COST FP1004

STSM report

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Glued-in rods in beech-LVL timber frames

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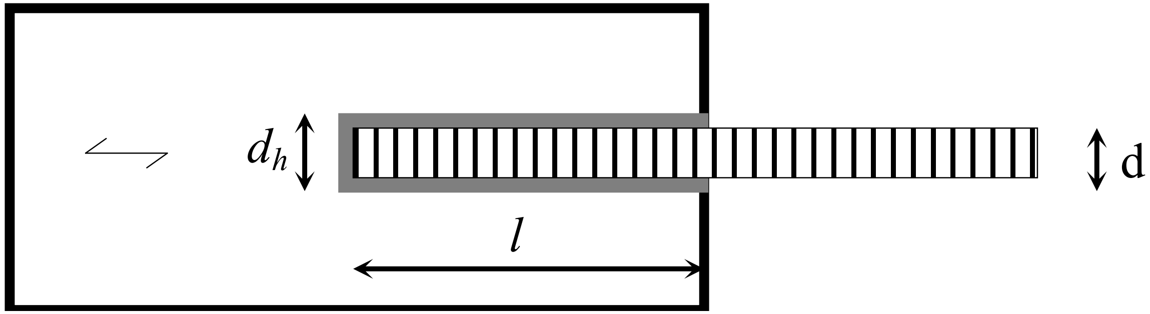
Glued in rods

STSM

- State of the art in GiR
- Comparison of design rules
- Online survey
- Laboratory tests (GiR in LVL)

