MODELING OF THERMAL, FILTRATION AND MECHANICAL PHENOMENA IN SELECTED SECTION OF A GRAVITY DAM

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Z_Soil Days 2010

Location of Solina Dam

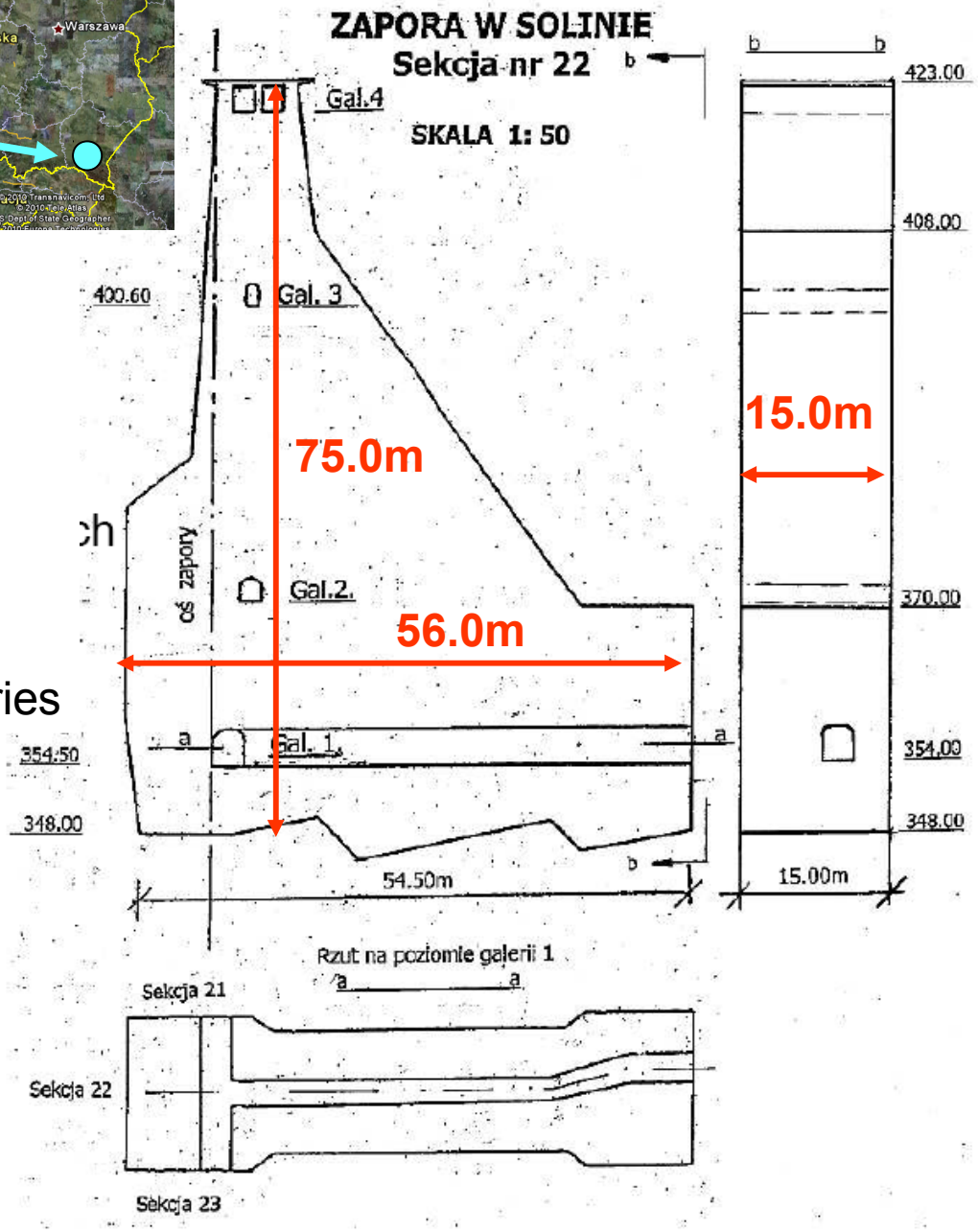
on San river, Carpathian region
south-east of Poland

Solina Dam –basic data

Hmax=75.0 m
total volume of water 474 mln m^3
area ~2100 ha

reversible power station
4 Francis type generators 200MW
yearly production of energy 230 GWh

Vb=820 000 m^3 in 43 sections
4 levels of communication-revision galeries

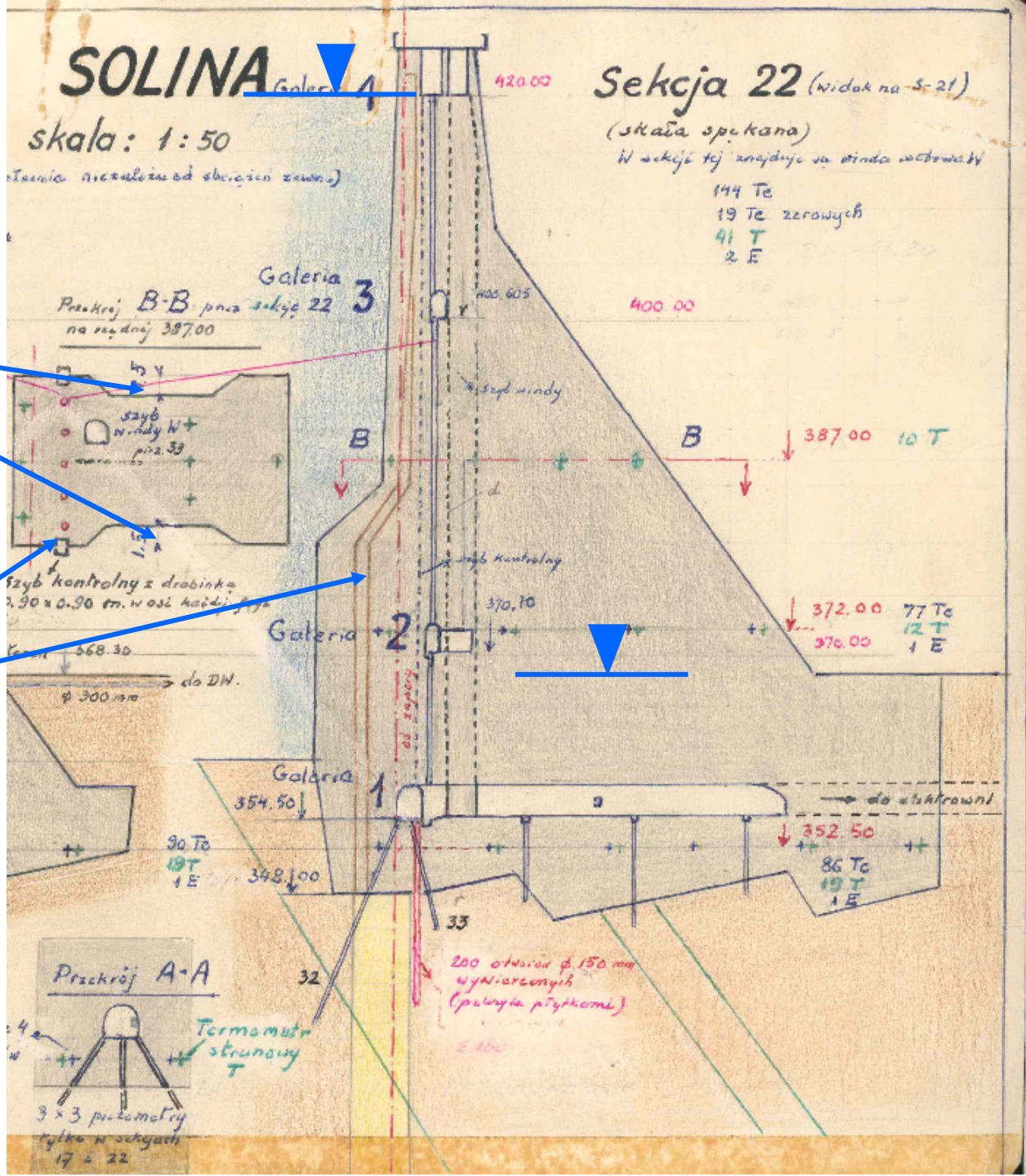


Section 22 – archival sketch

water filled internal cavities

sealing bands

Material:
-plain concrete



Assessment of Solina Dam

-revision of measurments record (temperature, displacements, water levels) in about 40 years period
-exclusion of abnormal (uncertain, false) data
-explanation of observed relation betwen measured fieds
-assessment of safety and indestructibility of concrete structures

3D FEM analysis of measured fields in selected section with Z_Soil

1. transient heat transfer problem $\Rightarrow \quad T = T(\mathbf{x}, t)$

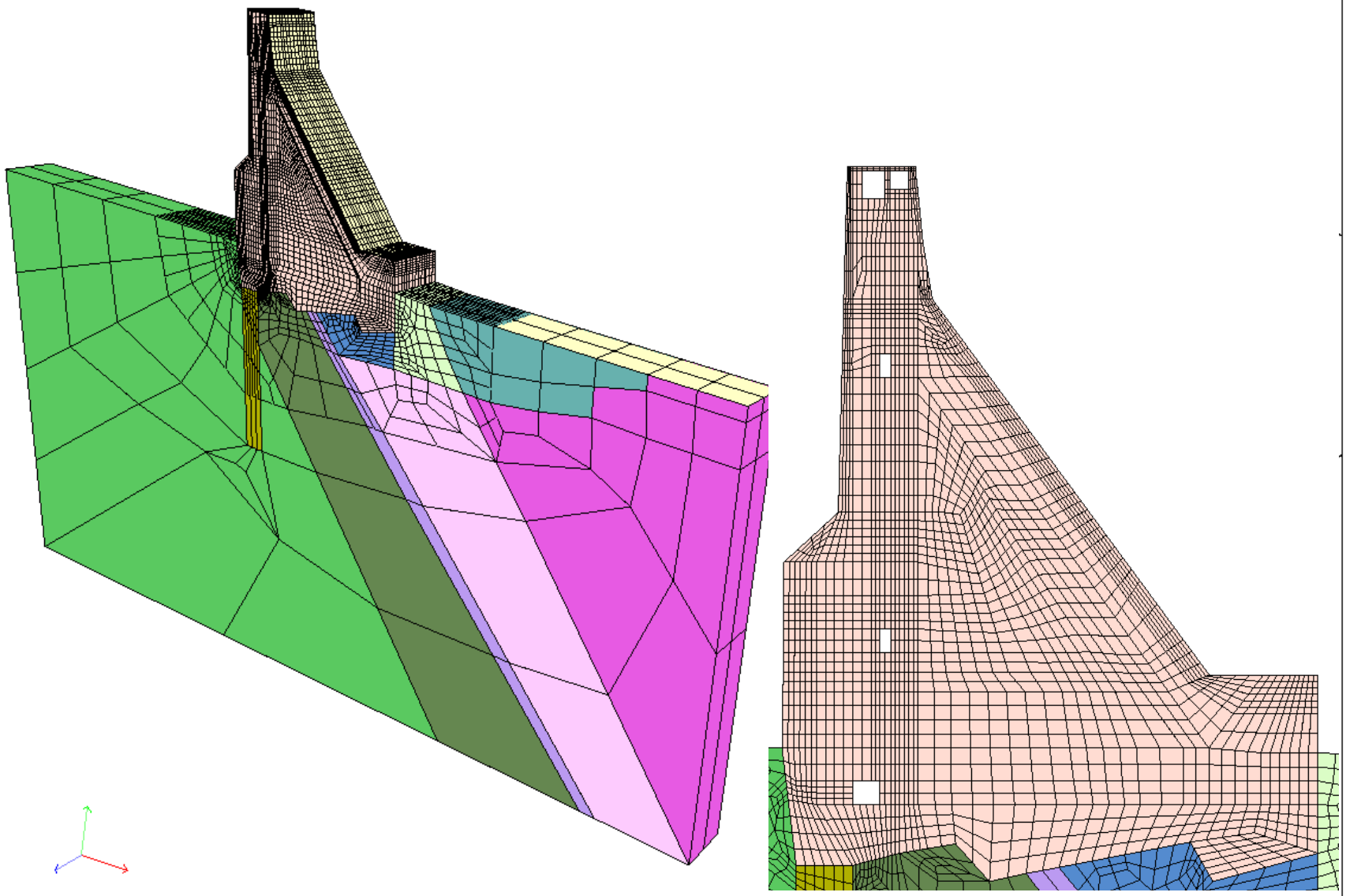
2. mechanical problem:

filtration (variable water lewel) + deformation (due to mechanical loads + imposed thermal strains)

$$\Delta\varepsilon^{o} = \alpha \cdot \Delta T(\mathbf{x}, t)$$
$$p = p(\mathbf{x}, t)$$

