Proposed changes to EC2-1-2

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Structure in Fire Forum

Edinburgh 5th September 2016

CEN/TC 250/SC2/WG1/TG5 - EN 1992-1-2

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Amendment to Annex C

Present situation for tabulated data for columns in EN 1992-1-2:

3 methodologies (Method A, Method B, Annex C) which are not consistent

Method A (empirical) $l_{0,fi} \leq 3$ m

Method B (calculation) $\lambda_{fi} \leq 30$

Annex C informative (calculation) $\lambda_{fi} \leq 80$

Annex C (Informative)

(1) Tables C.1 to C.9 provide information for assessing columns in braced structures with a width up to 600 mm and slenderness up to λ = 80 for standard fire exposure.

(3 sets of 3 tables for different ω each with low, moderate and high first order moment for R30 to R 240)

Table C.1 : Minimum dimensions and axis distances for reinforced concrete columns; rectangular and circular section. Mechanical reinforcement ratio ω = 0,1. Low first order moment: e = 0,025*b* with e ≥ 10 mm

Standard fire resistance	λ	Minimum dimensions (mm) Column width b_{min}/axis distance *a*			
		Column exposed on more than one side			
		n = 0,15	*n* = 0,3	*n* = 0,5	*n* = 0,7
1	2	3	4	5	6
R 30	30	150/25*	150/25*	150/25*	150/25*
	40	150/25*	150/25*	150/25*	150/25*
	50	150/25*	150/25*	150/25*	200/25*
	60	150/25*	150/25*	200/25*	250/25*
	70	150/25*	150/25*	250/25*	300/25*
	80	150/25*	200/25*	250/30:300/25*	350/25*

Annex C

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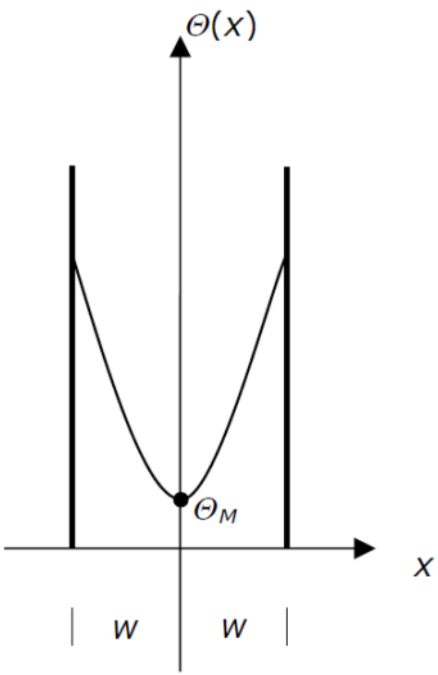
Current Annex C

- some of the values given in Annex C are unsafe
- The tables are difficult to interpolate between

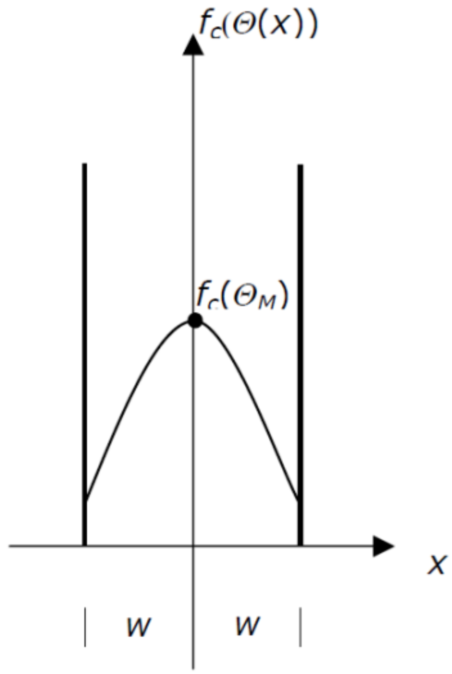
ID	Overall geometry			Load		Fire resistance (min)					
						Annex C	France CimFeu	Germany Frilo	SAFIR EN	SAFIR ETC	Simplified method
	L_0 (m)	h (m)	b (m)	N_{Ed} (MN)	e_N (m)	R_{fi} (min)	$R_{fi,calc}$ (min)	$R_{fi,calc}$ (min)	$R_{fi,calc}$ (min)	$R_{fi,calc}$ (min)	$R_{fi,calc}$ (min)
Ex. 1	10,104	0,500	0,500	1,348	0,013	180	<30	27	29	74	30
Ex. 2	9,526	0,550	0,550	0,815	0,100	180	60<R<90	82	84	92	81
Ex. 3	12,702	0,550	0,550	0,815	0,200	60	<30	30	26	26	25
Ex. 4	2,887	0,250	0,250	0,230	0,010	240	150	155	161	172	151
Ex. 5	6,062	0,300	0,300	0,331	0,010	120	60<R<90	85	87	96	85
Ex. 6	9,526	0,550	0,550	3,706	0,014	120	30<R<60	55	59	103	64

