Hollow core floor systems: increasing performances with composite action

S. Bernardi

CERIB

Study and Research Centre for the French Concrete Industry

Precast prestressed hollow core floors

World annual production ≈ 200 millions m^2

2 millions m^2 in France

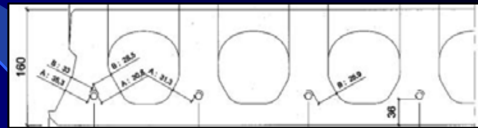
Principally used for:

- offices buildings
- commercial and industrial buildings
- parkings

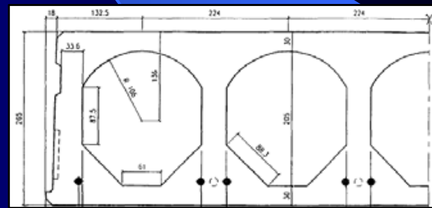
Precast prestressed hollow core floors

Hollow core slabs produced in France:

- 12 cm ≤ thickness ≤ 40 cm
- 60% extruded / 40% slipformed
- 95% with protruding tendons

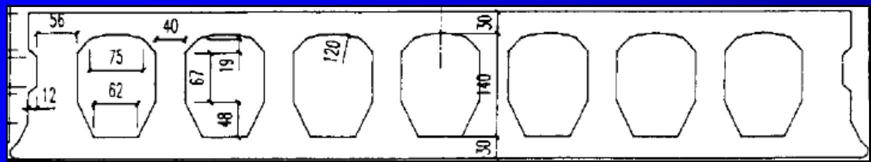


16 cm

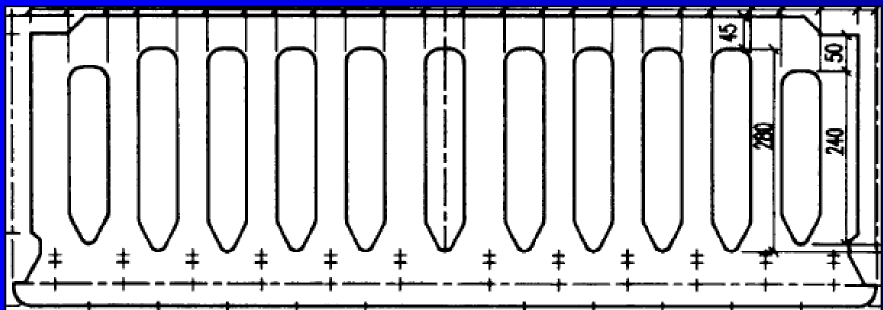


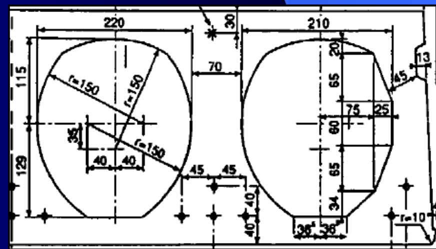
26,5 cm

20 cm



40 cm





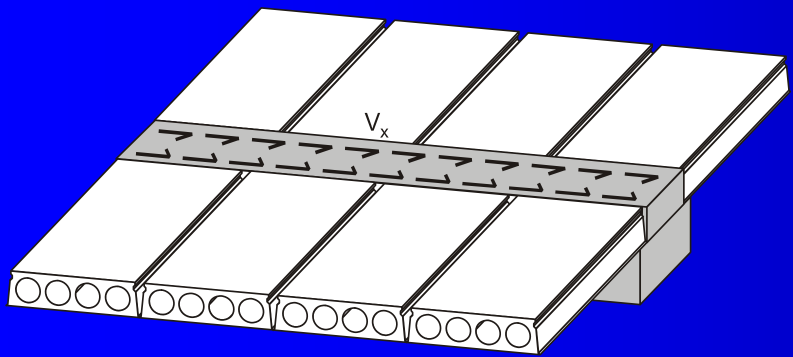
32 cm

Types of supports

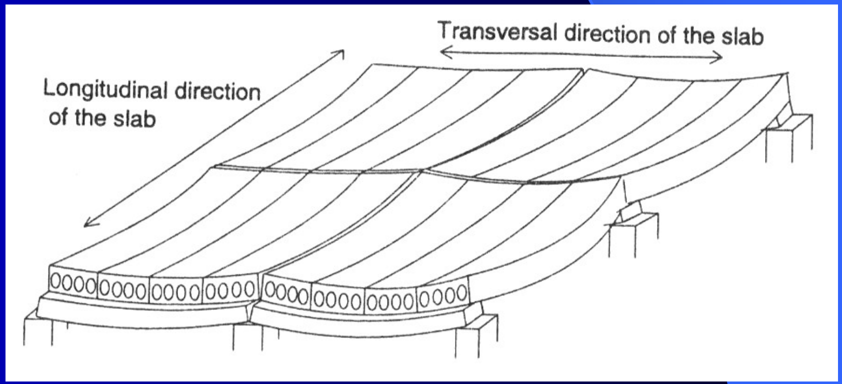
- reinforced concrete walls
- reinforced concrete beams
- prestressed concrete beams
- metallic beams

rigid supports

flexible supports



increase of bending and shear capacities of the beam?

