INTERNATIONAL PRESTRESSED HOLLOWCORE ASSOCIATION

HOLCOFIRE

Behaviour of prestressed hollowcore floors exposed to fire

Flexible supports and fire

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Contents

- Introduction
- Reduction of shear capacity with flexible supports under ambient conditions
- Tests on flexible supports at ambient and fire
- Parameters in flexible supports and fire
- Principles for flexible supports and fire
- Conclusions and recommendations
- Calculation example

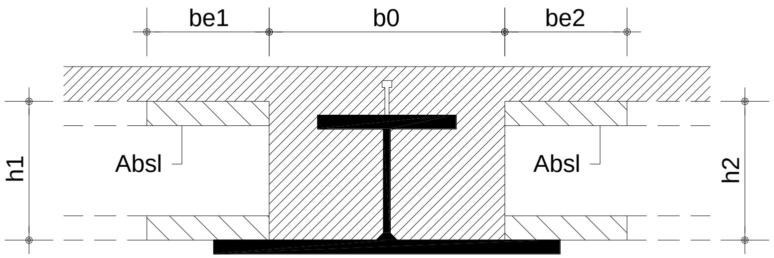
Slim floor structure with hcs

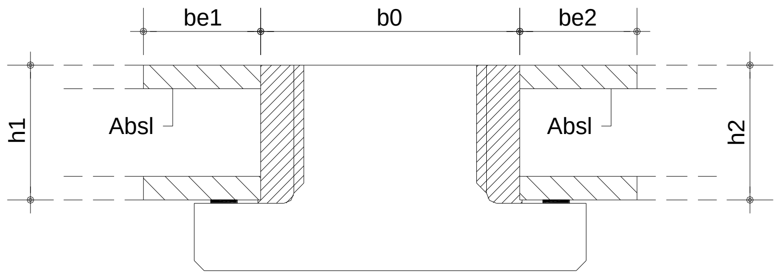
Advantages of slim floors

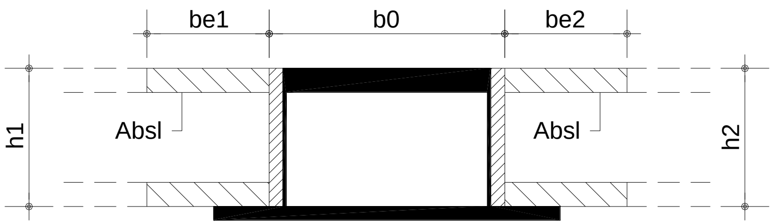
- Developed in 1980s in Scandinavia
  - Fast erection
  - Low self weight
  - High stiffness
  - Low span-to-depth ratio
  - Interior walls can be freely arranged
  - Freedom to arrange ductwork at soffit

