

# Control of Hardening Concrete

- b4cast

simulation of temperatures, strengths and stresses

- Heat-Box

Measuring of Heat of Development

- HeatWatch

Monitoring temperatures, maturities and strengths on site

# Durability / Serviceability / Appearance

It is very important to be careful about the hardening process of concrete. Inappropriate construction methods can cause:

- Freezing before the concrete is strong enough
- Too early evaporation leading to a weak cover layer
- Too high temperature differences leading to crack-formation
- Lack of final strength due to too high temperatures
- Lack of strength at form-removal, prestressing or loading

# Construction Method

- In all cases the concrete structure will be directly damaged and the durability, functionality and appearance will be substantially reduced.
- On the other hand it is also important not to make more arrangements than necessary.
- By making a simulation prior to start-up of a project the risk of damages are reduced or eliminated.

# Objectives

- Thermal Analysis (freezing, early evaporation, strength)
- Stress Analysis (crack-formation)
- Evaluate alternatives
  - Concrete mixtures
  - Placing sequence
  - Artificial cooling
  - Thermal protection

# General Process

Define  
Construction



Temperature  
Analysis

Heat of hydration  
Thermal properties  
Boundary conditions



Temperature Field



Mechanical properties  
Creep function  
Boundary conditions



Stress  
Analysis



Stress/Strength



# Thermal Analysis

- Heat of Hydration (Heat-Box)
- Initial Temperatures
- Thermal Boundary Conditions

# Thermal Analysis - Results

History and distribution of:

- Temperature
- Maturity
- Material Properties for evaluation and as input for stress analysis
- Thermal strains as input for stress analysis

# Stress Analysis

- Thermal Strains
- Mechanical properties  
as thermal expansion, E-modulus,  
autogenous shrinkage, creep (functions  
of temperature history)
- External supports
- Self weight

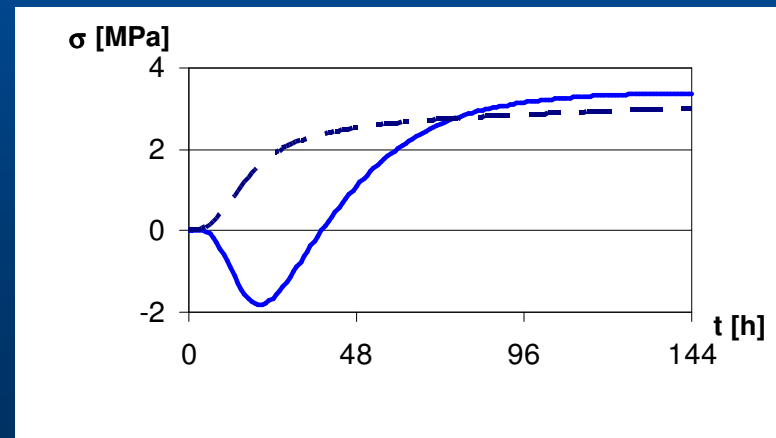
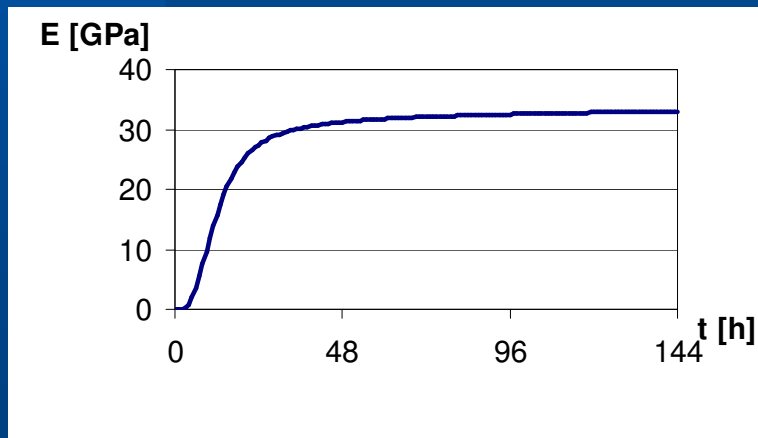
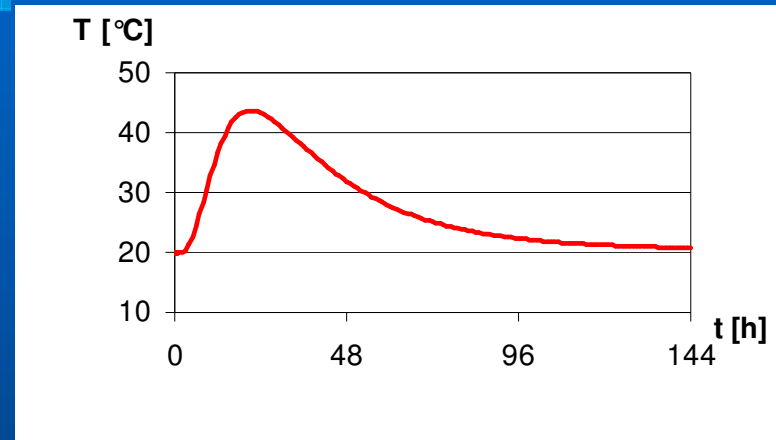


# Stress Analysis - Results

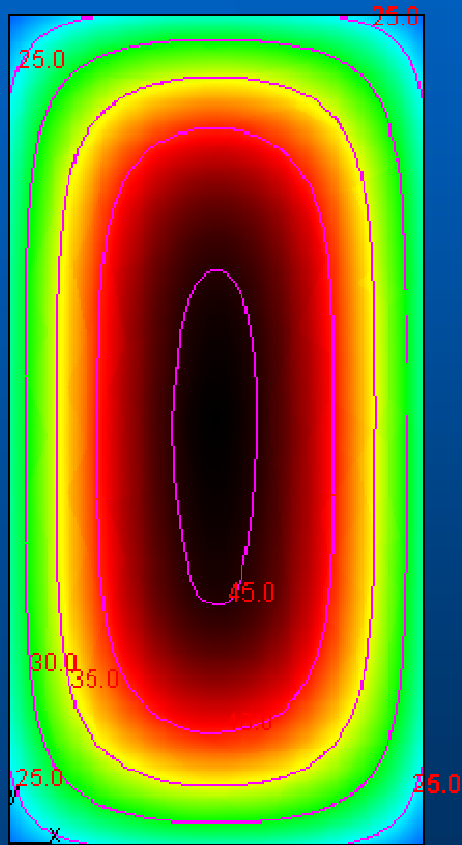
History and distribution of:

- Stress-components
- Ratio between maximum principal and actual tensile strength (exploitation)