Proposed simplified method

Comes from work done by Jesper Jensen (Denmark)



Temperature distribution



Concrete strength distribution

Rim Zone

As a simplification, the width of the rim zone, a_z, can be determined by:

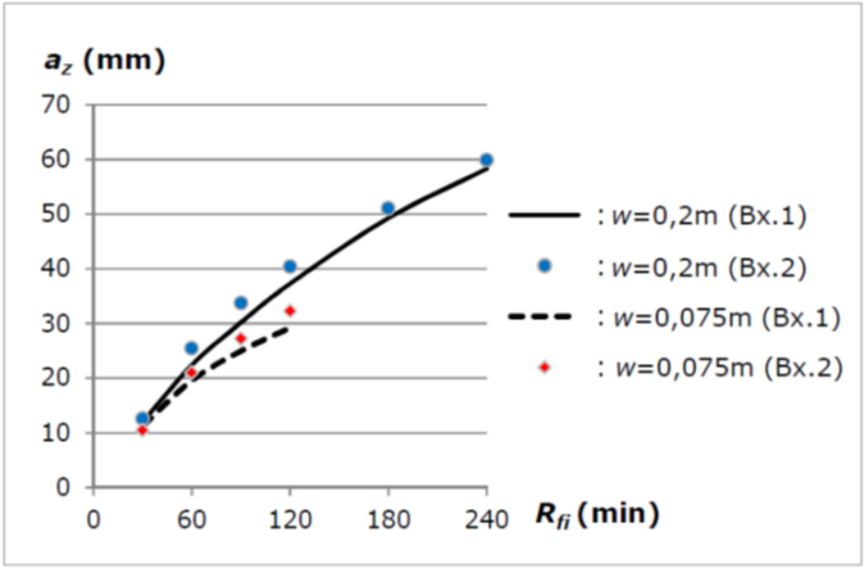
$$a_z = a_{z0} \cdot \sqrt{1 + i_1 \cdot i_2}$$

where:

