Transition between Bending and shear failure for RC Beams without shear reinforcement

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INVESTIGATION OF V$_{MIN}$

- Eurocode shear formula:

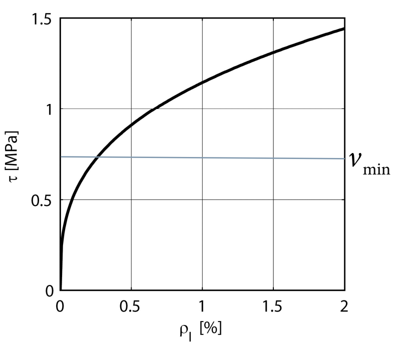
$$V_{Rd,c} = \left[C_{Rd,c}k(100\boxed{\rho_l}f_{ck})^{1/3} + k_1\sigma_{cp}\right]b_w d$$

$$V_{Rd,c} = (v_{\min} + k_1\sigma_{cp})b_w d$$

with

$$v_{\min} = 0.035k^{3/2}f_{ck}^{1/2}$$

$$k = 1 + \sqrt{\frac{200}{d}} \leq 2.0$$



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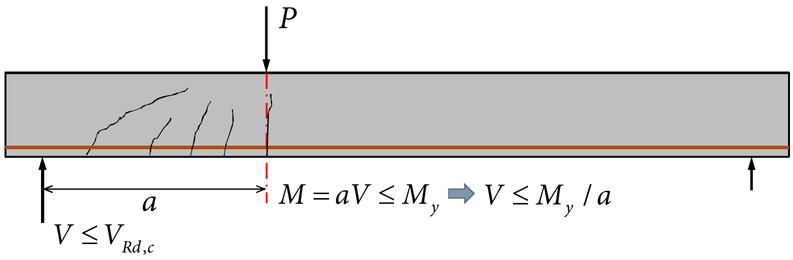
V_{MIN} -> V_{bd}

- The minimum average shear stress that can cause a shear failure before the yielding of flexural reinforcement



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V_{MIN} IN EC2

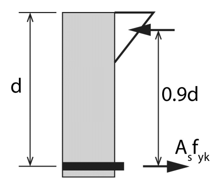
- Bending failure criterion

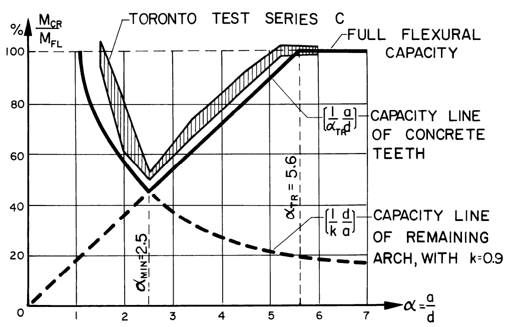
$$V \leq M_y / a$$

with

$$M_y = A_s f_{yk}(0.9d)$$

$$a = 2.5d$$





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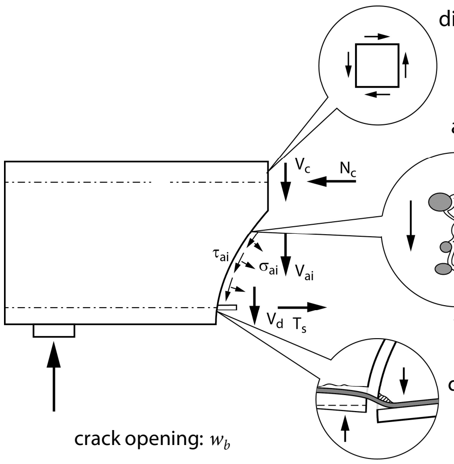
V_{MIN} BASED ON A PHYSICAL MODEL



direct shear transfer

$$V_c = \frac{2}{3}\frac{z_c}{z}V$$

aggregate interlock

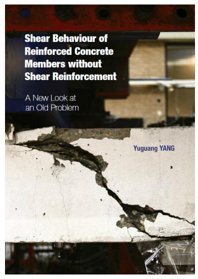
$$V_{ai} = f_c^{0.56} s_{cr} b \frac{0.03}{\boxed{w_b} - 0.01}(-978\boxed{\Delta}^2 + 85\boxed{\Delta} - 0.27)$$

dowel action

$$V_d = 1.64 b_n \phi \sqrt[3]{f_c}$$

crack opening: w_b

shear displacement: Δ_{cr}



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FEM STUDIES – VARIABLES

- Beam depth d, $d = 255, 355, 455$ or 755 mm
- Concrete strength f_{cm} , $f_{cm} = 34$ or 68 MPa
- Reinforcement ratio ρ
- Shear slenderness ratio a/d