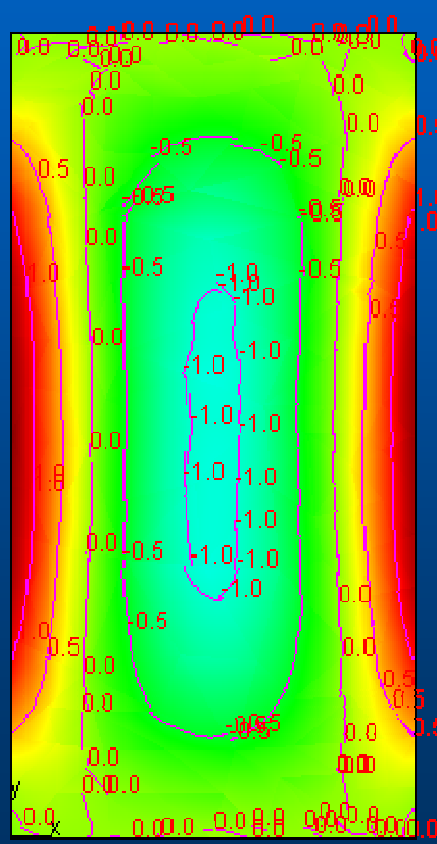
# External restraining



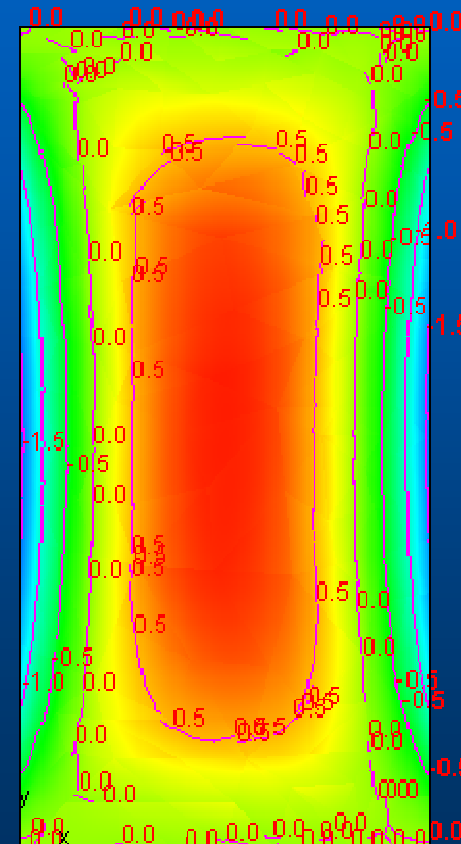
# Internal restraining



Max. temperature

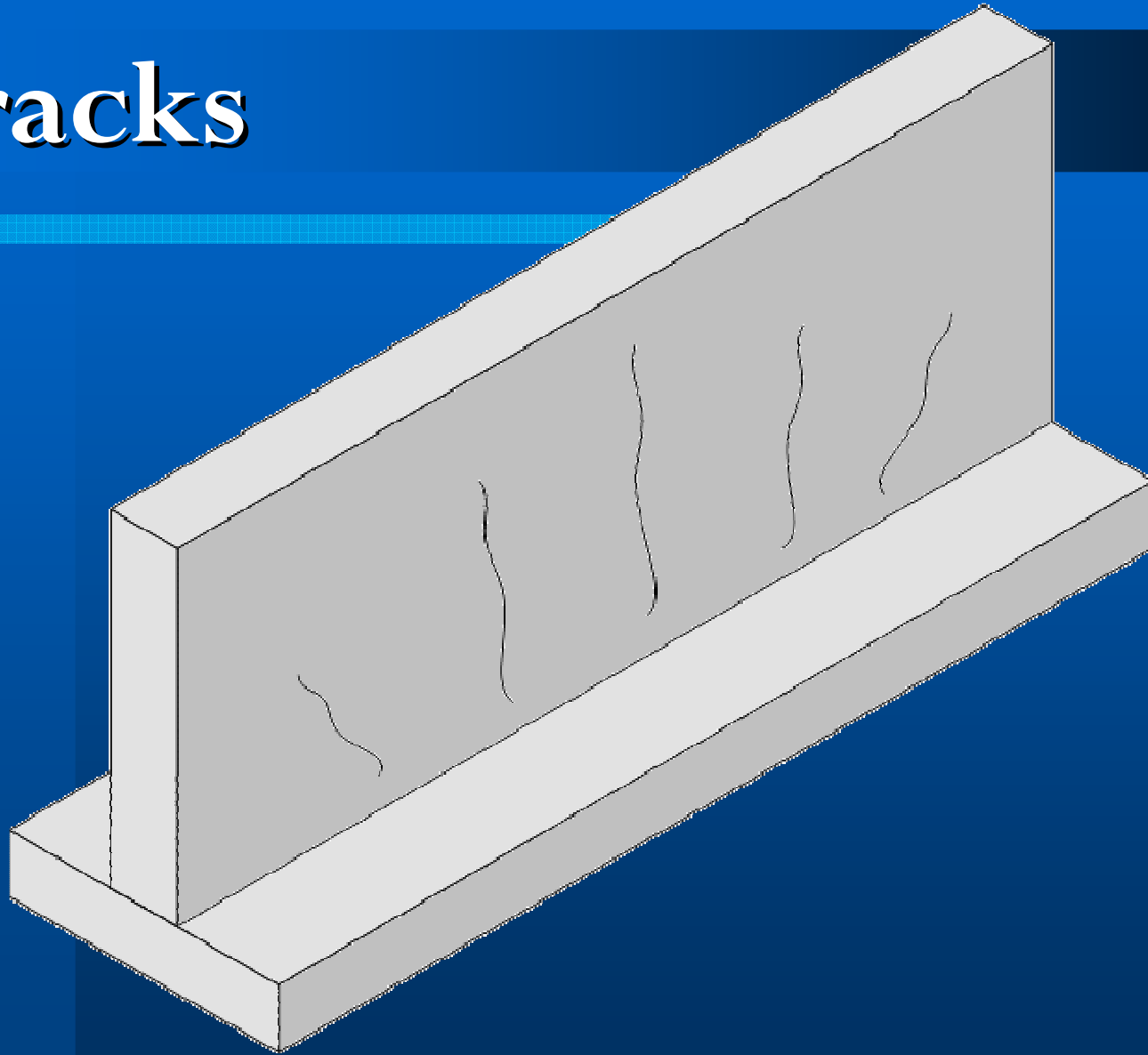


$T = 24$ h



$T = 120$ h

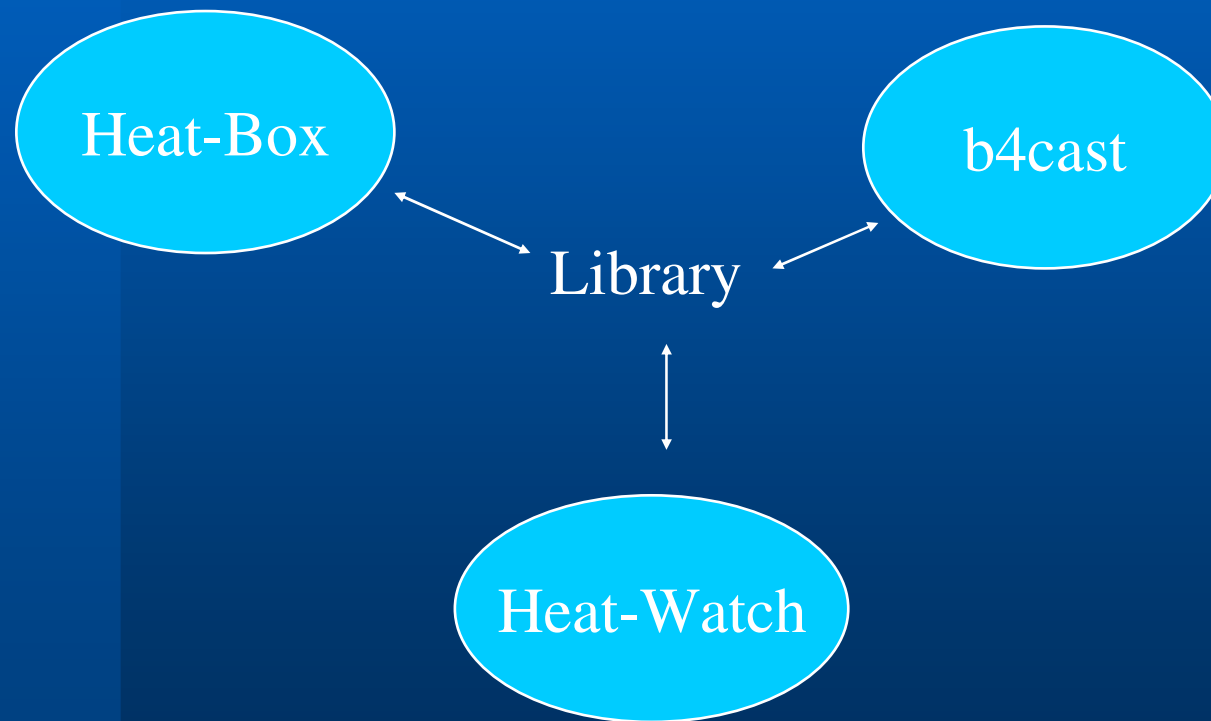
# Cracks



# Improving Construction Method

- Location of construction joint
- Placement sequence
- Casting schedule
- Selection of form materials
- Times at which formwork is removed
- Use of insulation
- Use of cooling pipes/heating cables
- Use of cold/warm concrete
- On-site monitoring of temperatures

# Materials



# Material Properties

**Material**

Material Name:  Description:

Maturity based on Arrhenius

Ref. Temperature:  °C

Activation Energy Factor I:  J/mole

Activation Energy Factor II:  J/mole

Maturity based on Nurse-Saul

Datum-Temperature:  °C

Temperature-Time

Equivalent time Ref. Temperature:  °C

Powder Content:  kg/m<sup>3</sup> Heat Generation:  Disabled

Density:  kg/m<sup>3</sup> Tensile Strength:  Disabled

Heat Capacity:  kJ/kg/°C Compression Strength:  Disabled

Th. Conductivity:  kJ/m/h/°C Mechanical Properties:

**Material-Mechanical Properties**

Disabled

Disabled

Disabled

Disabled

Disabled

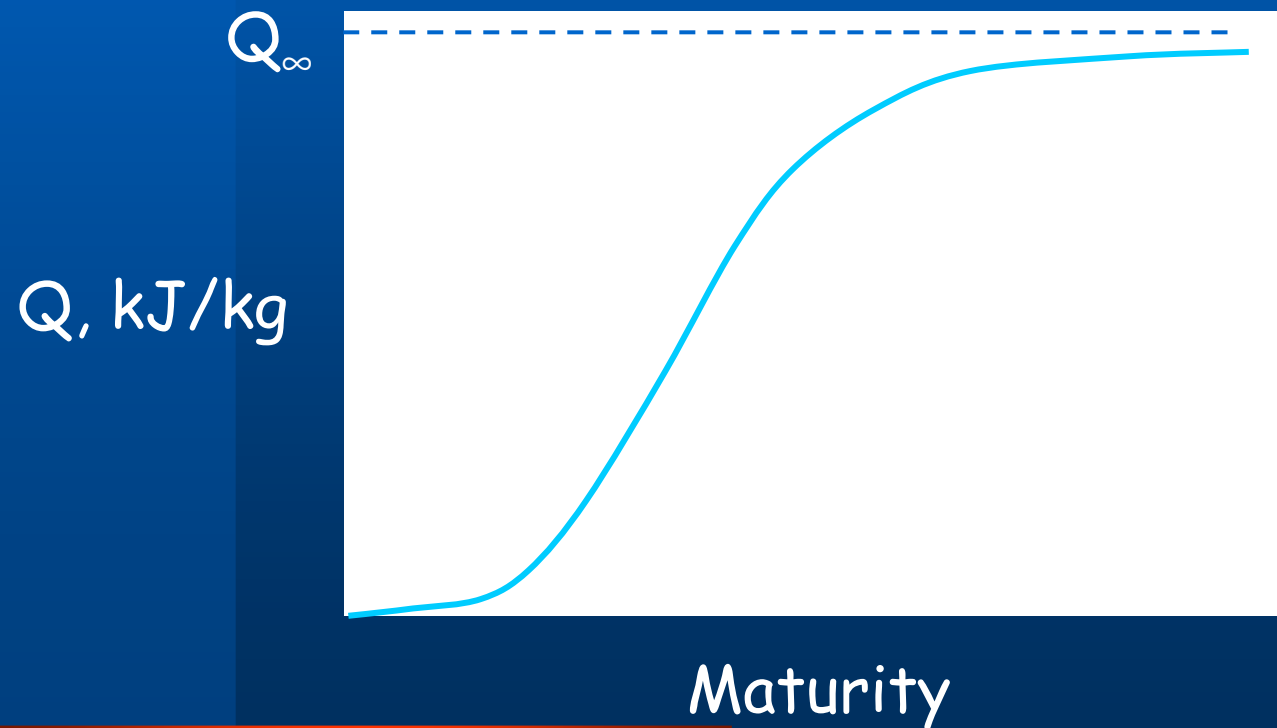
Disabled

Disabled

Disabled

Disabled

# Heat Development



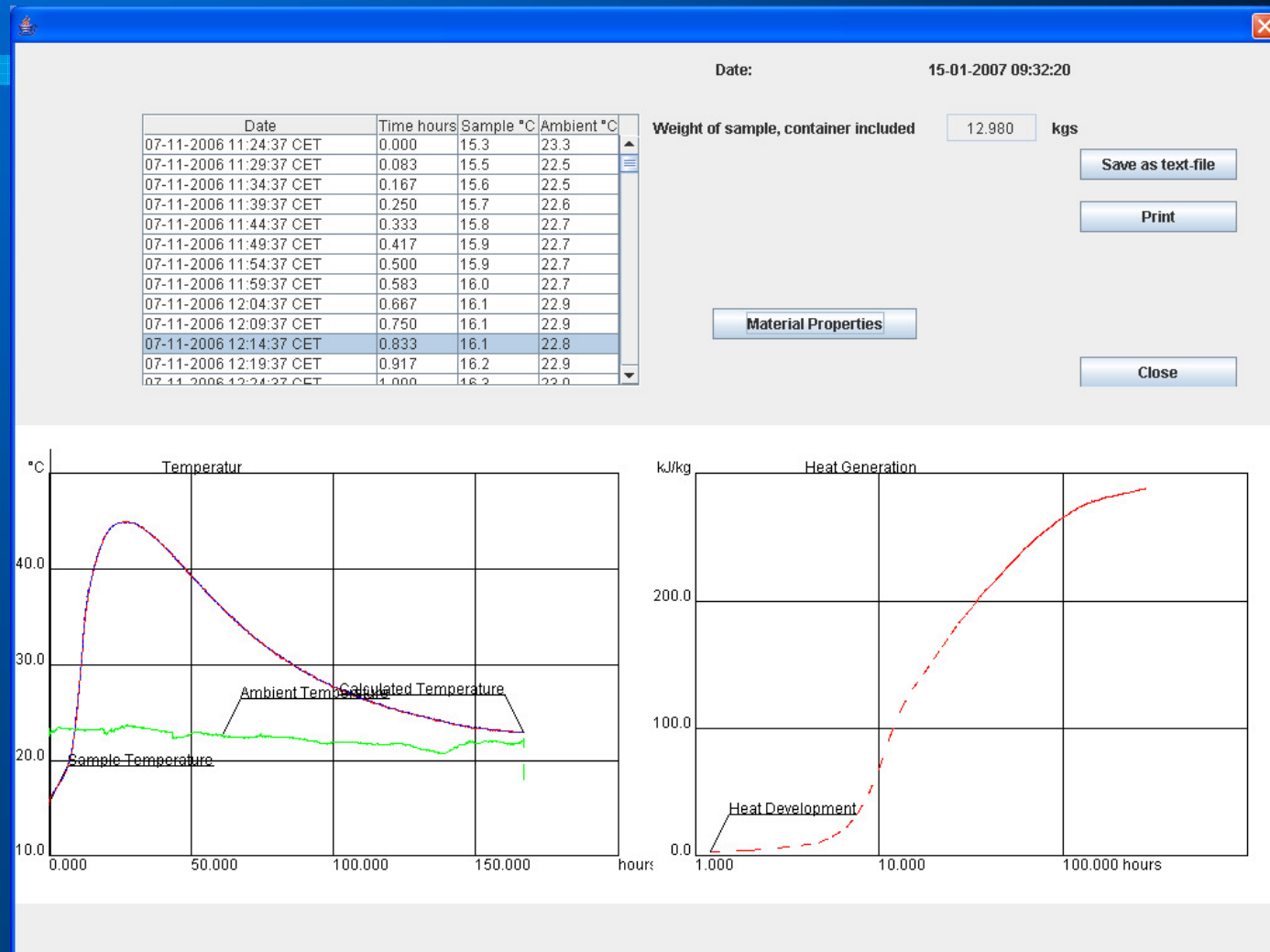


# Semi-adiabatic calorimetry

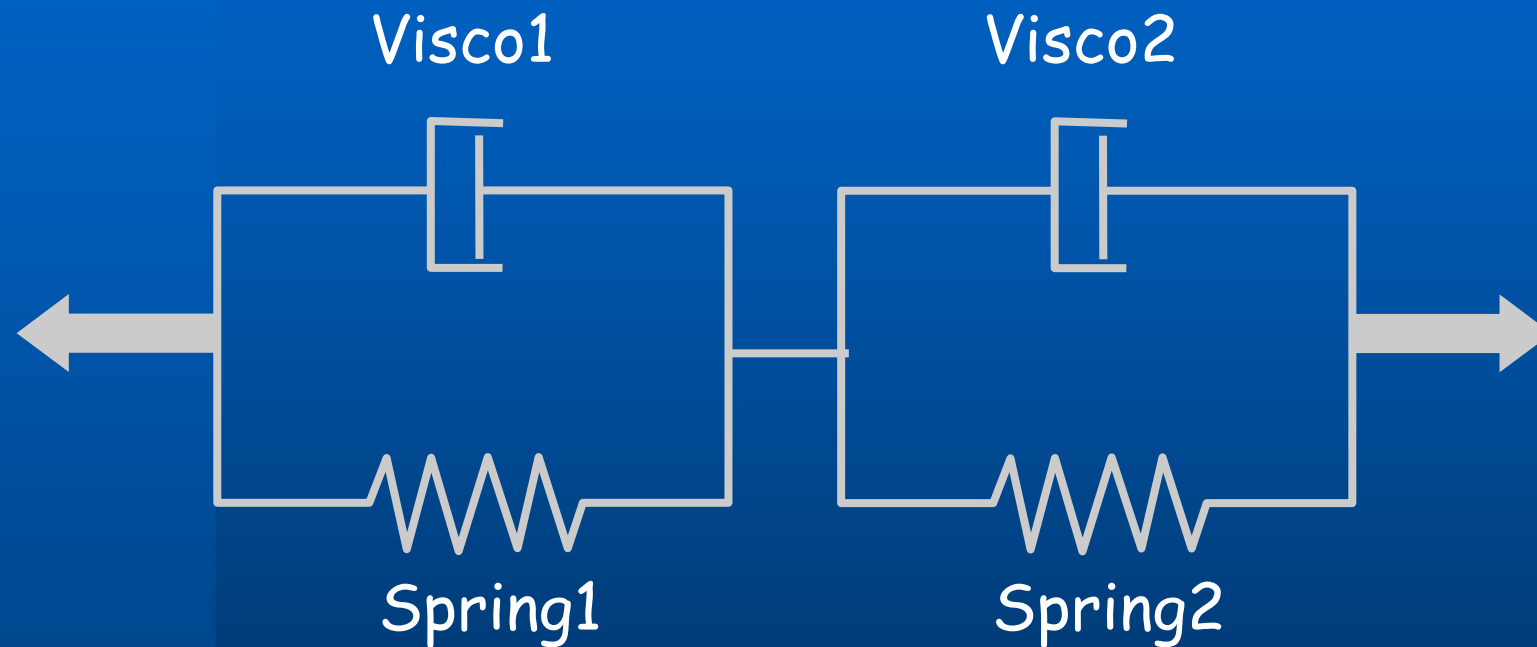
## Heat-Box



# Heat-Box



# Creep Model

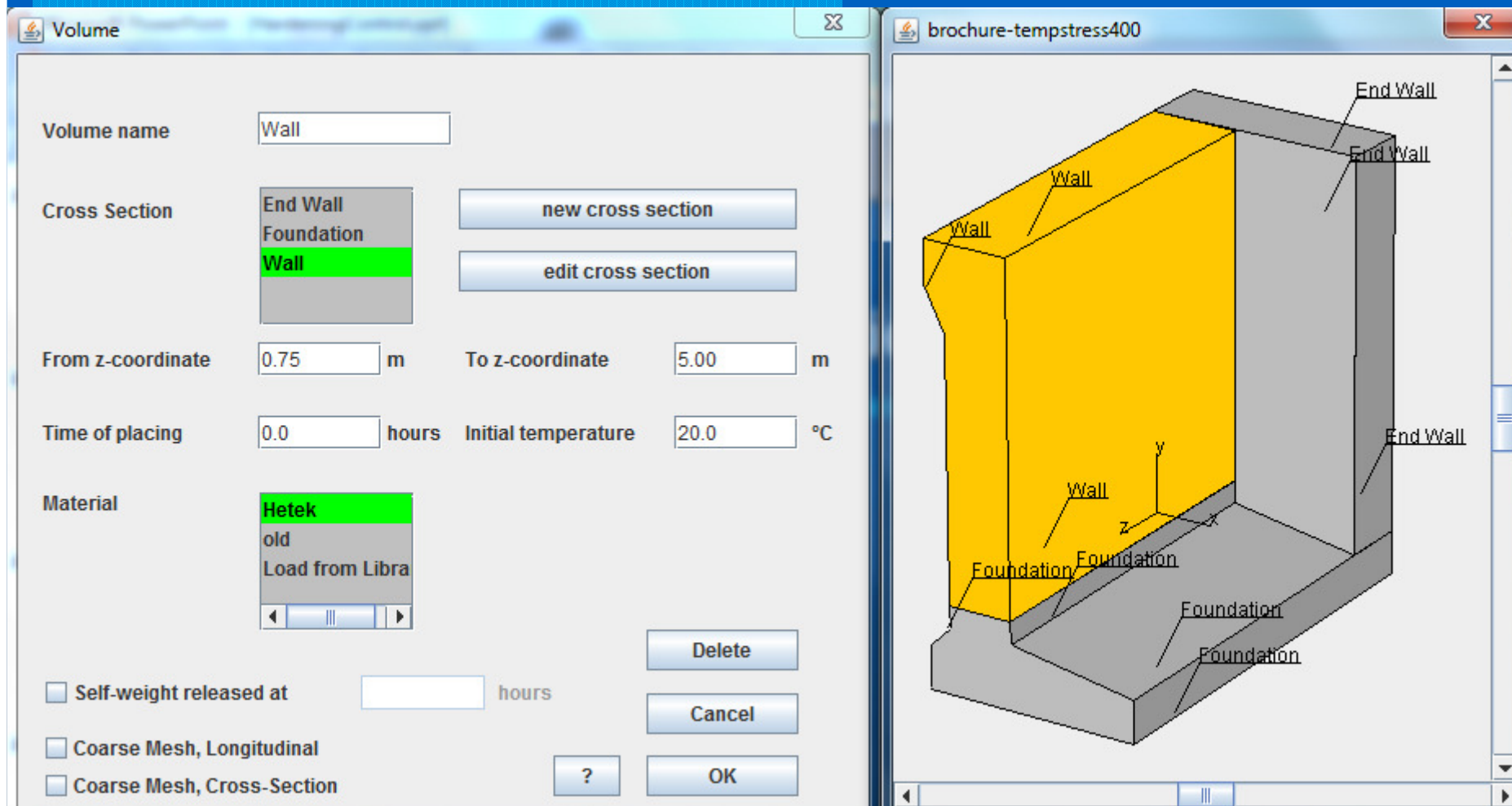


- Values specified as function of maturity

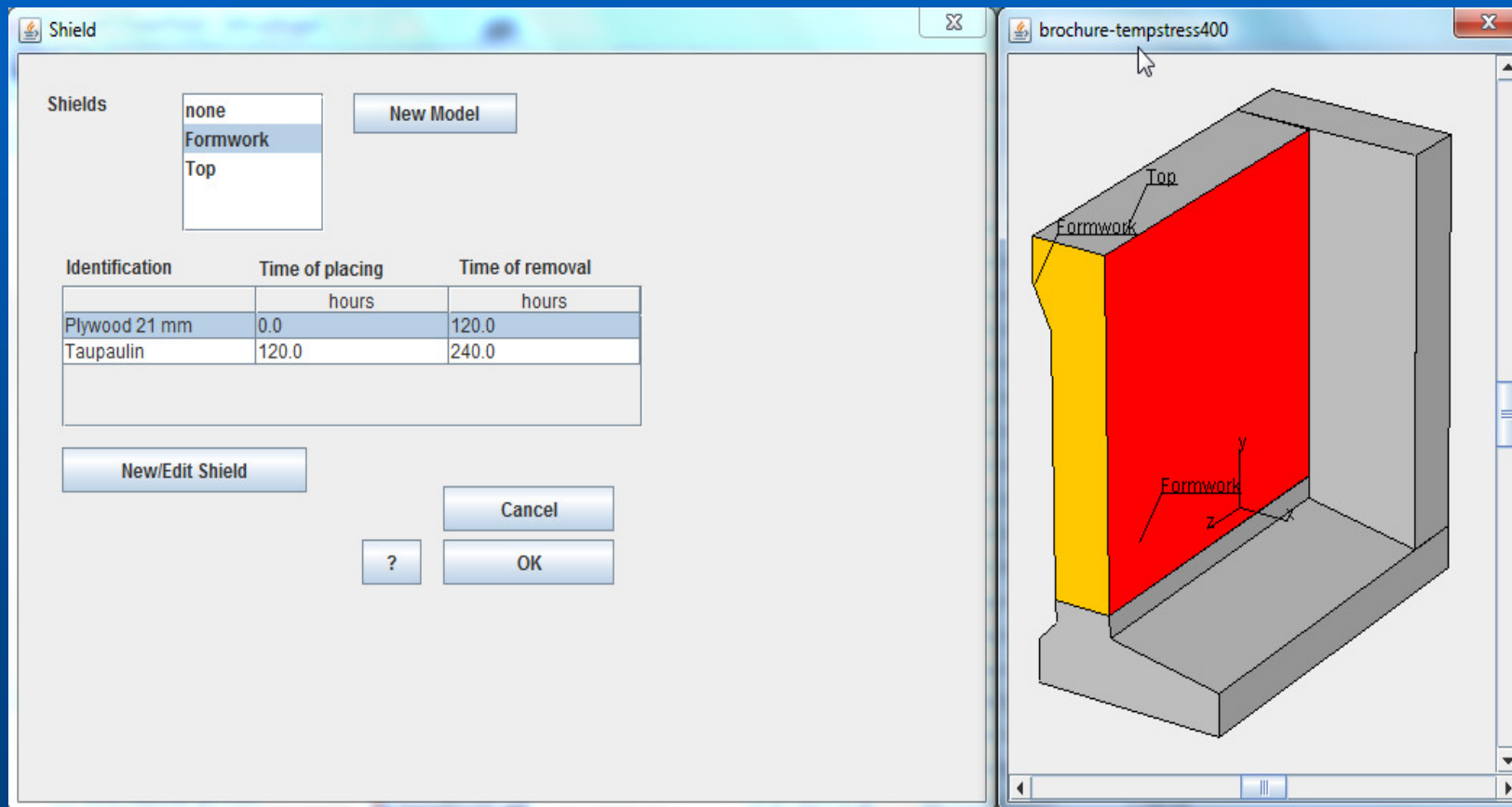
# Construction Method

- Define volumes corresponding to different placements
- Specify times of placement of each volume
- Boundary conditions for surface of volumes
  - Insulation properties of formwork (database)
  - Ambient conditions (time histories)
  - Presence of cooling pipes (database)

