Udvikling af innovative betonelementer – Testhus på DTU

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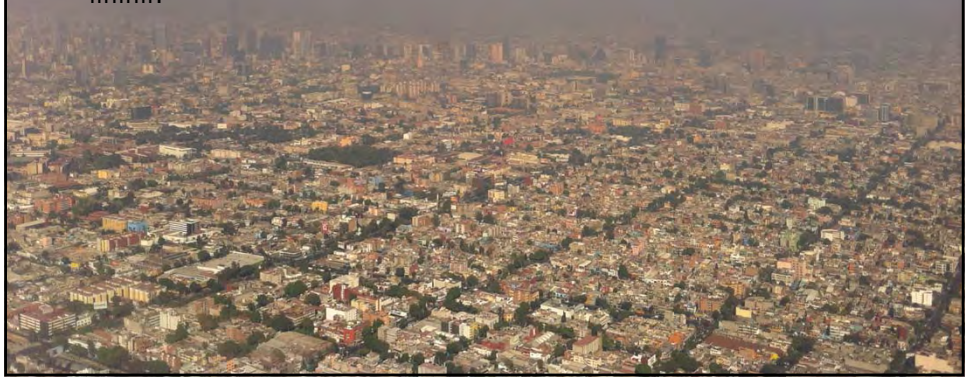
Outline

- Sandwich elements – the vision
- The Connovate project
- 4 PhD projects at DTU Structural Engineering
  - Sandwich elements under fire
  - Structural analysis and design
  - Thermal properties
- The test house at DTU
  - Sandwich panel design
  - Configuration of the test house
- Conclusions

Sandwich elements – the challenge

- Resource and energy depletion
- Environmental footprints - CO_2 emissions and more…..
- Deterioration and service life
- ……..



Sandwich elements – the vision

- Resource efficiency
- Structural and thermal efficiency
- Durability
- Constructability
- Esthetics
- ……..

Sandwich elements – the vision

- Resource efficiency
- Structural and thermal efficiency
- Durability
- Constructability
- Esthetics
- ……

Højteknologifonden

DTU

Connovate – optimized building system using High Performance Concrete

The Connovate project is a multi-disciplinary project sponsored by 'Højteknologifonden' running until end of 2013 with the aim of developing a completely new modular concrete sandwich element system based on advanced insulation materials and High Performance Concrete (HPC)

The current partners comprise:

- Arkitema, Ambercon, Connovate (*Project management, design, production, IPR*)

- DTU Management (*System configuration*)
- DTU Mechanical Engineering (*Joints and mounting technology*)
- IPU Technology Development (*Joints and mounting technology*)
- Delta (*Acoustics*)
- DBI (Fire testing and certification)
- DTU Civil Engineering (Material/structure, fire, thermal performance, multi-functional optimization, indoor climate)

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4 PhD projects at DTU Civil Engieering

Kamil Hodicky (Ph.D. Studerende)
'Structural Analysis and development of Advanced Sandwich Elements for Sustainable Buildings'
Advisor: Prof. Henrik Stang

Thomas Hulin (Ph.D. Studerende)
'Fire Analysis and Development of Advanced Sandwich Elements for Sustainable Buildings - Integrated Structural and Materials Modelling'
Advisor: Prof. Henrik Stang

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4 PhD projects at DTU Civil Engineering

Sanne Hansen (Ph.D. Studerende)
'Optimization of thermal performance of sandwich panel of high performance concrete'
Advisor: Prof. Svend Svendsen

Tomas Mikeska(Ph.D. Studerende)
'Energy performance of ventilation, heating and cooling systems integrated in sandwich panel of high performance concrete'
Advisor: Prof. Svend Svendsen

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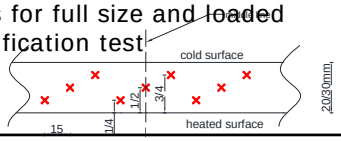
Fire analysis and testing

Scope of the research
- o Understand the role of the individual components on material and element level
- o Give development directions for a fire-resistant panel

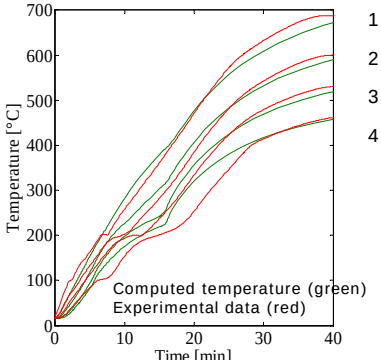
Research methods
- o Furnace tests (ISO834) (DBI)
- o Modelling

