Fire design of HC Floors
Conclusions from fire tests

Arnold Van Acker

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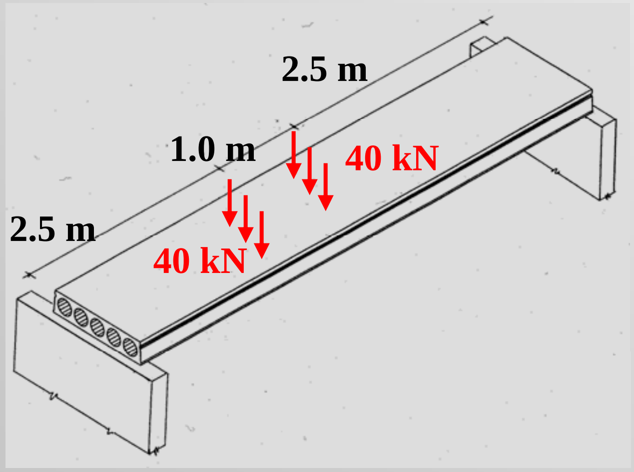
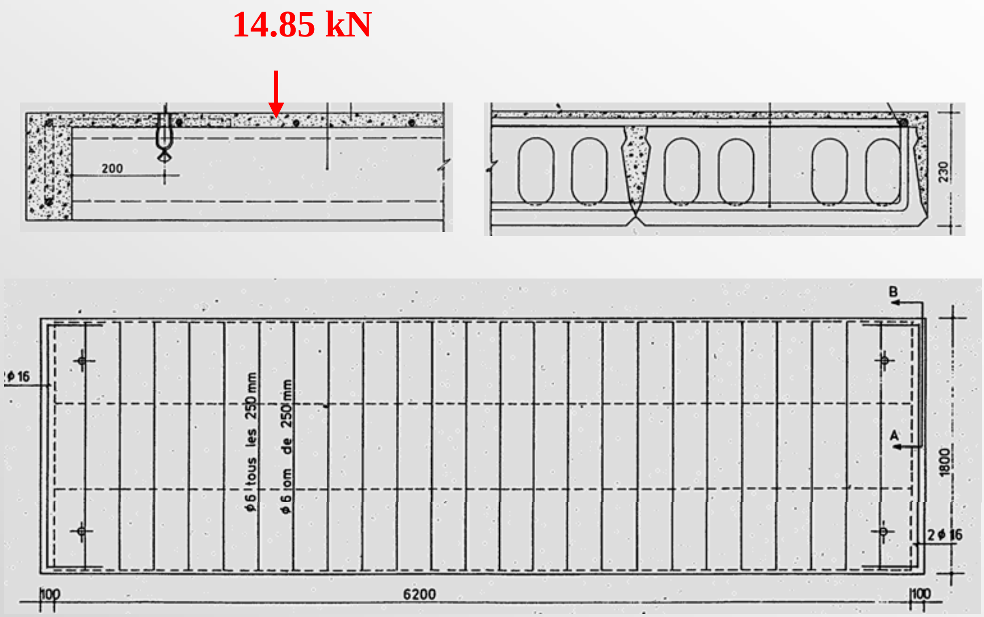
- First experiences
- Flexural capacity
- Shear capacity
- Connections
- Conclusion

Experiences from first fire tests

- **1972-1980**

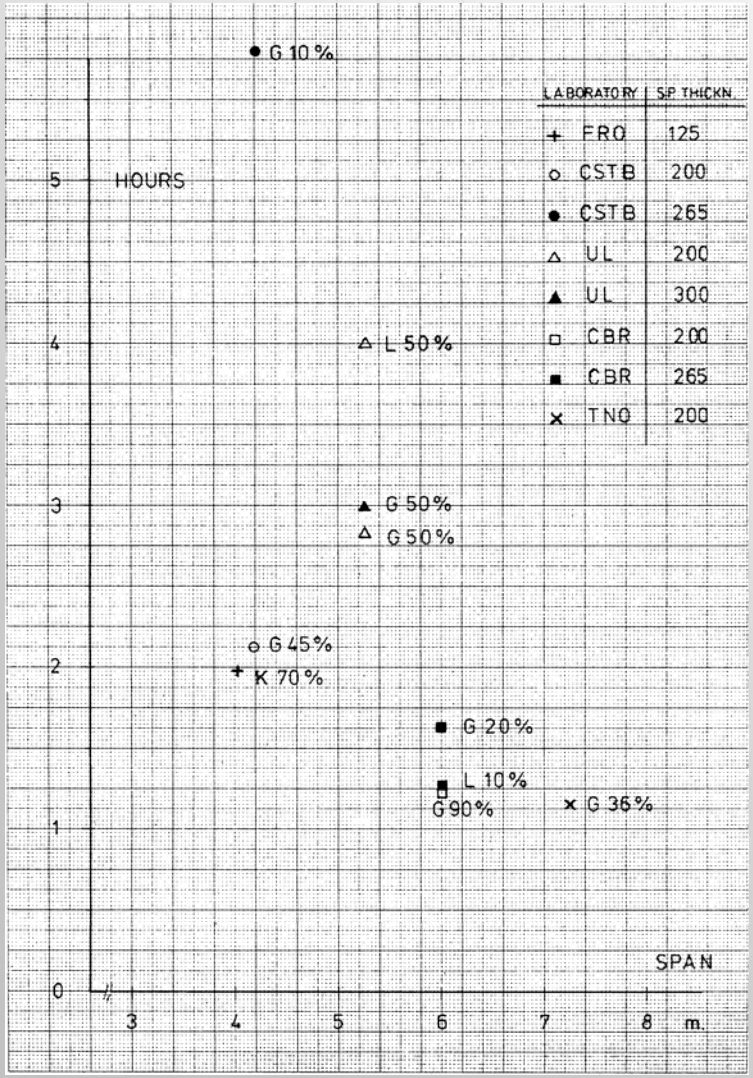


Test Ergon on simply supported single unit in 1972: shear failure after 30 min.