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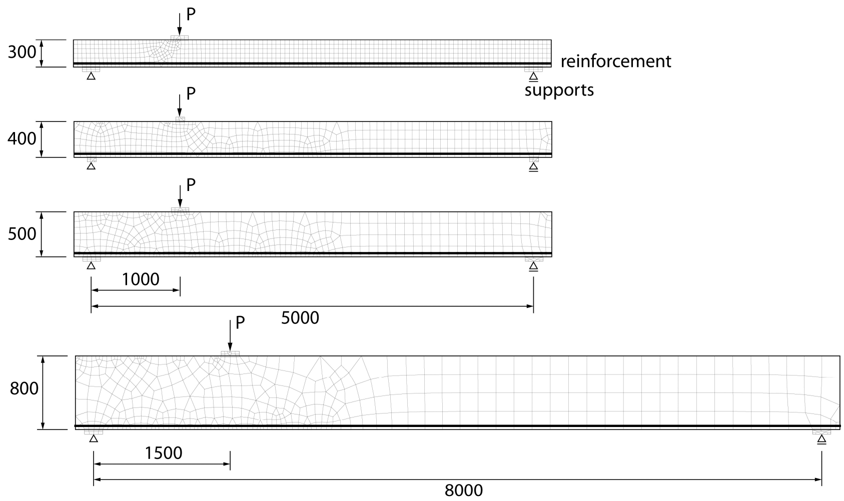
FEM – MESHES



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FEM – MODEL CONFIGURATIONS

- Concrete properties based on FEM guideline and Model Code 1990
- Smeared crack model, fixed crack model
- to

Low Strength Concrete	
Compressive strength f_{cm}	= 34.0 MPa
Tensile strength f_{ctm}	= 2.81 MPa
Elastic Modules E_c	= 34.0 GPa
Fracture Energy G_f	= 70.2 N/m

High Strength Concrete	
Compressive strength f_{cm}	= 68.0 MPa
Tensile strength f_{ctm}	= 4.46 MPa
Elastic Modules E_c	= 42.6 GPa
Fracture Energy G_f	= 111.4 N/m

$$v_u \quad 6 \quad \sqrt{f_{cm}} \quad 1+120\frac{w}{16+D_{max}}$$

Modified Compressive Field Theory, Colins et.al.

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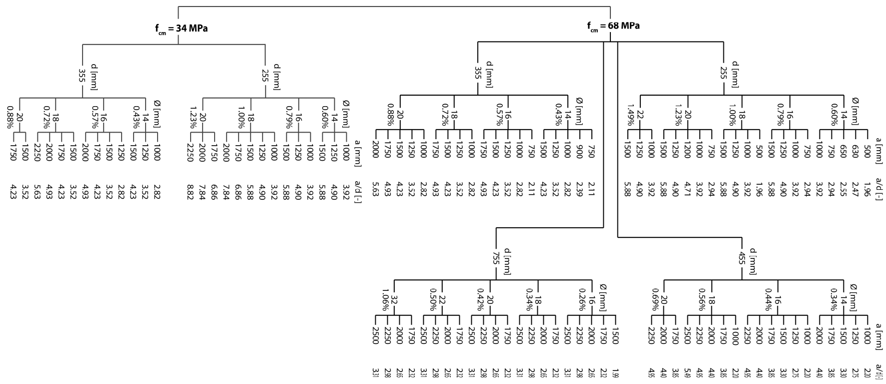
FEM-MODELS

- 115 models



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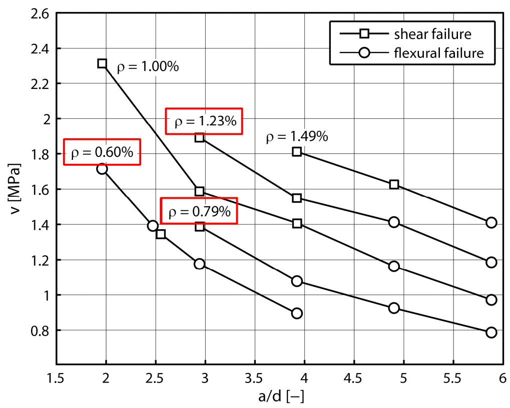
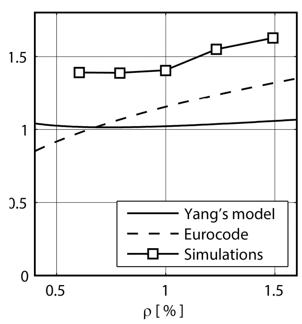
PREDICTIONS

