INTERNATIONAL PRESTRESSED HOLLOWCORE ASSOCIATION

HOLCOFIRE

Behaviour of prestressed hollowcore floors exposed to fire

Spalling and horizontal cracking

Ronald Klein-Holte

Introduction

Spalling and horizontal cracking

?

hollow core phenomena
or
concrete phenomena

Introduction

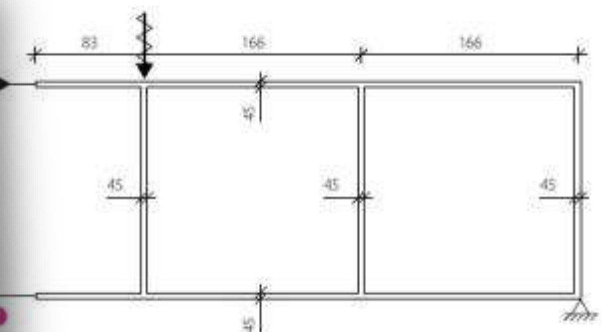
Contents:

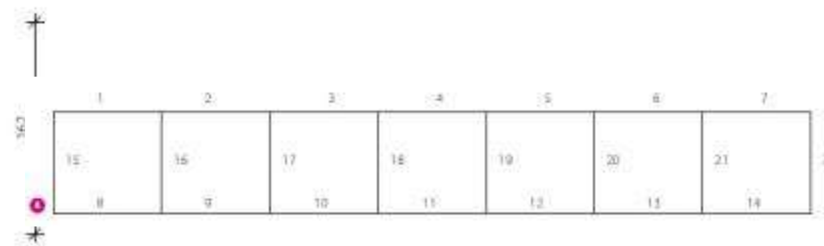
- Exploratory research in The Netherlands
- Towards a simple frame model
- Towards floor field interaction
- Tests (R-series)
- Conclusions

Exploratory research

Research done in The Netherlands

Shear test on webs and simple frame calculations by prof. ir. Cees Kleinman (TU Eindhoven)



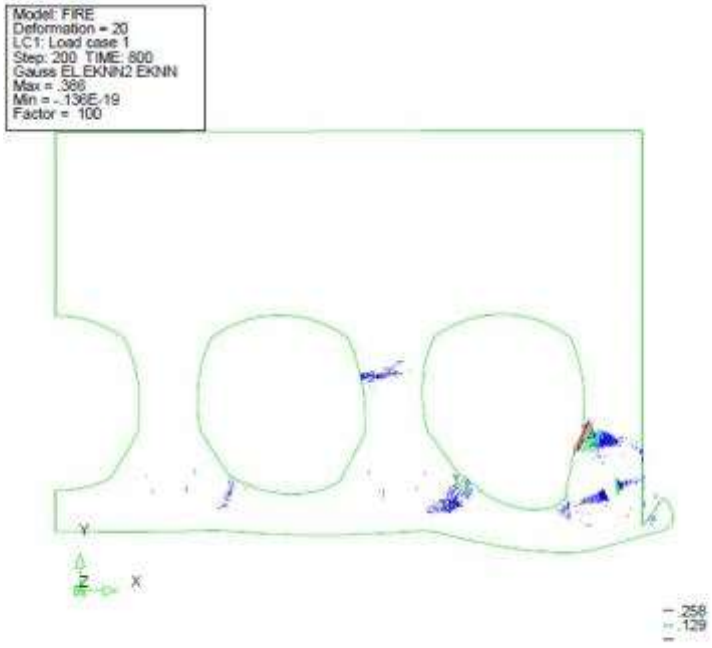


Conclusion: preventing the deformation of the upper flange, due to expansion of the bottom flange, is a very negative effect.

Exploratory research

Research done in The Netherlands

DIANA analysis of behaviour “around the joint”:
TNO commissioned by Veiligheidsregio Rijnmond



Exploratory research

Research done in The Netherlands

Fire tests on small samples of hollow core slabs

By prof. ir. D. Hordijk (in cooperation with BFBN)

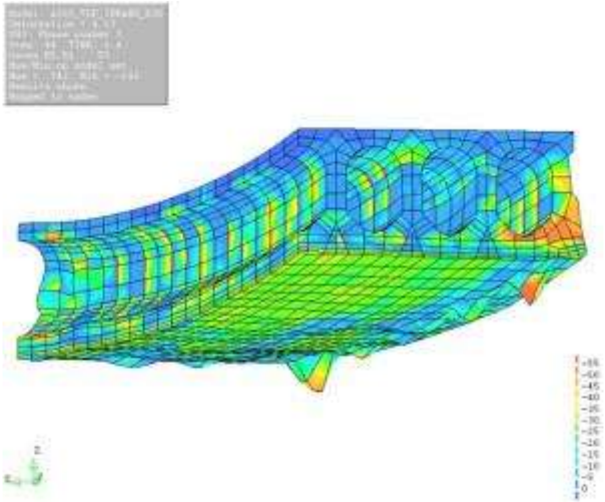
Published in Dutch magazine for structural engineers
CEMENT 2011 nr. 5

Exploratory research

Research done in The Netherlands

FEM analysis DIANA 3D

By ABT consultants in cooperation with BFBN



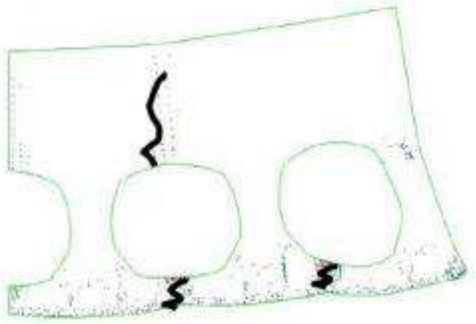


Figure 10: cross section without constraint in cross direction

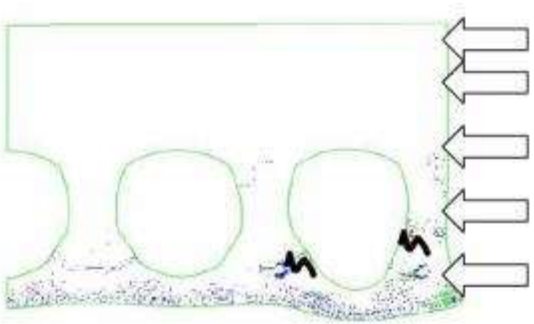


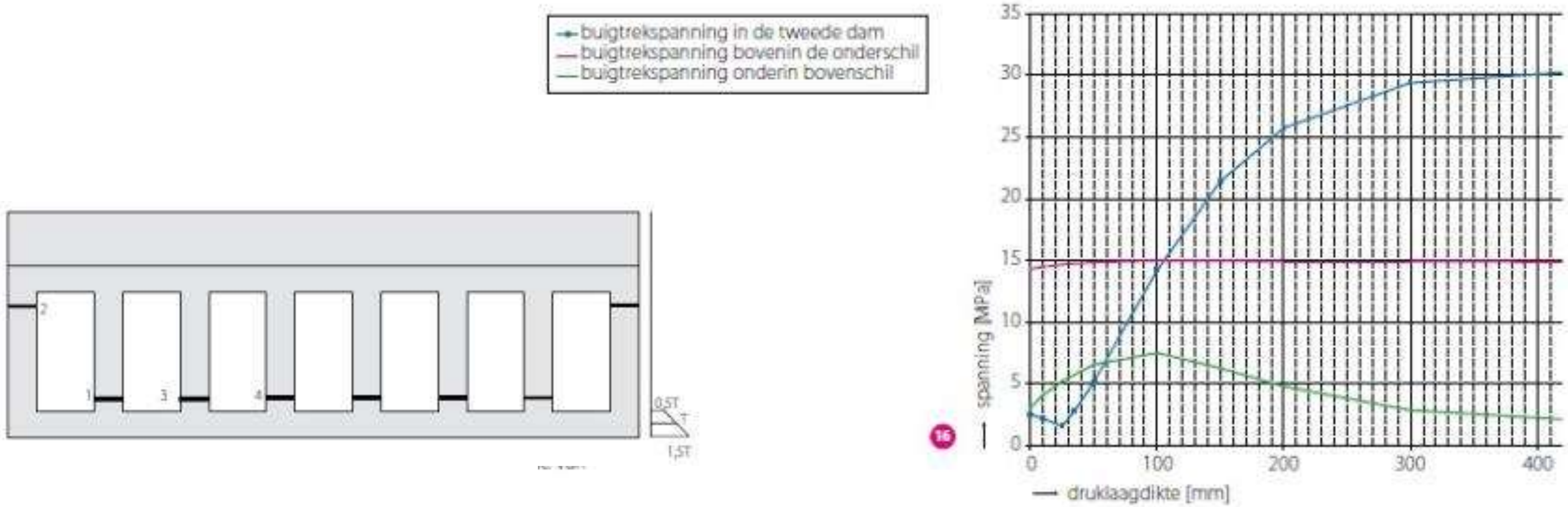
Figure 11: cross section with constraint in cross direction

Exploratory research

Research done in The Netherlands

Frame model in DIANA 2D

By A. Breunese (Efectis The Netherlands) in cooperation with BFBN



Exploratory research

Research done in The Netherlands

- Study only on single slabs; no floorfield interaction.
- FEM 3D models are time consuming and definition of material properties and boundary conditions are not clear. The results are not always easy to understand.
- Fire load in frame models were very simplified. So only principle behaviour is shown.