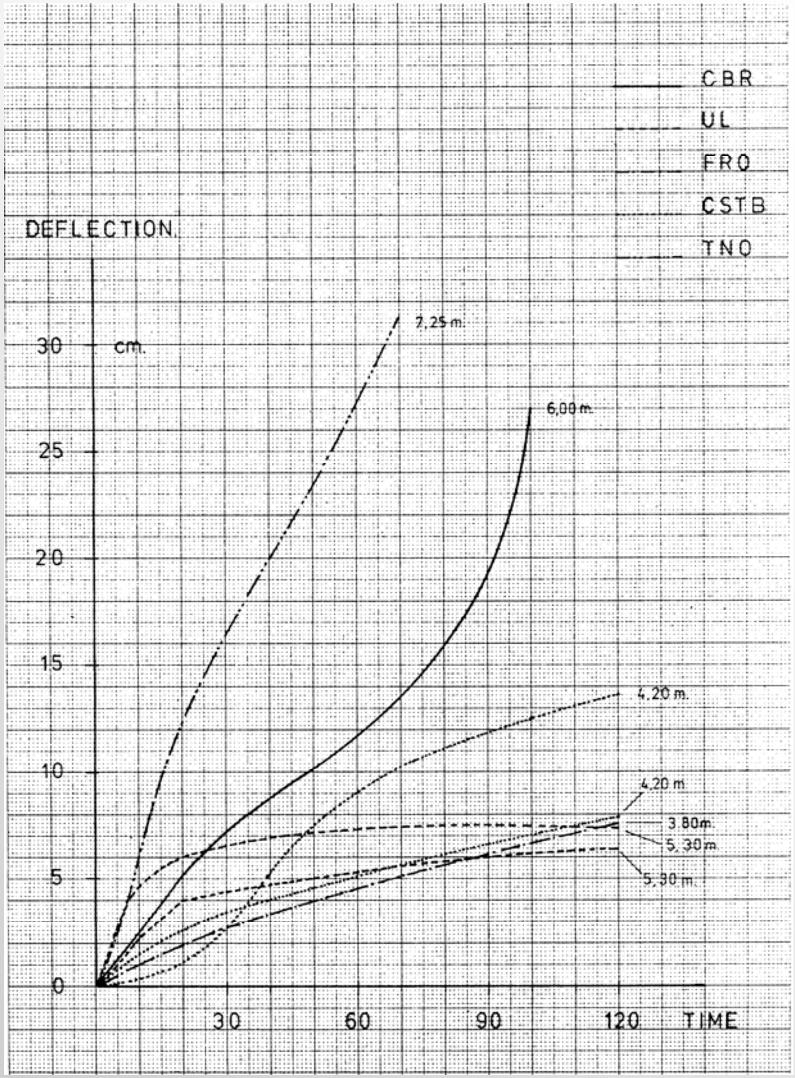


Test Echo on floor with connections in 1980: deflexure 1/30e span after 126 min.

Fire tests on HC units world wide



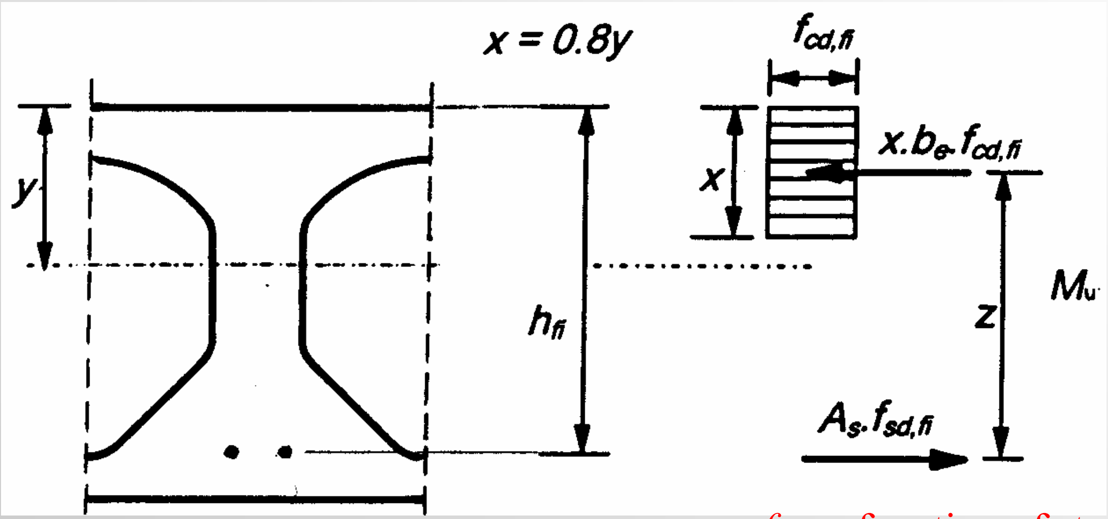
Fire resistance



Deflection

Flexural capacity

Simple calculation method



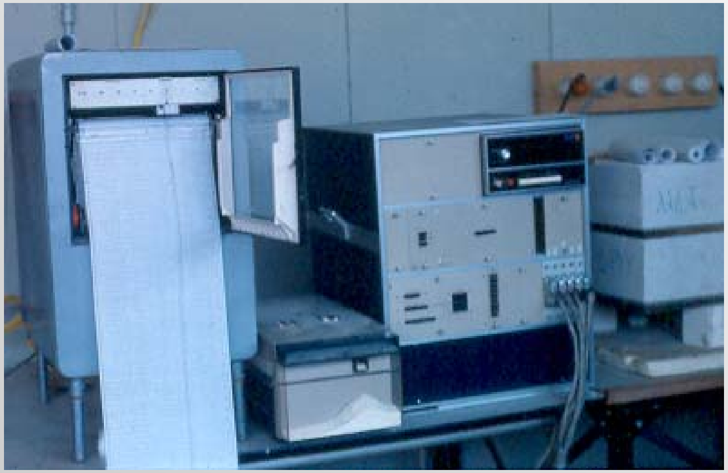
$f_{sd,fi}$ function of steel temperature

Calculation model at ULS

Temperature profiles

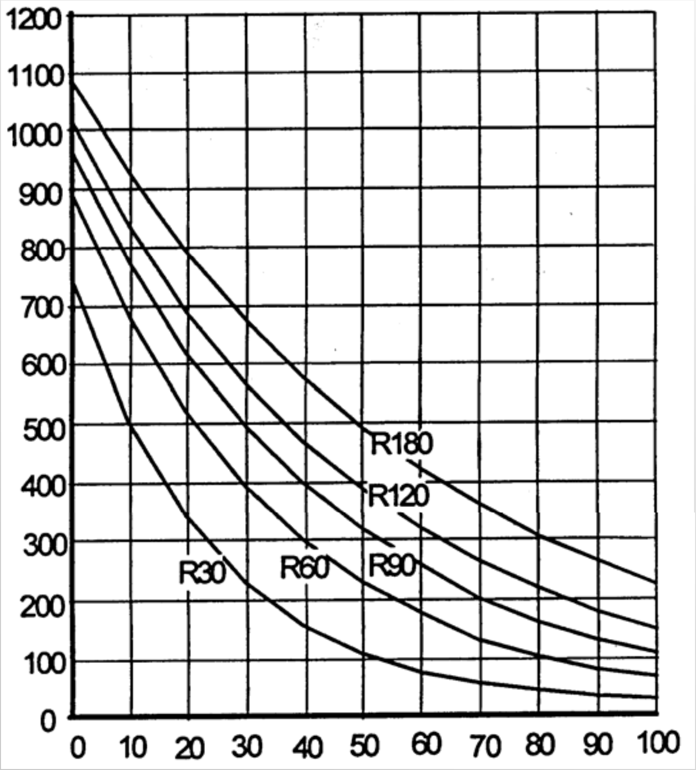
⇨ **Special test furnace at Ergon in Belgium**