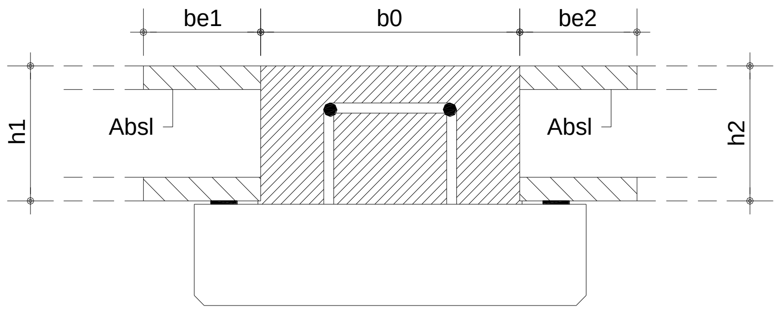
Various types of slender beams

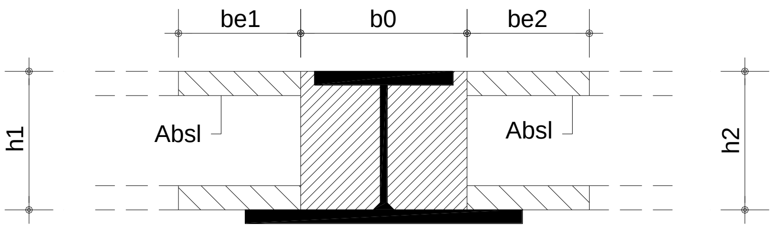
- Steel beams
- Concrete beams





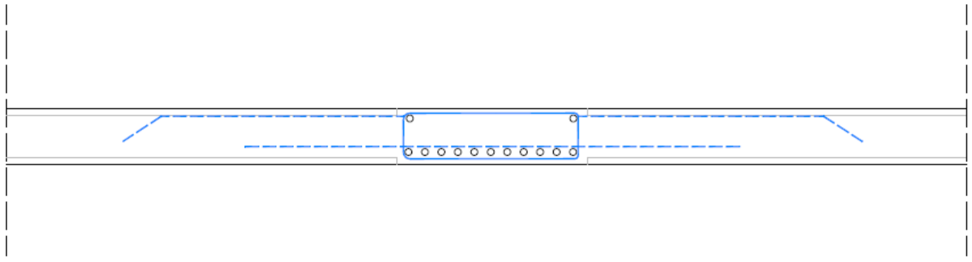


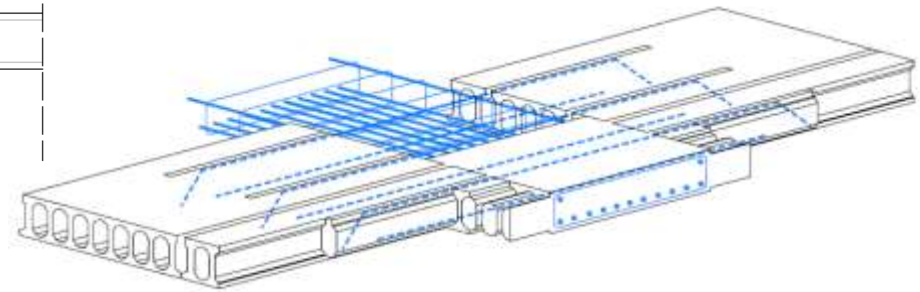


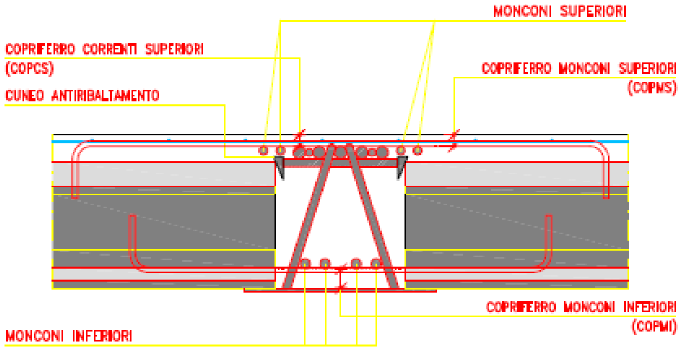


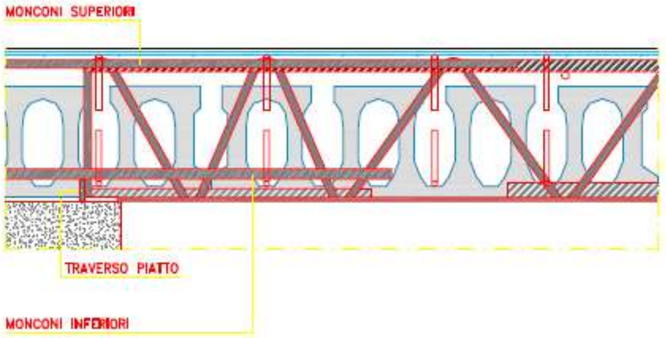
Various types of slender beams

- But also cast in-situ versions

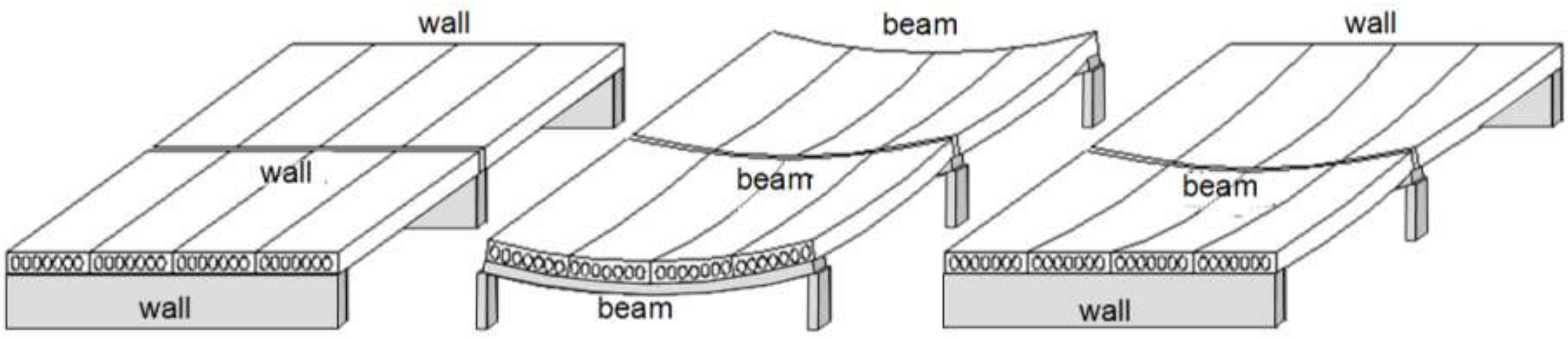


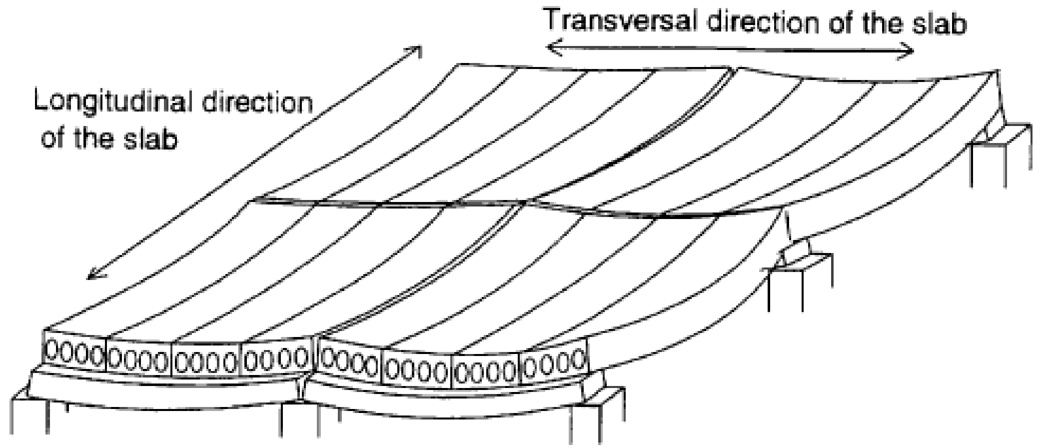




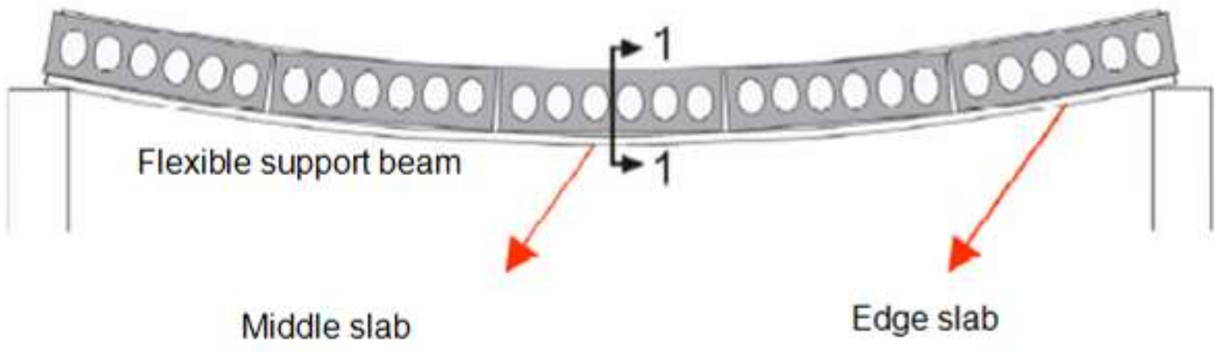


Rigid – flexible support





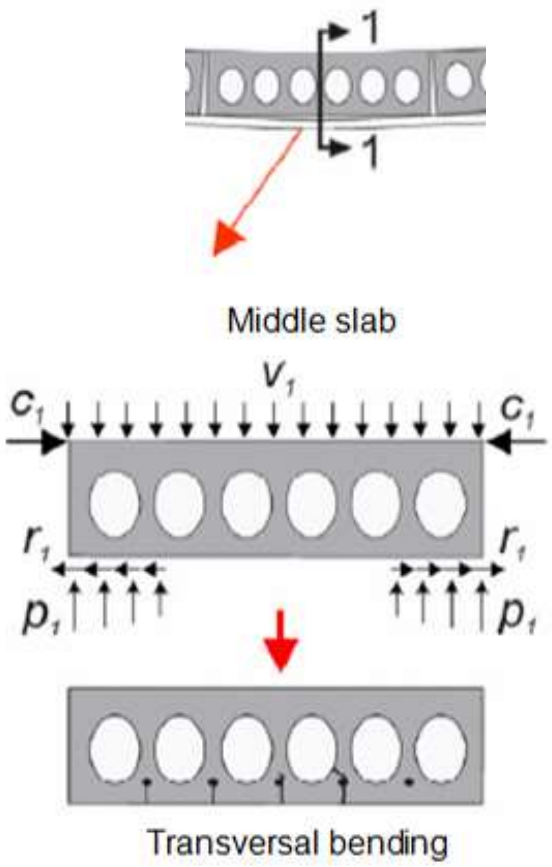
Influence of flexible supports



- Limited stiffness of beam → deformation
- Composite action between beam and slabs
- Additional stresses are introduced:
  - At mid span
  - At support

