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Non-rigid supports

Ronald Klein-Holte
Consolis VBI | The Netherlands

Organized by

INTERNATIONAL PRESTRESSED HOLLOWCORE ASSOCIATION

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IPHA Design Course
Hollow core slab and Floor design

Non-rigid supported hollow core floor

INTERNATIONAL PRESTRESSED
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Introduction

Need for flexible, adaptable space

❑ Reduce the number of columns
❑ Long spans >> hollow core floor
❑ With integrated steel, concrete or composite beams
❑ Minimize the structural depth >> possibilities for an additional storey
❑ Clear route for services

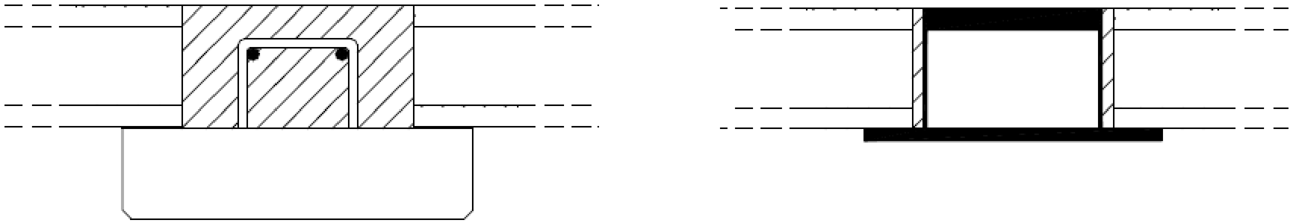
Introduction

Non-rigid supported hollow core floor

- Reduce the number of columns
- Long spans >> hollow core floor
- With integrated steel, concrete or composite beams
- Minimize the structural depth >> possibilities for an additional storey
- Clear route for services

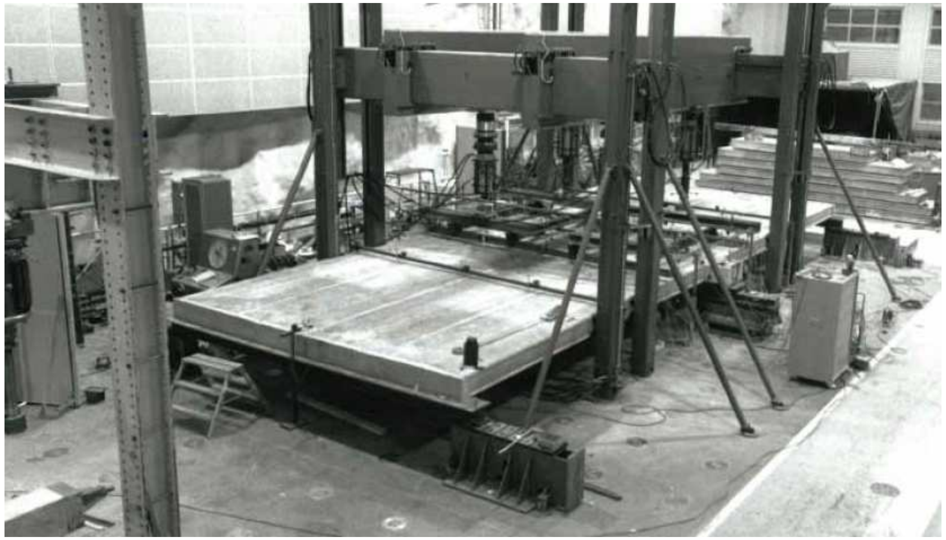
Introduction

Integrated beams – Shallow beams



Introduction

Integrated beams – Shallow beams



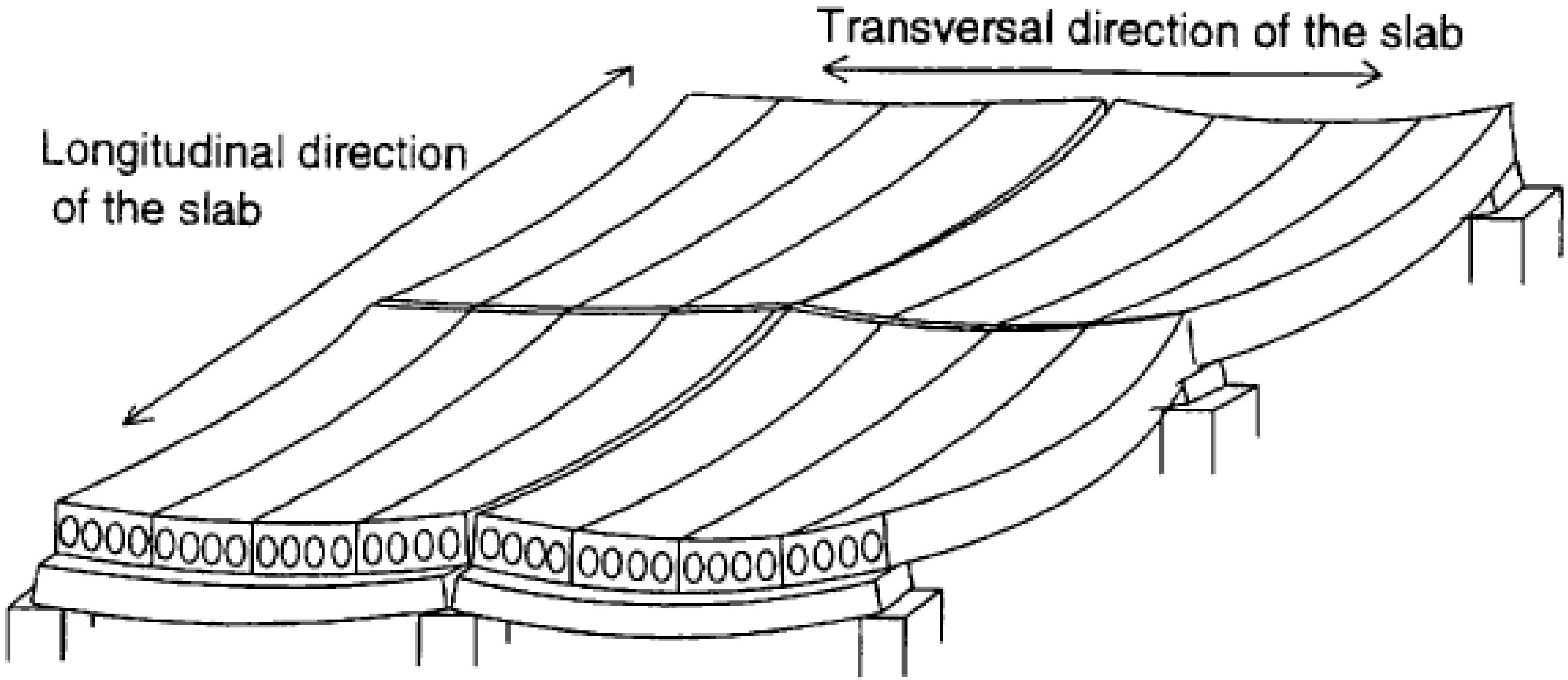
Preliminary tests showed that the

resisting shear force was influenced

by the behaviour of the integrated beam.

Mechanical behaviour

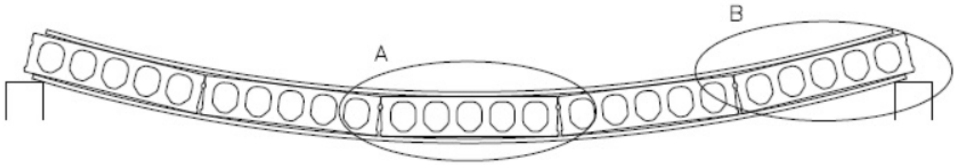
Bending in two directions



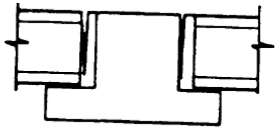
Mechanical behaviour

Bending in two directions

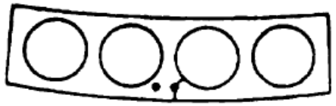
Due to loading the floor and the beam deflect.