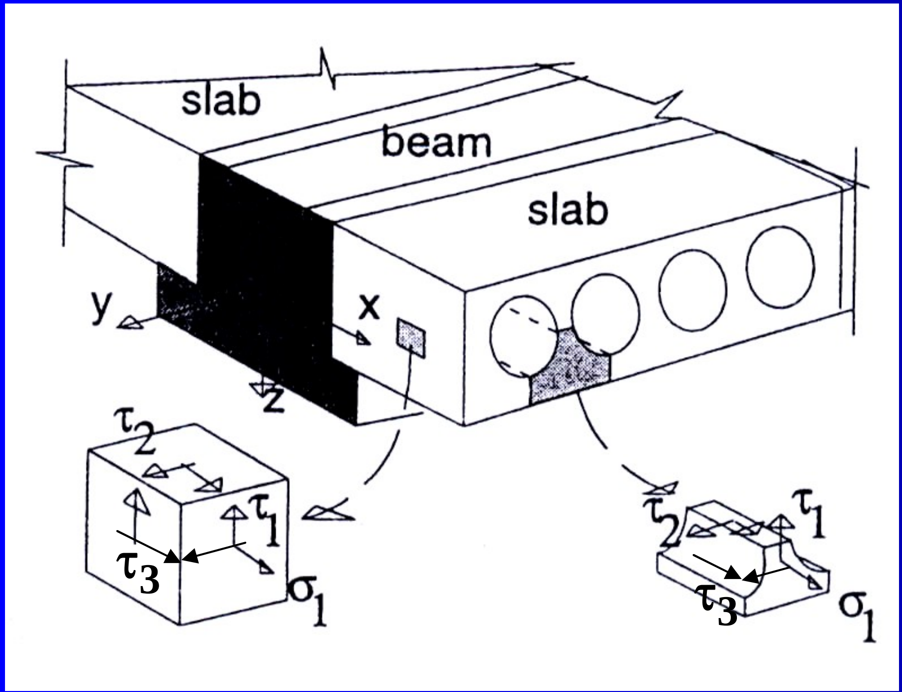


reduction of the shear capacity of hollow core slabs?

CERIB

Composite action

Stresses state in the web



σ_1 is due to the effective prestressing force

τ_1 is due to the vertical shear force

τ_2 is due to the shear flow in the transversal direction

τ_3 is due to the shear flow in the longitudinal direction

CERIB

Research in CERIB

Aims

First to elaborate an analytical model for designing beams when hollow core slabs behave as compressive flange (rigid supports)	Secondly to identify the configurations where the flexibility of the support shall be considered (flexible supports)

- ❑ **numerical modelling**
- ❑ **full scale tests**

Experimental study

Description of the floors tested

Hollow core slabs:

- thickness= 26,5 cm / length= 8,00 m
- strands: 10 T12,5 (protruding length = 10 cm)
- concrete class C60/75

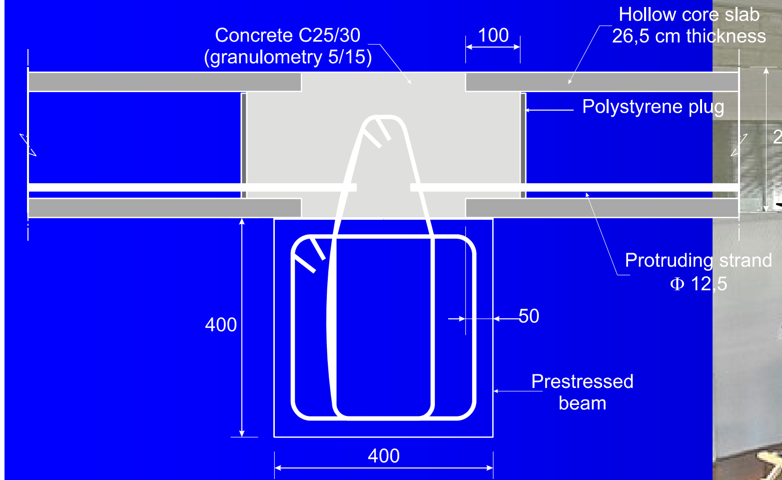
Middle beam for 1^{st} test:

- prestressed concrete beam
- section= 40 x 40 cm
- length= 4,50 m
- strands: 10 T15,2 (σ_{p0} = 1517 MPa)
- passive: 5 Φ12
- concrete class C50/60