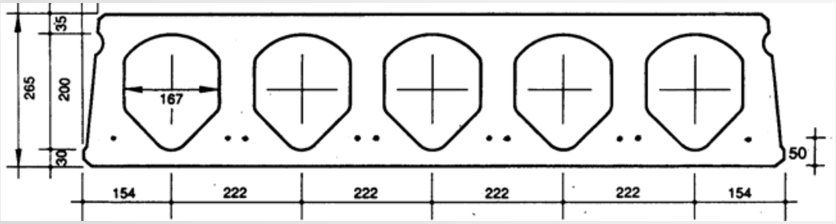
Calculation flexural capacity

- **Temperature profiles EN 1168**



Flexural capacity

- **Simply supported HC 265 mm**

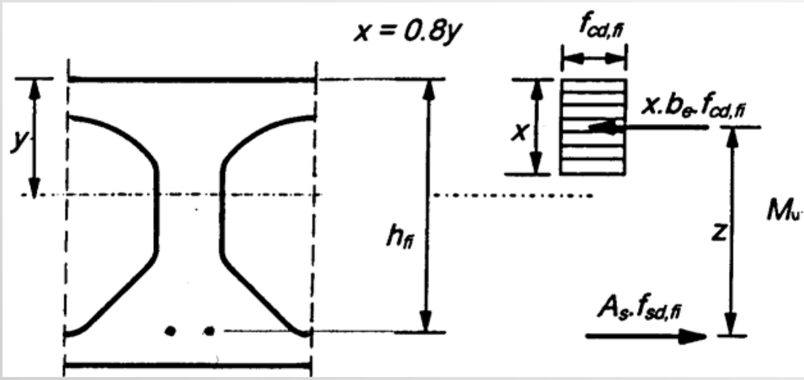


Self weight inclusive joints: 3.86 kN/m²
Prestressing: 2 ø ⅜ ‘ + 8 ø ½’ strands, axis distance 50 mm
f_{ck} = 45 kN/mm²
$f_{cd,fi}$ = 45/1.20 = 37,5 kN/mm² (EN1992-1-2 gives γ_m = 1.00)

Axis distance 50 mm	R60	R90	R120	R180
θ_i $f_{py}/0.9\ f_{pk}$ f_{py}	230 0.82 1525	320 0.66 1228	385 0.53 986	490 0.32 595

Temperature and corresponding steel strength for different fire durations

Calculation flexural capacity



$$x.b_e.f_{cd,fi} = A_s.f_{sd,f}$$

$$z = h_{fi} - \frac{x}{2}$$

After 60 minutes fire exposure

$$N_a = (2x51.6 + 8x93)x1525 = 1292kN$$

$$x = \frac{1292827}{1200x37,5} = 28,7mm$$

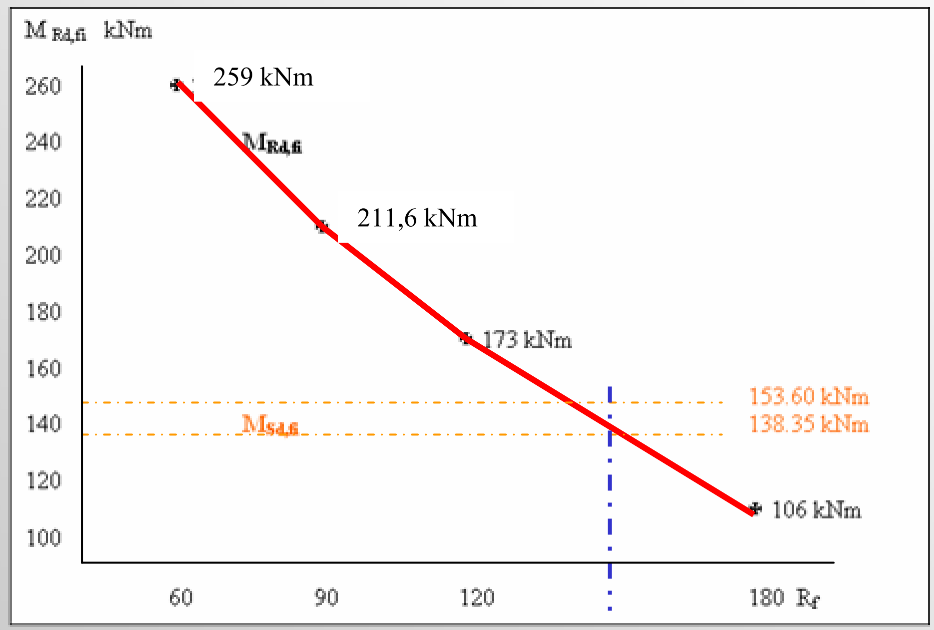
$$M_{Rd,fi} = 1292x(265 - 50 - \frac{28,7}{2}) = 259kNm$$

After 90 minutes fire exposure

$$N_a = (2x51.6 + 8x93)x1228 = 1040kN$$

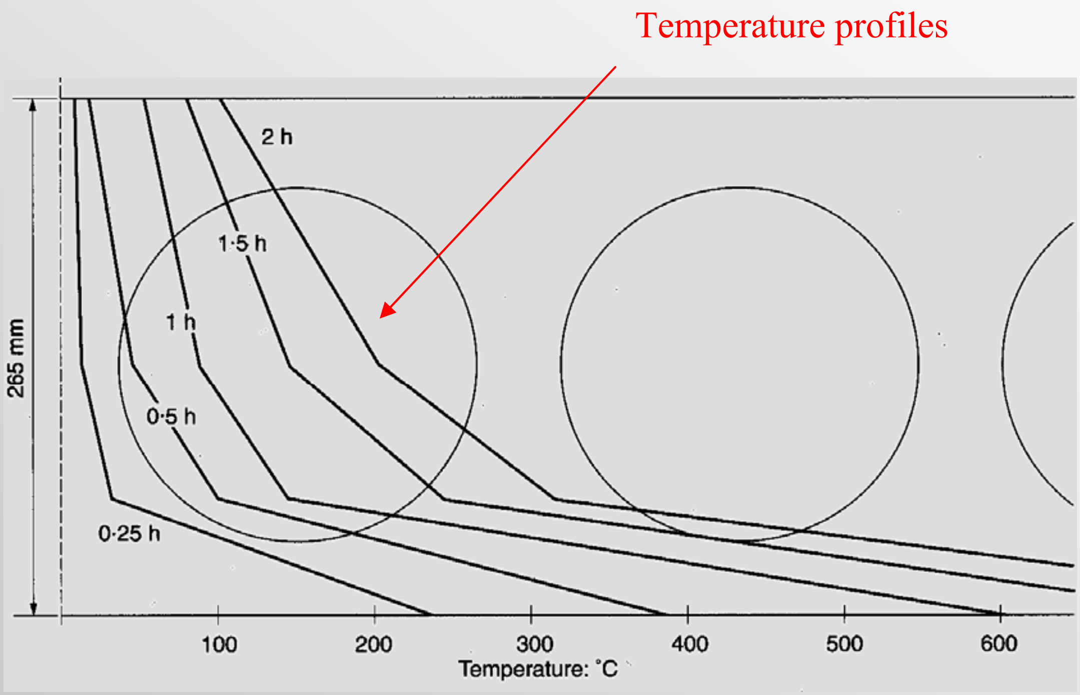
$$x = \frac{1040362}{1200x37,5} = 23,12mm$$