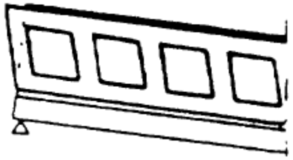
Cracks at the interface of beam and in situ concrete or in situ concrete and end of the hollow core unit.



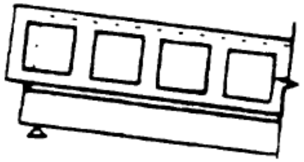
Longitudinal cracks along strands (A)



Shear deformation of the hollow core slab (B) or



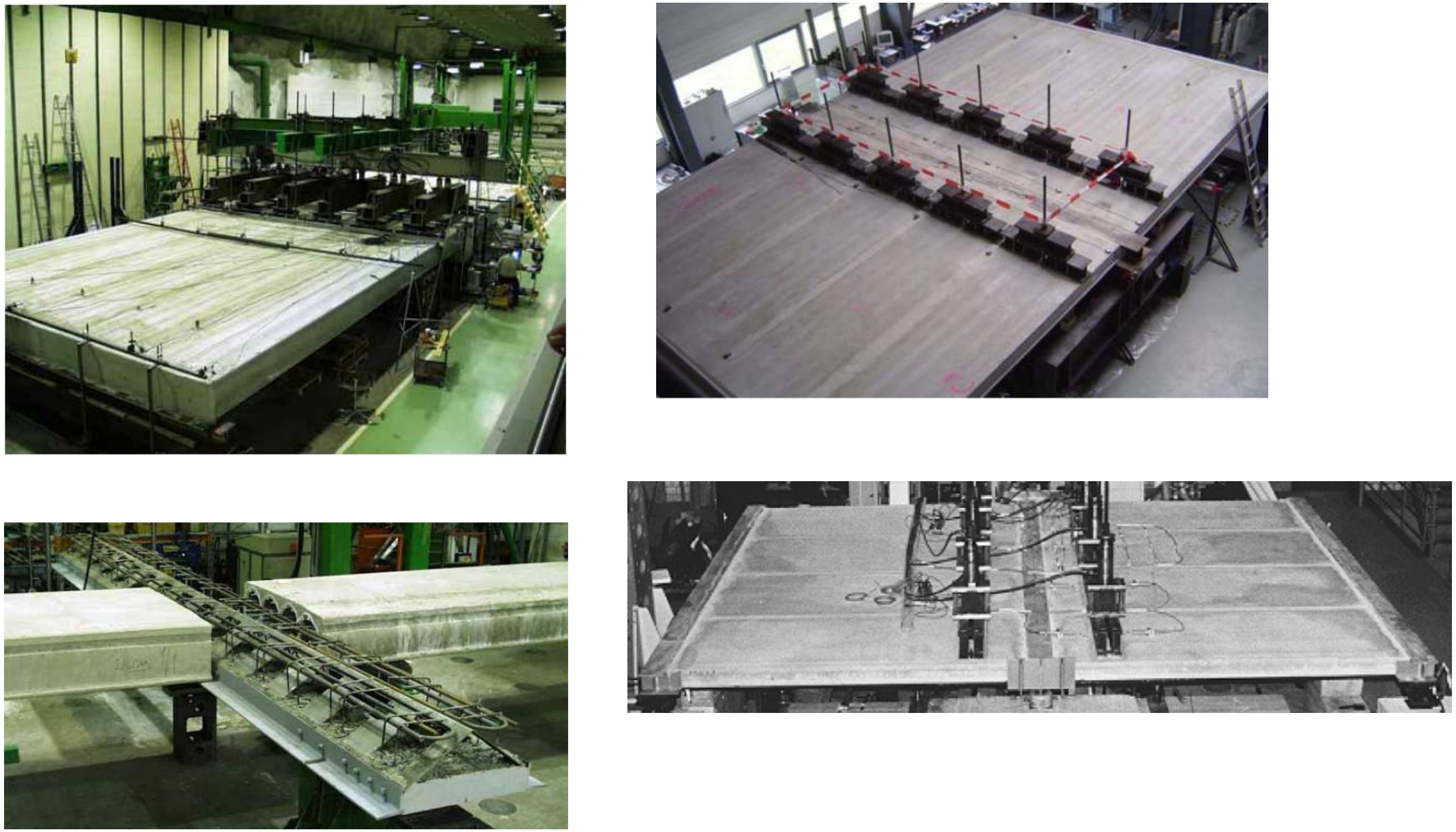
sliding of hollow core slab along the beam (B)



