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Structural topping and composite action

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Structural topping and composite action

interface characteristics and composite action, calculation of interface shear capacity

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Structural topping on the HC units may significantly increase capacity.

Concrete – concrete composite structure

↓

topping is fully anchored and bonded to the hollow core elements

↓

two concretes may be designed as monolithic.

The main benefit from composite action is increased bending resistance and flexural stiffness

Note: Benefit from a structural topping decreases as the span increases. The self-weight of the topping nullifies the additional capacity.

Other reasons for use of structural topping:

- to provide horizontal action,
- to improve acoustic performance of the floor,
- to improve the dynamic characteristic (vibration performance),
- to adjust camber differences between the precast units,
- to tie the floor slabs to beams, thereby ensuring a secure bearing and increasing the flexural and shear strength of the beams,
- to take up negative moments due to restraint at the support
- to improve the water tightness.

Requirements for topping layer

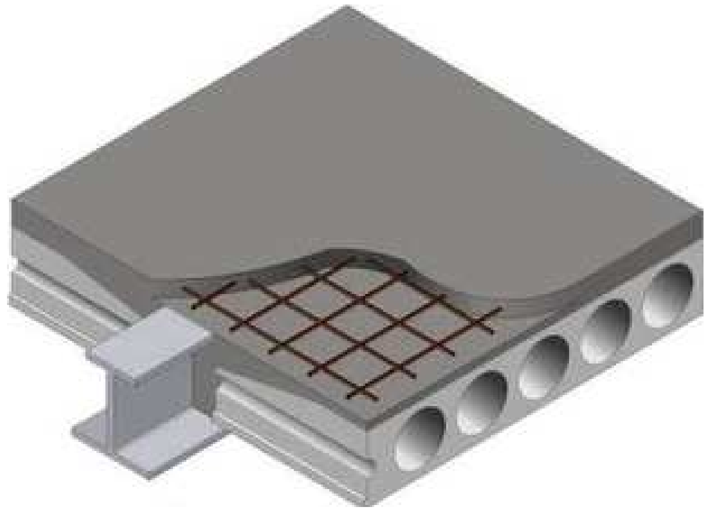
The minimum thickness of a structural topping at the highest point:

40 mm (plain concrete) and 50 mm (RC),

increasing (with slab and beam cambers) up to 100 mm.

Thick toppings should be avoided by using deeper hollow core slabs.

The grade of in-situ concrete is usually C25/30 to C30/37.



Requirements for topping layer (fire situation)

Thickness of topping in the mid span should not exceed 50 mm.
(or 0.25 times the slab thickness)

Reinforcement of the topping layer in the support zone should not be larger than ϕ 6 mm at 150 mm spacing.

A variant solution is to use steel fibre concrete for the topping.

Failure to meet the above conditions can be critical with regard to horizontal web cracking.

Composite action

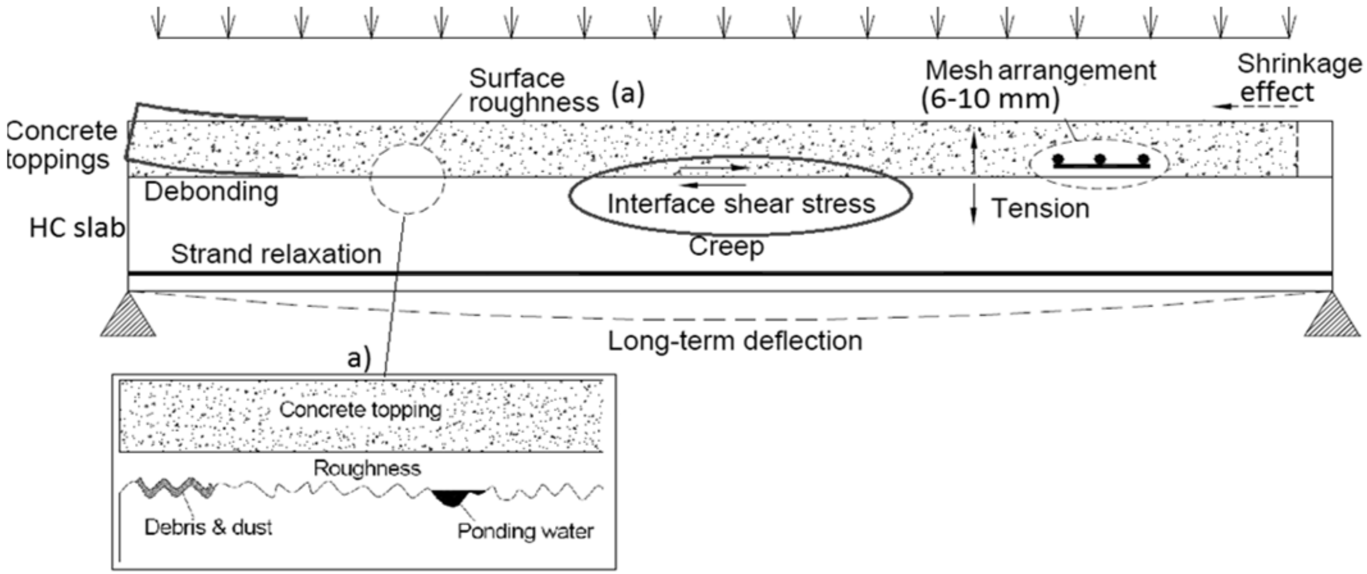
Factors affecting the composite action

Factors related to the execution of the structure:

material characteristics of concrete,

surface characteristics of the interface,

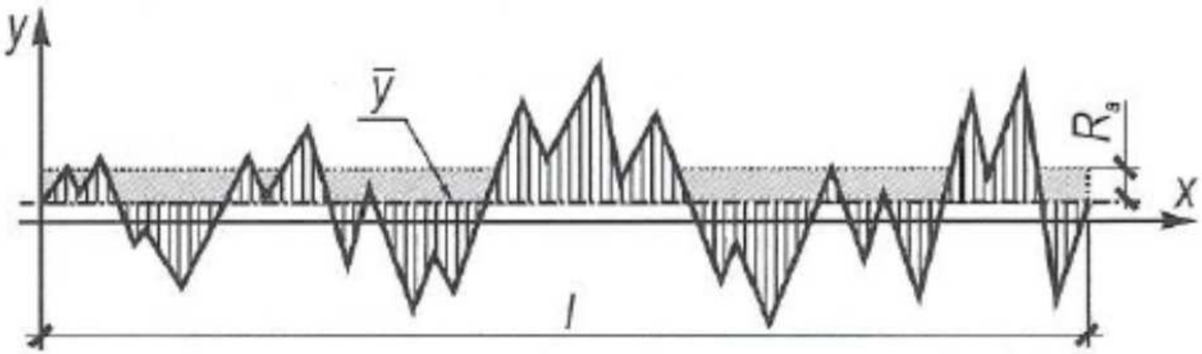
moistening, contamination, presence of laitance, etc.



Surface roughness

MC2010

The basic parameter which characterises the surface of the precast element is the average roughness R_a – this represents the medium deviation of the surface profile from the medium line.

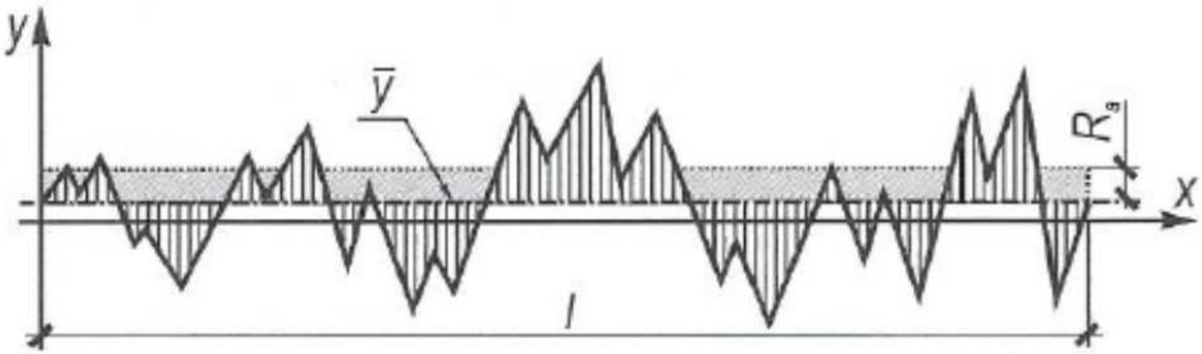


In MC2010 the classification due to the roughness has been defined:

- very smooth – for a non-measurable R_t;
- smooth – for $R_t < 1.5$ mm;
- rough – for 1,5 mm $\leq R_t < 3.0$ mm;
- very rough – for $R_t \geq 3.0$ mm.

Surface roughness of HC elements

MC2010



The average roughness R_a can be measured by means of the engineering method - a sand patch method.

Usually, the top surface of hollow core units has roughness

$$1.0 \text{ mm} < R_a < 2.0 \text{ mm (raking surface)}$$

so it should be classified in the category 'smooth' or 'rough'.

Interface characteristics

EN 1992-1-1

Eurocode 2 p.6.2.5 distinguishes different types of surface:

- very smooth: a surface cast against steel, plastic or specially prepared wooden moulds
- smooth: a slipformed or extruded surface, or a free surface left without further treatment after vibration;
- rough: a surface with at least 3 mm roughness at about 40 mm spacing, achieved by raking, exposing of aggregate
- indented.

The top surface of extruded or slipformed HC units belongs rather to the category 'rough'.
The top surface of wet cast units may be 'smooth' or 'rough' depending on the degree of surface preparation, e.g. raking the surface after leveling.

Interface characteristics

EN 1992-1-1
fib Bulletin 6

Interface surface characteristics are described by the following parameters:

c – adhesive coefficient and μ – friction coefficient.

In the *fib* Bulletin 6 slightly higher values of coefficient *c* were given.