Glued in rods

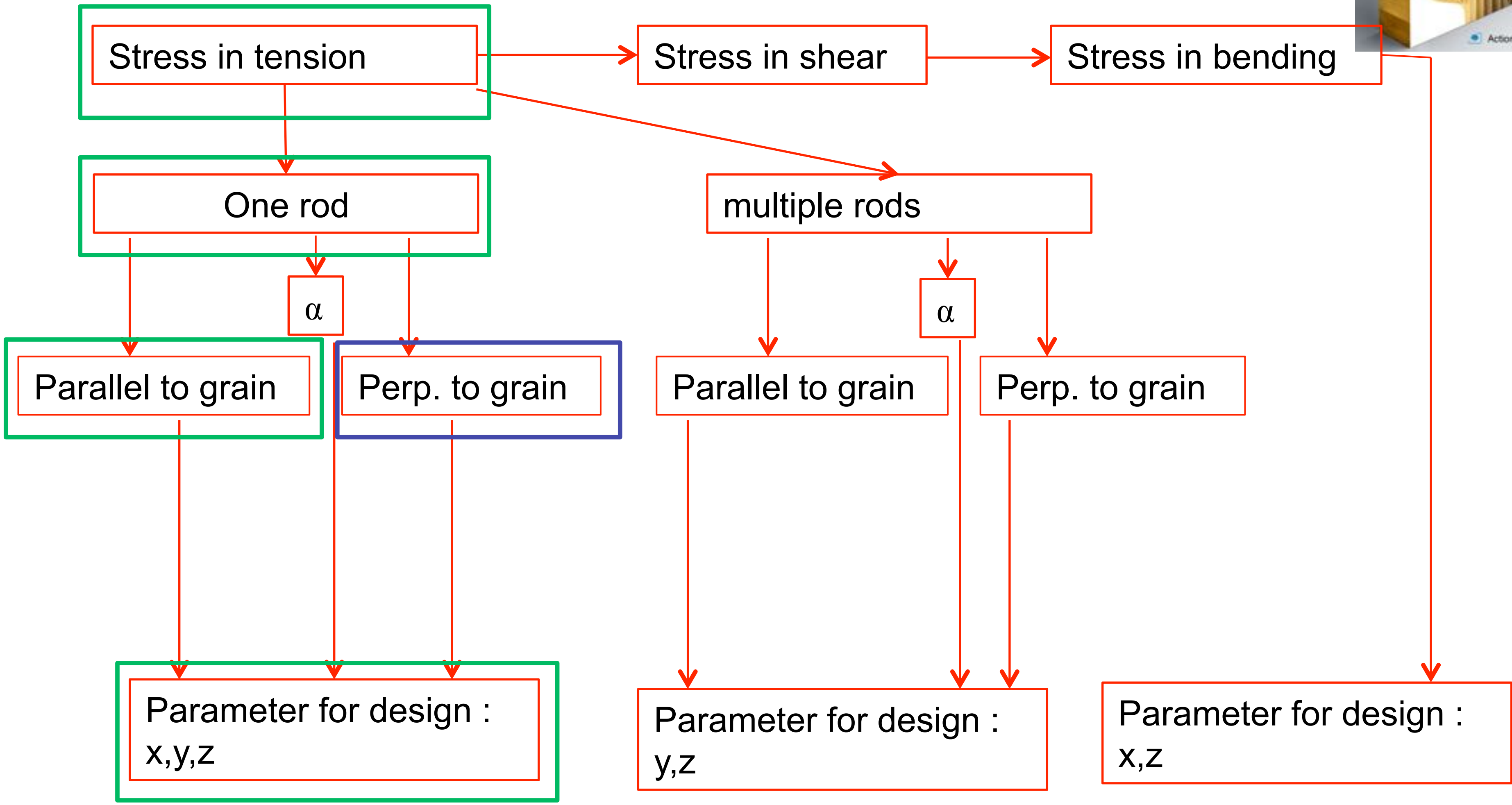


d = diameter of rod
l = anchorage length
d_h = diameter of hole
e = glue line thickness

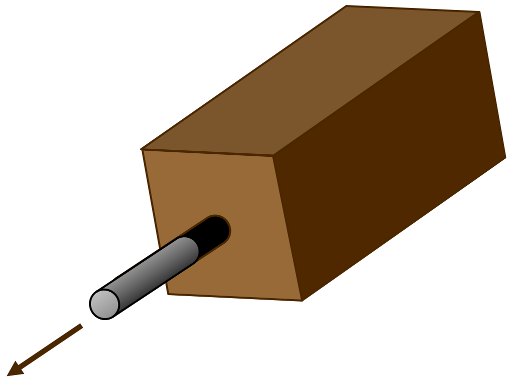
Three materials:

- Main body - Timber (hardwood, softwood, glulam, CLT, LVL)
- Rod – steel or FRP
- Adhesive – PUR, PRF, EPX

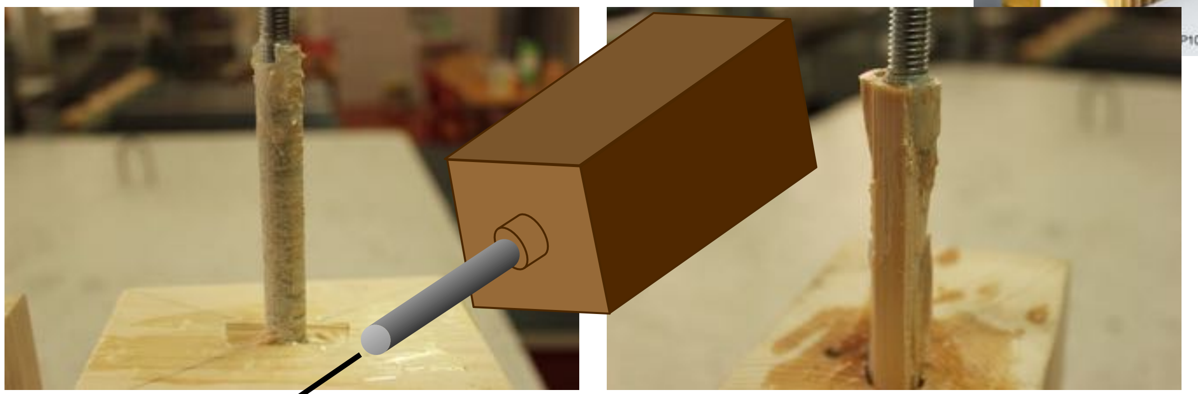
Design philosophy



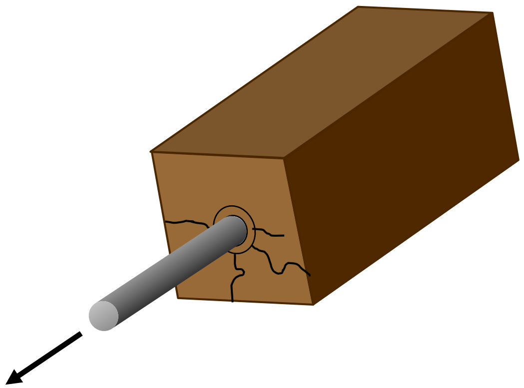
Design philosophy – failure modes



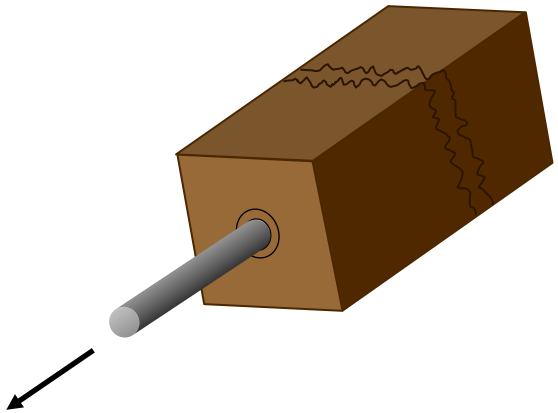
Steel-adhesive zone,
yielding of the rod