$$M_{Rd,fi} = 1040x(265 - 50 - \frac{23,12}{2}) = 211,6kNm$$



Shear capacity

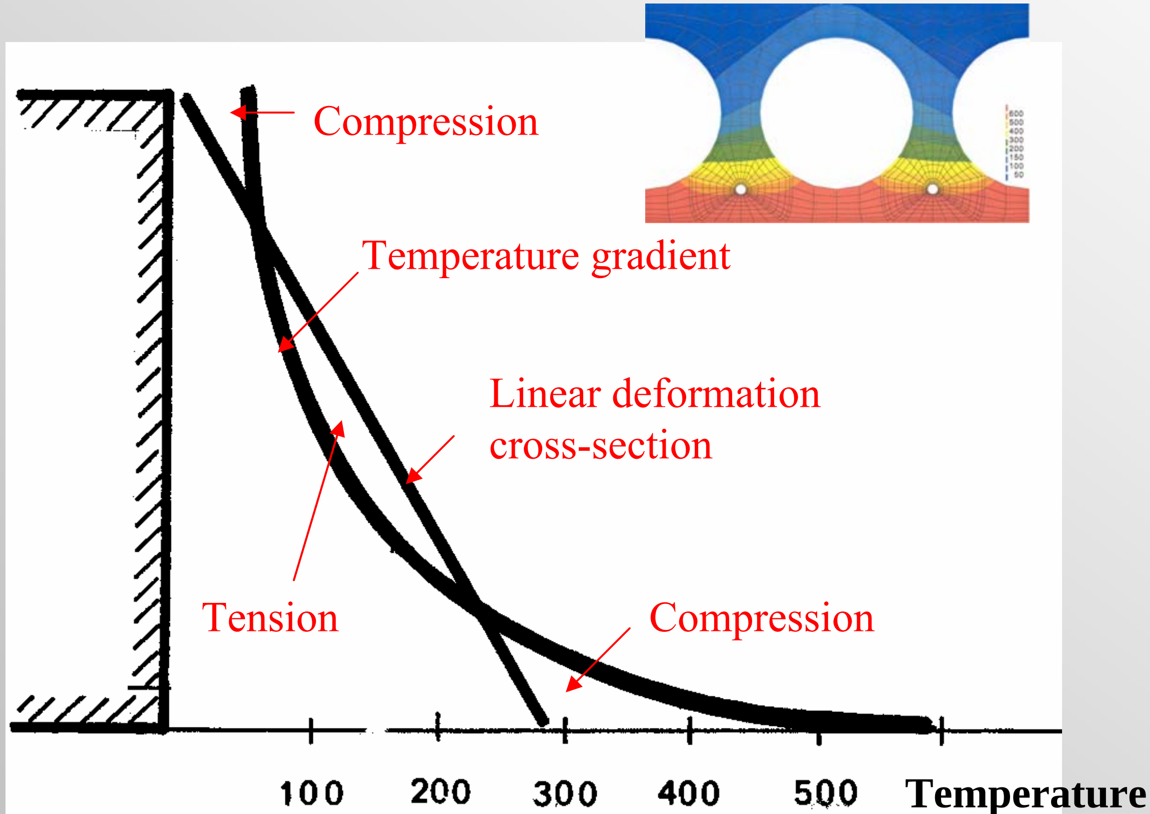
- **Induced thermal stresses**

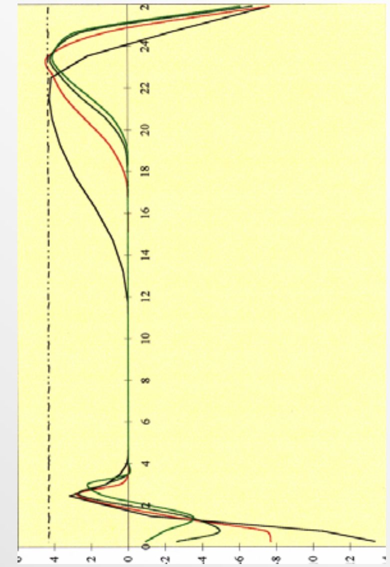


Non-linear shape of temperature profiles

Shear capacity HC floors under fire

⇨ Research done in Belgium

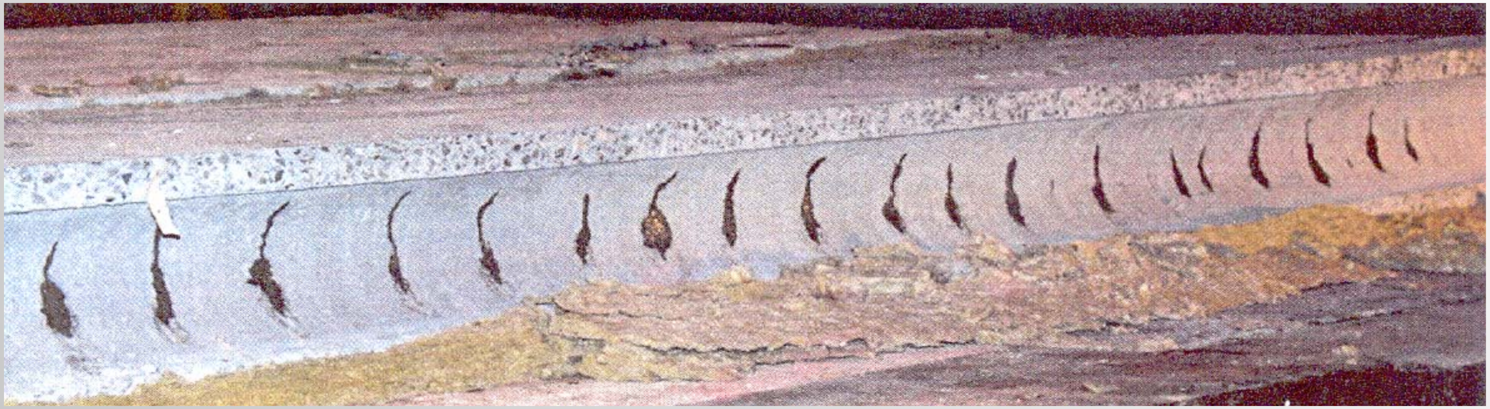




Induced stresses due to the non-linear temperature distribution

Induced stresses due to the incompatibility between non-linear temperature profile and linear deformation of the cross-section