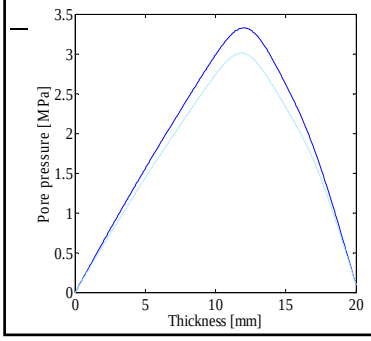
Research strategy
- o Small scale elements to study the material behaviour
- o Medium scale elements displaying the various stages of the sandwich construction (structural ribs, insulation layers, shear connectors, front plate)
- o Large scale elements for full size and loaded situation for the certification test

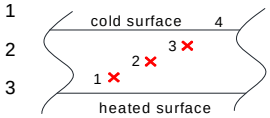
Above: elements on test furnace.

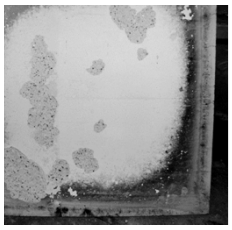


Left: disposition of the thermocouples through the specimens thickness









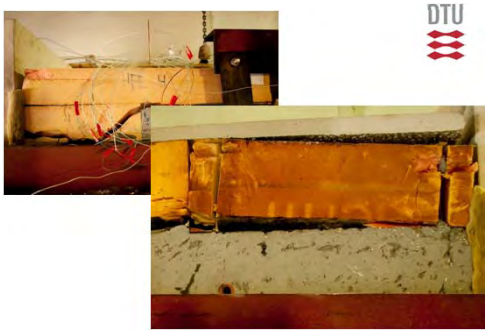
HPC presenting surface dammage

HPC with FRP mesh presenting spalling

Results
- o No major influence of the thickness on spalling
- o Strong influence of moisture content
- o FRP mesh helps reducing spalling probability
- o Coupled temperature-pressure model predicts temperature close to experimental values and pressure in accordance with literature
- o Spalling is a product of combined (internal) pore pressure and (external) restraint from temperature gradients

Medium scale

Specimens to be tested
Left: insulation and structural rib
Right: insulation, structural rib and front plate



Concrete/insulation interaction showing severe debonding

Results

- No spalling observed
- Importance of rib reinforcement due to temperature rise to sustain bending
- Efficiency of FRP mesh for pressure release
- High insulation debonding (action of pressure and temperature through thermal bending)
- Critical role played by good concrete formulation

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Large scale

Loaded plate showing cracking at ribs and load/temperature induced curvature on the edges

Full scale sandwcih panel loaded to 50t throughout the test

Scope

- Behaviour of the full construction at full scale under a 90min exposure
- Loaded as for an office building

Test specimens

- Sandwiches 3000x3000mm
- Variations on structural rib placement

Results

- No Spalling observed
- Cracking at rib/plate link
- High bending at edges
- No failure
- Modelling shows very high stresses indicating total failure
- Hypotheses: first cracks relax thermal stresses which redistribute in the panel so that it survives. Need to combine with a damage model (ongoing)

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Structural analysis and development

Scope of the research

- Understand structural performance and support design
- Understand risk of cracking
- Provide background for fire analysis
- Perform structural and multi-objective optimization

Research methods

- Material characterization
- Structural testing
- FEM Modelling

Research strategy

- Testing at material scale: effective shrinkage, strength, stiffness and strength
- Medium scale elements displaying the various details of the sandwich construction (structural ribs, insulation layers, shear connectors, front plate)
- Large scale elements for full size and loaded situation for the certification test

Air-pillow test setup for structural in-pane stiffness testing and front plate cracking

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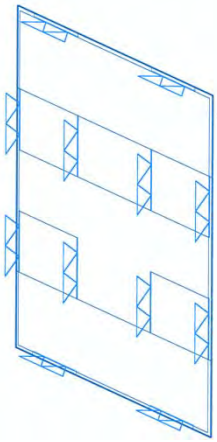
Assessing the risk of (early age) cracking (I)



