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Early Age Concrete (EAC)

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Nonlinear Analyses for the built environment

Content

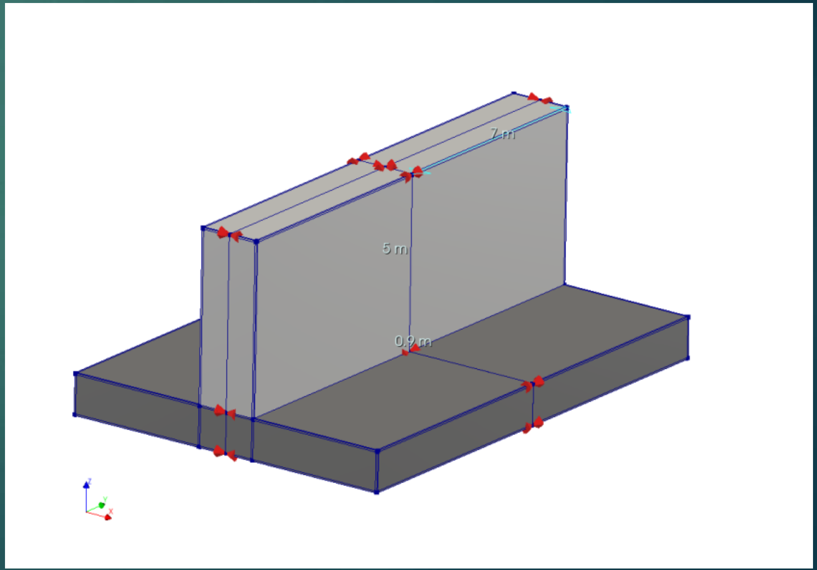
- Overview
- Approaches
- Pros and cons
- conclusions

Overview

- Engineers must demonstrate that no cracking occurs during the adiabatic process.
- Limited information, time, and budget are available for the analysis.
- Analyses are often commissioned by contractors or subcontractors.

Example to demonstrate

- Bunker silo wall
- 14 m long wall 5 meter high and 1.8 m thick
- Assumed adiabatic rise of 40 reaching 60 ℃
- Restrained horizontal bedding stiffness of gravel

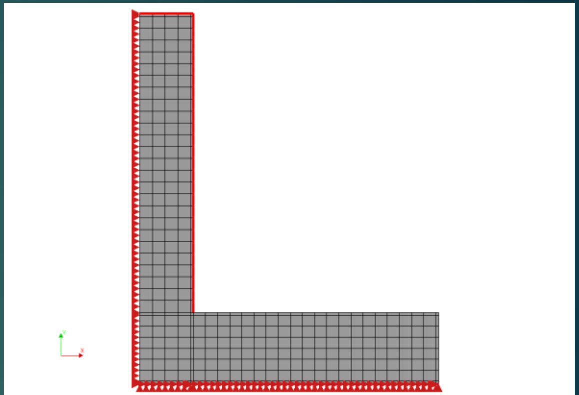


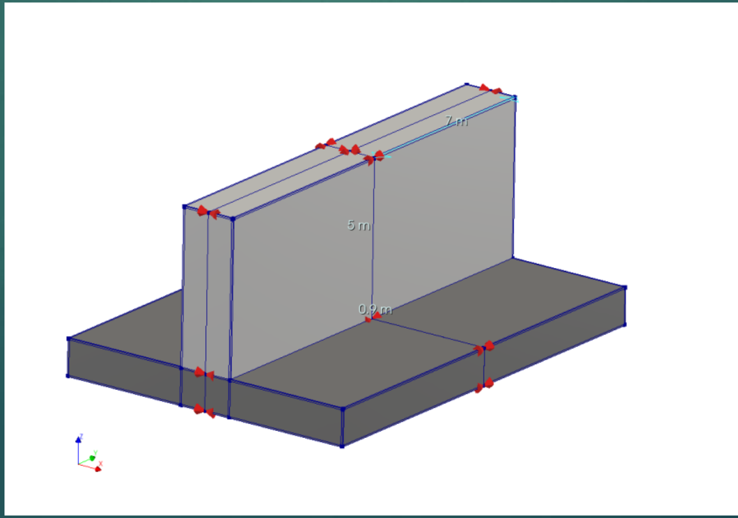
approaches

- Common
  - 2D plane strain
  - 2.5D plane stress
- Less common
  - 2.5D plane stress extended model
  - 3D model

2D plane strain

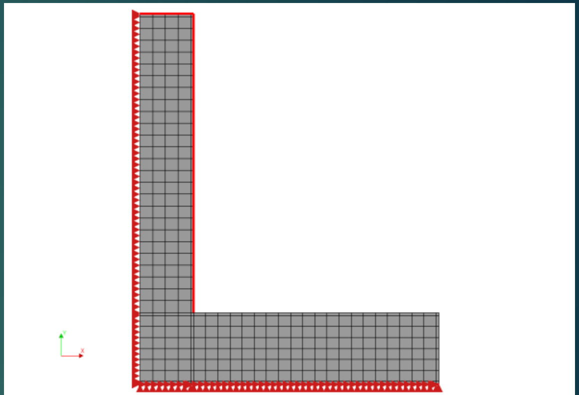
- Fast approach in modelling time.
- Strain out of plane being 0 means high out of plane stresses.
- Progressive in heating up and conservative in cooling down





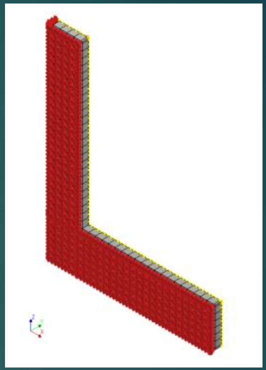
2D plane stress

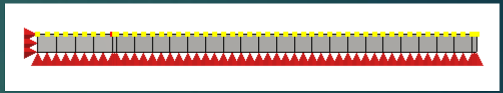
- Fast approach in modelling time.
- Stress out of plane is 0
- Only in plane stress is checked.
- Progressive in all cases



2.5D plane stress

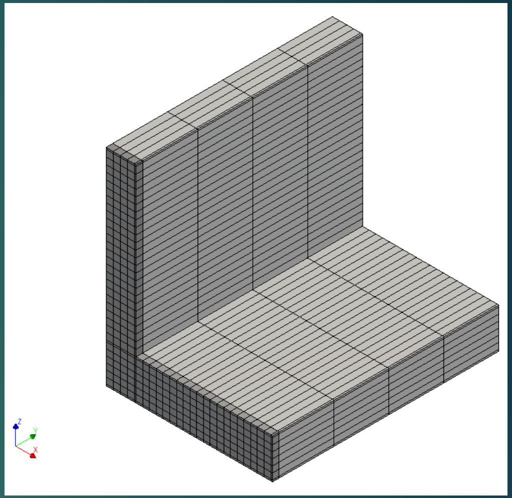
- (Fast) approach in modelling time.
- Software tweaks the out of plane stiffness.
  - Constant rotation of the plane (straight)
  - A translation stiffness of 0 or a certain value.
- Out of plane stress reduced both, in the young heating phase as in the cooling phase (a bit more realistic).





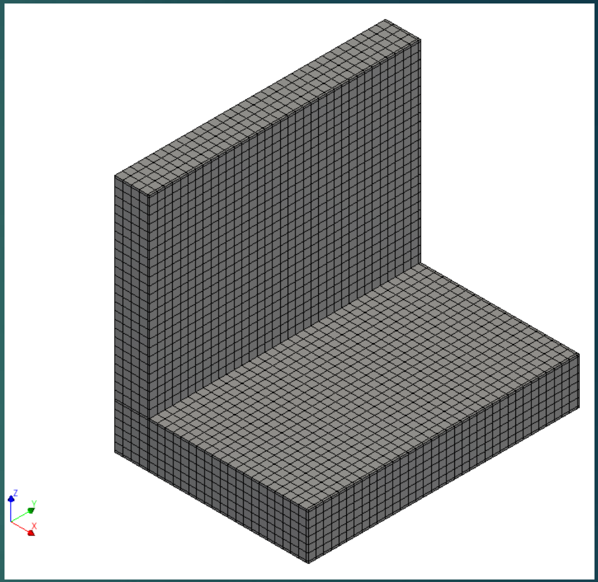
2.5D plane stress extended model

- (Reasonable Fast) approach in modelling time.
- Real out of plane stiffness.
  - No constant rotation of the plane (realistic)
  - Realistic translation stiffness
- Out of plane stress correctly reduced both, in the young heating phase as in the cooling phase.