Holcofire frame model

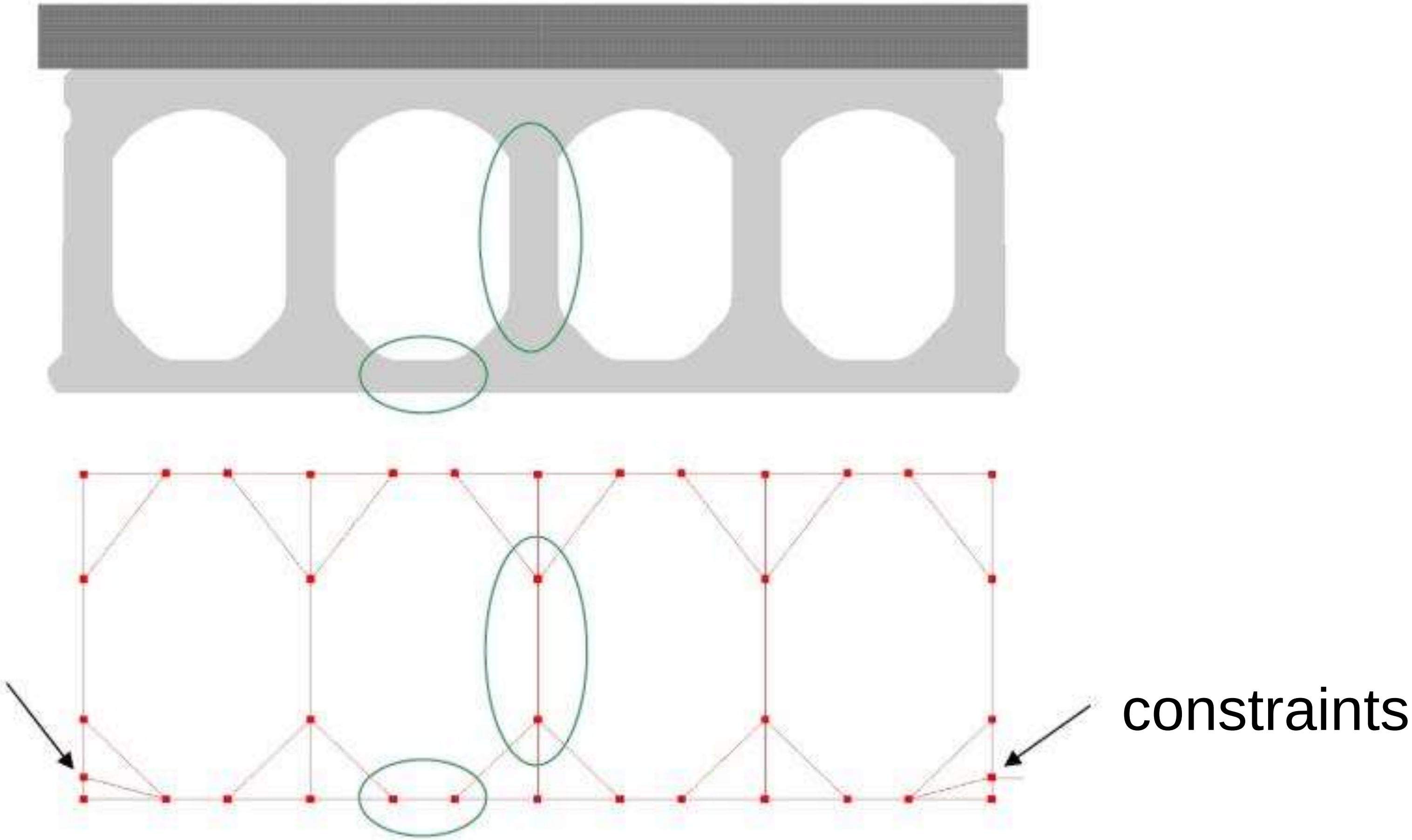
Towards a simple 2D frame model

- Extend/verify existing models/results with more realistic fire load
  .
- Results must remain on level “easy to understand.”

- Expand model with influence of a floorfield (blocking effects).

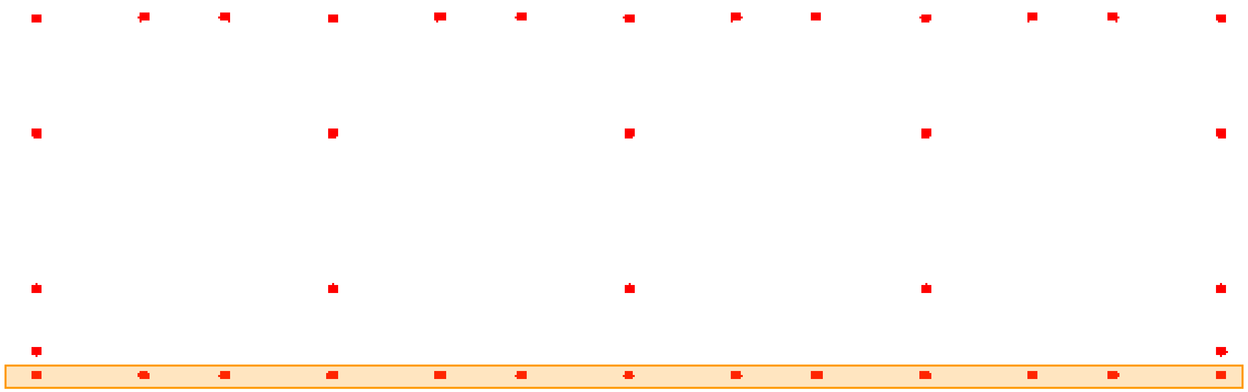
Holcofire frame model

Node and rod model of hollow core cross-section

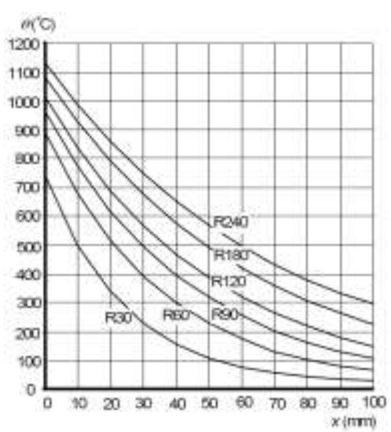


Holcofire frame model

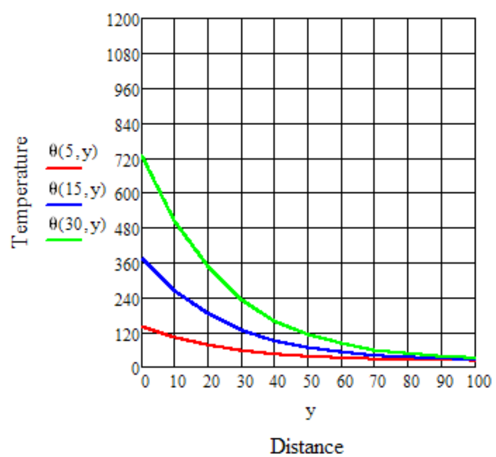
Temperature load under flange



Only the under flange is assumed as influenced by fire!



Temperature at distance y from the soffit on time t:



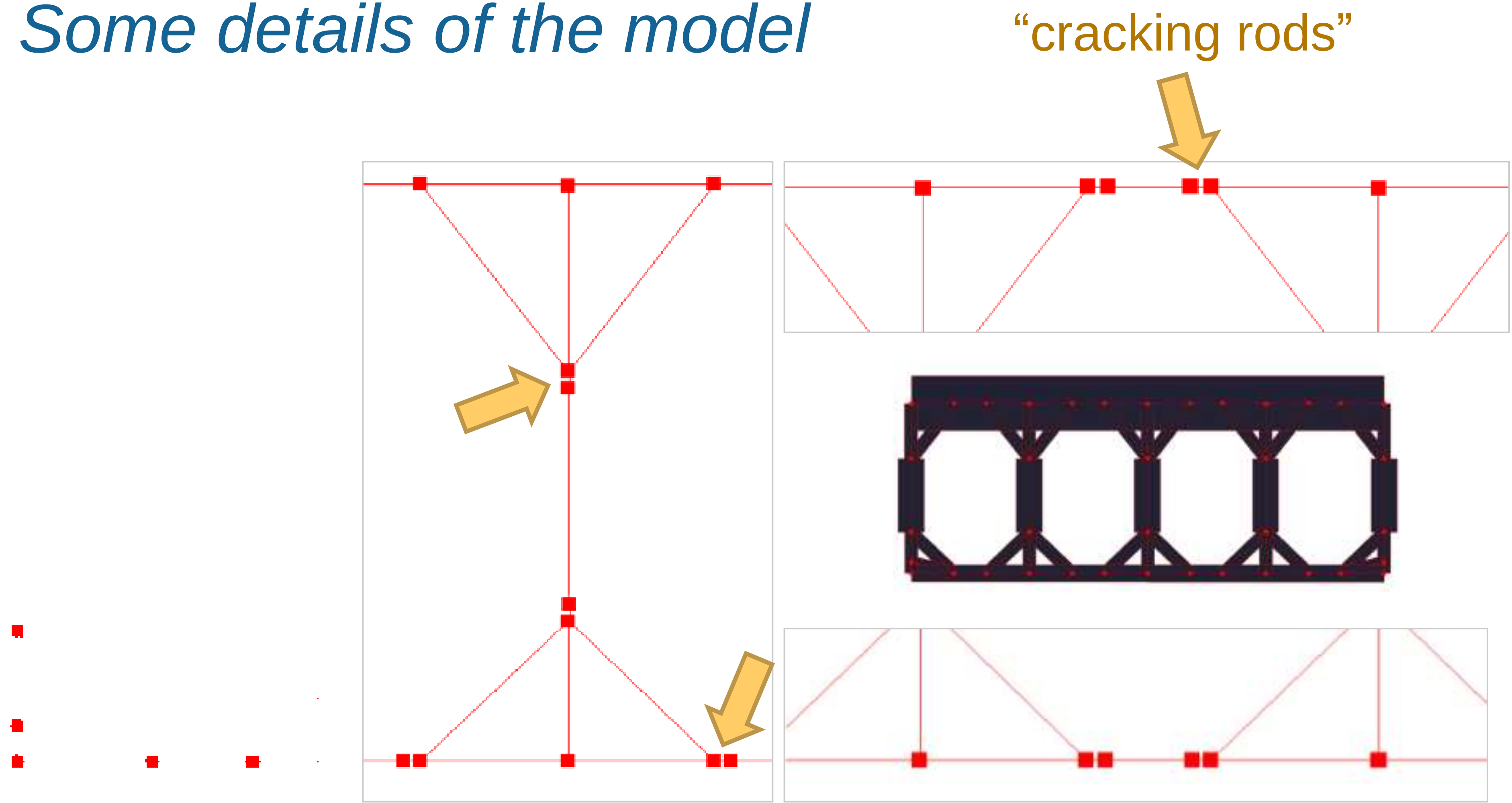
Fire exposure: $FE = 10$ minutes

Average Temperature in Bottomflange: $ATB := \dfrac{\int_0^{UF} \theta(FE,y)\,dy}{UF} - 20 = 111$

