FprEN 1992-1-1 shear behaviour of reinforced concrete members without shear reinforcement

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Agenda

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$\tau_{Rd,c}$ formula in FprEN 1992-1-1

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01

Introduction of $\tau_{Rd,c}$ formula in FprEN 1992-1-1

FprEC 1992 shear provision

- EC 1992

$$V_{\mathrm{Rd,c}} = \left[C_{\mathrm{Rd,c}} k \left(100 \rho_1 f_{\mathrm{ck}}\right)^{1/3} + k_1 \sigma_{\mathrm{cp}} \right] b_{\mathrm{w}} d$$

$$V_{\mathrm{Rdc,min}} = \left(v_{\min} + k_1 \sigma_{\mathrm{cp}}\right) b_{\mathrm{w}} d$$

$$v_{\min} = 0.035 \cdot k^{3/2} \cdot f_{\mathrm{ck}}^{\ 1/2} \qquad k = 1 + \sqrt{\frac{200}{d}} \leq 2.0$$

$$\sigma_{\mathrm{cp}} = \frac{N_{\mathrm{Ed}}}{A_{\mathrm{c}}} < 0.2 f_{\mathrm{cd}} \qquad \rho_1 = \frac{A_{\mathrm{sl}}}{b_{\mathrm{w}} d} \leq 0.02$$

- FprEC 1992

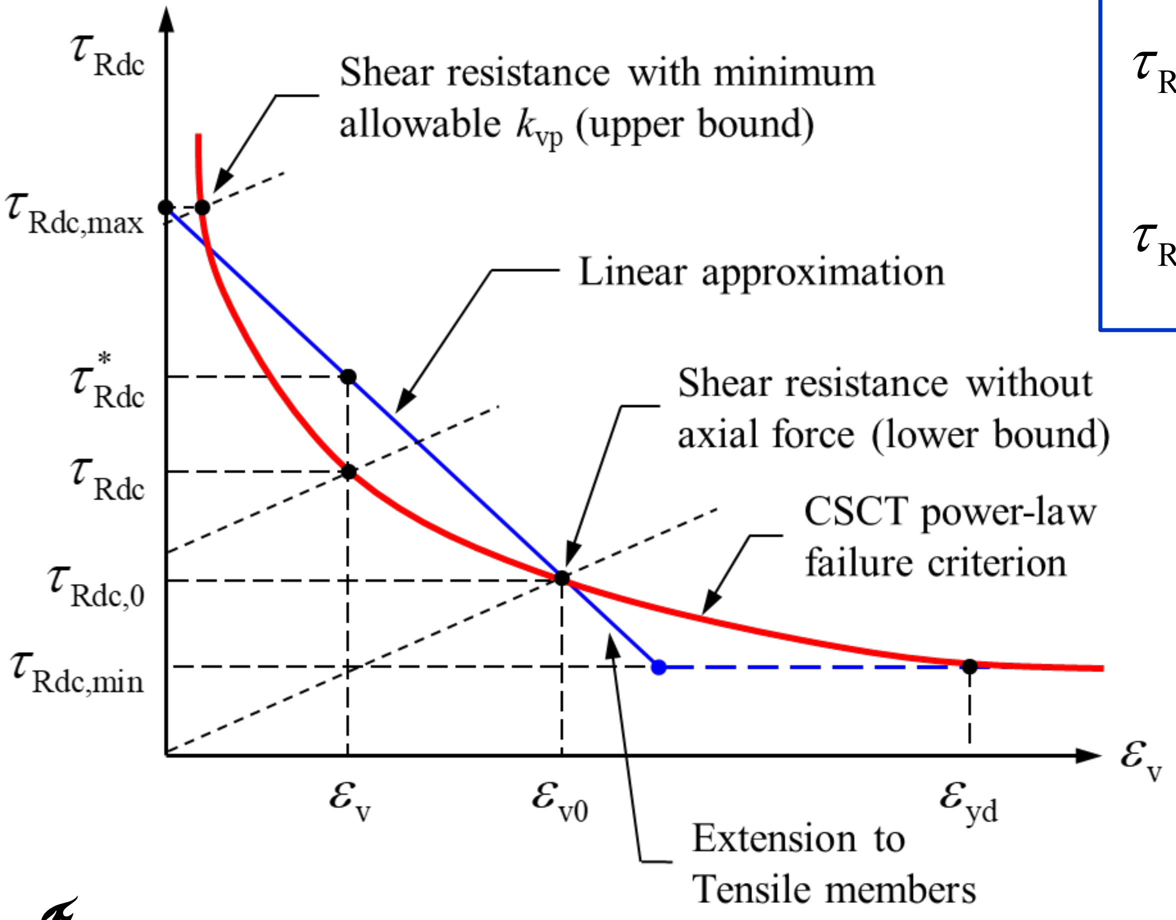
$$\tau_{\mathrm{Rd,c}} = \frac{0.66}{\gamma_{\mathrm{v}}} \left(100 \rho_1 f_{\mathrm{ck}} \frac{d_{\mathrm{dg}}}{d}\right)^{1/3} \geq \tau_{\mathrm{Rdc,min}} \qquad (8.27)$$

$$a_{\mathrm{v}} = \sqrt{\frac{a_{\mathrm{cs}}}{4} d} \qquad (8.29)$$

$$a_{\mathrm{cs}} = \left| \frac{M_{\mathrm{Ed}}}{V_{\mathrm{Ed}}} \right| \geq d \qquad (8.30)$$

$$k_{\mathrm{vp}} = 1 + \frac{N_{\mathrm{Ed}}}{\left|V_{\mathrm{Ed}}\right|} \frac{d}{3 a_{\mathrm{cs}}} \geq 0.1 \qquad (8.31)$$