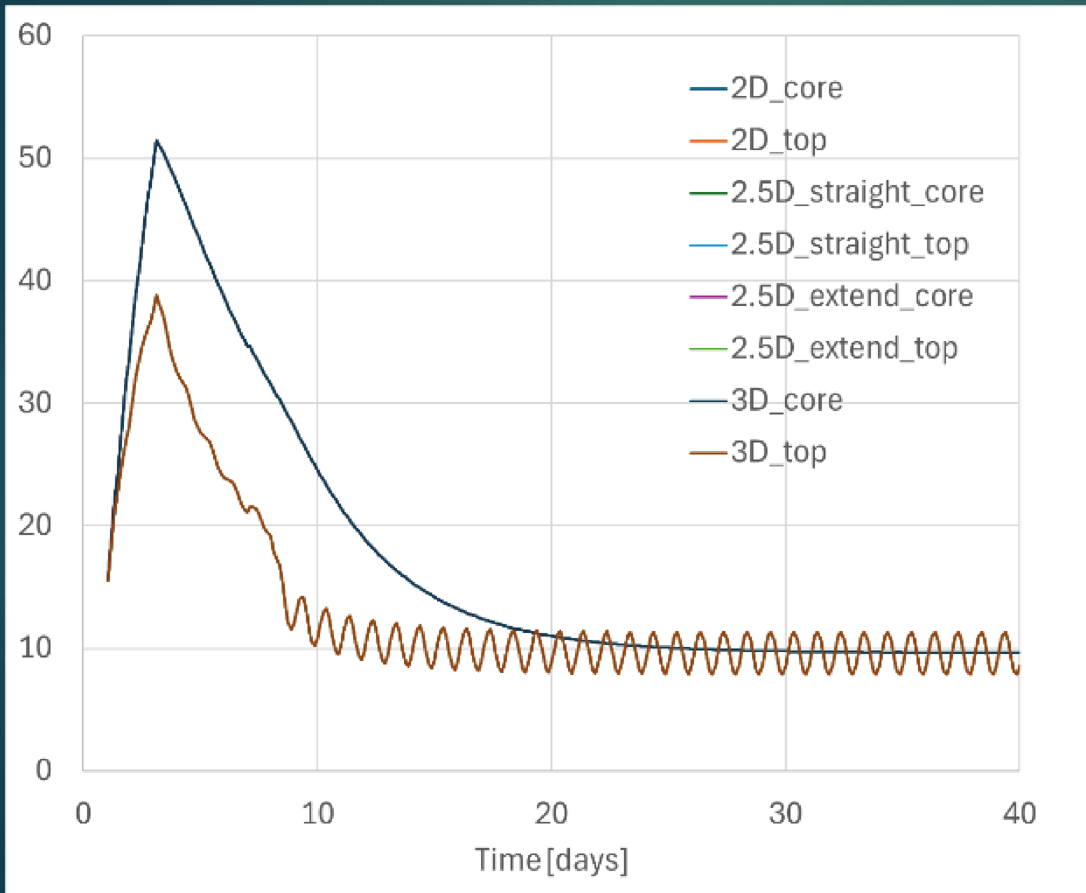


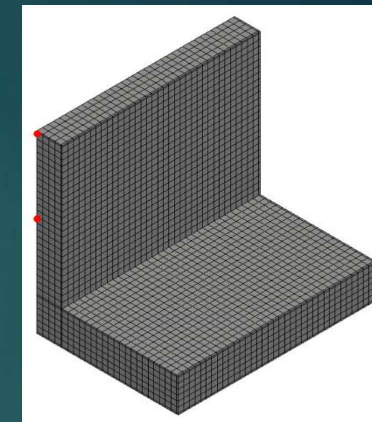
3D volume model

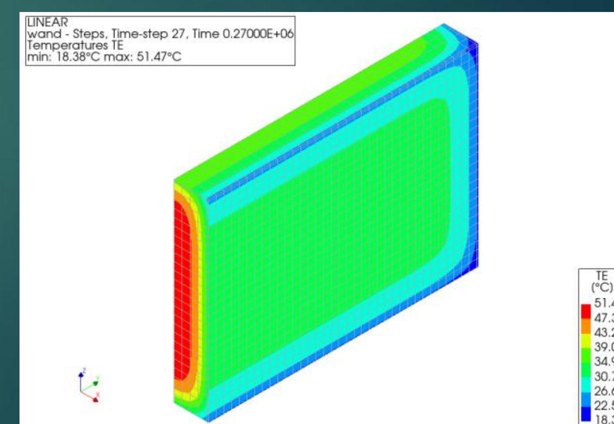
- (Slowest) approach in modelling time.
- Real out of plane stiffness.
  - No constant rotation of the plane (realistic)
  - Realistic translation stiffness
- Realistic behaviour over the entire model



Comparison temperature

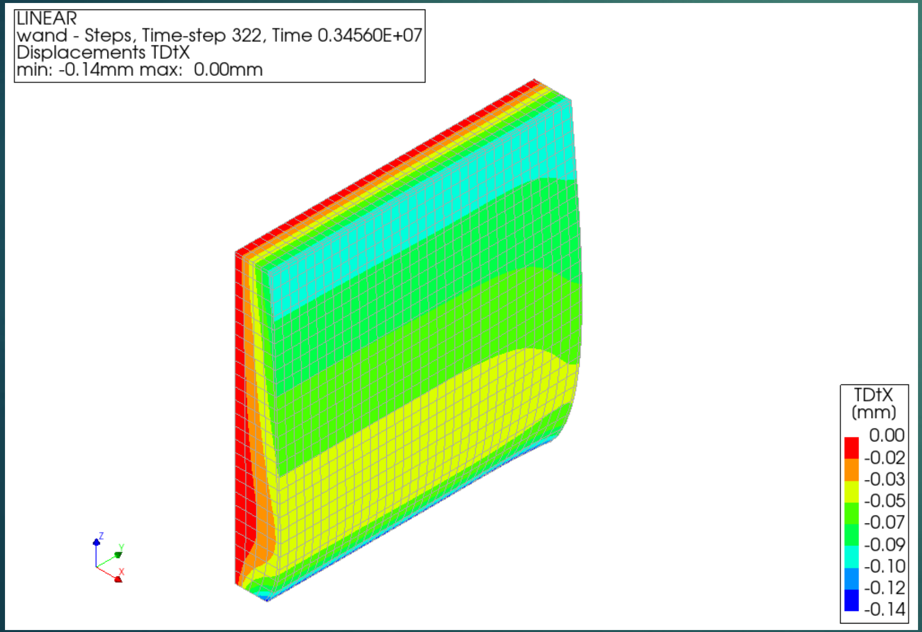


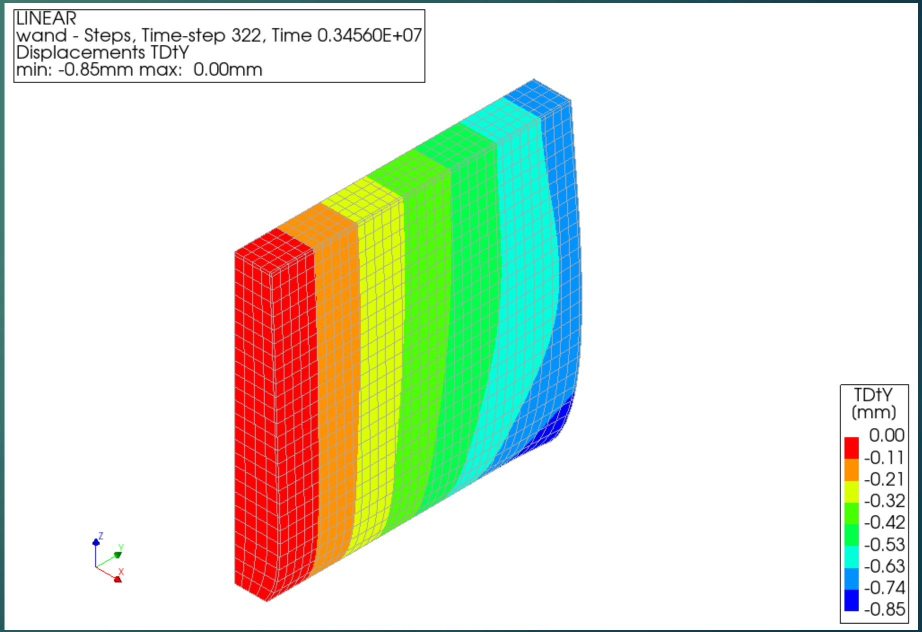




Comparison displacements

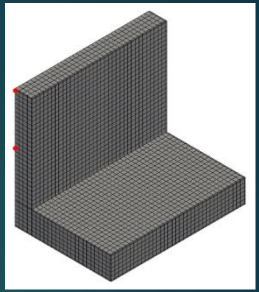
- Only 2.5D extended and 3D modelling can give realistic out of plane deformations.

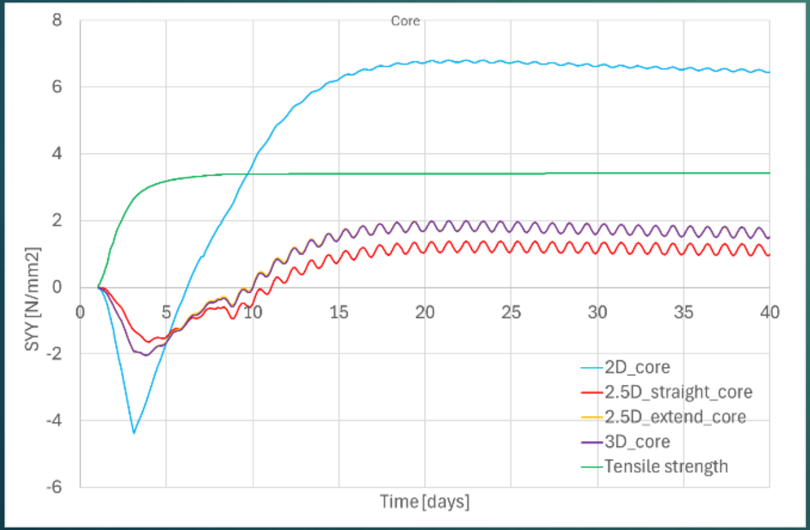


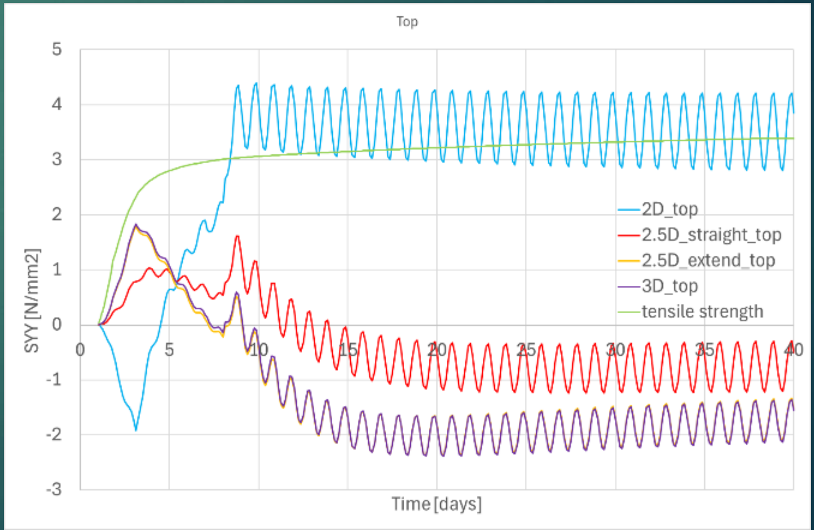


Comparison stress

- 2D overshoots the out of plane stresses (safe, but not sustainable)
- 2.5D straight plane undershoots stresses, this is not a safe approach.
- 2.5D extended and 3D modelling give comparable realistic output.