Temperaturegradient in Bottom Flange: $TBF := \dfrac{\theta(FE,UF) - \theta(FE,0)}{UF} = -4.4$

Holcofire frame model

Some details of the model



Holcofire frame model

Some details of the model

- Semi-non-elastic behaviour through predefined cracked rod positions, When a rod cracks:
  - Under compression: introduce a hinge
  - Under tension: no connection (nodes can move; crack can open)

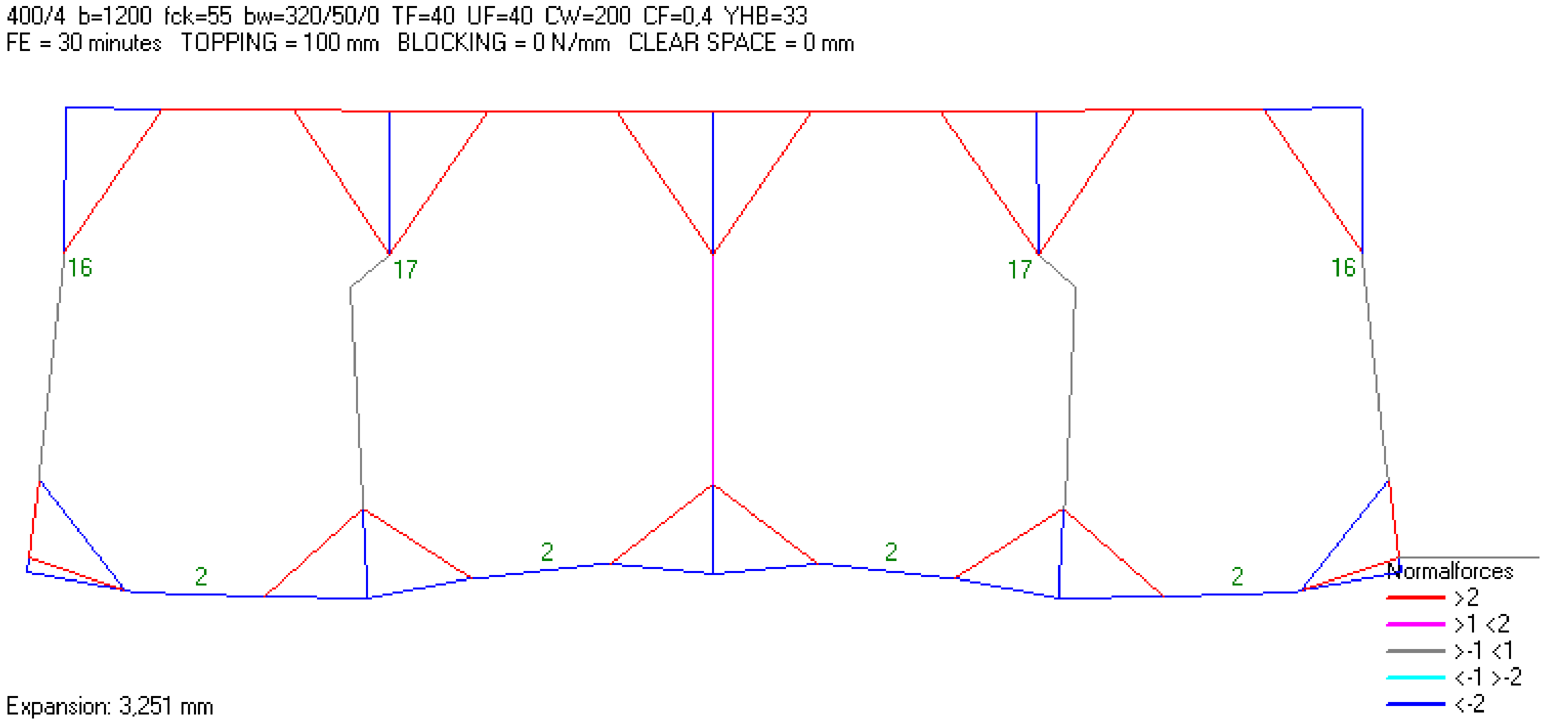
- The stifness of the under flange is temperature/time dependent

- Modelling of floorfield action through:
  Blocking spring and optional free space (joint or shrinkage cracks)

- Compression failure of under flange is checked. (spalling)