Influence of flexible supports

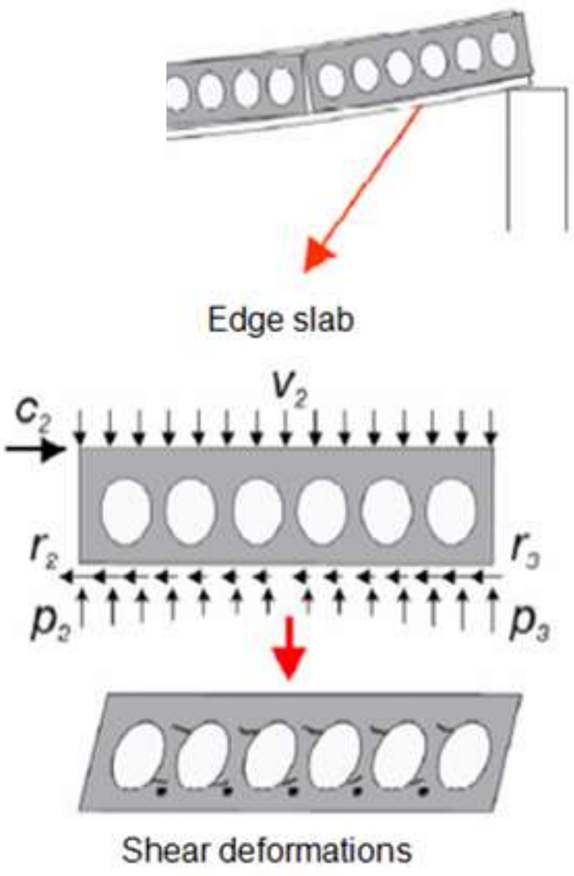
- At mid span at ambient conditions
  - Additional bending stresses
  - Tensile stresses in soffit
  - Splitting cracks along strands
  - Reduced amount of anchored strands
  - Reduction of shear capacity



- But this phenomenon is not determinir lower shear capacity at flexible suppor

Influence of flexible supports

- At support at ambient conditions
  - Deflection of the beam
  - Friction at interface
  - Deformation is hindered
  - Horizontal force is introduced
  - Additional transverse shear stresses τ_2 in the webs of slab
  - Reduction of shear tension capacity



Recent flexible support tests

- Roggendorf [RWTH Aachen 2010] at ambient conditions

test	V_{fl}/V_r [-]	deflection of IFB u_{max} [mm]
1	0.66	56.2 (L/107)
2	0.61	31.4 (L/191)
3	0.68	31.5 (L/190)
4	0.60	29.1 (L/206)
5	0.52	26.8 (L/224)
6	0.78	34.9 (L/172)
7	0.71	32.5 (L/185)
8	0.57	29.8 (L/201)

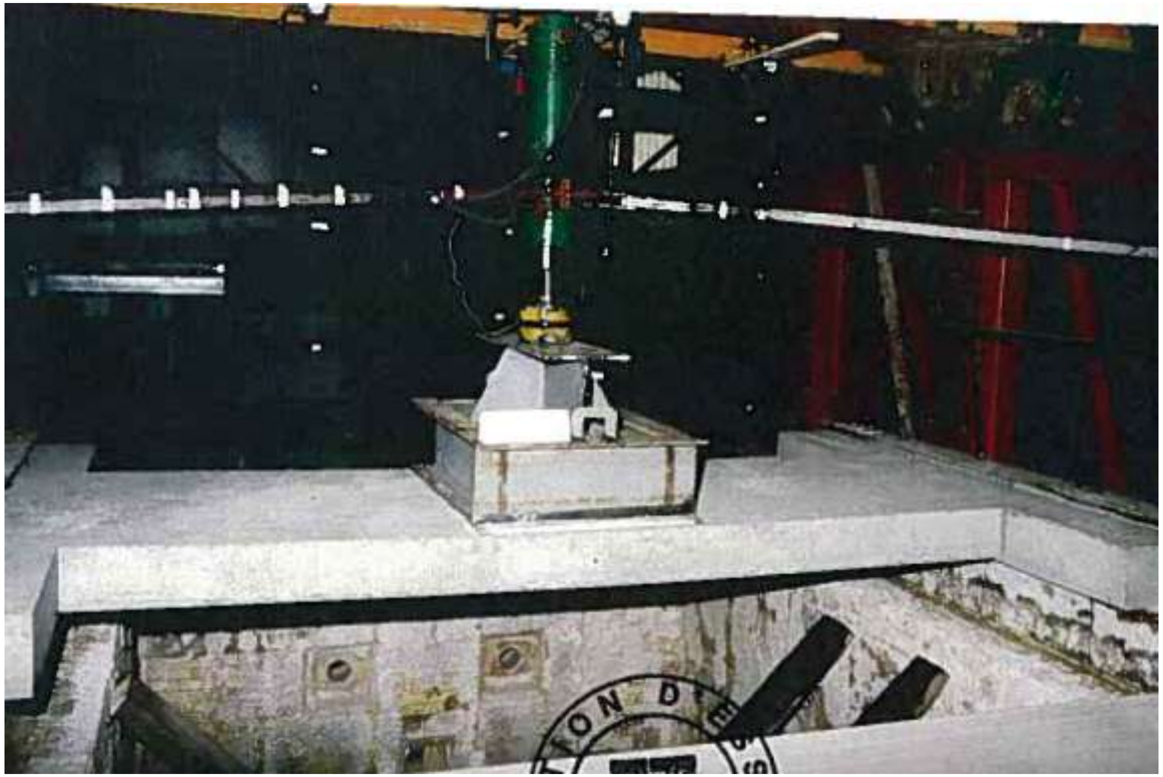
All flexible support tests at fire

- Holcofire database 1966-2010
  - 18 test results of 162 fire test results
  - Flexibility of support doubtful due to short spans

Holcofire fire test #	Fire test name	test year	Fire curve	Slab depth [mm]	topping [mm]	slab width [mm]	total web width [mm]	Total area of strand [mm2/slab]	Axis distance [mm]	Expo sed length of test set up, [m]	width of test set-up [m]	no of slabs	time [min]	Failure after fire
H80	CTICM 93-G-127	1993	ISO 834	160	0	1200	558	416	45	6,4	6	5	32	SB
H81	EMPA 95-1	1994	ISO 834	160	80	1200	526	624	30	4,7	2,4	3	122	R-NO
H82	EMPA B2-1	1995	ISO 834	200	0	1200	472	624	30	4,7	2,4	3	122	R-NO
H83	EMPA B2-2	1995	ISO 834	200	0	1200	472	624	30	4,7	2,4	3	49	SA
H84	EMPA B2-3	1995	ISO 834	200	0	1200	472	624	30	4,7	2,4	3	74,6	OT
H85	EMPA B2-4 PL	1995	ISO 834	200	0	1200	472	624	30	4,7	2,4	3	75,4	SA
H86	EMPA B3-1	1995	ISO 834	200	0	1200	472	624	30	4,7	2,4	3	96,6	SA
H87	EMPA B3-1 PL	1995	ISO 834	200	0	1200	472	624	30	4,7	2,4	3	97,4	R-NO
H88	CTICM 95-E-467	1995	ISO 834	160	50	1197	530	624	50	4	2,4	2	50	SB
H89	CTICM 95-E-533	1995	ISO 834	160	50	1197	530	624	30	4	2,4	2	100	R-DF
H90	CTICM 96-U-349	1996	ISO 834	160	50	1197	530	624	30	4	1,2	1	71	R-DF-SB
H91	CTICM 96-U-350	1996	ISO 834	160	0	1197	530	624	30	4	1,2	1	42	DF-SB
H143	BRE test1	2007	parametric	200	0	1200	330	651	31	7	17,76	15	60	R-NO
H144	BRE test2	2007	parametric	200	0	1200	330	651	31	7	17,76	15	60	R-NO
H145	SPTRI Peikko P802216A	2009	ISO 834	270	0	1200	286	930	35	5,8	3,6	4	60	R-NO
H146	SPTRI Peikko P802216B	2009	ISO 834	270	0	1200	286	930	35	5,8	3,6	4	60,4	R-NO
H147	SPTRI Peikko P802216C	2009	ISO 834	270	0	1200	286	930	50	5,8	3,6	4	120	R-NO
H148	SPTRI Peikko P802216D	2009	ISO 834	270	0	1200	286	930	50	5,8	3,6	4	180	R-NO