FprEC 1992 shear provision



$$\tau_{Rd,c} = \tau_{Rdc,0} + 0.2\frac{A_c}{a_{cs} b_w}\sigma_{cp} \leq 2.15\tau_{Rdc,0}$$

$$\tau_{Rd,c} = \tau_{Rdc,0} + 0.25\frac{d}{a_{cs}}\sigma_{cp} \leq 2.15\tau_{Rdc,0} \quad \text{(for R-section)}$$

$$\tau_{Rdc,0} = \frac{0.66}{\gamma_v}\left(100\rho_l f_{ck}\frac{d_{dg}}{\sqrt{a_{cs} d/4}}\right)^{1/3}$$

$$\tau_{Rdc,max} = \frac{0.66}{\gamma_v}\left(100\rho_l f_{ck}\frac{d_{dg}}{0.1\sqrt{a_{cs} d/4}}\right)^{1/3} = 2.15\tau_{Rdc,0}$$

$$a_{cs} = \left|\frac{M_{Ed}}{V_{Ed}}\right|$$

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FprEC 1992 shear provision

- I.8.3.1 Detailed verification of members not requiring shear reinforcement

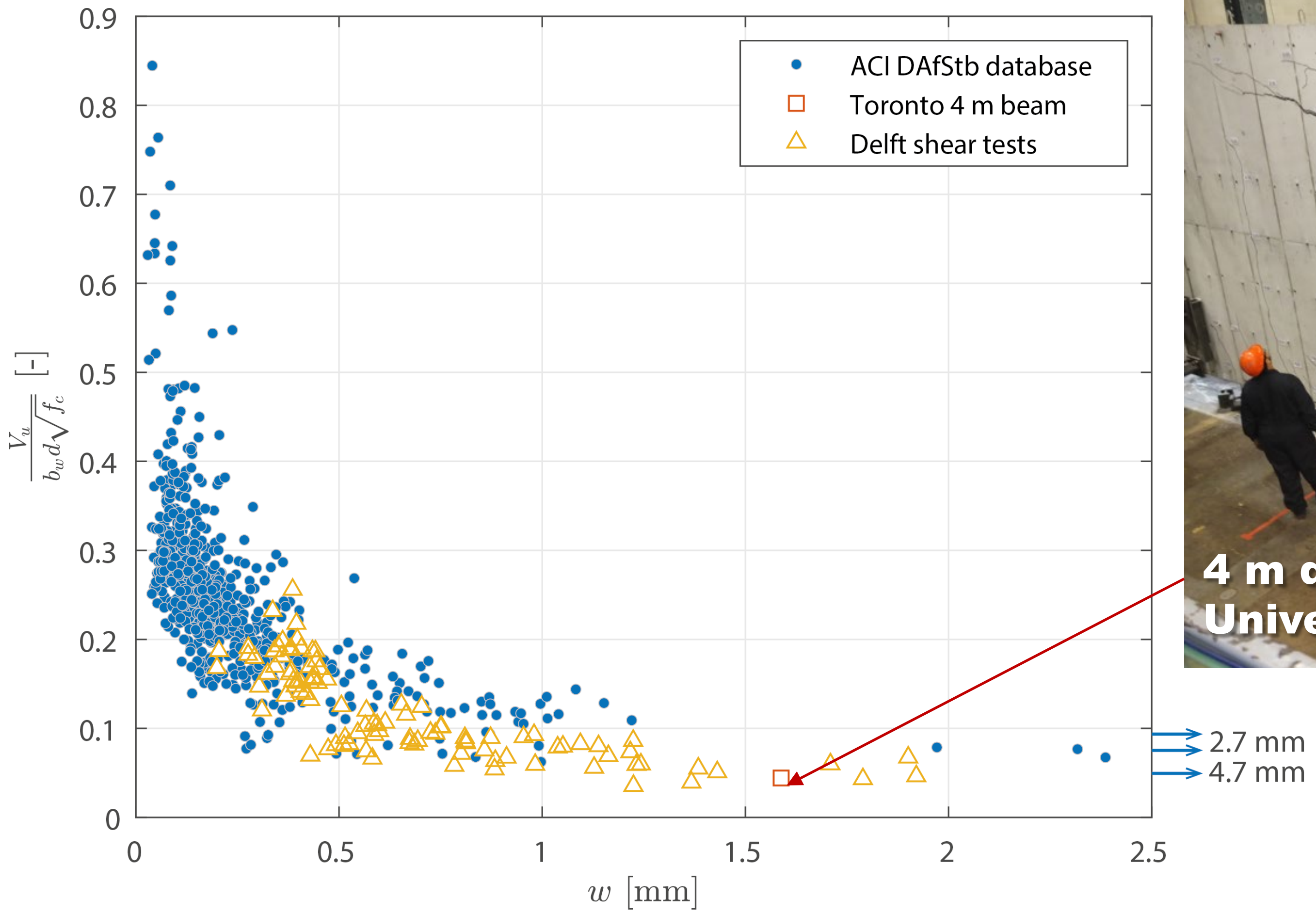
$$\tau_{\mathrm{Rd,c}} = 0.33 \frac{\gamma_{\mathrm{def}}^{2/3}}{\gamma_{\mathrm{v}}^{2}} \frac{\sqrt{f_{\mathrm{ck}}}}{1 + 24\gamma_{\mathrm{def}} \cdot \varepsilon_{\mathrm{v}} \cdot \frac{d}{d_{\mathrm{dg}}}} \quad (\mathrm{I.7})$$

- ε_v is the strain in the longitudinal reinforcement which considers implicitly all effects covered by 8.2.2(3) to (5);
- γ_{def} = 1.33
- γ_v = 1.4

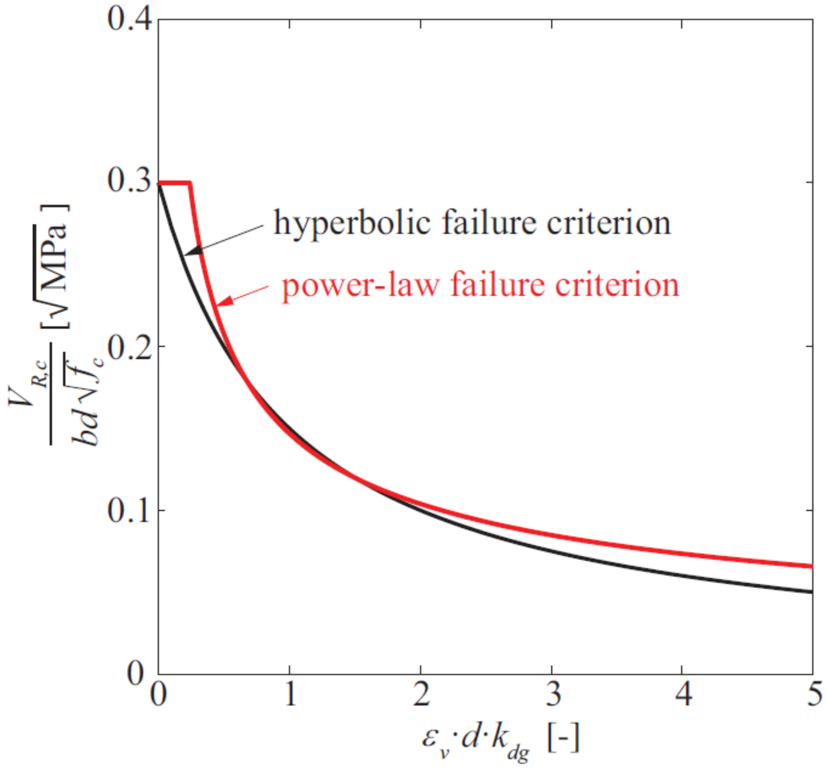
$$k_{\mathrm{vd}} = 1.35 \left(100 \rho_{\mathrm{l}} \frac{d_{\mathrm{dg}}}{d} \right)^{1/10} \leq 1.0 \quad (\mathrm{I.8})$$