Holcofire frame model

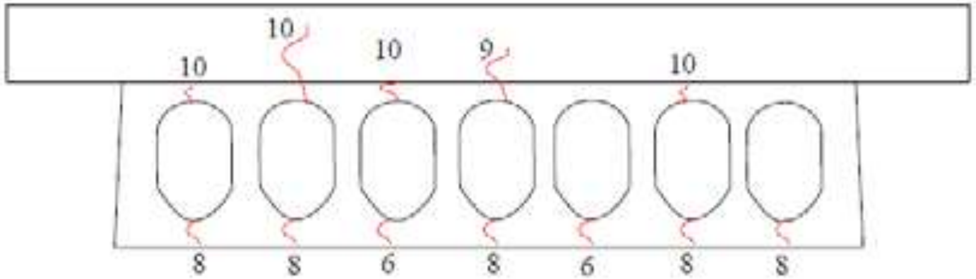
Output

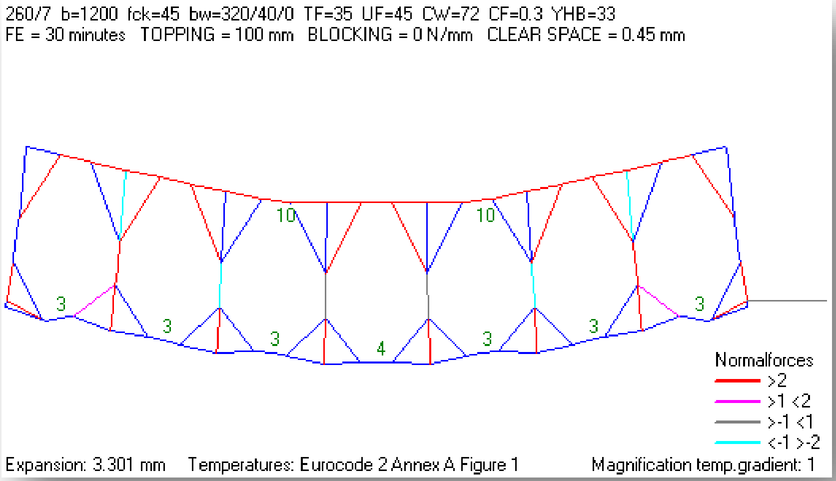


Holcofire frame model

Comparison with test result

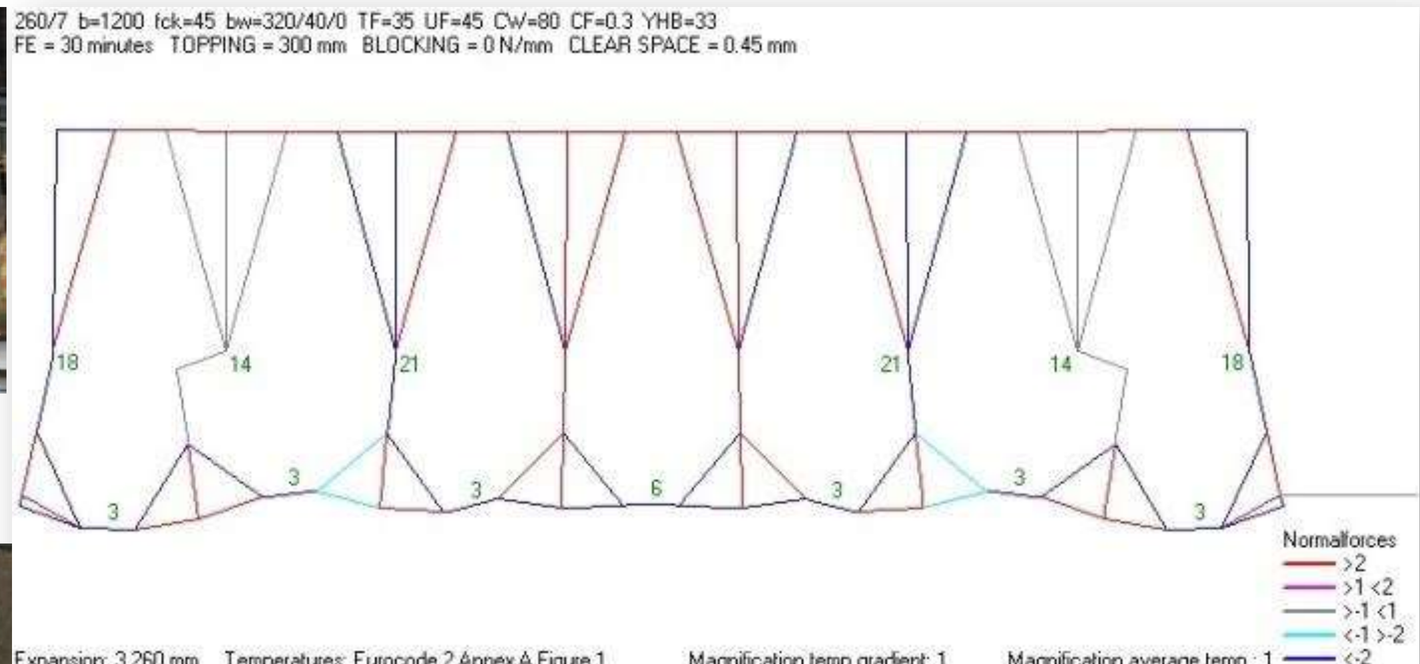
HC260 + 100 mm topping

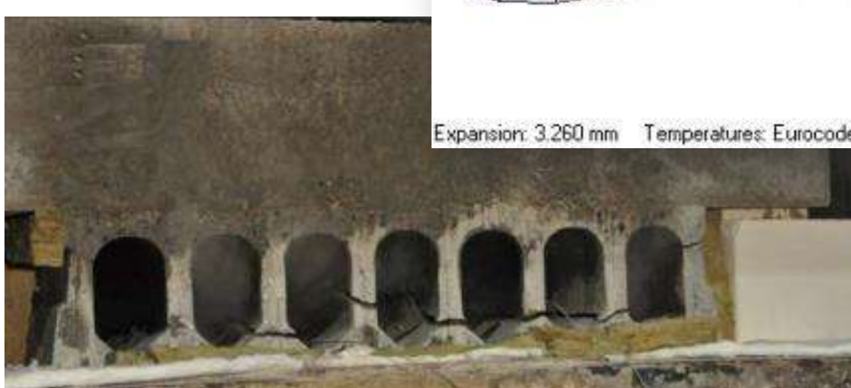




Holcofire frame model

Comparison with test result

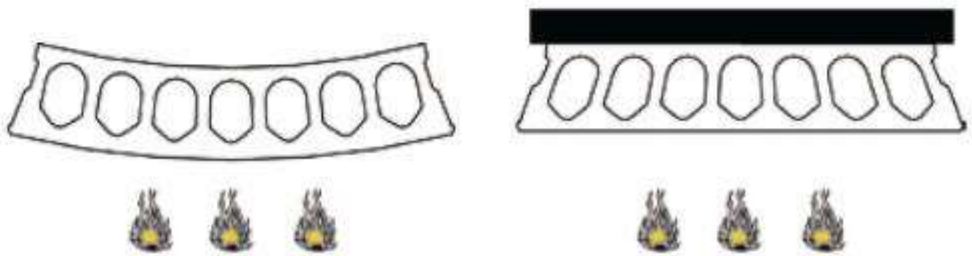




No energy or dynamic effects are taken into account in the model!

Holcofire frame model

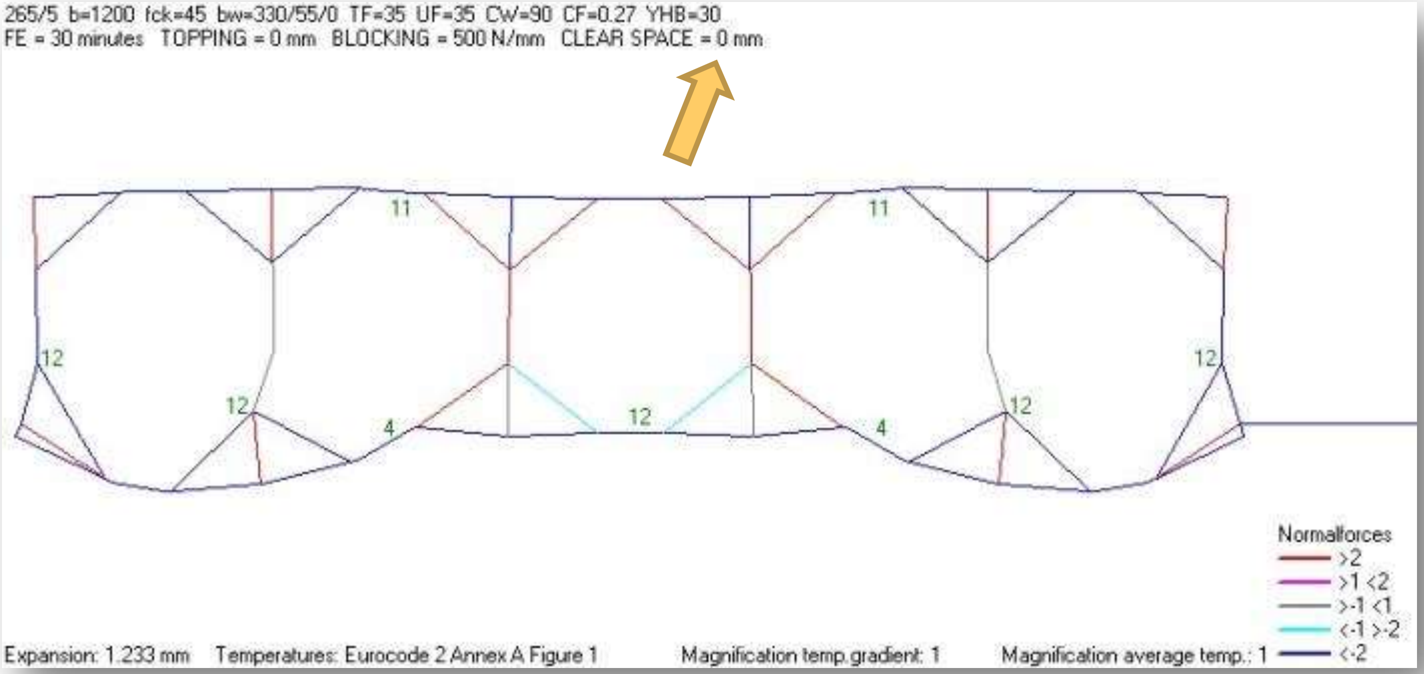
General behaviour for free cross-sections:



In case of a free cross-section the stiffness of the top flange due to e.g. a structural topping is strongly influencing the occurrence of horizontal cracks in the webs.

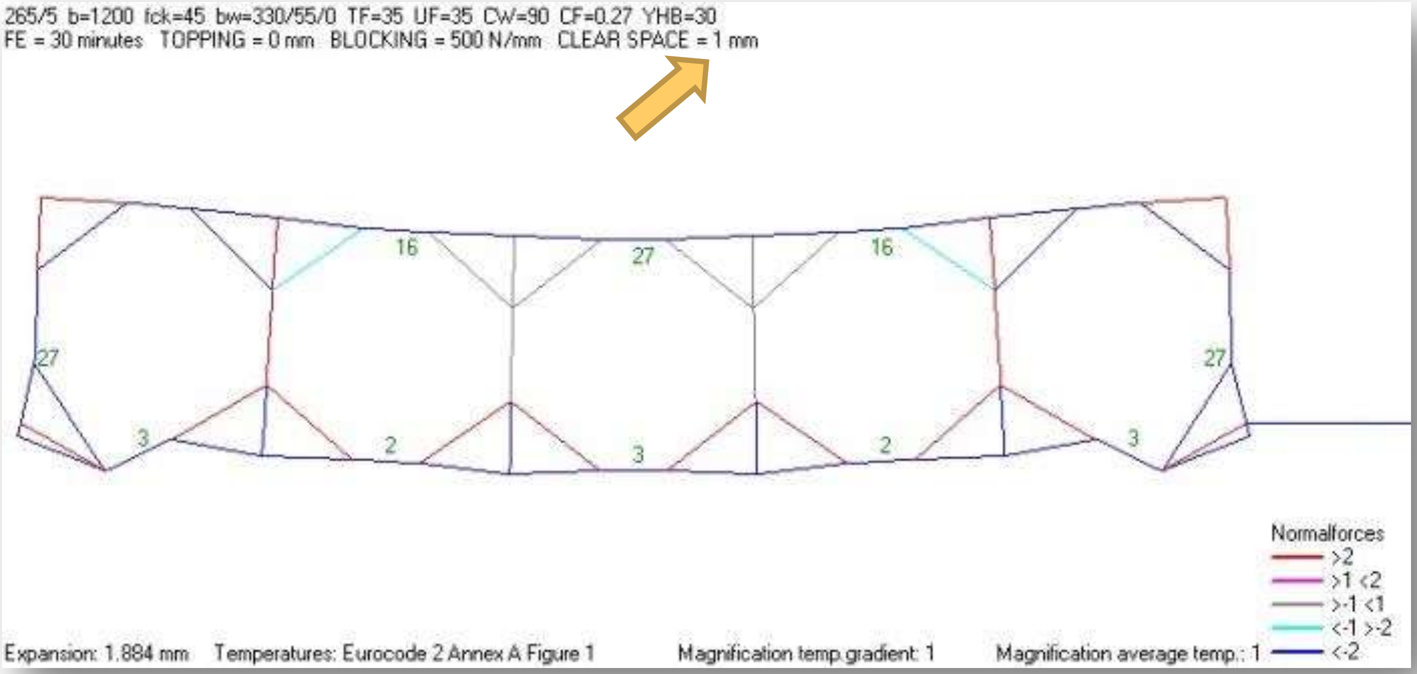
Restraining effects

Holcofire Frame Model:



Restraining effects

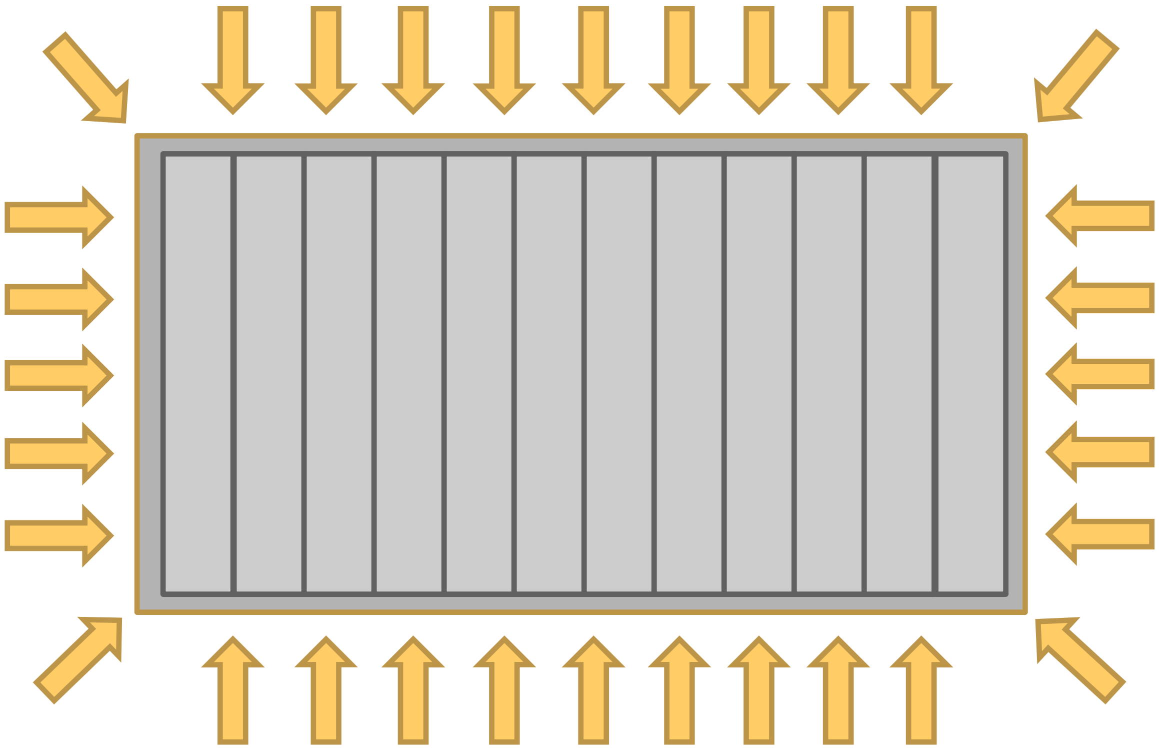
Holcofire Frame Model:



Restraining effects

Due to the structure:

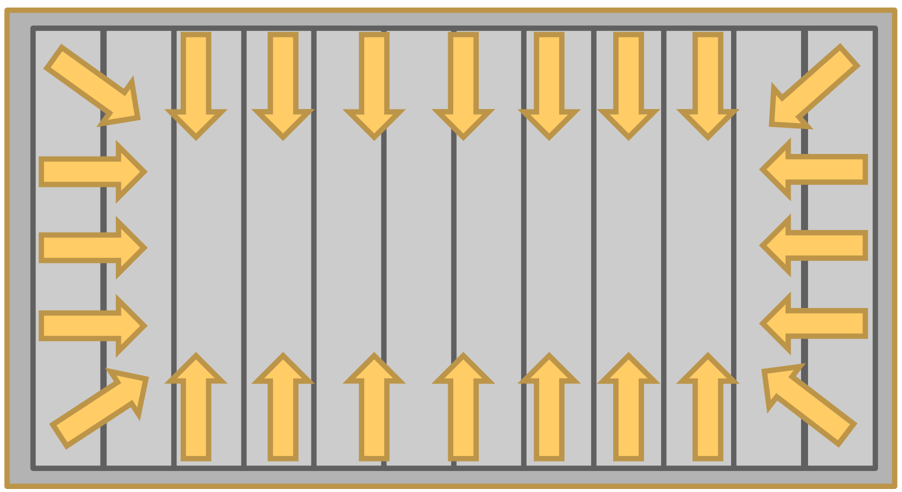
Surrounding structure:

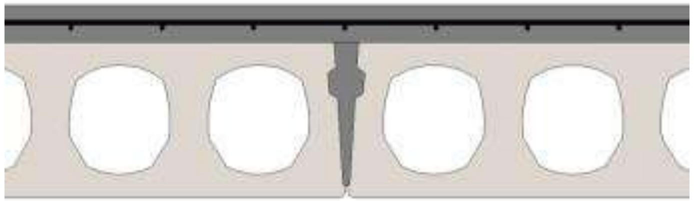


Restraining effects

Due to the structure:

Reinforced structural topping or tying reinforcement:



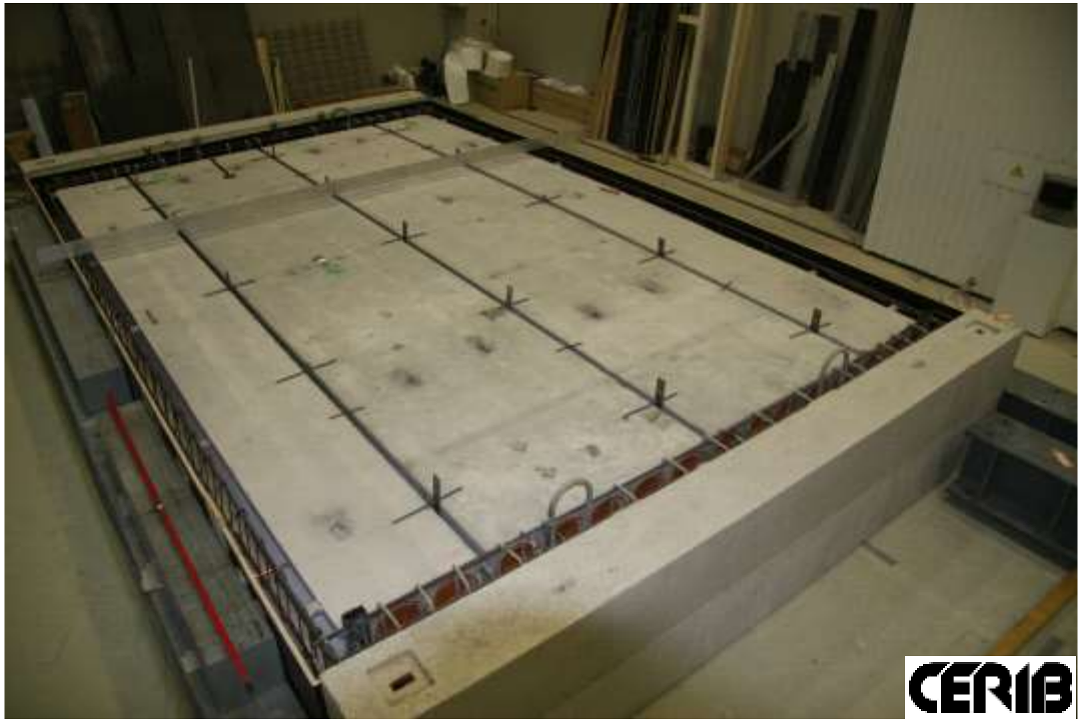


Order of size of the blocking spring:
Assume concrete to be cracked:
The magnitude is governed by the amount of reinforcement:
2 beams: $A_s = 1360\ mm^2$
Topping: $A_s = 1360\ mm^2$
$K_{reinf} = A_s \cdot E_s / L_{system} = 4.5\ 10^5$

Average k-value over the length of joint:
$4.5\ 10^5 / 5300 = 85$ N/mm

Restraining effects

Fire tests (Holcofire R-series):



- Peripheral tie beam around the floor
- Precast support beam bxh = 300x400 mm2
- Hollow core depths 255, 260, 200 and 265 mm
- Toppings of 100, 100, 50/70 mm and without topping.

Span the furnace in long direction (one test span in short direction)

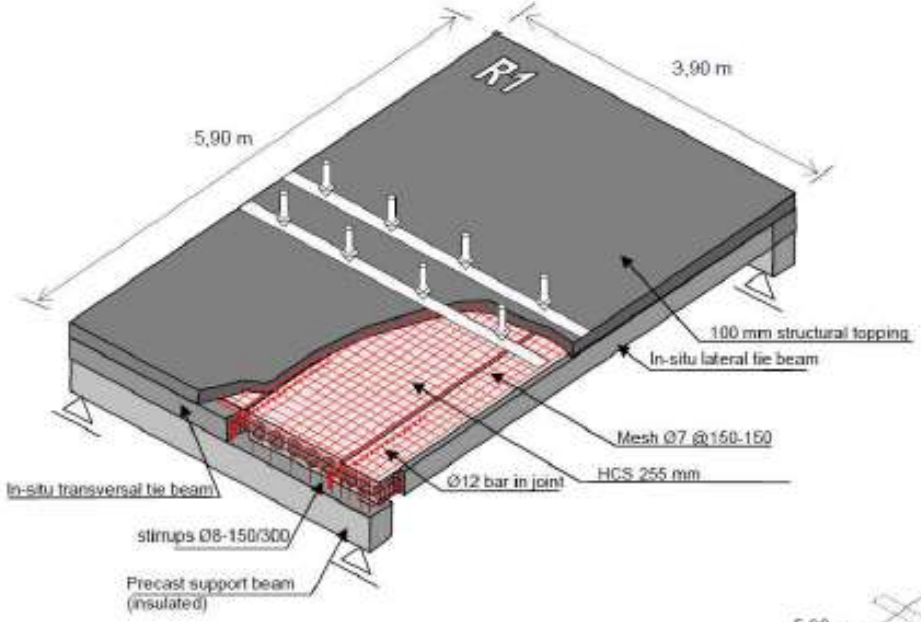
5.90 m length

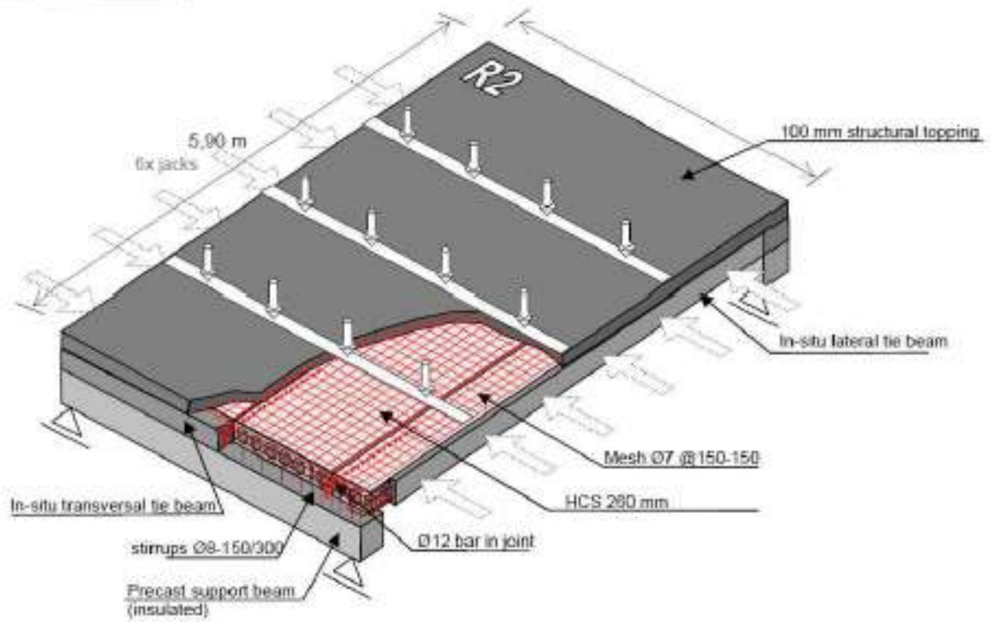
3.90 m width

2 full slabs, 2 fitting slabs (one test: 4 full slabs)