- d = 260 mm, f_{cm} = 68 MPa





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EXPERIMENTAL PROGRAM

- Variables
  - Reinforcement ratio ρ_l
  - Concrete strength f_{cm}
  - Beam depth d

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EXPERIMENTAL PROGRAM

- Series 1: 8 beams with 4 reinforcement ratios

f_{cm} [MPa]	h [mm]	rebar config.	r [%]	M_y [kN·m]	v_{EC} [MPa]
70	300	1 Ø10 + 2 Ø16	0.60%	69.4	0.97
70	300	3 Ø16	0.75%	87.0	1.05
70	300	1 Ø12 + 2 Ø20	0.93%	106.0	1.13
70	300	3 Ø20	1.18%	134.4	1.22

- Series 2: 10 beams with different concrete strength and beam depth

f_{cm} [MPa]	h [mm]	rebar config.	r [%]	M_y [kN·m]	v_{EC} [MPa]
40	300	3 Ø12	0.44%	44.5	0.73
40	300	3 Ø16	0.75%	87.0	0.87
40	300	1 Ø12 + 2 Ø20	0.93%	106.0	0.94
70	500	2 Ø16 + 1 Ø20	0.49%	167.9	0.81
70	500	3 Ø20	0.64%	237.1	0.90

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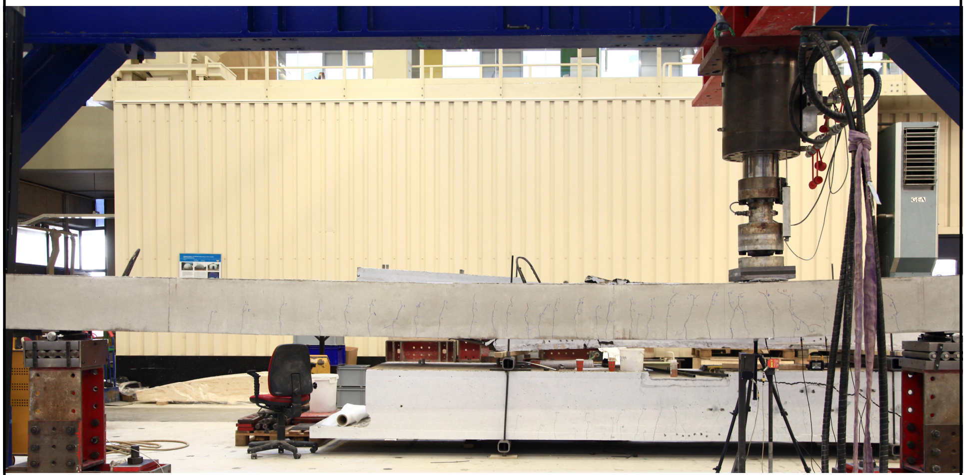
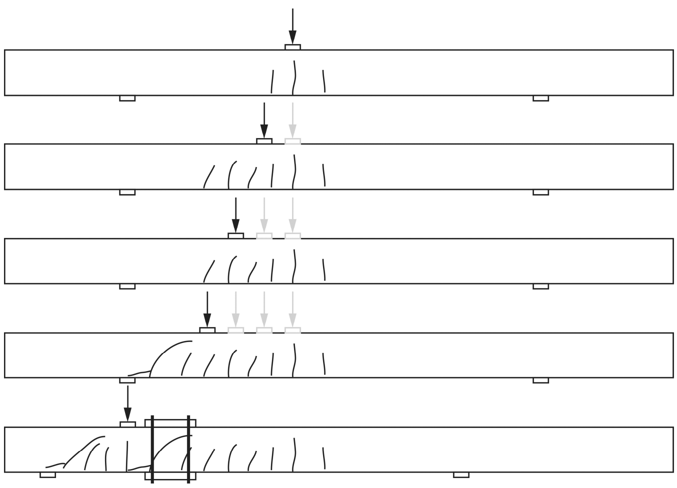
TEST SETUP



