Shear behaviour of RC Members without Shear Reinforcement in Combination of Larger Depth and Low Reinforcement Ratio

Delft Shear dataset

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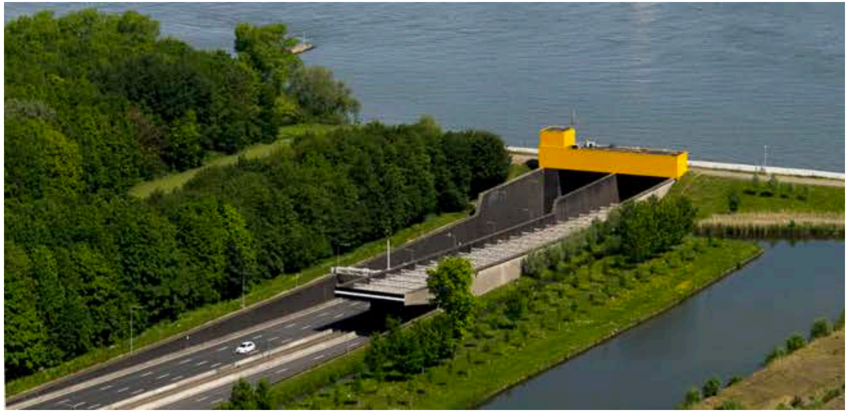
Shear tests on concrete slab strips

- Reinforced concrete slab is a widely applied structure type
- No shear reinforcement, low longitudinal reinforcement ratio, large effective depth, plain bars



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Eurocode shear expression

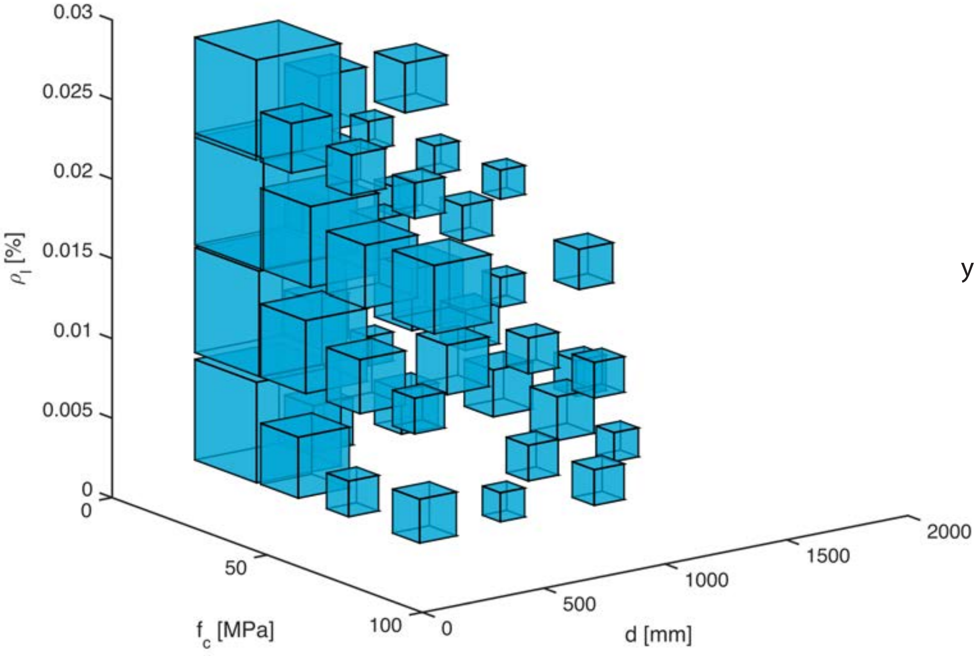
- Based on regression analysis of a shear database

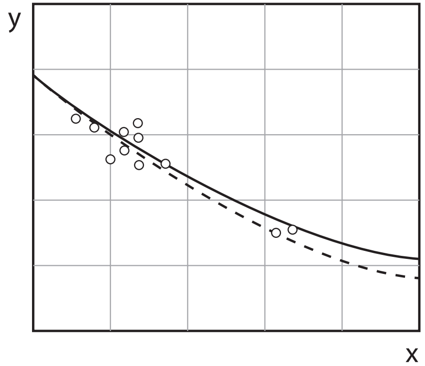
$$V_{Rd,c} = \left[C_{Rd,c} k (100 \rho_l f_{ck})^{1/3} + k_1 \sigma_{cp} \right] b_w d$$

$$v_{min} = 0.035 k^{3/2} f_{ck}^{1/2} \quad \text{with} \quad k = 1 + \sqrt{\frac{200}{d}} \leq 2.0$$

Distribution of test data

$$V_{Rd,c} = \left[C_{Rd,c} k (100 \rho_l f_{ck})^{1/3} + k_1 \sigma_{cp} \right] b_w d$$





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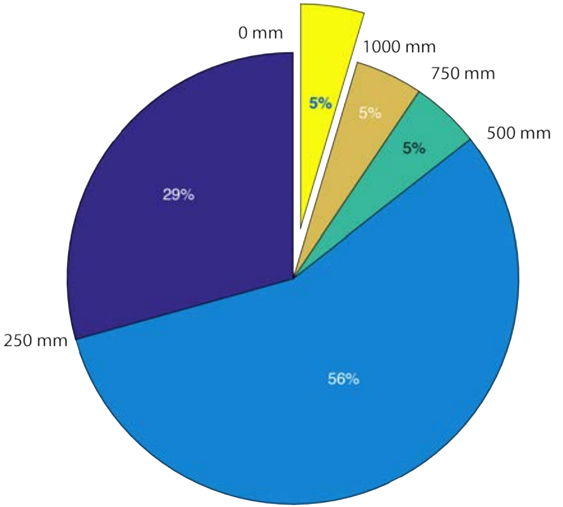
Experimental research program

