IPHA TECHNICAL SEMINAR 2017

October 25–26. Tallinn, Estonia

Openings, cut-outs, fixings

Bruno Della Bella
Gruppo Centro Nord | Italy

Organized by

INTERNATIONAL PRESTRESSED HOLLOWCORE ASSOCIATION

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OPENINGS, CUT-OUTS, FIXINGS

Bruno Della Bella –Gruppo Centro Nord

IPHA TECHNICAL SEMINAR 2017

“Hollowcore Slab and Floor Design background and examples”

Tallinn, Estonia October 25-26, 2017

REFERENCE TO *fib* H.C. RECOMMENDATIONS

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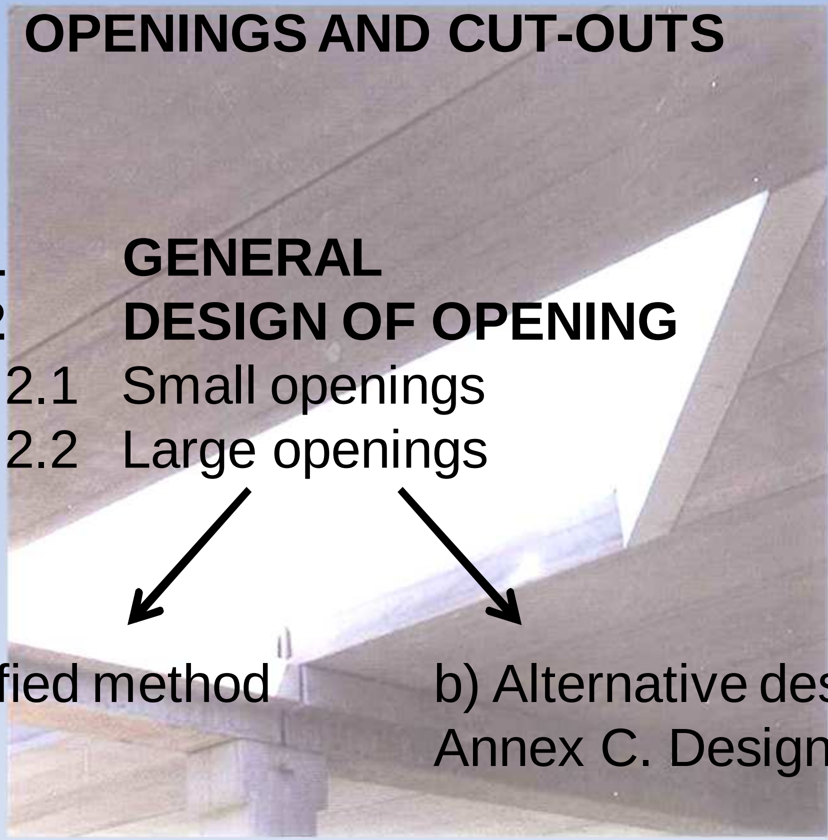


CHAPTER 4.16 OPENINGS AND CUT-OUTS

POINT 4.16.1 GENERAL

POINT 4.16.2 DESIGN OF OPENING

4.16.2.1 Small openings

4.16.2.2 Large openings

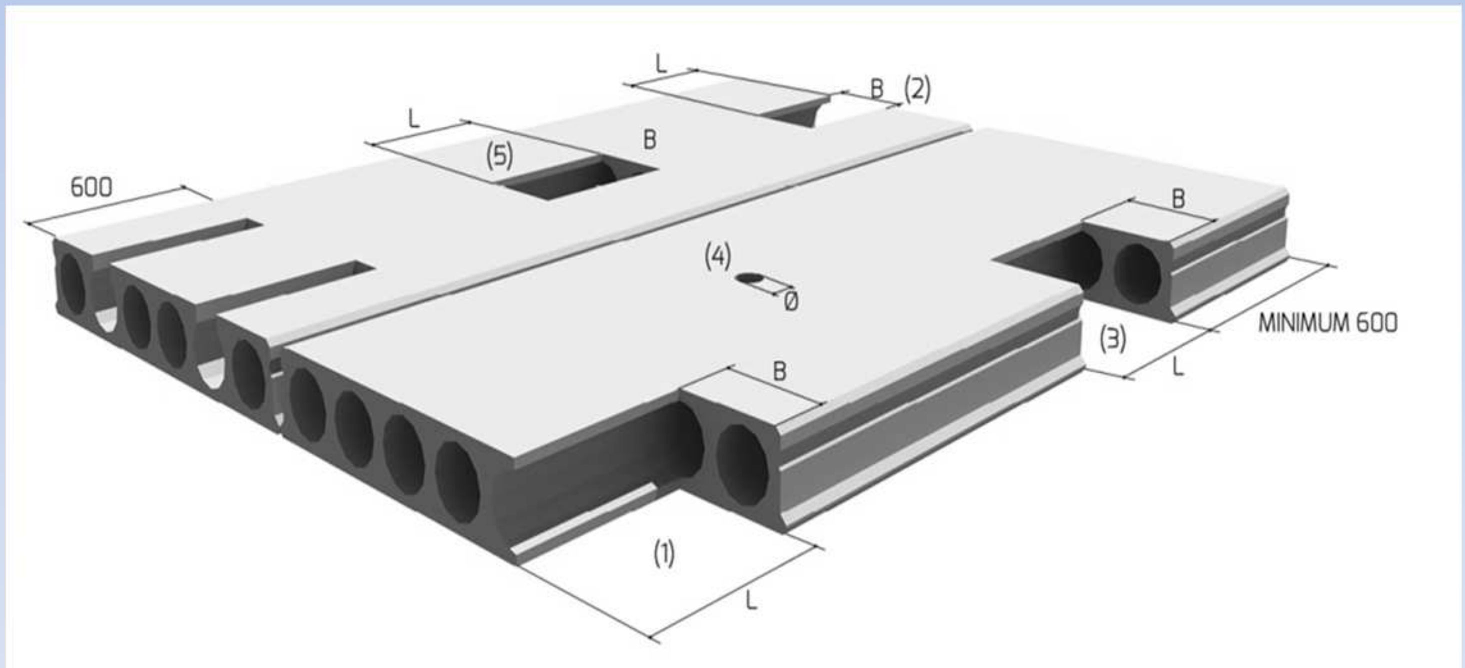
a) Simplified method

b) Alternative design method and Annex C. Design chapter

CHAPTER 4.15 LIGHT LOAD FIXINGS

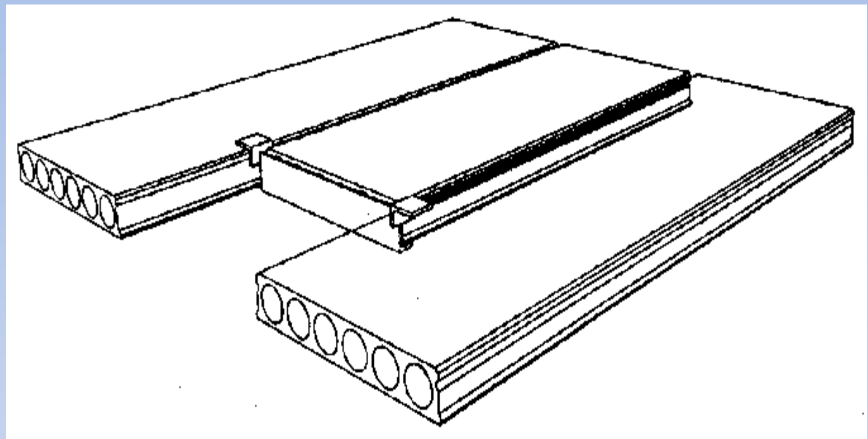
OPENINGS, CUT-OUTS, GENERAL

- Different location in slabs and different variety of sizes and dimensions
- Small cut-out (< 300÷400 mm) during casting on fresh concrete or by saw after hardening