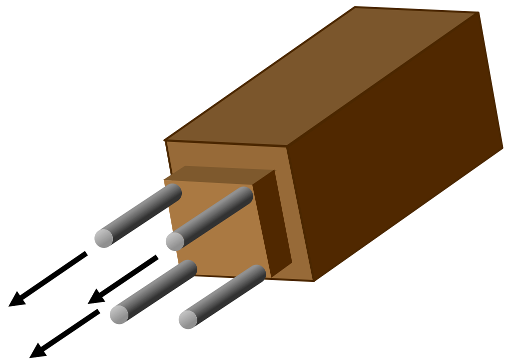
Wood-adhesive zone a) bond failure, b) cohesive failure in the wood near to the bond line



Splitting failure of the wood



Tensile failure - wood



Group shear failure

Design rules - history

1988.
- Riberholt

1990s
- German
- Russian
- New Zealand (Buchanan)
- Swedish

1993
- Kangas V-shape

1997.
- EC5, Part 2: Design of Bridges

1998.-2001.
- GIROD project
- French standards

2001.
- Bernasconi
- IRL/CNR rules
- EC5, final draft

2004.
- DIN1052:2004-08

2007.
- Steiger, Widmann, Gehri

2008.
- DIN1052:2008-12
- Rossignon, Espion

Möhler, Hemmer Riberholt, Turkovsky, Buchanan, Deng

Carling, Kangas, Gehri, Blass, Aicher, Johansson, Townsend, Gerold, Ehlbeck

Harvey, Ansell, Bainbridge, Bernasconi, Mettem, Faye

Gustafsson, Bengtsson, Serrano, del Senno, Piazza, Broughton

Feligioni, Lavisci Steiger, Widmann, Gehri, Tomasi

Rossignon, Espion, Otero, Yeboah, Gardele, Morlier

Riberholt, 1988.

$$R_{ax,k} = f_{w1} \times \rho_c \times d \times l_g \qquad l_g < 200mm$$

$$R_{ax,k} = f_{ws} \times \rho_c \times d \times l_g^{0,5} \qquad l_g \geq 200mm$$

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f_{w1}= glue strength factor (for EPX, PRF = 37, for PUR= 46 N/mm^2)
f_{ws}= glue strength factor (for EPX, PRF = 520, for PUR= 650 N/mm^2)
ρ_c = characteristic density [kg/m3]
l_g = anchorage length [mm]
d = smaller diameter between the rod and the hole

GIROD

$$P_f = \tau_f \times \pi \times d \times l \times (\tanh\omega/\omega)$$

Adhesive	d mm	l mm	a mm	l_{geo} mm	Failure load, P_f kN	$P_f/(\pi d\, l)$ N/mm²	τ_f N/mm²	l_m mm	G_f [1] Nmm/mm²
EPOXY	16	160	115	4070	62.61	7.79	10.5	3600	1.89
	16	320	115	16300	77.36	4.81			
PRF	16	160	115	4070	63.83	7.94	8.9	11000	4.15
	16	320	115	16300	98.43	6.12			
PUR	16	160	115	4070	58.98	7.33	9.7	3960	1.77
	16	320	115	16300	74.09	4.61			

1) G_f calculated from l_m with the assumption E_r=205000 N/mm².

Table 1 – Tests results for determination of material property parameter τ_f and l_m. The failure load indicated is the average value of 10 tests in each set.

EN 1995-2 (2003)

$$R_{ax,k} = \pi \times d_{equ} \times l_a \times f_{ax,k} \times (\tanh\omega)/\omega$$

$l_{min} = \max(0{,}4d^2,\ 8d)$

$l_a/d < 18$

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l_a= anchorage length [mm]

d_{equ} = equivalent diameter = min (d_{hole}, 1.25d) [mm], $d=d_{nom}$ for threaded rods and $d=1{,}1\times d_{nom}$ for deformed reinforcing bars

$f_{ax,k}$ = 5,5 N/mm^2

$$\omega = \frac{0.016\ l_a}{\sqrt{d_{equ}}}$$

DIN 1052:2008-12 (2008)

$$R_{ax,d} = \pi \times d \times l_{ad} \times f_{k1,d}$$

$l_{ad} \leq 250$ mm: $f_{k1,k} = 4{,}0$ [N/mm²]
250 mm $< l_{ad} \leq 500$ mm: $f_{k1,k} = 5{,}25 - 0{,}005 \times l_{ad}$ [N/mm²]
500 mm $< l_{ad} \leq 10000$ mm: $f_{k1,k} = 3{,}5 - 0{,}015 \times l_{ad}$ [N/mm²]