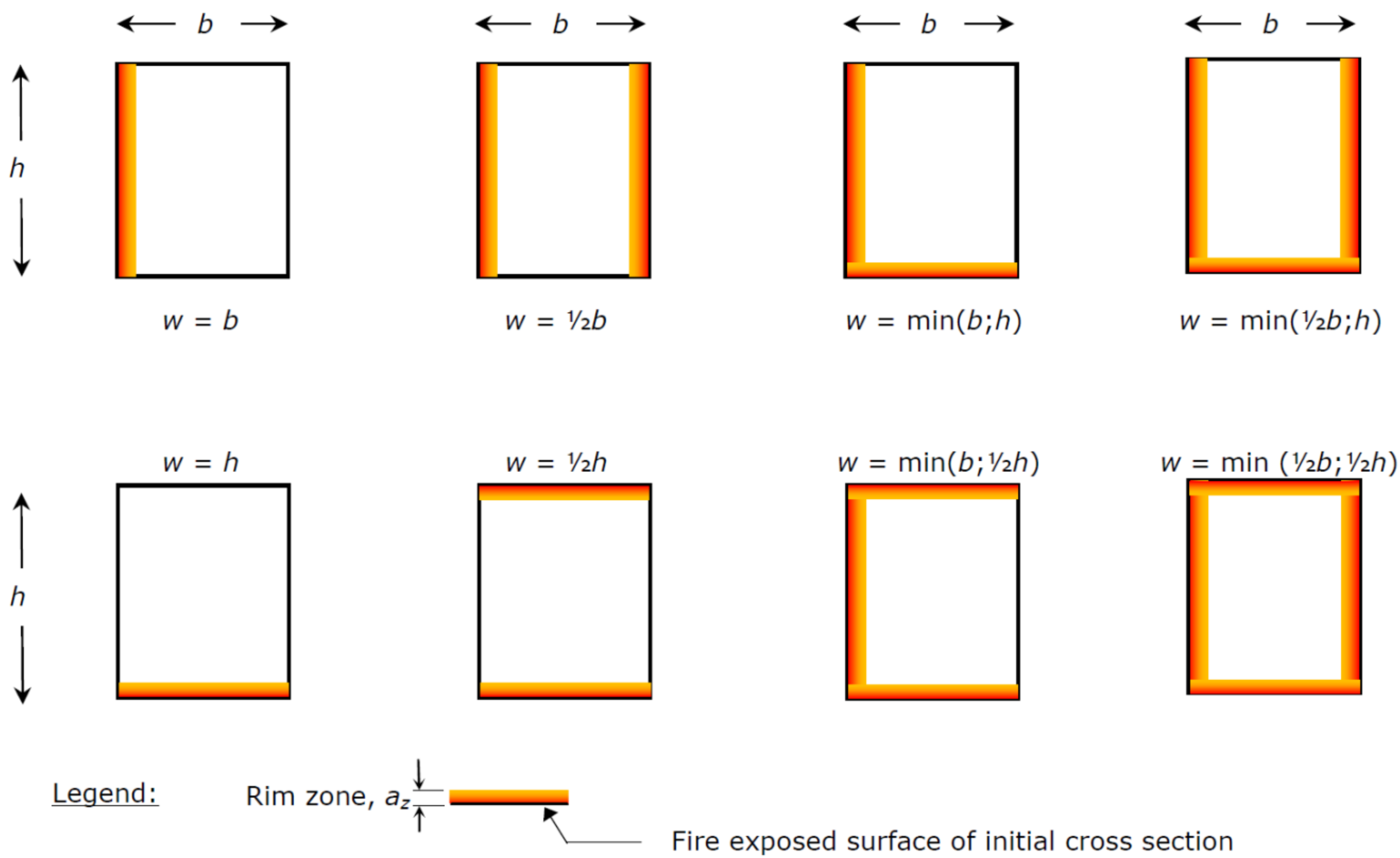
$a_{z0} = 0{,}011$ m

$$i_1 = \frac{R_{FI} - R_0}{R_0} \qquad 30 \text{ min} \leq R_{FI} \leq 240 \text{ min} \;,\; R_0 = 27 \text{ min}$$

$$i_2 = \begin{cases} \sqrt{\dfrac{w}{w_0}} & 0{,}075 \text{ m} \leq w < 0{,}20 \text{ m} \;,\; w_0 = 0{,}0125 \text{ m} \\ 4{,}0 & w \geq 0{,}2 \text{ m} \end{cases}$$



Defining w



b
h
w = b
w = ½b
w = min(b;h)
w = min(½b;h)
w = h
w = ½h
w = min(b;½h)
w = min (½b;½h)
Legend:
Rim zone, a_z
Fire exposed surface of initial cross section