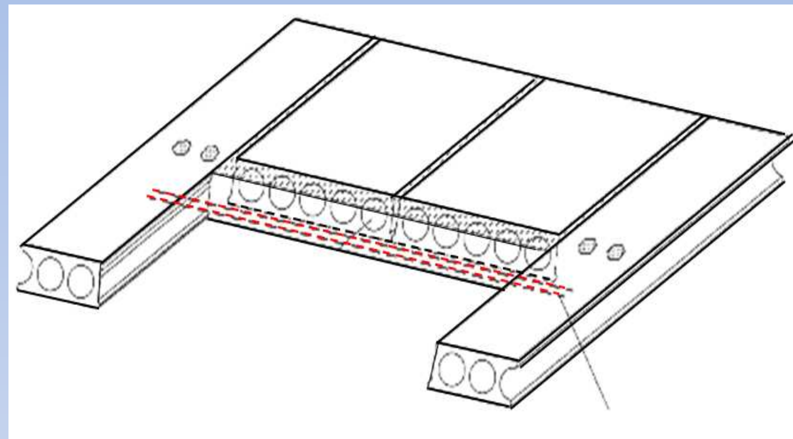


OPENINGS, CUT-OUTS -GENERAL

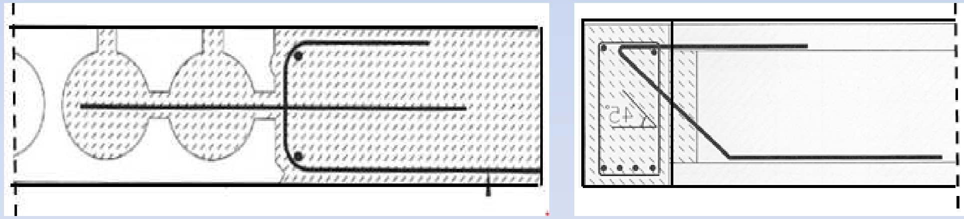
- Larger cut-out or opening require steel or cast in-situ trimmer beams



a) Steel trimmer beam



b) Cast in-situ trimmer beam



Reinforcement of concrete trimmer beam

SMALL OPENINGS - DESIGN

- Maximum size of small openings

Length/width (mm)	Depth of unit < 300 mm $\ell \times b$	Depth of unit ≥ 300 mm $\ell \times b$
- Corner (1)	600×400 mm	600×300 mm
- Front (2)	600×400 mm	600×200 mm
- Edges (3)	1000×400 mm	1000×300 mm
- Centre (4)		
Round holes	core minus 20 mm	Ø 135 mm
Rectangular openings	1000×400 mm	1000×400 mm

- Moment capacity of slab with opening

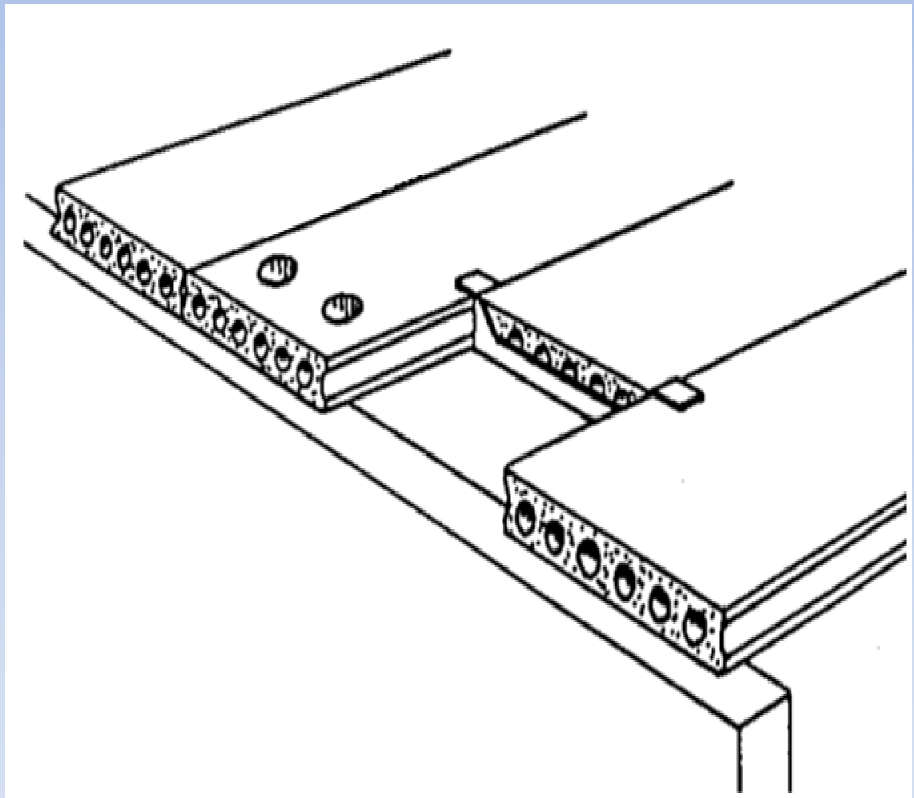
$$M_o = M_{slab} \frac{N_{strand}}{N_{strand\ orig}}$$

- Shear capacity of slab with opening

$$V_o = V_{slab} \frac{b_w - b_{op}}{b_w}$$

LARGE OPENINGS – SIMPLIFIED DESIGN

- **Large opening** when >1/3 strand are cut or opening ≥ 1200 mm

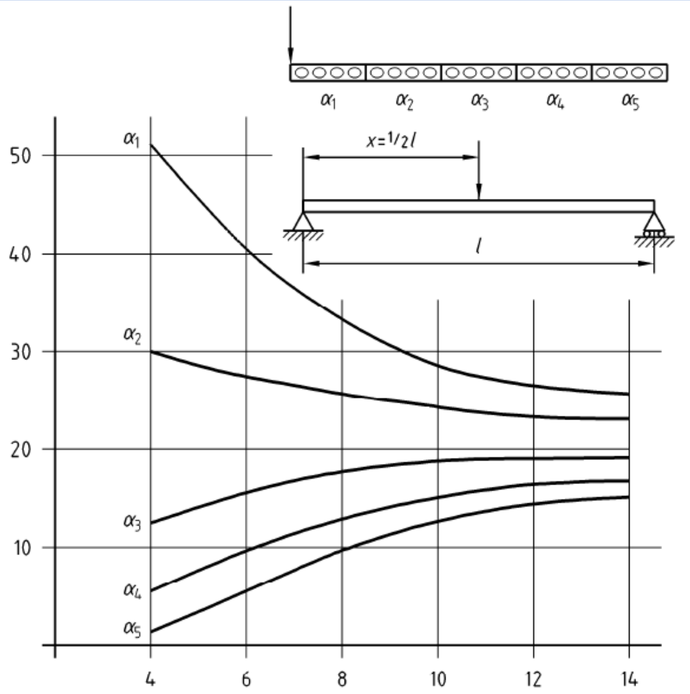


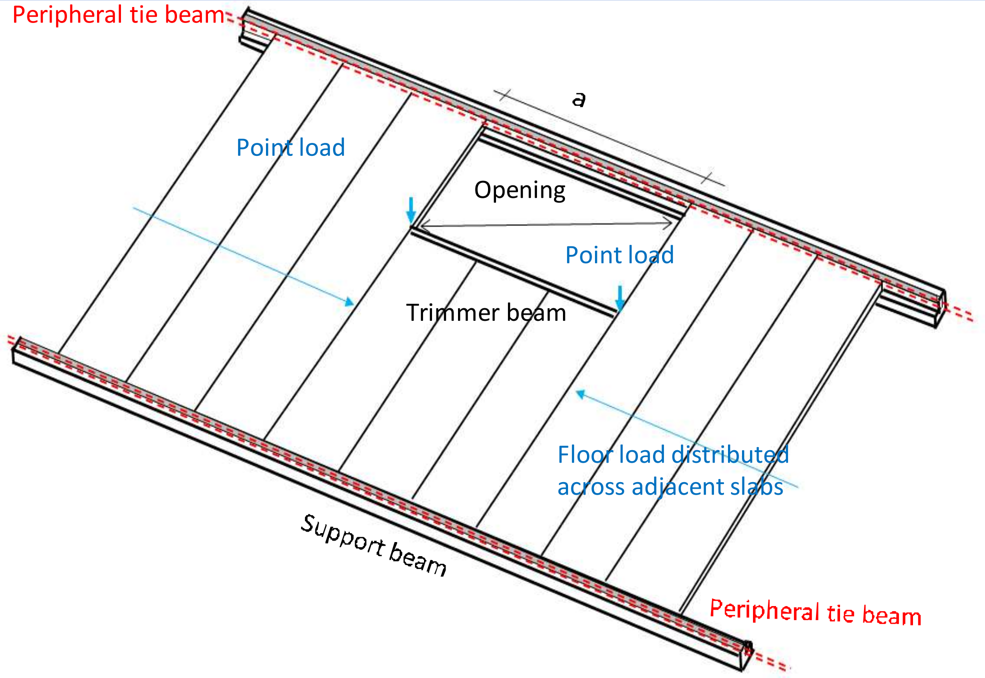
LARGE OPENINGS – SIMPLIFIED DESIGN

- Floor divided in modulus of 1200 mm

- Calculate the “point loads” from trimmer beams

- The adjacent hollow core slabs to be designed for additional loads, according to graph of Sect 4.5 (also may refer to EN1168)





Remarks on simplified design method

- For large opening close to support (< 1/8 L) the effect of torsion + shear to be taken into account

- For small openings, the method give very conservative results.