Roughness	Adhesive coefficient c		Coefficient of friction μ	
	Eurocode 2 (EN 1168)	*fib* Bulletin 6	Eurocode 2 (EN 1168)	*fib* Bulletin 6
very smooth	0.025÷0.1	0.02	0.5	0.5
smooth	0.2	0.35	0.6	0.6
rough	0.4	0.45	0.7	0.7
indented	0.5	0.50	0.9	0.9

Calculation of the interface shear capacity

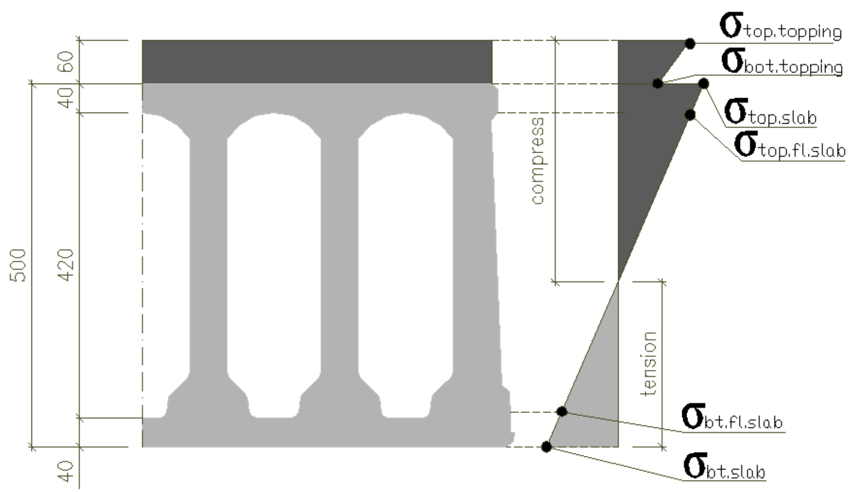
EN 1992-1-1

$$\tau_{Ed} \leq \tau_{Rd}$$

$$\tau_{Ed} = \frac{\beta \cdot V_{Ed}}{z \cdot b}$$

where:

β is the ratio of the longitudinal force in the topping area and the total longitudinal force in the compression zone, calculated for the section considered;



z is the lever arm of composite cross-section;

b the width of the interface.

Interface shear resistance of the composite element without transverse reinforcement

EN 1992-1-1

$$\tau_{Rd.j} = c \cdot f_{ctd} + \mu \sigma_n \quad \leq \quad 0.5 \cdot \nu \cdot f_{cd}$$

where:

c – is the adhesive coefficient,

μ – is the friction coefficient,

σ_n – is the normal stress per unit area caused by the minimum external normal force across the interface that can act simultaneously with the shear force, positive for compression,

$$\sigma_n \leq \quad 0.6 \cdot f_{cd}$$

f_{cd} – is the design compress strength of the concrete,

f_{ctd} – is the design tensile strength of the concrete.

Interface shear resistance

MC2010

$$\tau_u = \tau_a + \mu(\rho \cdot \kappa_1 \cdot f_y + \sigma_n) + \kappa_2 \cdot \rho \cdot \sqrt{f_y \cdot f_{cc}} \leq \beta_c \cdot \nu \cdot f_{cc}$$

where:

τ_a is the strength due to the adhesion and mechanical interlock.

For the joint without reinforcement or with a small amount of reinforcement (ρ < 0.05%), it can be assumed that $\tau_u = \tau_a$

The medium values of τ_a and μ:

Roughness	Adhesive bond stress τ_a [MPa]	Coefficient of friction μ [-]
smooth	~ 0.5–1.5	0.5–0.7
rough	~ 1.5–2.5	0.7–1.0
very rough	~ 2.5–3.5	1.0–1.4

Adhesive bond stress

MC2010

Given values of adhesive bond stress for individual surface roughness are the mean values

The design values can be found:

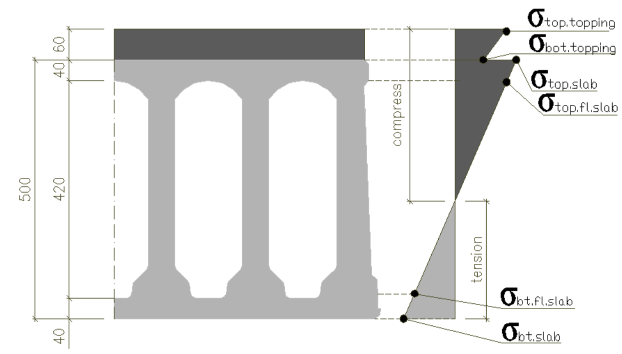
$$\tau_{a.d} = \frac{1}{\gamma_c} \tau_{a.m} \cdot \frac{f_{ctk0,05}}{f_{ctm}}$$

Roughness	Mean adhesive bond stress $\tau_{a.m}$ [MPa]	Design adhesive bond stress $\tau_{a.d}$ [MPa]
smooth	0.5 – 1.5	0.23 – 0.70
rough	1.5 – 2.5	0.70 – 1.15
very rough	2.5 – 3.5	1.15 – 1.60

Exemplary calculation results

Assumptions:

- HC500 slab made of C50/60 concrete.
- RC topping with a height of 60mm, made of C20/25 concrete
- simply supported slab
- loads:
  self-weight g_d=6kN/m^2,
  additional static load Δg_d=1kN/m^2
  service load of q_d=5kN/m^2.