- work with 8.2.2(3)

Relate shear capacity with crack width



Eurocode proposal



Crack width

- Based on CSCT
- Hyperbolic failure cri

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

- Power-law failure criterion

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

Dwarskrachtweerstand gebaseerd op scheurwijdte

Dwarskracht in de volgende generatie Eurocode betonconstructies (1)

Betonnen plaatconstructies kunnen worden uitgevoerd zonder dwarskrachtwapening, als de rekenwaarde van de optredende dwarskracht V_{Ed} kleiner is dan de rekenwaarde van de dwarskrachtweerstand van de plaat zonder dwarskrachtwapening $V_{Rd,c}$. De huidige formulering voor $V_{Rd,c}$ is empirisch afgeleid. Nieuwe inzichten laten duidelijk de beperkingen van deze aanpak zien. Daarom wordt deze formule vervangen in de volgende generatie Eurocode betonconstructies. De aangepaste formule relateert de dwarskrachtcapaciteit aan de scheurwijdte en de ruwheid van de scheur.

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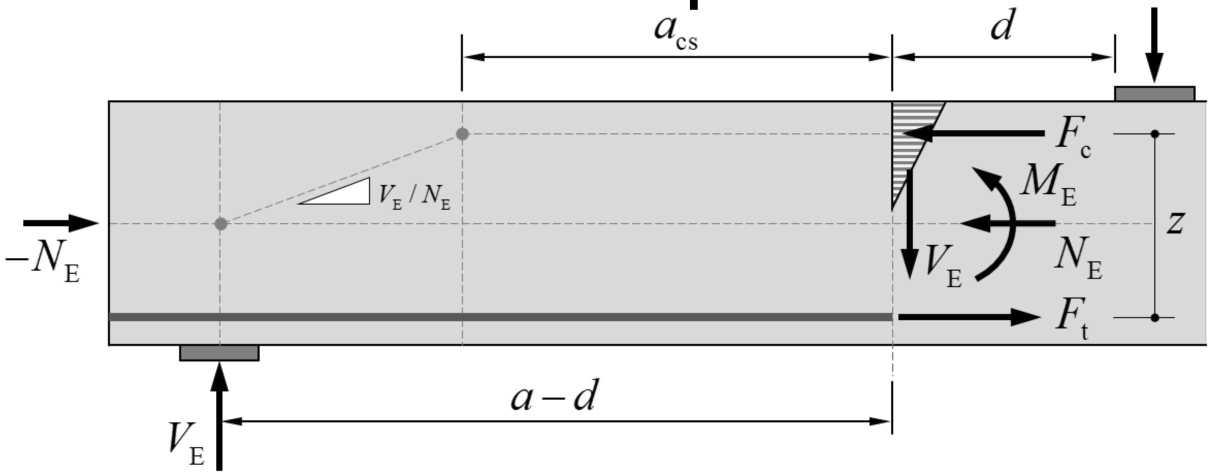
Effect of prestressing

Background of k_{vp}



$$\varepsilon_v = \frac{|M_E| + N_E \cdot e_c}{A_{sl} \cdot E_s \cdot z} = \left(1 + \frac{N_E \cdot e_c}{|M_E|}\right) \frac{|M_E|}{A_{sl} \cdot E_s \cdot z}$$

$$= k_{vp} \cdot \frac{|M_E|}{A_{sl} \cdot E_s \cdot z} = k_{vp} \cdot \frac{|V_E| \cdot a_{cs}}{A_{sl} \cdot E_s \cdot z}$$

No axial force $\quad k_{vp} = 1 + \frac{N_E \cdot e_c}{|M_E|} = 1$

Compressive axial force $\quad k_{vp} = 1 + \frac{N_E \cdot e_c}{|M_E|} < 1$

Tension in rebar at failure $\quad k_{vp} = 1 + \frac{N_E \cdot e_c}{|M_E|} \geq 0$

Hageman study

Adviesbureau ir. J.G. Hageman B.V.

Dossier 10943
Impact van de nieuwe EC2 op de dwarskrachtbeoordeling van bestaande brugdekken