Calculation of reduced section

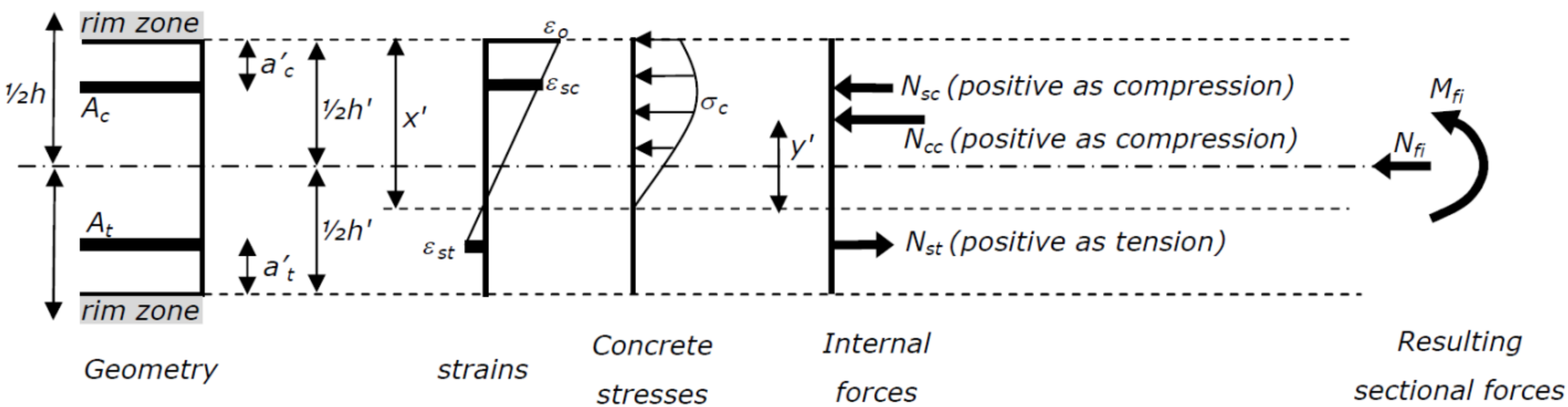


Figure Bx.5: Definitions for sectional analysis, symmetric fire

Buckling Modes

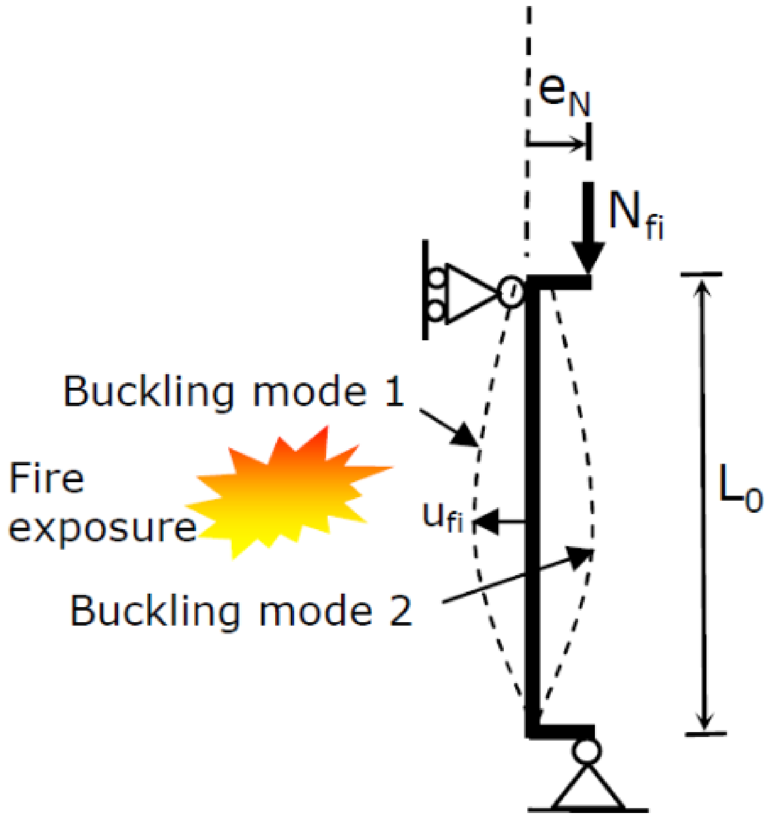


Figure Bx.13: Basic static model, column subjected to asymmetric fire

Temperature Distribution

In a concrete volume exposed to standard fire at one surface, the temperature can be calculated from:

$$\Theta\ (x,t) = 345 \cdot \log\{8 \cdot (t - \Delta t) / 60 + 1\} \cdot \exp\{ -x \cdot \sqrt{0{,}9 \cdot k / t}\ \} \qquad \text{(Ax.1)}$$

t is the duration of the standard fire (in sec), $t \geq 1800$ sec

x is the distance from exposed surface (in m)