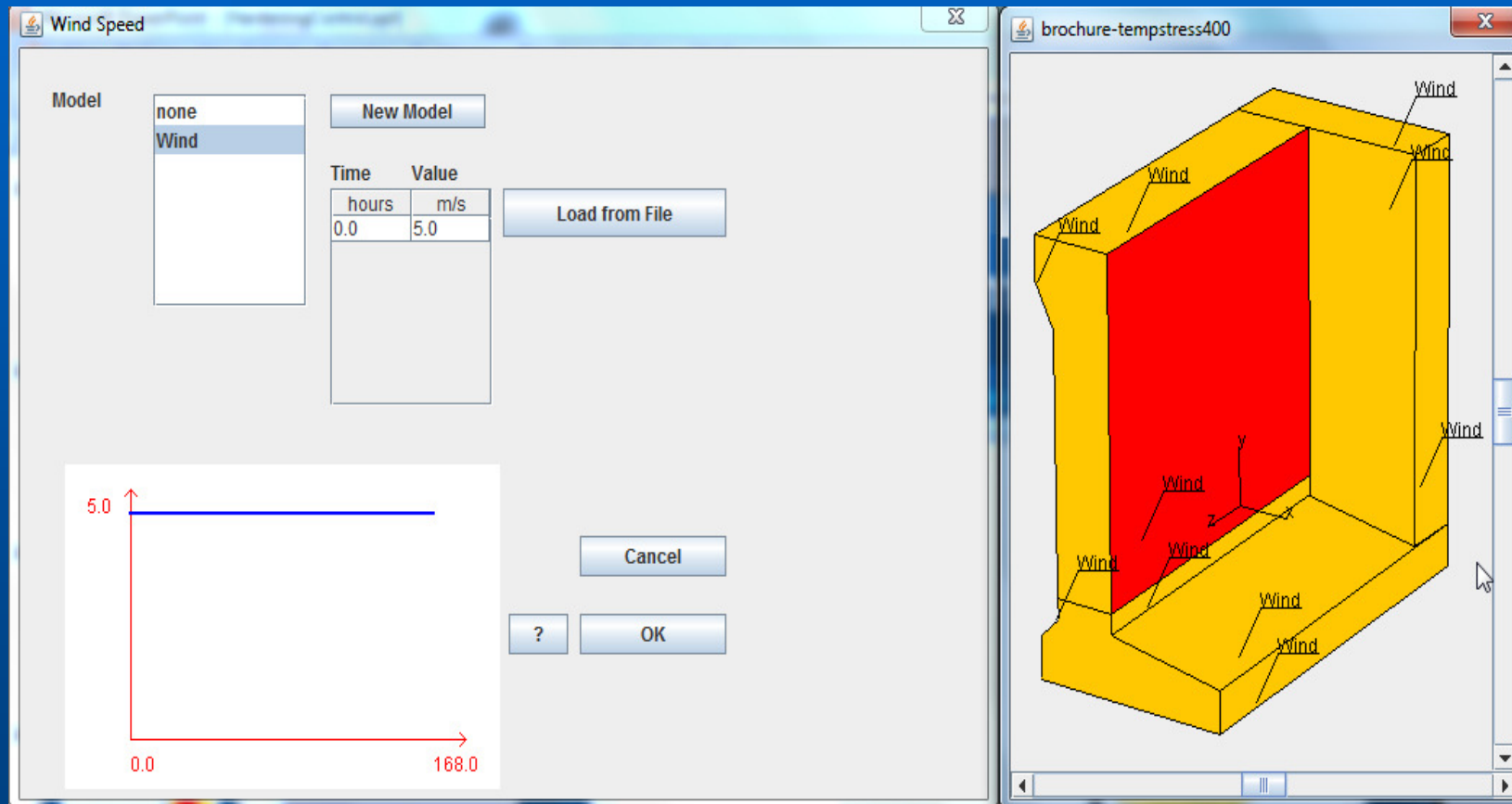
# Definition of Castings



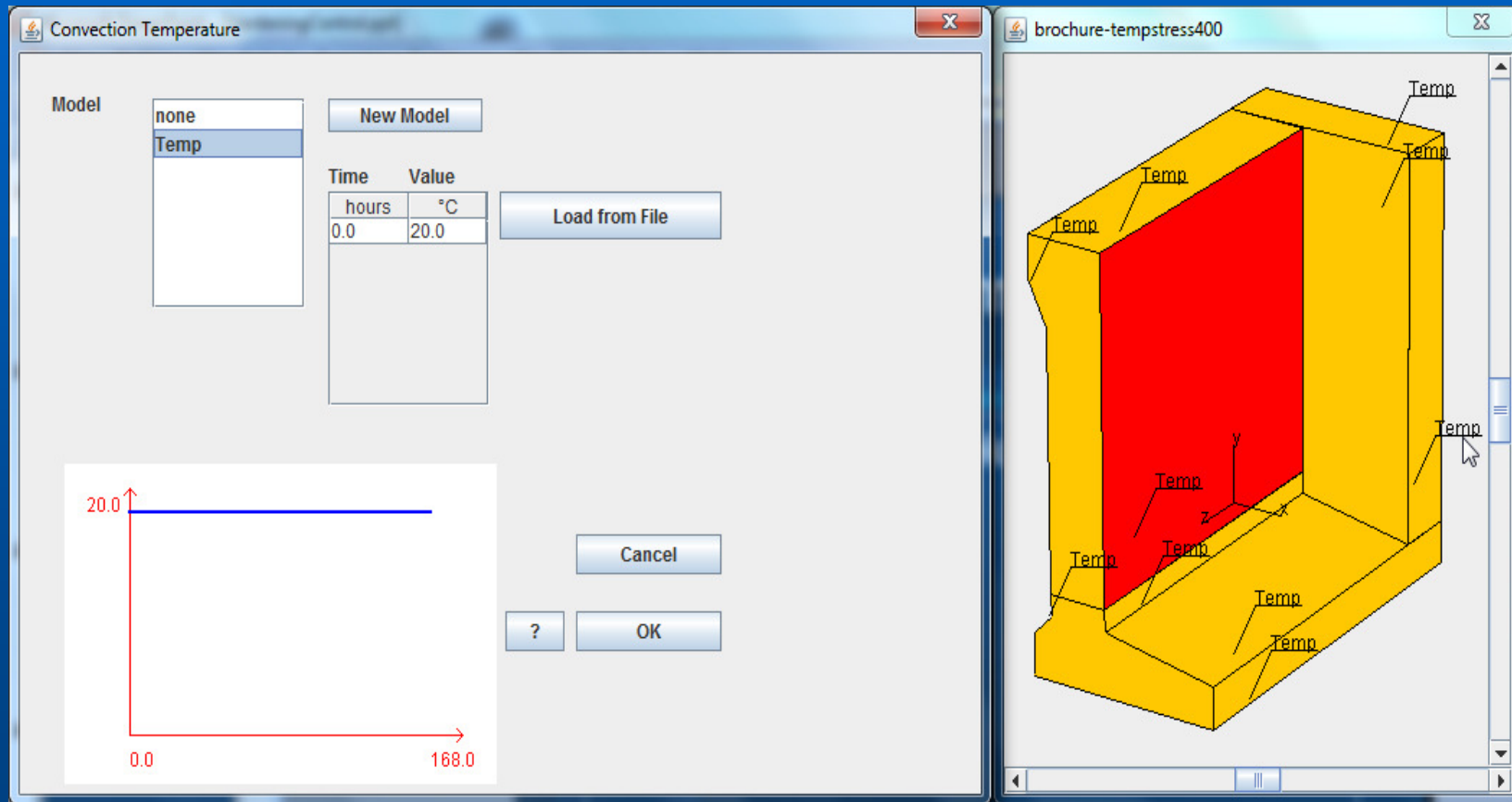
# Definition of Formwork



# Definition of wind-speeds



# Definition of ambient temperatures





# Transmission coefficients

**Convection Transmission Coefficient**

Model

- none
- Formwork+Wind
- Top+Wind
- Wind+ no shield

New Model

Time	Value
hours	kJ/m <sup>2</sup> /h/...
0.0	18.8
120.0	19.6
240.0	90.0

This model is based on a wind and a shield model and cannot be edited

Cancel

?

OK

**brochure-tempstress400**

Labels in 3D model: Wind+ no shield, Top+Wind, Formwork+Wind, Wind+ no shield, Wind+ no shield, Wind+ no shield, Wind+ no shield, Wind+ no shield, Wind+ no shield, Wind+ no shield.

# Cooling/Heating pipes/wires

Identification: Pipe 1

On: 12.0 hours

Off: 36.0 hours

Layout

x-coordinate	y-coordinate	z-coordinate
m	m	m
1.00	1.30	0.00
1.00	1.30	4.70
1.00	1.60	4.70
1.00	1.60	0.00

Load from File

Cooling pipe

Type: PEL28/32 New/Edit

Flow: 2.4 m<sup>3</sup>/h

Open circuit Inlet-Temperature: 12 dgr

Closed circuit without cooling

Closed circuit with cooling Effect: [ ] kJ/h  
Target Temperature: [ ] °C

Heating cable none New/Edit

Delete Cancel OK ?

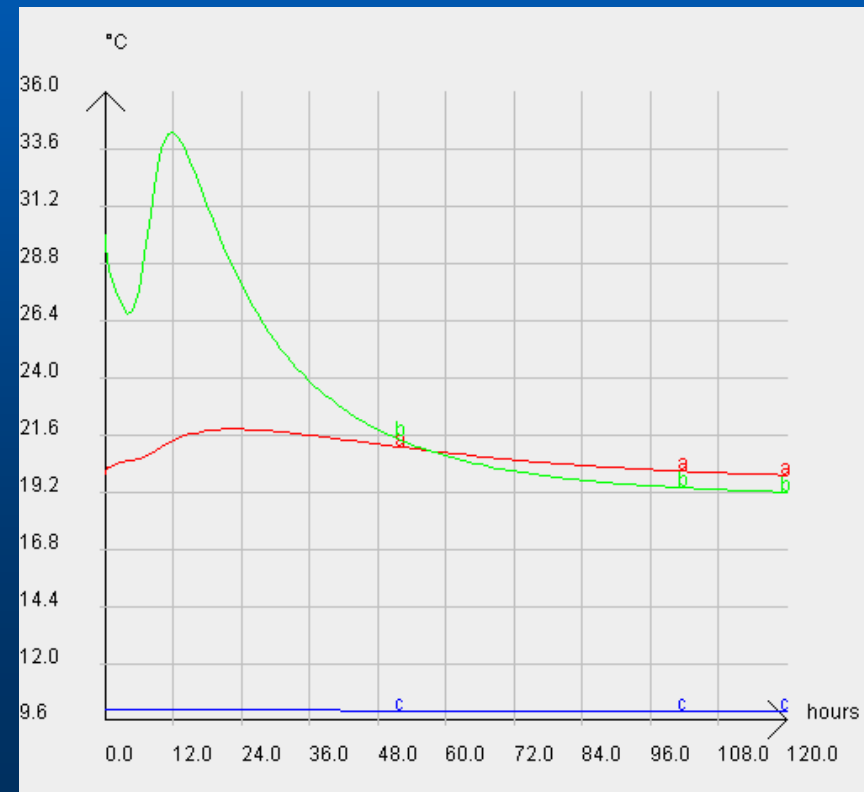
brochure-tempstress400

Pipe 1

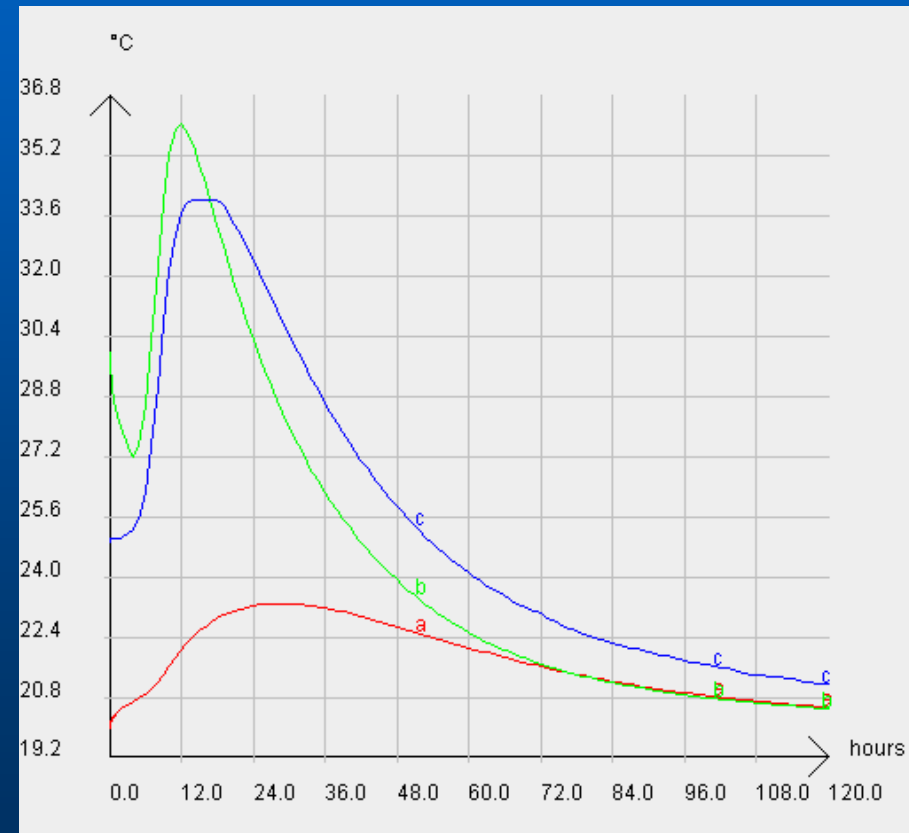
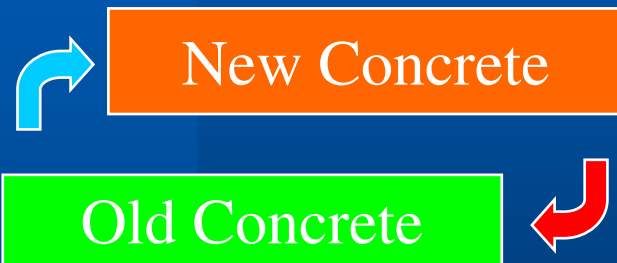
# Open circuit