EXPERIMENTAL PROGRAM

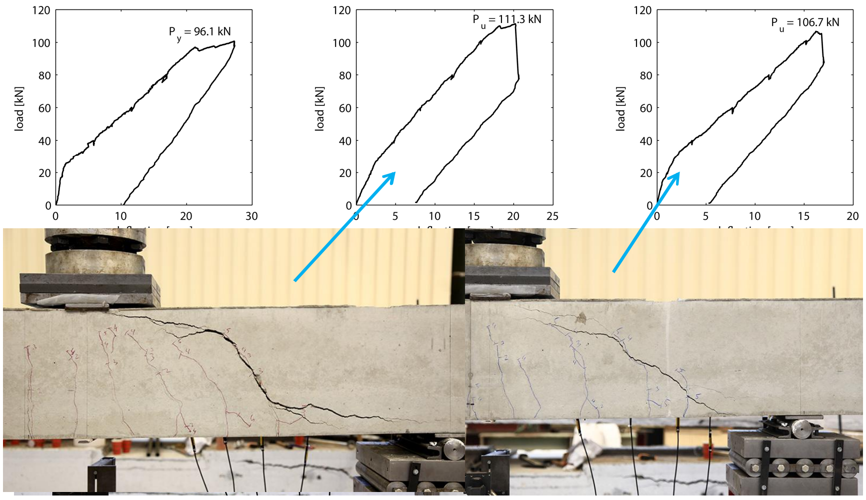


RESULTS

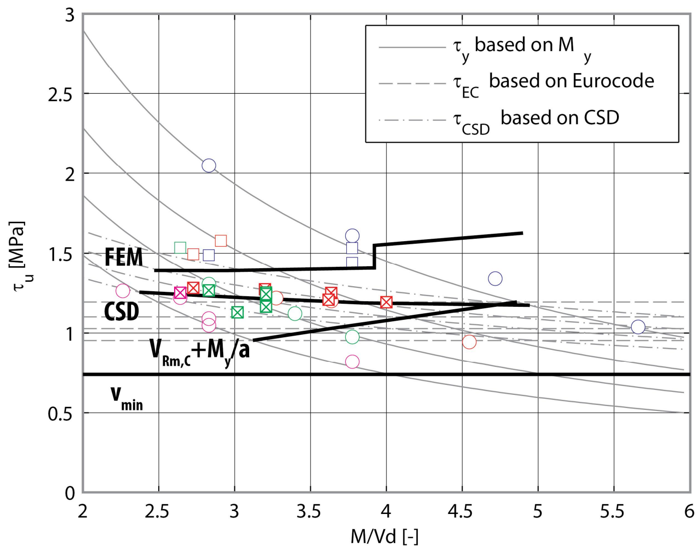
Bending: A751A1

Shear + bending: A751B1

Shear: A751B2

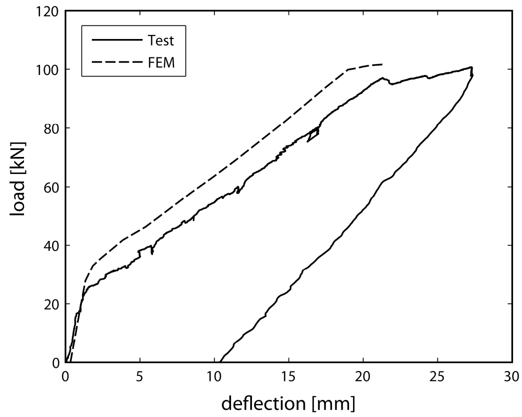


RESULTS



COMPARISON WITH TEST RESULTS

- A751A1: a = 1000 mm, 3Ø16 mm bars



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RWS NLFEA SAFETY FORMAT

- Global Resistance Factor Method (GRF)

$$f_{cm} = 0.85 f_{ck} \qquad f_{ym} = 1.1 f_{yk} \qquad P_d = P_u / \gamma_{GL}$$

- Partial Safety Factor Method (PF)

$$f_{cd} = f_{ck} / \gamma_{RD}\gamma_c \qquad f_{ctd} = f_{ctk} / \gamma_{RD}\gamma_c \quad \ldots$$

$$P_d = P_u$$

- Estimation of COV of resistance (ECOV)

$$P_d = P_u / \gamma_{RD}\gamma_R \qquad \gamma_R = e^{\alpha_R \beta V_R} \qquad V_R = \frac{1}{1.65}\ln\left(\frac{P_{u,m}}{P_{u,c}}\right)$$