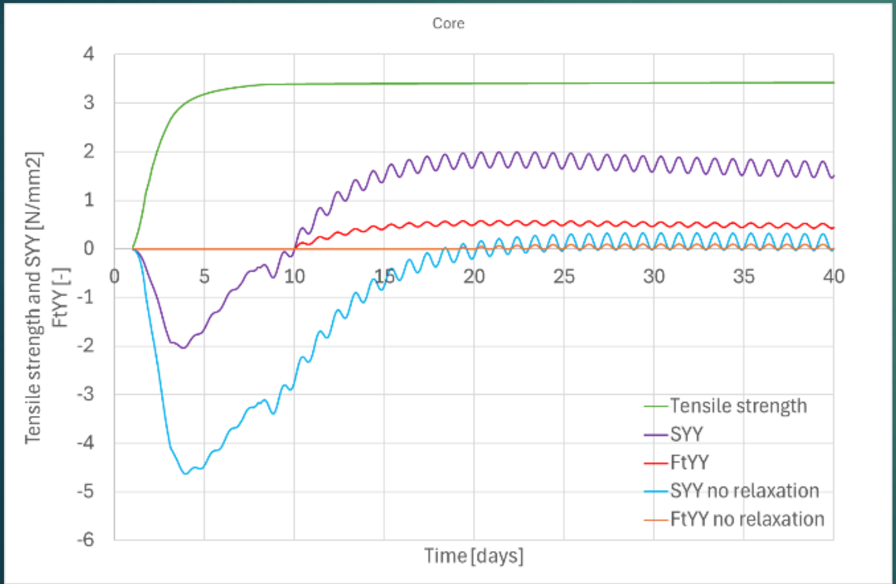


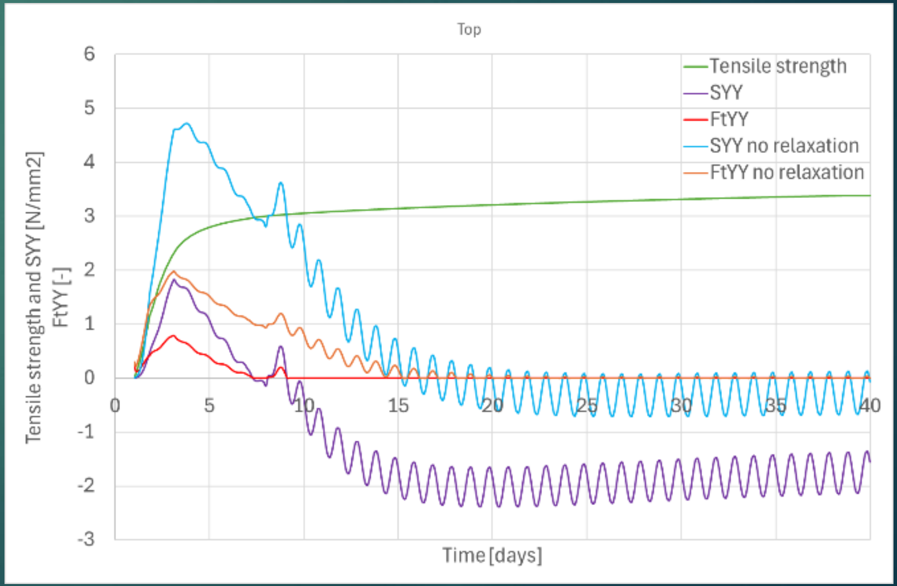




Creep and Relaxation in time

- Depending on different parameters this can be a positive or negative effect.
- Negative in the first phase where compression is lowered
- Positive in the next phase reducing tensile stress





Conclusions

- 2D plane strain overestimate the stresses. Fast, but not economical/sustainable
- 2.5D straight plane underestimate the stresses, Could be unsafe.
- 2.5D extended model is the most optimal modelling approach.
- 3D modelling is necessary in cases of non-orthogonal shapes or clashing/connection shapes. A difficult geometry can be taken into account in a realistic way.

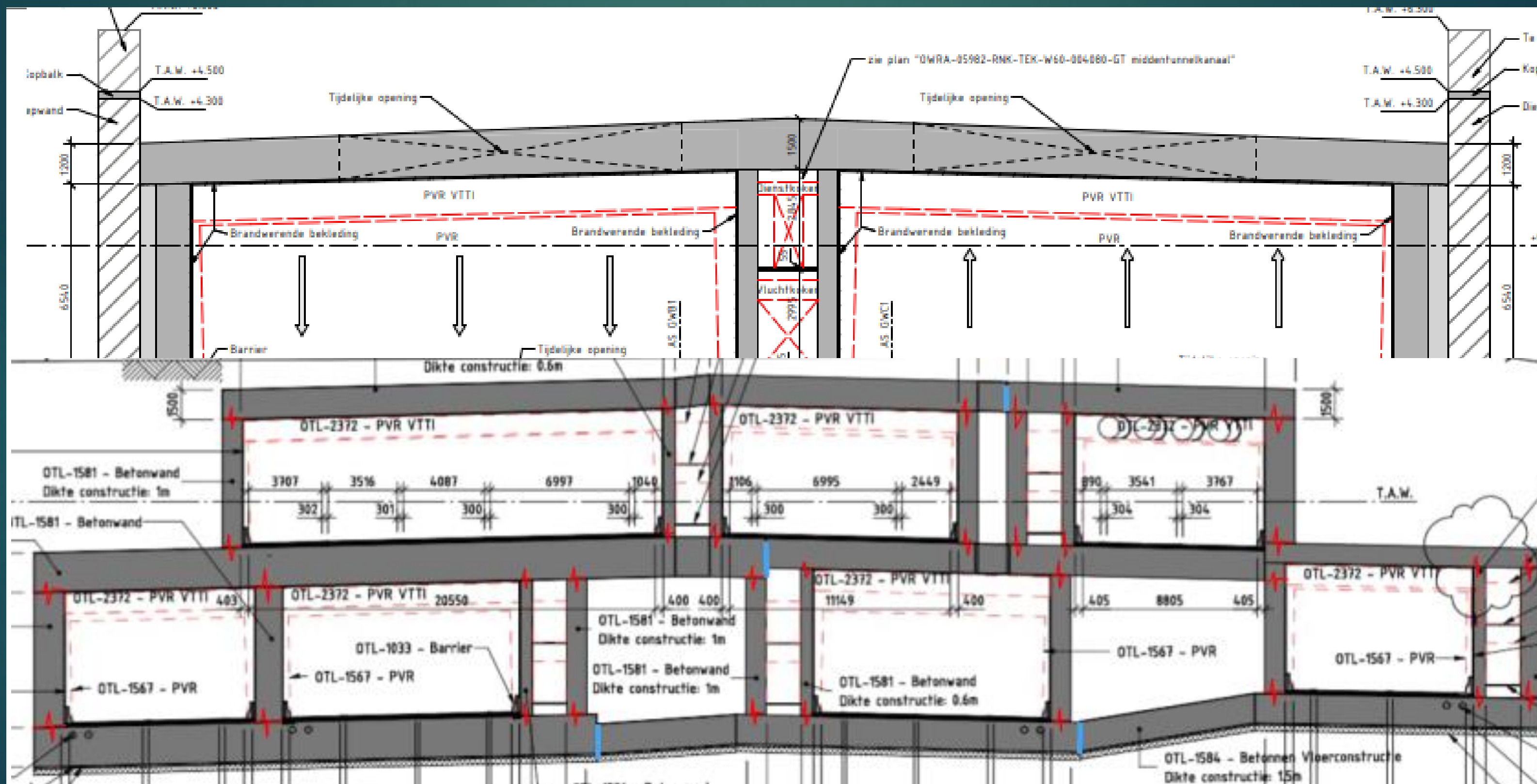
  These models can also be used for predicting real crack widths instead of just a unity check on the Ftu/crackindex.

  The effect of reinforcements can be taken into account. In that approach also hybrid, steel fibers in combination with traditional reinforcements (SFRC) can lead to less crack widths and avoidance of unnecessary use of cooling pipes. It can minimise the environmental impact in a project, which is an important factor in our point of view.
- Creep and relaxation is very important to get more realistic behaviour. Without relaxation the stresses and the crack index will be overestimated which could lead to wrong predictions and therefor modification of the design or even cooling options.