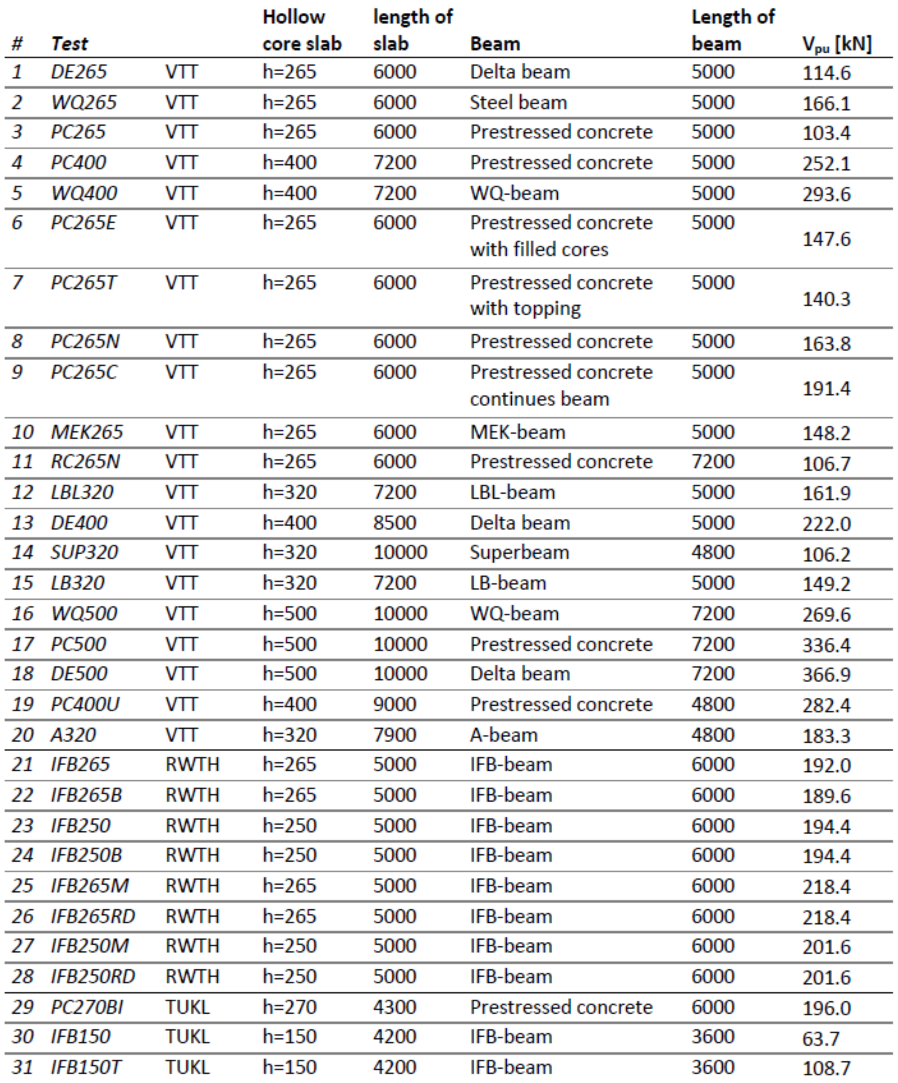
=> non-intended composite action

Full scale tests

Tests in the 1990’s and 2000’s

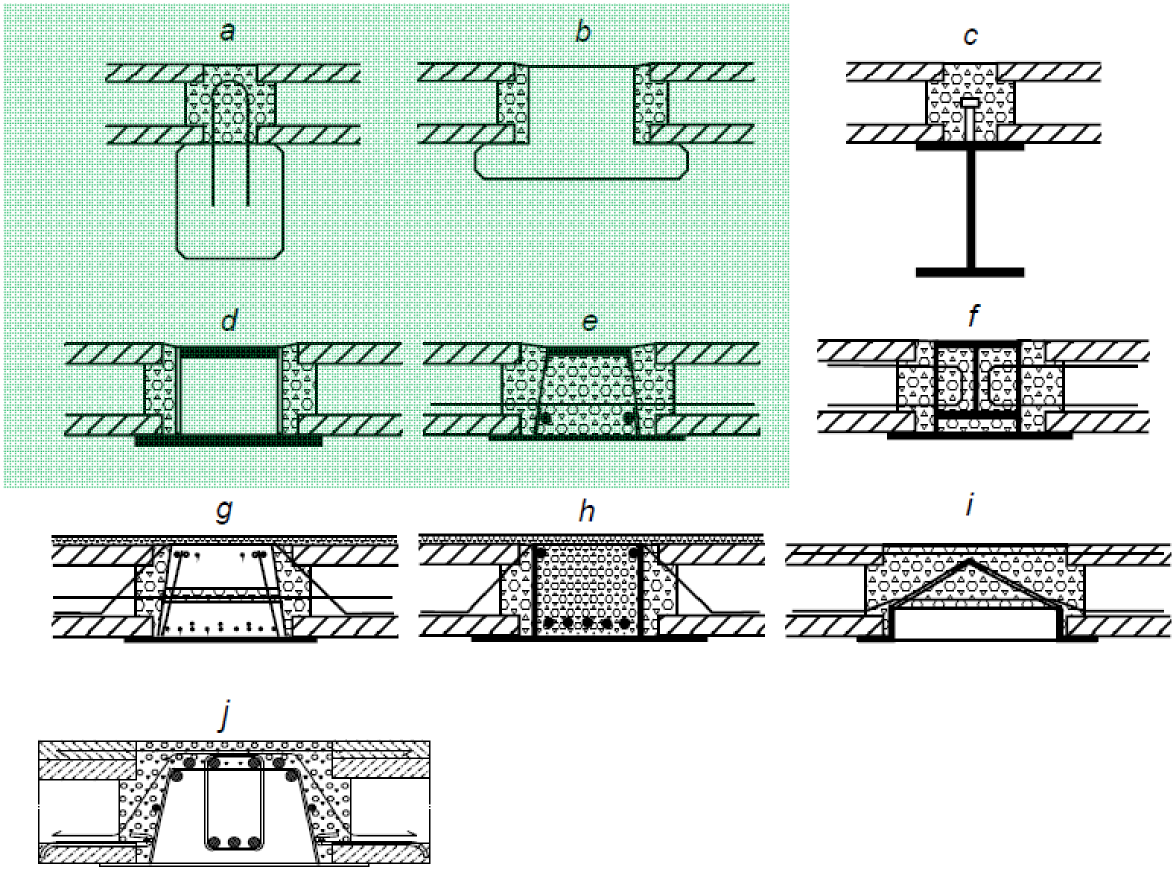


Full scale tests



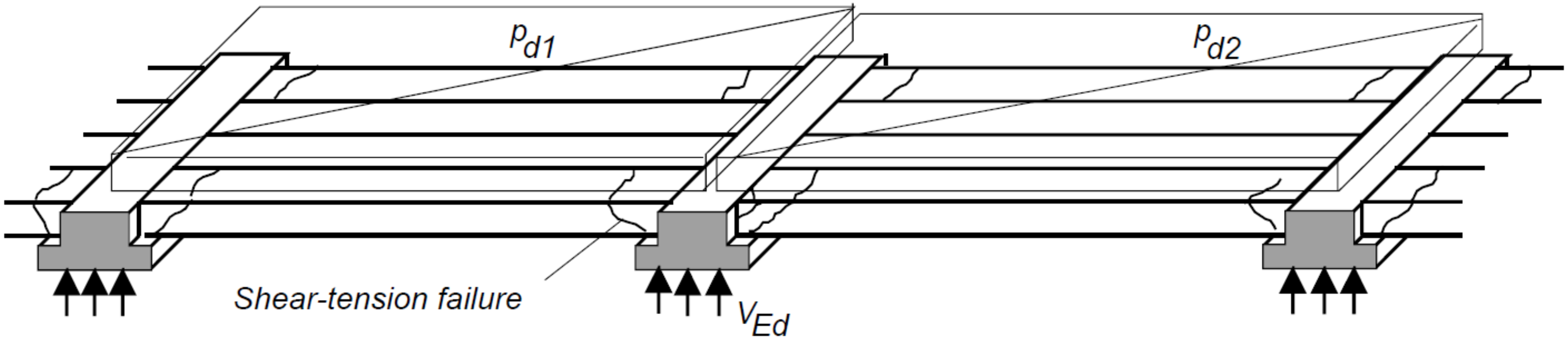
#	Test		Hollow core slab	length of slab	Beam	Length of beam	V_{pu} [kN]
1	*DE265*	VTT	h=265	6000	Delta beam	5000	114.6
2	*WQ265*	VTT	h=265	6000	Steel beam	5000	166.1
3	*PC265*	VTT	h=265	6000	Prestressed concrete	5000	103.4
4	*PC400*	VTT	h=400	7200	Prestressed concrete	5000	252.1
5	*WQ400*	VTT	h=400	7200	WQ-beam	5000	293.6
6	*PC265E*	VTT	h=265	6000	Prestressed concrete with filled cores	5000	147.6
7	*PC265T*	VTT	h=265	6000	Prestressed concrete with topping	5000	140.3
8	*PC265N*	VTT	h=265	6000	Prestressed concrete	5000	163.8
9	*PC265C*	VTT	h=265	6000	Prestressed concrete continues beam	5000	191.4
10	*MEK265*	VTT	h=265	6000	MEK-beam	5000	148.2
11	*RC265N*	VTT	h=265	6000	Prestressed concrete	7200	106.7
12	*LBL320*	VTT	h=320	7200	LBL-beam	5000	161.9
13	*DE400*	VTT	h=400	8500	Delta beam	5000	222.0
14	*SUP320*	VTT	h=320	10000	Superbeam	4800	106.2
15	*LB320*	VTT	h=320	7200	LB-beam	5000	149.2
16	*WQ500*	VTT	h=500	10000	WQ-beam	7200	269.6
17	*PC500*	VTT	h=500	10000	Prestressed concrete	7200	336.4
18	*DE500*	VTT	h=500	10000	Delta beam	7200	366.9
19	*PC400U*	VTT	h=400	9000	Prestressed concrete	4800	282.4
20	*A320*	VTT	h=320	7900	A-beam	4800	183.3
21	*IFB265*	RWTH	h=265	5000	IFB-beam	6000	192.0
22	*IFB265B*	RWTH	h=265	5000	IFB-beam	6000	189.6
23	*IFB250*	RWTH	h=250	5000	IFB-beam	6000	194.4
24	*IFB250B*	RWTH	h=250	5000	IFB-beam	6000	194.4
25	*IFB265M*	RWTH	h=265	5000	IFB-beam	6000	218.4
26	*IFB265RD*	RWTH	h=265	5000	IFB-beam	6000	218.4
27	*IFB250M*	RWTH	h=250	5000	IFB-beam	6000	201.6
28	*IFB250RD*	RWTH	h=250	5000	IFB-beam	6000	201.6
29	*PC270BI*	TUKL	h=270	4300	Prestressed concrete	6000	196.0
30	*IFB150*	TUKL	h=150	4200	IFB-beam	3600	63.7
31	*IFB150T*	TUKL	h=150	4200	IFB-beam	3600	108.7