$\Theta\ (x,t)$ is the temperature at the distance x from the exposed surface (in °C), $\Theta\ (x,t) \geq 20$°C

$\Delta t = 720$ sec represents a delay between the surface temperature in the concrete and the temperature in the fire compartment as an approximation for the effects of evaporation at the beginning of the fire.

$k = \rho \cdot c_P / \lambda = 2{,}9 \cdot 10^6$ sec / m^2

Calculation by Spreadsheet

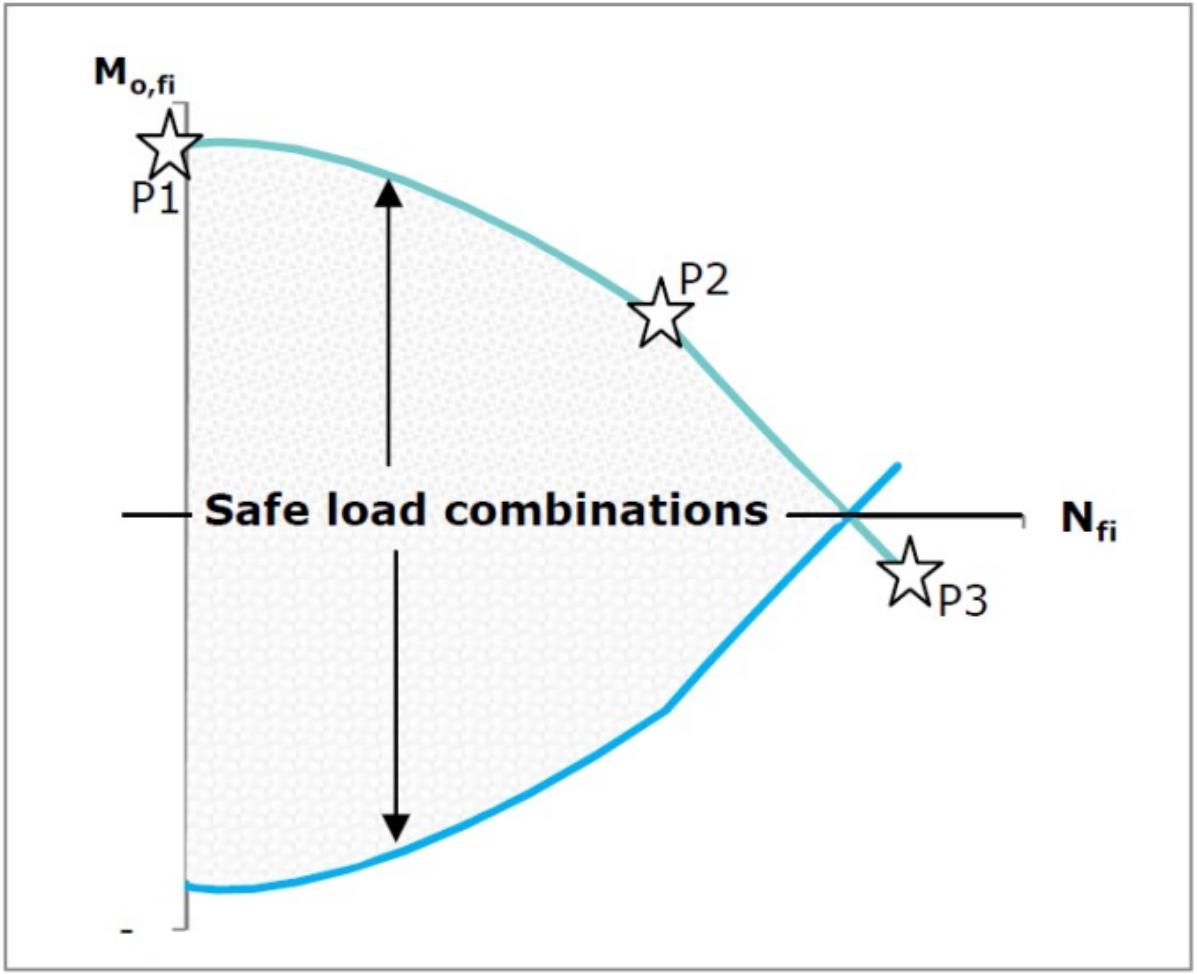


Figure Bx.7: Principle for *N-M* diagram

Proposed New Annex C

R90		h (mm):		600			500			400			300			250			200		
			n_{FI}:	0.2	0.4	0.6	0.2	0.4	0.6	0.2	0.4	0.6	0.2	0.4	0.6	0.2	0.4	0.6	0.2	0.4	0.6
		e_N (mm)	a (mm)	$\lambda_{fi,max}$			$\lambda_{fi,max}$			$\lambda_{fi,max}$			$\lambda_{fi,max}$			$\lambda_{fi,max}$			$\lambda_{fi,max}$		
ω =	0.1	20	25	49	42	33	47	40	29	44	36	23	34	26		29	18		21		
		20	45	55	49	39	55	46	35	53	41	29	41	30	16	35	22		25		
		20	65	55	55	46	55	53	42	55	47	35	48	35	22	40	25		26		
		20	85	55	55	52	55	55	47	55	51	40	48	36	25	37	25	14	22		
		50	25	45	37	25	42	33	19	37	26		24								
		50	45	55	44	31	52	40	24	46	32	9	32	13		23					
		50	65	55	51	37	55	46	30	54	37	15	39	18		28					
		50	85	55	55	43	55	50	35	55	40	19	39	17		26					
		100	25	38	27		32	19		23											
		100	45	48	34	9	42	25		33											
		100	65	55	40	16	51	31		41			16								
		100	85	55	44	19	55	34		43			16								
ω =	0.2	20	25	52	42	31	50	40	27	46	35	21	35	24		30	16		21		
		20	45	55	51	39	55	48	35	55	43	29	45	31	15	39	22		27		