τ_{Rd} [kPa]							
EC 2 EN 1168		**fib Bul. 6**		**MC2010**		**ACI 318M-11**	
smooth $cf_{ctd}+\mu\sigma_n$	290+6= 296	smooth $cf_{ctd}+\mu\sigma_n$	508+6= 514	smooth	500-700	clean, free of laitance and intentionally roughened	550
rough $cf_{ctd}+\mu\sigma_n$	580+8= 588	rough $cf_{ctd}+\mu\sigma_n$	652+8= 660	rough	700-925		

Exemplary calculation results

Contribution of friction forces in the interface shear strength

The magnitude of the $\mu\sigma_n$ component depends on the level of service load.

Assumptions:

- span of HC slab - 16m
- service loading in the range of 3.5kN/m² to 10.0kN/m²

		EC2	fib Bul. 6	EC2	fib Bul. 6	EC2	fib Bul. 6	EC2	fib Bul. 6
Live load q [kN/m²]		3.5		5.0		7.5		10.0	
smooth	cf_{ctd} [kPa]	290	508	290	508	290	508	290	508
	$\mu\sigma_n$ [kPa]	5.2		6.5		8.8		11.0	
	$\mu\sigma_n / (cf_{ctd}+\mu\sigma_n)$	2%	1%	2%	1%	3%	2%	4%	2%
rough	cf_{ctd} [kPa]	580	652	580	652	580	652	580	652
	$\mu\sigma_n$ [kPa]	6.0		7.6		10.2		12.9	
	$\mu\sigma_n / (cf_{ctd}+\mu\sigma_n)$	1%	1%	1%	1%	2%	2%	2%	2%

Experimental tests results

Specimen	Surface condition	Max. force F_{test} [kN]	Shear stress [MPa]	Topping f_{ctm} [MPa]
DRY-MFX-1	Machine finished	206.8	1.45	2.9
DRY-MFX-2		152.1	1.06	2.5
DRY-SBX-1	Sandblasted	161.9	1.13	2.9
DRY-SBX-1		215.3	1.50	3.1
DRY-LRX-1	longitudinally raked	223.3	1.56	2.9
DRY-LRX-2		205.1	1.43	3.1
DRY-TBX-1	Transversely broomed	287.8	2.01	3.1
DRY-TBX-2		319.4	2.23	3.4
DRY-MFG-1	Machine finished, grouted	275.8	1.93	2.9
DRY-MFG-2		377.2	2.63	3.1
DRY-LRG-1	Longitudinally raked, grouted	276.7	1.93	3.1
DRY-LRG-2		266.0	1.86	3.1
WET-MFX-1	Machine finished	198.4	1.38	3.1
WET-MFX-2		127.7	0.89	3.1
WET-SBX-1	Sandblasted	267.8	1.87	3.0
WET-SBX-2		225.1	1.57	3.1
WET-LBX-1	longitudinally broomed	222.0	1.55	3.1
WET-LBX-2		144.1	1.01	2.9
WET-TBX-1	Transversely broomed	257.5	1.80	2.9
WET-TBX-2		247.8	1.73	3.3
WET-MFG-1	Machine finished, grouted	157.5	1.10	2.9
WET-MFG-2		165.5	1.15	2.9
WET-LBG-1	Longitudinally broomed, grouted	247.3	1.73	2.7
WET-LBG-2		218.4	1.52	2.6

Ryan M. Mones, Sergio F. Breña, *Hollow-core slabs with cast-in-place concrete toppings: A study of interfacial shear strength*, PCI Journal Vol. 53, I. 3, 124-141, 2013

Mones R. , *Interfacial strength between prestressed hollow core slabs and cast-in-place concrete toppings*, Master's Thesis in Civil Engineering, 2012

Additional interface transverse reinforcement

When the resulting interface capacity is insufficient

transverse reinforcement should be placed

in the longitudinal joints between the hollow core units.