Integrated beams – Shallow beams



Full scale tests

Shear-tension failure



Publications

VTT WORKING PAPERS 148

Matti Pajari

Prestressed hollow core slabs
supported on beams

Finnish shear tests on floors in 1990–200

Thomas Roggendorf

Zum Tragverhalten von
Spannbeton-Fertigdecke
bei biegeweicher Lageru

1

CODE CARD No 18
Design of hollow core slabs supported on beams

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1. INTRODUCTION
2. SCOPE
3. ULTIMATE LIMIT STATE
4. SERVICEABILITY LIMIT STATE
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6. BACKGROUND DOCUMENTS AND REFERENCES

ANNEX A: Evaluation of unit shear flows $v^1_{\ell 1}$ and $v^1_{\ell 2}$

ANNEX B: Design parameters $b_{hc}/A_{v\ell}$ (horizontal shear
hollow core slabs) and β_f (reduction of the ho
and the compressive stress σ_{cp} at the critical
prestress

ANNEX C: Factors that influence the horizontal transvers
of the hollow core slabs

ANNEX D: Worked example

ANNEX E: Material properties of the concrete, comparis
and former concrete code of Finland, RakMK
complementary section that appears only in th

Note: This English edition for the Code Card No 18
edition from 01.05.2012, but some changes w
Finnish edition so as to amend its use. T
example was changed so as to make it r
phenomena included. The translation and ec
Matti V. Leskelä and was supported financial
Update and modifications to the Finnish vers
not all of the types of shallow floor beam a
edition are included. Also the data in the wor
is different from the one in the Finnish editio
examples are similar.

Code Card No18 English edition for Peikko Group Oy with updates 25.11.2012
Based on the Eurocode edition in Finnish 01.05.2012

CUR
Civieltechnisch Centrum Uitvoering Research en Regelgeving

CUR/BmS - Aanbeveling 104

Vloeren van kanaalplaten met
geïntegreerde liggers

Aanvullende bepalingen op	NEN 6720:1995 (VBC 1995) NEN 6770:1997 (TGB Staalconstructies) NEN 6071:2001 (Brandwerendheid betonconstructies) NEN 6072:2001 (Brandwerendheid staalconstructies) NEN 6722:2002 (VBU 2002)

orpen waarvoor nog geen
ontstaan tevens situaties
g regelgeving ontbreekt,
toepassing belemmerd.
den waarom CUR/BmS-
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twikkeling in. Onderzoek
de stalen of betonnen lig-
rking van de kanaalplaten
e tot dan niet werd onder-
oelaatbare ontwerpdwars-
negentig in opdracht van
kennis opgeleverd. Bij dit
ste kanaalplaten, met een
maximale hoogte van een
venmin voor kanaalplaten

ngere tijd gecontroleerd
aan de eisen die in deze
lerzoek. Aandacht wordt
e geïntegreerd moet wor-
verhogen, kan de toelaat-
i.

S-voorschriftencommissie
oment van publicatie van

B.V.

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bulletin 6

fib
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Special design
considerations for
precast prestressed
hollow core floors

guide to good practice

Design model

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Codecard 18
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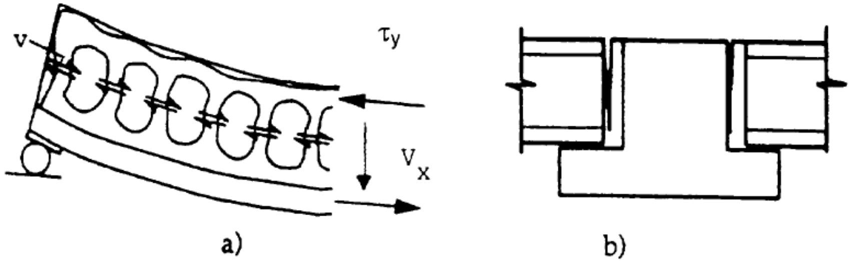


Shows the shear forces in a composite structure when the cracks in b) cannot transfer any stresses.

Roggendorf:

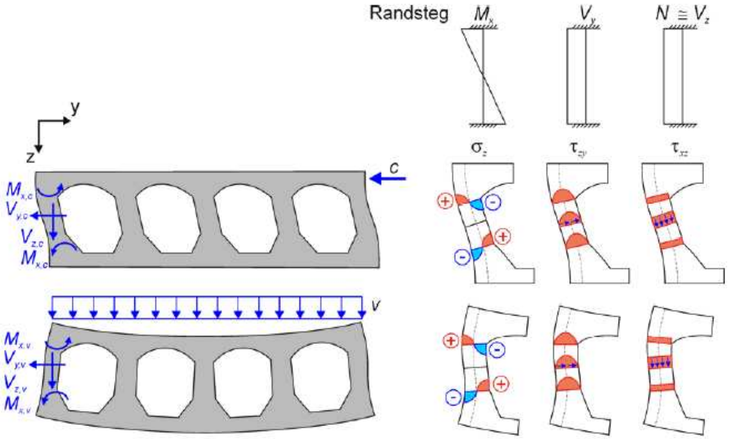


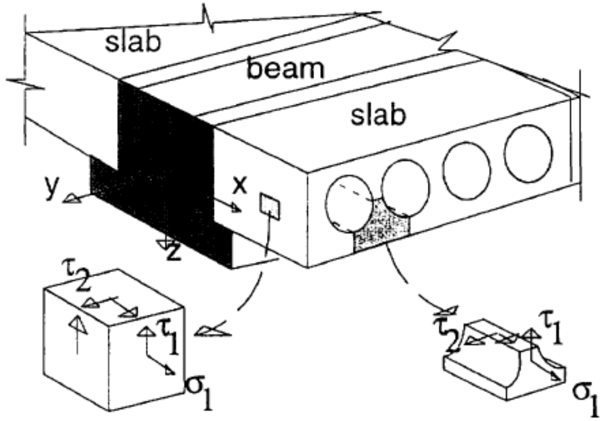
Bild 5.5: Schnittgrößen und Spannungskomponenten im Randsteg infolge der horizontalen Schubkraft *c* und Querbiegung

Design model

The failure is controlled by the tensile principal stress of the concrete, which equals to the design strength value when the failure is assumed to follow.

The principal tensile stress is calculated according to the transformed plane stress condition:

$$\sigma_I = fct = \frac{\sigma}{2} + \sqrt{\left(\frac{\sigma}{2}\right)^2 + {\tau_1}^2 + {\tau_2}^2}$$



Design model

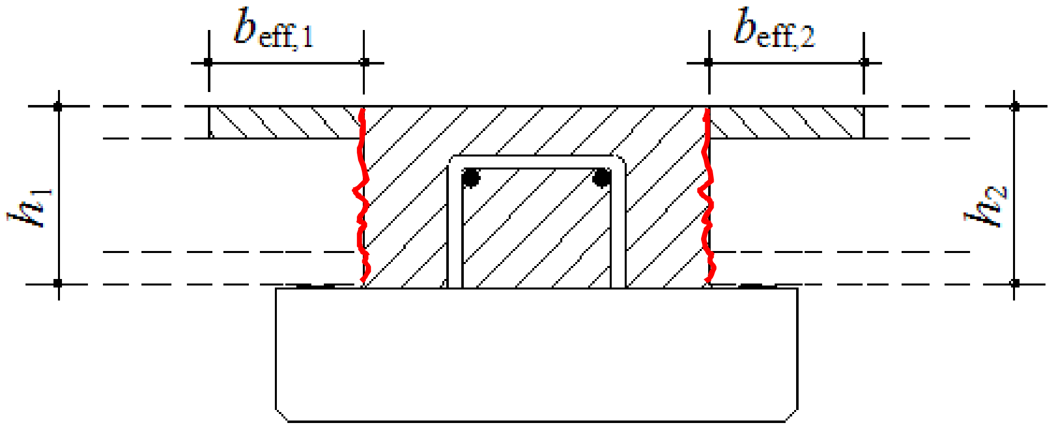
$$\sigma_I = fct = \frac{\sigma}{2} + \sqrt{\left(\frac{\sigma}{2}\right)^2 + {\tau_1}^2 + {\tau_2}^2}$$

Where τ_2 is shear stress due to the non-intended composite action in the direction of the beam.