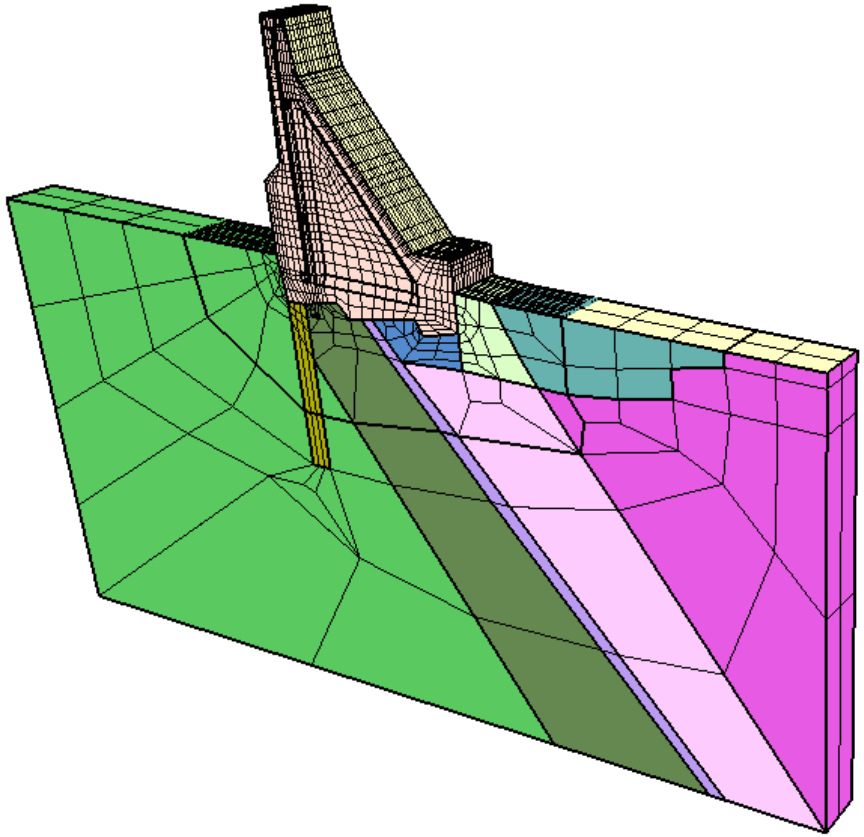
$$\Rightarrow \begin{cases} \mathbf{u} = \mathbf{u}(\mathbf{x}, t) \\ \boldsymbol{\sigma} = \boldsymbol{\sigma}(\mathbf{x}, t) \end{cases}$$

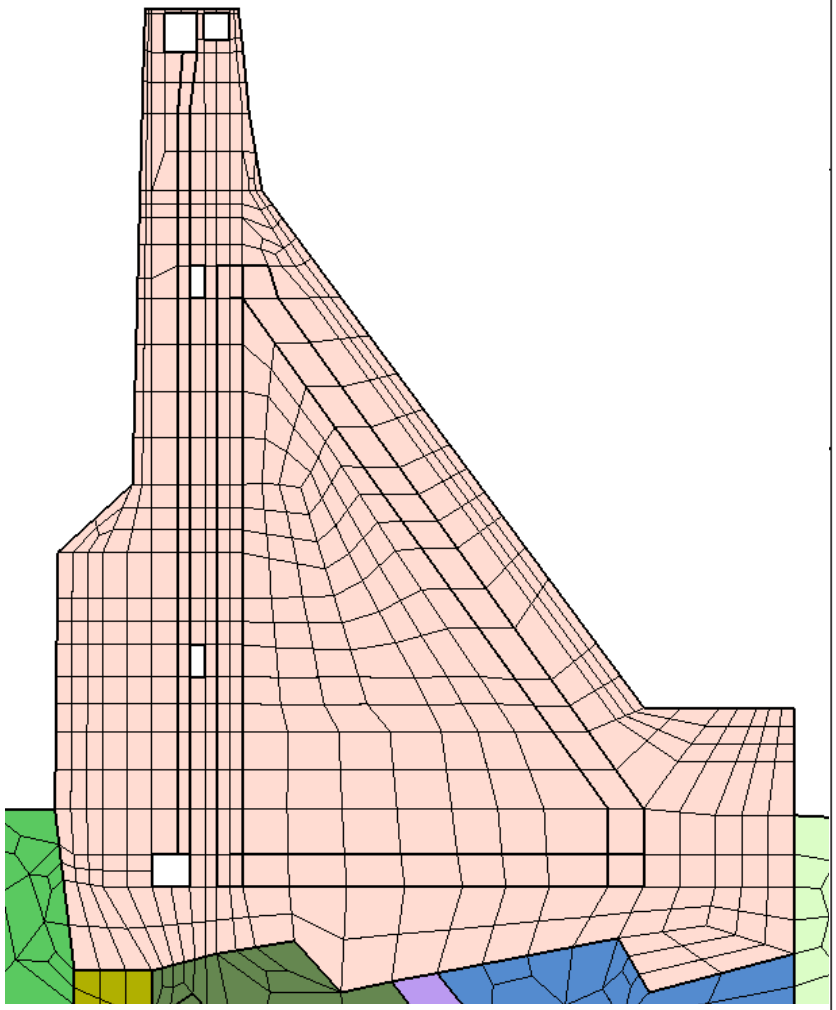
Section 22- FEM mesh for thermal modeling (denser)

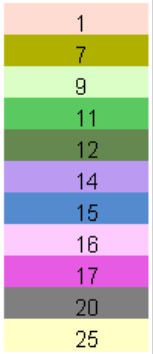


FE MESH
TIME = 536.000[day]
Z_SOIL 7.35 License : DEVELOPER Project : s22-3d_HN3ITCNFF Date : 25.11.2007

Section 22- FEM mesh for mechanical modeling (rough)







FE MESH
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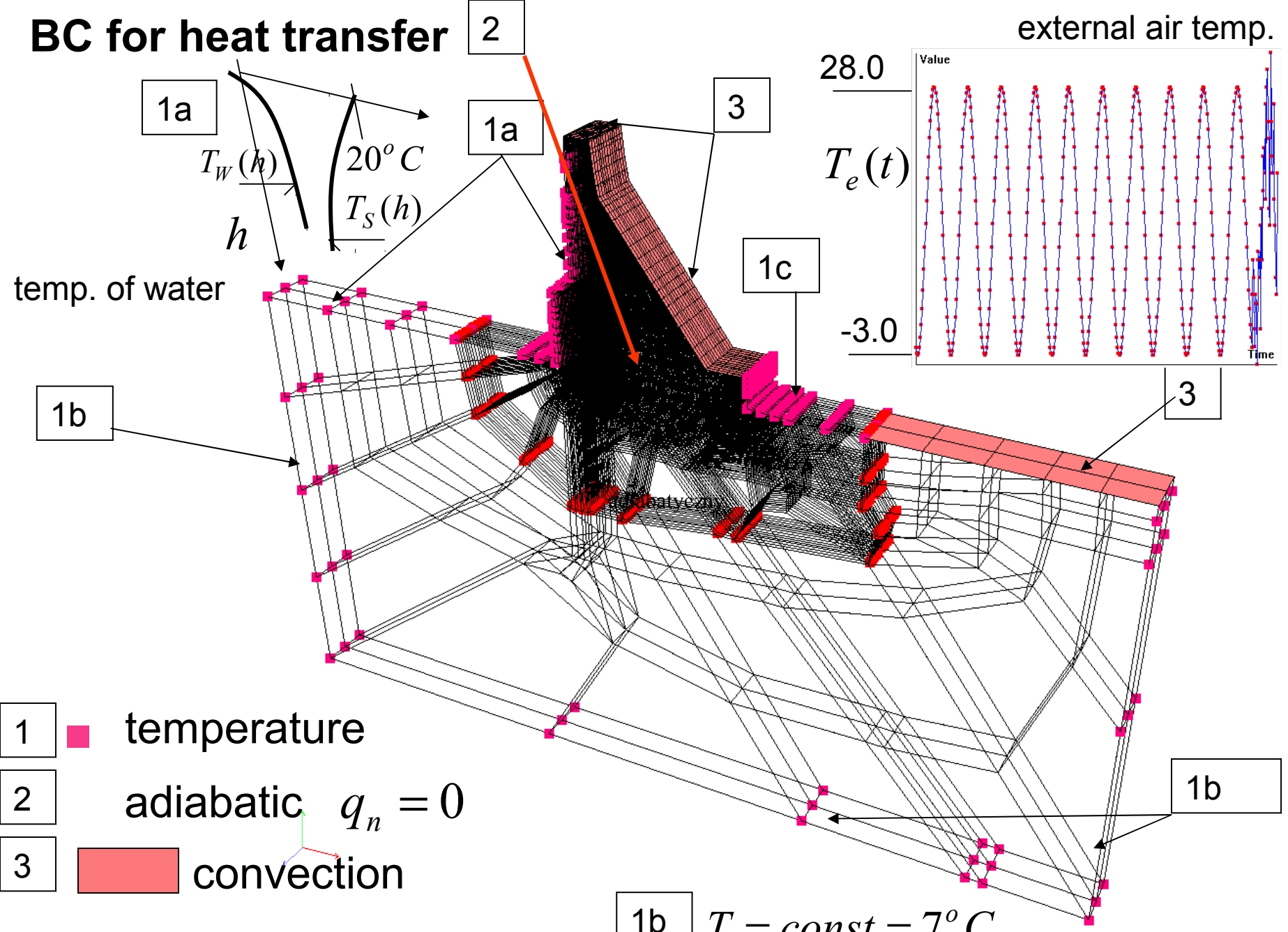
Z_SOIL 7.35 License : DEVELOPER Project : s22-3d_HNCN_10Lat Date : 25.11.2007

BC for heat transfer



BC type 1 (known temperature)

$$T(\mathbf{x},t)=\bar{T}(h,t)$$

1a – water temp. based on time records of measurments in 3 points of upstream face at different levels

Tw601(level 369.5), Tw602(level 401.5), Tw603 (lewel 412.0)

+ linear interpolation for points beetwen

1b – generic temperature in subsoil =yearly average T_{1b} =7.0°C

1c – temperature zone of power-station building T_{1c} =10.0°C

BC type 2 (adiabatic, no heat flow)

- side surfaces
- water in internal cavities.
- internal galeries

$$q_n = 0$$

BC type 3 (convective)