- Better accuracy, but always conservative, in case of larger openings (1 or 2 slab openings)

The following slides summarize an extensive research program carried out by ASSAP and the University of Parma during the last ten years

UNIVERSITÀ DI PARMA

PARAMETRIC NUMERICAL STUDY ON HC FLOORS WITH LARGE OPENINGS FOR THE DEVELOPMENT OF DESIGN CHARTS

Research program funded by ASSAP hollow core slabs **Association of manifacturers of hollow core slabs**

Roberto Cerioni, *full professor* roberto.cerioni@unipr.it
Patrizia Bernardi, *assistant professor* patrizia.bernardi@unipr.it
Elena Michelini, *assistant professor* elena.michelini@unipr.it

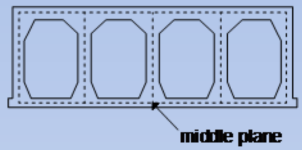
Department of Engineering and Architecture (DIA),
University of Parma, p.co Area delle Scienze 181/A – 43124 PARMA
+39 0521 90 5709/5928

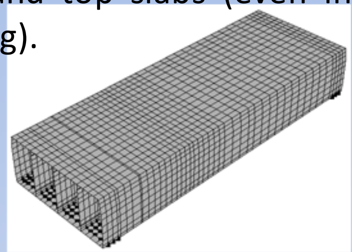
RESEARCH PROGRAM

Geometry

single HC unit

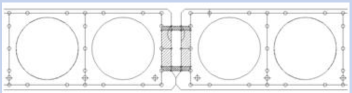
FE mesh, with *four-node, multi-layered shell elements* representing the middle plane of the webs and of the bottom and top slabs (even in presence of concrete topping).

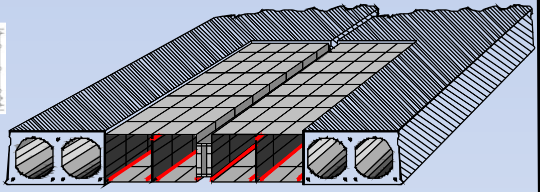




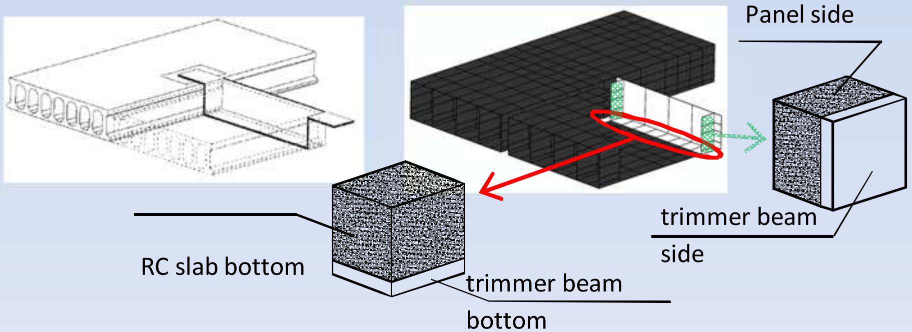
assembled HC panels

RC longitudinal joint modeled through *vertical shell elements* able to transmit shear stresses.





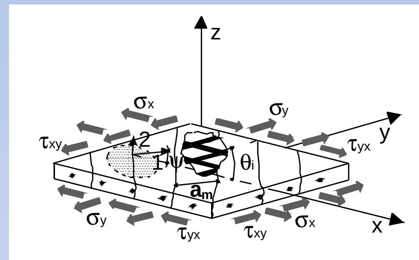
modelling of the large opening



Materials constitutive models

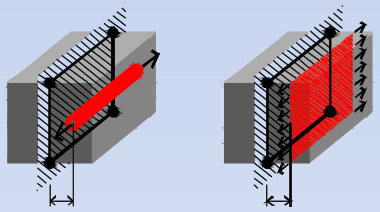
(Implemented into ABAQUS FE code)

panels and RC joints *smeared crack non linear model* for uncracked and cracked Reinforced Concrete ("2D-PARC model", Cerioni, Iori, Michelini, Bernardi, 2008, "Multi-directional modeling of crack pattern in 2D R/C members", Eng Fract Mech, vol. 75 pp. 615-628).



In the cracked stage: contributions offered by
- *aggregate bridging*
- *aggregate interlock*
- *dowel action*
- *tension stiffening*

prestressing bars



Rebar layer hosted in a shell element with an initial given prestress

Elastic-hardening law

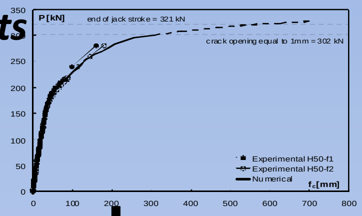
steel trimmer beam

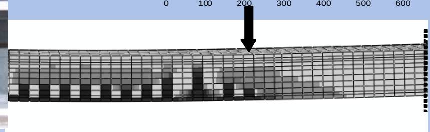
Elastic-hardening law

RESEARCH PROGRAM

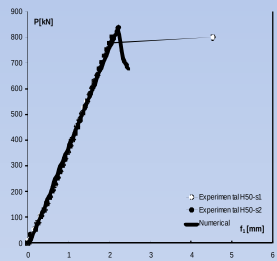
Tests on *single HC units*

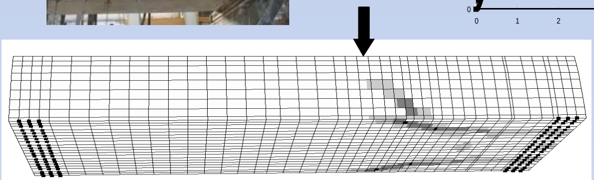
Bending test (Bernardi et al., RDB PC Italy, 2003)



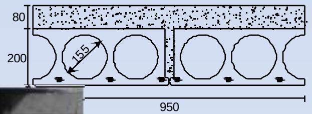


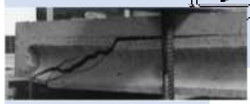
Shear test (Bernardi et al., RDB PC Italy, 2003)

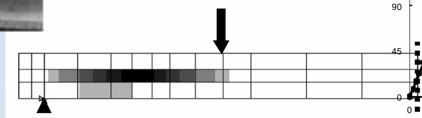


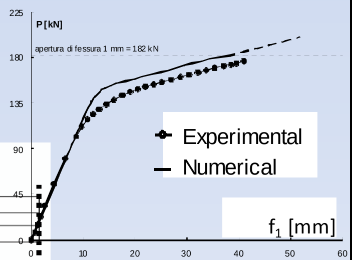


Shear test on HC with RC topping and one RC joint (Girhammar & Pajari, KTH, 2008)



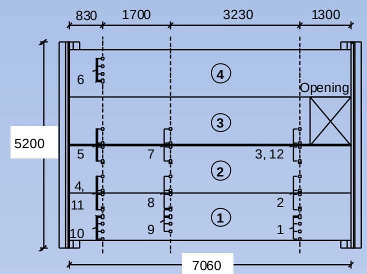


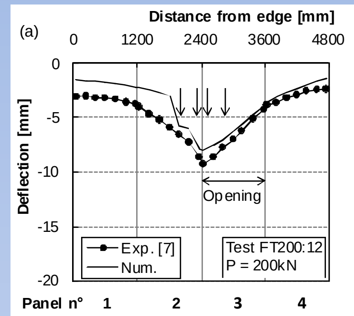


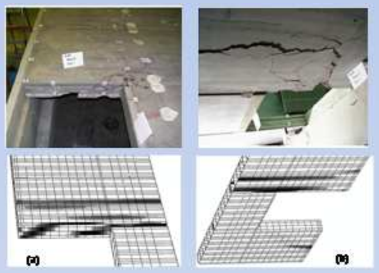


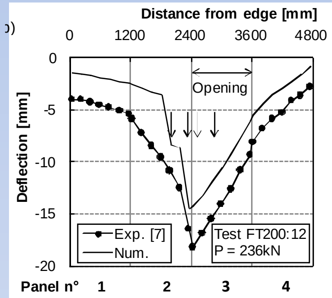
Tests on *HC floors*

With or without opening (Pajari, VTT, 2004)