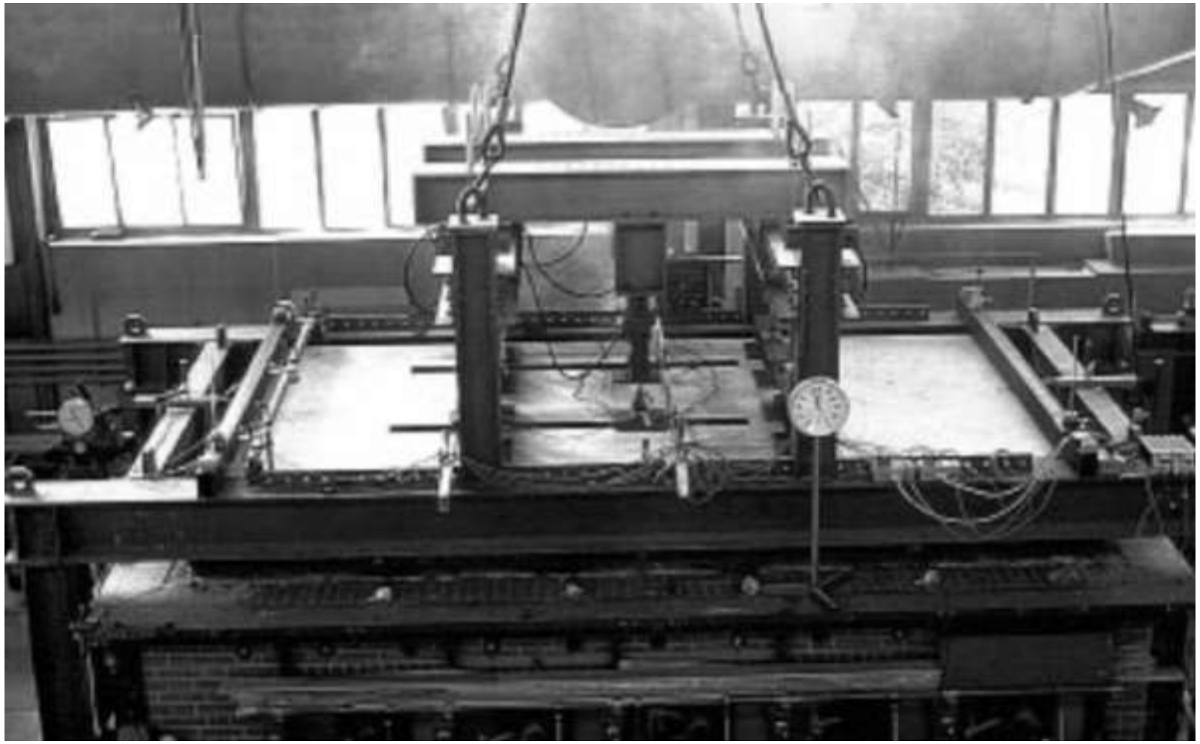
Recent flexible support tests at fire

- CTICM [France, 1993-1996] at fire
  - Not very positive results



Recent flexible support tests at fire

- Borgogno & Fontana [EMPA, 1994-1995] at fire
  - Good results
  - B2-2, B2-4PL and B3-1 failed in shear at 49, 75, 97 minutes



Recent flexible support tests at fire

- Bailey [Cardington, 2007] at fire
  - Not indended at flexible support test
  - Good results, in both tests 60 minutes natural fire

Recent flexible support tests at fire

- Peikko tests [Sweden SP, 2009] on Dealtabeam
  - Short spans of slabs (2.4 m)
  - Good results: 60, 120 and 180 minutes of fire

Conclusions from fire tests

- Although some studies do exist with bad and good result, flexible supports and fire has not been comprehensively studied
  - Size of furnaces, maximum 4 x 6 m
  - Short spans of slabs
  - Too costly
- But a new Holcofire experiment would most probably not yield to new insights or new information → "desk study"

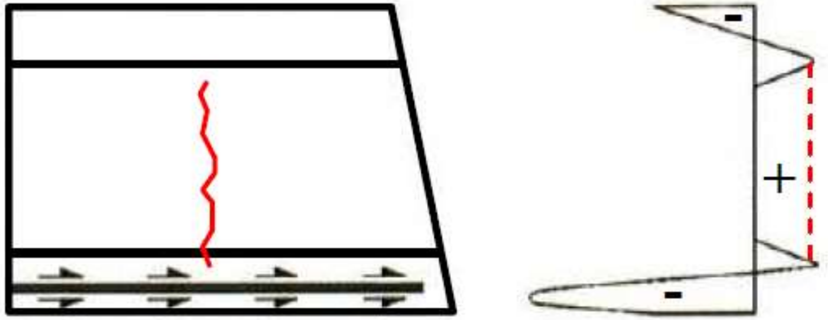
Parameters flexible support and fire

a. Induced thermal stresses and vertical web cracking
b. Thermal expansion of underflange
c. Deflection of the supporting beam
d. Continuous supporting beam
e. Imposed loading
f. Web width
g. Tensile strength of the concrete
h. Type of connection with the supporting beam
i. Structural topping

Parameters flexible support and fire

a. Induced thermal stresses and vertical web cracking

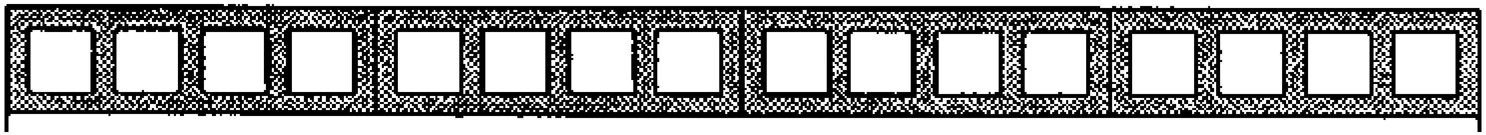
- After 15 minutes vertical cracking at regular distances
- By definition shear tension cannot occur anymore
- Same as in rigid supports and fire
- Significantly different than flexible support at ambient conditions