- downstream face
- upstream face, above water

$$q_n = \alpha_c (T - T_e)$$

convection coefficient (according to the Design Code PN –91/B-02020):

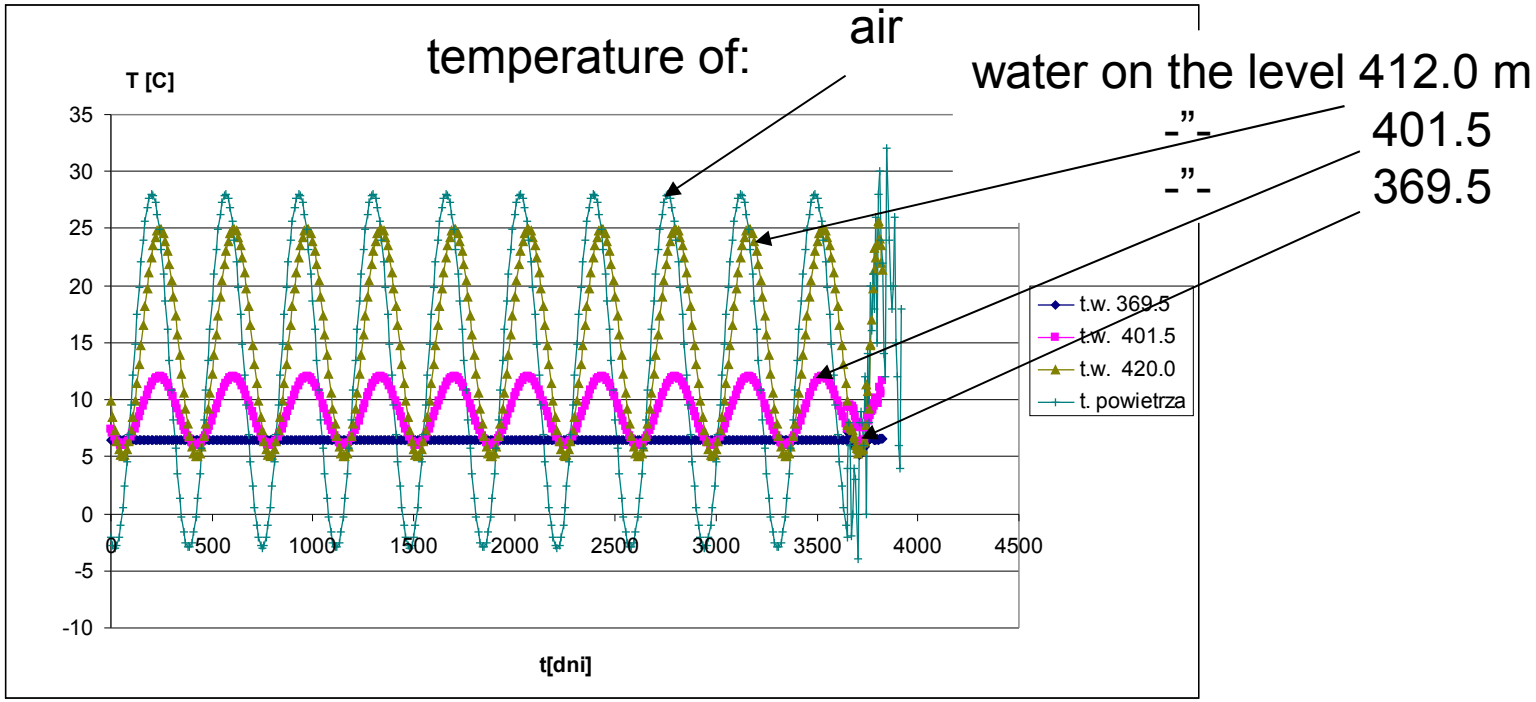
$$\alpha_c = 23[W/m^2K] = 2000[kJ/(m^2 \cdot day \cdot K)]$$

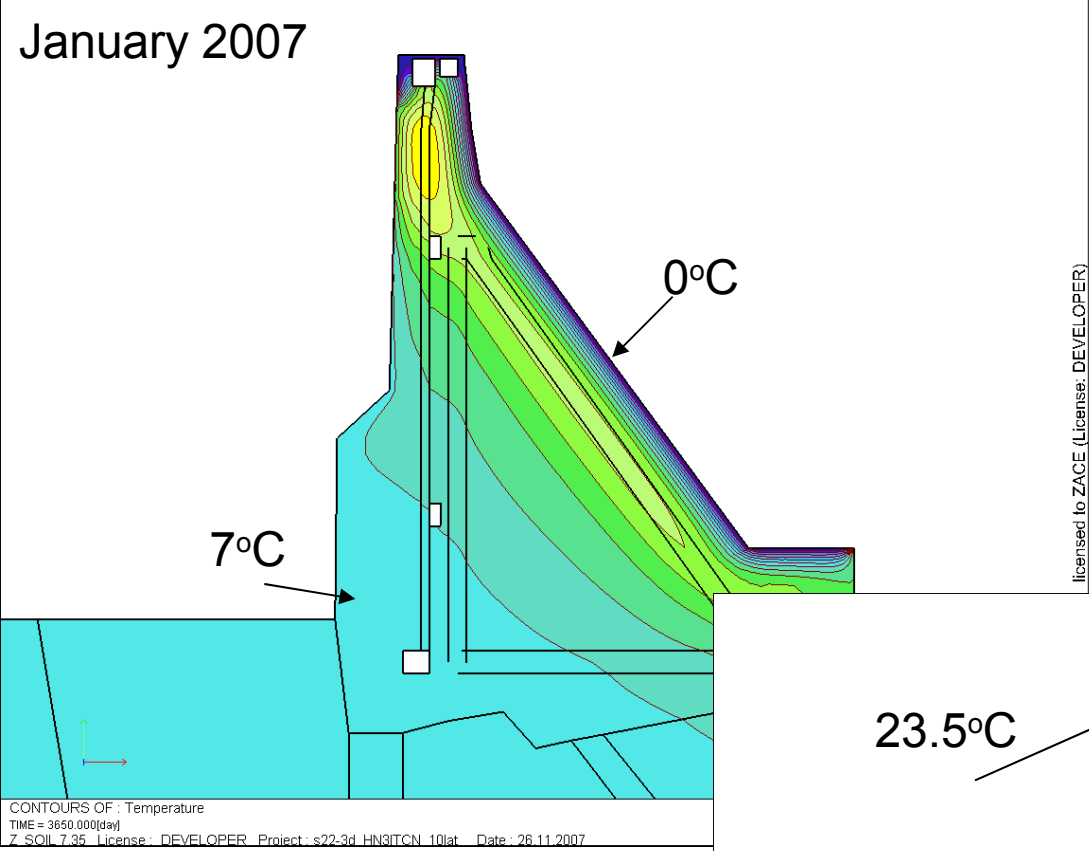
$$T_e(t) = T_A(1 - \Delta T/(2T_A)\cdot\cos(2\pi t/365))$$