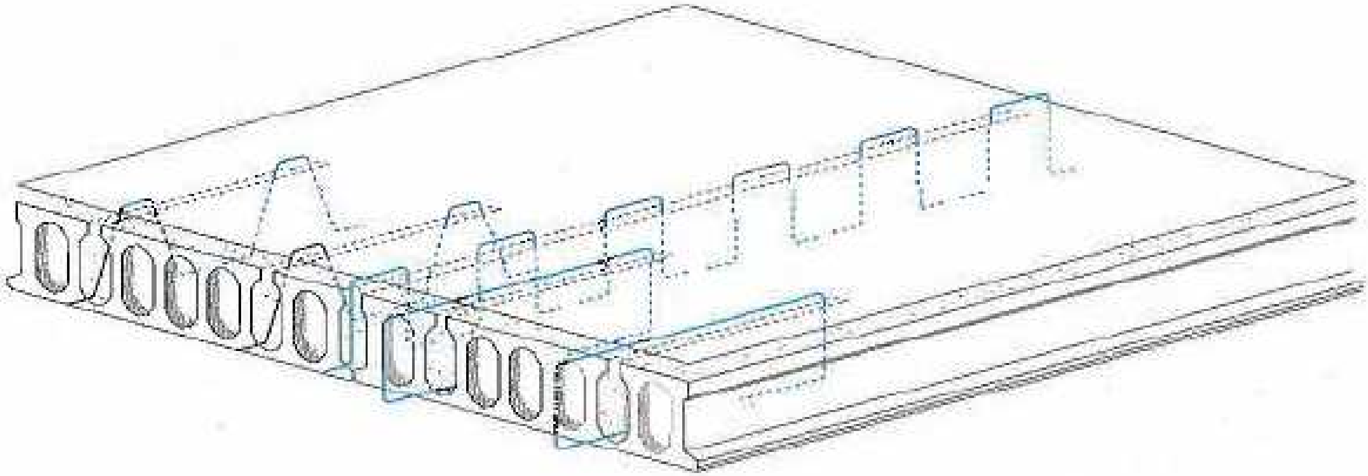


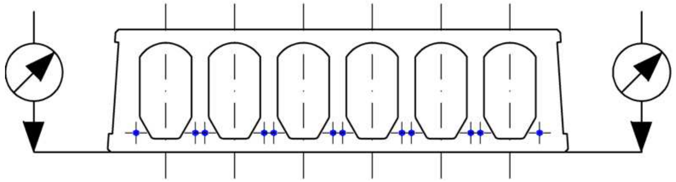
Fig. 3.6 Possible connecting reinforcement between hollow core floor and the corroborant cast in situ topping

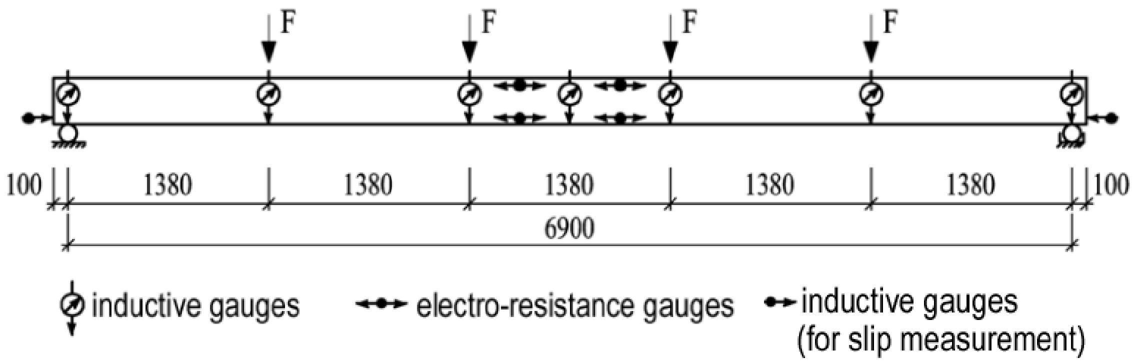
Drawing from: The Hollow Core Floor Design and Applications, ASSAP MAnual, Italy 2002

Experimental tests

Short-term and long-term tests of hollow core elements under bending

Ajdukiewicz A. et al.,
Experimental study on effectiveness of interaction between pretensioned hollow core slabs and concrete topping,
ACCE, No.1, 2008