15-20 min is too short to elaborate

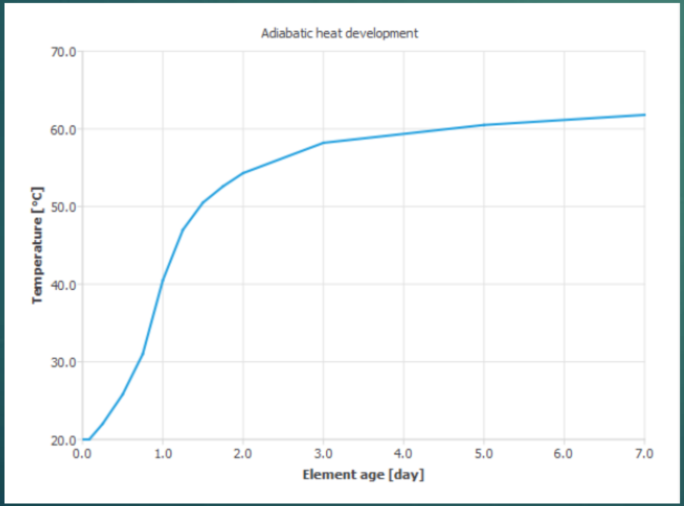
- On cooling pipes
  - Positive effects and why to omit them
- On Steel fiber addition
  - We often encounter dense reinforcement zones where concrete can hardly be poured through.
  - Nonlinear design analysis can optimise the reinforcement.
  - Steel fibers in addition can reduce the normal amount of reinforcement and also help reducing crack risks in mass concrete structures.

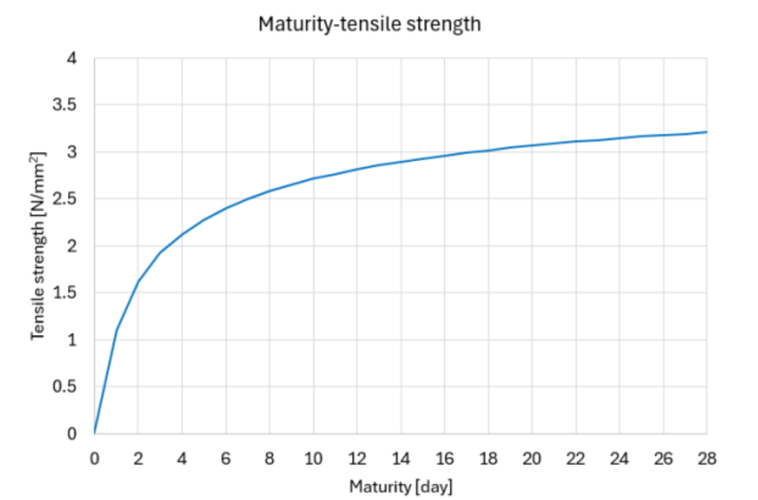
example braiding tunnel segments



Input parameters needed

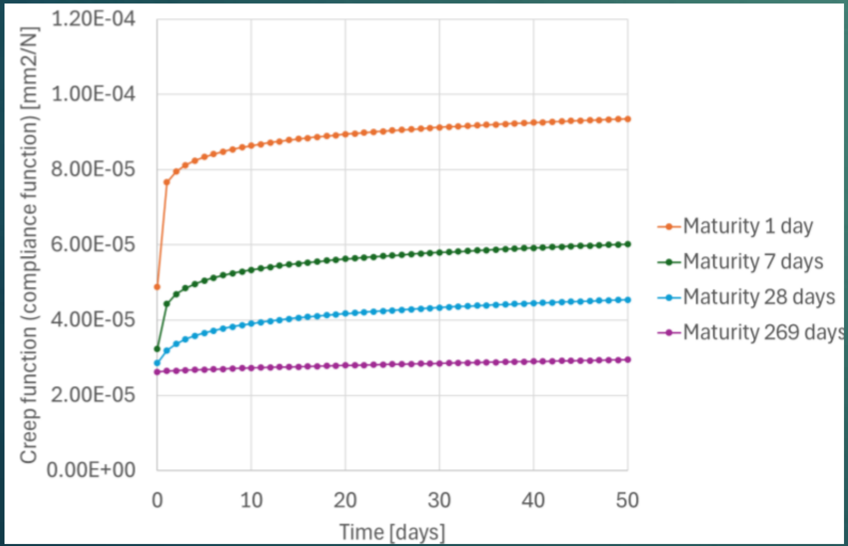
- Concrete
  - Adiabatic curve (CUR67 or NEN 12390)
  - Tensile strength as function of maturity or time
  - Creep in compression and tension (relaxation)
  - Shrinkage autogenous and drying

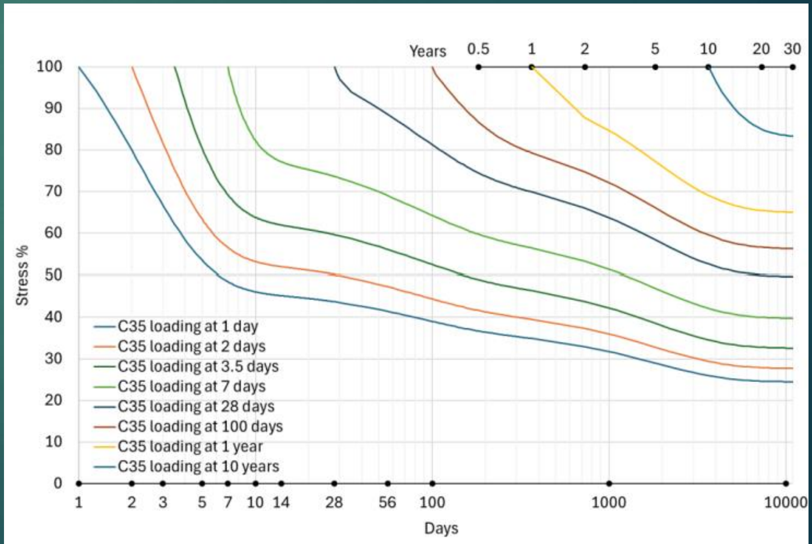




Creep and Relaxation in time

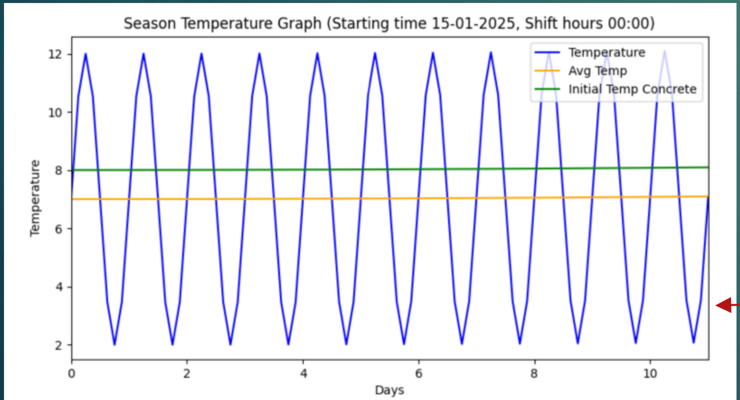
- Creep function (compliance function J) for several ages concrete
- Stress reduction (creep, relaxation) for several time of loading
- Creep and relaxation via visco elasticity model with "Kelvin chains"
- The positive early compression stress upto day 2 is reduced with 50% on day 10, but negative cooling at day 3 with 35% at day 10.



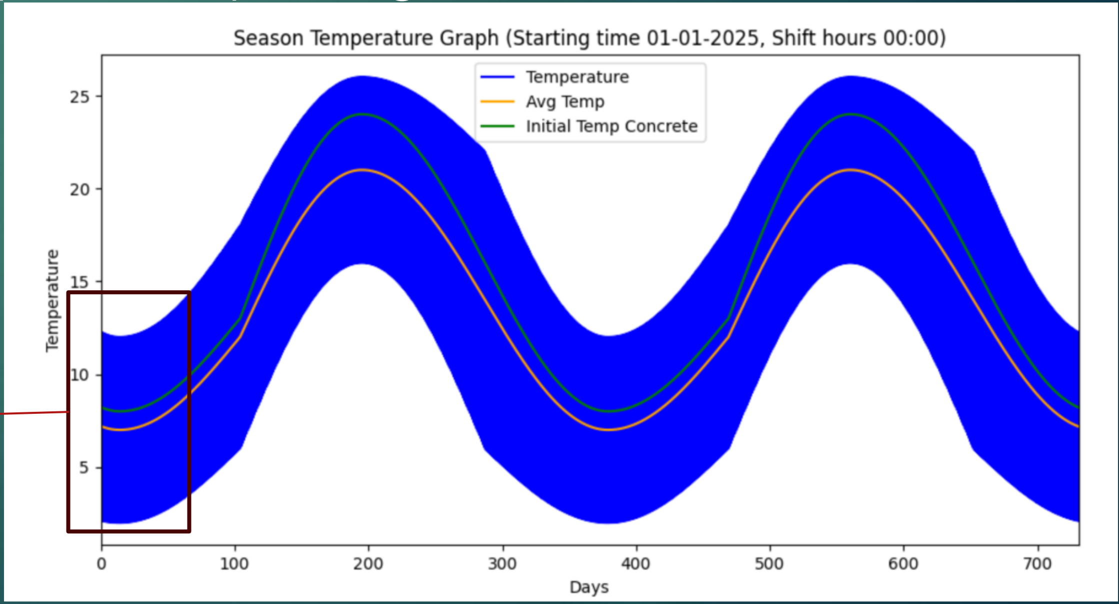


Input parameters

- Boundaries
  - Convection as function of time (remove formwork etc)
- Temperature
  - Temperature seasonally and daily change