Parameters of yearly temperature cycles - T_A awerage

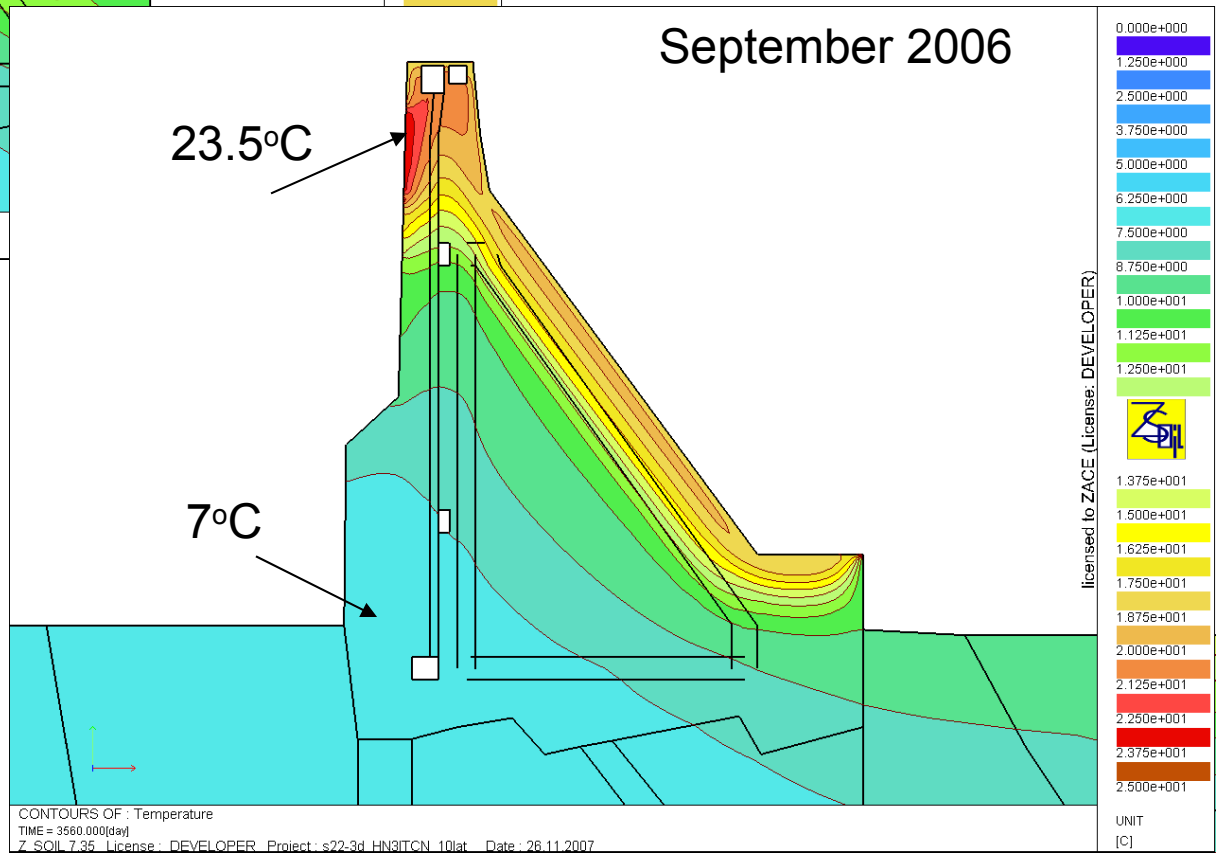
- ΔT amplitude

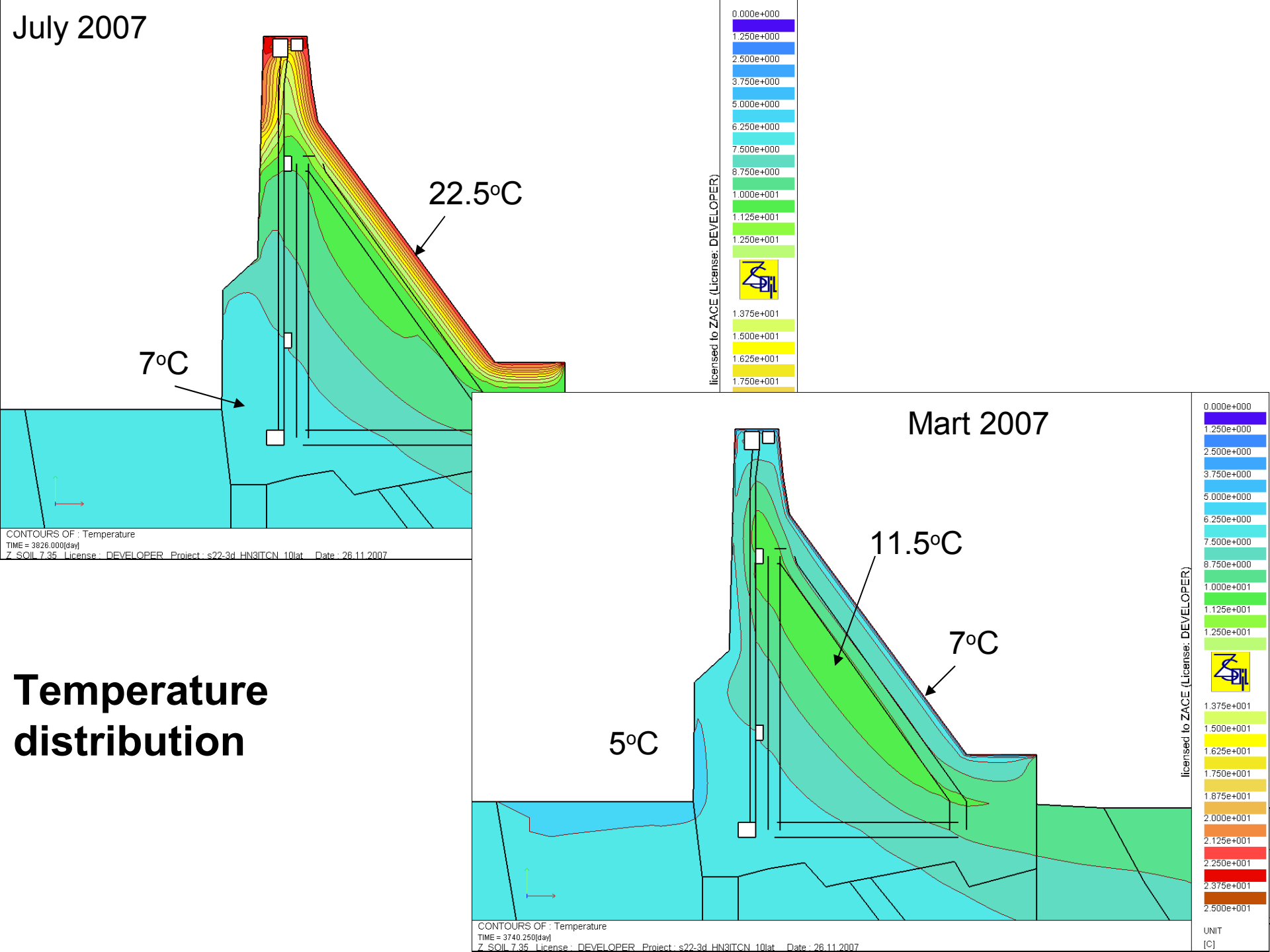
	T_A [°C]	ΔT[°C]	Tmin [°C]	Tmax [°C]
water on 369.5	6.5	0	6.5	6.5
401.5	9	6	6	12
412.0	13.5	22	2.5	24.5
Air	11	28	-3.0	25