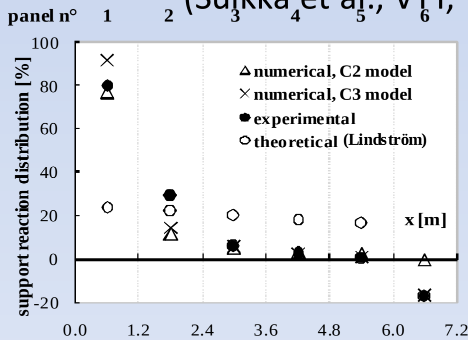


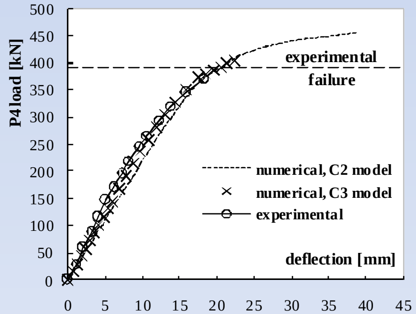






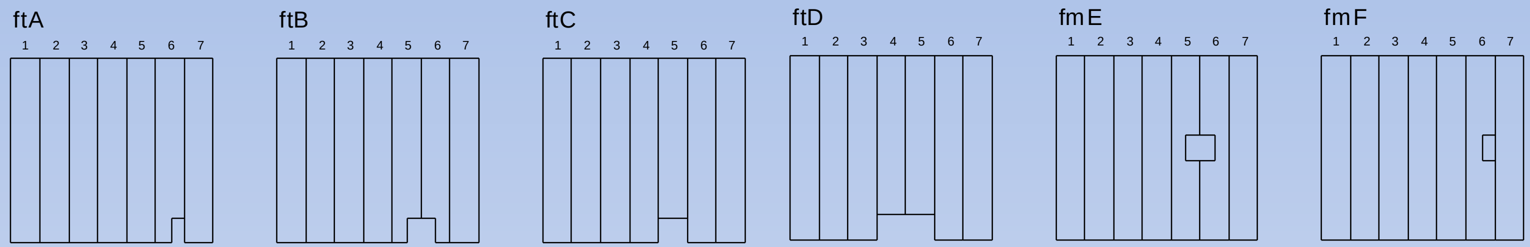
Without opening and with support reaction comparisons (Sujkka et al., VTT, 1991)

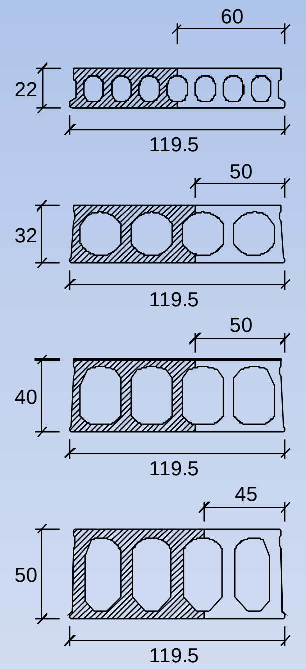




Step III: Definition of the case studies for the development of design charts

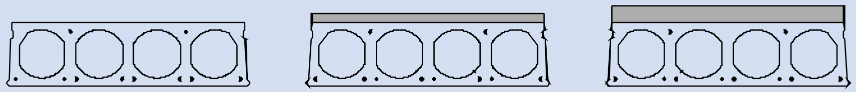
- simply supported HC floor constituted of ***7 units***
- **4 slab thickness** (220 mm, 320 mm, 400 mm, 500 mm)
- ***6 opening cases***, characterized by different dimensions and positions





Opening name	*Opening position*	*N°of involved panels*	*Opening dimensions*		
			H22	***H32 - H40***	***H50***
ftA	slab end	1	60 x 120 cm	50 x 120 cm	45 x 120 cm
ftB	slab end	2	120 x 120 cm	100 x 120 cm	90 x 120 cm
ftC	slab end	1	120 x 120 cm	120 x 120 cm	120 x 120 cm
ftD	slab end	2	240 x 120 cm	240 x 120 cm	240 x 120 cm
fmE	slab midspan	2	120 x 120 cm	100 x 120 cm	90 x 120 cm
fmF	slab midspan	1	60 x 120 cm	50 x 120 cm	45 x 120 cm

- ***concrete topping thickness*** (0 – 40 – 80 mm)



- ***floor slenderness ratio H/L*** (1/25 – 1/30 – 1/35)
- ***imposed floor service load*** (5 – 10 – 15 kN/m²) (prestressing strands arrangement)

Step IV: Reporting of results -ULS design charts (δ,L/H) for end slab openings

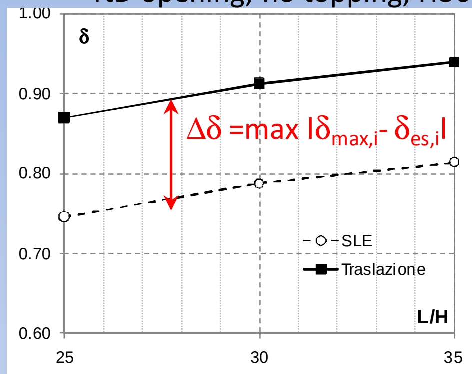
$$\delta = \left(V_{i,op} - V_{int}\right) / V_{int}$$

$V_{i,op}$= shear force on the i[th] slab of the floor with openings
V_{int} = shear force acting on the corresponding slab of the floor without openings

Procedure:

1) Evaluation of δ by enveloping the numerical results at SLS, referred to different reinforcement ratios.
2) Determination of the SLS design curve for each value of concrete topping.
3) Offset of the SLS design curves of the quantity $\Delta\delta = |\delta_{max} - \delta|$, δ_{max} being the maximum value assumed by δ during the loading history until the reaching of M_{rd} or of the numerical failure.

ftD opening, no topping, H30



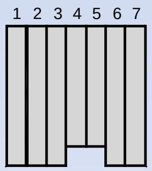
ULS shear verification:

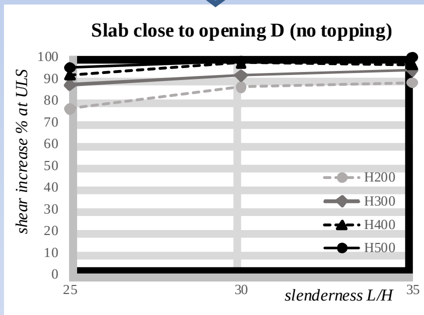
$$V_{sd} = \gamma_{G1}\left(G_1 + G_{1,cast}\right) bl/2 + \left(\gamma_{G2} G_2 + \gamma_Q Q\right) bl/2 \left(1 + \delta\right) \le V_{Rd}$$

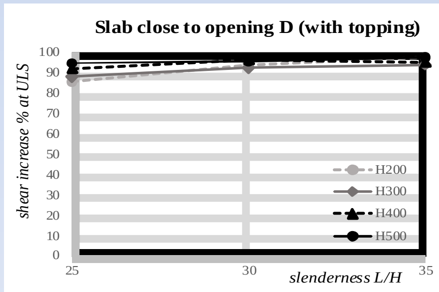
Evaluated on the effective cross-section

b = slab width
l = design span
G_1 = slab dead weight
$G_{1,cast}$ = dead weight of all the cast in situ elements (joints and concrete topping)
G_2, Q = 2[nd] phase loads, applied after floor assembly

Example: ftD opening







Step IV: Reporting of results-ULS design charts (d,L/H) for openings placed at midspan

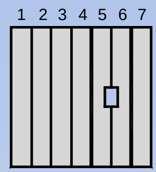
$$\delta = \left(M_{i,op} - M_{int}\right) / M_{int}$$

$M_{i,op}$= maximum bending moment of the i^{th} slab at midspan of the floor with openings

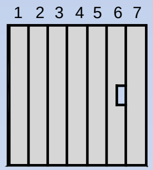
Procedure:

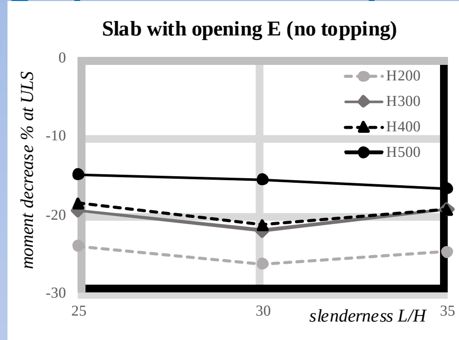
1) Evaluation of δ by enveloping the numerical results at SLS, referred to different reinforcement ratios.
2) Determination of the SLS design curve for each value of concrete topping.
3) Offset of the SLS design curves of the quantity $\Delta\delta = | \delta_{max} - \delta |$, δ_{max} being the maximum value assumed by δ during the loading history until the reaching of M_{rd} or of numerical failure.