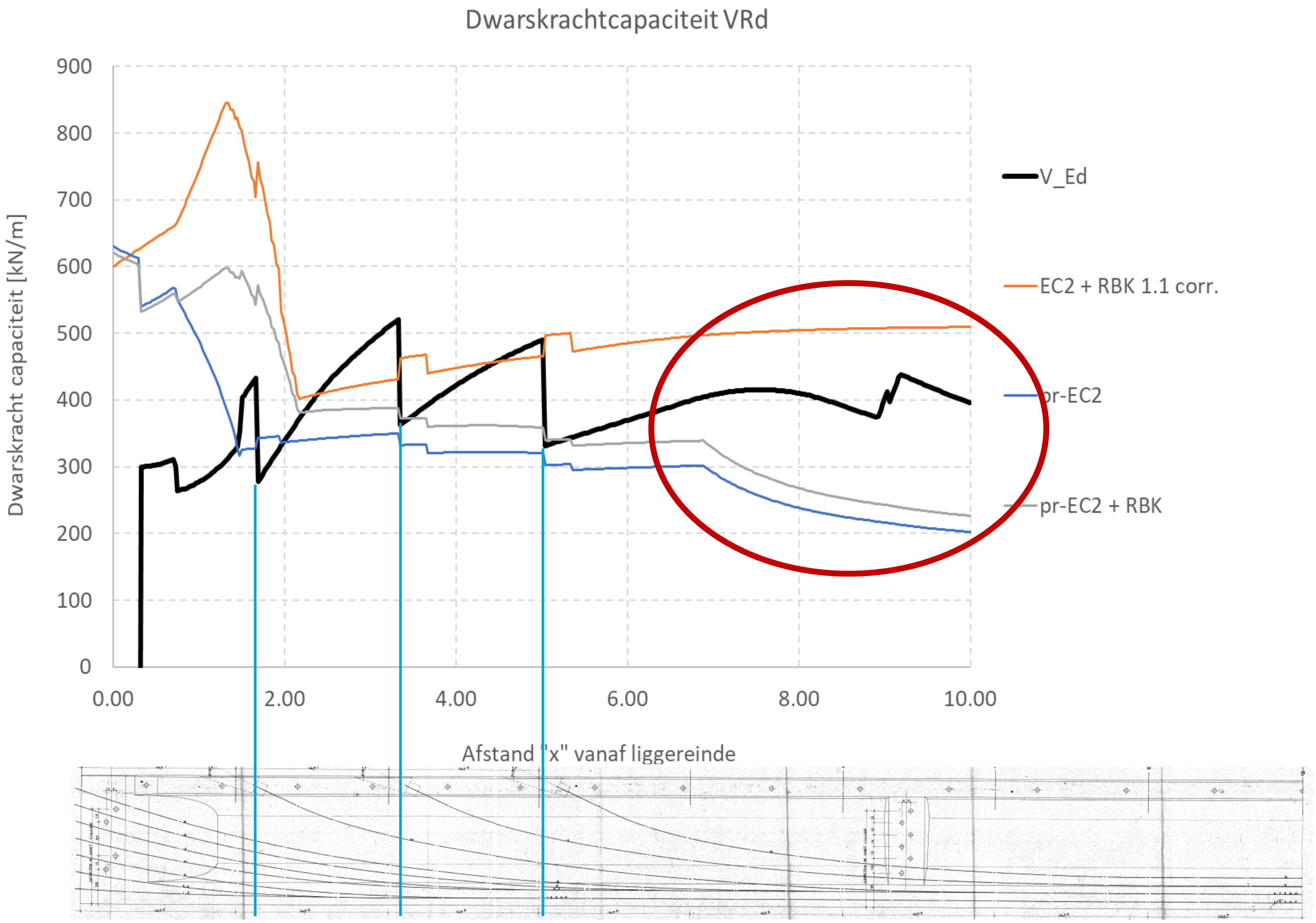
Rapport 10943-2-6
Case studies van voorgespannen brugdekken zonder dwarskrachtwapening (groep 2)

18 januari 2023

Case studies:
2A: Jachtlaan (44E-105)
2B: Hamersbrug (44D-117)

Shear capacity of members with large a_{cs}/d

- Hageman report 10943-2-6 (Hamersbrug)



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- CSCT Original

$$\frac{V_R}{\sqrt{f_c}\cdot b\cdot d}=\frac{1}{3}\cdot\frac{1}{1+120\cdot\frac{\varepsilon\cdot d}{d_g+d_{g0}}}$$

- CSCT FprEC

$$\frac{V_R}{\sqrt{f_c}\cdot b\cdot d}=\frac{0.3}{1+48\cdot\varepsilon_v\frac{d}{d_g}}$$

- FprEC Main

$$\frac{V_R}{\sqrt{f_c}\cdot b\cdot d}=0.015\left(\frac{a_{cs}}{d}\right)^{1/4}\left(\frac{d_{dg}}{\varepsilon_v\cdot d}\right)^{1/2}$$

$(a_{cs}/d=4)$

$$\frac{V_R}{\sqrt{f_c}\cdot b\cdot d}=0.021\left(\frac{d_{dg}}{\varepsilon_v\cdot d}\right)^{1/2}$$

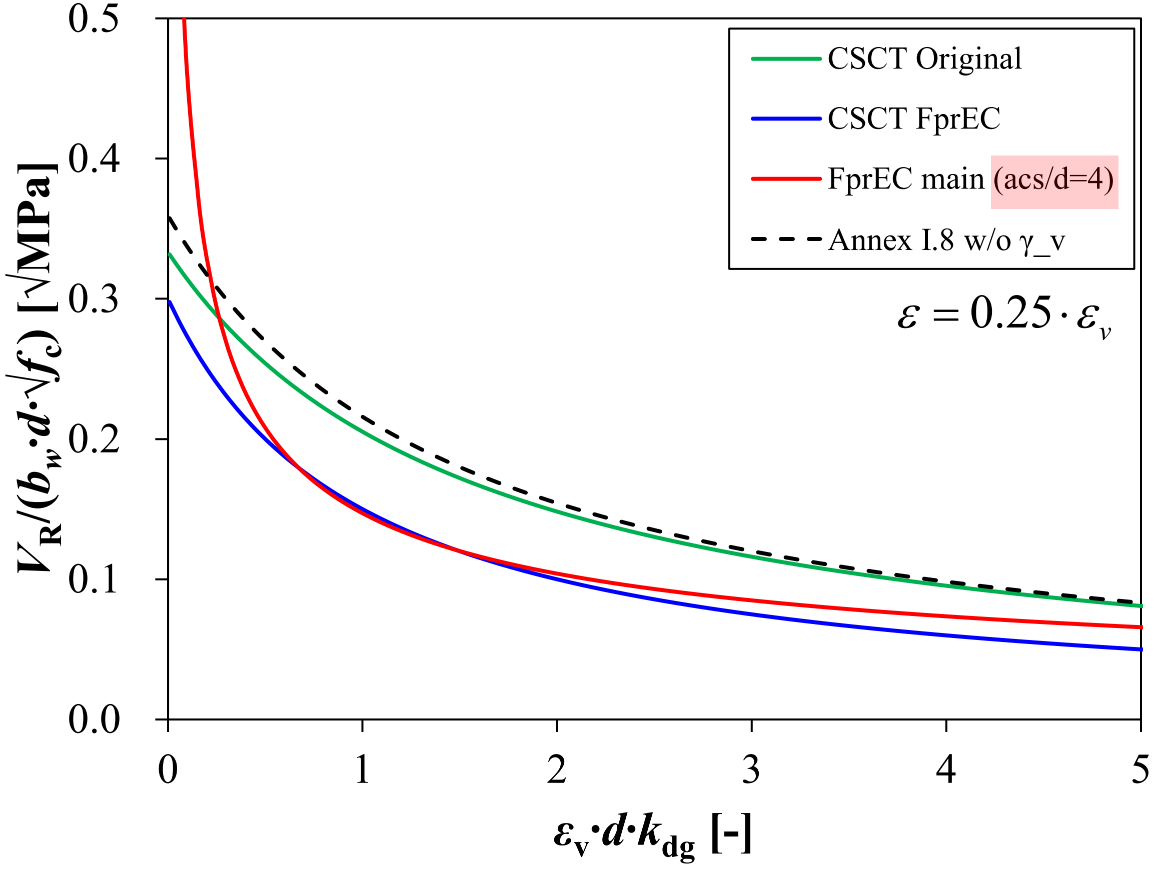
- FprEC
- Annex I.8

$(\gamma_{def}=1.33)$

$$\frac{V_R}{\sqrt{f_c}\cdot b\cdot d}=0.33\frac{\gamma_{def}^{2/3}}{\gamma_v}\frac{1}{1+24\gamma_{def}\cdot\varepsilon_v\cdot\frac{d}{d_{dg}}}$$