Temperature distribution

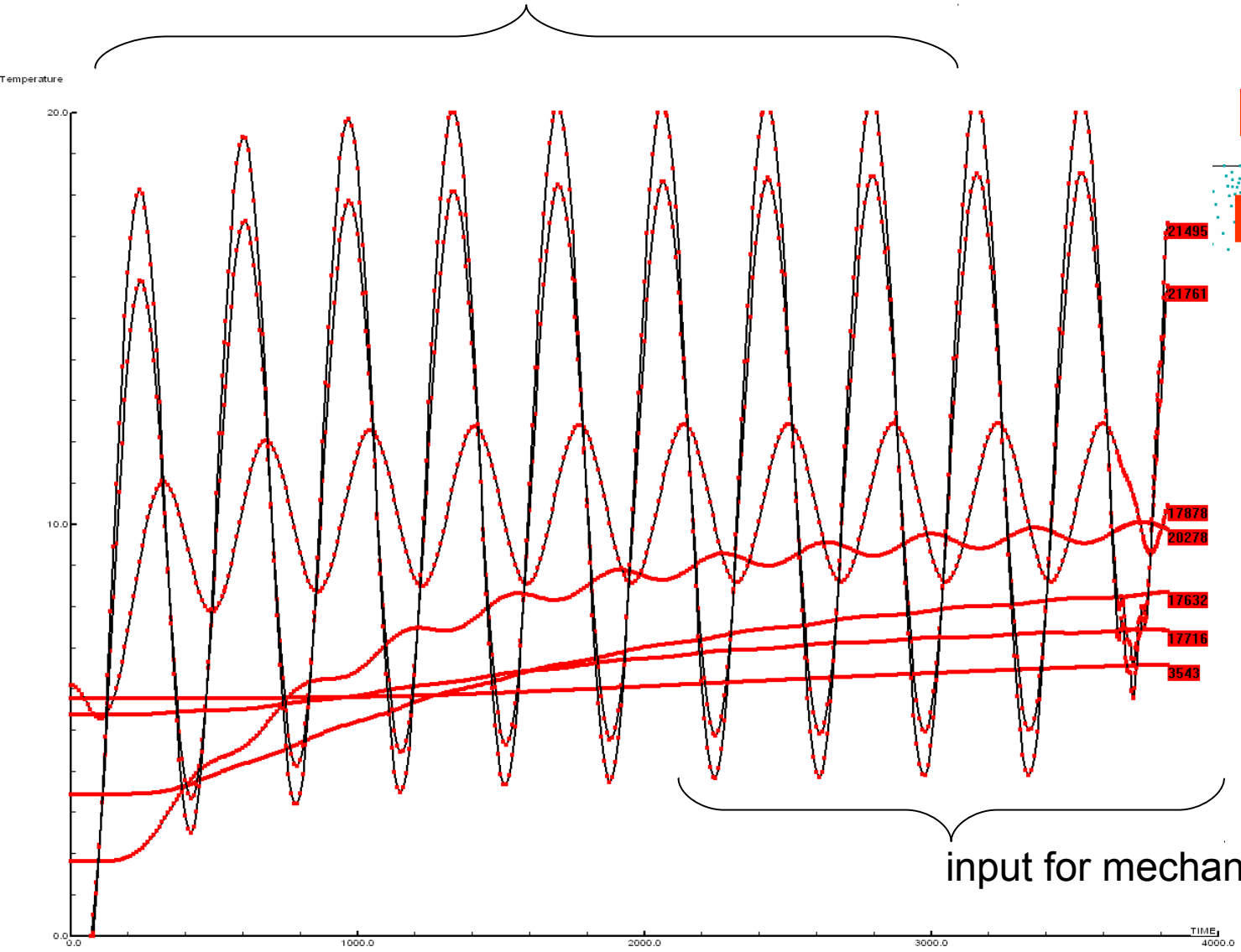


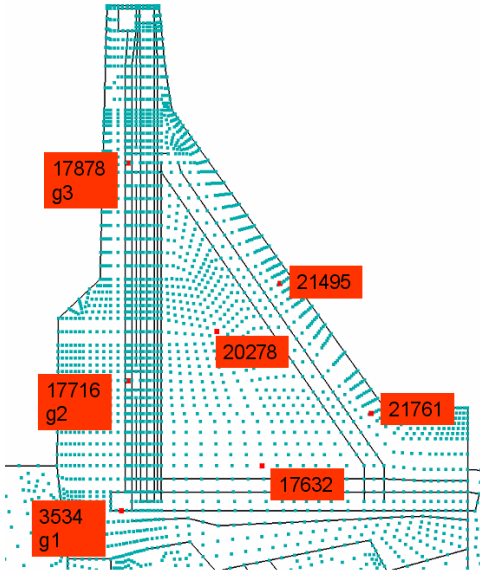


Temperature distribution

Temperature histories in 10 years simulation

influence of initial condition (steady state) gradualy vanishing





input for mechanical analysis

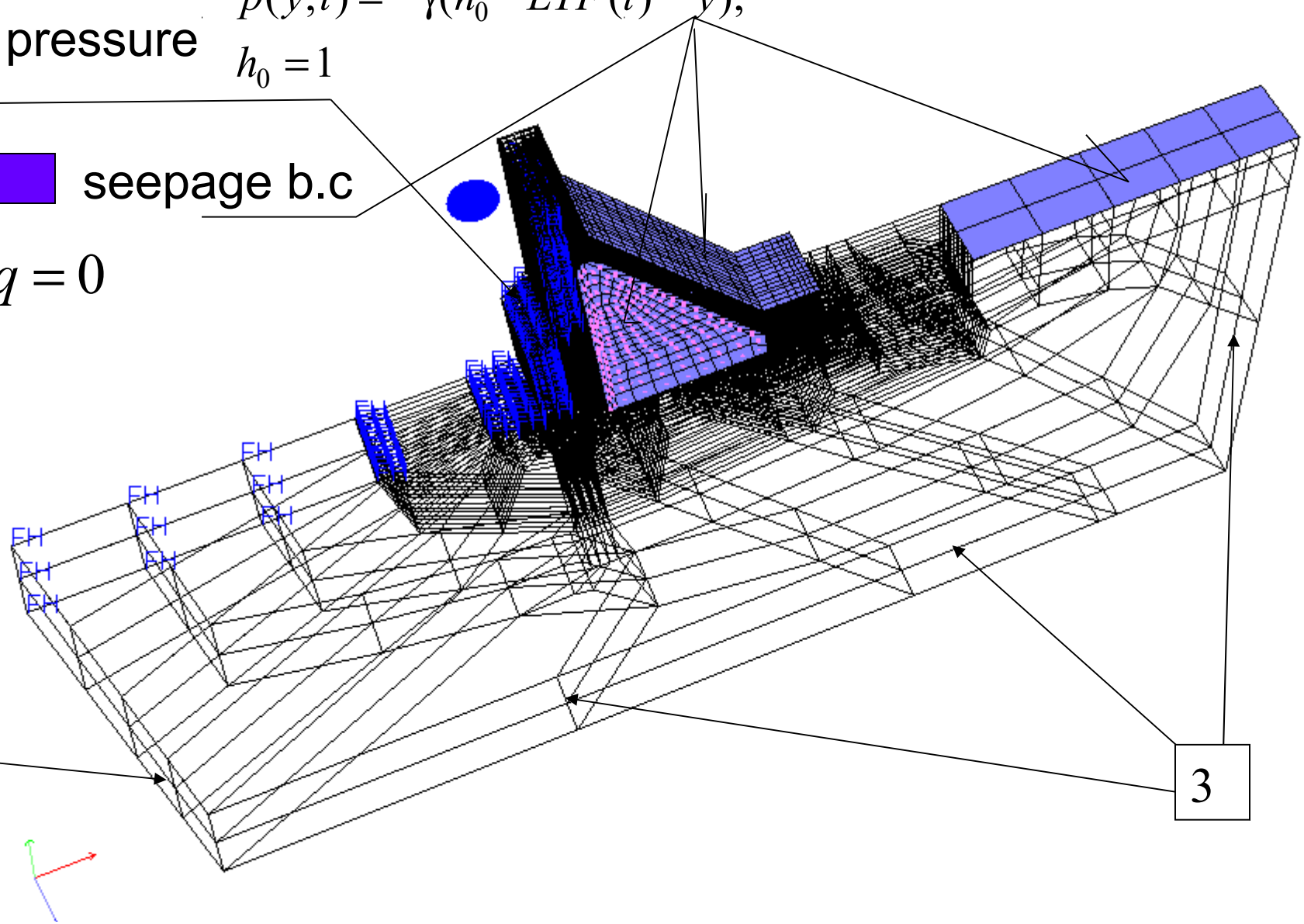
BC for filtration

1 pressure

$$p(y,t) = -\gamma(h_0 * LTF(t) - y);$$
$$h_0 = 1$$

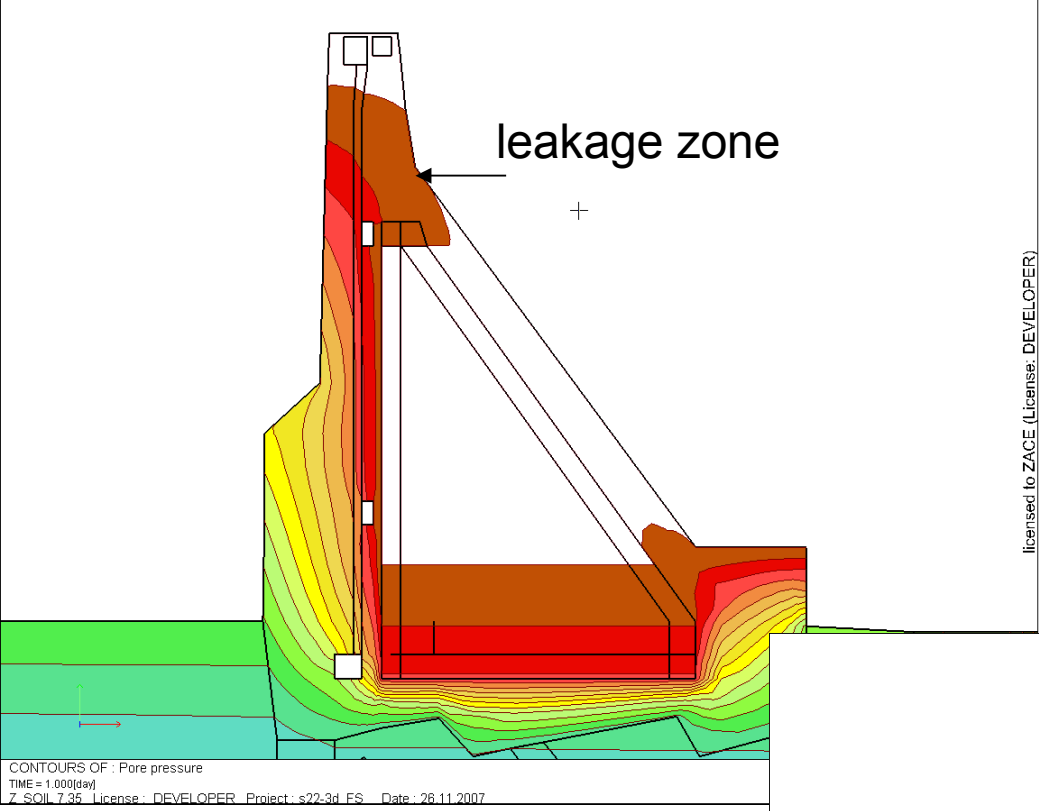
2 seepage b.c

3 $q = 0$

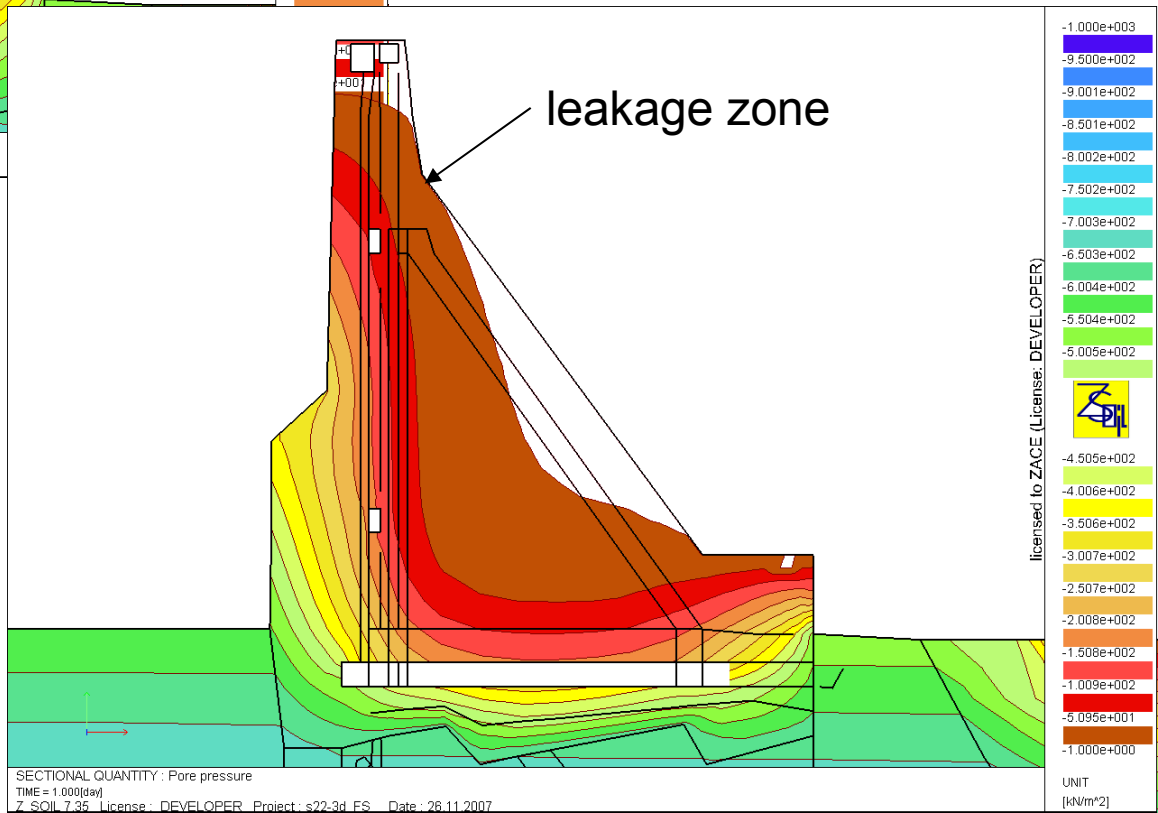


Pressure fields

in the side of section 22

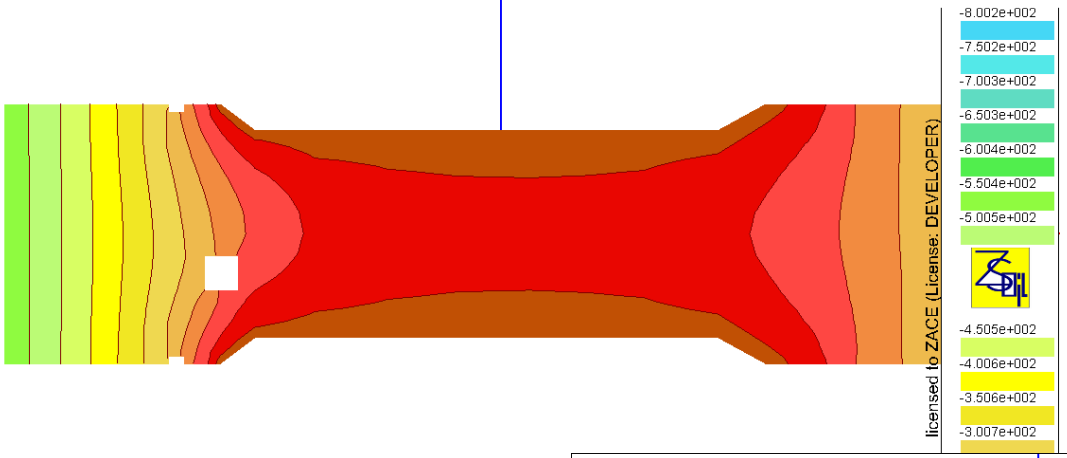


in the mid cross-section

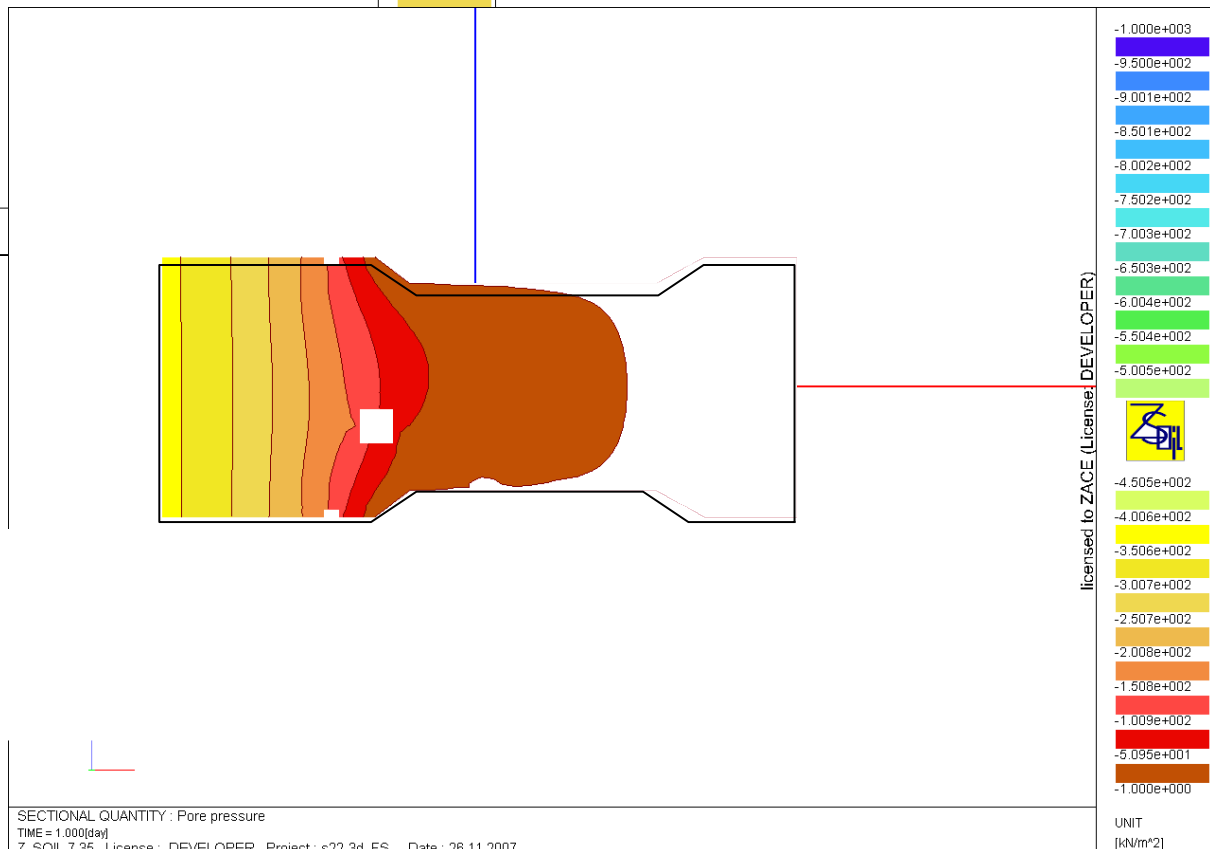


Pressures at 362.5m

(mean water level in cavity)