$f_{k1,d}$ = design value of bond line strength
l_{ad} = anchorage length [mm]

6mm $\leq d \leq$ 30 mm

$$l_{ad,min} = \max\{0{,}5 \times d^2; 10 \times d\}$$

Pull – out strength ???

$$R_{ax} = \pi \times d \times l \times f_v$$

d

d_h

$d_{equ} = \min(d_h, 1.25d)$

$1.15d < d_h < 1.4d$

$6\text{mm} \leq d \leq 30\text{ mm}$

Pull – out strength ???

$$R_{ax} = \pi \times d \times l \times f_v$$

l

$l_{ef} = l - 1{,}5d$

$l_{ef} = l - 3cm$

$l_{min} = \max(0{,}4d^2, 8d)$ $l_{ad,min} = \max\{0{,}5 \times d^2; 10 \times d\}$ $5d < l < 20d$

$l_a/d < 18$

Pull – out strength ???

$$R_{ax} = \pi \times d \times l \times f_v$$

$\tau_f \times (\tanh\omega/\omega)$

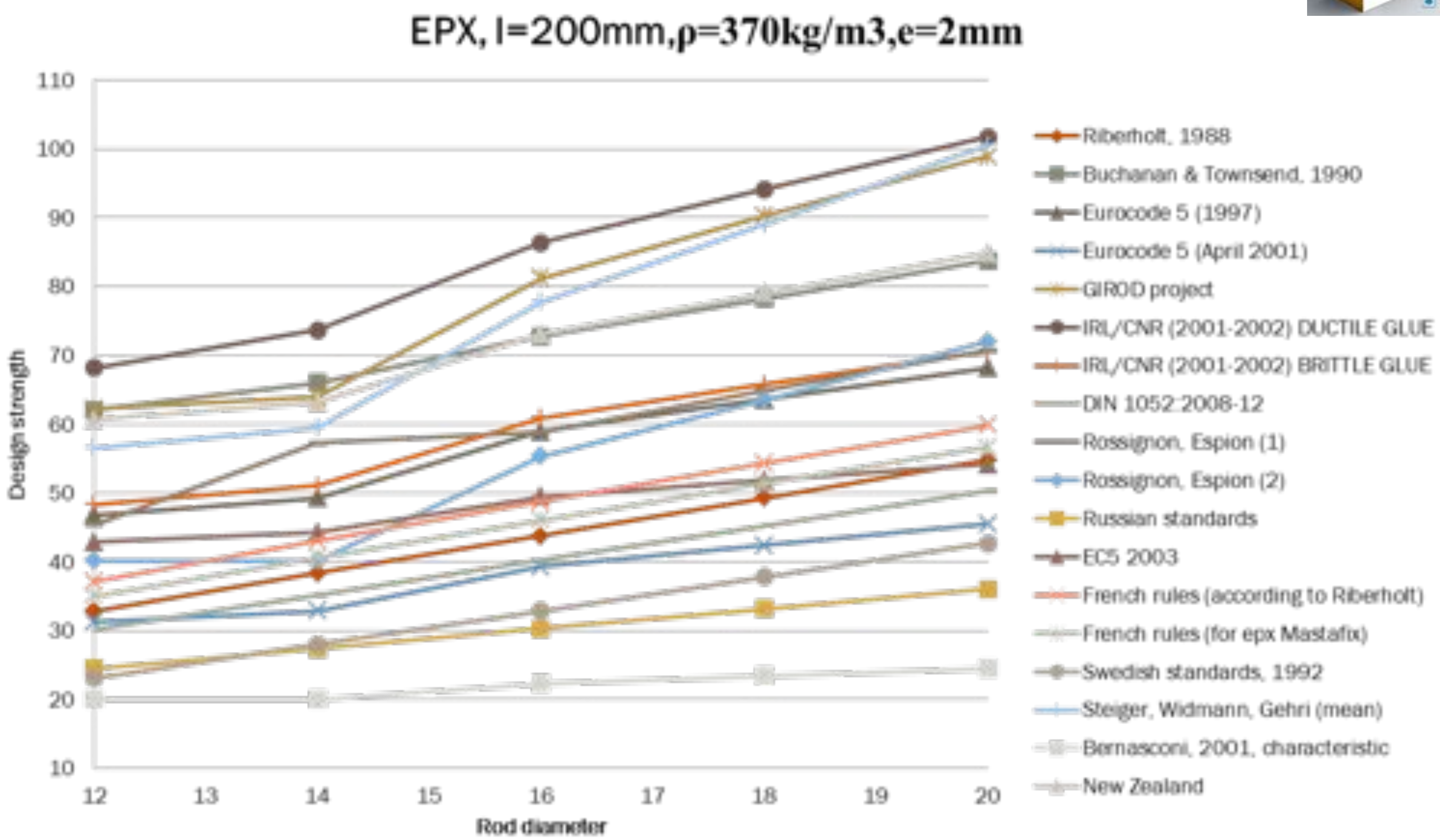
$$f_{v3} = 3.4\,(\mathrm{N/mm^2}) \quad \text{for } l/d \le 10$$