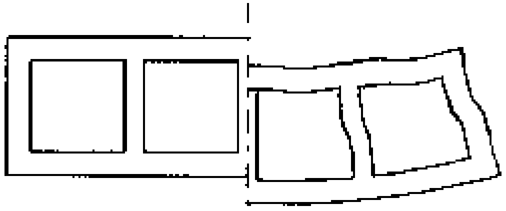


Parameters flexible support and fire

b. Thermal expansion of underflange

- Compressive stresses in underflange
- Additional curvature of hollow cores
- At support compressive stresses
- At mid span lower compressive stresses which results in lower spalling chances

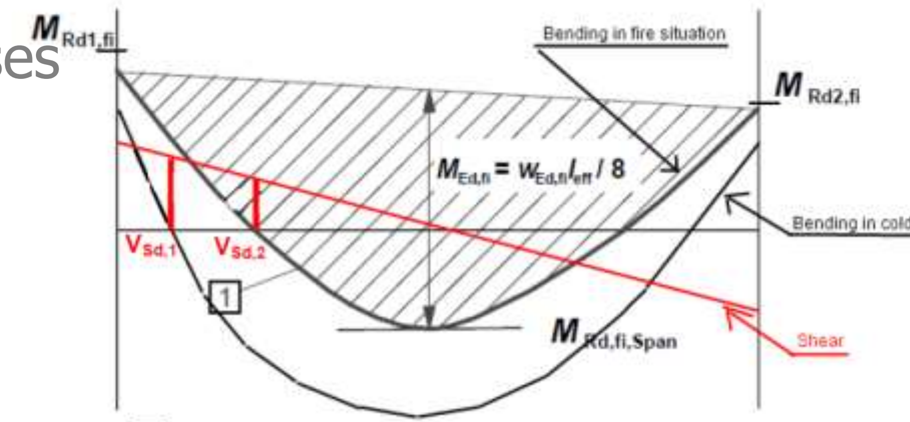




Parameters flexible support and fire

d1. Continuous supporting beam

- Due to fire point of zero moment moves
- Shear load at zero moment point is lower
- Significant decrease of shear stresses



1 Free moment diagram for uniformly distributed load under fire conditions

D2. Floor continuity

- reduce floor deflection
- Reduce beam deflection by enlarging beam compression flange
- reduce transversal shear flow and increase compression at upper flange at cold and also at fire

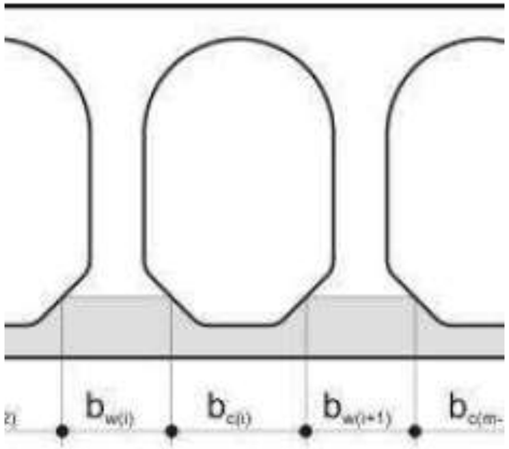
Parameters flexible support and fire

e. Imposed loading

- Design value of imposed loading is much smaller frequent load value $\psi 1$

f. Web width

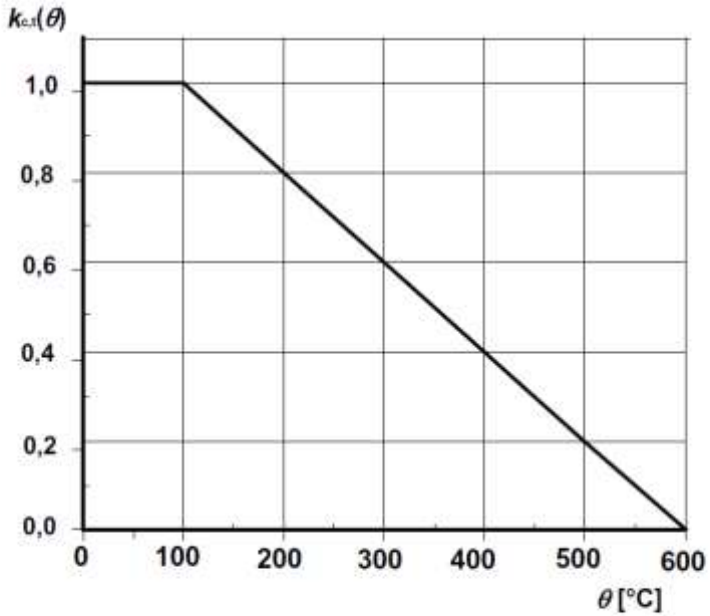
- Same for rigid and flexible support
- Same for ambient and fire conditions



Parameters flexible support and fire

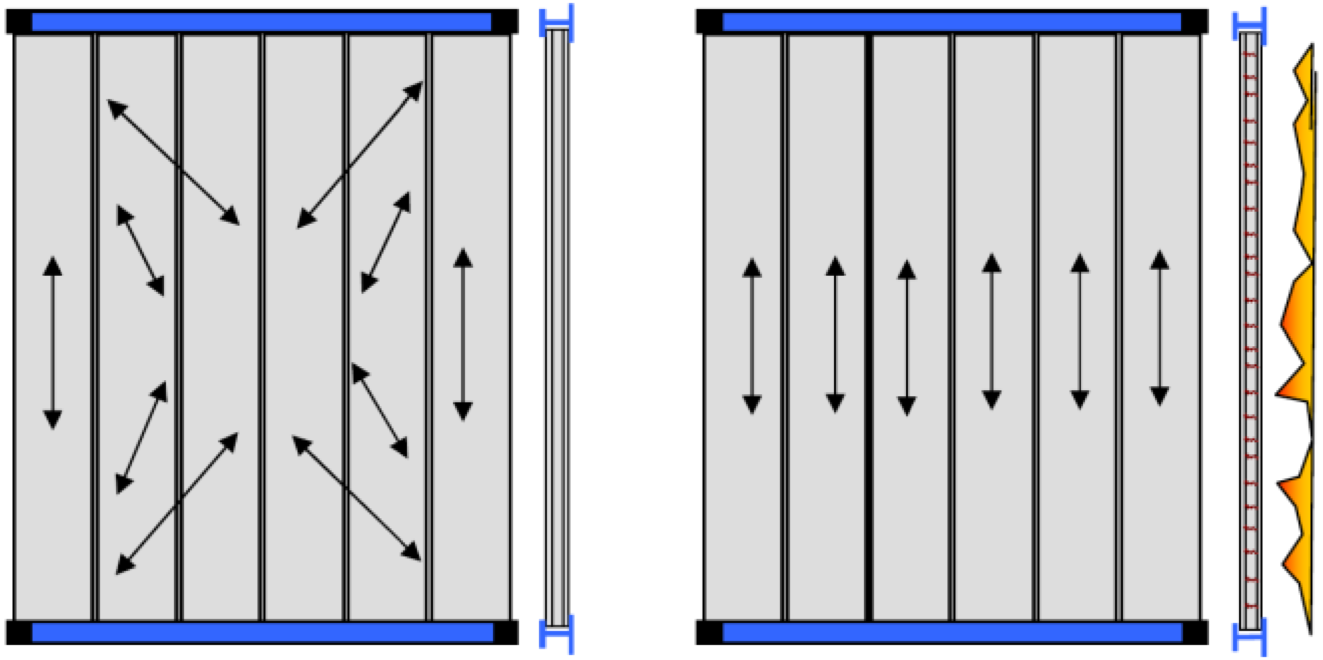
g. Tensile strength of the concrete

- No differences between rigid or flexible support
- Decrease during fire according to EN1992-1-2 Figure 3.2