- Shear behaviour of RC slab strips with **REALISTIC** design parameters for infrastructure

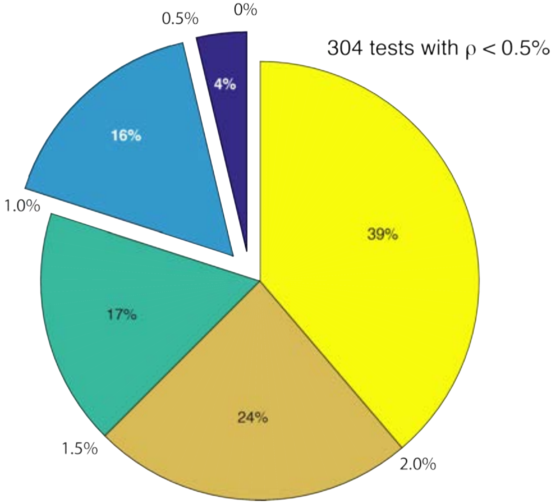
ACI-DAfStb shear database
784 tests (filtered data)
24 tests with h > 1000 mm
and ρ < 1%

Few tests of plain bar reinforced members

36 tests with *h* larger than 1000mm



29 tests with ρ < 0.5%



Experimental program

- At TU Delft a large research program on shear behaviour of concrete slab strips was carried out since 2016
- In total **154** tests with **99** tests of shear failure **with repetitions**
- 7 test series with main variables including
  - Concrete strength: f_{cm} = 20 MPa and f_{cm} = 65 MPa
  - Specimen depth: h = 300, 500, 800 and **1200** mm
  - Rebar type: Plain bars with f_{ym} = 284 MPa and normal ribbed bars with f_{ym} = 550 MPa
  - Reinforcement ratio: **0.27%** - 1.20%
  - Loading positions: *a/d*

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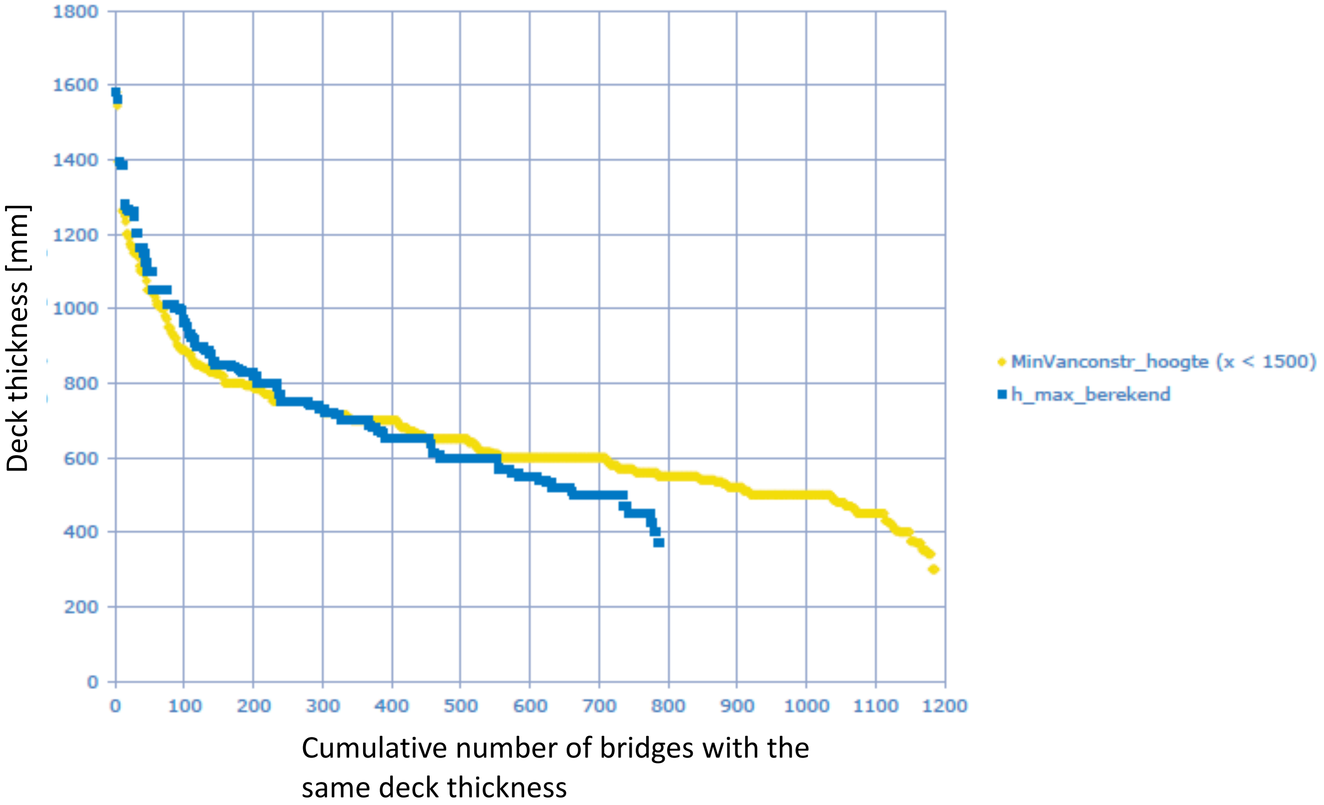
Thickness range of Dutch slab bridges