Zoomed in: Daily temperature



Model setup

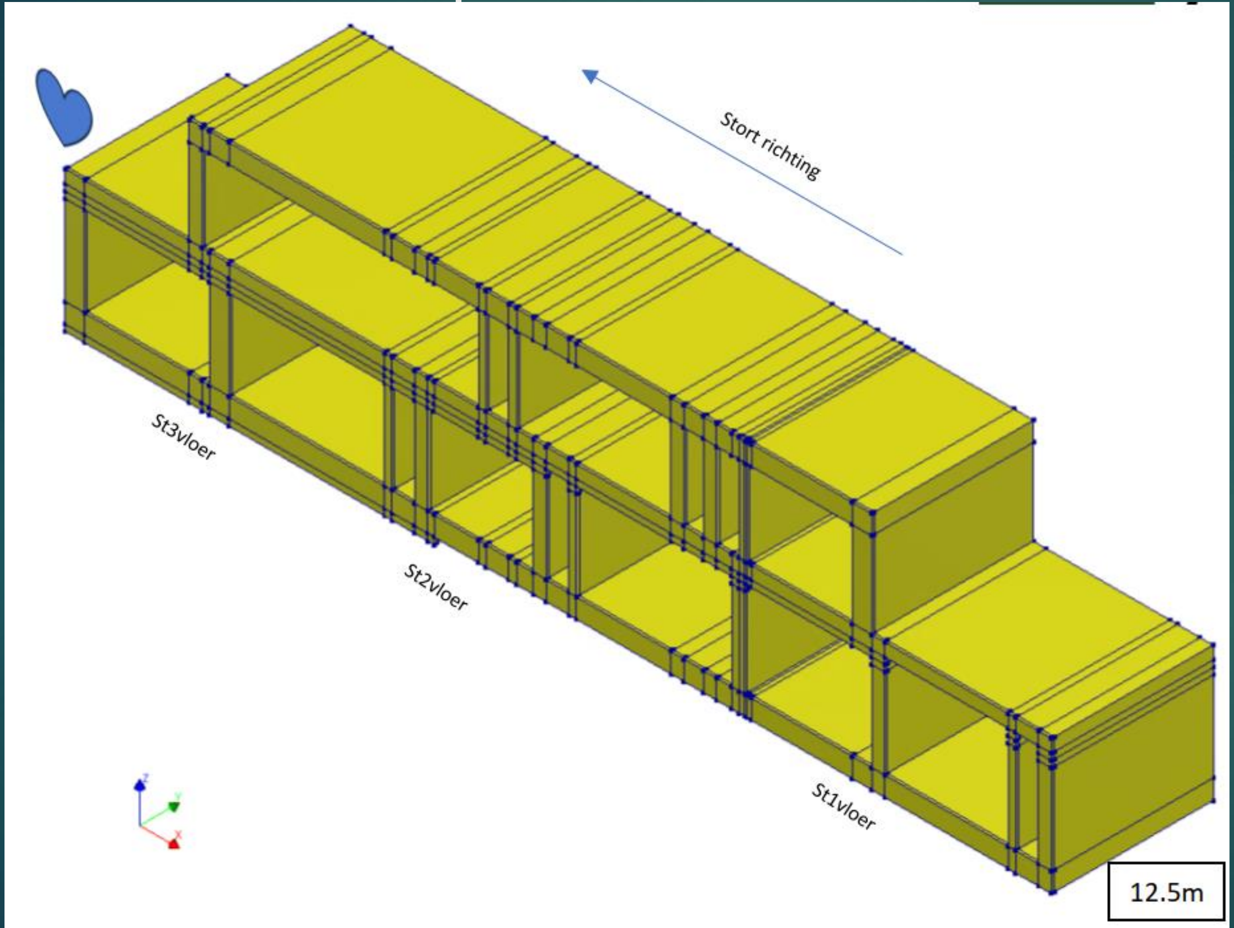
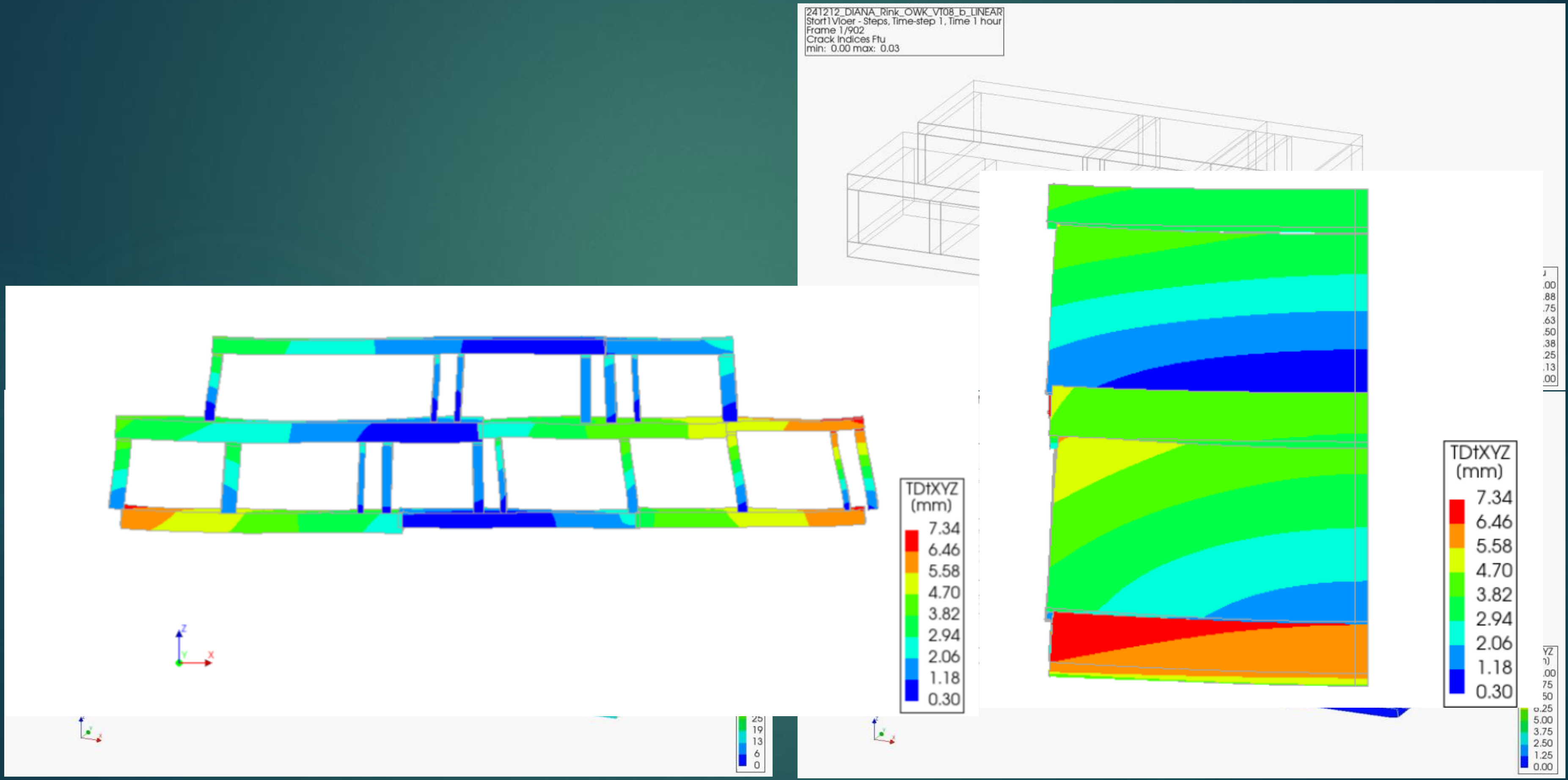


Fig. 8: 3D model doorsnede VT08, 3D view

Construction phases



How to constraint computer time ?