$$f_{v3} = 3.9 - 0.05 l/d\,(\mathrm{N/mm^2}) \quad \text{for } 10 < l/d \le 20$$

$$f_{v,0,mean} = 7.8 \frac{\mathrm{N}}{\mathrm{mm^2}} \left(\frac{\lambda}{10}\right)^{-1/3} \left(\frac{\rho}{480}\right)^{0.6}$$

$f_{v,k} = 1{,}2 \times 10^{-3} \times (d_{equ})^{-0.2} \times \rho_k^{1.5}$

Comparison of design rules



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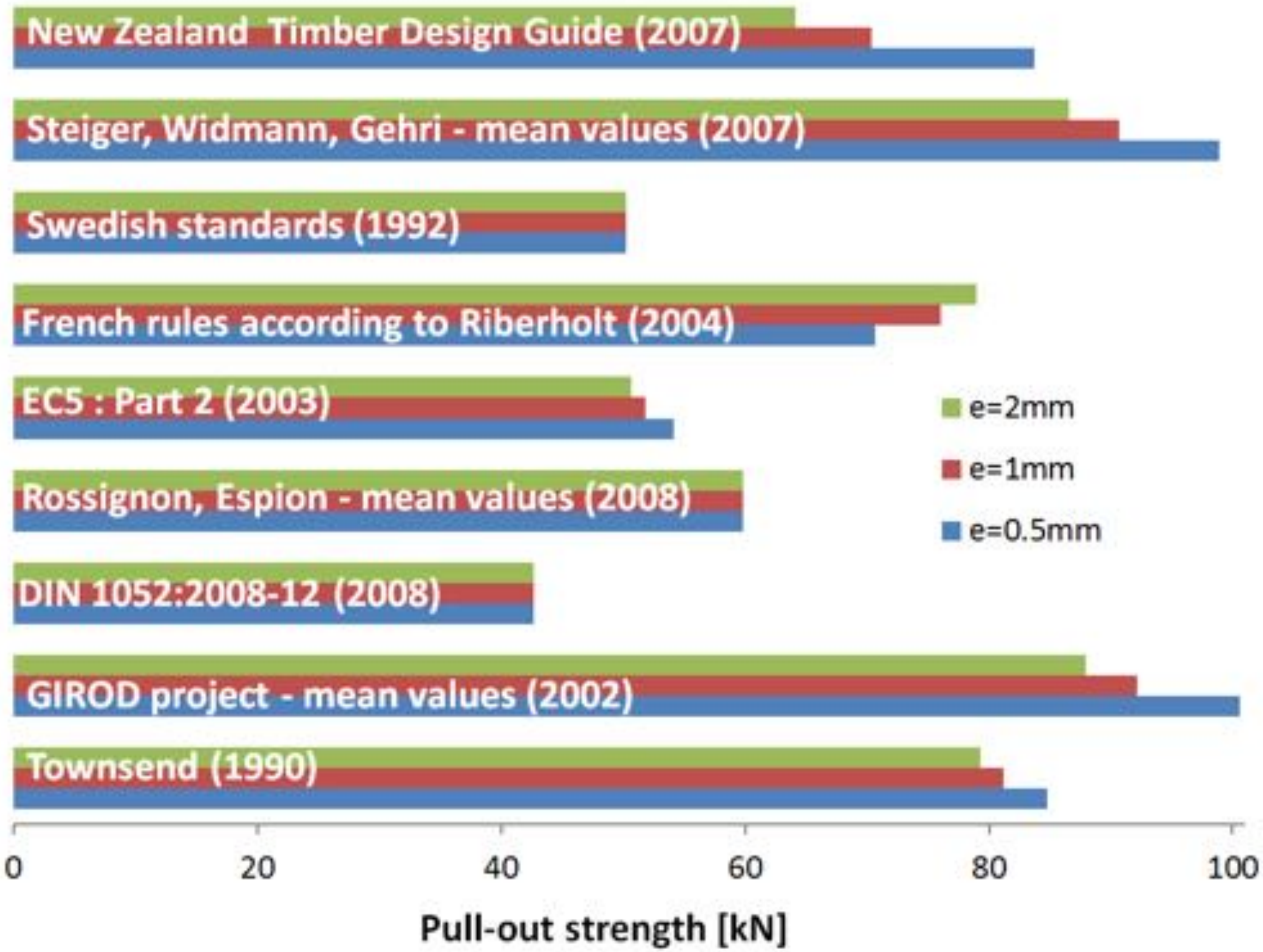