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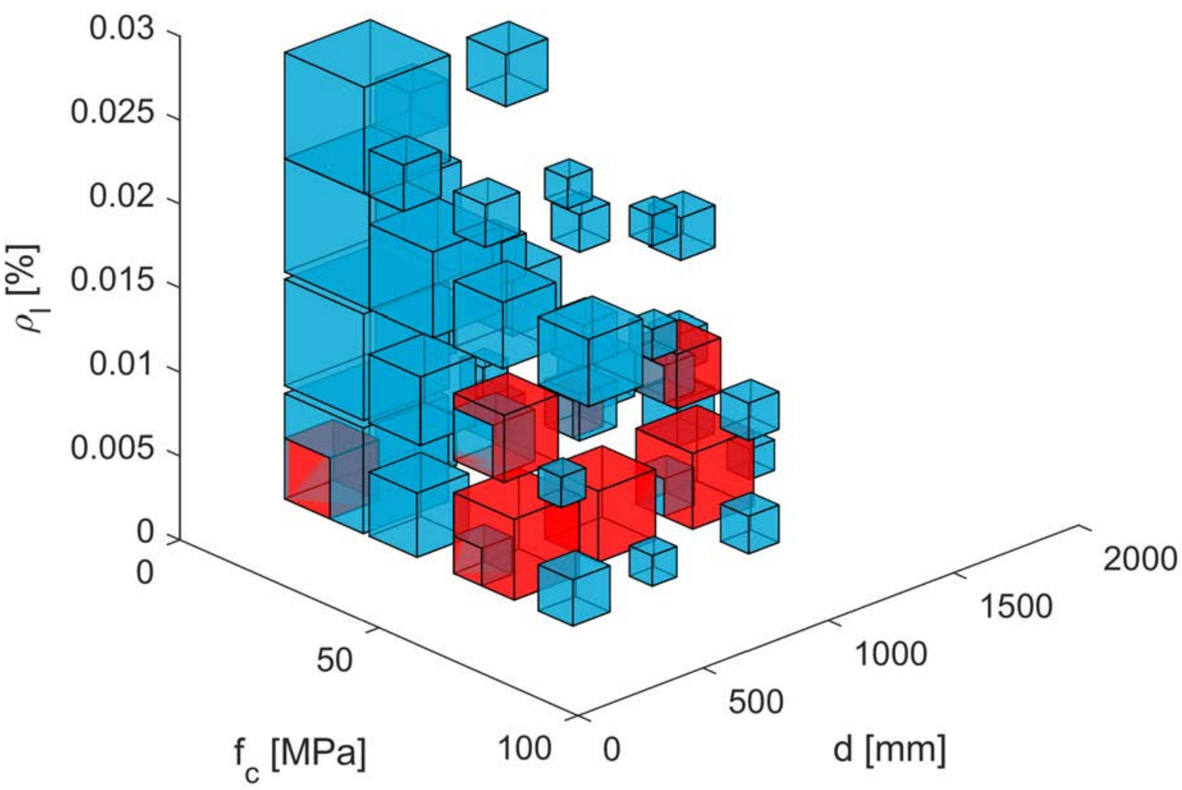