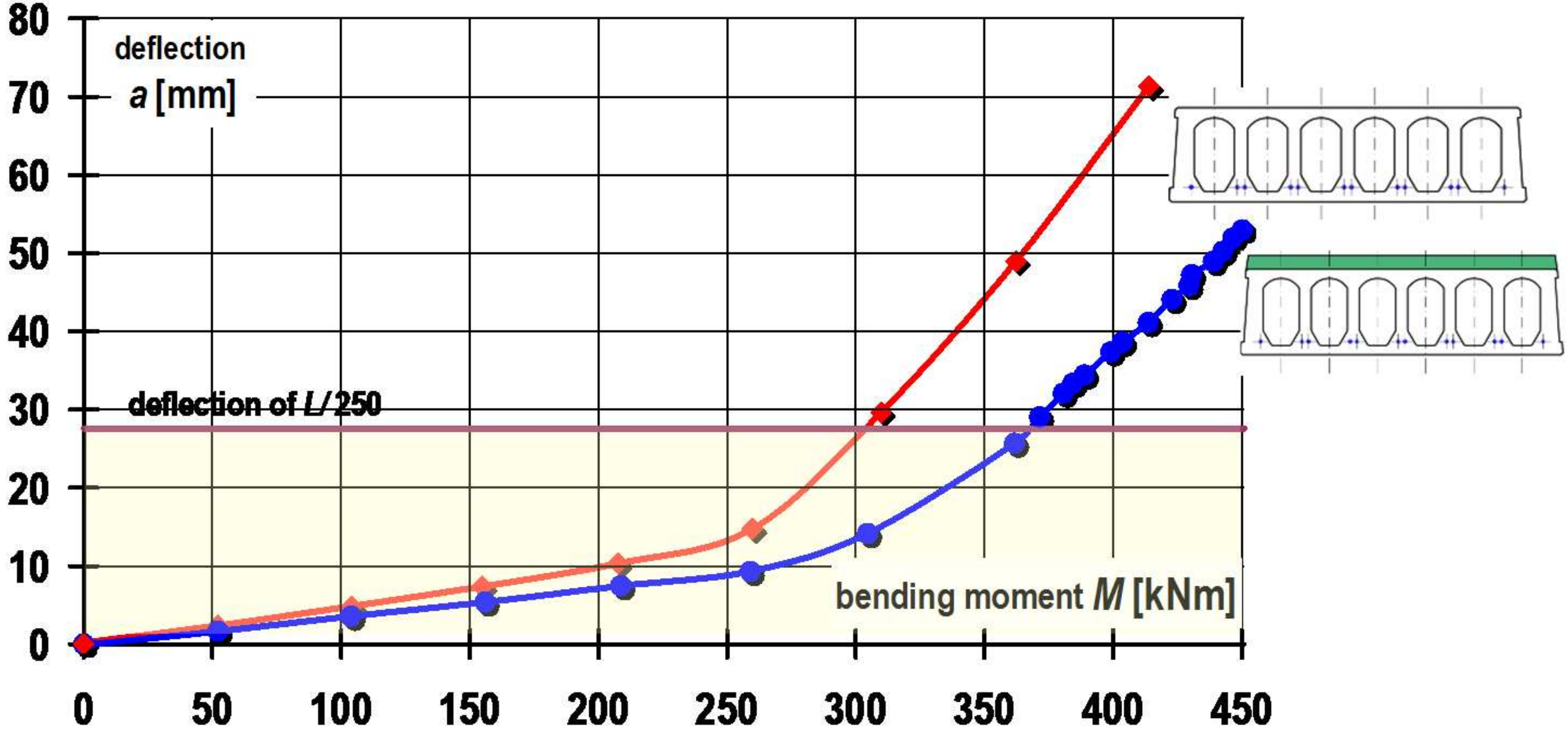




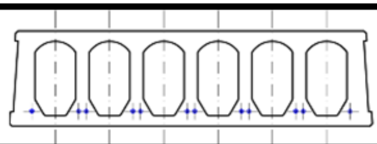
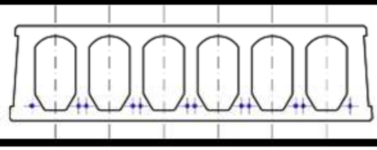
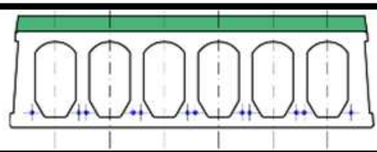
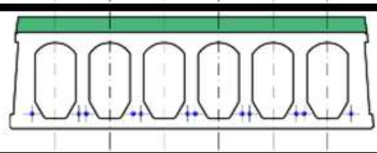
Experimental tests results