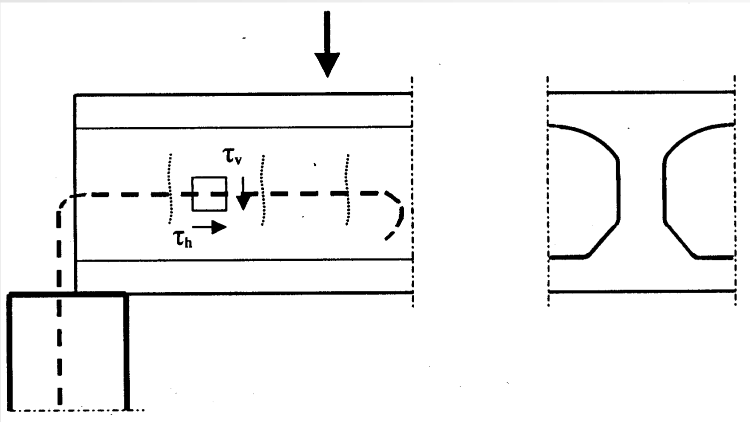
Induced thermal stresses

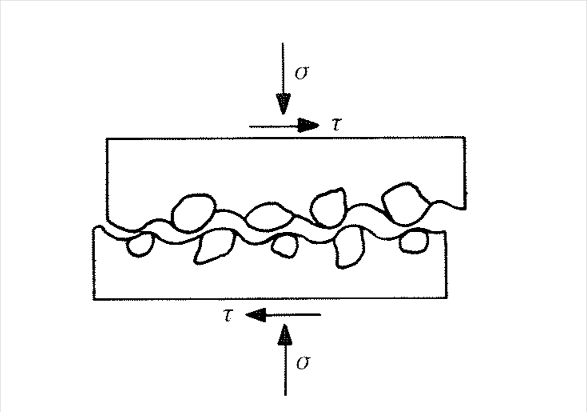


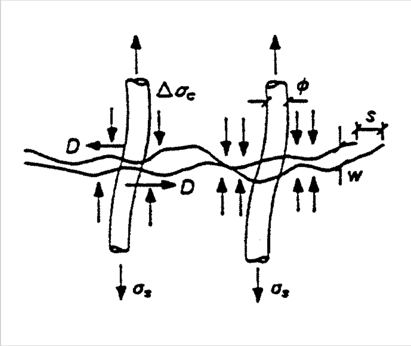
Cracking of the webs due to induced thermal stresses during fire test on sample cut from hollow core slab

Design recommendations

- Shear transfer through aggregate interlock



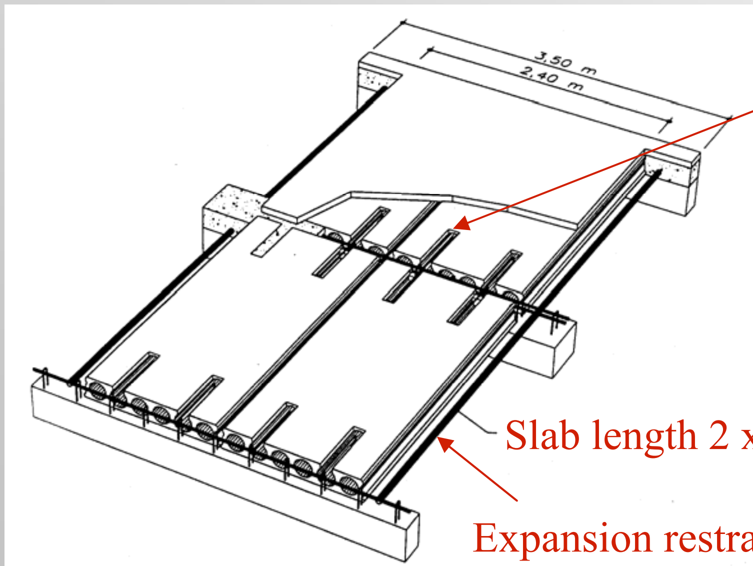




Cracked concrete sections can take up shear through aggregate interlock on condition that the cracks are not opening

Tests in Belgium

- **Shear resistance of hollow core floors**



4 tests with extruded and slip-form slabs

Shear

- **Preparation test floor**

Peripheral tie

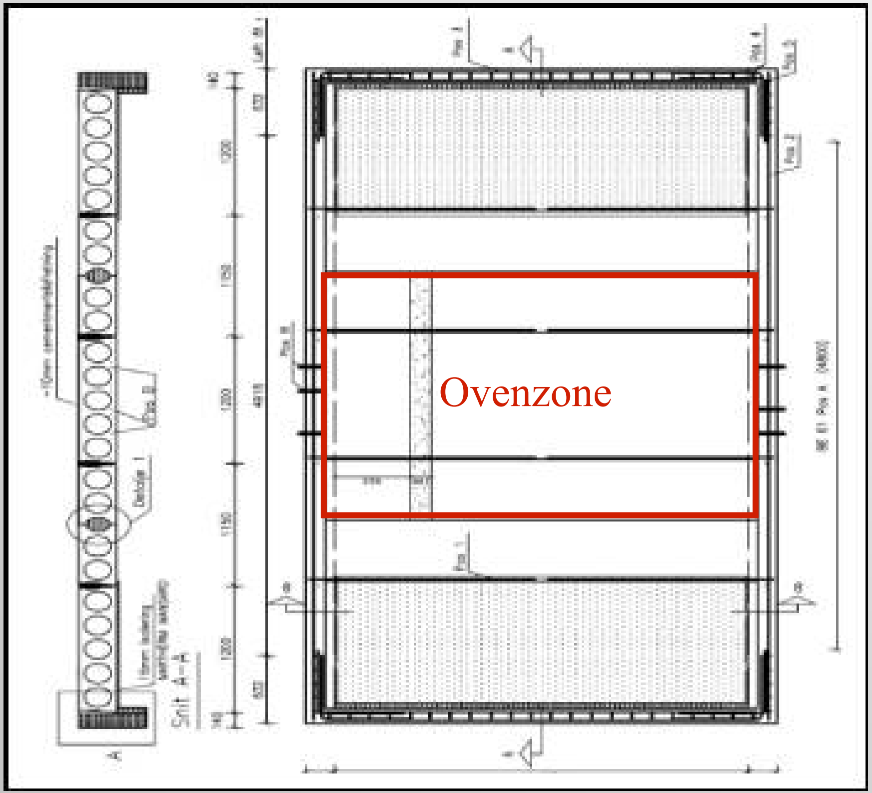
Longitudinal bars to simulate the blocking of the expansion by the surrounding structure