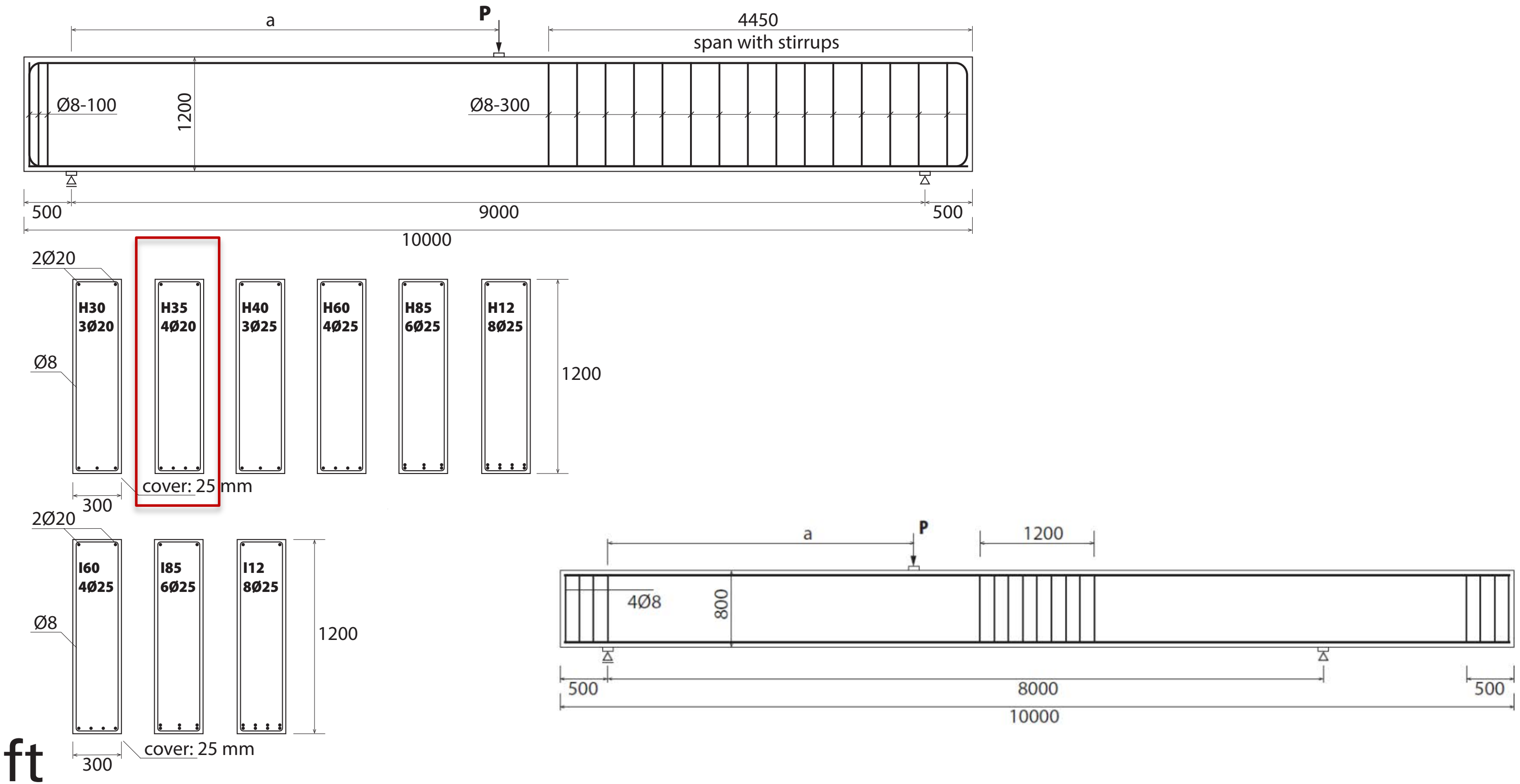
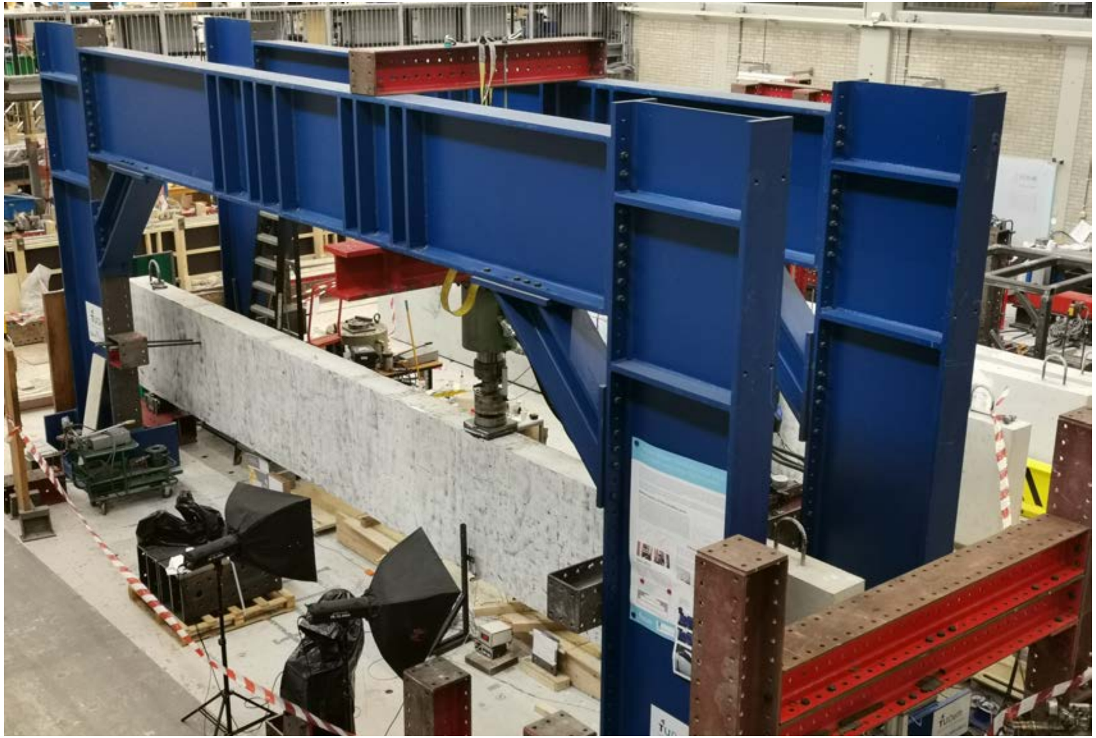