RESULTS

SHORT-TERM TESTS OF HCS-1 and HCS-2 ELEMENTS UNDER FIRST LOADING



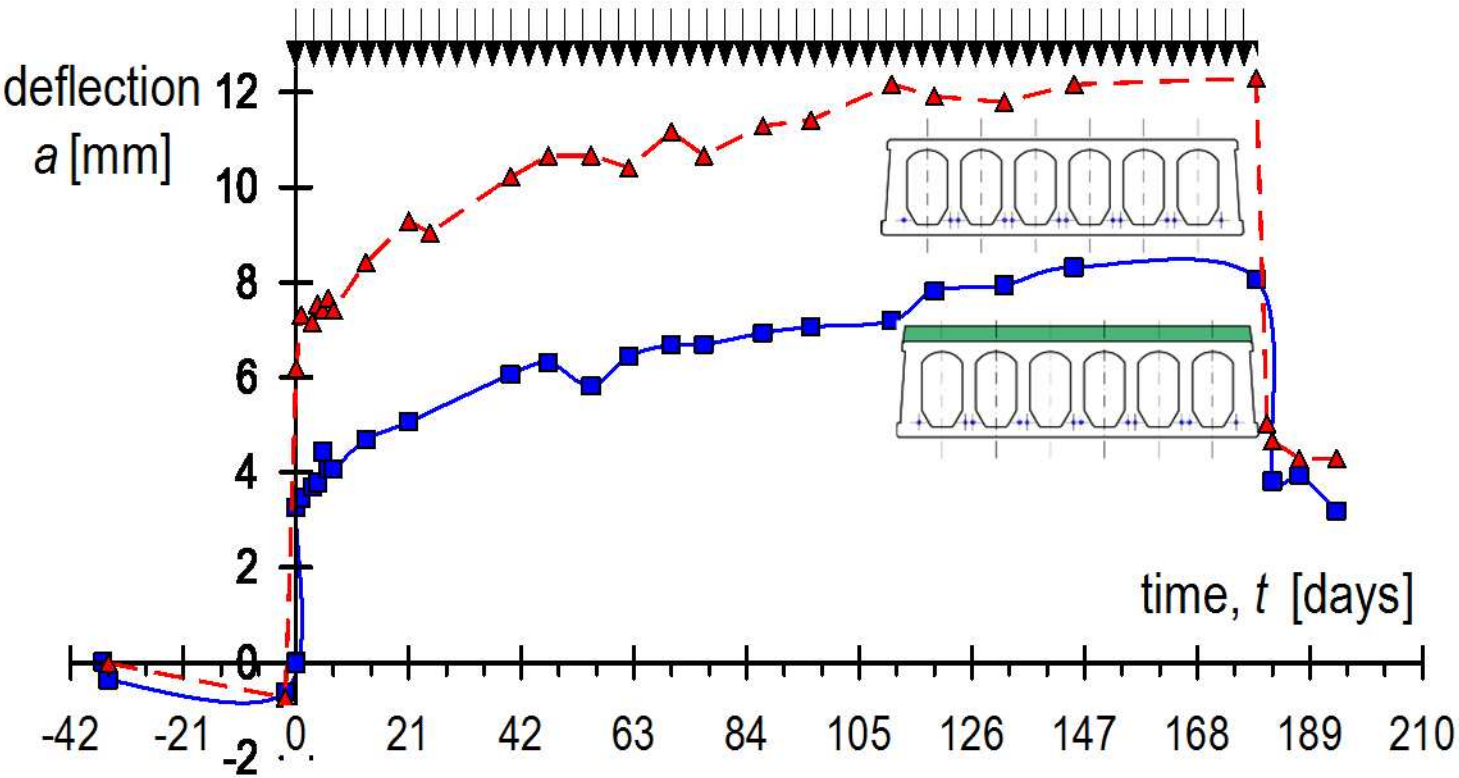
Experimental tests results

Slab symbol		M_{cr} [kNm]	a_{cr}	M_u [kNm]
HCS-1		306	*l* / 468	502
HCS-3		295	*l* / 539	512
According to EN 1992-1-1:2004		282	-	413
HCS-2		345	*l* / 488	614
HCS-4		335	*l* / 592	625
According to EN 1992-1-1:2004		320	-	451

ultimate bending moment - increase of more than 22%,
cracking moment - increase of almost 13%.