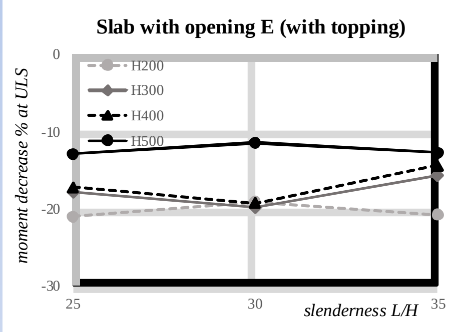
Example: fmE opening



Example: fmF opening







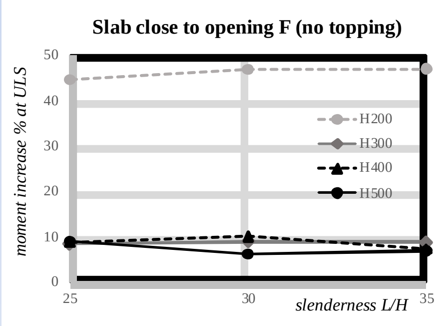
ULS bending resistance verification:

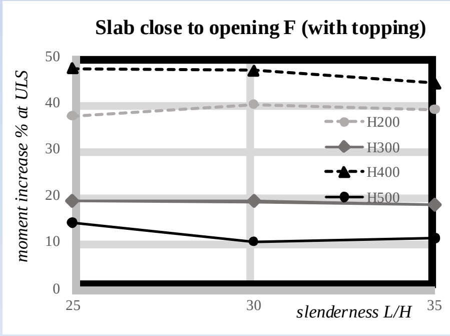
$$M_{Ed} = \frac{(\gamma_{G1} G_1 + \gamma_{G2} G_2 + \gamma_Q Q) l^2}{8} b\,(1+\delta) \leq M_{Rd}$$

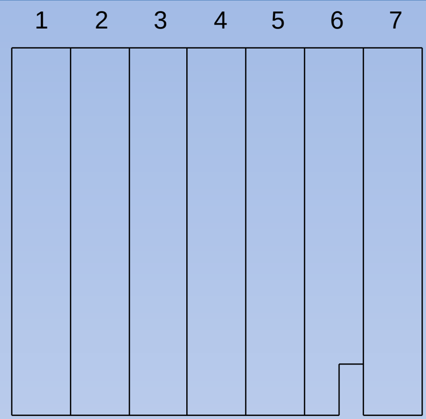
b = slab width

l = design span

Evaluated on the effective cross-section

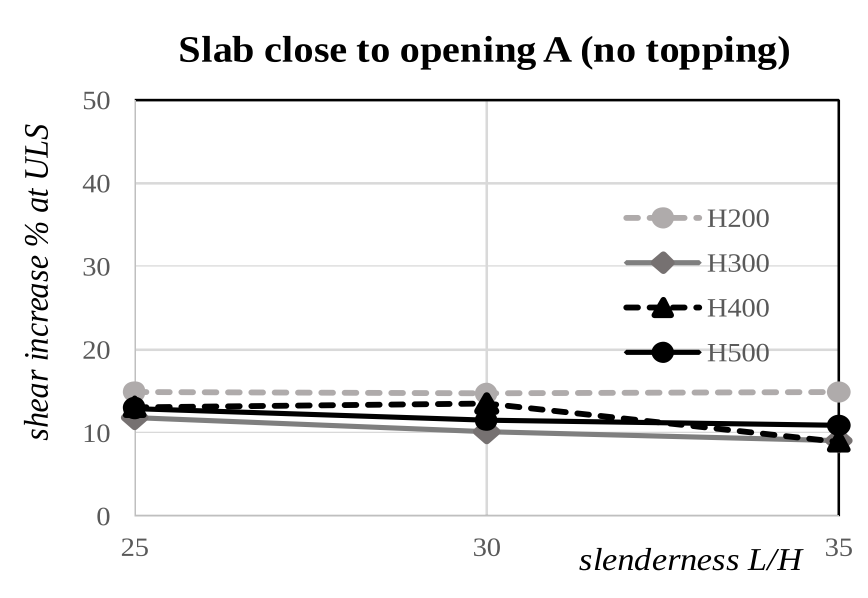


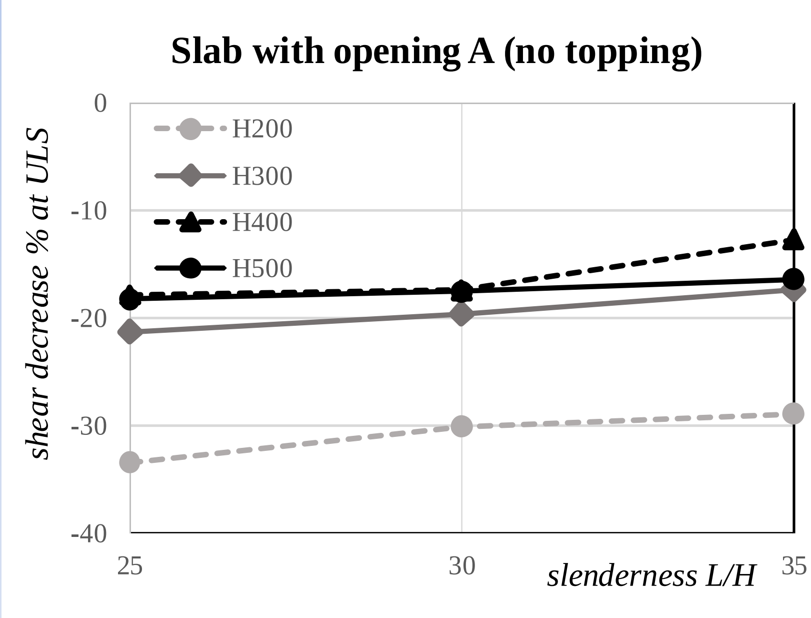




Opening A (with and without topping: see ANNEX C)

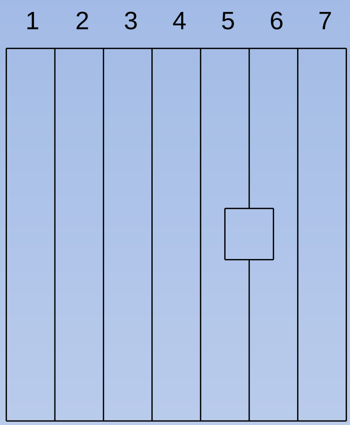
- Shear increase % of slab close to opening A
- Shear decrease % of slab with opening A according to following design charts





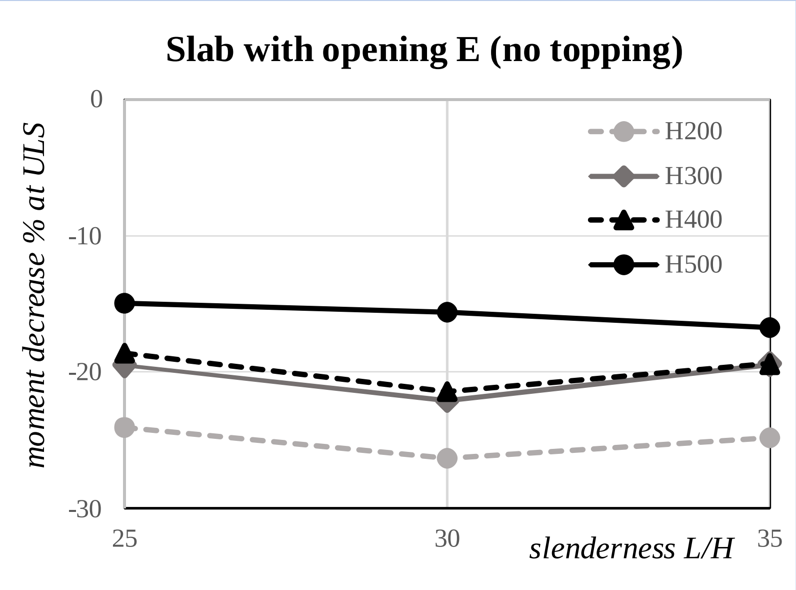
Opening B, C and D same procedure, see ANNEX C

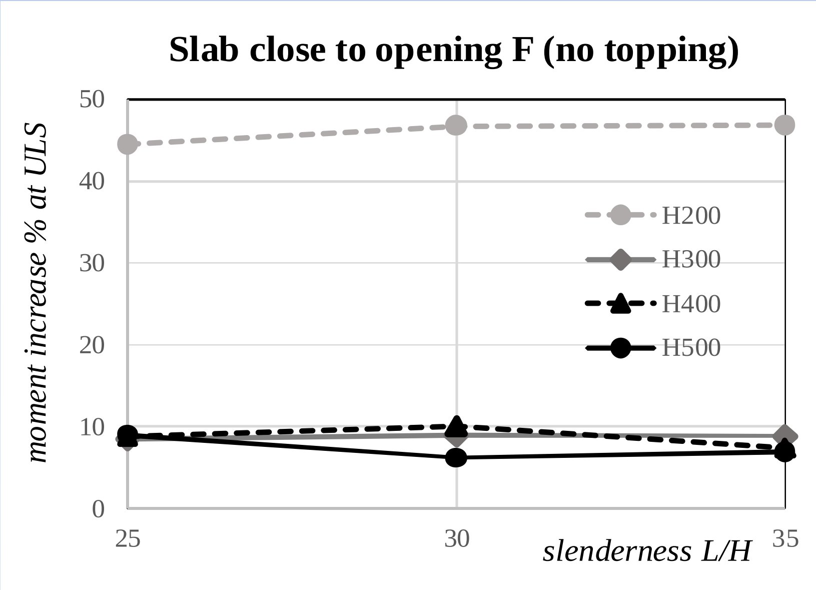
DESIGN CHARTS FOR LARGE OPENINGS



Opening E (with and without topping: see ANNEX C)