$T_{inlet}$



# Closed circuit

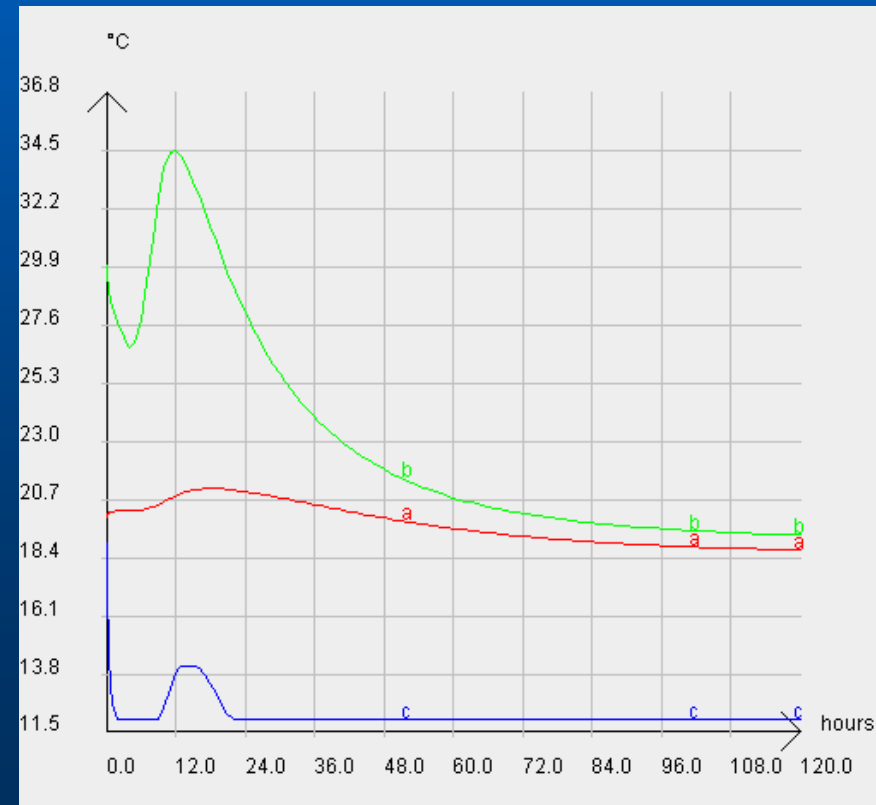


# Closed circuit with cooling plant

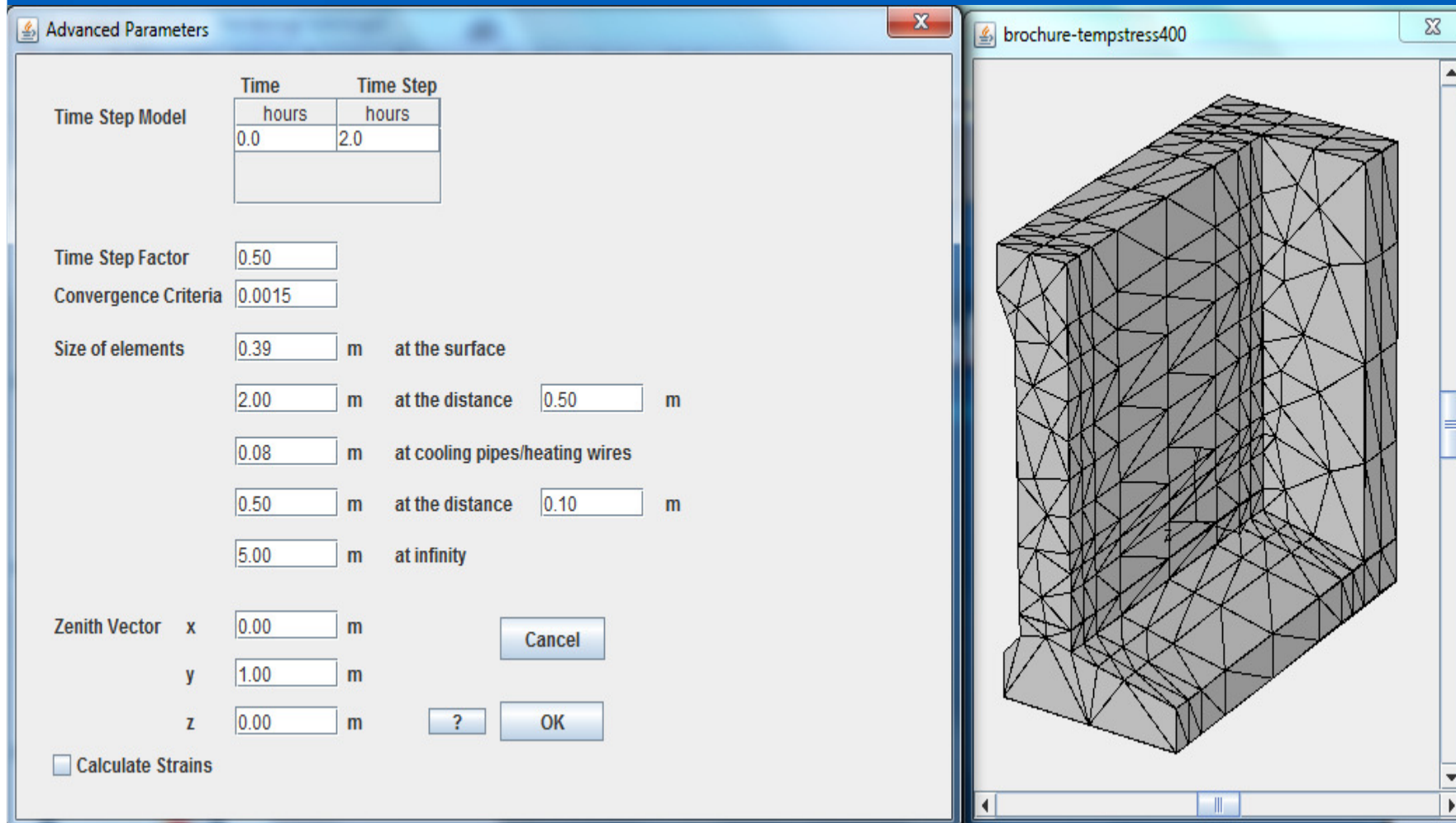


Old Concrete

$T_{\text{target}}$   
Max. effect



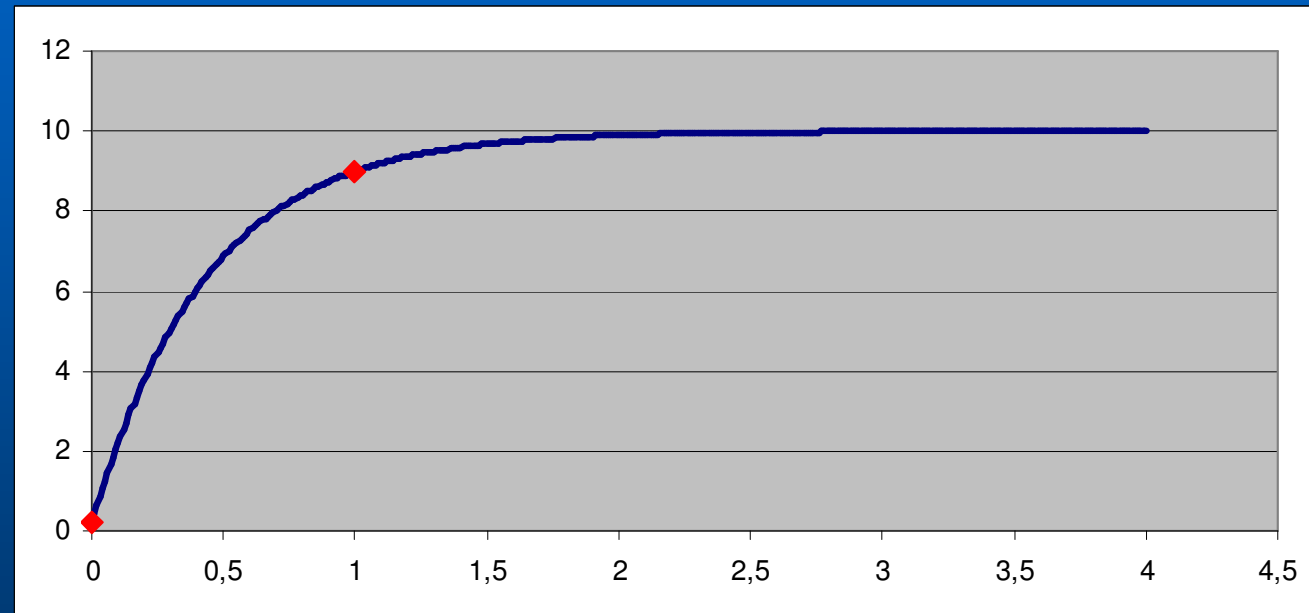
# Automatic meshing



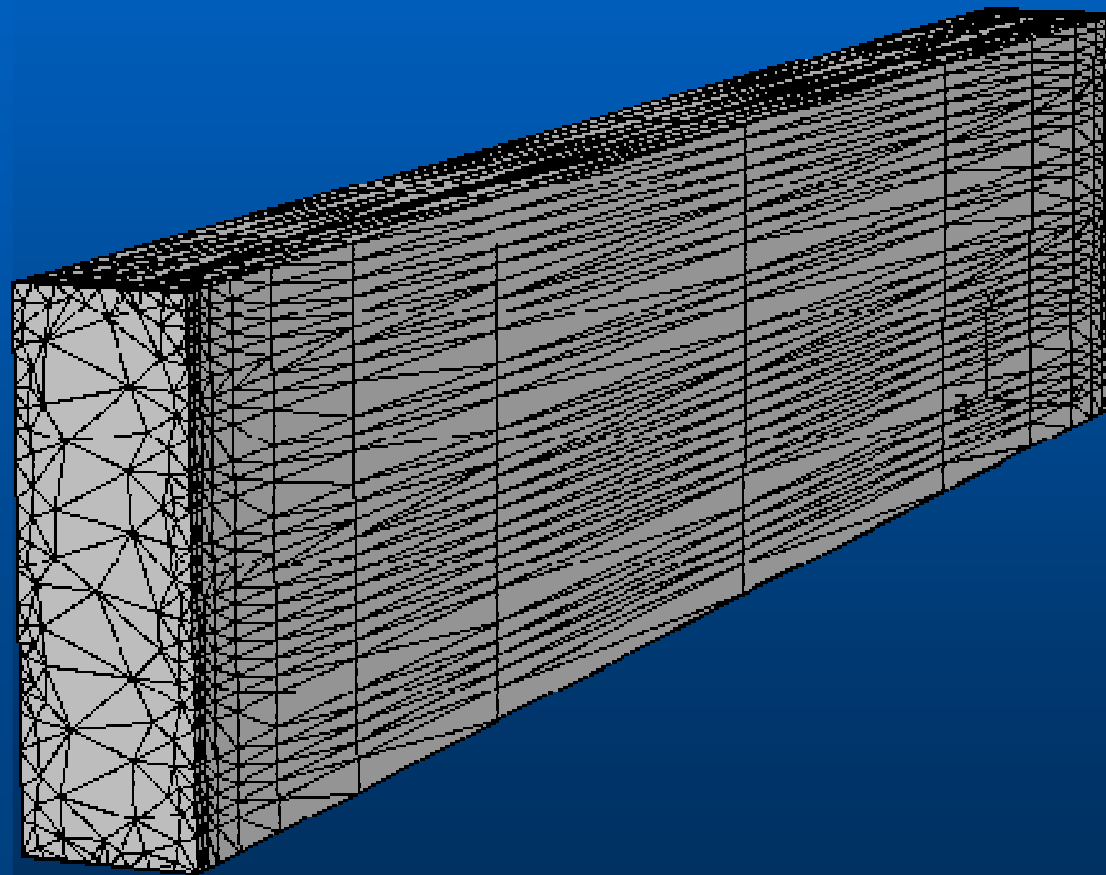
# Meshing

Density:

- at surface
- at distance  $x$
- at infinity

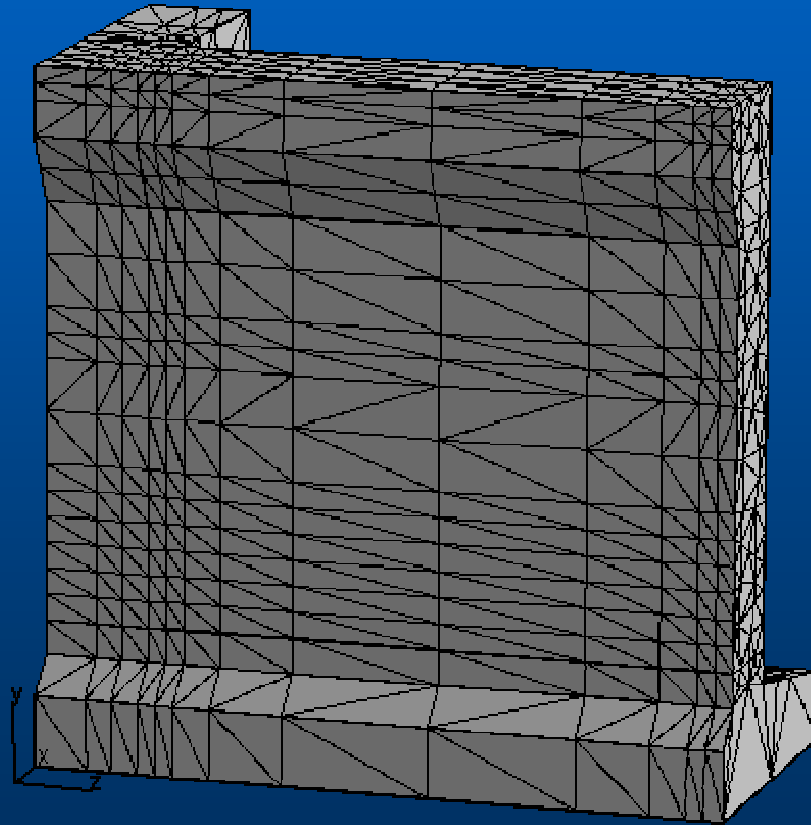


# Density of mesh

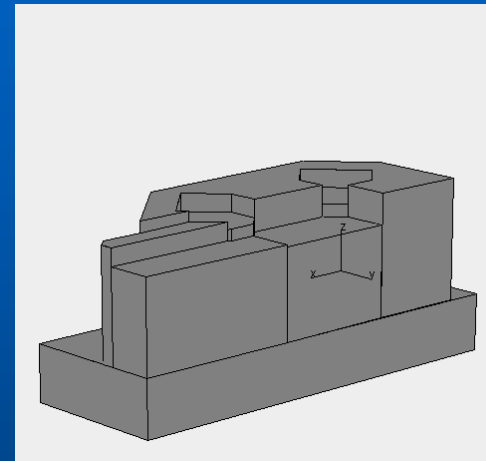
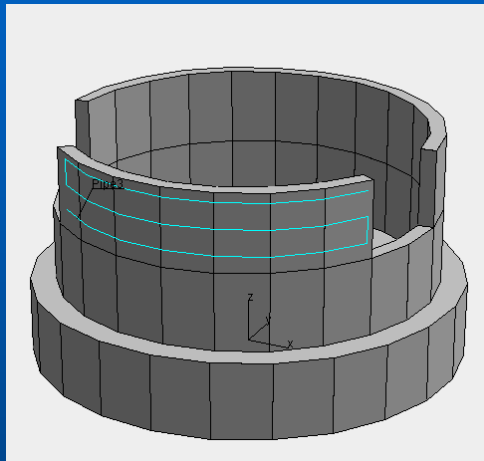
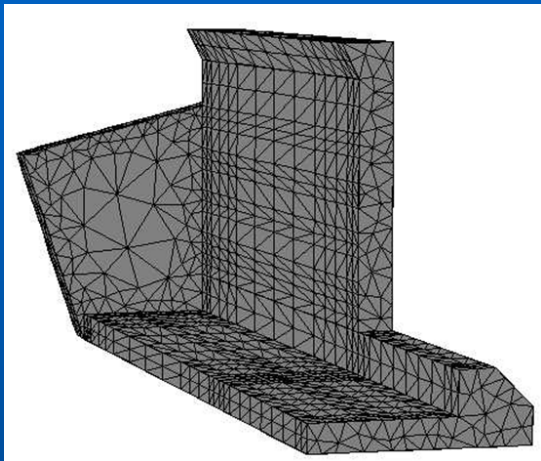




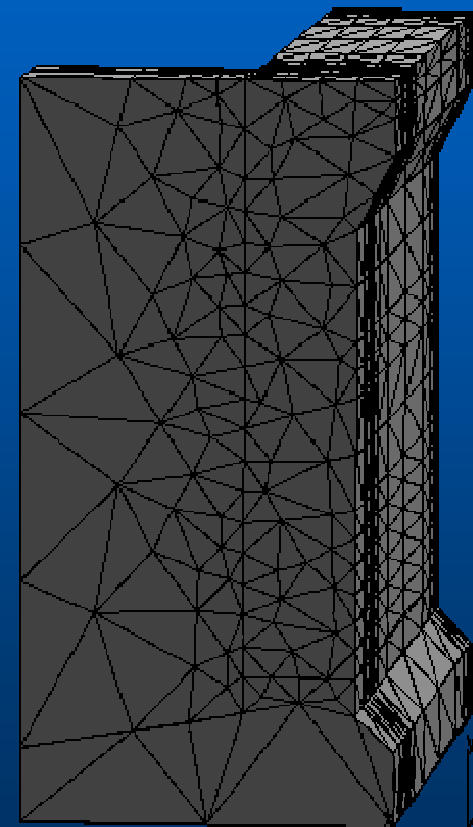
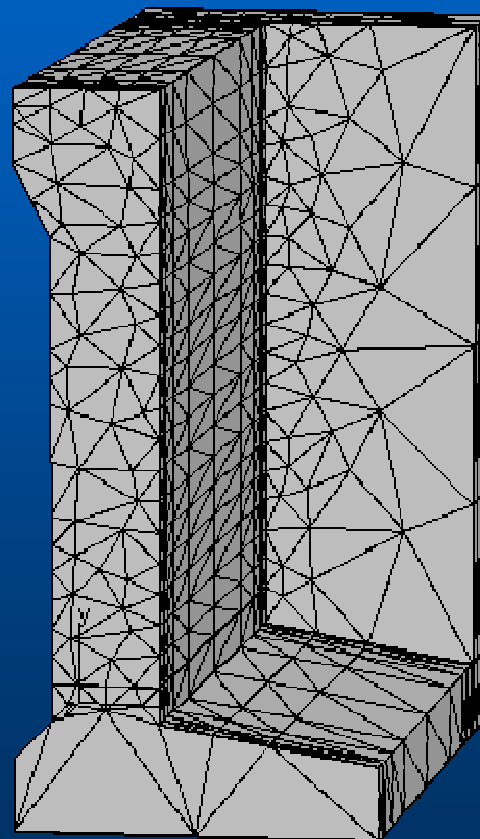
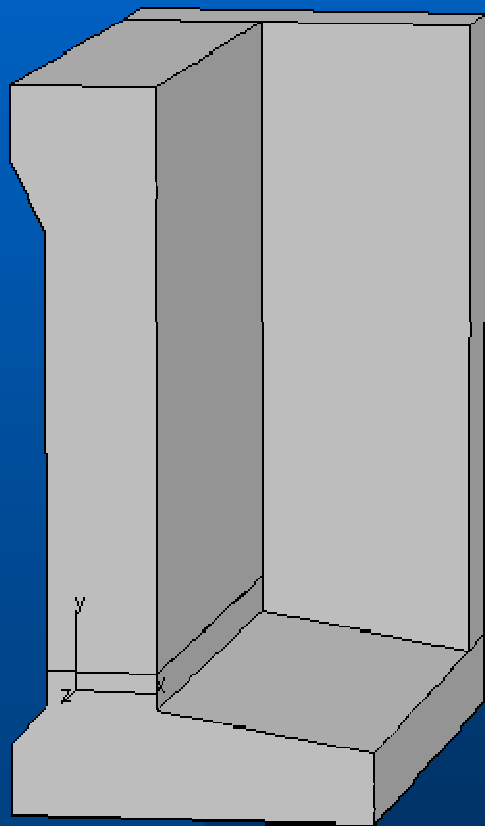
# Meshing