0.03
0.025
0.02
0.015
0.01
0.005
0
ρ_l [%]
0
50
100
f_c [MPa]
0
500
1000
1500
2000
d [mm]

Test specimens



Configurations of the tests



H351

- Key parameters $f_{cube,m} = 86.9\ \text{MPa}$ $\boxed{\rho = 0.36\%}$ $a = 4500\ \text{mm}$

  $d = 1160\ \text{mm}$ $M / Vd = 3.88$

- Estimation of design codes:

EC current	MC 2010	ACI 318-19	Yielding Load
218.0 kN	134.5 kN	198.1 kN	159.8 kN

- H351 and H352

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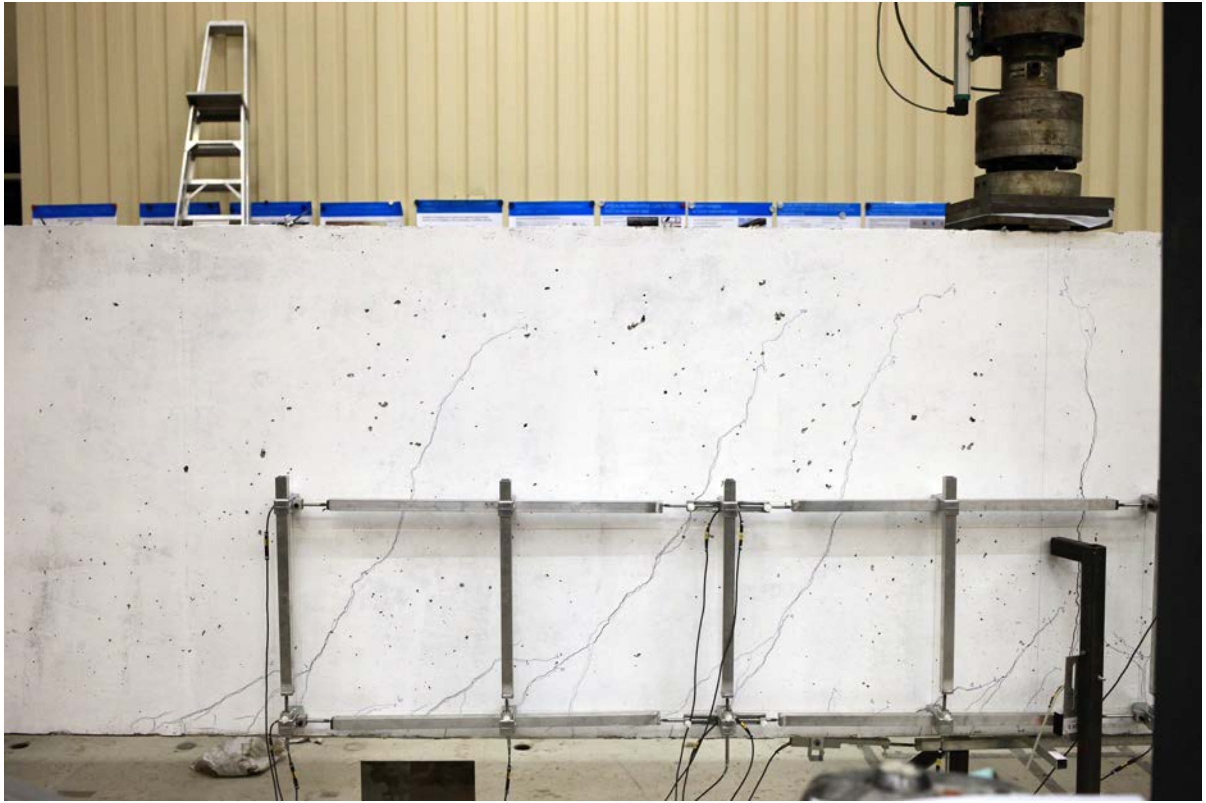
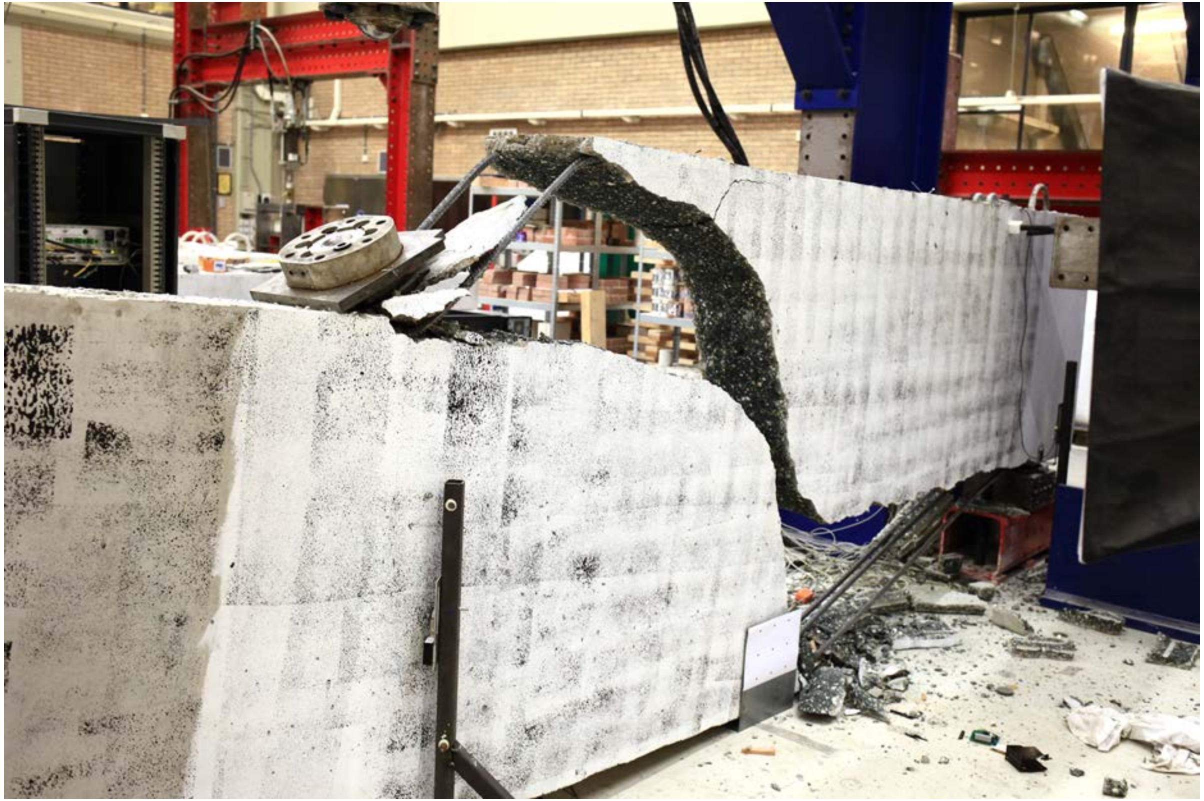
H351 before failure



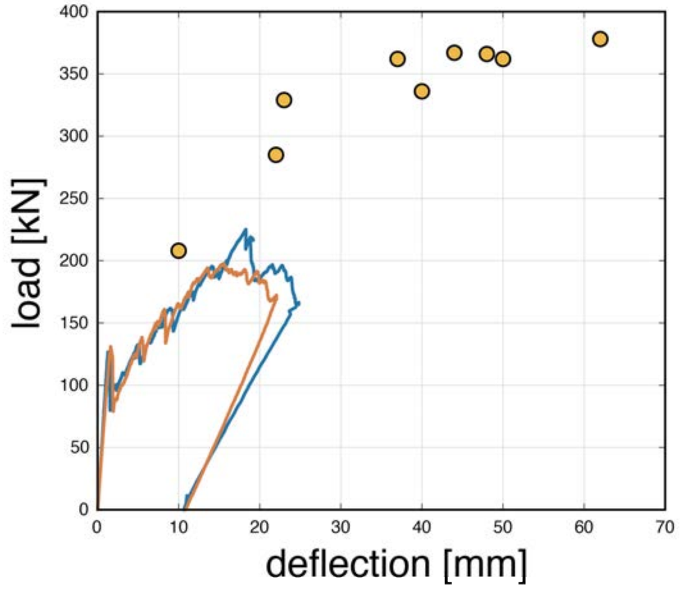
H351 after failure



H351 after failure

EC current	MC 2010	ACI 318-19	Yielding Load	Vtest
218.0 kN	134.5 kN	198.1 kN	159.8 kN	**104.7 kN**