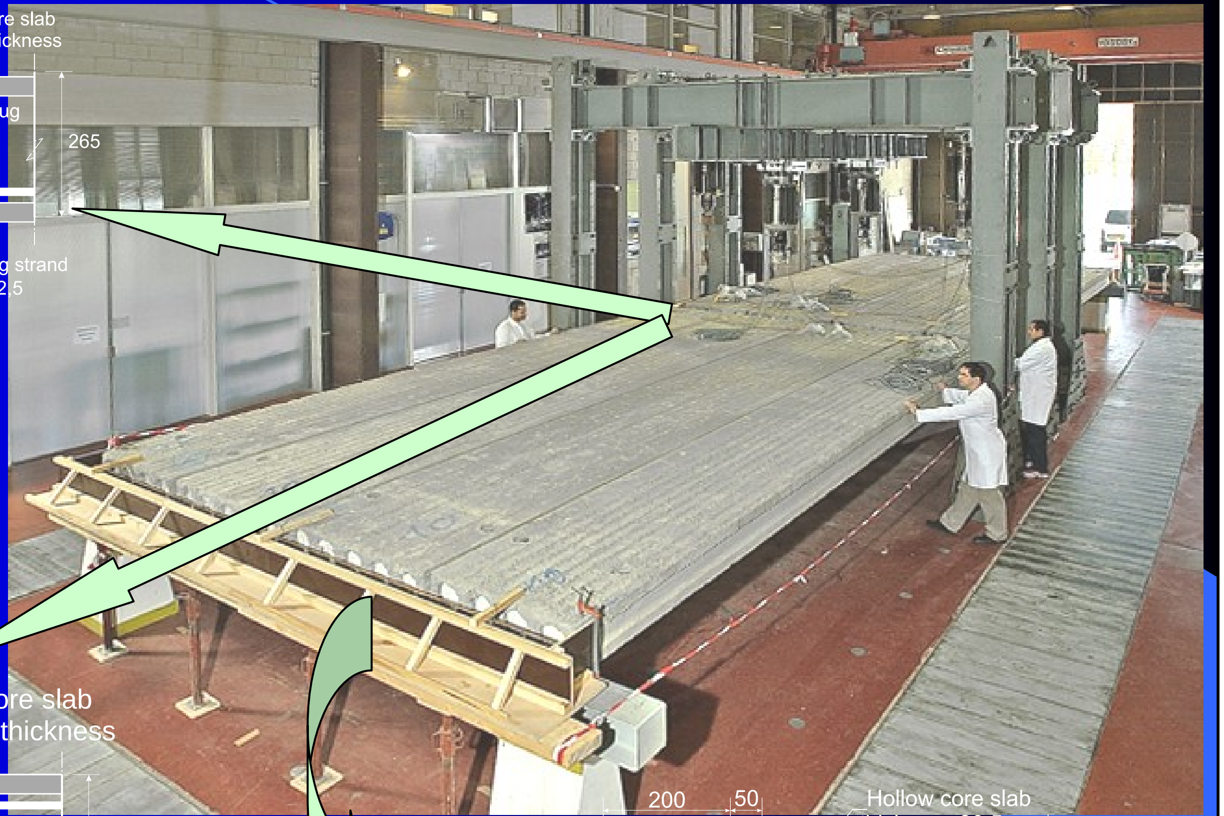
Middle beam for 2_{nd} test:

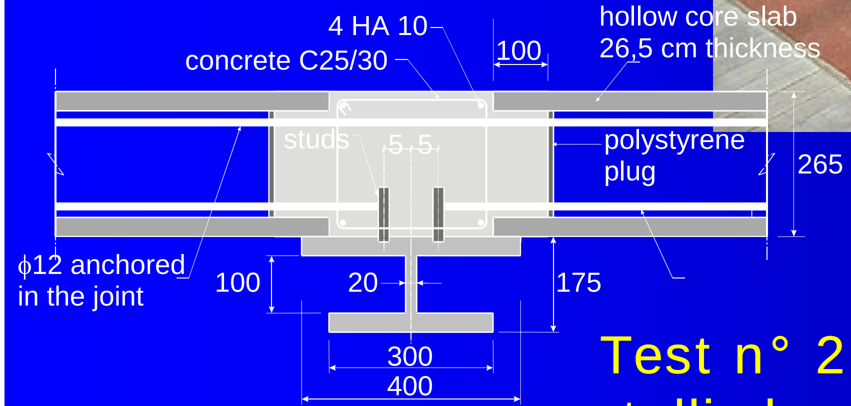
- metallic beam
- I profile (height= 17,5 cm)
- length= 4,50 m
- steel grade 240