Challenge: how to describe/derive τ_2 ?

Design model

Beam model



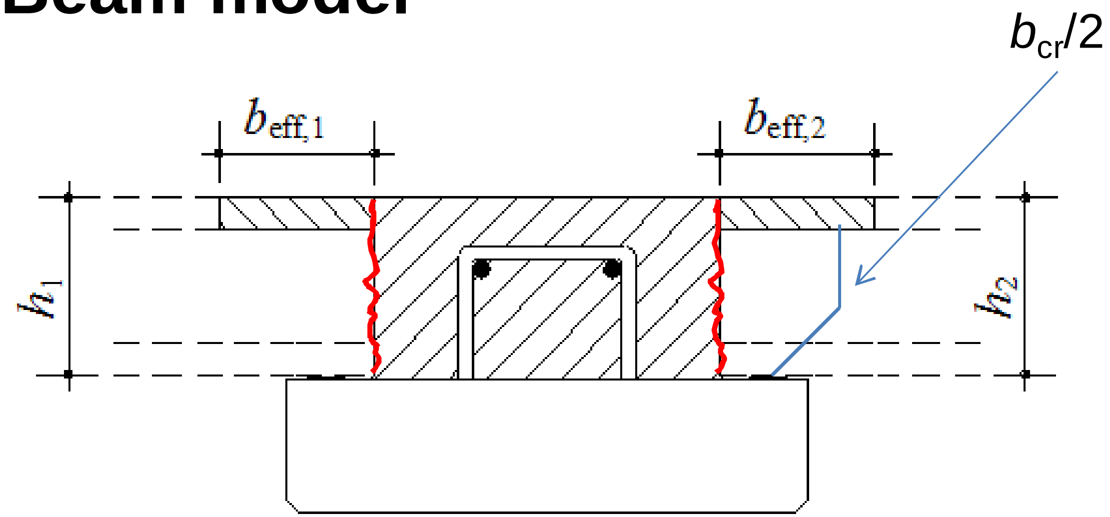
The horizontal shear flow due to the non-intended composite action:

$$\tau = V \cdot \frac{S}{b \cdot I}$$

$$v_{yd} = V_{beam} \cdot \frac{ES_{topflanges}}{EI_{beam}}$$

Design model

Beam model



Distribution:

$$b_{cr}(y) = 2y \ngtr h$$

The shear stress in transverse direction due to the non-intended composite action:

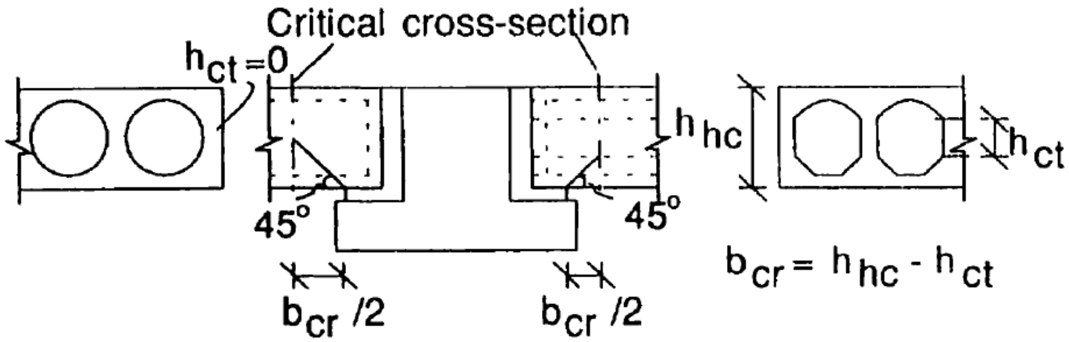
$$\tau_2(y) = \frac{3 \cdot vyd \cdot bslab}{4 \cdot bcr(y) \cdot bw(y)}$$

Design model

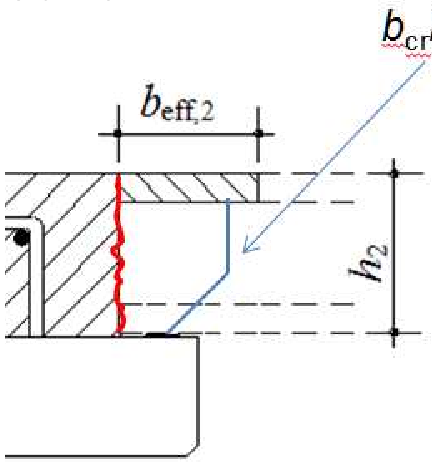
Beam model

b_{cr}

fib Bulletin 6:



Current:



$$b_{cr}(y) = 2y \ngtr h$$

Design model

Beam model

The principal stress included the transverse shear stress:

$$\sigma_I = fct = \frac{\sigma}{2} + \sqrt{\left(\frac{\sigma}{2}\right)^2 + {\tau_1}^2 \boxed{+ {\tau_2}^2}}$$

τ_2 is a function of $ES_{\text{topflangens}}$; respectively a function of b_{eff}.

How to derive b_{eff} ?

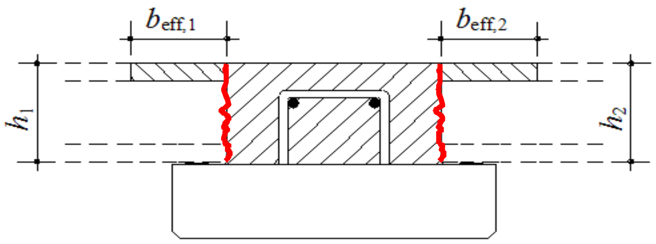
Calibration of the design model to the tests

Coefficient k_{cd}

Depth of hc slab	Concrete beam	With concrete filled steel beam	Steel beam
150 mm	0.026	0.021	0.010
200 mm	0.026	0.021	0.010
260 mm	0.029	0.023	0.011
320 mm	0.031	0.022	0.013
400 mm	0.035	0.022	0.014
500 mm	0.040	0.028	0.020

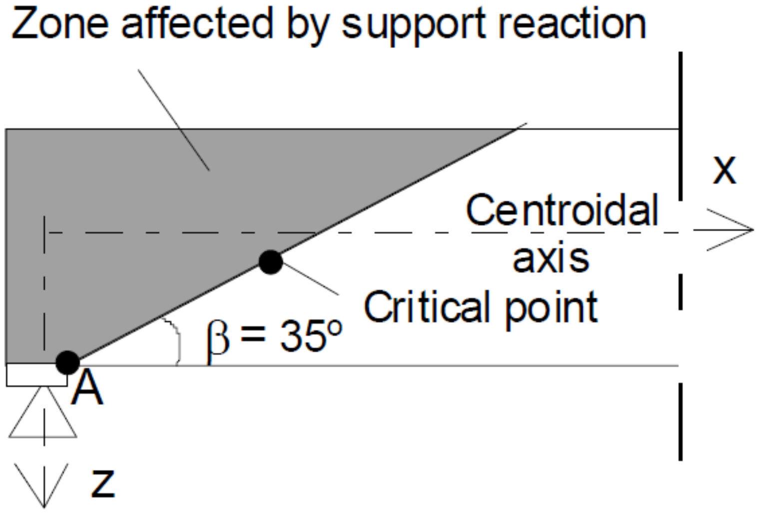
The design width: $$b_{eff} = L \cdot kcd$$