Restraining effects

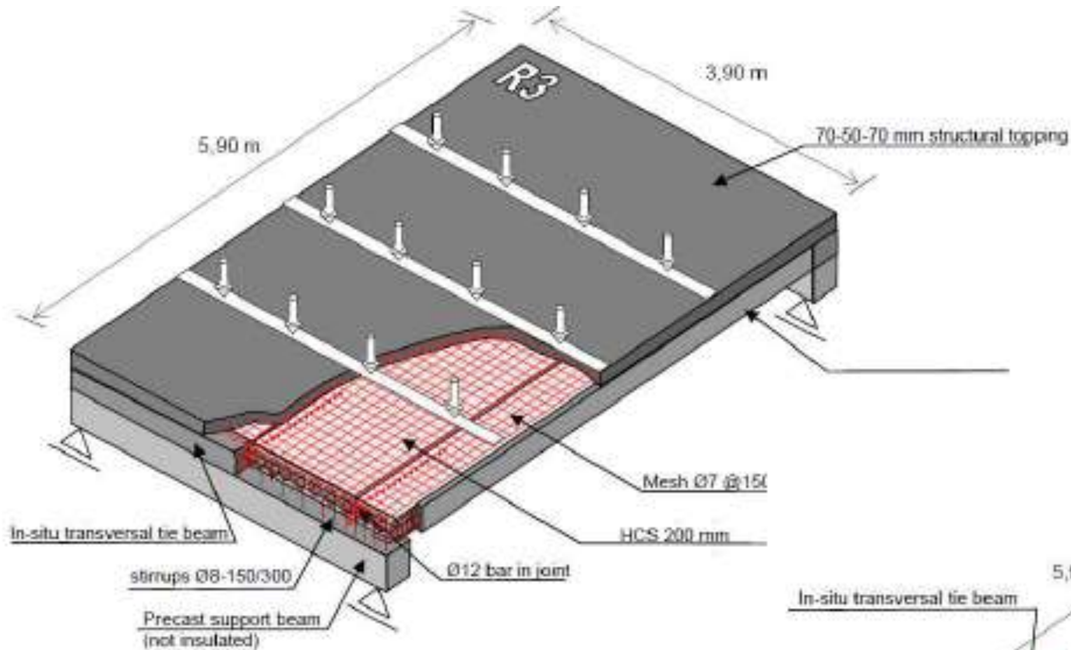
Holcofire R-series: R1 and R2

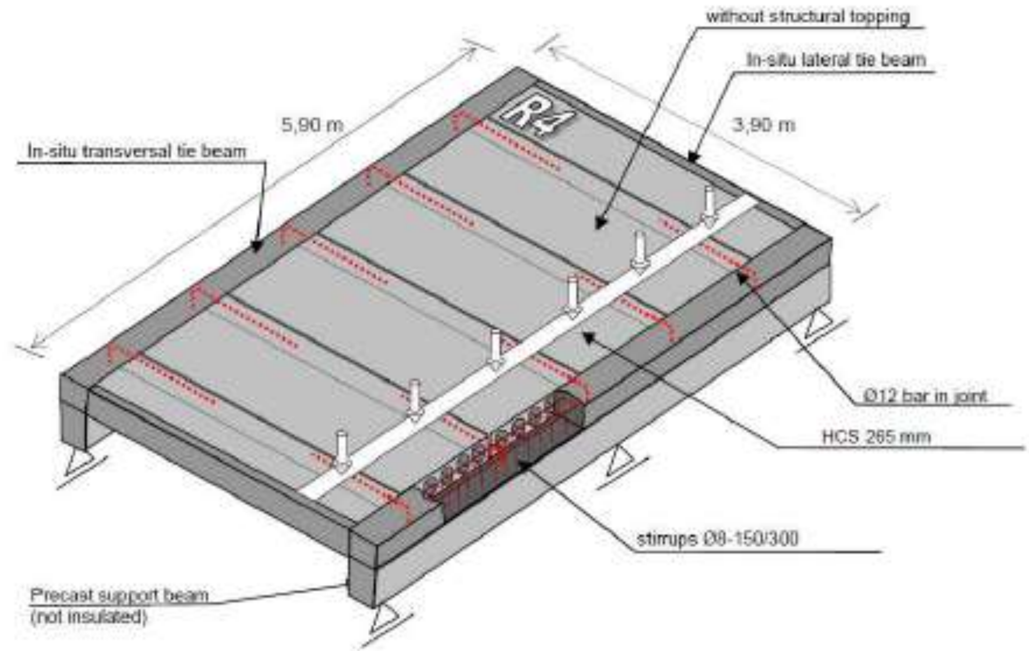




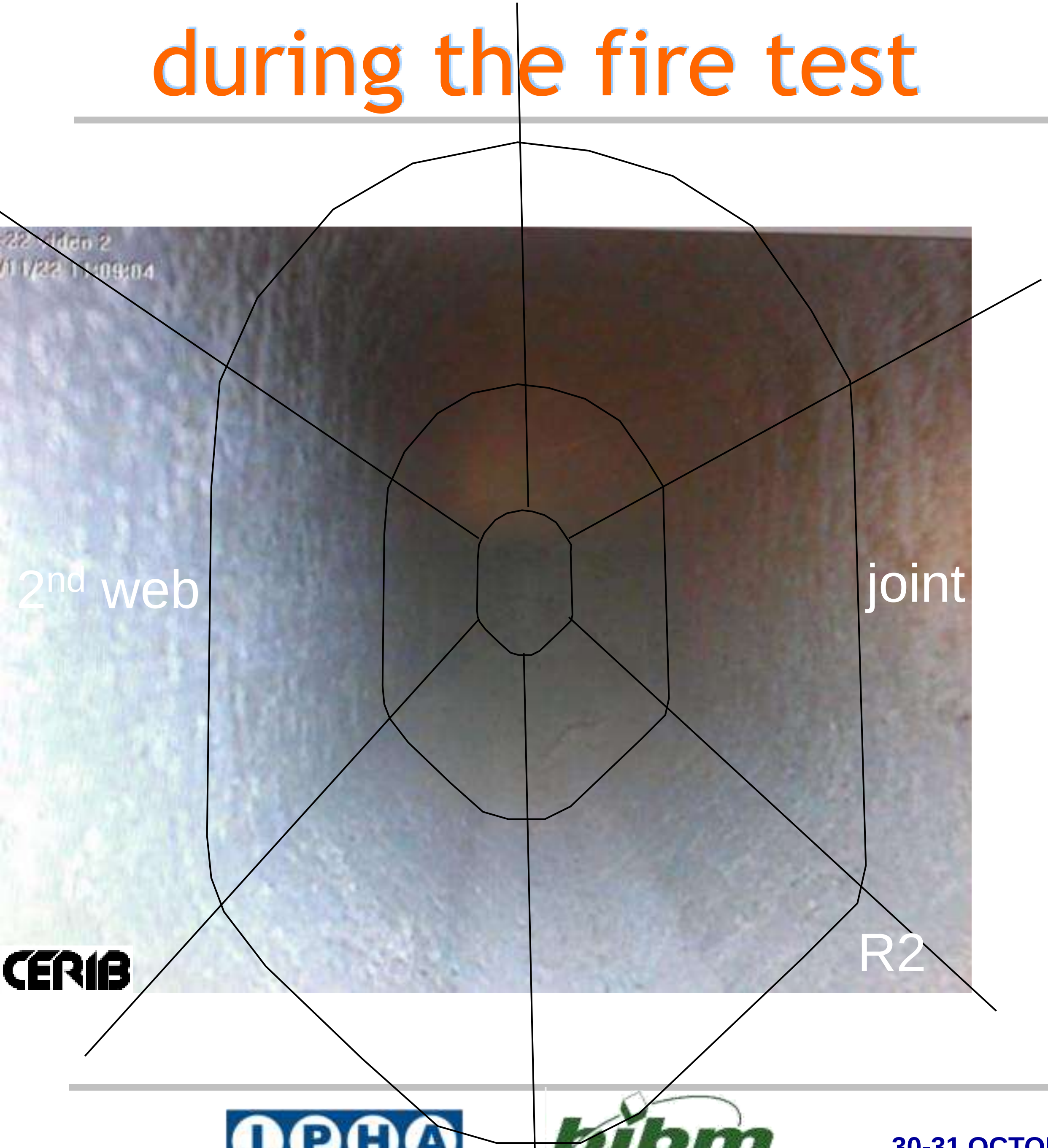
Restraining effects

Holcofire R-series: R3 and R4

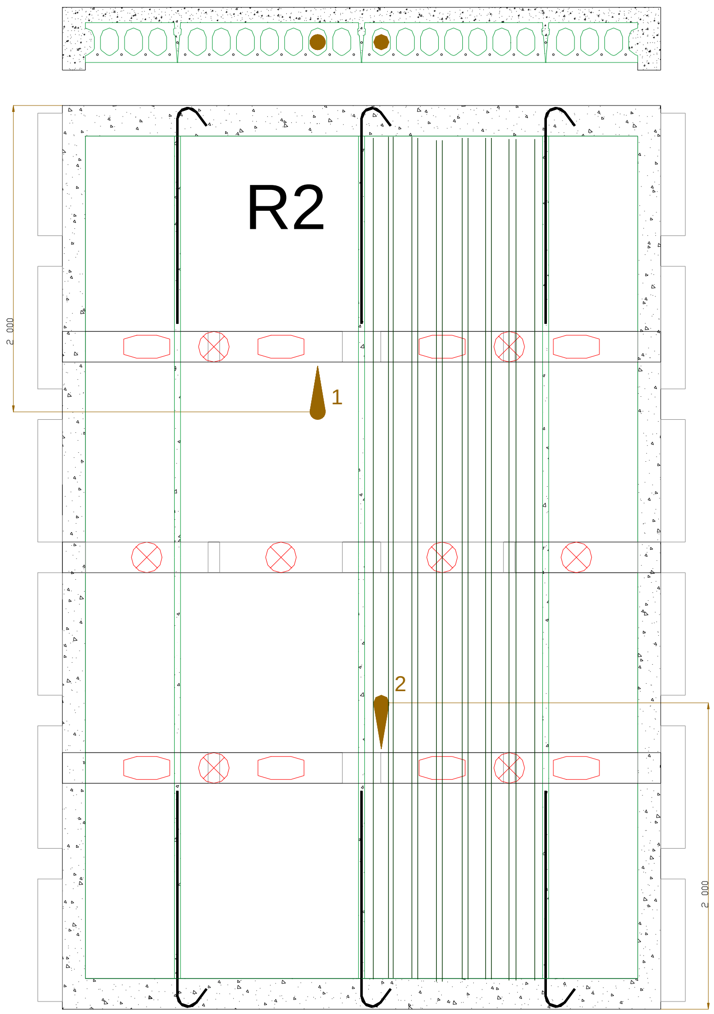




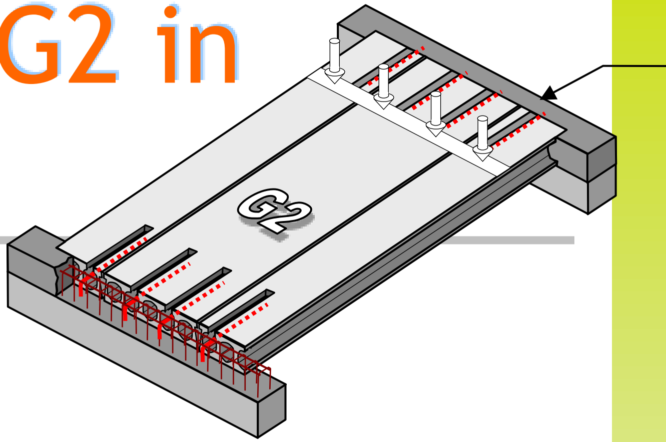
Observations in R2 camera in core, during the fire test



Vidéo during the test inside the hollow-core



What was seen in fire test G2 in order to compare with R2



G2 - 16 minutes

G2 - 18 minutes

G2 - 23 minutes

G2 - 46 minutes

- Innovative core camera in core in fire test developed at Cerib registered vertical cracking according to theory

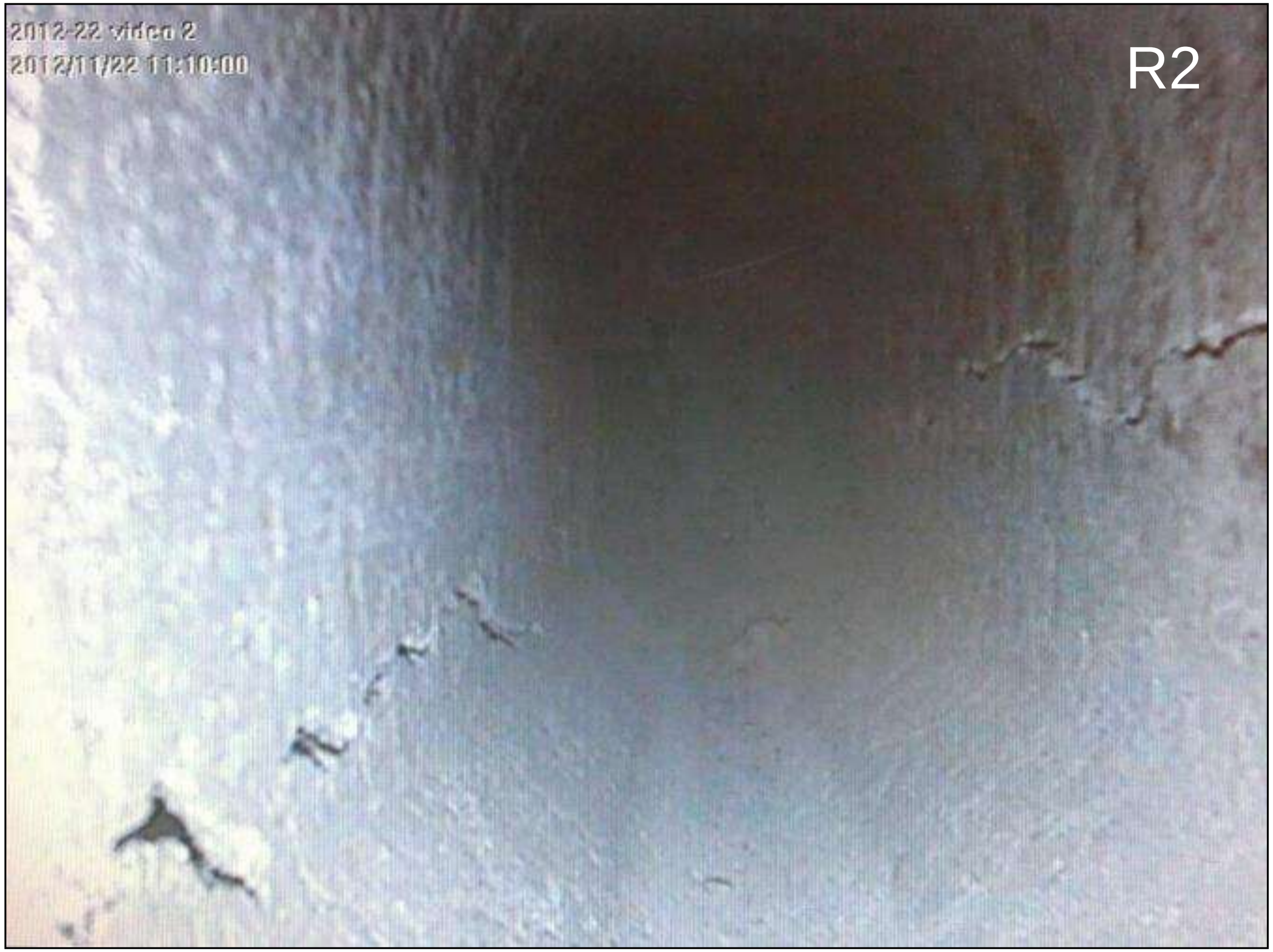
Fellinger [2004]

R2 camera in core, at 16’

G2 - 16 minutes

R2 camera in core, at 17'

G2 - 18 minutes



R2 camera in core, at 21'

G2 - 23 minutes

Results of fire tests R2

- Observations
  → 260 mm with 100 mm topping
  → F = 30 kN on floor (G = 6.4 kN/m^2, q=1.4 kN/m^2)
  → Horizontal cracking between 16′ and 19′
  → In combination with spalling at soffit
  → Test continued, fire stopped at 91′ (REI90)
  → Loaded up to bending failure at 291 kN

- Conclusions
  → Bending capacity close to theoretical capacity of ≈ 110 kNm/slab at 90′