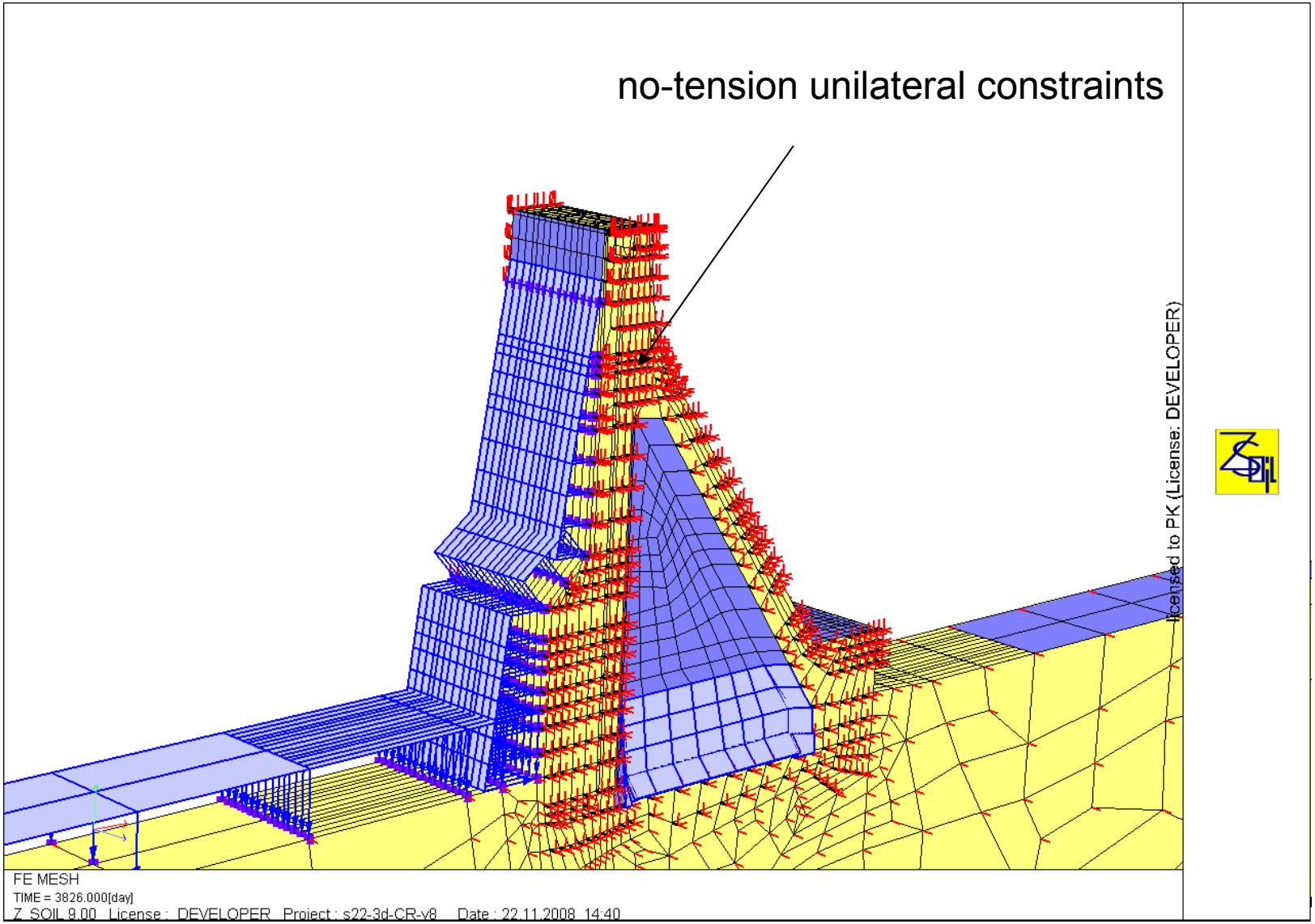
SECTIONAL QUANTITY : Pore pressure
TIME = 1.000[day]
Z_SOIL 7.35 License : DEVELOPER Project : s22-3d_FS Date : 26.11.2007



SECTIONAL QUANTITY : Pore pressure
TIME = 1.000[day]
Z_SOIL 7.35 License : DEVELOPER Project : s22-3d_FS Date : 26.11.2007

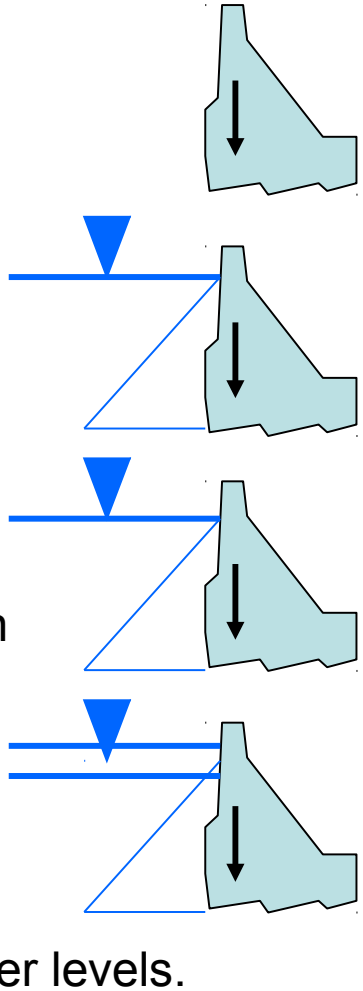
Pressures at 380.5
(aprox. in half of dam height)

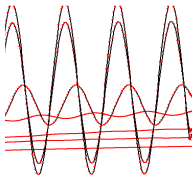
Section 22. Loads and BC for mechanical analysis



Simulation scenario:

- initial state – gravity loads, $\boldsymbol{u}=0$
- T=1 state after reaching normal water level
  WG=416.2m.n.p.m
- 2000D<T<3650D, $\Delta T=10D$
  4 cycles of the year oscillation of thermal condition
  (artifitialy created)
- 3655D<T<3826D, $\Delta T=7D$
  state since 01. 01. 2007 to 13.07.2007
  simulation under measured temperatures and water levels.





$$\Delta\varepsilon^{o} = \alpha \cdot \Delta T(\mathbf{x}, t)$$

Analisys option:

concrete model – linear elastic

- no creep
- creep

Creep model

$$\boldsymbol{\sigma}^{n+1} = \boldsymbol{\sigma}^{n} + \mathbf{D}(\Delta\boldsymbol{\varepsilon} - \Delta\boldsymbol{\varepsilon}^{o} - \Delta\boldsymbol{\varepsilon}^{pl} - \Delta\boldsymbol{\varepsilon}^{cr})$$

$$\mathbf{D}_0(\nu) = \frac{1}{E}\mathbf{D}(E,\nu)$$

$$\boldsymbol{\varepsilon}^{cr} = \mathbf{D}_0^{-1}\boldsymbol{\sigma}\, C(t,\tau)$$

$$C(t,\tau) = A(1 - \exp(-\frac{1}{B}(t-\tau))$$

parameters:

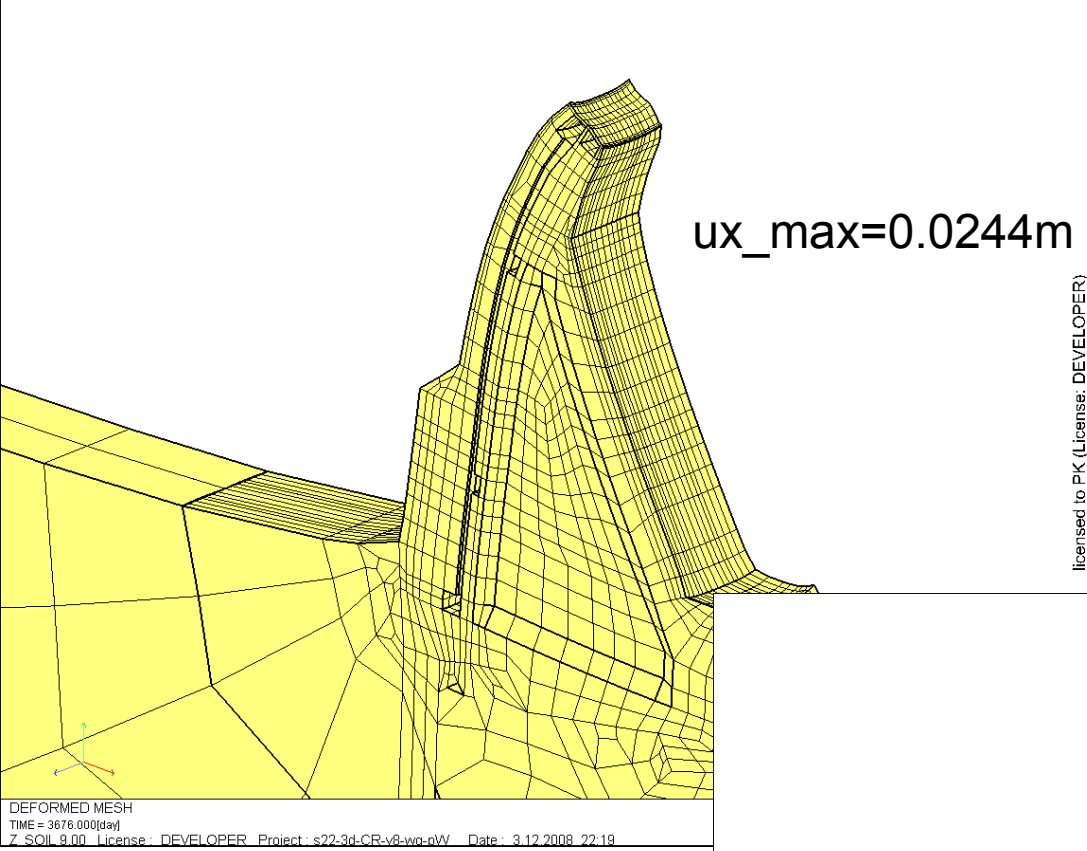
$$\phi = 1.0, \quad A = \frac{\phi}{E}, \quad E = 34220\text{MPa}$$ (measured)

A = 3.268e-008 [1/kPa] (basing on Design Code PN/B-03264 for humidity of concrete RH=80%)

retardation time
B = 33.3[d]