Test results

Test N°	Floor thickness mm	Test load kN	ISO fire exposure minutes	Failure load at end of test kN	V_{Rd} at normal temperature kN	Shear loading/ V_{Rd}
T1 A B	**200** **200 + 50**	**100** **100**	**83** **83**	**178 (B)** **254 (B)**	**79/slab**	**86.8 %**
T2 A B	**200** **200**	**100** **100**	**120** **120**	**292 (B)** **324 (B)**		
T3 A B	**200** **200**	**100** **100**	**120** **120**	**254 (B)** **267 (B)**		
T4 A B	**265** **265 + 30**	**100** **100**	**120** **120**	**305 (B)** **305 (Sh)**	**148/slab**	 **56.2 %**

Research in Denmark

- Shear capacity hollow core floors



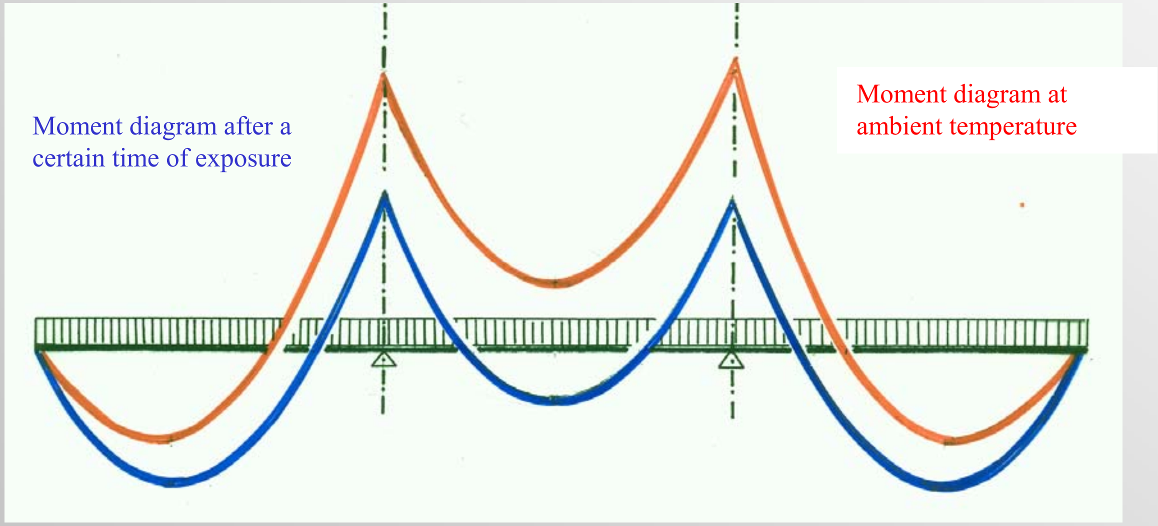
- 60 min ISO fire + 90 min. cooling (load applied)
- Uniforme belasting:

  1th test 65 % V_{Rd} : no failure
  2nd 75 % V_{Rd} : no failure
  3nd 80 % V_{Rd} : shear failure after 45’