(≈ 0.4) (≈ 32)

$$\varepsilon_v=\frac{M_E}{z\cdot A_s\cdot E_s}=\frac{v_E\cdot a_{cs}}{z\cdot\rho_l\cdot E_s}$$



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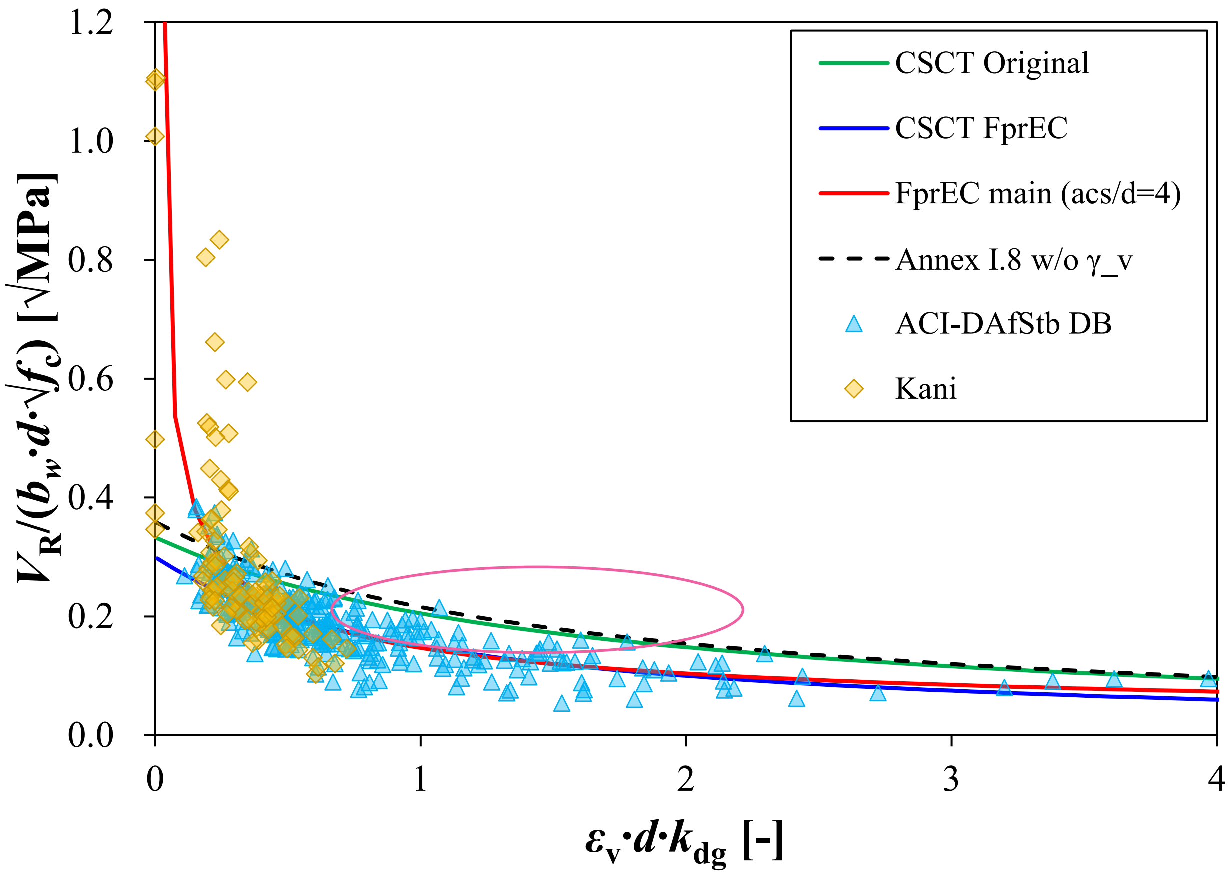
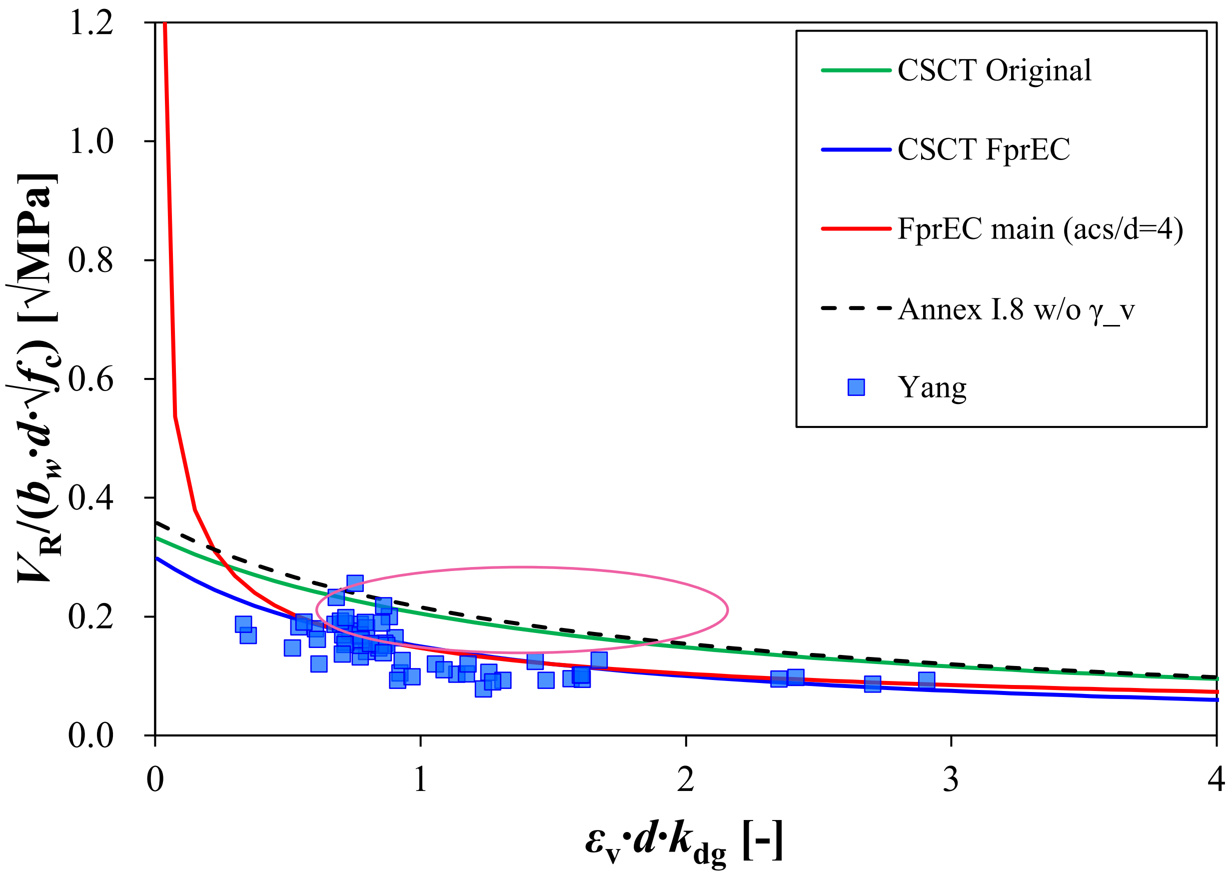
Verification with RC members