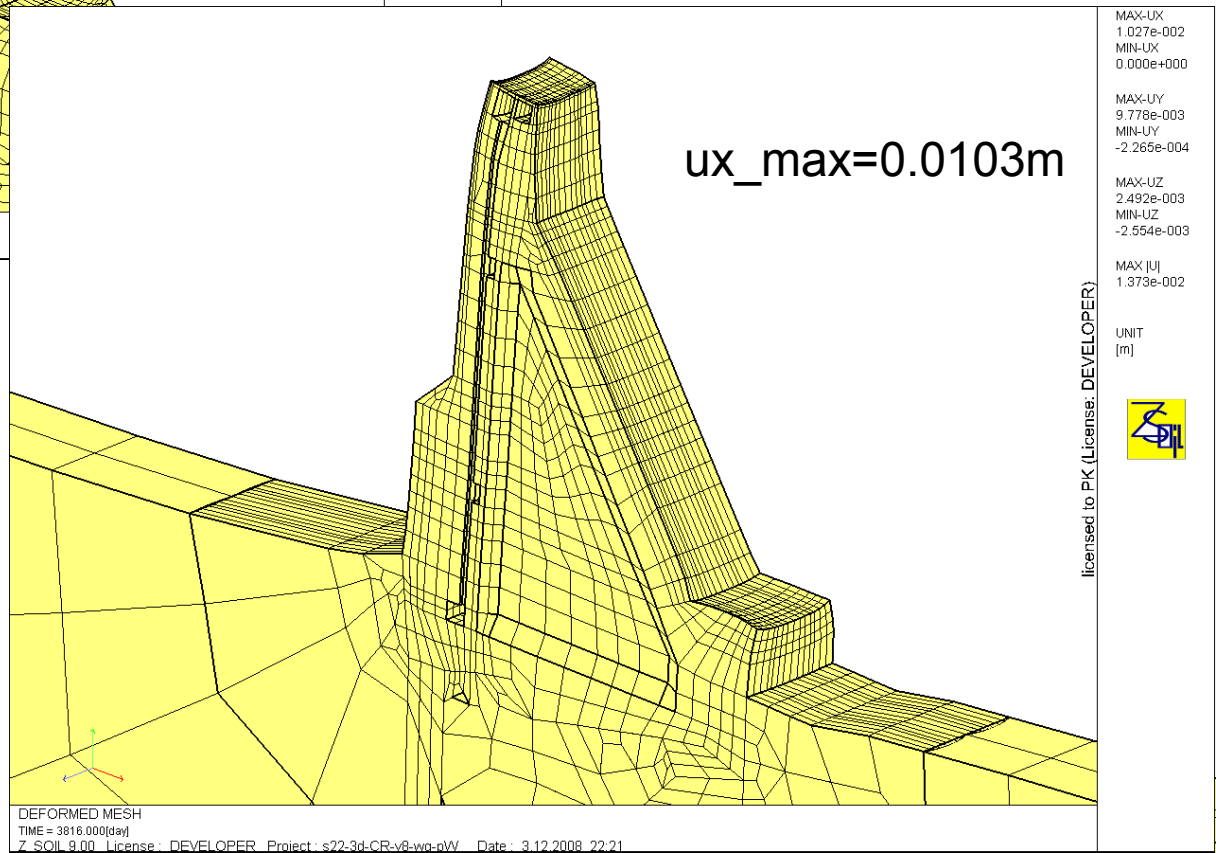
Deformation

a) winter 2006/2007



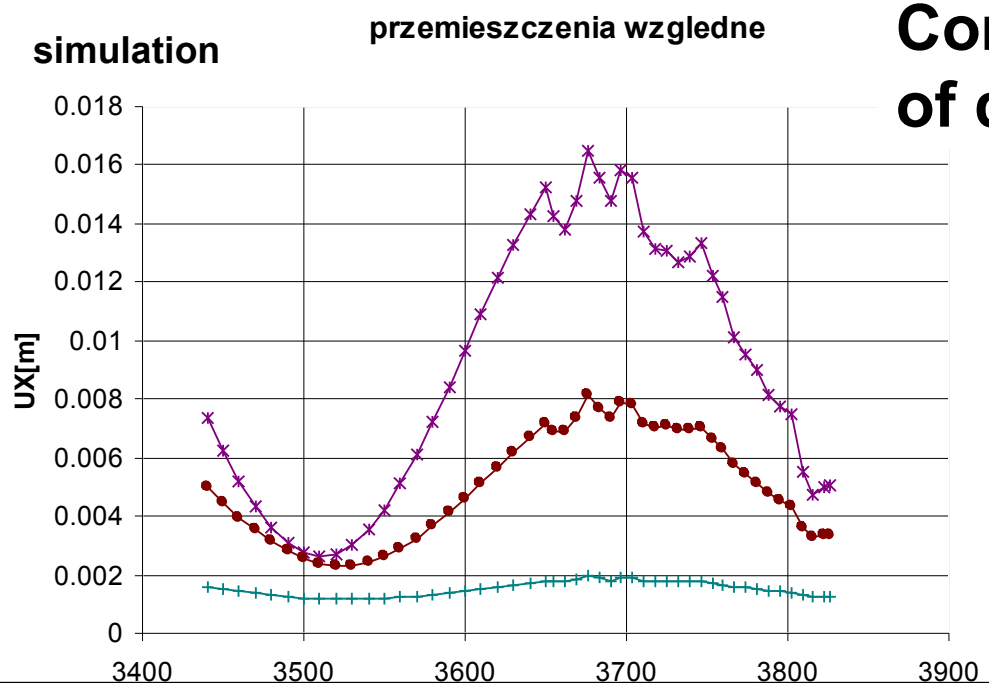
ux_max=0.0244m

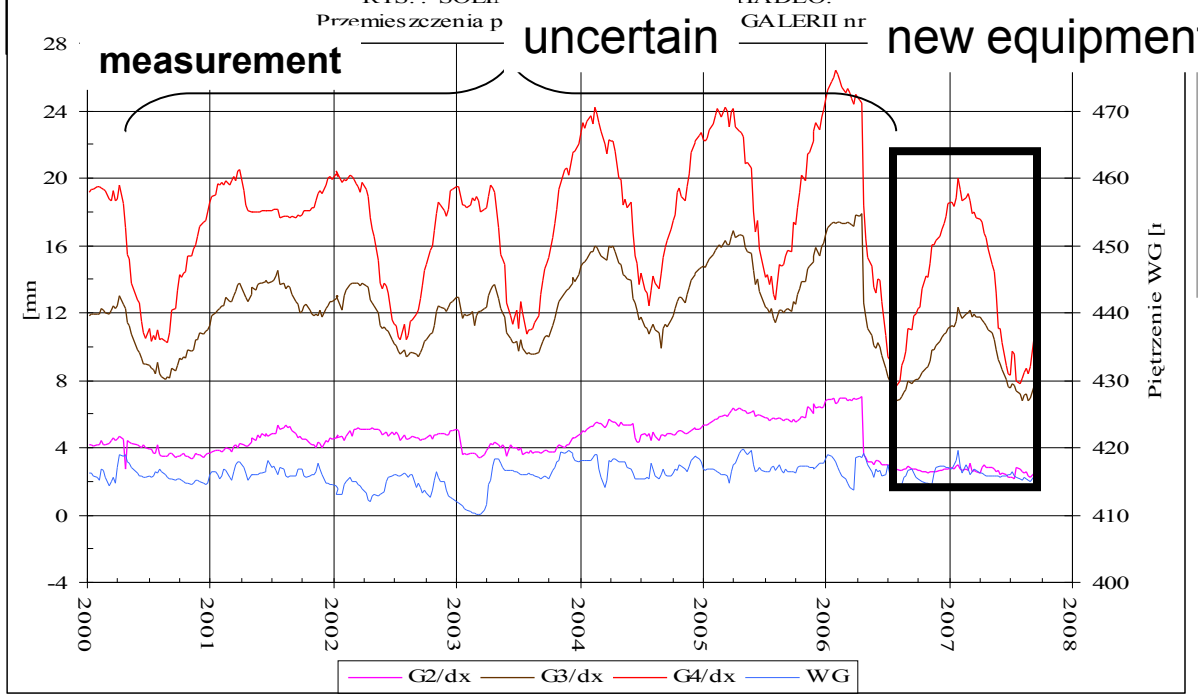
b) summer 2007



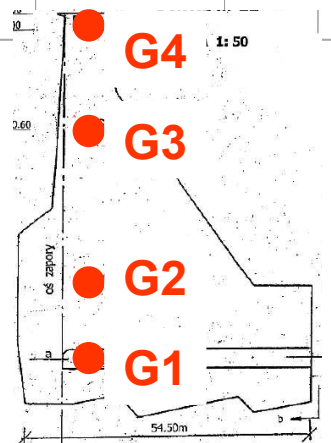
ux_max=0.0103m

Comparison of amplitudes of displacements Ux



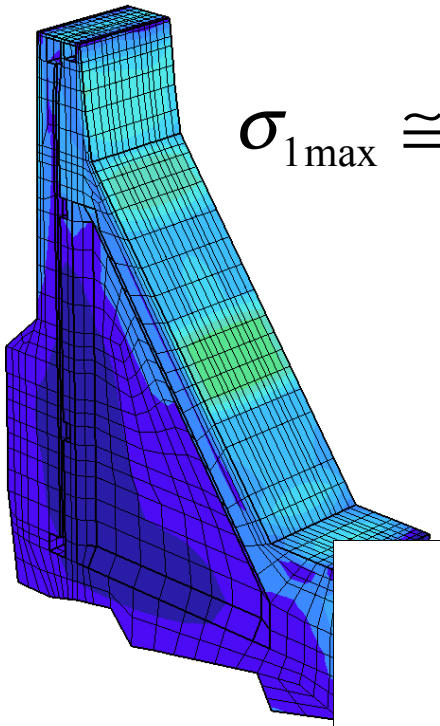


	simulation / measurement		
	ı	a Gi-G1[mm]	wanadło [mm]
zima 2006/07	G 3	8.1	12.0
lato 2007	G 3	3.2	7.0
amplituda	G 3	**4.9**	**5.0**
zima 2006/07	G 4	16.5	20.0
lato 2007	G 4	4.7	8.0
amplituda	G 4	**11.8**	**12.0**

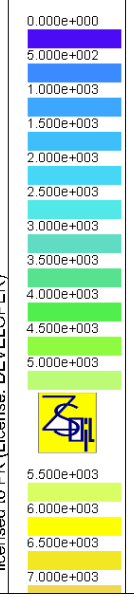


Stresses σ1

considering creep
a) winter

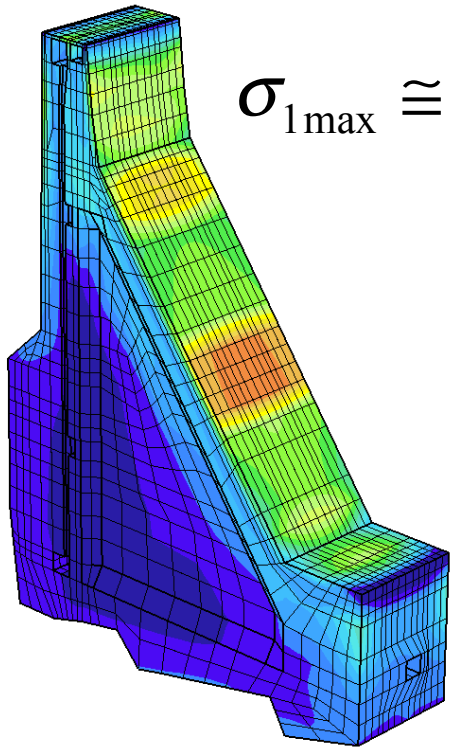


$$\sigma_{1\max} \cong 3.5MPa$$



CONTOURS OF : Effective stress-1
TIME = 3676.000[day]
Z_SOIL 9.00 License : DEVELOPER Project : s22-3d-CR-v8-wg-pW Date : 4.12.2008 22:51