Info: www.bef.dk/sw343.asp

Restrained supports

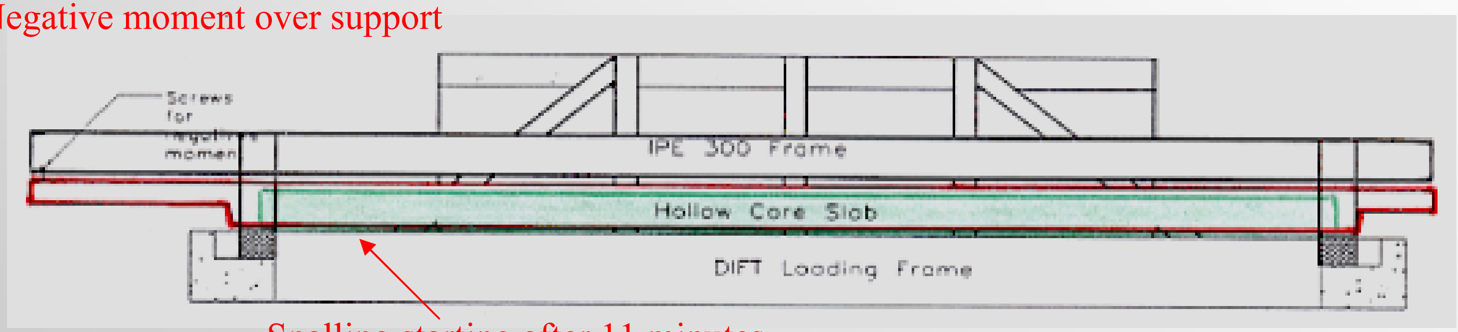
- **Induced support moment**



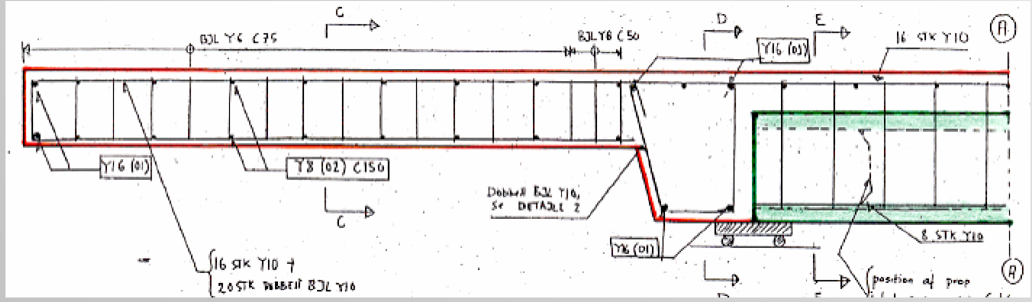
Flexural capacity

- **Test on restrained support**

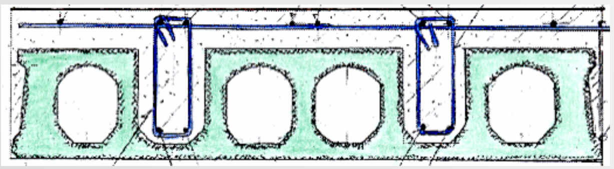
Negative moment over support



Spalling starting after 11 minutes



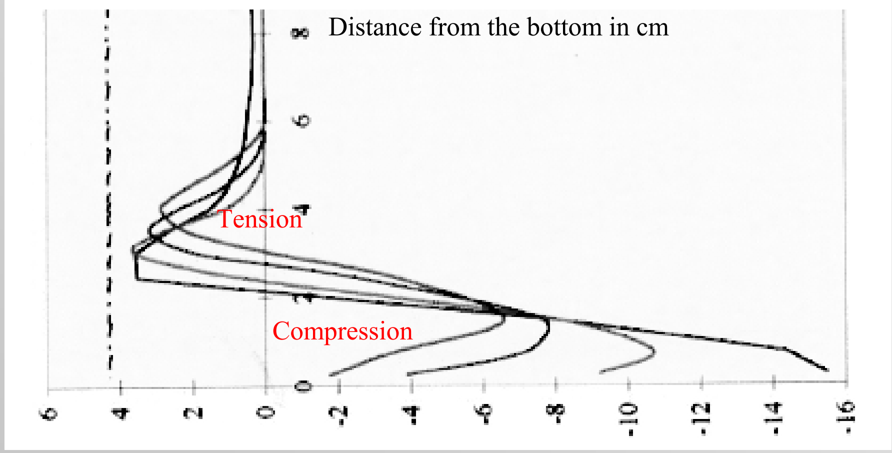
HC 220 mm + 80 mm topping



Heavy spalling at soffit near support after 23 min. fire exposure

Causes of spalling

- **Cumulation of compressive stresses from**
  - Prestressing
  - Hindered longitudinal expansion
  - Force couple to take up the support moment due to heavy loading
  - Induced thermal stresses



Design recommendations

- **Calculation of stresses**

  - Stresses at the underflange due to support moment $M_{neg,fi}$
  - Prestressing force σ_{cp}
  - Compression stresses due to temperature gradient $\sigma_{c,grad}$
  - Compression stresses due to possible blocking of the thermal expansion by the surrounding structure $\sigma_{dil,fi}$

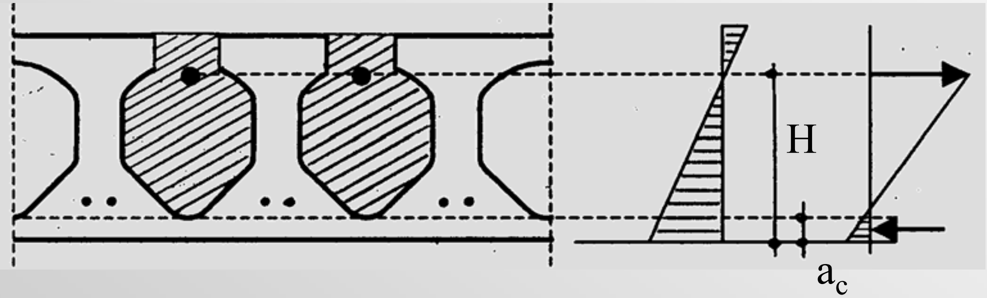
$$\sigma_{Ed,fi} = \sigma_{c,Mneg,fi} + \sigma_{cp} + \sigma_{c,grad} + \sigma_{dil,fi}$$

$$\sigma_{Ed,fi} \leq f_{cd,fi}$$

and $\varepsilon < \varepsilon_{c1,\theta} \cong 0,025$

Design recommendations

- **Calculation example for 90 min. exposure**



$$F_s = f_{s,y} \,.\, A_s$$

$$F_c = \frac{1200.a_c.\sigma_{c,\max}}{2}$$

$$\sigma_{c,M_{neg}} = \frac{\sigma_{c,\max,M_{neg}}}{2} = \frac{f_{sy} \cdot A_s}{1200 \cdot a}$$

$\sigma_{cp} = x$ N/mm² (x symbolizes the stress in the concrete of the underflange at ambient temperature)

strand temperature at 90 minutes fire for 50 mm axis distance: 320 °C

$f_{p,y} / 0.9\, f_{pk} = 0.66$ (Table figure 2)

$\sigma_{cp,fi} = 0.66\, x$

Assumption: $\sigma_{prest,\theta} + \sigma_{dil,\theta} \cong \sigma_{prest}$ at ambient temperature

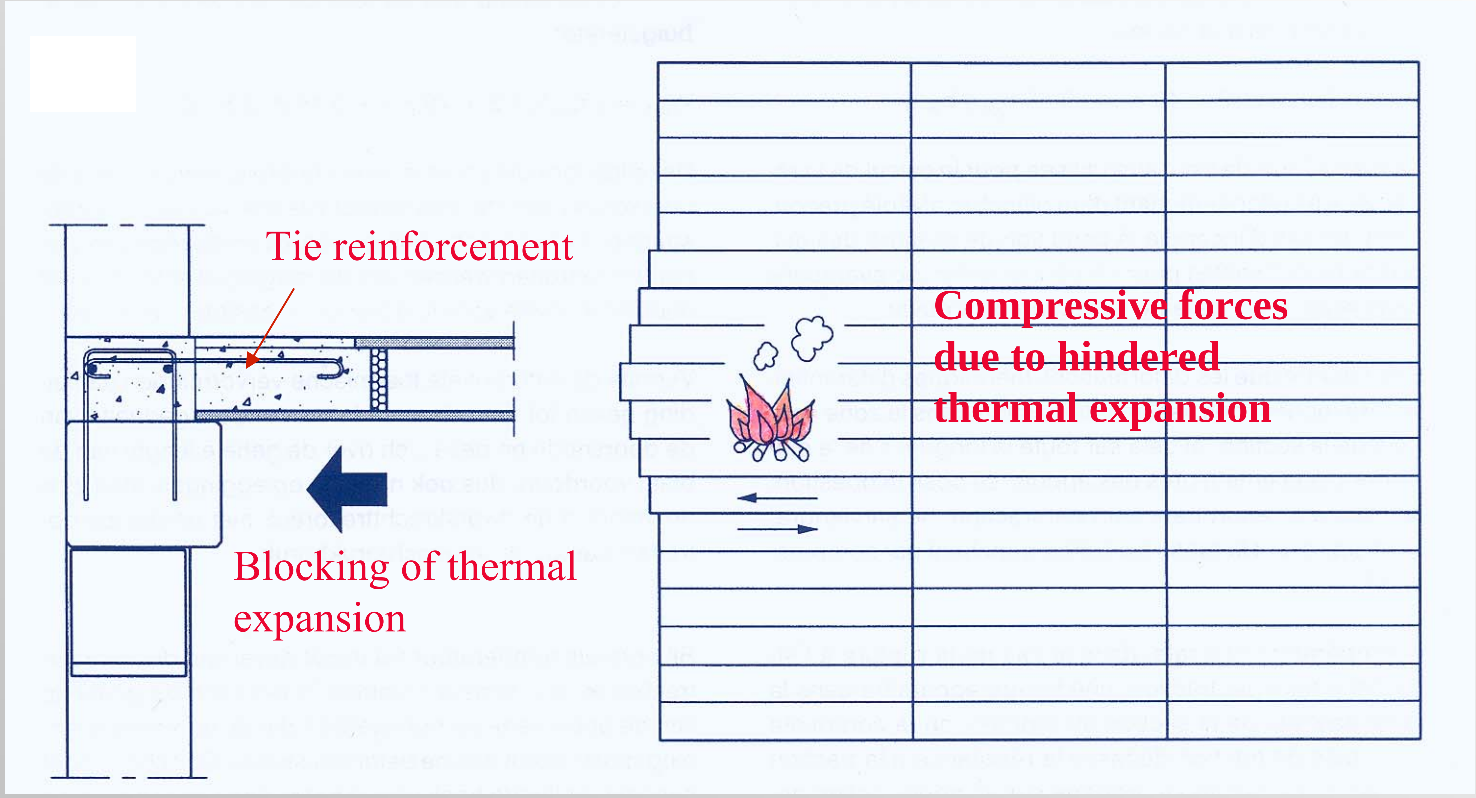
$$\sigma_{d,\theta} = \sigma_{c,Mneg} + \sigma_{prest,\theta} + \sigma_{c,grad}$$

$$= \frac{f_{sy} \cdot A_s}{1200 \cdot a} + \sigma_{prest'max} + 8 \text{ N/mm}^2$$