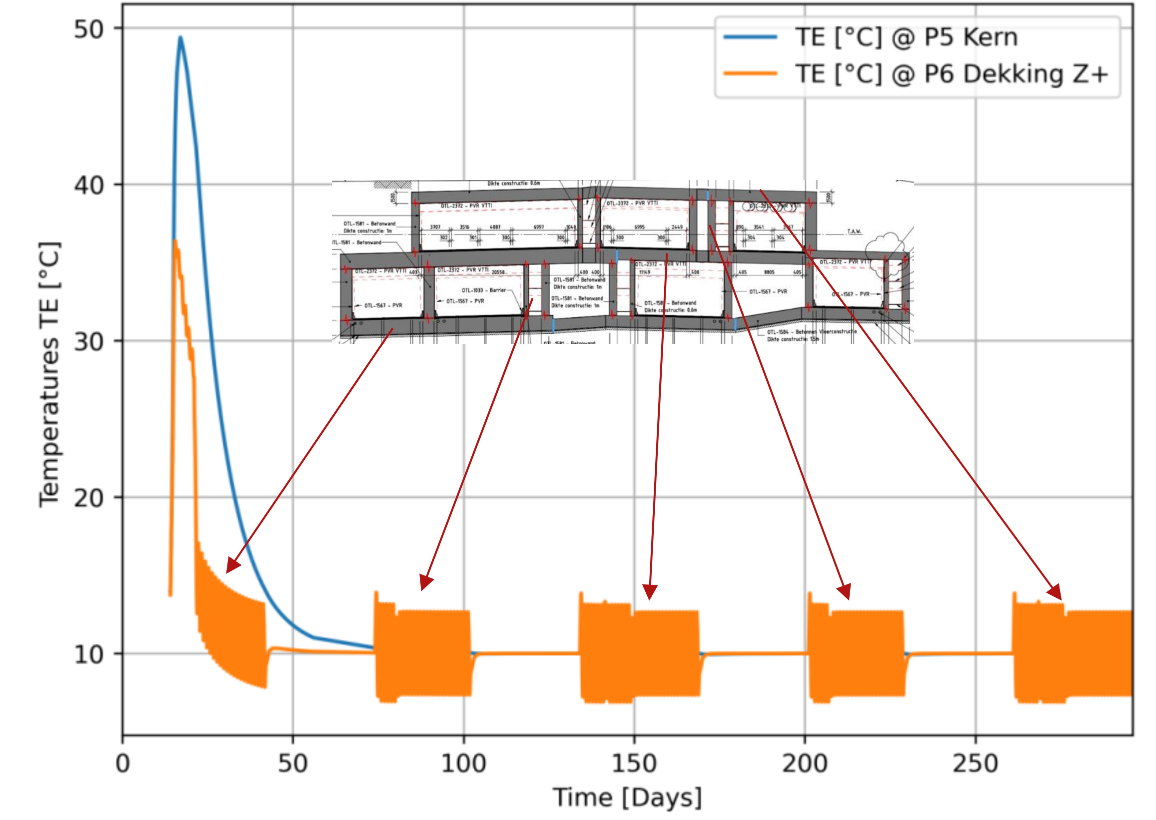
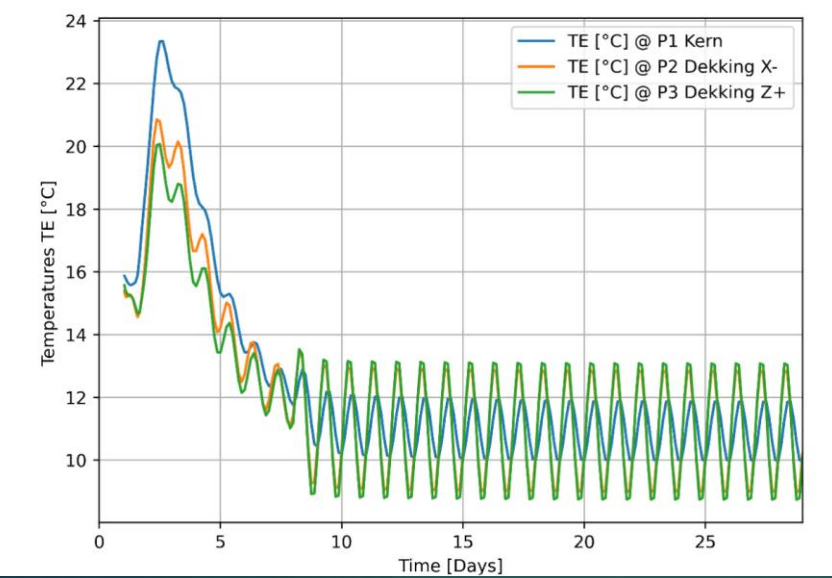
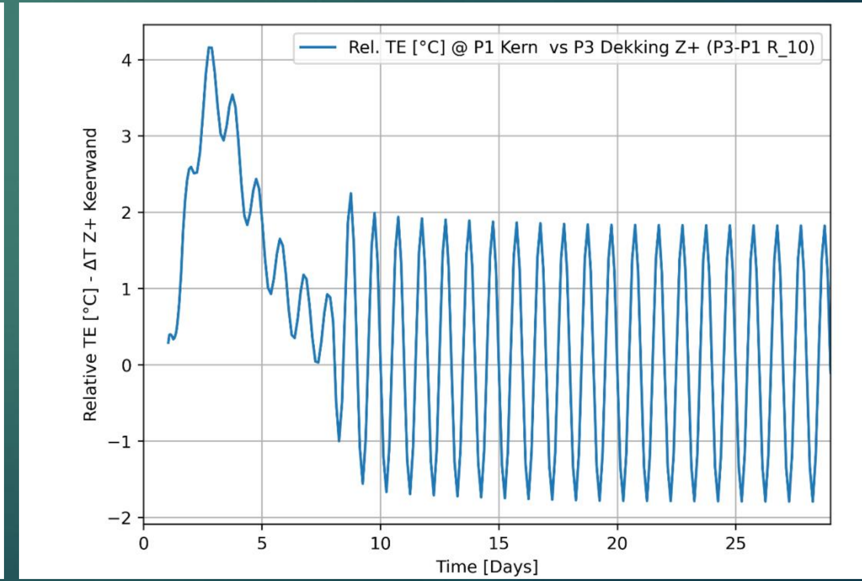


Fig. 14: Temperatuur in de constructie over de tijd st3vloer

Checking criteria Temperature

Result		Description
T1	T1 ≤ 65	Maximum core temperature
ΔT1	ΔT1 ≤ 20	Maximum temperature difference between the core and the cover
ΔT2	ΔT2 ≤ 20	Temperature difference between the core and the cover after demoulding
ΔT3	ΔT3 ≤ 20	Temperature difference between the cover and the mean environment temperature





Checking Crack index

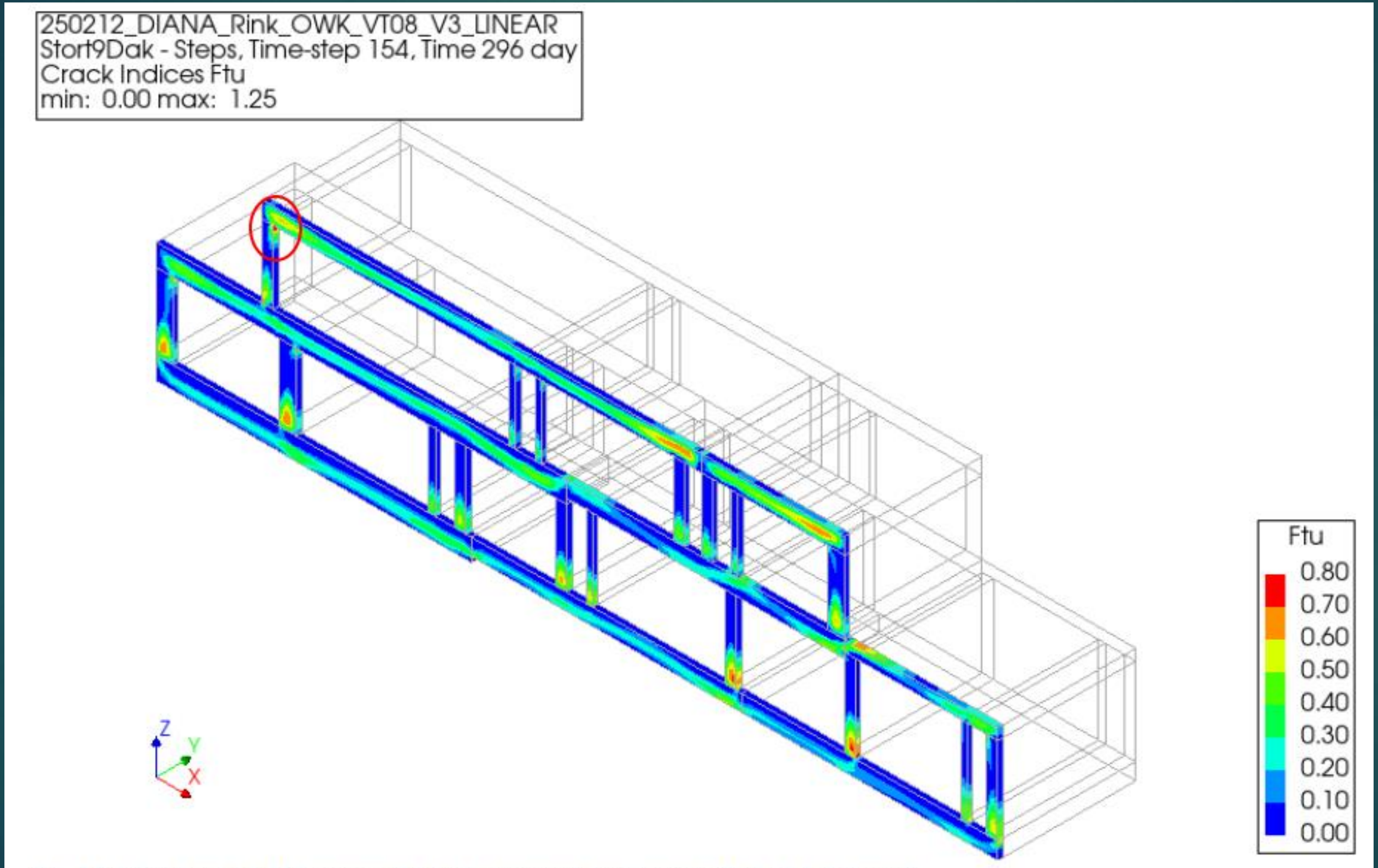


Fig. 17: UC scheur na 296 dagen, eindtijd, aangepaste legenda: Ftu > 0.7 in "rood"