  → Strands remained well anchored in support
  → Second load path was present

Results of fire tests R-series

- **R1: 255 mm with 100 mm topping**
  - → F = 280 kN (G=6.3 kN/m^2, q= 13 kN/m^2)
  - → Horizontal cracking or horizontal shear crack at 13′
  - → Shear flexural failure at 37′ as load was high

- **R2: 260 mm with 100 mm topping**
  - → F = 30 kN on floor (G=6.3 kN/m^2, q =1.4 kN/m^2)
  - → Horizontal cracking between 16′ and 19′
  - → In combination with spalling at soffit
  - → Test continued, fire stopped at 91′ (REI90 granted)
  - → Loaded up to bending failure at 291 kN

Results of fire tests R-series

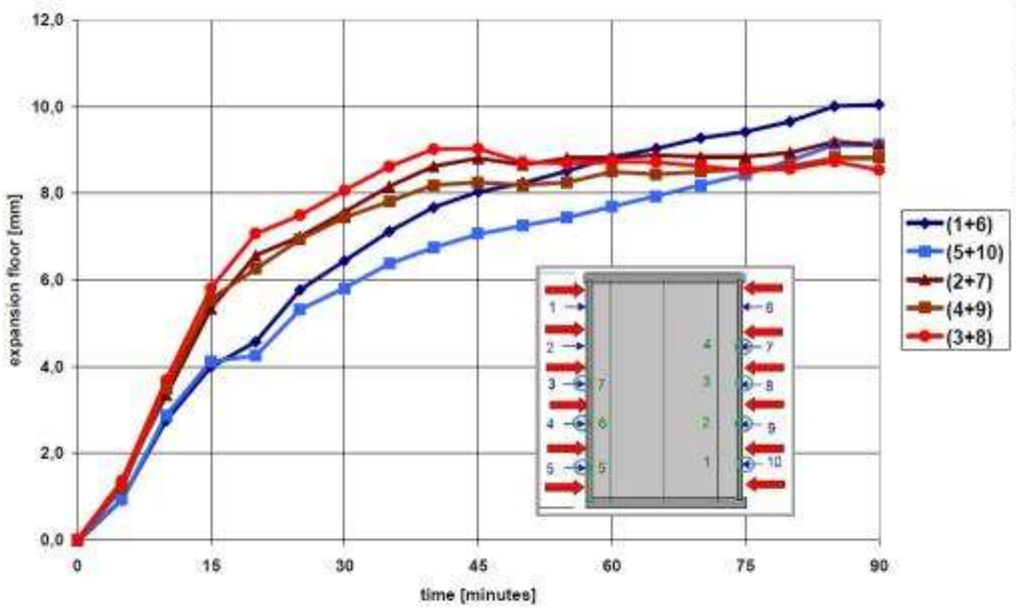
- **R3: 200 mm with 50-70 mm topping**
  → F = 30 kN (G=4.6 kN/m², q=1.4 kN/m²)
  → Horizontal cracking between 13′ and 15′
  → In combination with spalling at soffit
  → Test continued, fire stopped at 91′ (REI90 granted)
  → Loaded up to bending failure at > 119 kN
- **R4: 265 mm without topping**
  → Shear load F = 52 kN/m
  → After 21′ loud bang, test continued
  → After 56′ test stopped for safety reasons (EI) hole in floor.
  → Shear load resistance was still sufficient (R)
  → After dismantling the floor there was only <u>one</u> slab with spalling on the soffit and cracked webs