$\sigma_{d,\theta} \leq f_{cd,\theta}$ (average strength in the underflange after θ minutes fire exposure)

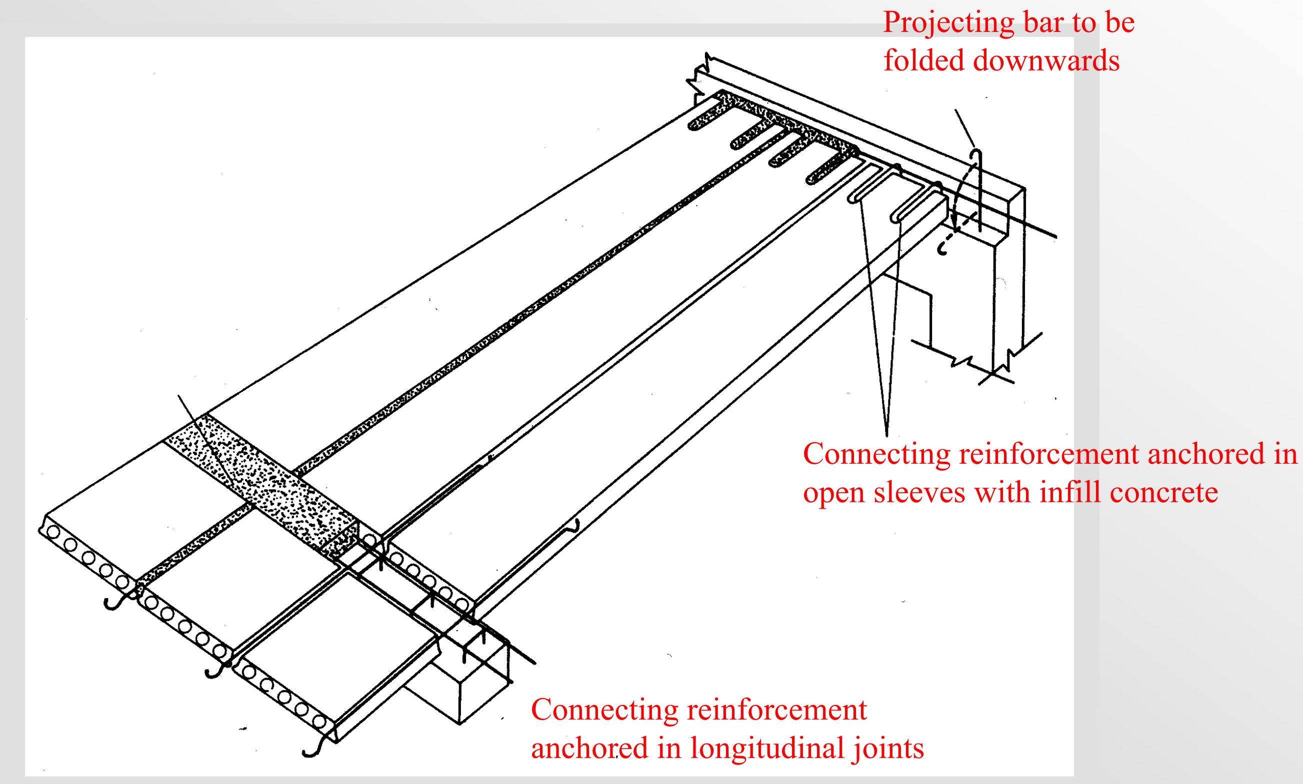
Support connections

- **Function: keep thermal cracks closed**



Support connections

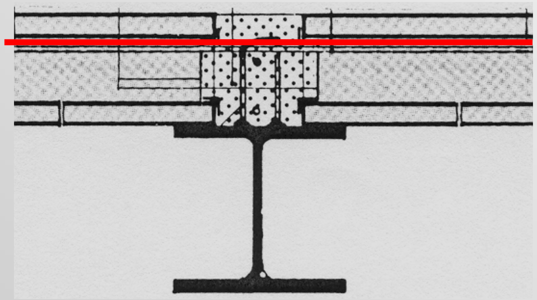
- Alternative solutions

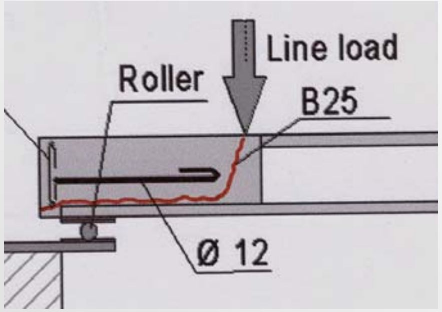


Connections with steel profiles

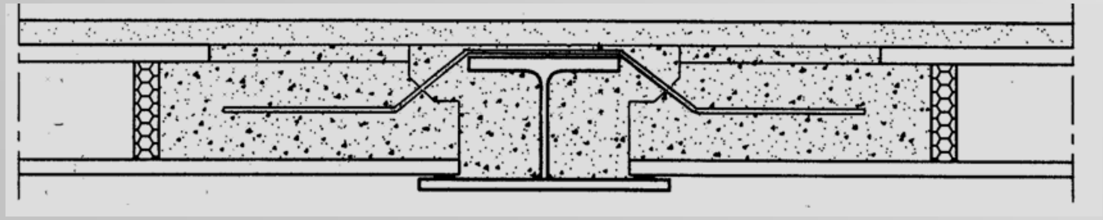
- **Keeping thermal cracks closed**

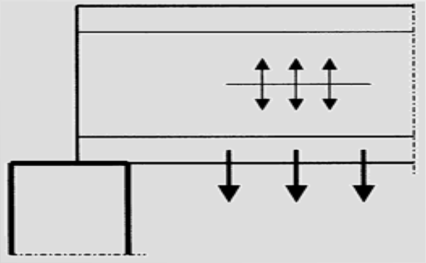
Tie reinforcement





- **Avoid additional tensile stresses in the webs**






Thank you for your kind attention