- Moment decrease % of slab with opening E
- Moment increase % of slab close to opening E according to following design charts





Opening F same procedure, see ANNEX C

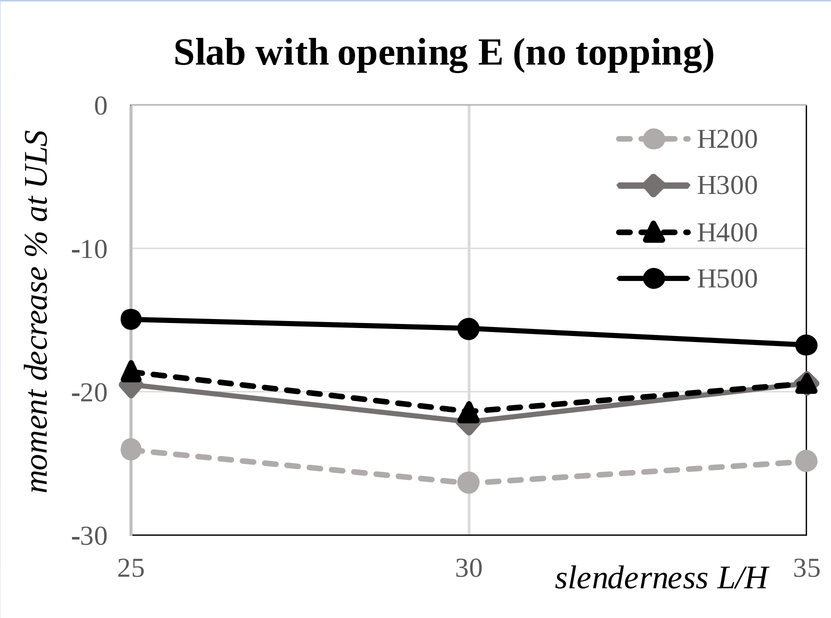
Example 1 – HC floor with opening at midspan

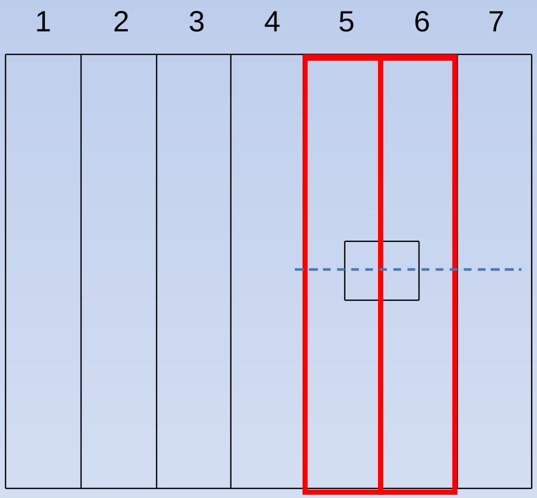
INPUT DATA

Opening type: E, 1000 x 1200 mm, hollow-core slab with no topping
Floor dimensions: H=300 mm, L/H of 35 => L = 35 x 300 = 10500 mm
Applied loads: 2nd phase load q =10 kN/m², dead weight g_1 = 3.8 kN/m²

➔ $M_{Ed} = 1.2 \times (1.35 \times 3.8 + 1.5 \times 10) \times 10.5^2/8 = 332.9$ kNm

Design of the slab interested by the opening

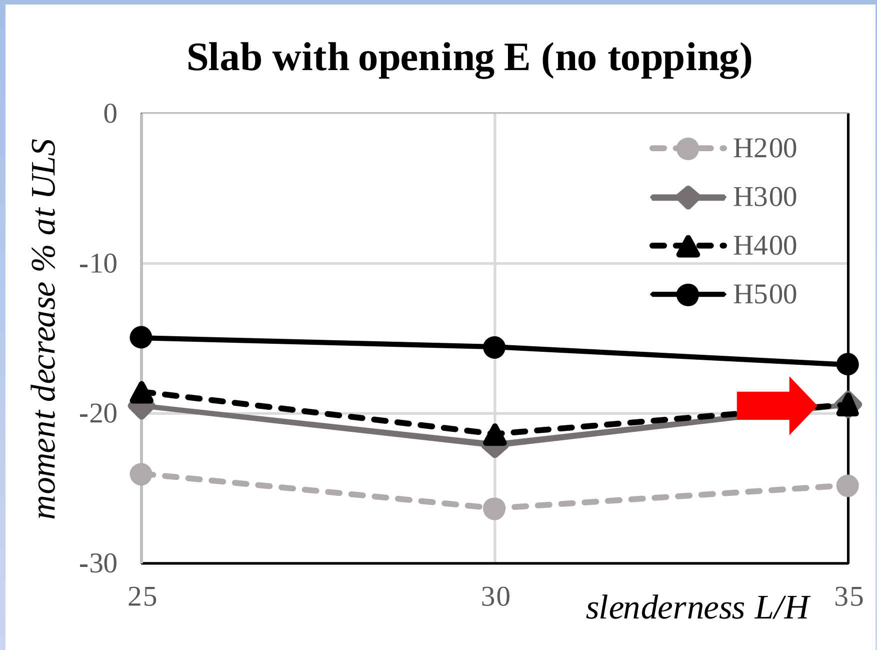




design of slabs 5 or 6

LARGE OPENINGS - EXAMPLE OF CALCULATION

Design of the slab interested by the opening



NOMENCLATURE

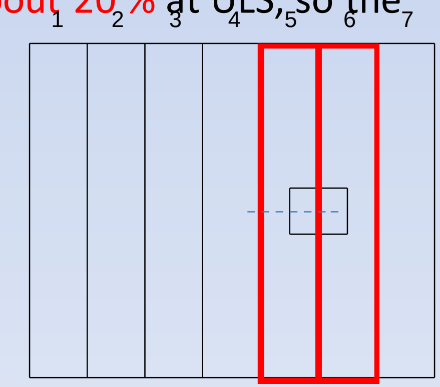
M_{Ed} = acting bending moment at ULS (without influence of the opening);

$M_{Ed,open}$ = acting bending moment on the slab with the opening;

$M_{Rd,open}$ = bending capacity of the slab interested by the opening (evaluated on the effective resistant cut cross section, with approximately half width and half reinforcement for a symmetric arrangement);

$M_{Rd,whole}$ = bending capacity of the slab in a section not disturbed by the opening (uncut section)

From the chart: in the slab with the opening there is a moment decrease of about 20 % at ULS, so the effective moment on the cut slab according to design chart is:



$M_{Ed,open}$ = $(1+\delta)\ M_{Ed} = 0.80\ M_{Ed}$ = 266.32 kNm

$M_{Rd,open} \geq M_{Ed,open} = 0.80\ M_{Ed}$ = 266.32 kNm

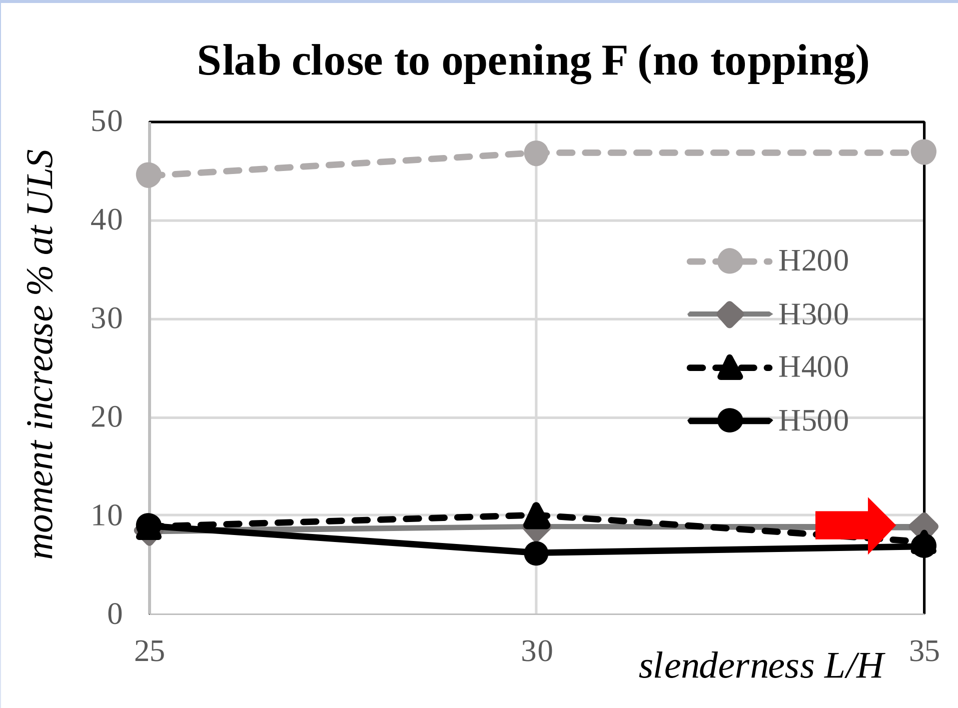
$M_{Rd,whole} \cong (1.20/0.70)\ M_{Rd,open} \geq 1.71 \times 266.32$ = 455.4 kNm