Experimental study

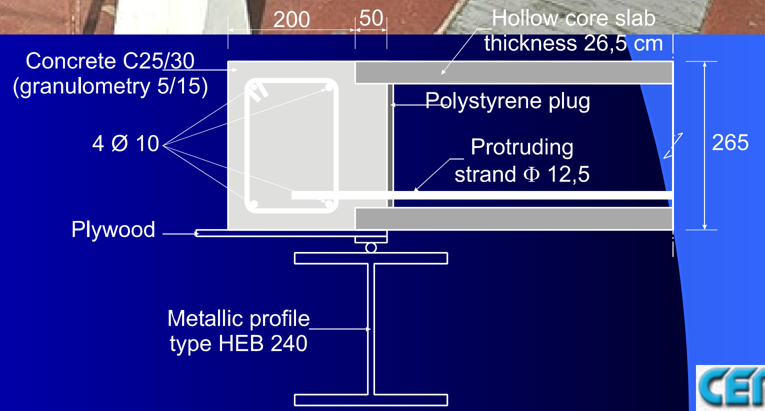


Test n° 1
concrete beam





Test n° 2
metallic beam



CERIB

Experimental study

Testing device

linear load at 1,20 m from the end of the slabs

Experimental study

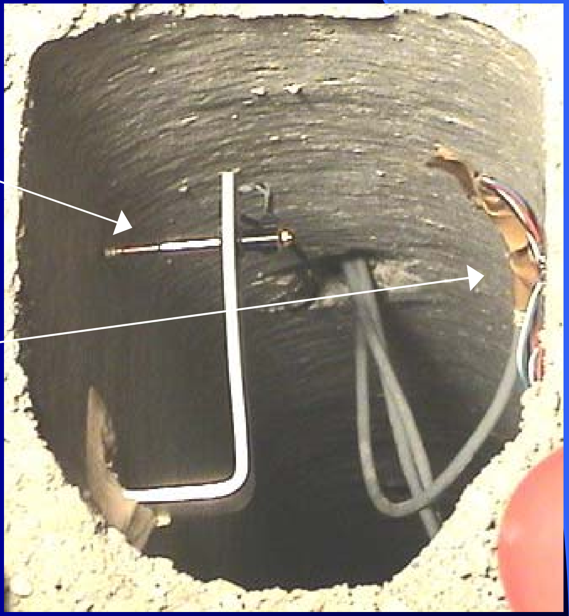
Measurement

Inductive transducers for:

- vertical displacement of slabs and beam
- differential horizontal displacement between the slabs and the middle beam
- crack width in the vertical joint concrete between the slabs and the middle beam
- warping of the webs of hollow core slabs

Strain gauges for:

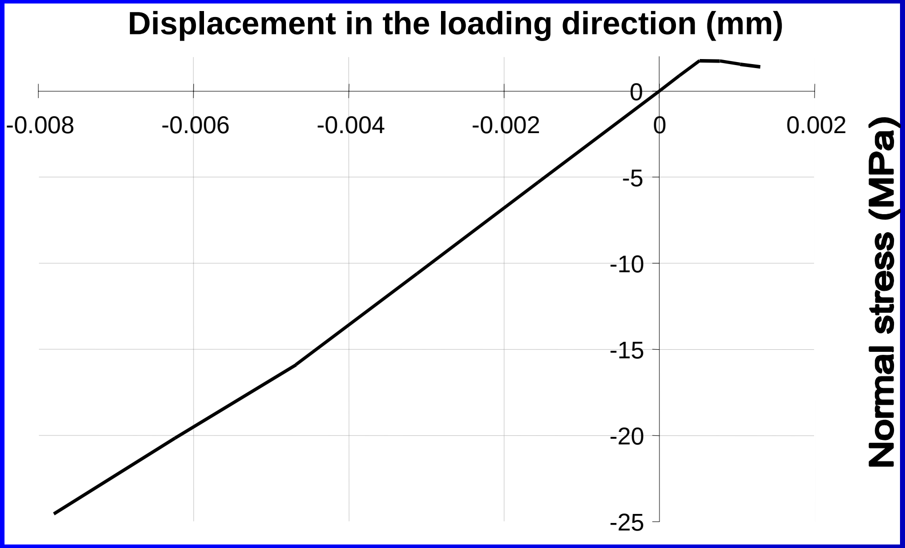
- tensile strain of the beam at mid-span
- principal strains in the webs