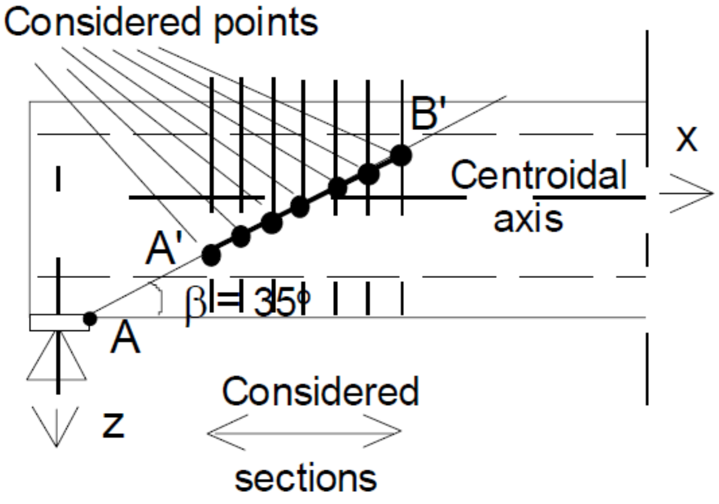
where *L* is the effective span length of the beam (distance between moment zero points)



Design model

Line of failure



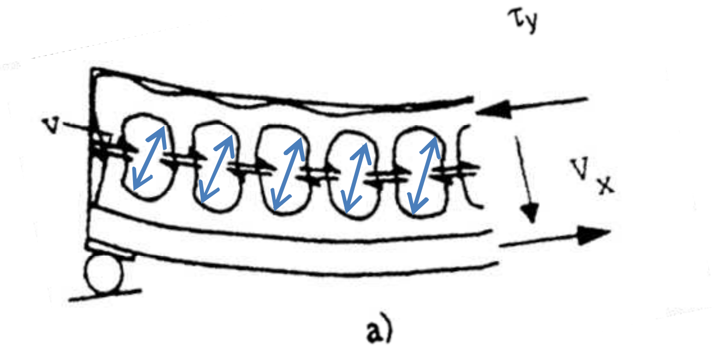


Influence of filled cores

Filled cores prevent the deformation of the hollow core cross section, in care of filled cores the shear stress τ_2 can be reduced with a factor β:

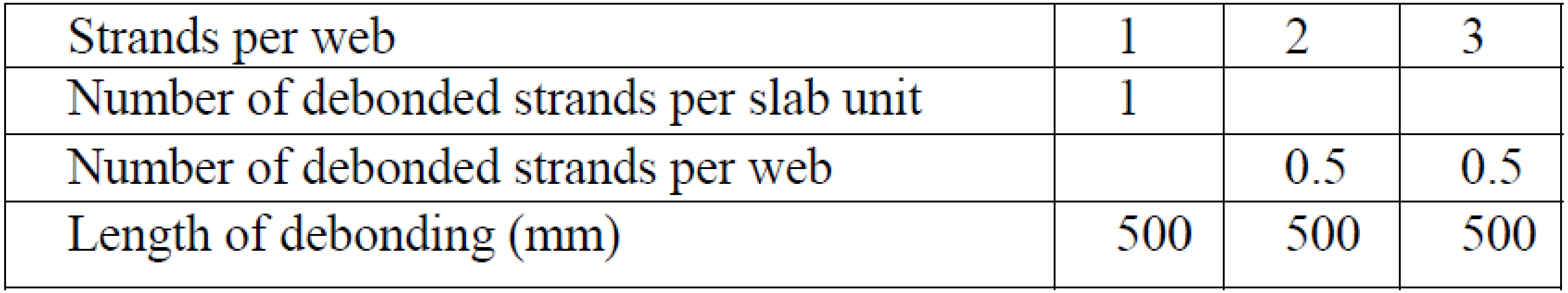
Slab thickness [mm]	200	265	320	400
Filling length < 50 mm	1.00	1.00	1.00	1.00
Filling length at least equal to the depth of void All voids filled	0.70	0.70	0.50	0.50

Values for β . For filling lengths shorter than depth of the core, linear interpolation may be applied.



Debonding of strands

Check (ULS) the slab at midspan (highest curvature), when exceeding f_{ctd} a number of debonded strands should be taken into account.



Strands per web	1	2	3
Number of debonded strands per slab unit	1		
Number of debonded strands per web		0.5	0.5
Length of debonding (mm)	500	500	500

Table 4.8-3: Debonding of strands

Serviceability limit state

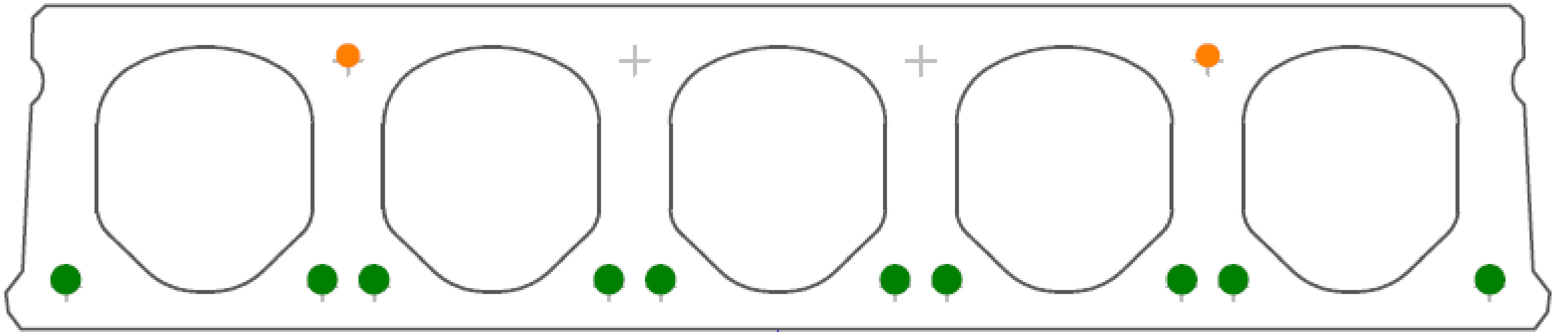
Check allowable strain and/or crack width:

$\varepsilon_{cr} \times 10^3$	w_k [mm]
0,4	0,1
0,7	0,2
1,0	0,3
1,3	0,4

$$\varepsilon_2 = \frac{M_{Edadd} \cdot z}{EI}$$

Transverse shear stress

Example calculation



Slab length: 9.0 meter

Self weight: 3.6 kN/m2

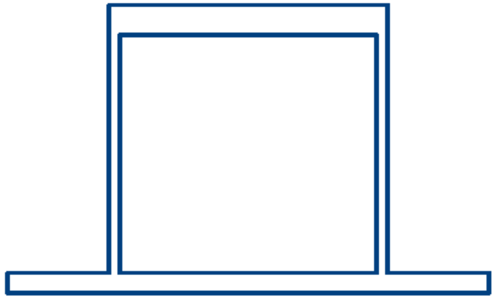
Dead load: 1.2 kN/m2

Live load: 5.0 kN/m2

Transverse shear stress

Example calculation

Beam:



THQ 265.10-240.30-450.20

Span of the beam: $L_{beam} = 5000$ mm

Depth of filled concrete in the cores: $FillingDepth = 50$ mm

Transverse shear stress

Example calculation

The composite beam: $k_{cd} := 0.011$

Effective width: $b_{eff} := L_{beam} \cdot k_{cd}$ $b_{eff} = 55$ mm

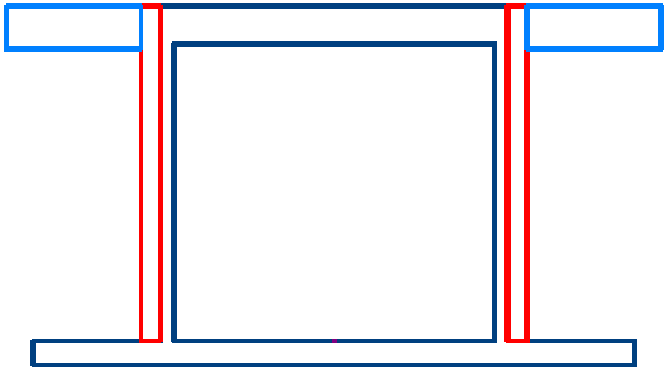
Influence of filled cores:

$\beta_f := \beta_{filledcores}(FillingDepth) = 1.0$

Transverse shear stress

Example calculation

The composite cross section for the calculation of the transverse shear stresses:



$$\mathbf{Txt} = \begin{pmatrix} \text{"Beam"} \\ \text{"Joint"} \\ \text{"Top flange"} \\ \text{"Under flange"} \\ \text{"Topping flange"} \\ \text{"Topping beam"} \end{pmatrix} \quad \mathbf{A} = \begin{pmatrix} 21500 \\ 7950 \\ 6800 \\ 0 \\ 0 \\ 0 \end{pmatrix} \quad \mathbf{Y} = \begin{pmatrix} 112.2 \\ 132.5 \\ 248.0 \\ 0.0 \\ 0.0 \\ 0.0 \end{pmatrix} \quad \mathbf{I} = \begin{pmatrix} 575804167 \\ 186096250 \\ 418882267 \\ 0 \\ 0 \\ 0 \end{pmatrix} \quad \mathbf{E} = \begin{pmatrix} 210000 \\ 29962 \\ 36283 \\ 36283 \\ 29962 \\ 29962 \end{pmatrix}$$

Transverse shear stress

Example calculation

$$EA_{0.1} := \sum_{j=0}^{hollowcore} \left(\mathbf{E}_j \cdot \mathbf{A}_j\right) = 4999923191$$

$$ES_{0.1} := \sum_{j=0}^{hollowcore} \left(\mathbf{E}_j \cdot \mathbf{A}_j \cdot \mathbf{Y}_j\right) = 599321638805$$

$$Y_{0.1} := \frac{ES_{0.1}}{EA_{0.1}} = 119.9 \quad mm$$

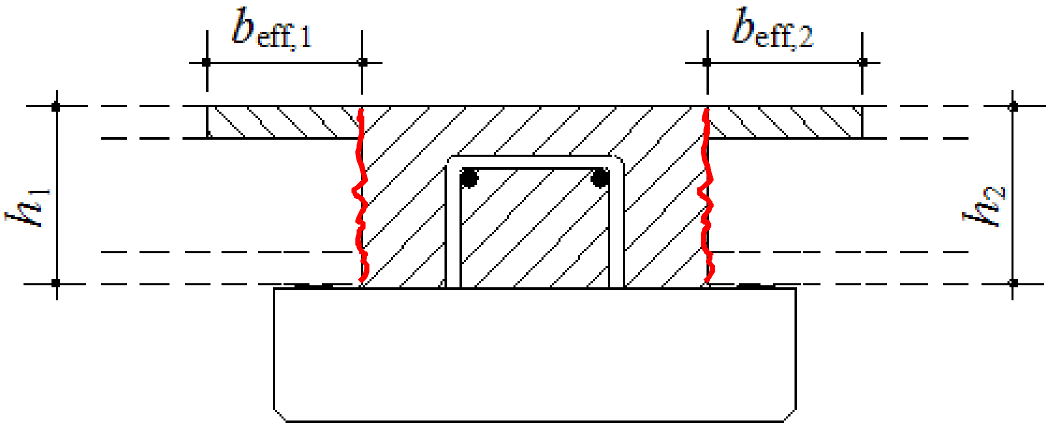
$$EI_{0.1} := \sum_{j=0}^{hollowcore} \left(\mathbf{E}_j \cdot \mathbf{I}_j\right) - \frac{ES_{0.1}{}^2}{EA_{0.1}} = 6985467693888 4$$

Transverse shear stress

Example calculation

Moment of area of the top flange:

$$ES_{f.1} := \mathbf{E}_{topflange} \cdot \mathbf{A}_{topflange} \cdot \left(\mathbf{Y}_{topflange} - Y_{0.1}\right) = 31613906539$$



Transverse shear stress

Example calculation

Loads on the beam:

design load beam due to added load:

$$q_{d.add.beam} := \left(\gamma_g \cdot p_{g3} + \gamma_q \cdot p_q\right) \cdot \left(SL + 2 \cdot \frac{SlabOffset}{1000}\right) = 83.1 \text{ kN/m}$$

The shear force in the beam inducing a transversal shear flow:

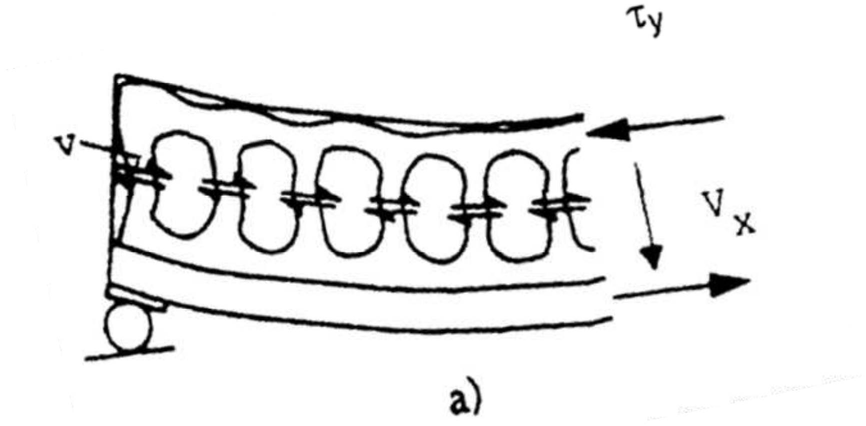
$$V_{Ed} = \left(q_{d.add.beam}\right) \cdot \frac{L_{beam}}{2} = 207631 \quad N$$

Transverse shear stress

Example calculation

Horizontal shear flow v_{yd} in the composite beam:

$$v_{yd} := V_{Ed} \cdot \frac{ES_{f.1}}{EI_{0.1}} \qquad v_{yd} = 94.0 \qquad \text{N/mm}$$



Transverse shear stress

Example calculation

Shear stress in the hollow core webs in transverse direction:

$$\tau_2(y) := \frac{3 \cdot v_{yd} \cdot b_{sl}}{4 \cdot b_{cr}(y) \cdot b_1(y)} \qquad \tau_2(90) = 1.36 \quad \text{MPa}$$

Shear stress due to the vertical load:

$$V_{Ed.hc} = 70633 \quad \text{N}$$

$$\tau_1(y) := \frac{V_{Ed.hc} \cdot S_{c1}(y)}{b_1(y) \cdot I_{i1}} \qquad \tau_1(90) = 0.98 \quad \text{MPa}$$

Transverse shear stress

Example calculation

Principal stress:

$$\sigma_1(\text{limit}, x, y) := -\frac{\sigma_{cp}(\text{limit}, x, y)}{2} + \sqrt{\left(\frac{\sigma_{cp}(\text{limit}, x, y)}{2}\right)^2 + \left(\tau_1(y) + \tau_{cp}(\text{limit}, x, y)\right)^2 + \left(\beta_f\,\tau_2(y)\right)^2}$$

Transverse shear stress

Example calculation

Critical point found:

$$y := \text{Position}\left(\sigma_1, \text{upper}\right) = 90 \qquad \text{mm}$$

$$x := X_{fail}(y) = 0.21 \quad \text{m}$$

$$\sigma_1(\text{upper}, x, y) = 1.37 \quad \text{MPa}$$

$$\sigma_1(\text{lower}, x, y) = 1.25 \quad \text{MPa} \qquad \sigma_{1.max} = 1.37 \quad \text{MPa}$$