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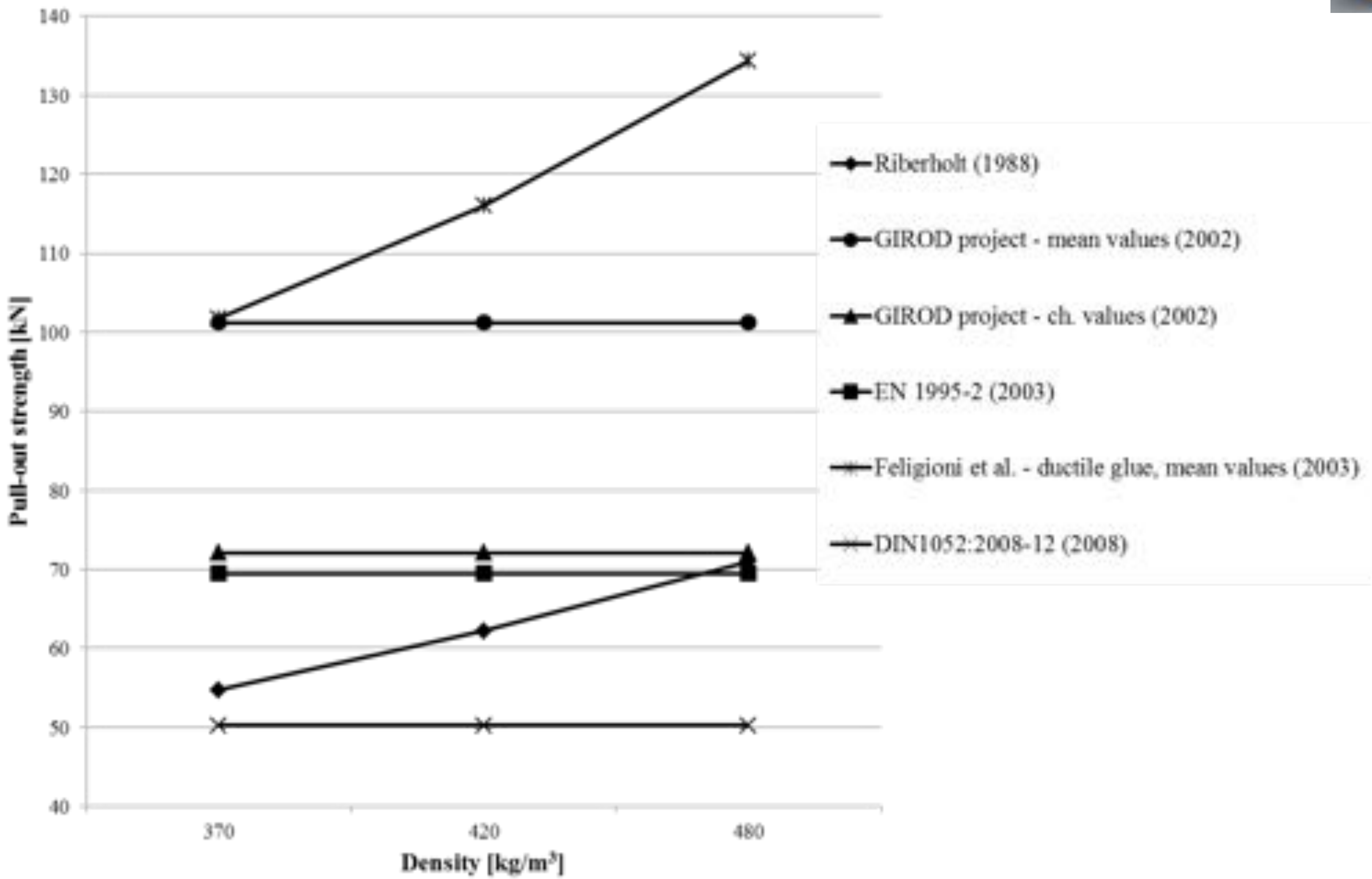
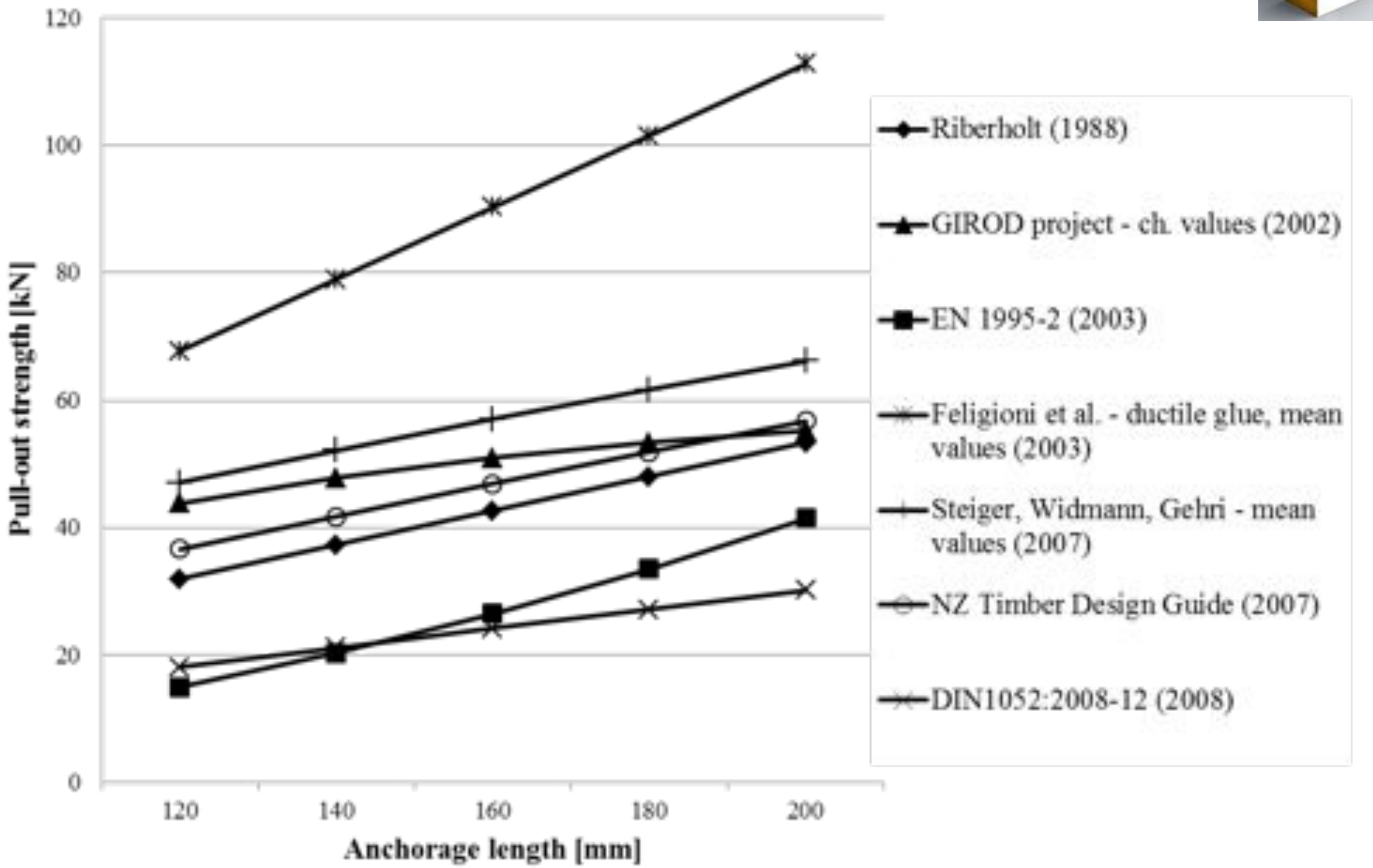