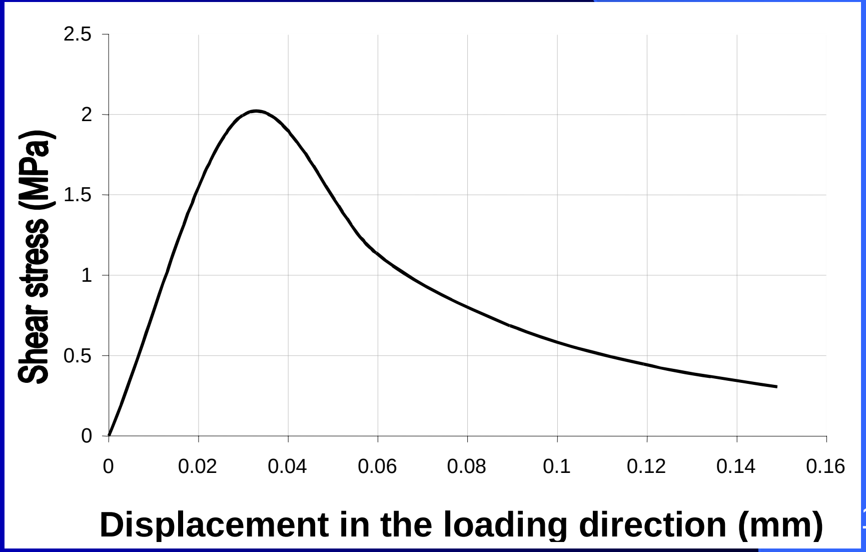


Numerical study

Finite elements model (Castem 2000)

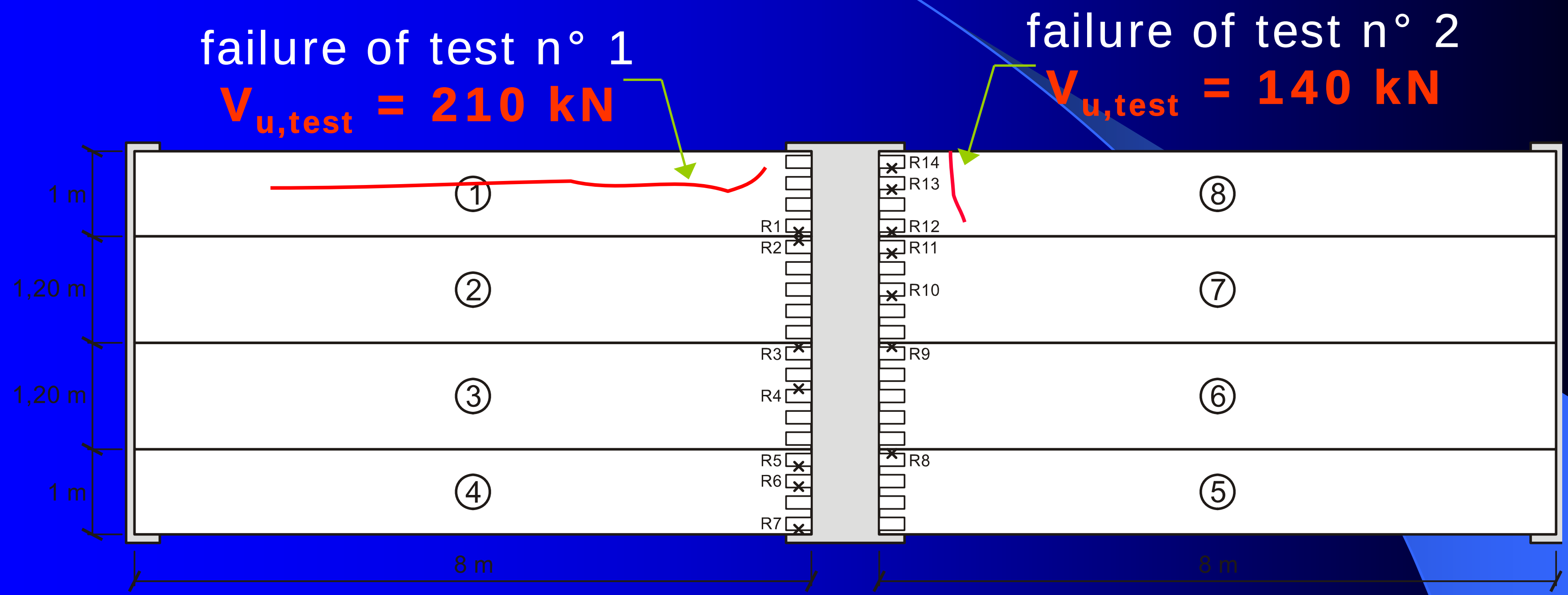
- 3D analysis with cubic elements for modelling slabs, beams and joints and bar elements for reinforcement
- elastic behaviour for concrete (slabs and beam) and steel
- isotropic damage law for the interfaces and joints





Experimental & Numerical results

Location of failure



Shear resistance ratio (design/test)	French rules		Eurocode 2	
	test No.1	test No.2	test No.1	test No.2
$\gamma_c = \gamma_s = 1{,}0$	1,74	2,24	1,50	1,94
$\gamma_c = 1{,}5$ / $\gamma_s = 1{,}15$	0,74	0,95	0,97	1,25