Welded wire truss shear connector system and front plate

Macro cracking observed after 3-6 months

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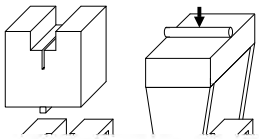
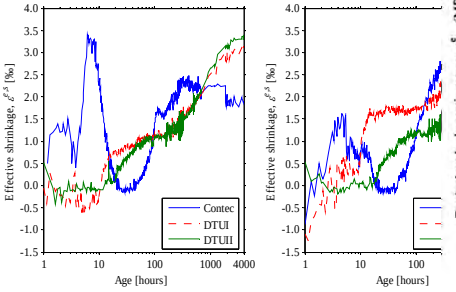
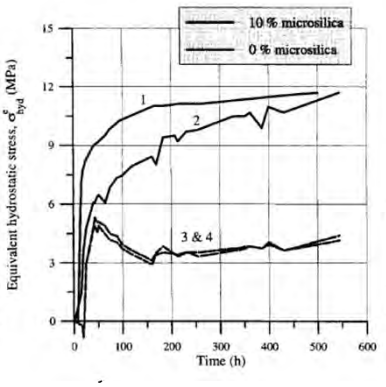
Assessing the risk of (early age) cracking (II)

- Wedge splitting test at 1,3,7,14 and 28days
- Inverse analysis
  - Splitting tensile strength
  - E-modulus
  - Fracture energy
  - Characteristic length







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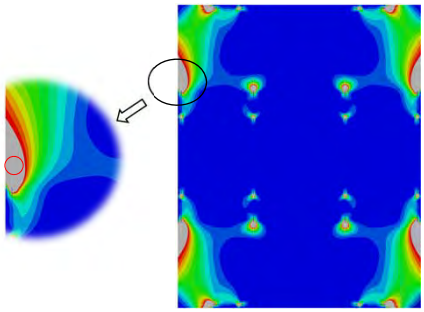
Assessing the risk of (early age) cracking (III)

Stress concentrations
at shear connectors



Analysis:
- LEFM
- Loading consisting of autogenous (effective) shrinkage, differential drying shrinkage, temperature difference front and back plate

Results:
- Predictions of risk of cracking
- Predictions of stable/unstable crack growth

Conclusions:
- Analysis predicts cracking according to observations
- Design of shear connectors for thin-walled HPC sandwich panels is a non-trivial issue - tools have been provided to assist this design

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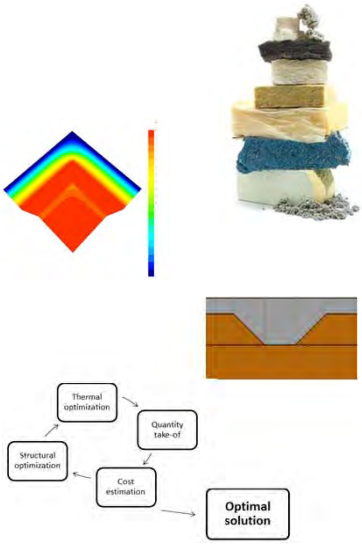
Thermal properties

- Investigation of different insulation types for thermal conductivity, stress/strength, moisture, fire category, lifetime, price etc.
- Simulations of 3D heat transfer for different solutions to evaluate where the critical points are and if they can be improved.
- What shape of ribs will allow you to have the smallest insulation thickness?
- Structural and thermal optimization process for thin-walled High Performance Concrete sandwich panels.



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The test house at DTU

- 2 storeys, 8x4 m
- NW, SW and SE façades are sandwich elements
- NE façade are renovation panels
- Built April 2013
- Reception next Friday, September 27th

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The test house at DTU

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Sandwichelement specification

U-værdi : 36cm (1-2 etager) 0,08 W/m2K
U-værdi : 40cm (1-4 etager) 0,07 W/m2K
Brandmodstandsevne : R60
Trykstyrke : + 100 Mpa
Bøjetrækstyrke : +10MPa
Tæthed : ikke målbar damppermabilitet
For- og bagpladetykkelse 30 mm

1/2 tykkelse ift. normale sandwichelementer
1/3 betonforbrug ift. normale sandwichelementer
1/3 vægt ift. normale sandwichelementer
40% cementforbrug ift. normale sandwichelementer