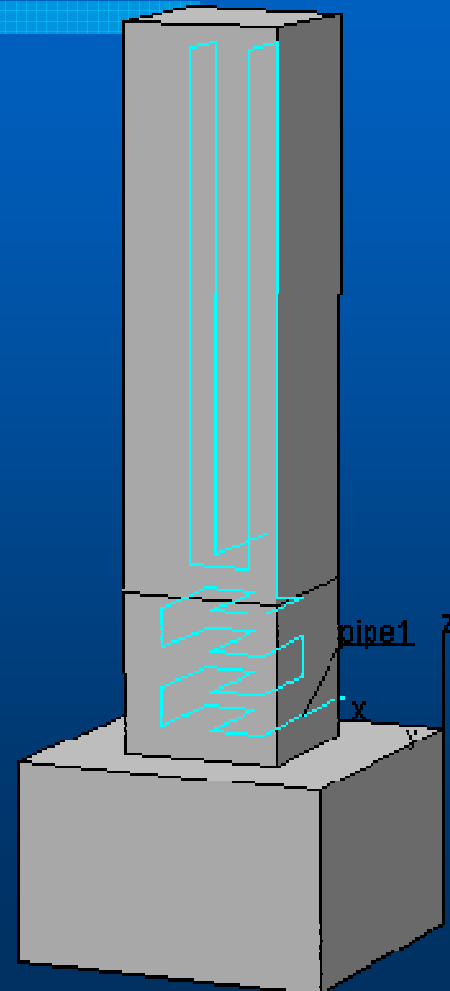
# Examples



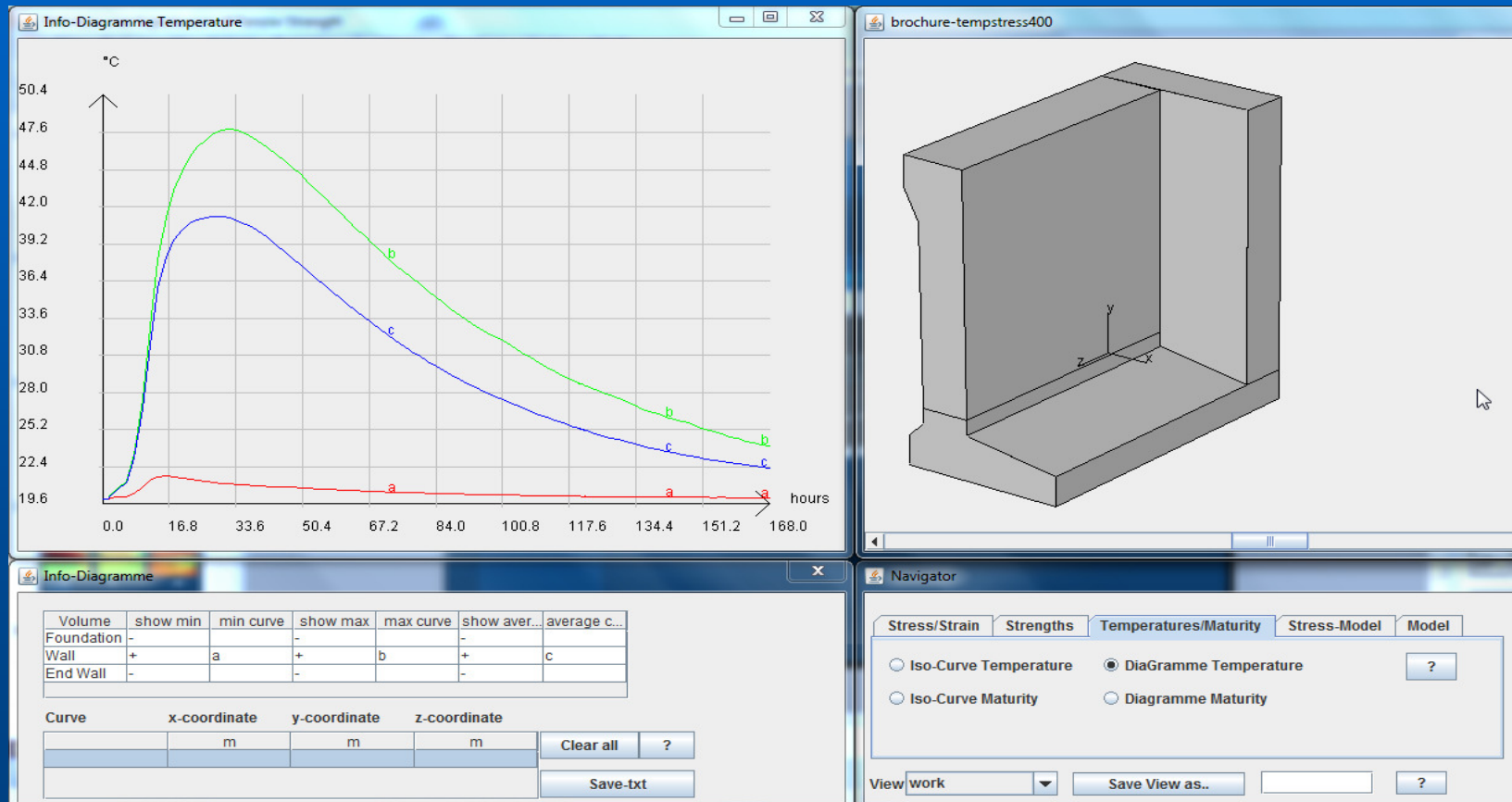
# Examples



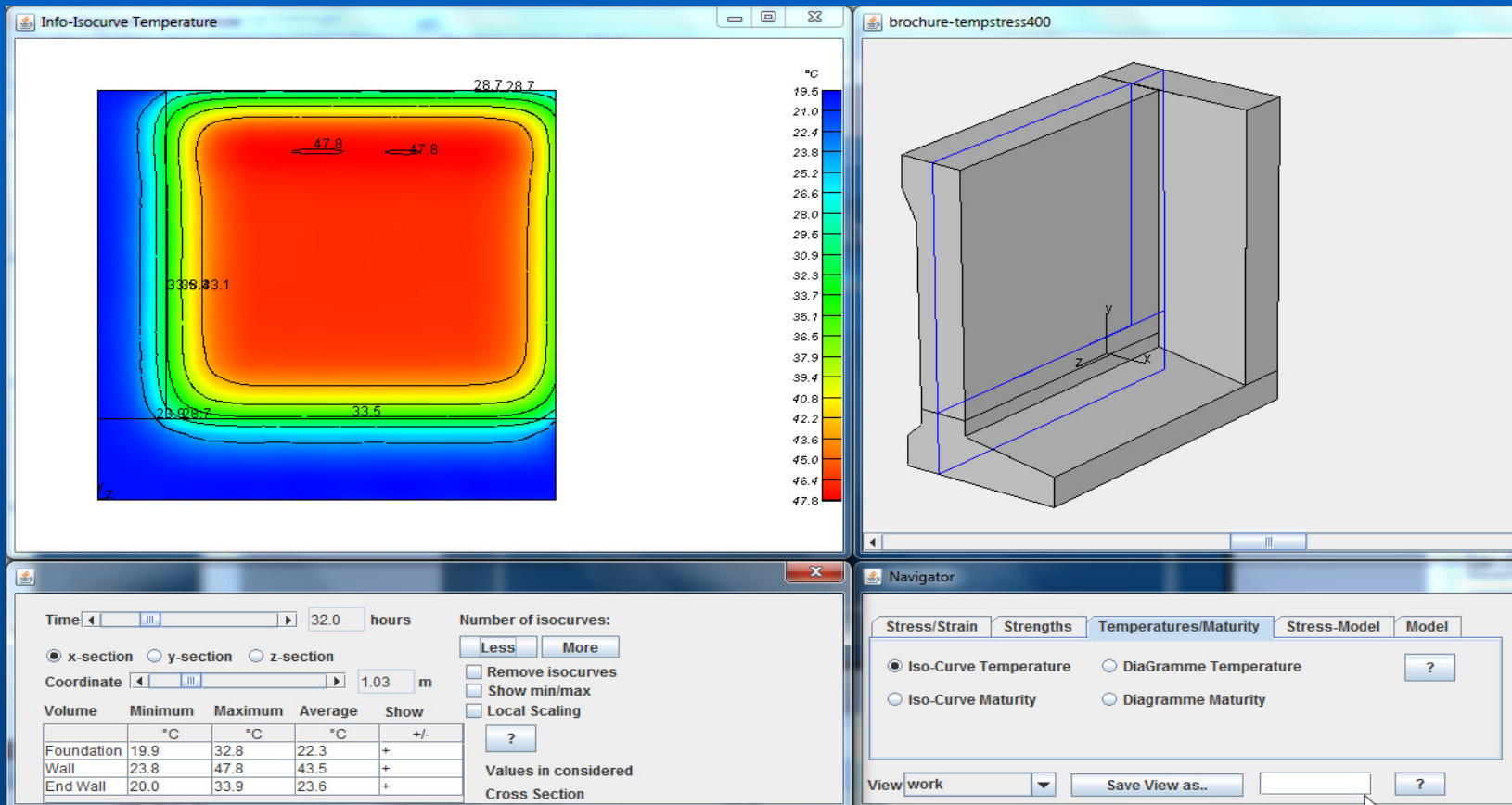
# Cooling



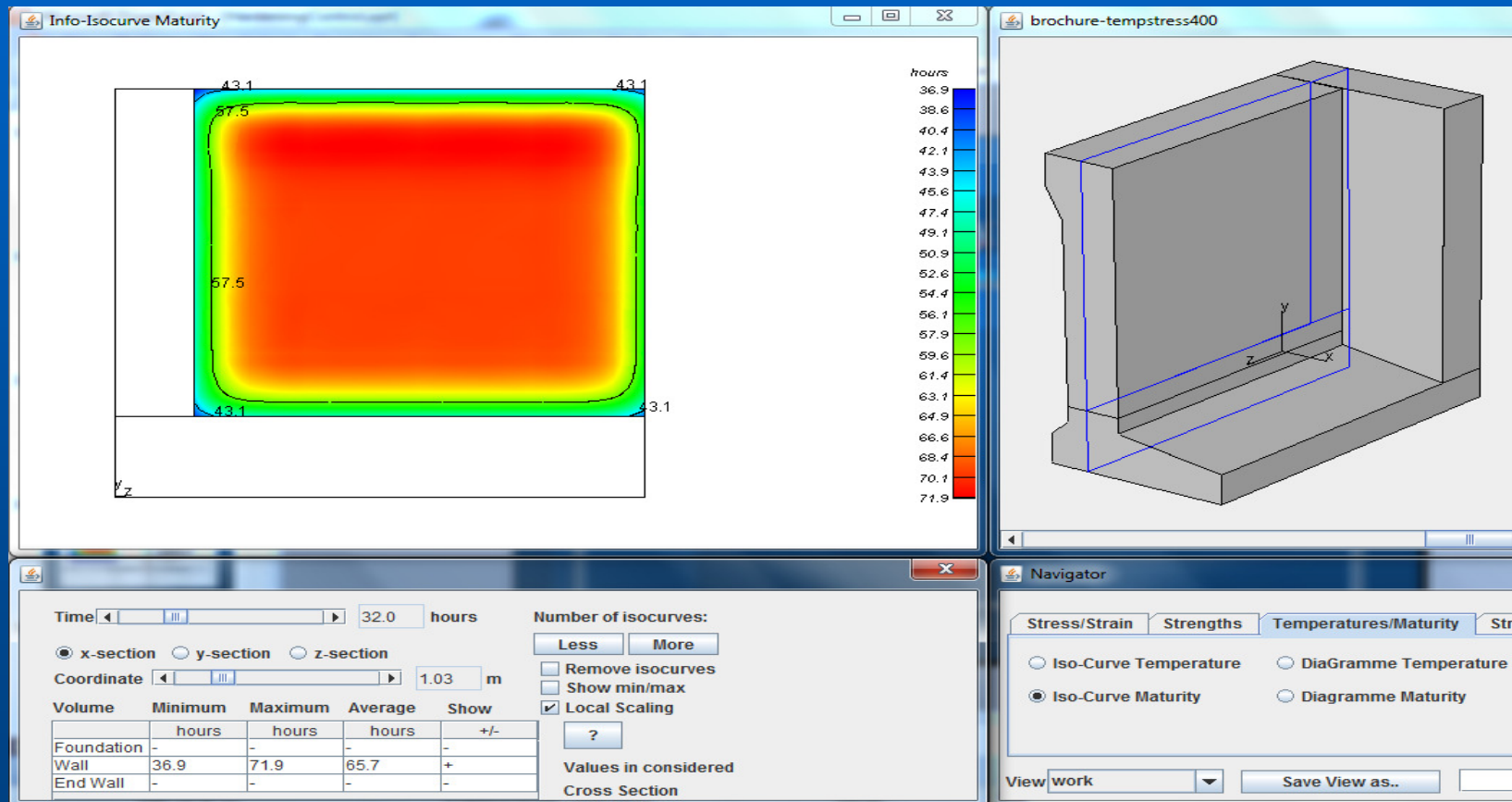
# Temperature histories



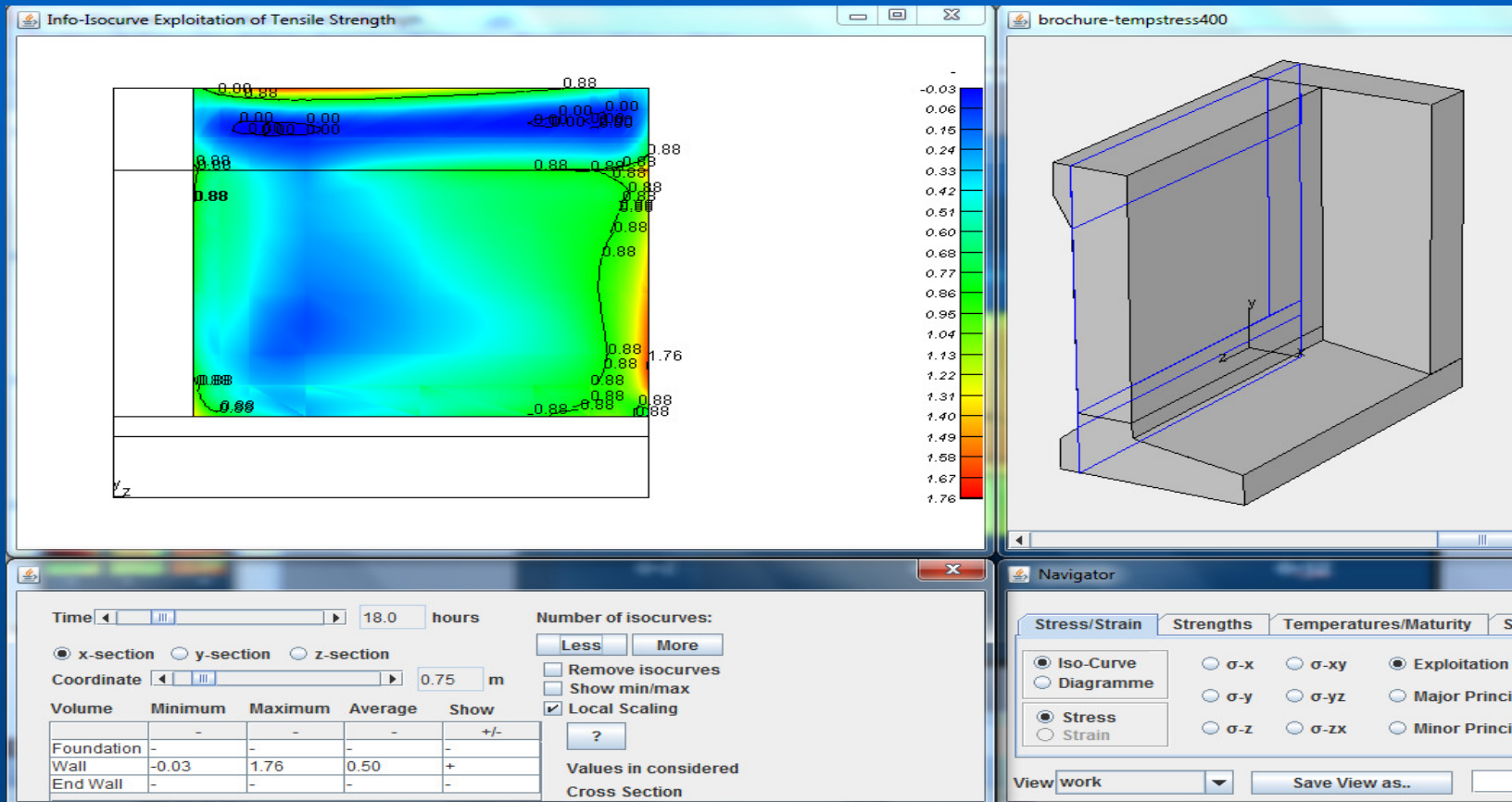
# Temperature distribution



# Same for maturity and strength

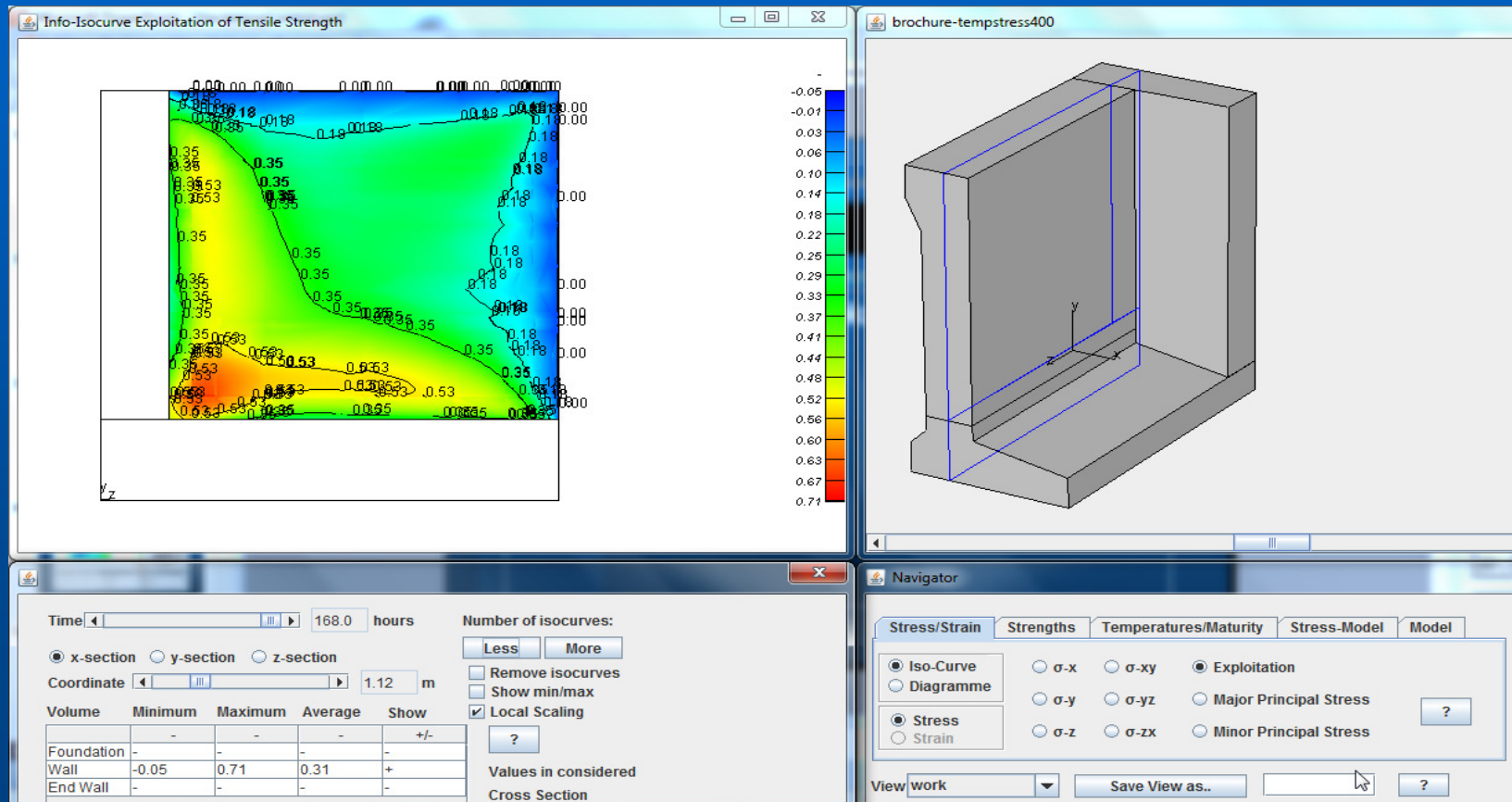


# Early exploitation at surface





# Exploitation at core after hardening

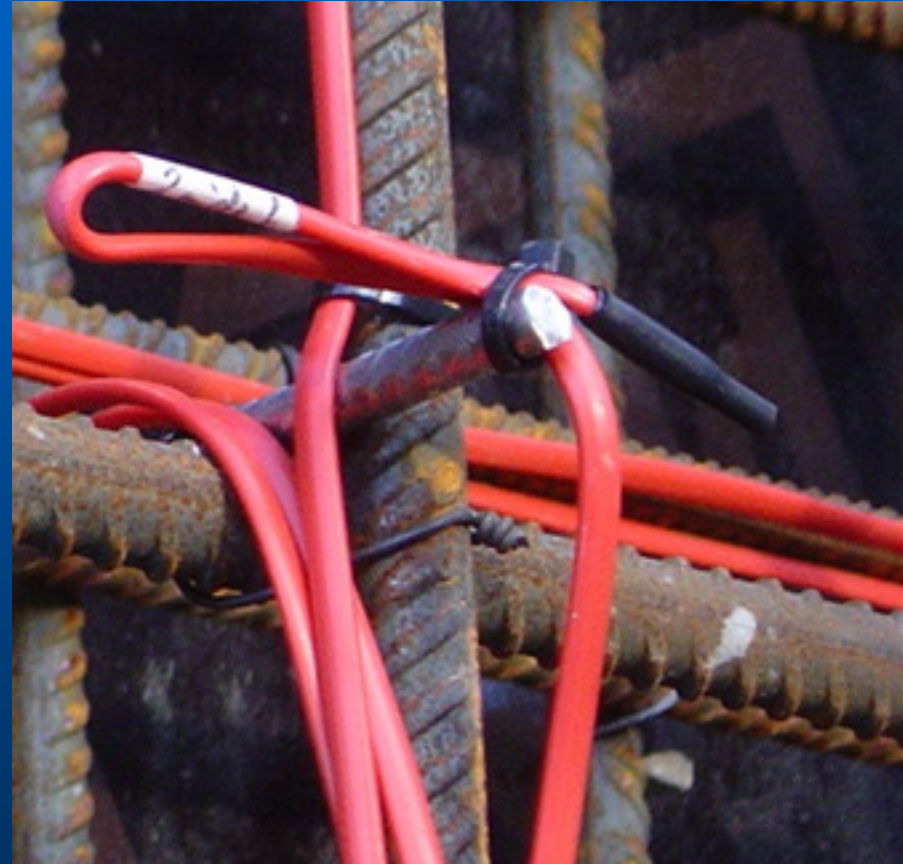


# Verification on site: HeatWatch

Monitoring and logging temperatures

Calculating maturity and strengths based on user-input

Fulfilling the requirements concerning freezing, evaporation, differences in temperature, maximum temperature level and strength.



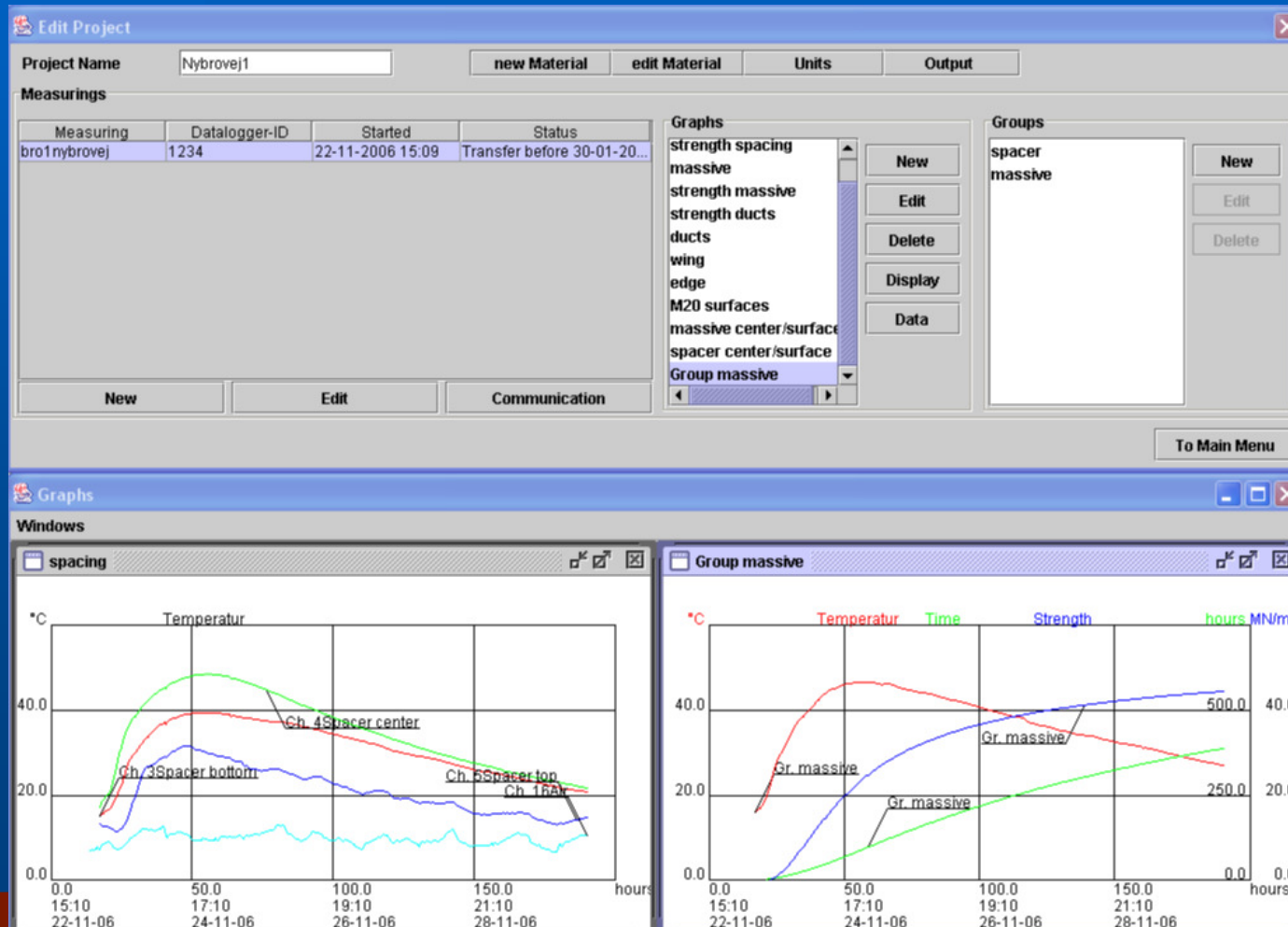
# HeatWatch

- 10-30 Thermocouples
- Connected by Internet or wireless local network
- Also mV and mA can be monitored and logged
- Warnings by SMS or e-mail
- Web-interface showing instant values



# HeatWatch

Averages and differences on measured data can be defined by the user



# Units

## User-defined units

Variable	Label	Conversion factor	Default-unit	No. of digits
Time	hours	1.0	hours	1