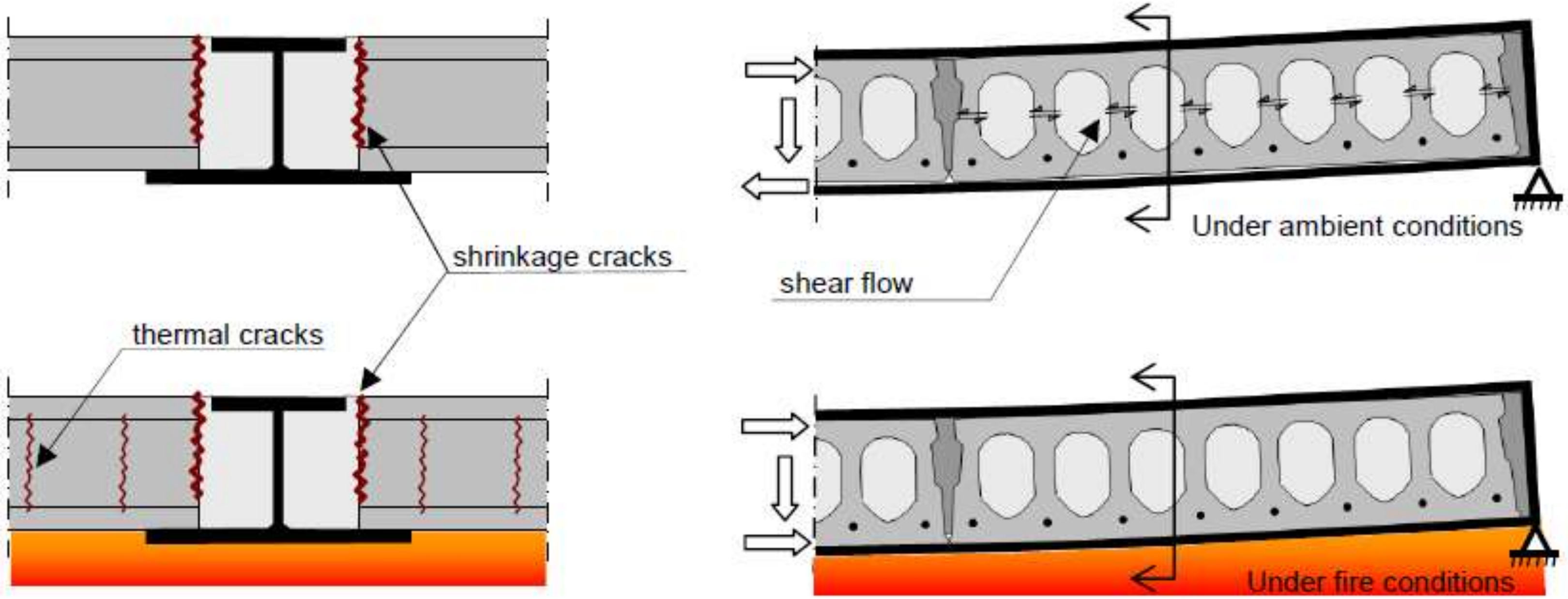
Principles flexible support and fire

- Ambient vs fire situation
  - Stiff floor field with load to stiff columns
  - Less stiifness with load in longitudinal direction



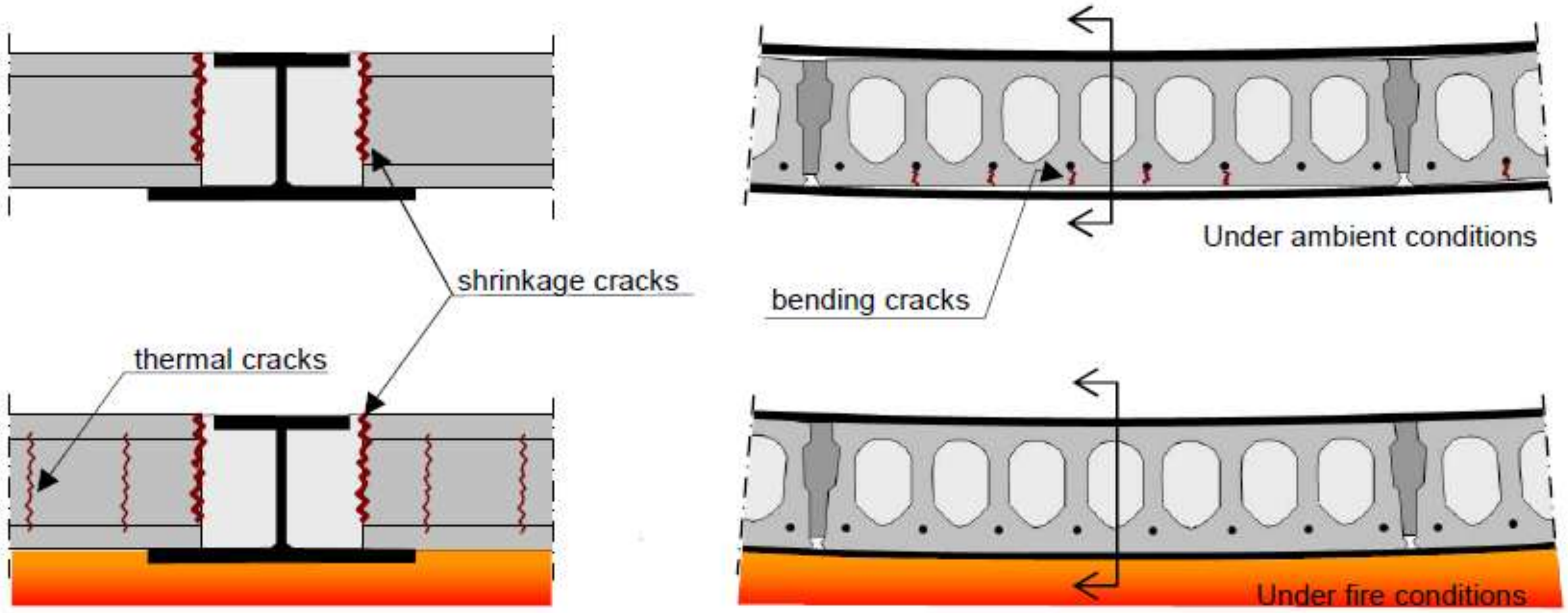
Principles flexible support and fire

- At support
  - Due to expansion of soffit another compression force is introduced that compensated additional shear stresses
  - Due to vertical web cracking by definition no shear tension