Checking Stresses clarifies

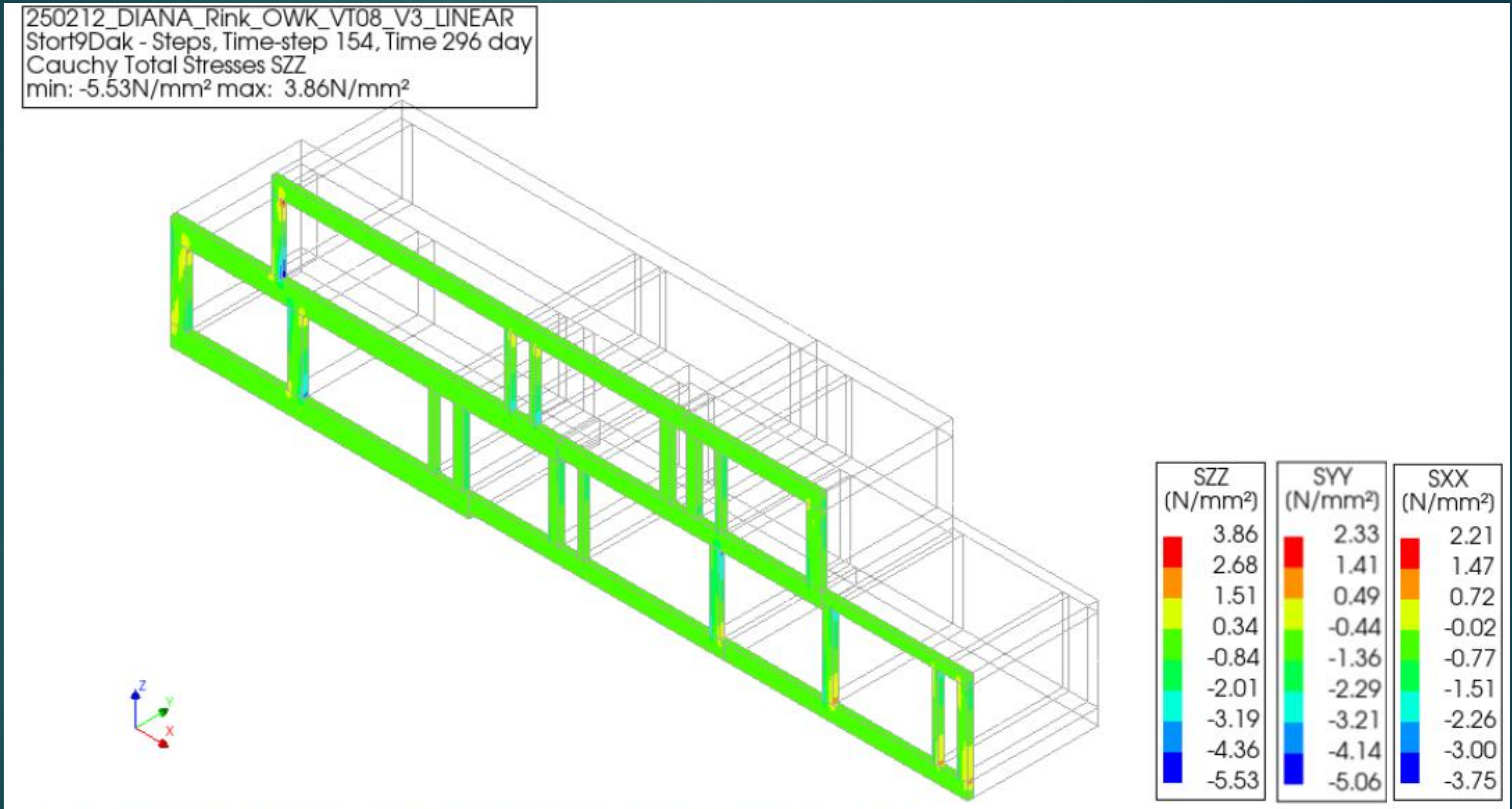


Fig. 22: Spanning in Z-richting, SZZ na 296 dagen (eind), in verticale richting > 3.21 MPa

Checking criteria crack index

- UC crack = σ_1 / f_{ctm}
  - UC crack < 1.0 (3D random variation shrinkage and correct constraints)
  - UC crack < 0.7 (simpler models 2/2.5D straight planes).
  - UC crack < 0.5 (When Cooling pipes are added)

Why is not UC crack < 1.0 used? UC crack < 0.7 conservative?

- Use fctm not the higher "splijt treksterkte"
- Use fctm is function of time (maturity) conform Eurocode or tests.

- Check in extreme fiber or at the cover or pick a point on the screen?
- Allow 10% of cross section (outer fiber/cover) temporary above UC>1.

Model setup

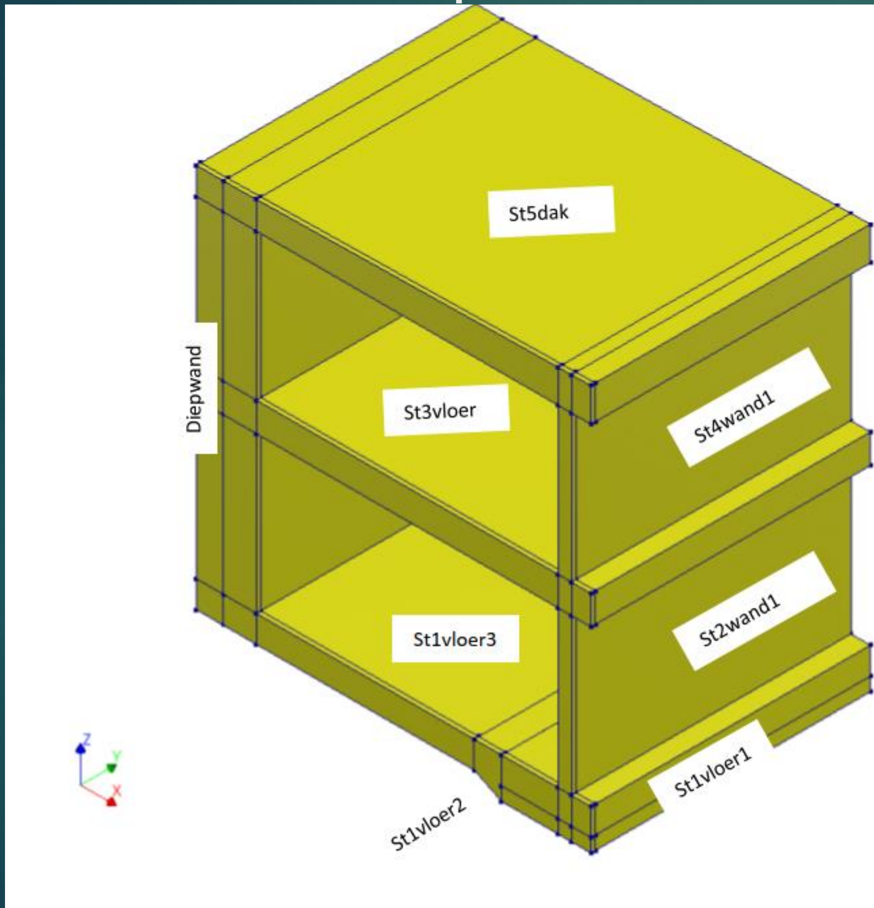
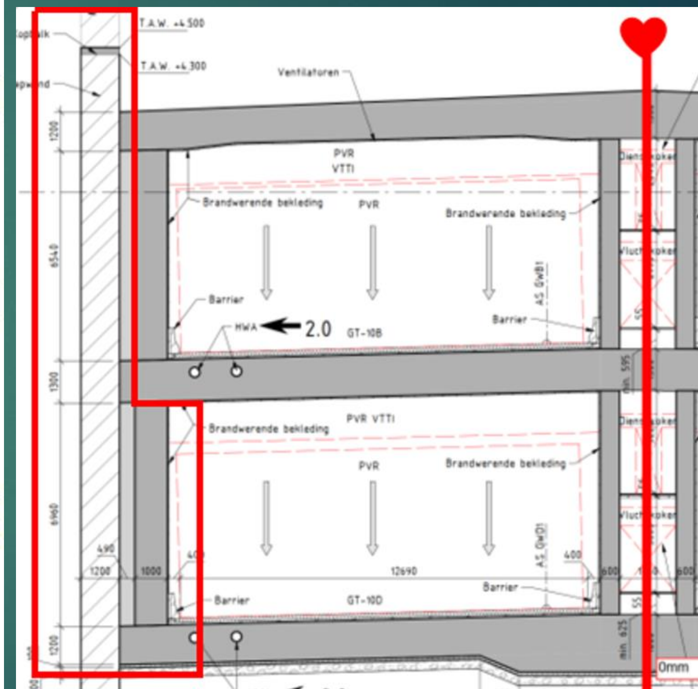


Fig. 10: 3D model GT doorsnede doorsnede 3-3



Unity Checks > 1. What next ?

- A solution when crack indices become too high.