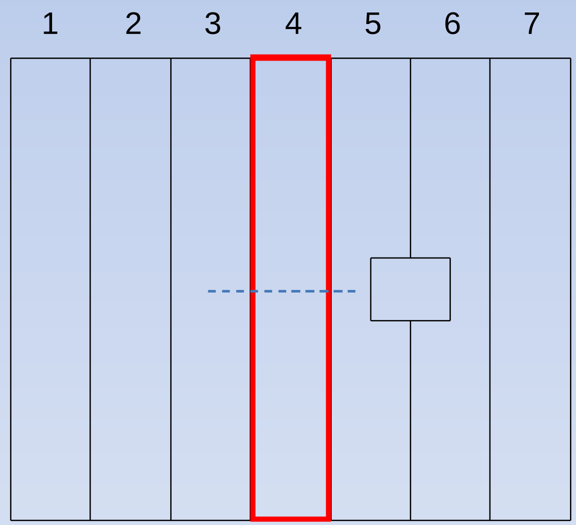
Example 1 – HC floor with opening at midspan

Design of the slab adjacent to the opening

It must be observed that in panels adjacent to the cut ones there is an increase of the acting moment and an additional reinforcement should be provided.

In this case, the same design chart of opening type F can be adopted also for type E opening, so obtaining for the same floor a **moment increase of 9 % at ULS**.

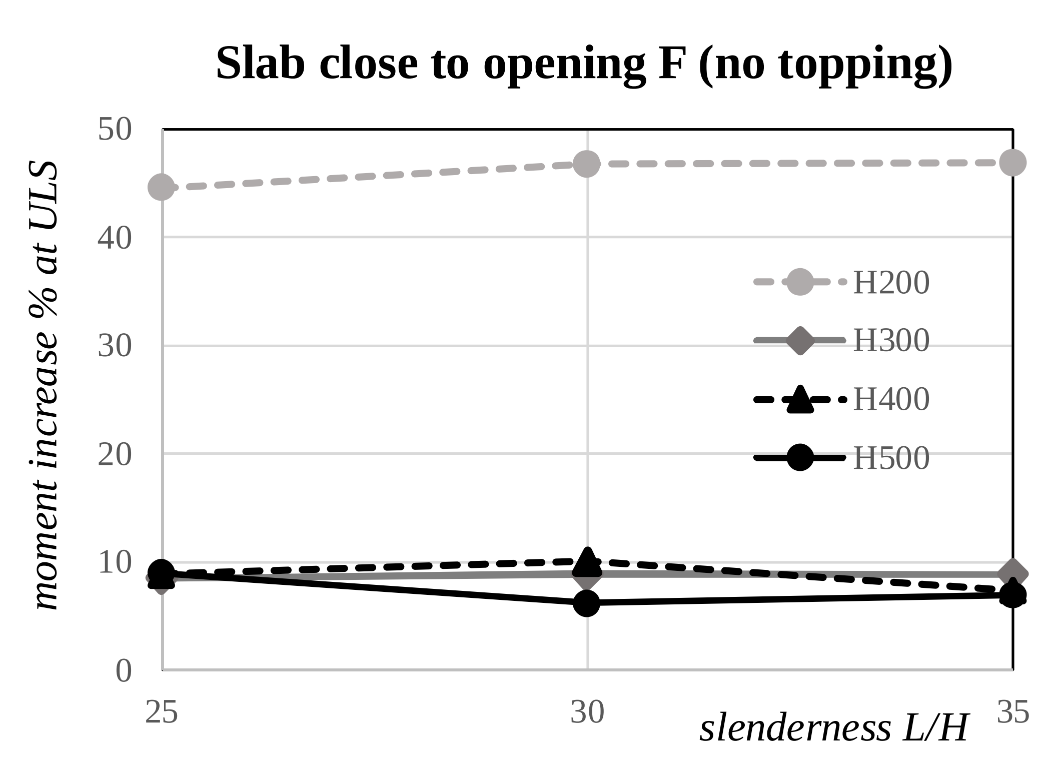




design of slab 4

Example 1 – HC floor with opening at midspan

Design of the slab adjacent to the opening



NOMENCLATURE

$M_{Ed,adj,\,op}$ = acting bending moment on the slab adjacent to the cut one;

$M_{Rd,adj,\,op}$ = bending capacity of the slab adjacent to the cut one;

The slab adjacent to the cut one must be designed for the following moment:

$M_{Ed,adj,\,op}$ = $(1+\delta)\ M_{Ed}$=1.09 M_{Ed} = 362.86 kNm;

$M_{Rd,adj,\,op} \geq M_{Ed,adj,\,op}$ = 1.09 M_{Ed} = 362.86 kNm.

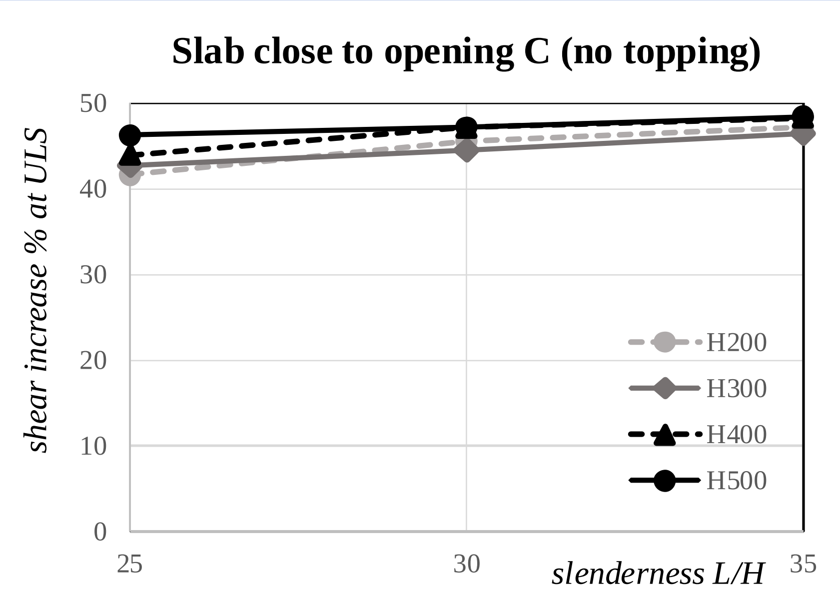
Example 2 – HC floor with opening at slab end

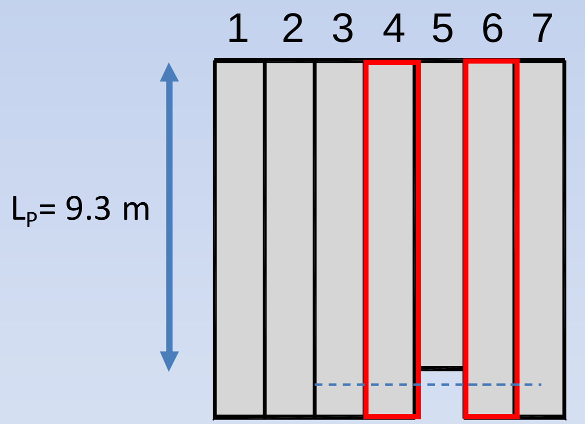
INPUT DATA

Opening type: C, 1200 x 1200 mm, hollow-core slab with no topping
Floor dimensions: H=300 mm, L/H of 35 => L = 35 x 300 = 10500 mm, L_P=10500-1200=9300 mm
Applied loads: 2[nd] phase load q =10 kN/m², dead weight g_1 = 3.8 kN/m²

➔ V_{Ed} = 1.2 x (1.35 x 3.8 + 1.5 x 10) x10.5/2 = 16.82 kN (uncut slabs, all loads applied)
➔ $V_{g1d,opening}$ = 1.2 x (1.35 x 3.8) x 9.3/2 = 28.6 kN (cut slab, dead load)