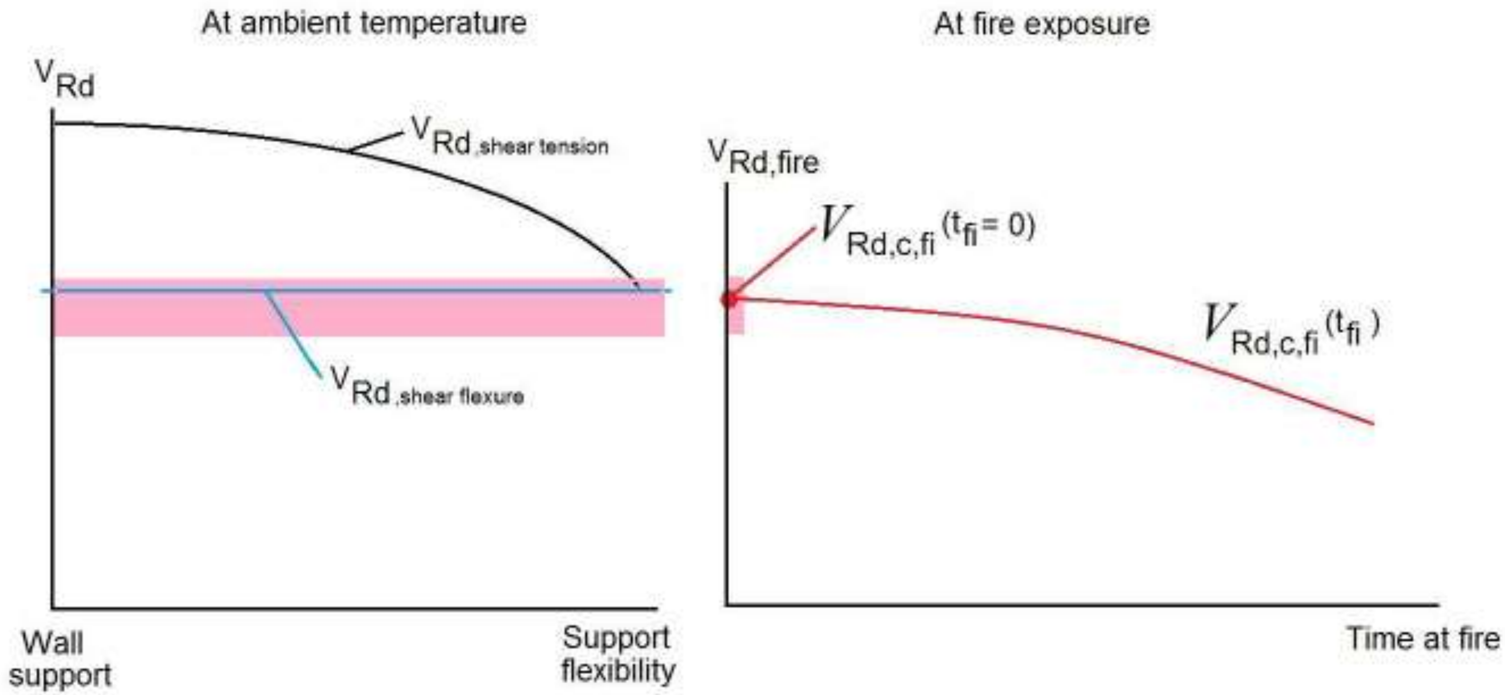
Principles flexible support and fire

- At mid span
  - Additional bending stresses are compensated by the expansion of the underflange
  - Strands remain well anchored during the fire



Principles flexible support and fire

- Due to thermal gradient vertical cracks initiate and shear capacity "drops" from shear tension to shear flexure which is dependent on time at fire → use EN1168 Annex G !!



Validation with fire tests

- In 3 tests shear failure observed
- Analysis from database study show > 100%

TEST ID		Fire test		EN1168 Annex G		Test/ Annex G [%]	
		Shear load [kN/m^1]	Time to failure [minutes]	Shear capacity [kN/m^1]	Time to failure [minutes]		
H83	EMPA B2-2 [1995]	35.1	49	32,9	36	106.7%	L/330
H85	EMPA B2-4 PL [1995]	35.8	75	29.6	37	121,4%	L/320
H86	EMPA B3-1 [1995]	28.6	97	15.1	30	189,4%	L/1200

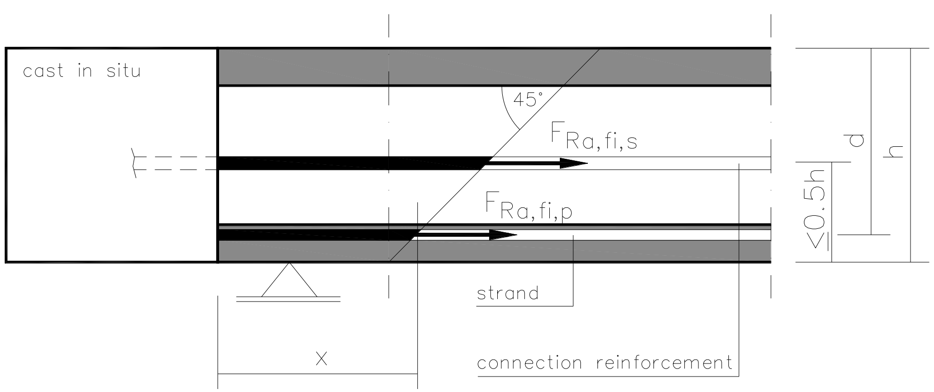
- Use of EN1168 Annex G is safe
  - Walraven/Vrouwenvelder: "It is a widely accepted procedure to put only one single specimen of a product to a fire test and approve it if the required time of fire duration is met without failure. The consequence is that the models of Annex G are considered as being confirmed if the mean value of the ratio between experimentally obtained and predicted results is at least equal to one".

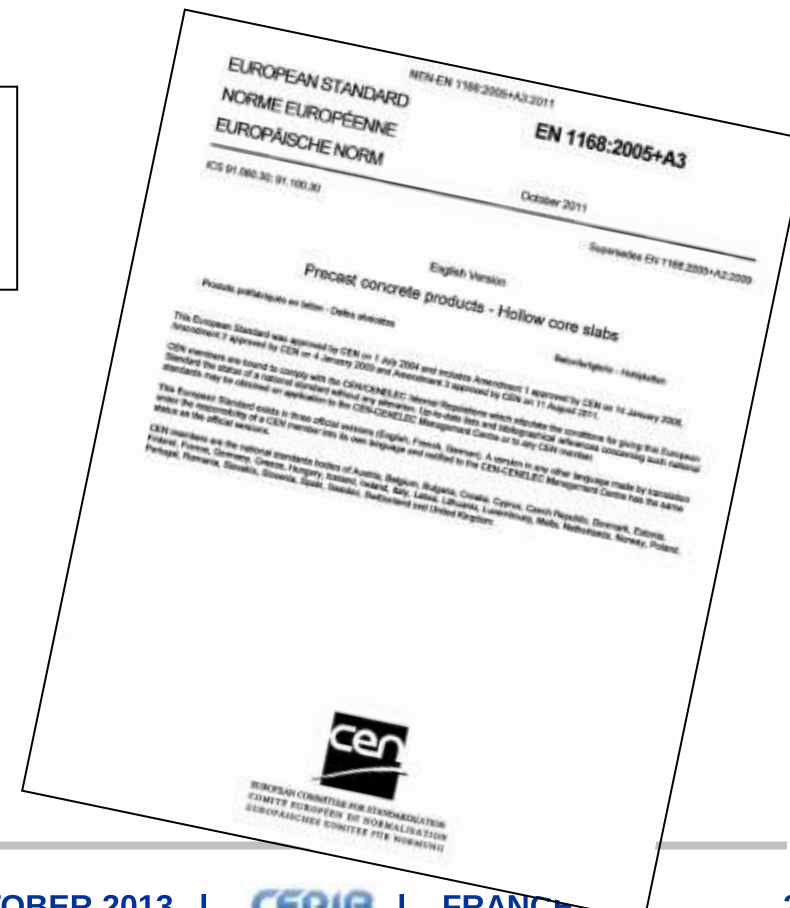
Conclusion and recommendation

- EN1168:2005+A3:2011 is recommended for hollow core slabs at fire on rigid and flexible supports