116.9 kN



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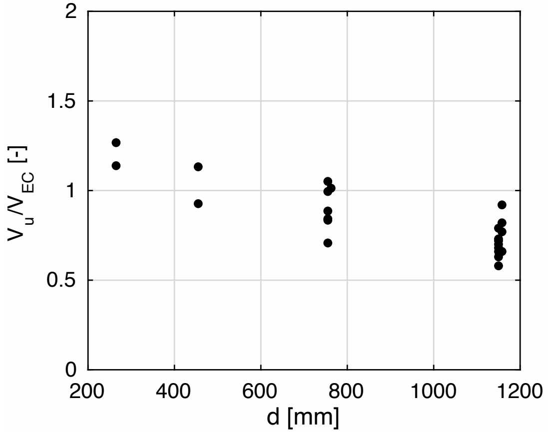
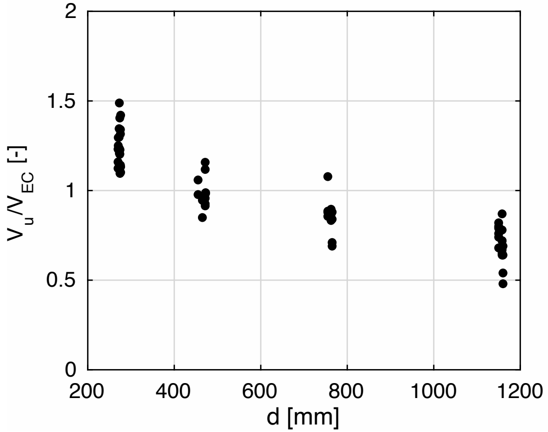
Validation with the current Eurocode





plain bars mean = 0.84, COV = 21.7% ribbed bars mean = 0.97, COV = 25.0%

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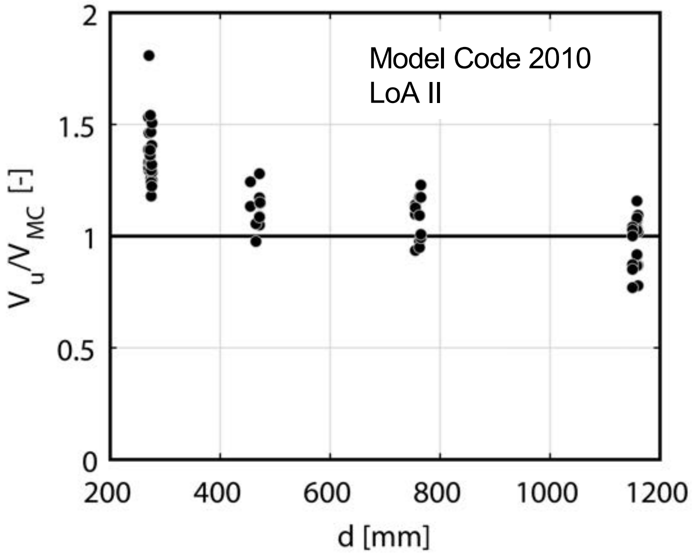
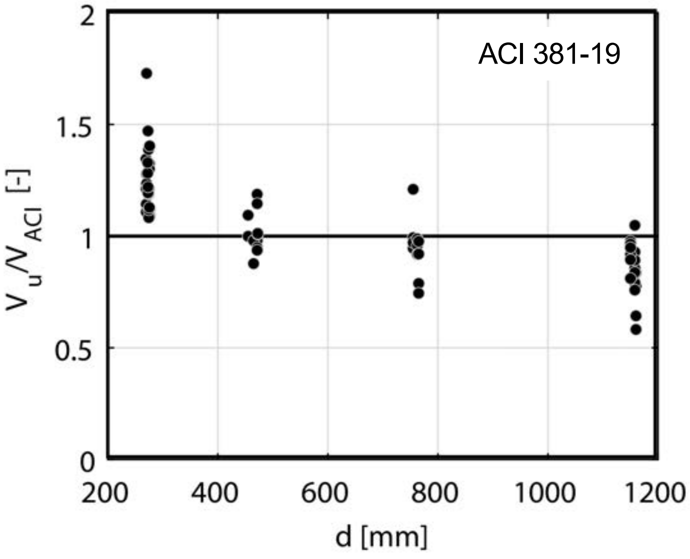
Effect of depth using Model Code 2010 and ACI 318-19





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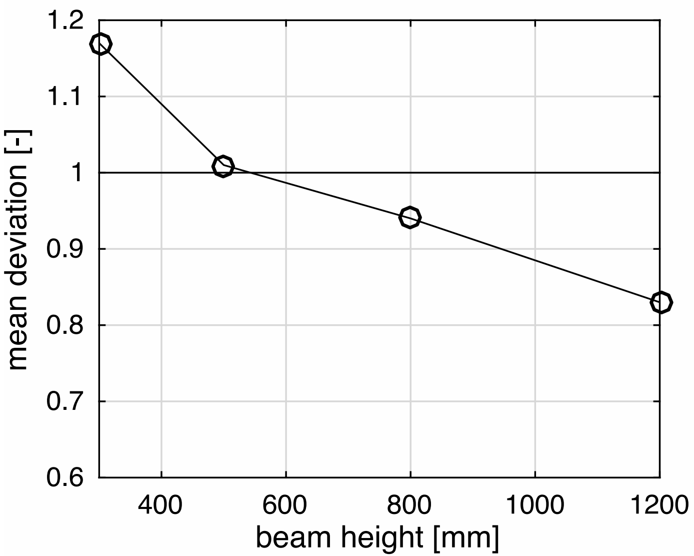
Eurocode proposal



h [mm]	300	500	800	1200
Mean(V_u/V_{nEC})	1.17	1.01	0.94	0.83
COV(V_u/V_{nEC})	10.5%	8.3%	9.9%	13.2%
No. of tests	25	11	12	18