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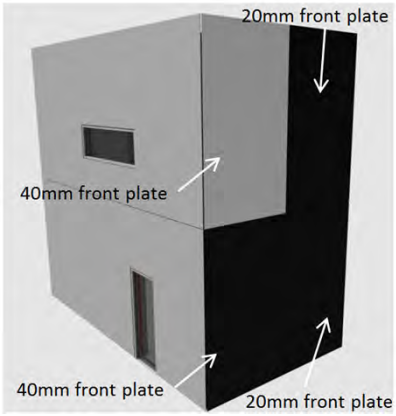
The test house at DTU

- Thin-walled sandwich elements are prone to structural cracking due to combined effect of high temperature loading and autogeneous shrinkage.
- BEFORE: Temperature load used for structural FE-model was applied based on a study of different thicknesses and colours of the HPC plate with applied estimated solar radiation.
- NOW: Thermocouples measurement in four elements oriented south-west have made it possible to monitor real temperature profiles.



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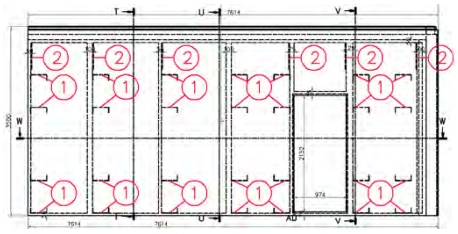
The test house at DTU

- Two types of shear connectors are studied in two elements in the ground level.
- The purpose of this investigation is to monitor structural behaviour of these connectors over their life time and to study strains and associated stresses in these connectors.



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The test house at DTU

- The behavior over time between the concrete and the Purenit around the window reveal will be analyzed.
- Relative humidity and temperature are measured in different joint solutions: Heel/toe solutions, traditional elastic joints and steel joints.
- Heat flow through the corners and selected surfaces will be measured with the use of a guarded hot box and compared to simulated results.

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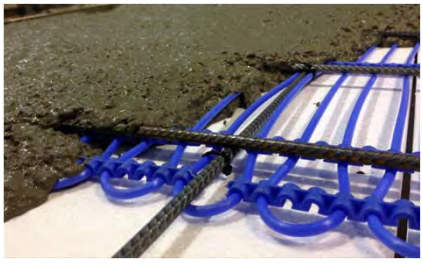
The test house at DTU

- Is it possible to dry out moisture from the roof construction, which may occur during the building process or caused by future leakage?
- Is it possible to integrate radiant heating and cooling systems into the sandwich elements of High Performance Concrete?



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Conclusions

- A multi-disciplinary project has been set-up to support the development of environmentally friendly, cost effective, innovative building system applying advanced materials
- In the project fundamental research projects have successfully been aligned with commercial development work providing support for this while at the same time conducting fundamental research and uncovering new knowledge
- New knowledge has been produced concerning the use of HPC – in particular in connection with thin-walled structures and critical issues have been and are being resolved with respect to
  - Fire
  - Risk of cracking
  - Structural, multi-objective optimization
- A experimental base for future investigations has been established in the form of a test house – including studies of structural behavior, thermal efficiency, indoor climate and climate control

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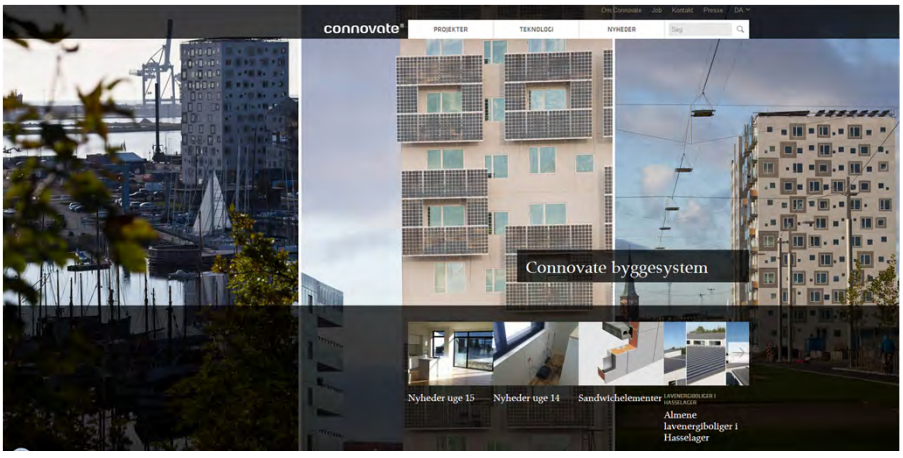
Læs mere på

www.connovate.com



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