The empirical shear equation under fire conditions is:

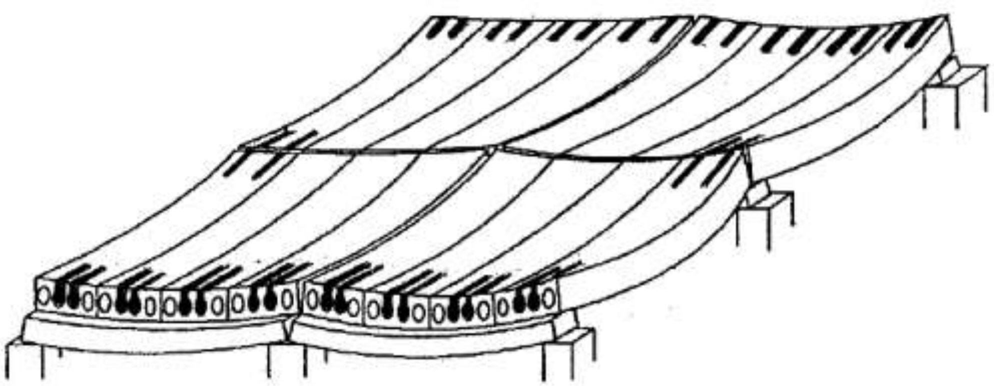
$$V_{Rd,c,fi} = [C_{\theta,1} + a_k \times C_{\theta,2}] \times b_w \times d$$





Conclusion and recommendation

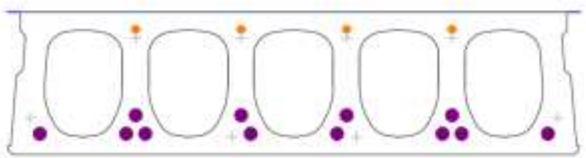
- The fire resistance of structures with hollow core slabs is improved by [ECCS/IPHA, 1998]:
  - The use of tying reinforcement to provide alternative load paths
  - A reinforced concrete topping to control the effect of cracking and to provide additional tying action for integrity reasons
  - Infilling of the hollow cores to strengthen the slab locally, and to permit placement of tie reinforcement
  - The effect of protection of the beam support to the hollow core slabs.



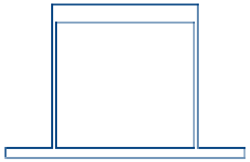
Calculation example

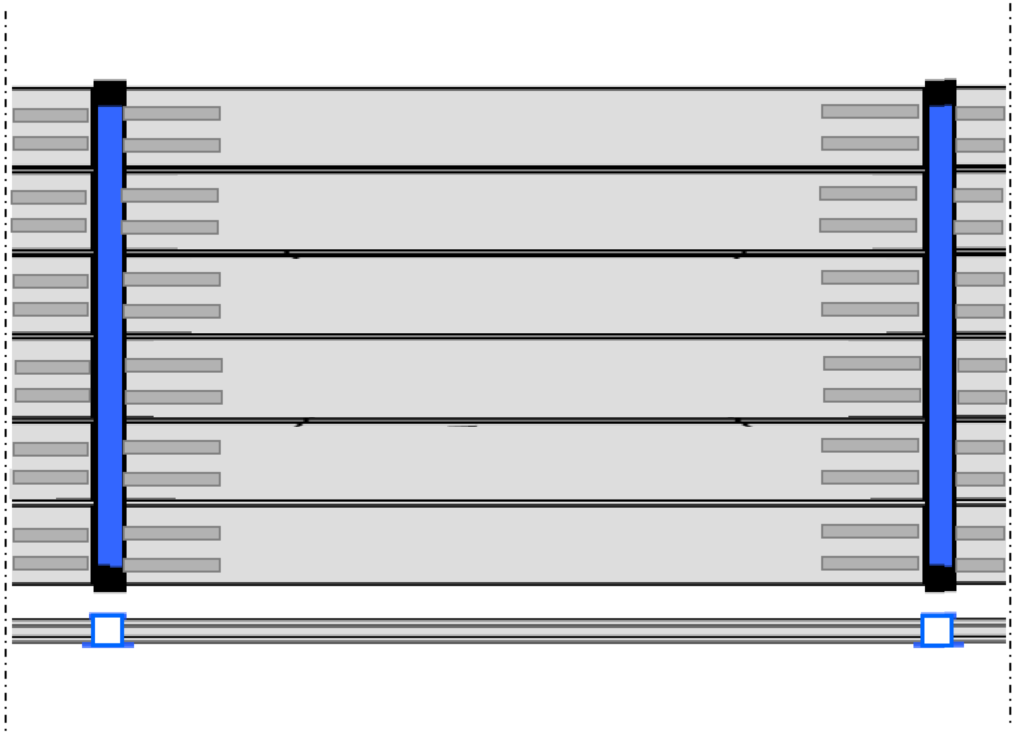
- Consider a floor field with module of 7,20 m x 12,60 m

- Hollow core 315 mm



- THQ320





- No structural topping

Calculation example

- Hollow cores
  - depth 315 mm with 5 cores cast in C45/55
  - 12 strands 12,5 mm at 46 mm and 87 mm axis distance and 4 upperstrands at 277 mm (X8X4-D4)
  - The span of the slabs is 12180 mm with 80 mm support length and filled cores for 50 mm
  - Total web width 316 mm
  - Thickness of upperflange / underflange 40 mm,
  - Connection reinforcement 2∅16 per slab in 2 cores
- Support:
  - beam THQ 320 with 7200 mm support length
- Loads:
  - self weight plus live load = 5,0 kN/m2
  - finishing = 1,0 kN/m2

Calculation example

	Rigid support	Flexible support
Ambient conditions	Uncracked situation = shear tension $V_{Rd,c}$ = 185,0 kN (EN1168) Cracked situation = shear flexure $V_{Rd,c}$ = 147,5 kN (EN1992) $V_{Rd,c,min}$ = 124,2 kN (EN1992)	Uncracked situation = shear tension $V_{Rd,c}$ = 170,9 kN (fib 6) Cracked situation = shear flexure $V_{Rd,c}$ = 147,5 kN (EN1992) $V_{Rd,c,min}$ = 124,2 kN (EN1992)
Fire situation	Cracked situation (thermal vertical web cracks) = shear flexure $V_{Rd,c,fi,30}$ = 106,8 kN (EN1168 Annex G) $V_{Rd,c,fi,120}$ = 92,9 kN/slab (EN1168 Annex G) *In capacity under fire 2∅16 connection reinforcement is taken into account*	