without creep
a) winter



$$\sigma_{1\max} \cong 8.0MPa$$

CONTOURS OF : Effective stress-1
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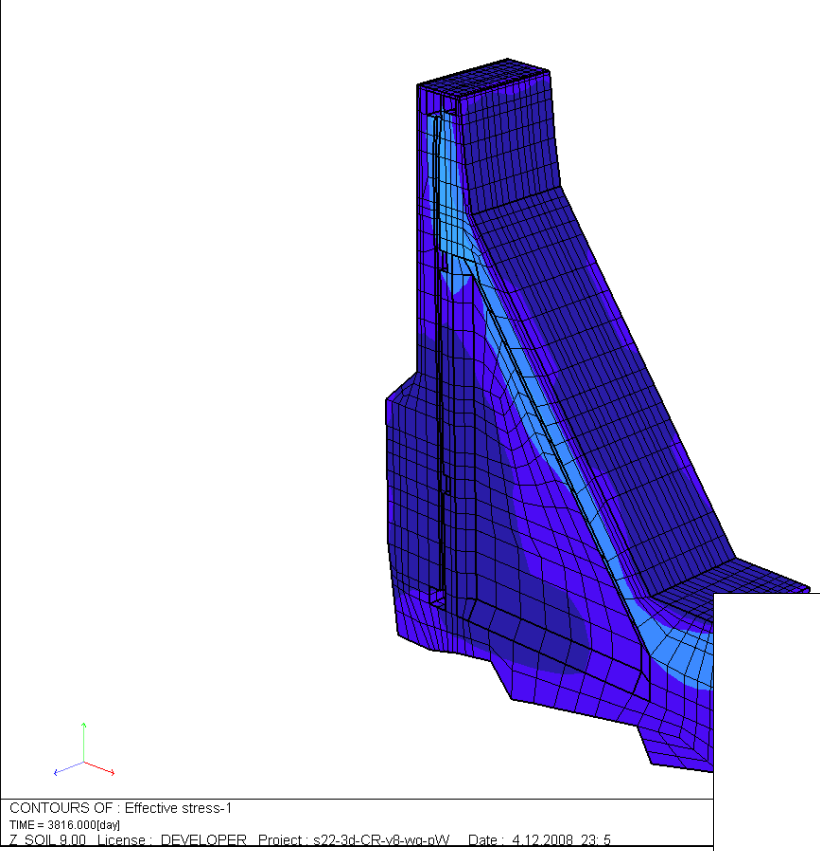
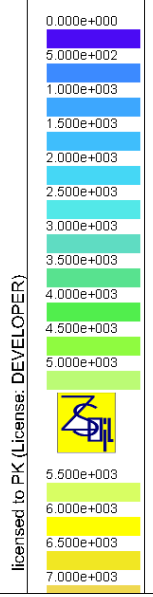
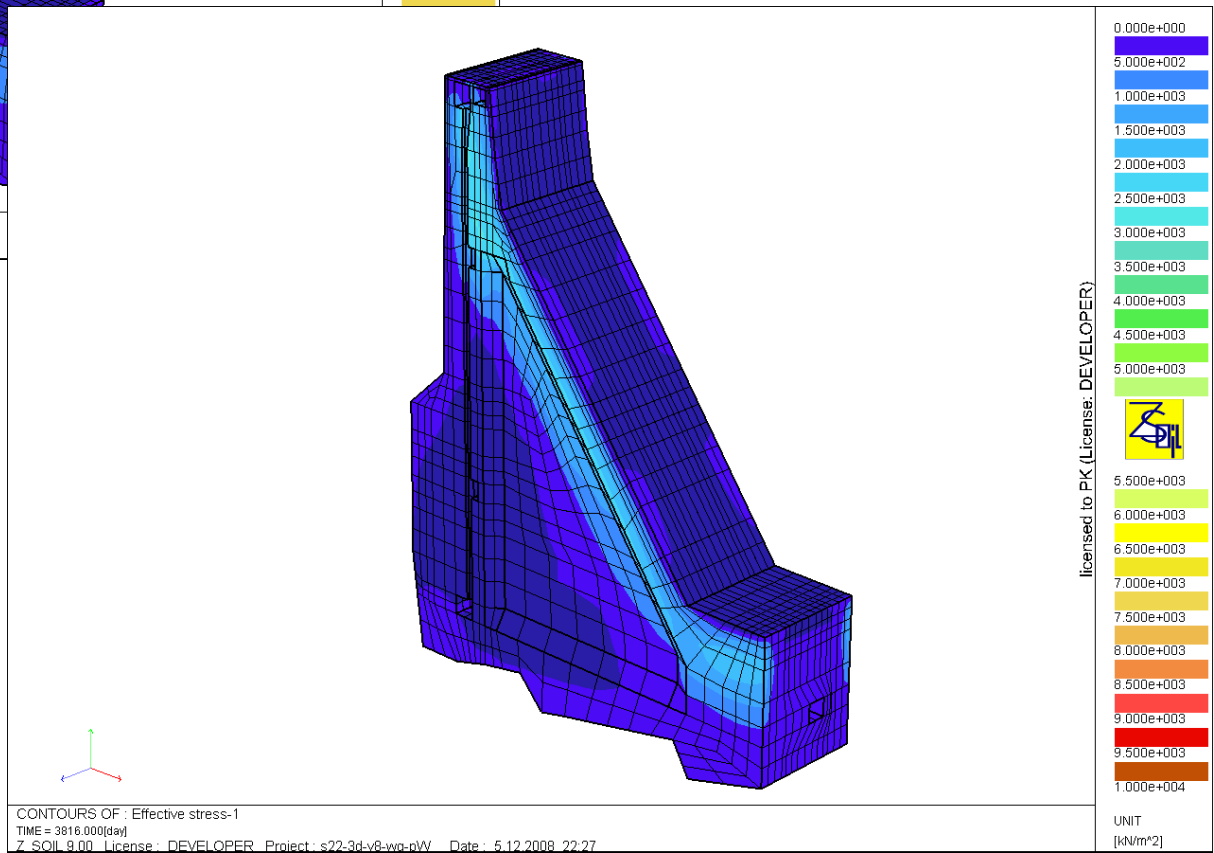
Stresses σ1

considering creep
b) summer



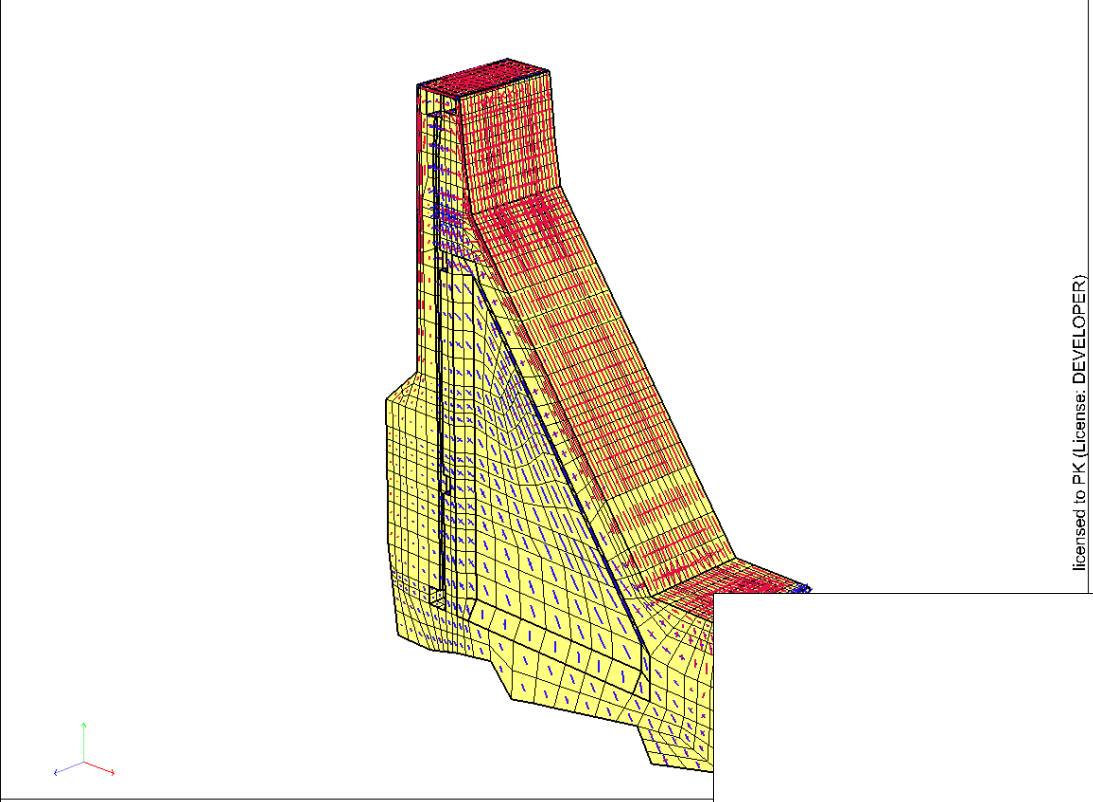


without creep
b) summer

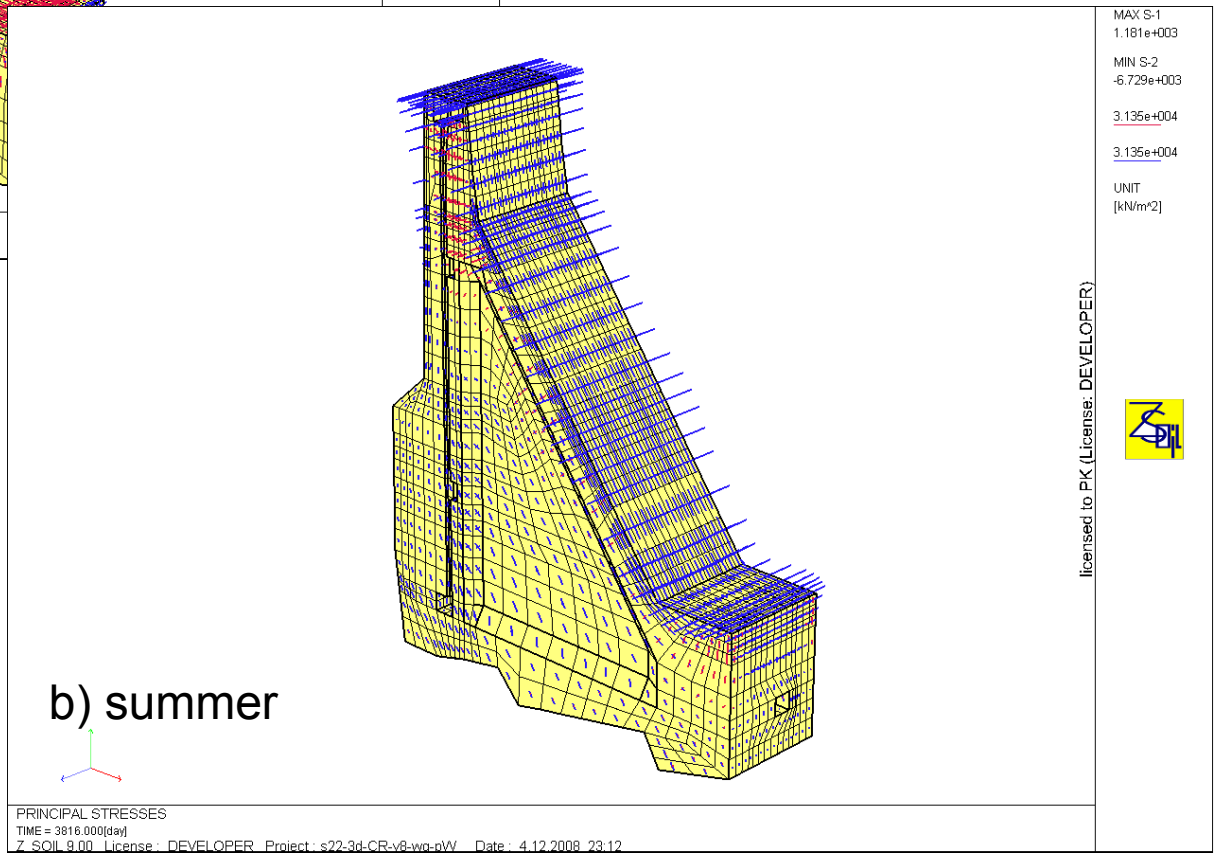


Principal stresses considering creep

a) winter



b) summer



Conclusions

1. Mechanical state of the structure is dominated by thermal processes due to yearly climatic cycle. Influence of the other factors (gravity, water pressure) is of less importance.

2. Good coincidence of displacement results with measurements (proper setup of thermal model)

3. In analysis of massive concrete structures where imposed strain originating from thermal processes are dominating, rheological phenomena (creep) **must** be taken into account

General conclusion

Z_Soil proved to be succesfull in simulation of this multi-field practical problem