Comparison of design rules



Online survey

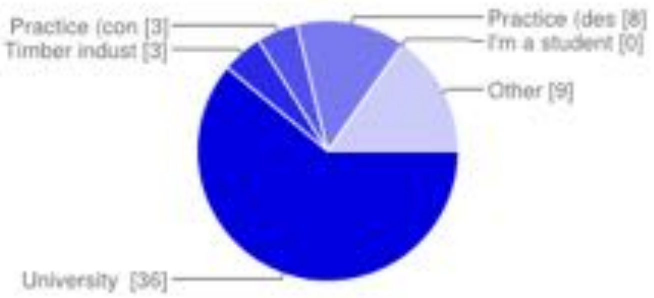
- **Objective:** to gather overall knowledge and interest in glued-in rods

Three parts:

- use of glued-in rods in practice (15 questions),
- **regulations and standards (8),**
- extent of scientific research on the subject (7).

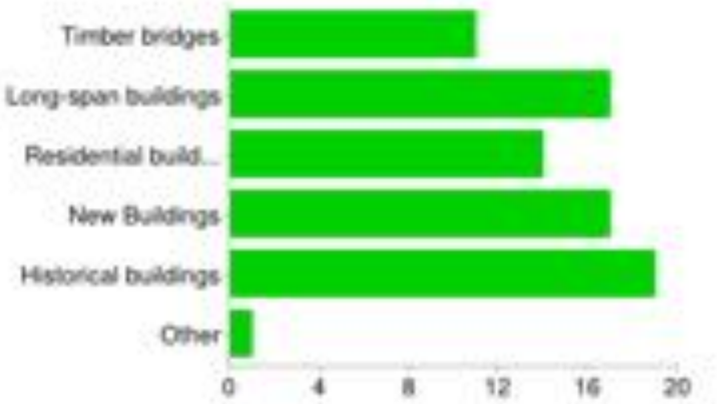
Online survey

From which type of intitution/company are you coming from?