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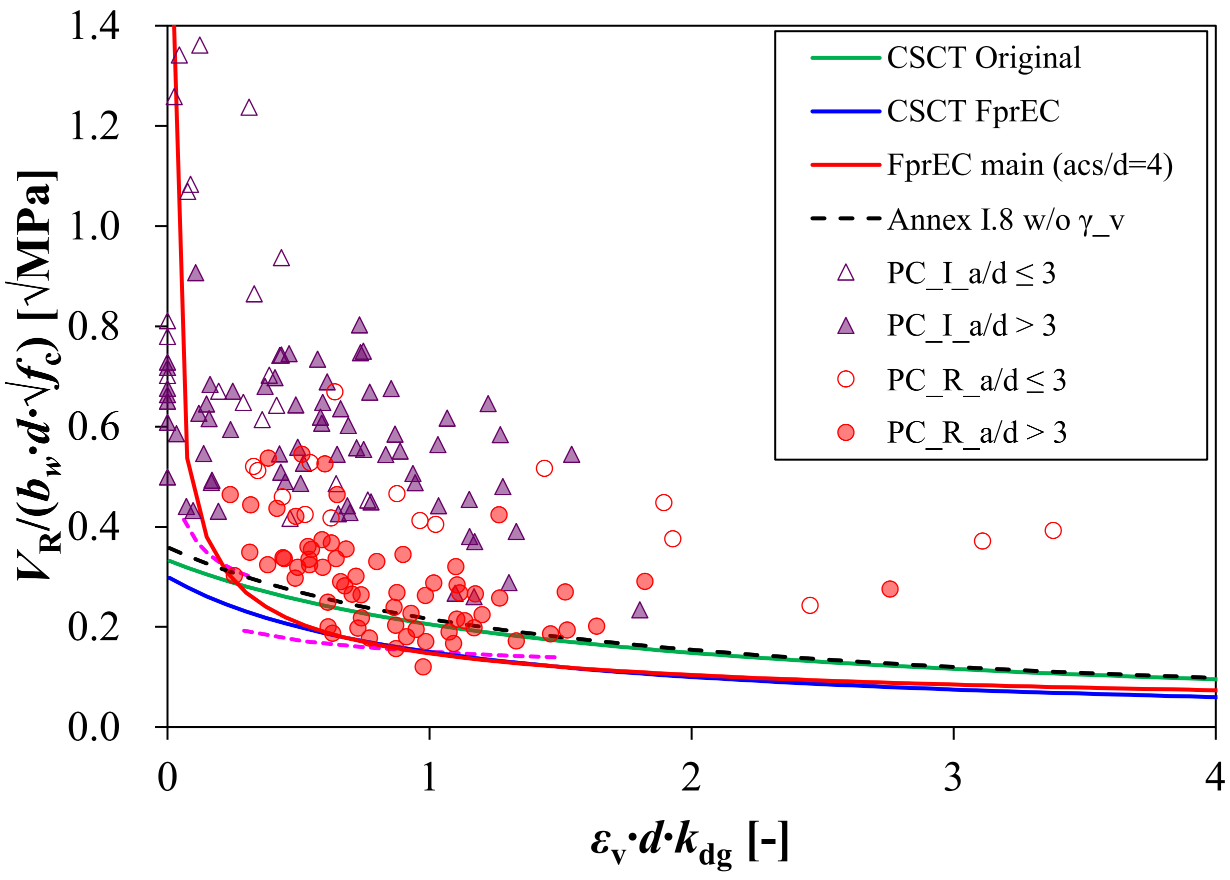
Verification