Experimental tests results

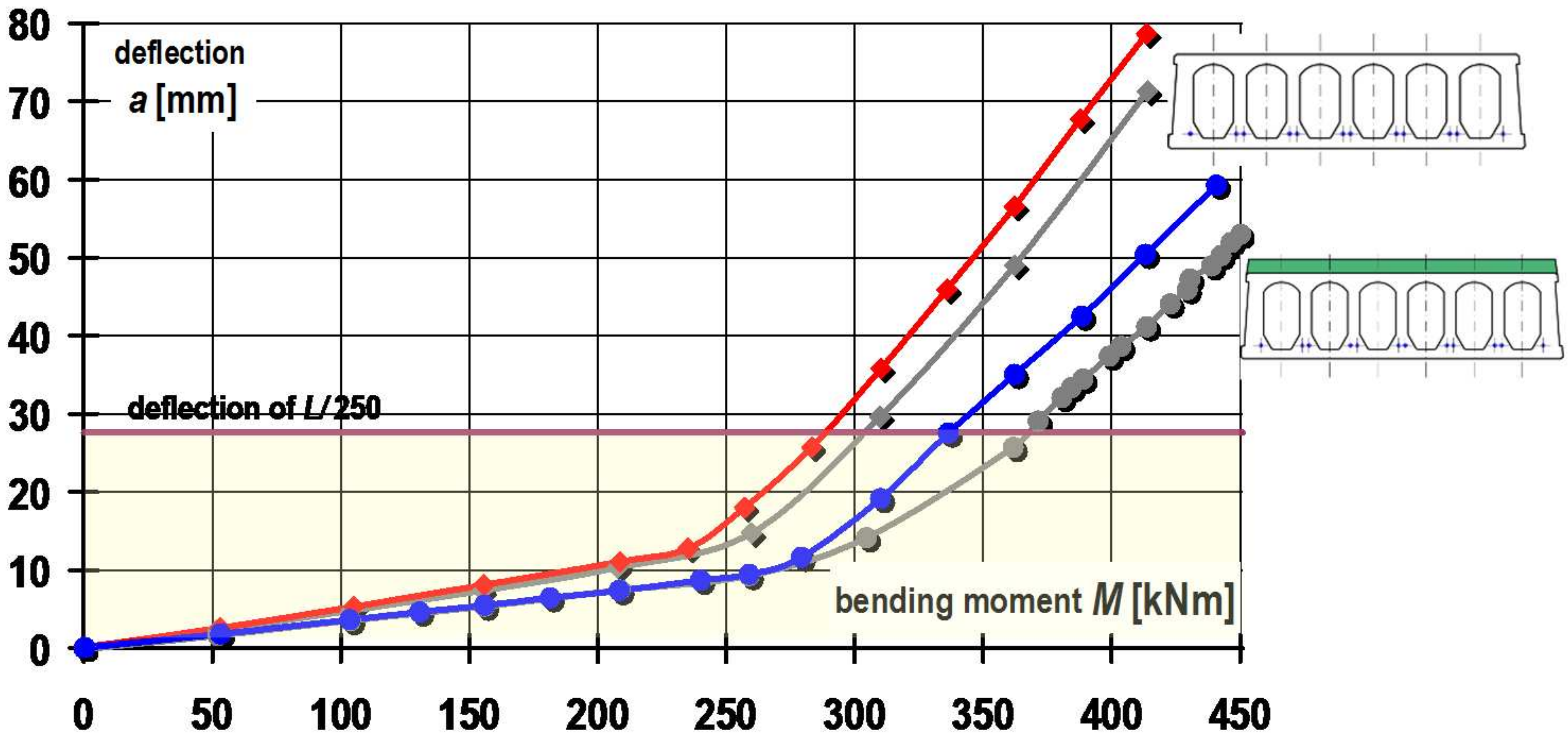
LONG-TERM TESTS
SLABS HCS-3 AND HCS-4



Experimental tests results

RESULTS

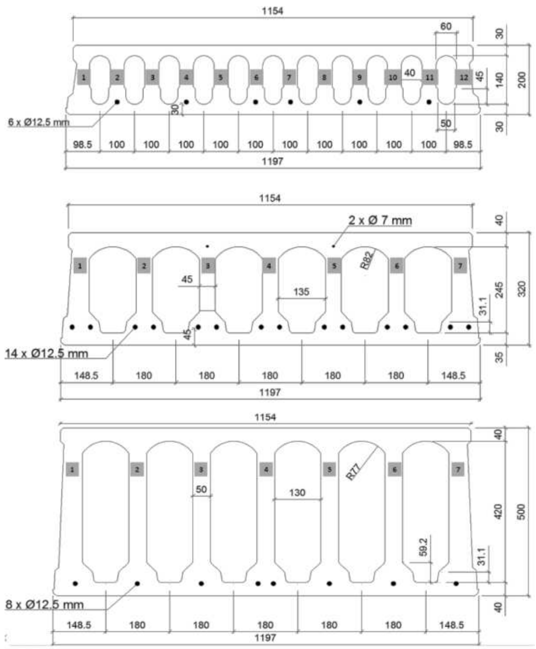
SHORT-TERM AND LONG-TERM TESTS

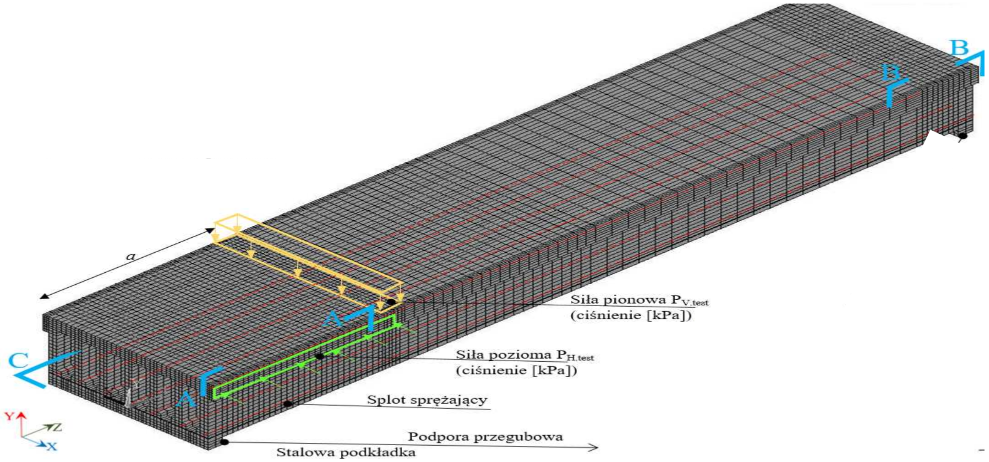


Experimental tests

RC topping influence on the shear capacity of HC slabs on flexible supports

Surma M.,
Shear capacity of prestressed hollow core slabs with concrete topping on flexible supports, PhD Thesis, Cracow University of Technology, Poland, 2017





Experimental tests results

An additional layer of RC topping has positive effect on the shear capacity of HC slabs on flexible supports.
The obtained increase of bearing capacity was between 10% and 60%. The efficiency increases with the decrease of nominal height of the slab.

The presence of RC topping layer increases the stiffness of the slab of about 30-60 %, which results in a reduction in vertical displacements.

Extensive research program has demonstrated that interface horizontal shear capacity is sufficient (no delaminations in the joint).

CONCLUSIONS

Application of structural topping is:

- increase the bending moment capacity (approx. 25%),
- increase the shear capacity (on rigid supports, up to 30**%**)
  (on flexible supports, approx. 40%),
- increase the flexural stiffness (approx. 15%, on flexible supports approx. 60%),
- increase the cracking moment (approx. 15%),
- provide horizontal action, improving acoustic and dynamic performance),
- cover the camber differences between the precast units,
- tie the floor slabs to beams,
- take up negative moments due to restraint at the support,
- improve the fire resistance and water tightness.

Thank you,

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