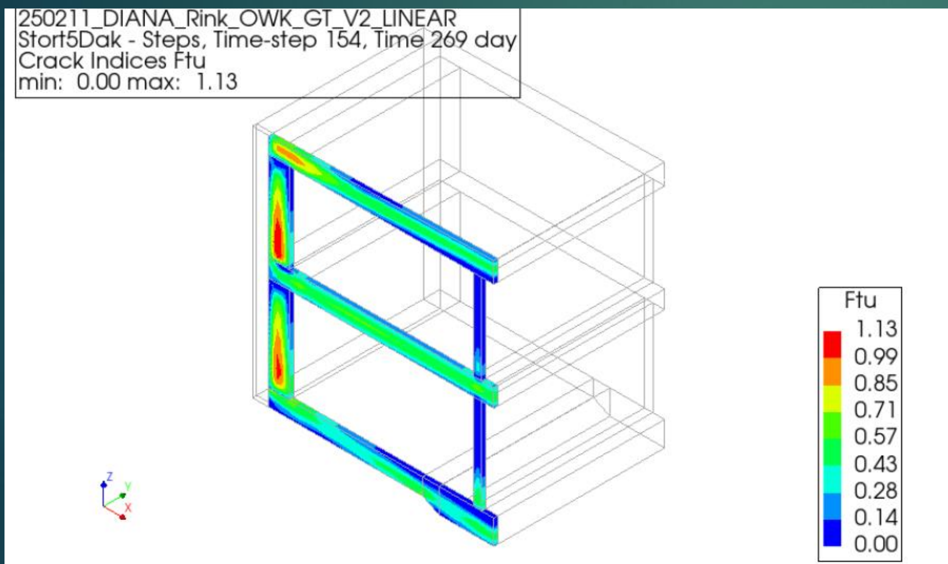
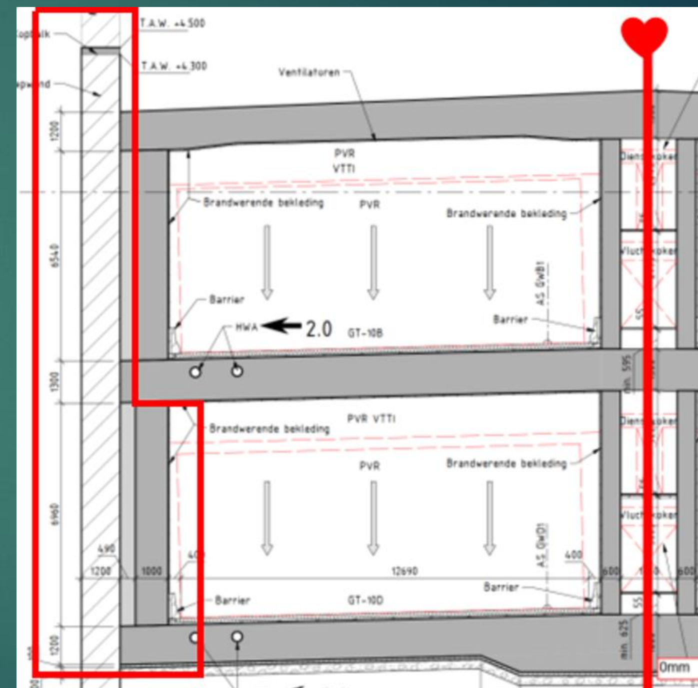
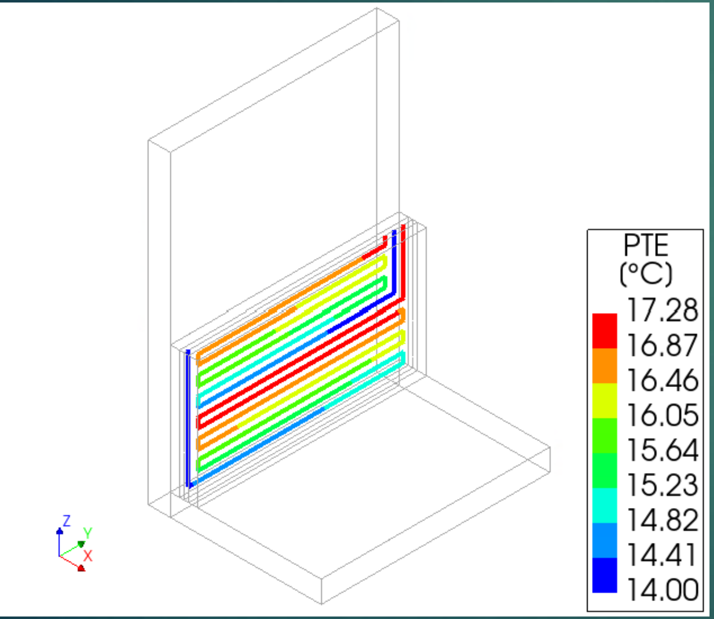


Fig. 29: UC scheur in Stort5Dak, Tijd 269 d (=Eind tijd)

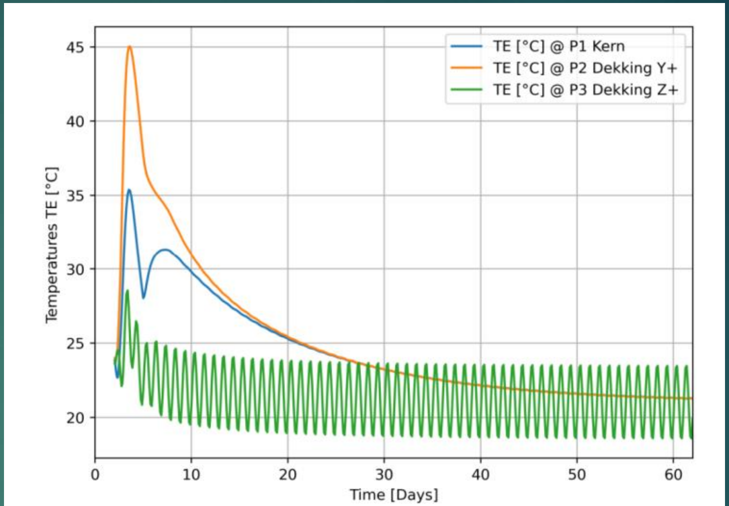


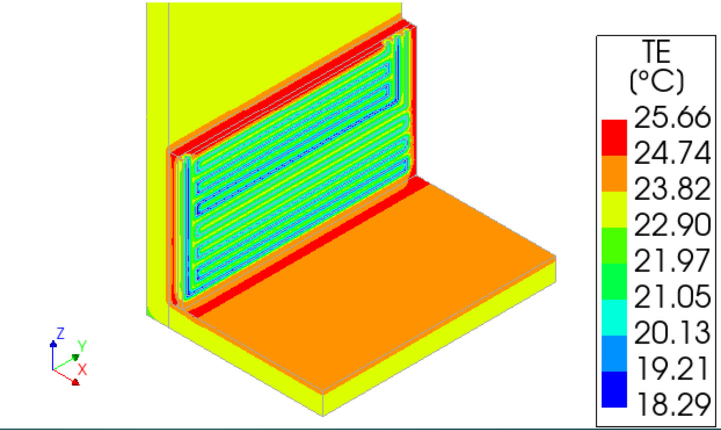
CoolingPipes

- Temperatures



Temperature water cooling Pipes

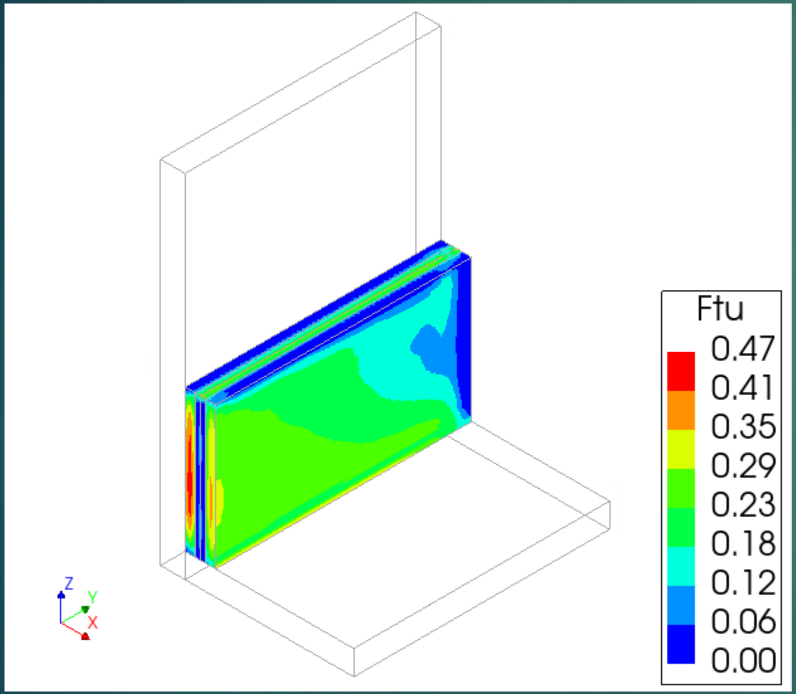


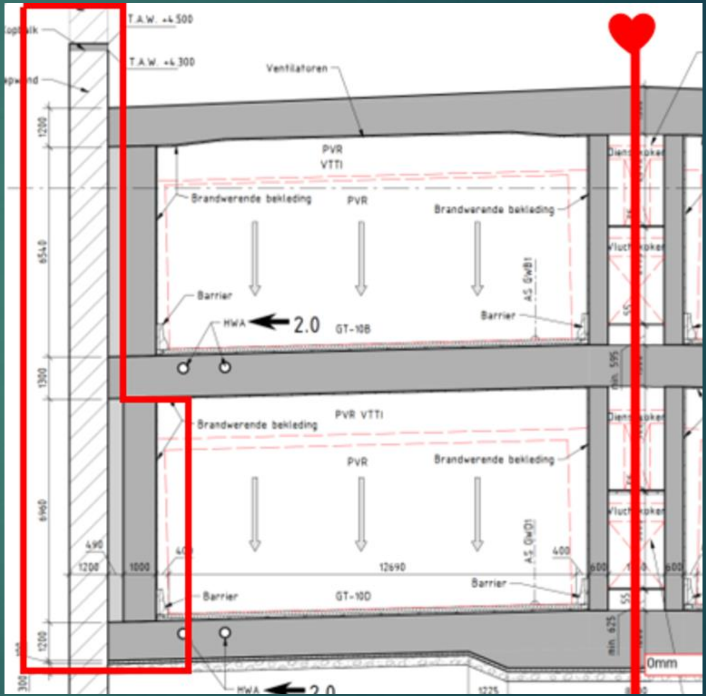


Temperature concrete

CoolingPipes

- Crack index





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