Design of the slab adjacent to the opening

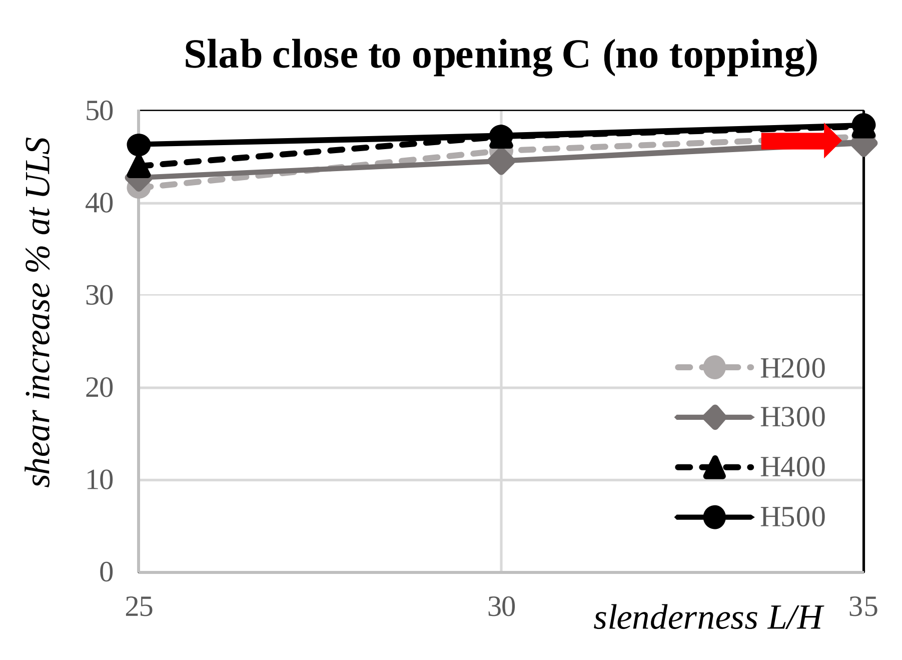




design of slabs 4 or 6

Example 2 – HC floor with opening at slab end

Design of the slab adjacent to the opening



NOMENCLATURE

V_{Ed} = acting shear force at ULS (without influence of the opening);

$V_{Ed,adj,\,op}$ = acting shear force on the slab adjacent to the cut one;

$V_{Rd,adj,\,op}$ = shear capacity of the slab adjacent to the cut one;

From the chart: in the slab close to the opening there is a shear increase of about 47 % at ULS, so the effective shear force on the slab according to design chart is:

$V_{Ed,adj,op}$ = 1.2 x [(1.35 x 3.8) + (1+δ) x (1.5 x 10)] x 10.5/2+ $V_{g1d,opening}$ /2 =

= 1.2 x [5.13+1.47 x 15] x 10.5/2 + 0.6 x (1.35 x 3.8) x 9.3/2 = 185.5 kN

$V_{Rd,adj,op} \geq V_{Ed,adj,op}$ = 185.5 kN

Some references concerning the research work

P. Bernardi, R. Cerioni, I. Iori, E. Michelini (2010) **Structural behaviour of hollow core floors with openings: a parametric numerical study.** In:3rd International fib Congress 2010. May 29 – June 2, 2010, Washington DC (USA).

P.Bernardi, R. Cerioni, N. Garutti, I. Iori, E. Michelini (2010) **Analisi non lineare ad elementi finiti di solai alveolari con cappa collaborante in presenza di aperture.** 143- 152, vol.1, In:18° Congresso CTE. 11-13 Novembre 2010, Brescia.

P. Bernardi, R. Cerioni, N. Garutti, E. Michelini (2012) **A non-linear approach for the analysis of hollow core floors with large openings - Part 1** CONCRETE PLANT INTERNATIONAL (ISSN:1437-9023) pp.166- 171 6 (2, April 2012).

P. Bernardi, R. Cerioni, N. Garutti, E. Michelini (2012) **A non-linear approach for the analysis of hollow core floors with large openings - Part 2** CONCRETE PLANT INTERNATIONAL (ISSN:1437-9023) pp.144- 149 6 (3, June 2012).

P. Bernardi, R. Cerioni, N. Garutti, E. Michelini (2012) **Numerical study on load distribution in HC floors.** In: SSCS 2012 - Numerical Modeling Strategies for Sustainable Concrete Structures. May 29 - June 1, 2012, Aix en Provence (France).

Same example through the SIMPLIFIED METHOD for mid-span opening

Point load P at corners of opening **P**= (L_P x B_{op} /2)x(3.8 x1.35+10.0x1.5)/2 **= 41.76 kN**

(With distance P from support L_P = (L –1.2)/2 = 4.65 m and width of opening B_{op} = 1.0 m)

Span L =10.5 m α_1 = 28% (from chart 4.5-7 for point loads at floor edge)

Moment increase due to Point loads $\Delta M = 0.28\ P \times L_P$ = 54.37 kNm

Since no topping at ULS $\Delta M_{SD} = 1.25 \times \Delta M$ = **67.96** kNm

Through SIMPLIFIED METHOD the slab adjacent to the opening must be designed for

$M_{Rd,adj\ op}$ = 332.90 + 67.96 = **400.85** kNm

Through DESIGN CHARTS the bending moment was **362.86** kNm

For the bending moment the **simplified method is 10% more conservative**

Same example through SIMPLIFIED METHOD for opening at slab end

Point load P at corner of opening is **P**= (L_P x B_{op} /2)x(3.8 x1.35+10.0x1.5)/2 **= 56.16 kN**

(With distance P from support L_P = L –1.2 = 9.3 m and width of opening B_{op} = 1.2 m)

Through SIMPLIFIED METHOD the slab adjacent to the opening must be designed for

V_{Ed} = 1.2 x (1.35 x 3.8 + 1.5 x 10) x10.5/2 = 126.82 kN (without openings)

$V_{EDadj.op}$ = 126.82+56.16 ≈ **183** kN **+ 85 (torsion effects) ≈ 268 kN**

Through DESIGN CHARTS the shear design was ~ **185** kN **including also all torsional effects**

For shear the **simplified method is largely more conservative**

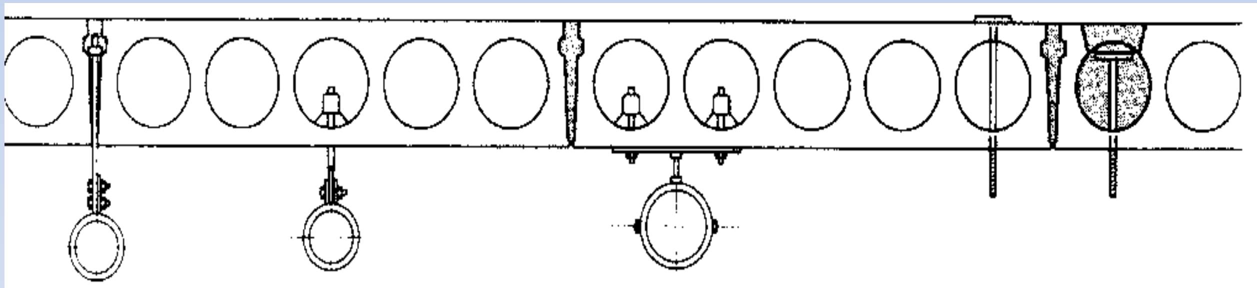
LIGHT LOAD FIXINGS

Fixing of suspension loads to soffit of H.C. floors may be foreseen in different way:

- Light loads (2.0÷5.0 kN) may be at soffit flange of H.C

- Medium-heavy load (>5.00÷10.00 kN) must be hanged through the extrados of H.C

Inserted steel plate



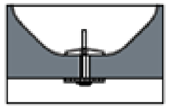
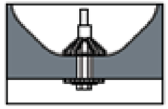
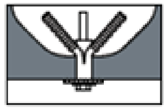
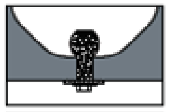
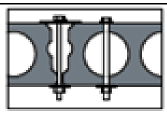
Light straps for ceiling and duct work

Toggle bolts only for vertical loads

Hanger thru bolt for heavier loads

LIGHT DEVICES

Some examples of possible fixing devices for load suspension at the soffit of H.C. slab and allowable load

Fixing type	Example of allowable load		Advantages	Inconveniences	Remarks
	M6 M8	0.4 kN 1.2 kN	- simple placing - cheap - safe: failure of anchor	Large drilling diameter	- drilling crater at inner side causes flexure of anchor and decreases bearing capacity
	M6	0.15 kN	- simple placing - cheap - safe: failure of anchor		- special devices are sometimes needed for insertion
	M8-M10-M12 HC150 HC200 HC265 HC320 HC400	 1.0 kN 2.5 kN 4.0 kN 4.0 kN 6.0 kN	- simple placing	- failure in concrete; - smaller capacity than fixing device itself, depending on type HC	- respect turn moment at placing
	M8-M10-M12 HC150 HC200 HC265 HC320 HC400	1.0 kN 2.5 kN 4.0 kN 4.0 kN 6.0 kN		- expensive / complex inserting technique - hardening needed before loading - temperature dependent - resin leakage may cause adherence of treaded bar to concrete, causing splitting of concrete skin	
	M6 to M16 loading up to 15 kN depending on steel top plate		- safe in use - capacity anchor bar determining	- difficult placing after floor finishing	- most indicated solution for larger loads

OPENING-CUT OUT AND FIXING