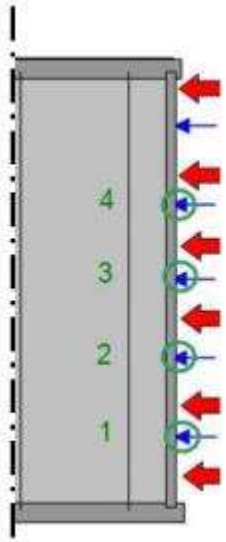
Restraining effects

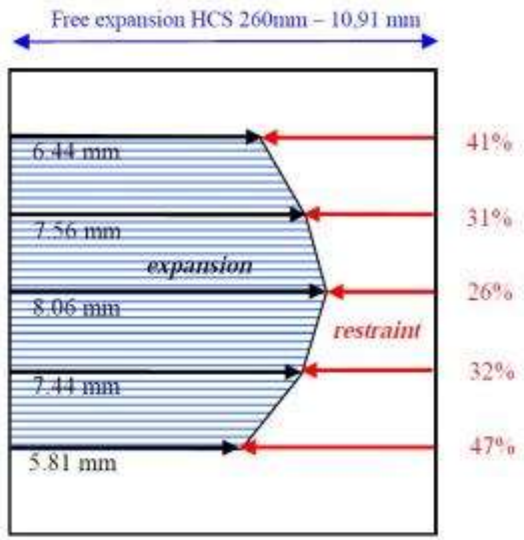
Fire tests R1,R2,R3,R4 soffit after execution:

Restraining effects

Test R2 horizontal displacement:



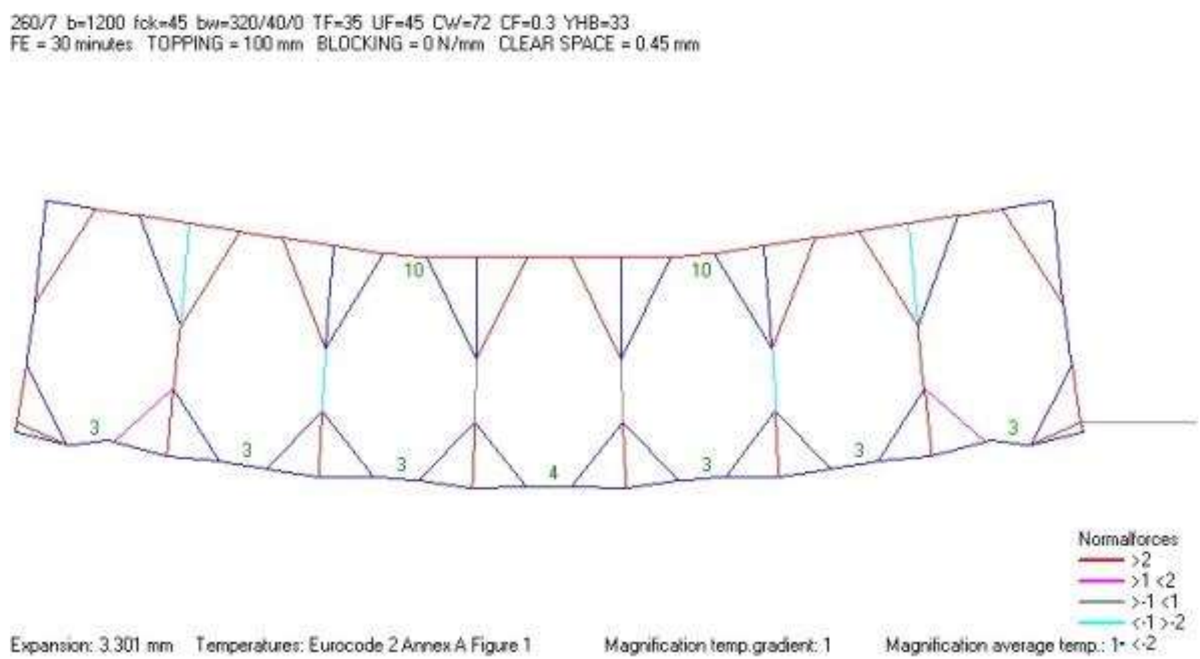




expansion at
30 minutes

Restraining effects

Test R2 expansion with Frame Model:

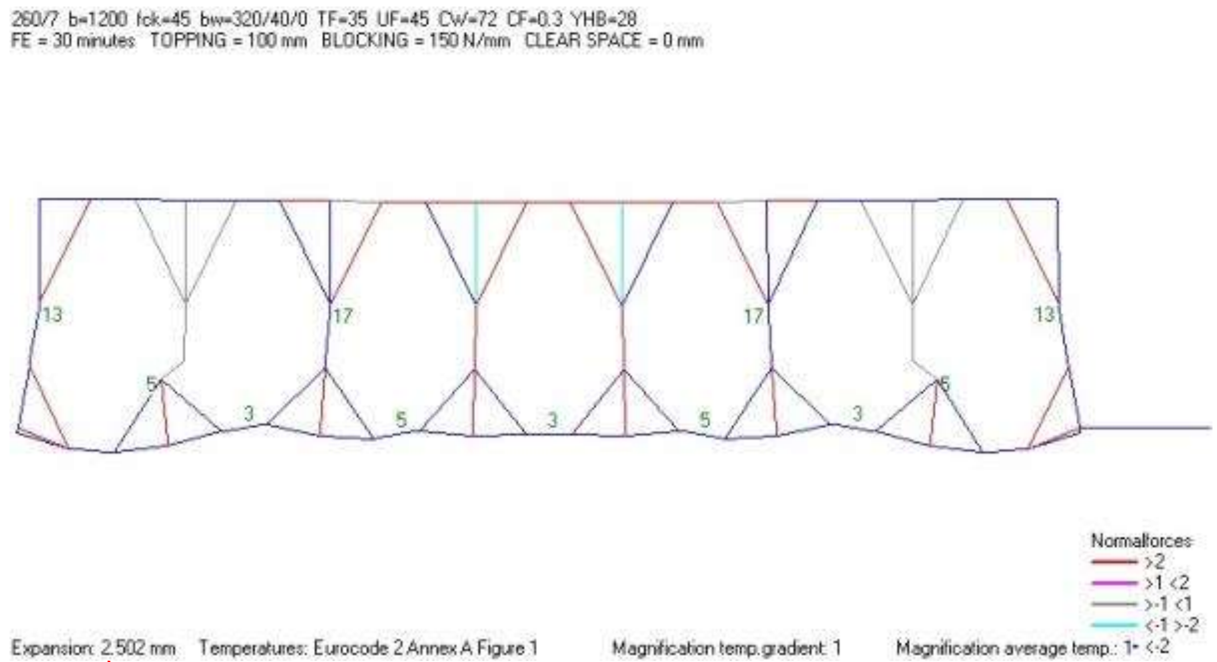


FREE

3.301 * 3.90 / 1.2 = 10.9 mm

Restraining effects

Test R2 expansion with Frame Model:



BLOCKING
150 N/mm

2.502 * 3.90 / 1.2 = 8.1 mm

Difference between FREE and RESTRAINT:
(10.9-8.1) / 3.9 = 0.34 mm /m !!

Restraining effects

Preliminary conclusions on tests

- Horizontal cracking did indeed occur and was observed on average around 15’ of ISO fire
- During the fire tests, despite the horizontal cracks and some local damage to the under flange, the strands remained well anchored into the support and the floor remained capable to sustain the moderate load
- Under high loading, the ultimate capacity was reached in R1, and a shear flexural failure occurred according to theoretical calculations
- Under moderate loading, and despite the horizontal cracks, and some local damage to the under flange during the severe fire conditions, the 90’ were reached in R2 and R3.
- After 90’ of ISO fire the bending capacity was tested in R2 and R3 and proved to be close to theoretical bending capacity at 90’

Conclusions

On spalling and horizontal cracking

- Blocking causes spalling. This spalling occurs because the compressive main stress reaches its limit.
- In contrast to free sections, where only horizontal cracks occur, in a restraint section (due to topping and/or floor field action), also spalling can occur. The stiffness of the upper flange due to a topping is not the main parameter for horizontal cracking anymore.
- Spalling on the soffit of one element will have a release effect with regard to spalling.
- A structural topping increases the EI-criterium

Conclusions

Considerations

- Blocking is an important parameter for hollow core floors, but this applies for all concrete structures and will cause spalling damage on the soffit.
- Horizontal web cracks can lead to local damage.
- The structure is the cause of restrainment; but it also provides the second load path.
- We are out of phase of unconscious incompetence.
- It is not to easy to translate the accidental case of fire into a numerical model.
- It is a myth that concrete structures only need to be cleaned after a serious fire.

Conclusions

Considerations with regard to spalling



- All concrete (floors) respond similar to fire.