EC current	EC pre D2	EC pre D3	MC 2010	Yielding load	Vtest
218.0 kN	187.3 kN	177.5 kN	134.5 kN	159.8 kN	104.7 kN
					116.9 kN

Eurocode proposal

(2) The design value of the shear stress resistance should be taken as:

$$\tau_{\mathrm{Rd,c}} = \frac{0{,}66}{\gamma_{\mathrm{V}}} \cdot \left(100\rho_{\mathrm{l}} \cdot f_{\mathrm{ck}} \cdot \frac{d_{\mathrm{dg}}}{d}\right)^{\frac{1}{3}} \geq \tau_{\mathrm{Rdc,min}} \tag{8.16}$$

where

$$\rho_{\mathrm{l}} = \frac{A_{\mathrm{sl}}}{b_{\mathrm{w}}d} \tag{8.17}$$

A_{sl} is the effective area of tensile reinforcement at the distance d beyond the section considered (see Figure 8.7);

d_{dg} is defined in 8.2.1(4);

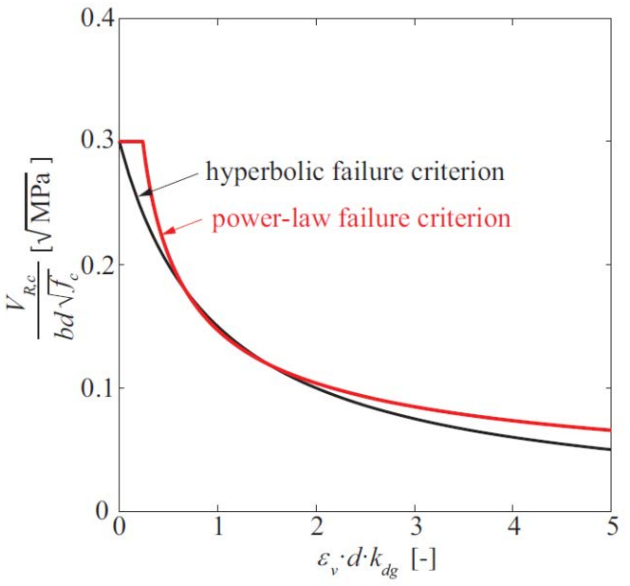
d is the nominal effective depth d_{nom}. The value d may be refined according to (3) and (4) for non-slender members and members with axial force.

Eurocode proposal

Shear Capacity depends on:

- the position of the critical shear crack with respect to the theoretical strut carrying shear;
- the opening of the critical shear crack;
- the roughness of the crack (which in turn depends on the aggregate size and the ratio between aggregate strength and strength of the cement paste).

Eurocode proposal



Crack width

- Based on CSCT
- prEC Draft1 version

$$\frac{V}{bd\sqrt{f_c}} = \frac{0.3}{1+48\dfrac{\varepsilon d}{16+d_{dg}}}$$

- prEC Draft2 version

$$\frac{V}{bd\sqrt{f_c}} = 0.021\left(\frac{d_{dg}}{\varepsilon d}\right)^{1/2}$$

- prEC Draft3 version

$$\frac{V}{bd\sqrt{f_c}} = k\left(\frac{d_{dg}}{\varepsilon d}\right)^{1/2} \quad k = 0.015\left(\frac{a_{cs}}{d}\right)^{1/4}$$

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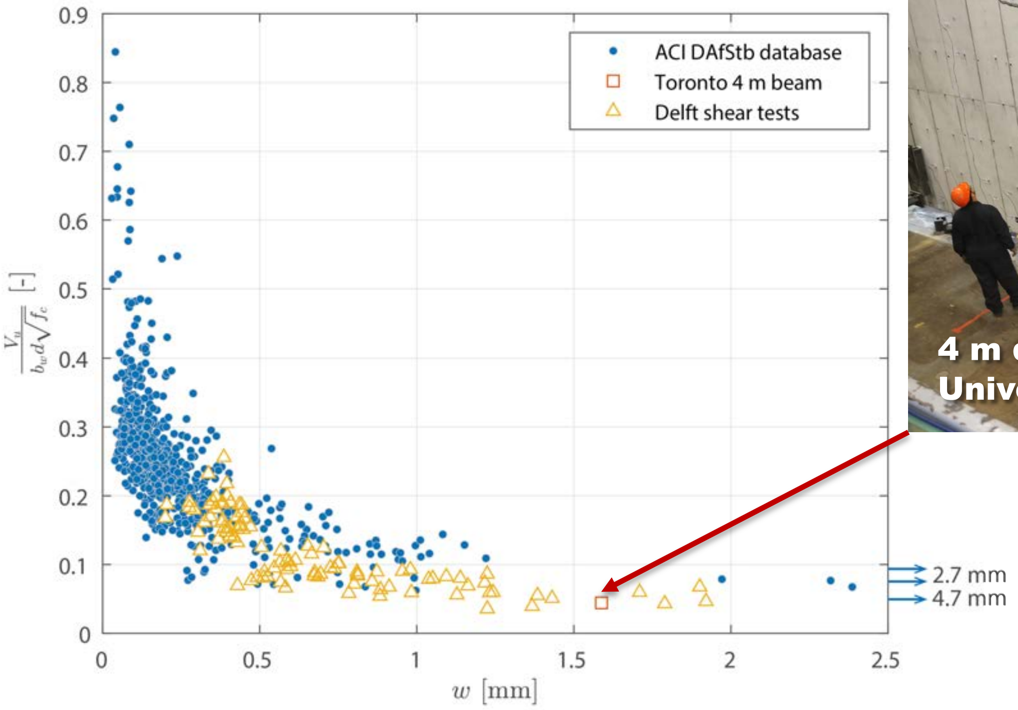
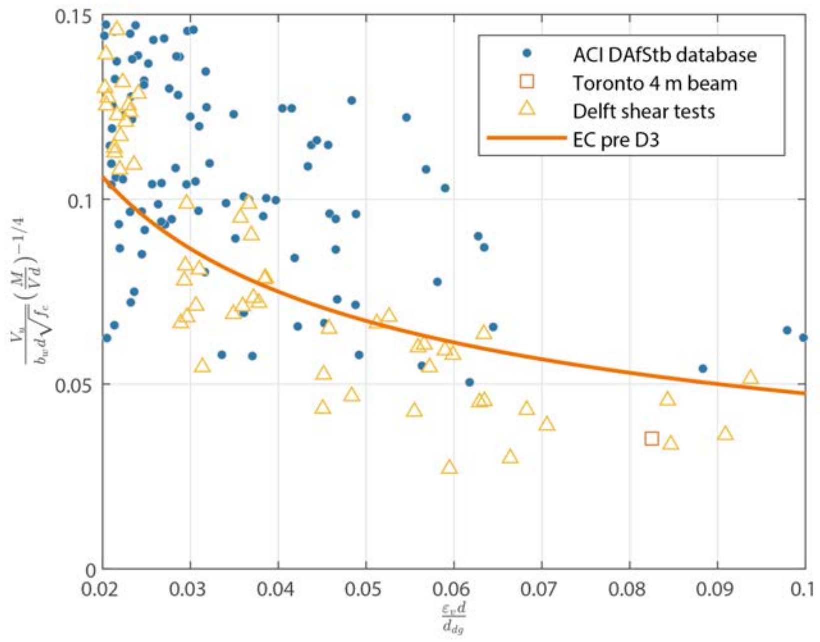
Relate shear capacity with crack width