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RWS NLFEA SAFETY FORMAT

- Global Resistance Factor Method (GRF)

  $f_{cm} = 51 \text{ MPa} \quad f_{ym} = 550 \text{ MPa}$

- Partial Safety Factor Method (PF)

  $f_{cd} = 38 \text{ MPa} \quad f_{yd} = 410 \text{ MPa}$

- Estimation of COV of resistance (ECOV)

  $f_{ck} = 60 \text{ MPa} \quad f_{yk} = 500 \text{ MPa}$

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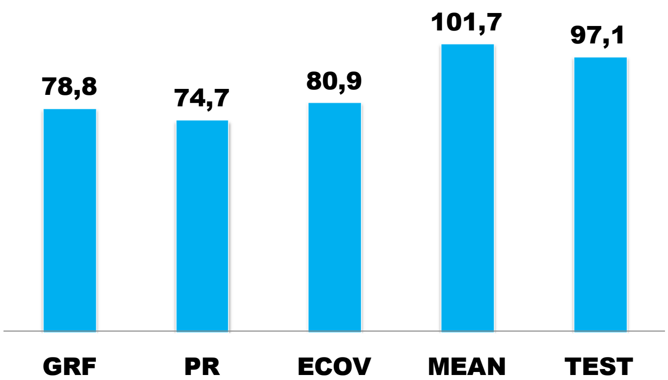
COMPARISON WITH TEST RESULTS

- All the simulations are bending failure



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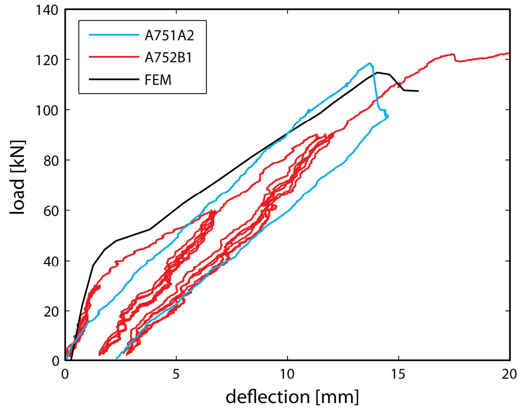
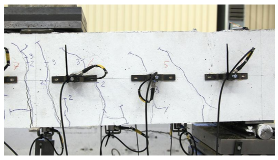
COMPARISON WITH TEST RESULTS

- A751A2 & A751B1: a = 750 mm





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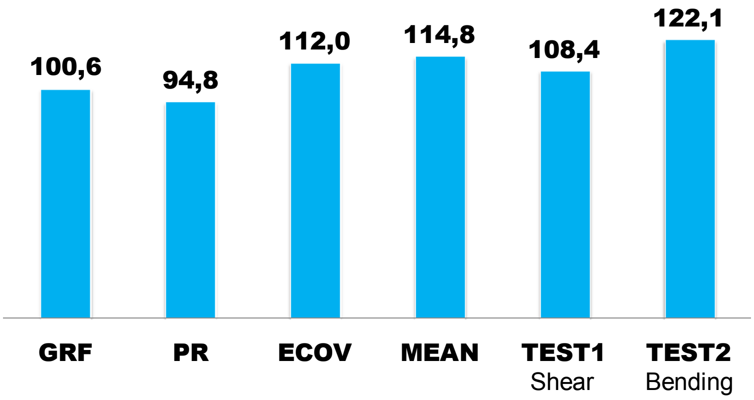
COMPARISON WITH TEST RESULTS

- Only with mean values shear failure is found.



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COMPARISON WITH TEST RESULTS

- Switch of failure mode

$$P_{u,m} = 114.8 \text{ kN} \qquad P_{u,c} = 116.9 \text{ kN}$$

$$V_R = \frac{1}{1.65} \ln\left(\frac{P_{u,m}}{P_{u,c}}\right) < 0 \qquad \gamma_R < 1.0$$

$$P_d = P_u / \gamma_{RD} \gamma_R$$

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CONCLUSIONS

- The CSD models gives quite accurate prediction on v_{min}
- NLFEA gives reasonable prediction when using the mean values of material properties
- The safety format has to be carefully interpolated when the failure model is changing

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Thanks for your attention.

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