CERIB

Experimental & Numerical results

Failure load

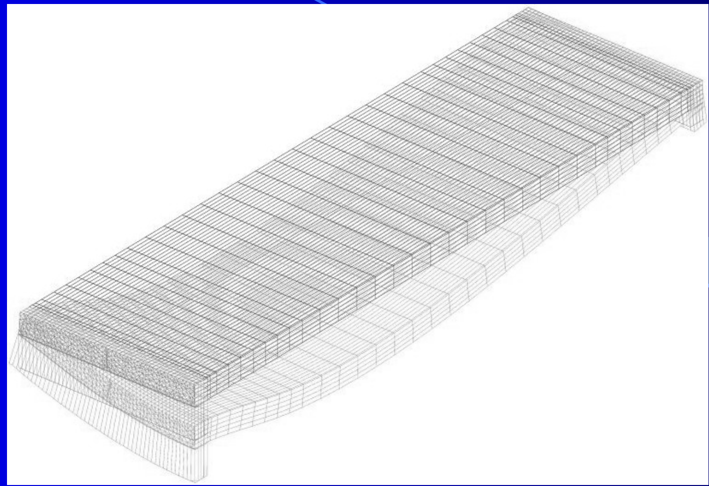
Test n° 1

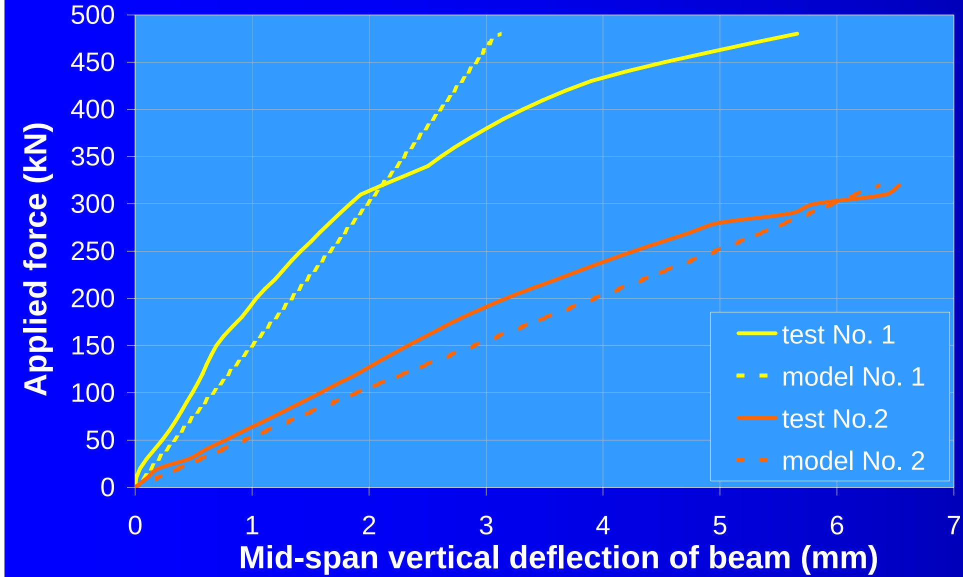
Test n° 2

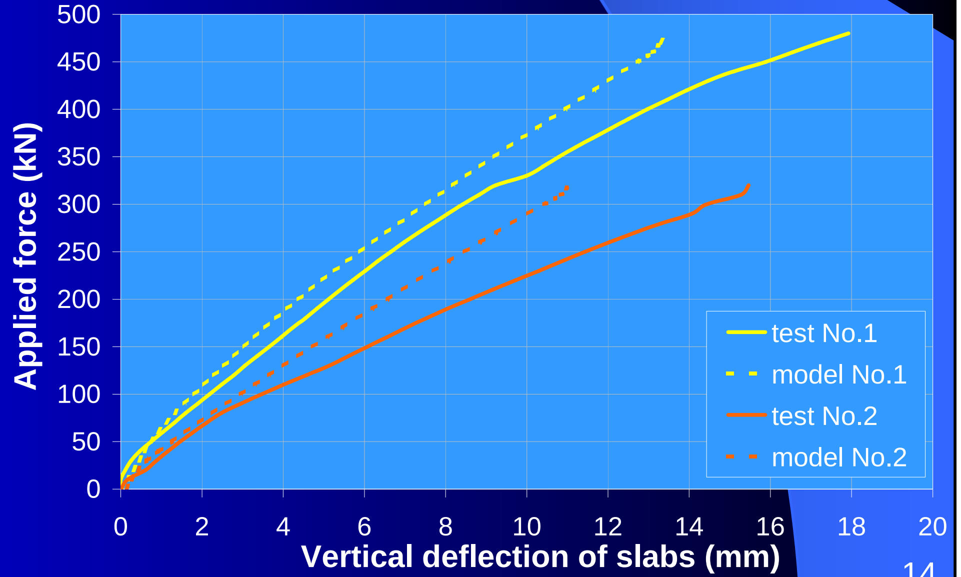
no longitudinal cracking along the strands