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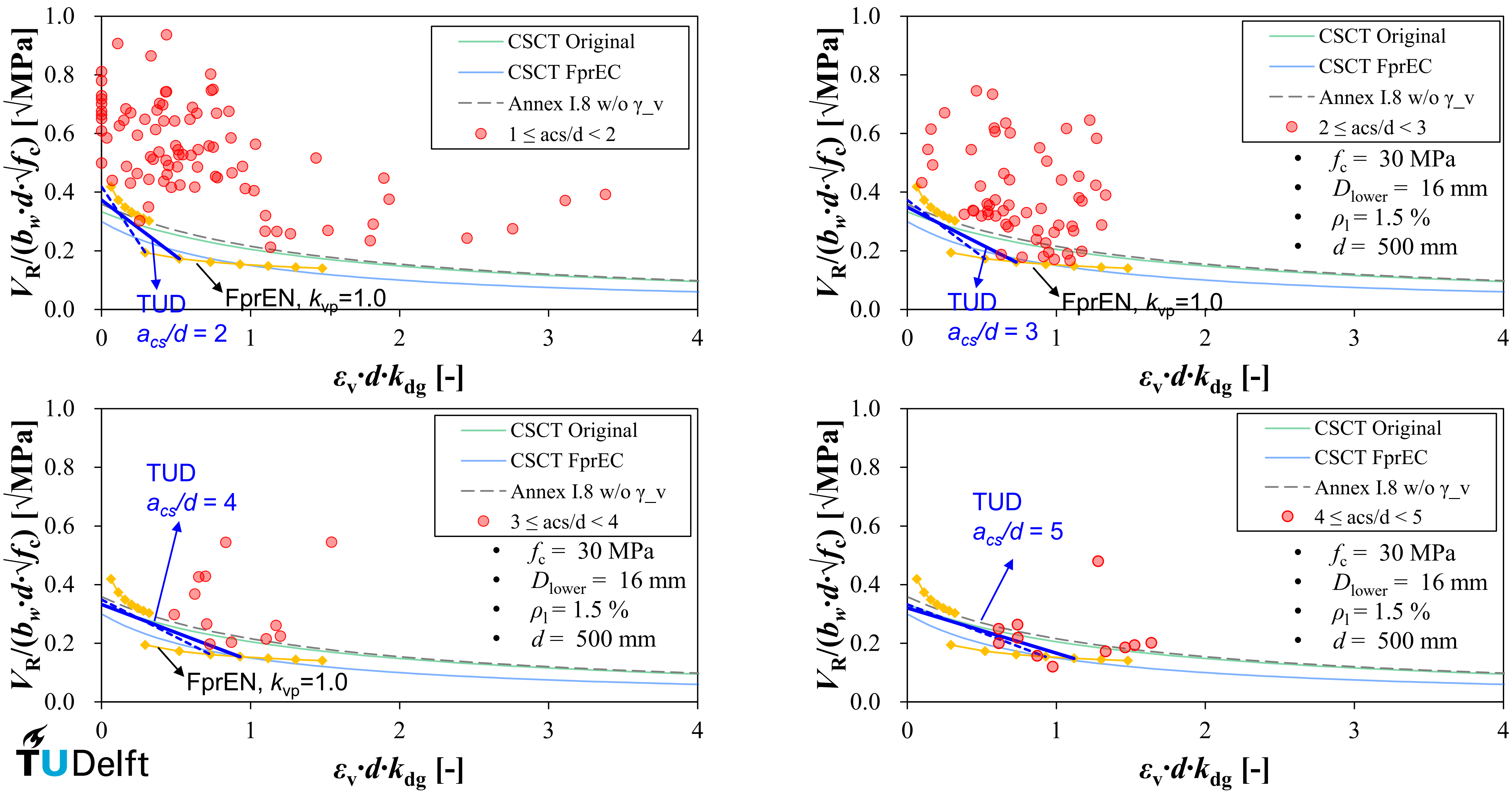
Effect of a_{cs}/d



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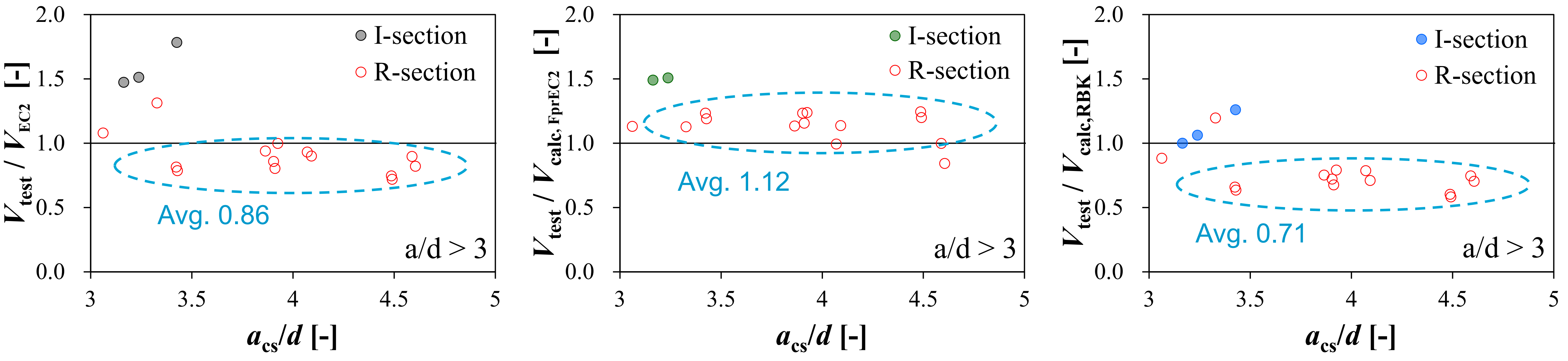
Behaviour of formulas with $a_{cs}/d > 3.5$



	Specimens with a/d >3						$a_{cs}/d > 3.5$	
Section type	All		Rectangular		I or T shape		Rectangular	
Nr. of specimens	136		67		69		12	
Expression	Mean	CoV	Mean	CoV	Mean	CoV	Mean	CoV
EC 1992	**1.66**	**0.271**	**1.33**	**0.232**	**1.96**	**0.161**	**0.86**	**0.098**
FprEC 1992	**1.41**	**0.176**	**1.33**	**0.147**	**1.47**	**0.181**	**1.12**	**0.113**
RBK	**1.19**	**0.219**	**1.10**	**0.236**	**1.66**	**0.177**	**0.71**	**0.094**

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03

Minimum shear resistance

Minimum shear resistance

(4) The minimum shear stress resistance may be calculated as:

$$\tau_{Rdc,min} = \frac{11}{\gamma_V} \cdot \sqrt{\frac{f_{ck}}{f_{yd}} \cdot \frac{d_{dg}}{d}} \qquad (8.20)$$

where

γ_V is the partial factor for shear design according to Table 4.3 (NDP) or Tables A.1 (NDP) and A.2 (NDP);

f_{yd} is the design value of the yield strength which has been used to design the flexural reinforcement;

d is the effective depth of the flexural reinforcement. For prestressed members see 8.2.2(6);

NOTE 1 For d refer to NOTE in (1).

d_{dg} is a size parameter describing the failure zone roughness, which depends on the concrete type and its aggregate properties. d_{dg} (mm) may be taken as:

— 16 mm + $D_{lower} \leq$ 40 mm for concrete with $f_{ck} \leq$ 60 MPa;

— 16 mm + D_{lower} $(60/f_{ck})^2 \leq$ 40 mm for concrete with $f_{ck} >$ 60 MPa.