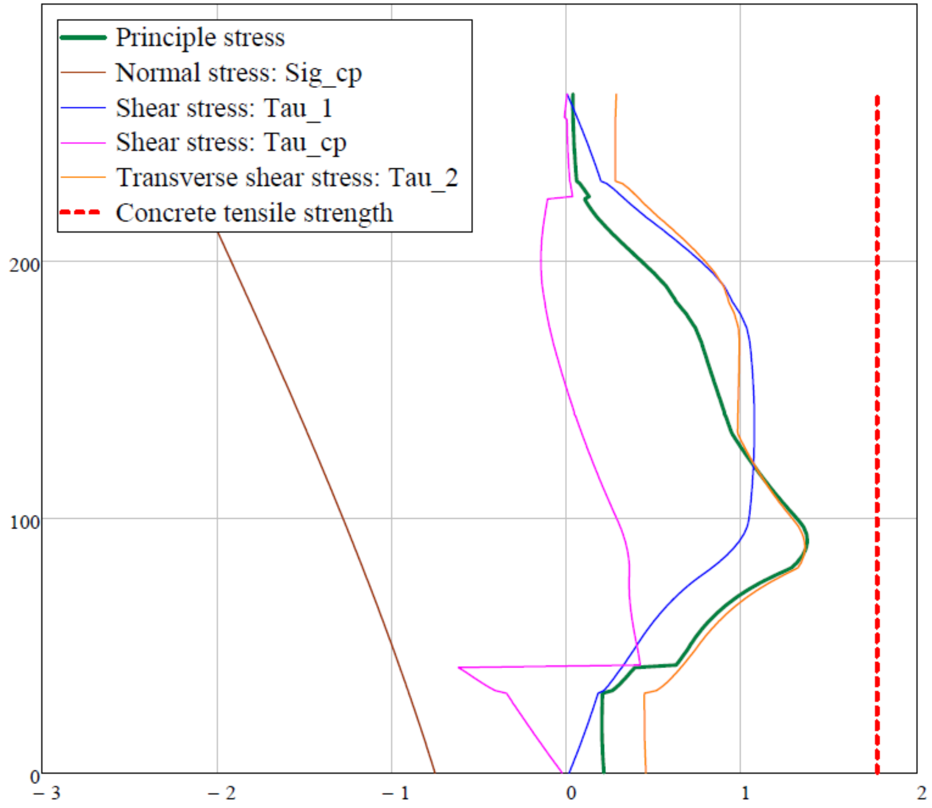
$$f_{ctd1} = 1.77 \quad \text{MPa}$$

$$\text{Requirement}\left(\sigma_{1.max} \le f_{ctd1}\right) = \text{"is fulfilled"}$$

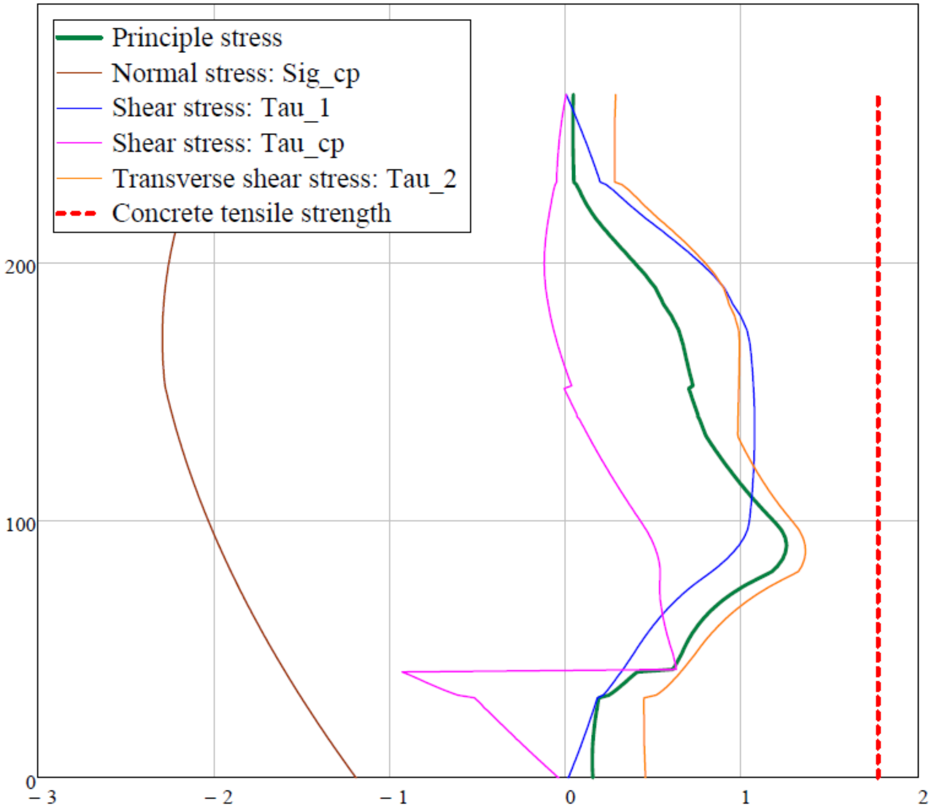
Transverse shear stress

Example calculation

The stress components: limit := upper

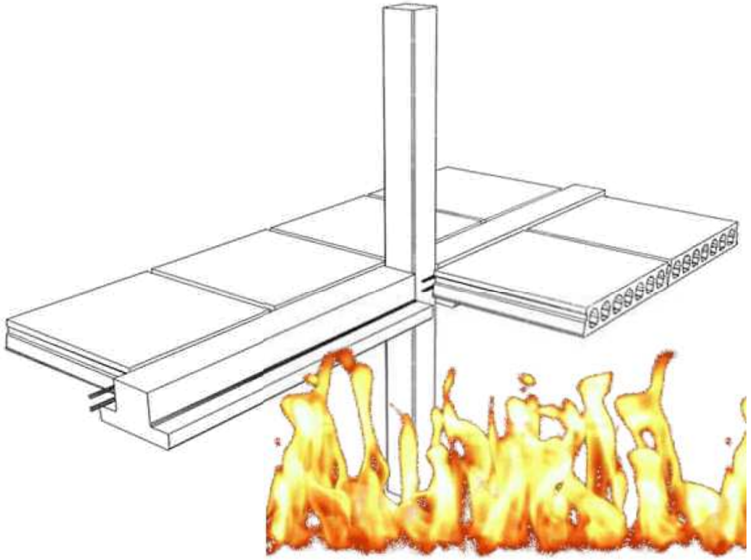


limit := lower



Non-rigid supported hollow core floor

Fire design



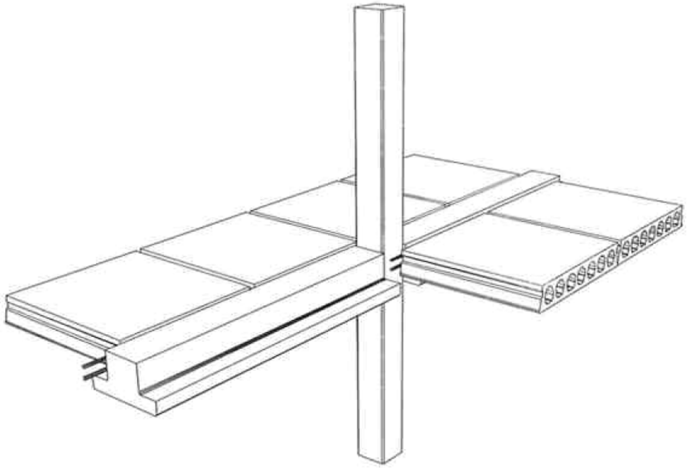
For shear resistance in fire:
Go down to the shear resistance in fire condition in cracked situation:

$$V_{Rd,c,fi} = \left[C_{\theta.1} + \alpha_k \cdot C_{\theta.2} \right] \cdot b_w \cdot d$$

Non-rigid supported hollow core floor

Summary

- ☐ The shear tension resistance is influenced by the properties of the beam.
- ☐ It is about non-intended composite action.
- ☐ For design: use the same approach as for shear tension capacity on rigid support; but add a shear stress due to this possible composite action
- ☐ For cracked sections the known shear flexure capacity applies
- ☐ In case of fire: cracked section => same design formula as rigid support



Thank you for your attention