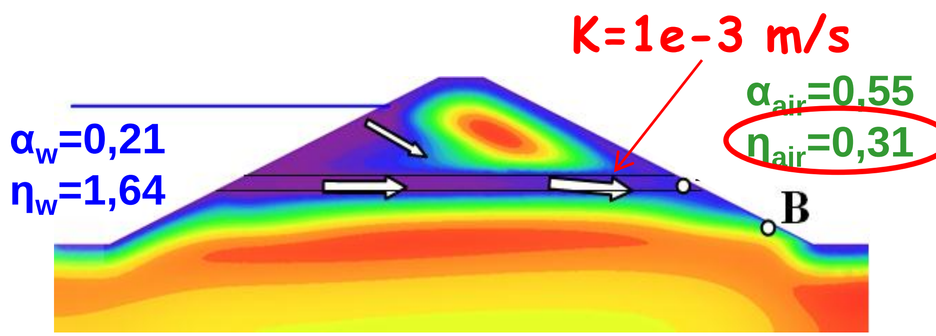
Decreasing the value of η_{air} for the value of hydraulic conductivity of suffosion zone equals K=1e-3 m/s











α_i - damping factor

η_i - characteristic time of the delayed system response

CONCLUSIONS

- Physical definitions of the IRFTA model parameters have enabled a precise description of the filtration-thermal field.
- Application of the IRFTA model for direct defining the parameters of developing suffusion process requires further tests.
- Monitoring of seepage zone hydraulic and geometrical parameters changes using IRFTA model seems to be very promising if the temperature sensor is located directly in the seepage zone.

  This conclusion correspond with the results of researches concerning the possibility of estimation of piping development dynamic by analysis of pipe water outflow temperature (Radzicki, Bonelli, 2010)

ACKNOWLEDGMENTS

The scientific studies described in this presentation were financed with resources allocated for 2010-2012 by the Polish Ministry of Science and Higher Education to the Research Project No. N N506 266339


Thank you
for your attention
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