Inconsistency

- Critical value of a_{cs}/d, 2.0 or 4.0
- Size effect
- f_{yk} or f_{yd} ?
- Effect of prestressing

Modification

- The current recommendation in FprEN 1992-1-1 on $\tau_{Rdc,min}$ requires further modification to be consistent theoretically and with the main formula

- A size effect factor is suggested in $\tau_{Rdc,min}$ to be consistent as the main shear formula

- For prestressing members, f_{yk} shall be replaced by $f_{p0.1k}$ - σ_{pw}

- For both ROK and RBK, we suggest the following expression:

$$V_{Rdc,min} = \frac{8,5}{\gamma_C} k_{v,min} \sqrt{\frac{f_{ck}}{f_{yk}} \cdot \frac{d_{dg}}{d}} \cdot b_w \cdot d \qquad V_{Rdc,min} = \frac{8,5}{\gamma_C} k_{v,min} \left(k_{cap}\right)^{3/2} \sqrt{\frac{f_{ck}}{f_{yk}} \cdot \frac{d_{dg}}{k_b \cdot d}} \cdot b_{w,gem} \cdot d \qquad k_{v,min} = \frac{4.7}{d^{1/4}} \leq 1.0$$

04

Bond factor

Bond effect of plain bar and prestressing strands

- The effect of plain bar should be accounted by recognizing the fact that plain bar has poor bond behaviour, accordingly a larger average crack spacing.
- bond factor k_b is the ratio between the crack spacing of members with ribbed bars and that with plain bars at the mid-depth of the member.
- k_b should be applied in front of d in the shear expression as d is used to represent crack spacing.

$$\tau_{Rd,c} = \frac{0.66}{\gamma_v} k_{vd} \left(100 \rho_l f_{ck} \frac{d_{dg}}{k_b d} \right)^{1/3}$$

Comparison with test results of plain bars

- Based on Delft shear data set on members with ribbed bar and plain bar, we suggest a bond factor for plain bars to be $k_b = 1.2$

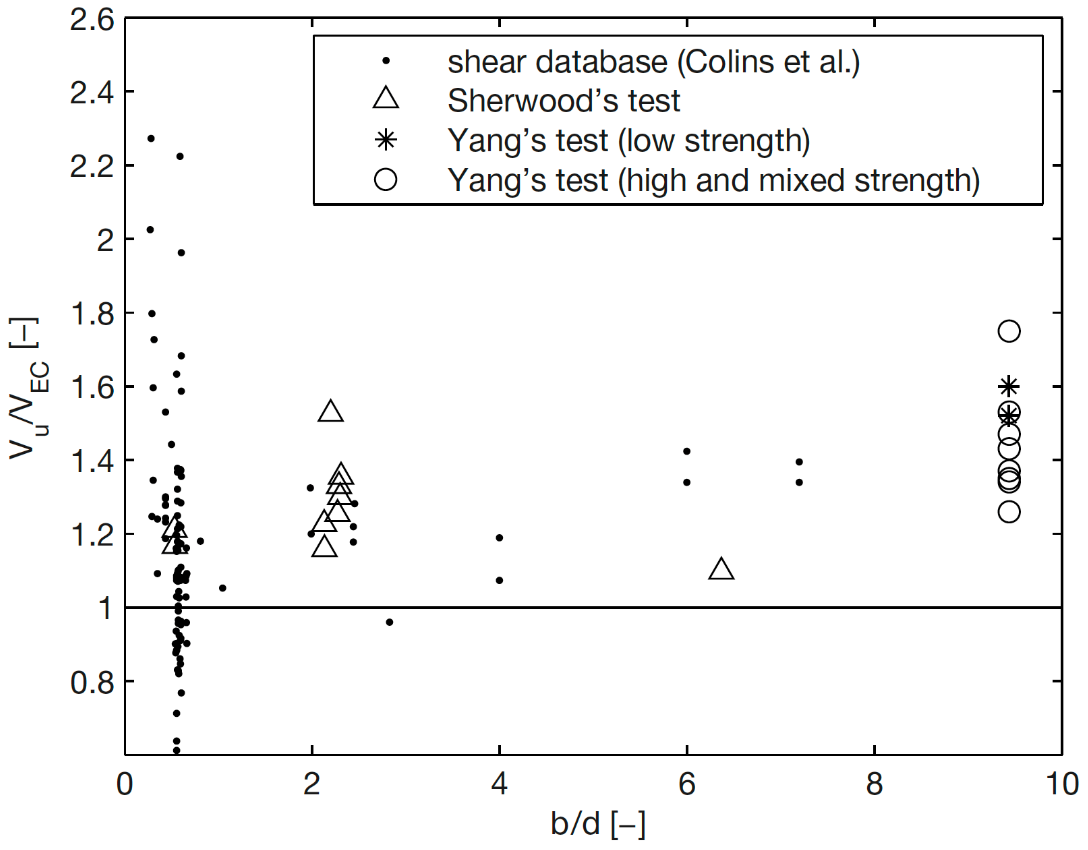
Group	Mean(V_{cal}/V_u)	COV
Ribbed bar specimens	0.93	12.7%
Plain bar specimens without k_b	1.00	11.9%
Plain bar specimens with k_b	0.93	11.9%

05

Slab factor

Slab factor

- In current RBK 1.2, the slab factor is $k_{cap} = 1.2$
- To consider the positive effect on the shear capacity for a slab member



Mechanisms related to slab factor

- Load distribution effect in width direction (For point load etc. shall not consider)
- Redistribution of inner forces considering spatial variation
- Aggregate interlock
- Lower scattering in slabs comparing to beams

Reasons to modify slab factor

- Next generation Eurocode has a different shear resistance factor
- Slab factors were mixed with the scatter of test data, new formula requires recalibration
- New experimental proofs (contradictory)

Results

New slab factor: $k_{cap} = 1.1$

Group	Mean (V_{test}/V_{prep})	CoV	No. of tests	Total ratio
***b/d* < 1.0**	1.10	14.2%	79	1.12
***b/d* > 2.0**	1.23	11.7%	32	

Summary

- FprEN 1992-1-1 shear formular for members without shear reinforcement is a crack based model. For the application in the Netherlands a few modifications have been made, they are implemented in ROK and RBK by Rijkswaterstaat
- Effect of prestressing at cross sections with large a_{cs}/d can be controlling
- The minimum shear resistance formula of FprEN 1992-1-1 is modified
- For plain rebars, a bond factor is provided
- A different slab factor is proposed

Bedankt voor uw aandacht!

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