Hollow core floor systems: increasing performances with composite action

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CERIB
Study and Research Centre for the French Concrete Industry
Precast prestressed hollow core floors

World annual production ≈ 200 millions m²

2 millions m² in France

Principally used for:
- offices buildings
- commercial and industrial buildings
- parkings
Precast prestressed hollow core floors

Hollow core slabs produced in France:

- $12 \leq \text{thickness} \leq 40$ cm
- 60% extruded / 40% slipformed
- 95% with protruding tendons

20 cm

40 cm
Types of supports

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

Rigid supports:
- Increase of bending and shear capacities of the beam?

Flexible supports:
- Reduction of the shear capacity of hollow core slabs?
Composite action

Stresses state in the web

\( \sigma_1 \) is due to the effective prestressing force

\( \tau_1 \) is due to the vertical shear force

\( \tau_2 \) is due to the shear flow in the transversal direction

\( \tau_3 \) is due to the shear flow in the longitudinal direction
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\textsuperscript{st} test:
- prestressed concrete beam
- section= 40 x 40 cm
- length= 4,50 m
- strands: 10 T15,2 (\(\sigma_{p0} = 1517\) MPa)
- passive: 5 \(\Phi12\)
- concrete class C50/60

Middle beam for 2\textsuperscript{nd} test:
- metallic beam
- I profile (height= 17,5 cm)
- length= 4,50 m
- steel grade 240
Experimental study

Test n° 1
concrete beam

Concrete C25/30 (granulometry 6/15)
Hollow core slab 26.5 cm thickness
Polystyrene plug
Prestressed beam
100 20 300 400
175
4 HA 10–concrete C25/30
φ12 anchored in the joint

Test n° 2
metallic beam

Concrete C25/30 (granulometry 6/15)
Hollow core slab 26.5 cm thickness
Polystyrene plug
Plywood
Metallic profile type: HEB 240

IPHA Workshop – 7 & 8 November 2005 – Delft
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

failure of test n° 1
$V_{u,\text{test}} = 210 \text{ kN}$

failure of test n° 2
$V_{u,\text{test}} = 140 \text{ kN}$

<table>
<thead>
<tr>
<th>Shear resistance ratio (design/test)</th>
<th>French rules</th>
<th>Eurocode 2</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>test No.1</td>
<td>test No.2</td>
</tr>
<tr>
<td>$\gamma_c = \gamma_s = 1,0$</td>
<td>1,74</td>
<td>2,24</td>
</tr>
<tr>
<td>$\gamma_c = 1,5 / \gamma_s = 1,15$</td>
<td>0,74</td>
<td>0,95</td>
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<tr>
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<td>1,50</td>
<td>1,94</td>
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<tr>
<td></td>
<td>0,97</td>
<td>1,25</td>
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</table>
Experimental & Numerical results

Failure load

Test n° 1

Test n° 2

no longitudinal cracking along the strands
Experimental & Numerical results

Deflection

- Mid-span vertical deflection of beam (mm)
- Applied force (kN)
- Vertical deflection of slabs (mm)

- Test No. 1
- Model No. 1
- Test No. 2
- Model No. 2
Experimental & Numerical results

Shear stresses

Vertical shear stress (MPa)

Applied force (kN)

Horizontal shear stress (MPa)

Applied force (kN)
Effective width:

\[ b_{\text{eff}} = \frac{L}{10} \] (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

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

transverse bending moment applied to the slabs

\[
M_D(x) = M_p(x) \frac{E_D I_D}{E_p I_p} \frac{1}{(1 - v^2)}
\]

- \( A_p \): 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:
  \[ \tau_3 = \frac{V_{sd}}{b_w h_{ct}} \]

\[ V_{sd} = \frac{1}{2} \frac{M_{ext} - M_p}{0.8 \cdot d} \]

### Design shear stresses

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<tr>
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<th>test No.2</th>
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<tbody>
<tr>
<td>( \tau_2 )</td>
<td>1.38 MPa</td>
<td>3.28 MPa</td>
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<tr>
<td>( \tau_3 )</td>
<td>1.52 MPa</td>
<td>3.60 MPa</td>
</tr>
</tbody>
</table>

(applied load = 300 kN / \( \gamma_G = 1.35 \); \( \gamma_Q = 1.5 \))

### Finnish rules

**Code Card 18**

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<th>test No.2</th>
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<tr>
<td>( \tau_{d1} )</td>
<td>1.39 MPa</td>
<td>2.85 MPa</td>
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(\( \gamma_G = 1.35 \); \( \gamma_Q = 1.5 \))
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?