University	36	61%
Timber industry	3	5.1%
Practice (construction)	3	5.1%
Practice (design)	8	13.6%
I'm a student	0	0%
Other	9	15.3%

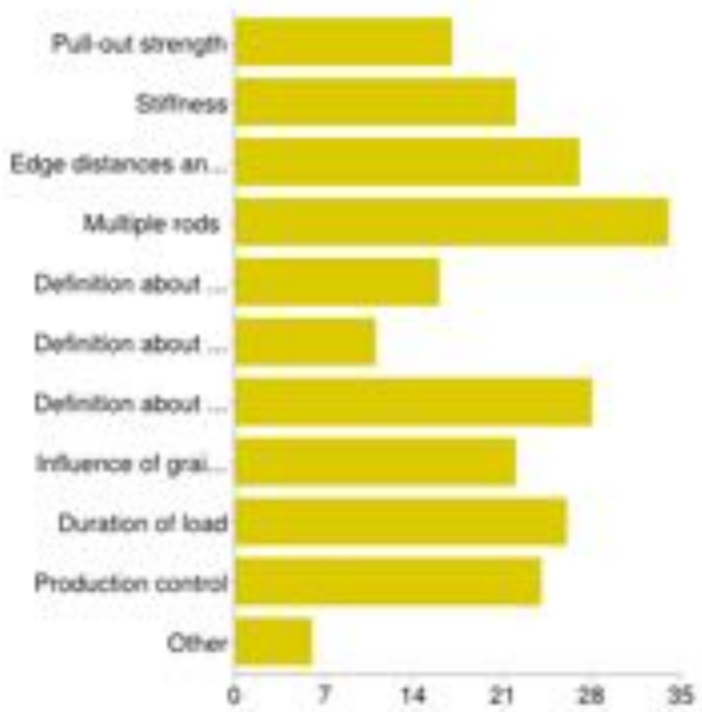
1.5. If you have ever designed a structure with GIR, in which buildings have you used it?



Timber bridges	11	18.6%
Long-span buildings	17	28.8%
Residential buildings	14	23.7%
New Buildings	17	28.8%
Historical buildings	19	32.2%
Other	1	1.7%

Online survey

2.6. Which parts of the standard related to GIR should be improved?



Pull-out strength	17	28.8%
Stiffness	22	37.3%
Edge distances and spacings	27	45.8%
Multiple rods	34	57.6%
Definition about materials used (wood species)	16	27.1%
Definition about materials used (rod materials)	11	18.6%
Definition about materials used (types of glue)	28	47.5%
Influence of grain angle	22	37.3%
Duration of load	26	44.1%
Production control	24	40.7%
Other	6	10.2%

Key problems, Stepinac et al., CIB (2013)

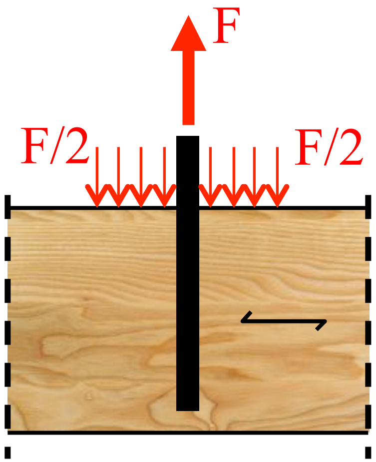
KEY PROBLEMS:

1. Unified EC5 design rules do not exist
2. Design rules were underestimating the load bearing capacity of the connection
3. Ductility should be treated as a key issue (e.g. ductility should be assigned to the steel rod and not to the adhesive)
4. There was no reliable rule for multiple rods (e.g. brittleness could lead to progressive failure in multiple rod connections)
5 .Lack of understanding on duration of load, the interaction between axial load and transverse load, and the influence of grain angle
6. Non user-friendly formulae.

Present situation and problems with standardization

- Timber – glulam, softwood, LVL??
- Rods – steel, FRP
- Adhesive – PUR, EPX, PRF
- Slenderness ratio
- Rod to grain angle
- Loading conditions
- Multiple rods
- Spacings and distances
- Service classes
- Durability and longterm behaviour
- Production method
- On site bonding or factory production

Laboratory tests



pull - compression

Results – failure modes

Thank you for your attention!