Dimension of structure	m	1.0	m	2
Dimension of cross-sec...	m	1.0	m	3
Dimension of shield	m	1.0	m	3
Thermal Conductivity	$\text{kJ/m/h/}^\circ\text{C}$	1.0	$\text{kJ/m/h/}^\circ\text{C}$	1
Heat Capacity	$\text{kJ/kg/}^\circ\text{C}$	1.0	$\text{kJ/kg/}^\circ\text{C}$	3
Density	$\text{kg/m}^3$	1.0	$\text{kg/m}^3$	1
Heat Generation	$\text{kJ/kg}$	1.0	$\text{kJ/kg}$	1
Cement Content	$\text{kg/m}^3$	1.0	$\text{kg/m}^3$	1
Activation Energy Factor I	J/mole	1.0	J/mole	1
Activation Energy Factor II	J/mole	1.0	J/mole	1
Coeff. of convective tran...	$\text{kJ/m}^2\text{h/}^\circ\text{C}$	1.0	$\text{kJ/m}^2\text{h/}^\circ\text{C}$	1
Flux	$\text{kJ/m}^2\text{h}$	1.0	$\text{kJ/m}^2\text{h}$	1
Coeff. of radiation	$\text{kJ/m}^2\text{h/}^\circ\text{C}^2/^\circ\text{C}^2$	1.0	$\text{kJ/m}^2\text{h/}^\circ\text{C}^2/^\circ\text{C}^2$	1
Wind Speed	m/s	1.0	m/s	1
Effect	$\text{kJ/h}$	1.0	$\text{kJ/h}$	1
Effect-line	$\text{kJ/m/h}$	1.0	$\text{kJ/m/h}$	1
Flow	$\text{m}^2\text{h}$	1.0	$\text{m}^2\text{h}$	1
Load	$\text{MN/m}^2$	1.0	$\text{MN/m}^2$	1
E-modulus	$\text{MN/m}^2$	1.0	$\text{MN/m}^2$	1
Thermal expansion coef...	-	1.0	-	7
Stress	$\text{MN/m}^2$	1.0	$\text{MN/m}^2$	1

Temperature

# Reports

All software delivers printed reports