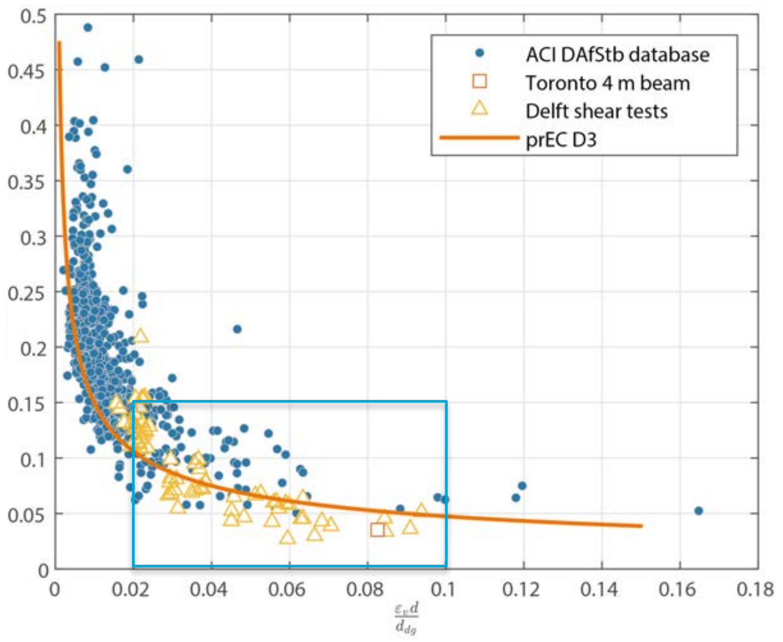
ACI-DAfStb shear database



Improvement based on EC proposal

- Shear failure criteria



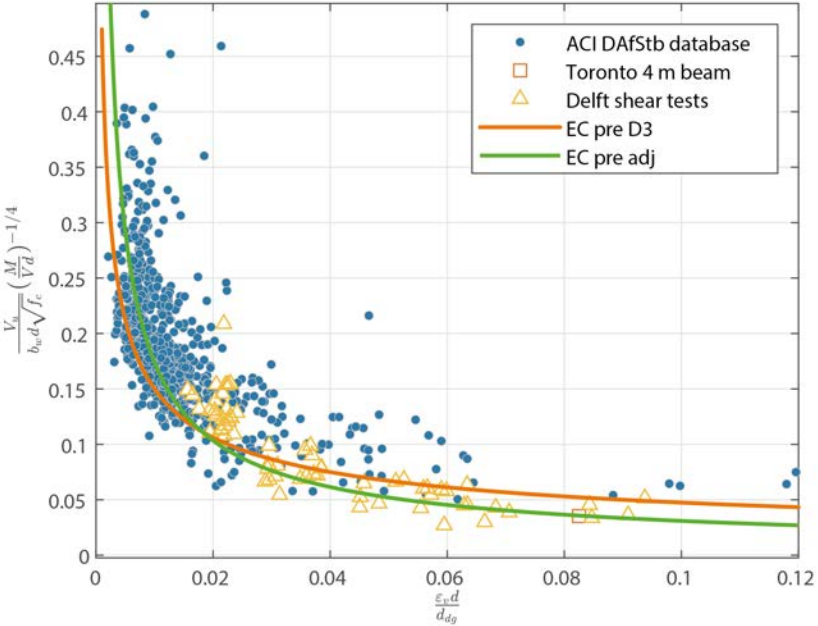


Adjustment of Eurocode proposal

- Annex I, I.8.3.1

(3) For linear members with an effect
should be used instead of the meth
Formula (8.16) should be multiplied witl

$$k_{\mathrm{vd}} = 1{,}35\left(100\rho_{\mathrm{l}}\frac{d_{\mathrm{dg}}}{d}\right)^{1/10} \leq 1{,}0$$



Conclusion

- Delft shear dataset extends the available shear data
- Our current shear models still needs to improve for infrastructures with realistic reinforcement ratio and large dimensions
- With the correction factor on size effect, Eurocode is safe

Questions?