Experimental & Numerical results

Deflection

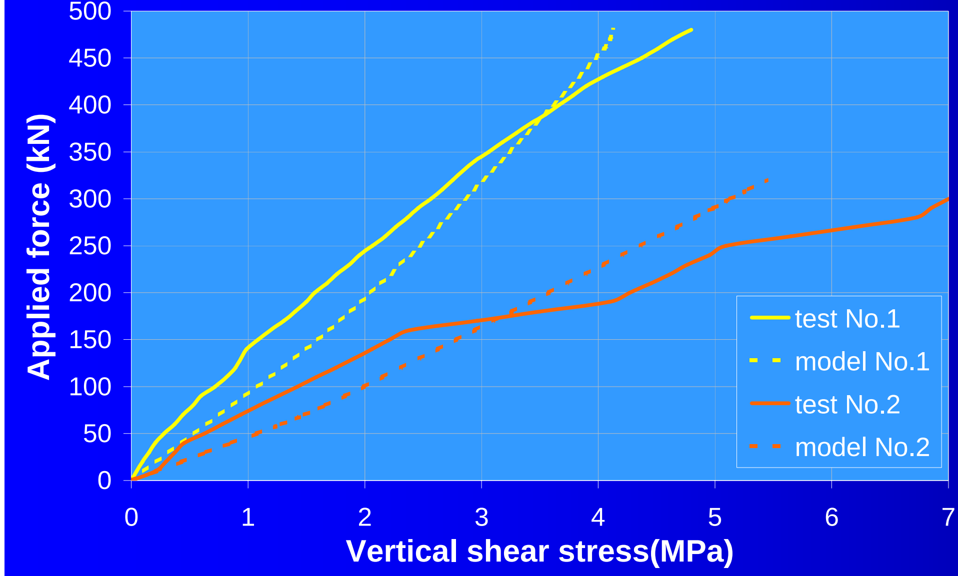


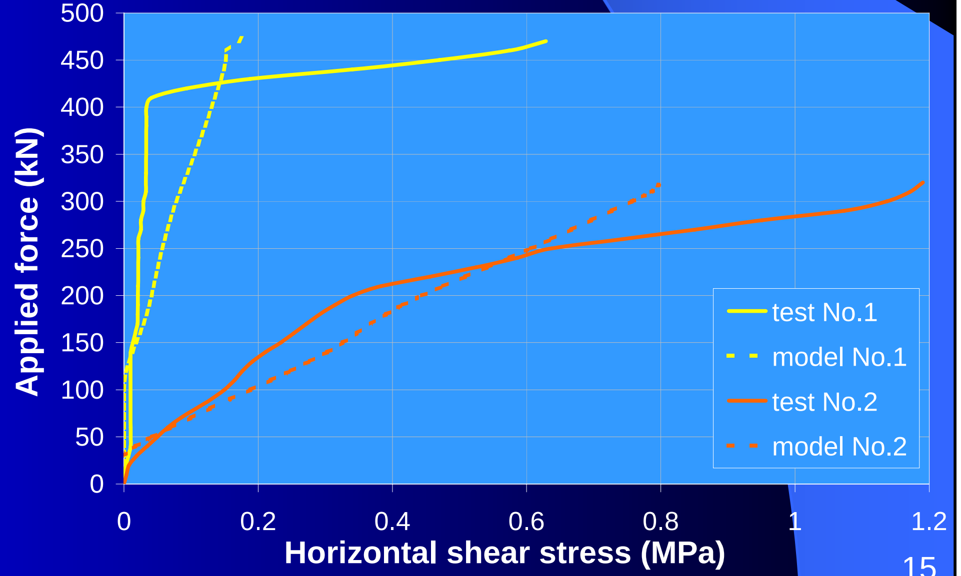




Experimental & Numerical results

Shear stresses

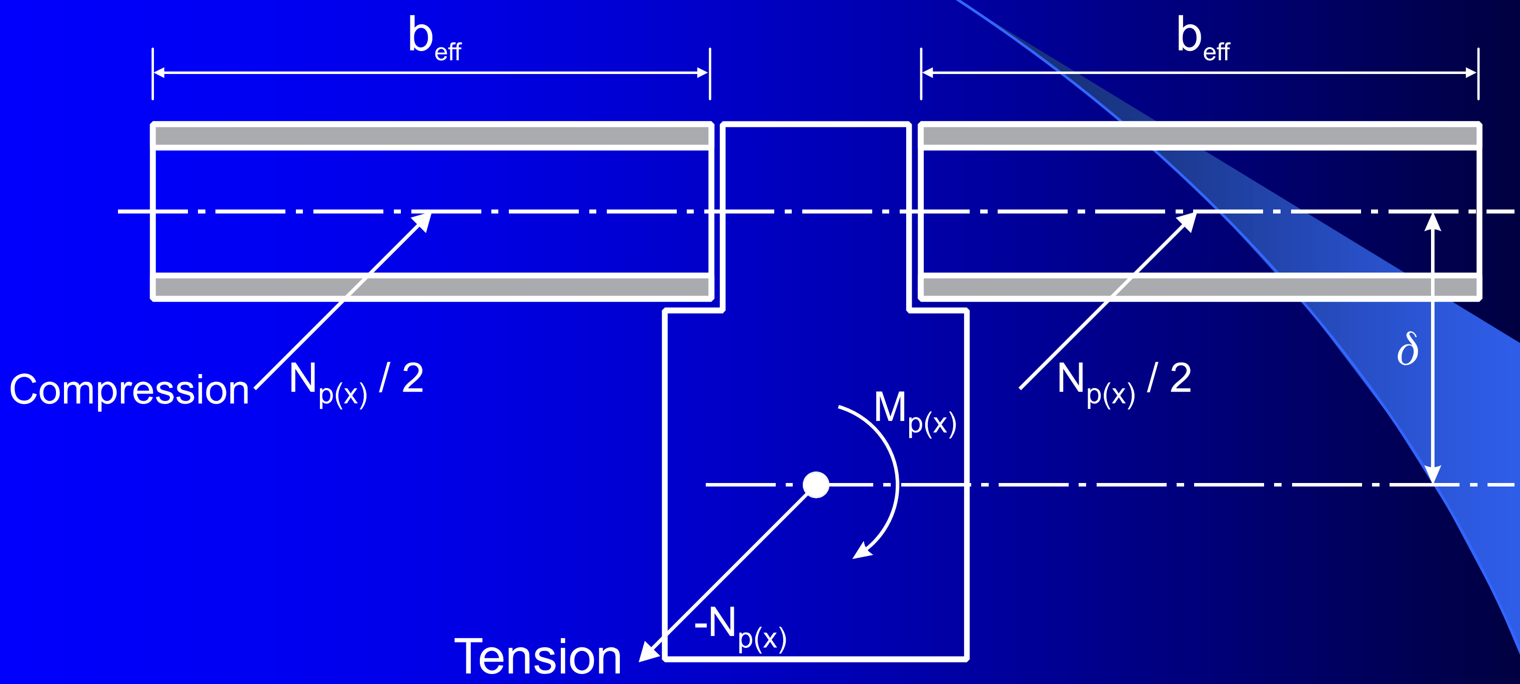




CERIB

Effective width

composite section



Effective width : $\mathbf{b_{eff} = L / 10}$ (L is the span of the beam)

Value confirmed by experimental results on deflection and normal stresses

Analytical model

bending moment applied to the beam

$$M_p = M_{ext}\,(1 - K)$$

reduction coefficient due to composite action

$$K = \frac{1}{\left[1 + \frac{I_p}{A_p\,\delta^2}\left(1 + \frac{E_p\,A_p}{E_T\,A_T}\right)\right]}$$

$$M_D(x) = M_p(x)\,\frac{E_D\,I_D}{E_p\,I_p}\,\frac{1}{(1-\nu^2)}$$

transverse bending moment applied to the slabs

A_p : cross section of the beam (precast beam + in-situ concrete

A_T : cross section of the compressive flange

I_p / I_D : second moment of area of the beam / of the hollow core slab

E_p / E_T / E_D : modulus of elasticity of concrete of the beam / of the flange / of the hollow core slab

Analytical model

❖ shear stress due to the shear flow in the transversal direction:

$$\tau_2 = \frac{V_{sd}}{b_w \, b_{eff}}$$

❖ shear stress due to the shear flow in the longitudinal direction:

$$\tau_3 = \frac{V_{sd}}{b_w \, h_{ct}}$$

$$V_{sd} = \frac{1}{2} \frac{M_{ext} - M_p}{0{,}8\,d}$$

	Design shear stresses	
	test No.1	test No.2
τ_2	1,38 MPa	3,28 MPa
τ_3	1,52 MPa	3,60 MPa

(applied load = 300 kN / γ_G = 1,35 ; γ_Q = 1,5)

Finnish rules
Code Card 18

test No.1	test No.2
1,39 MPa	2,85 MPa

Conclusions

- ✓ The influence of the rigidity of the support on the mechanical behaviour of the floor system has been highlighted.
- ✓ The outcome with the model is good with respect to the available experimental results.
- ✓ The design method will be incorporated into a new French standard for erection and design of hollow core floor systems.

Thank you for your attention

Questions ?