Validation Process

R90	h (mm):		600			500			400			300			250			200		
		n_{fi}:	0,2	0,4	0,6	0,2	0,4	0,6	0,2	0,4	0,6	0,2	0,4	0,6	0,2	0,4	0,6	0,2	0,4	0,6
17/03/2016	e_N (mm)	a (mm)	$\lambda_{fi,max}$			$\lambda_{fi,max}$			$\lambda_{fi,max}$			$\lambda_{fi,max}$			$\lambda_{fi,max}$			$\lambda_{fi,max}$		
ω = 0,1	20	25	49	42	33	47	40	29	44	36	23	34	26		29	18		21		
	20	45	59	49	39	57	46	35	53	41	29	41	30	16	35	22		25		
	20	65	70	56	46	66	53	42	60	47	35	48	35	22	40	25		26		
	20	85	76	62	52	72	58	47	63	51	40	48	36	25	37	25	14	22		
	50	25	45	37	25	42	33	19	37	26		24								
	50	45	55	44	31	52	40	24	46	32	9	32	13		23					
	50	65	65	51	37	61	46	30	54	37	15	39	18		28					
	50	85	72	56	43	66	50	35	57	40	19	39	17		26					
	100	25	38	27		32	19		23											
	100	45	48	34	9	42	25		33											
	100	65	58	40	16	51	31		41			16								
	100	85	64	44	19	56	34		43			16								
ω = 0,2	20	25	52	42	31	50	40	27	46	35	21	35	24		30	16		21		
	20	45	65	51	39	63	48	35	58	43	29	45	31	15	39	22		27		
	20	65	79	60	47	74	56	43	68	50	36	54	36	22	44	26		28		
	20	85	80	66	54	80	62	49	71	53	40	53	37	24	40	25		22		
	50	25	48	37	23	45	33	16	40	26		25			15					
	50	45	62	46	31	58	41	24	53	34		37	13		28					
	50	65	75	55	39	70	49	31	62	40	17	46	20		35					
	50	85	80	61	45	76	54	36	65	43	21	45	19		30					
	100	25	41	27		36	18		27											
	100	45	55	36	8	50	27		42			17								
	100	65	68	45	19	62	35		52	14		30								
	100	85	76	50	23	68	39		54	13		28								
ω = 0,5	20	25	56	41	26	54	38	22	51	33	15	36	18		31			20		
	20	45	76	53	38	73	50	34	68	44	27	51	30		44	20		29		
	20	65	80	66	49	80	61	44	80	54	37	63	39	21	51	28		32		
	20	85	80	73	57	80	68	51	80	58	42	61	39	23	45	25		22		
	50	25	53	35	16	50	31		46	22		27			18					
	50	45	73	48	30	70	44	22	63	35		44			35					
	50	65	80	61	41	80	55	34	77	45	20	56	24		43					
	50	85	80	68	48	80	61	40	79	48	23	54	23		36					
	100	25	47	24		42	11		35											
	100	45	68	39		63	30		55			30								
	100	65	80	52	22	79	42		68	25		44			24					
	100	85	80	58	29	80	47		70	26		40								
ω = 1,0	20	25	68	42	23	62	37	16	52	27		35			29					
	20	45	80	61	41	80	55	35	74	45	24	54	27		46	17		30		
	20	65	80	75	54	80	68	48	80	58	38	69	41	20	56	30		35		
	20	85	80	80	63	80	75	55	80	62	43	67	41	23	48	26		23		
	50	25	65	37	8	58	29		47	12		25								
	50	45	80	56	33	80	48	22	69	35		47			37					
	50	65	80	70	46	80	62	37	80	50	21	63	28		49			22		
	50	85	80	78	54	80	69	44	80	53	26	60	27		40					
	100	25	60	24		51			36											
	100	45	80	47		76	35		61			33								
	100	65	80	61	29	80	50		78	31		52			32					

Example of a new table for R90 :

- 1 Table per fire resistance class
- Table giving maximum slenderness of column as function of ω, n, dimensions, eccentricity
- Tables valid for braced and unbraced columns

Validation process:

Cyan	Selected examples for first control	(February 26th)
Green	Selected examples for further control	(March 16th)
Orange	Selected examples for further control	(May 2nd)

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Comparison of test results

Test ID	e_o (m)	h (m)	L (m)	a (m)	n	d (m)	f_{cm} (MPa)	f_y (MPa)	N (MN)	R_{fi}-test (min)	R_{fi}-calc (min)
TUBr-1	0,03	0,3	3,76	0,038	3	0,02	24,65	487	0,71	86	81
TUBr-2	0,00	0,3	3,76	0,038	3	0,02	24,65	487	0,93	84	84
TUBr-3	0,00	0,3	3,76	0,038	3	0,02	24,65	487	0,93	138	84
TUBr-4	0,03	0,3	4,76	0,038	3	0,02	24,65	487	0,65	63	67
TUBr-5	0,00	0,3	4,76	0,038	3	0,02	24,65	487	0,88	108	66
TUBr-6	0,03	0,3	5,76	0,038	3	0,02	24,65	487	0,6	61	55
TUBr-7	0,00	0,3	5,76	0,038	3	0,02	24,65	487	0,8	58	52
TUBr-8	0,00	0,2	3,76	0,038	2	0,02	24,65	487	0,42	58	38
TUBr-9	0,00	0,2	3,76	0,038	2	0,02	24,65	487	0,42	66	38
TUBr-10	0,00	0,2	4,76	0,038	2	0,02	24,65	487	0,34	48	30
TUBr-11	0,03	0,3	4,76	0,038	3	0,02	31,45	462	0,65	80	73
TUBr-12	0,03	0,3	4,76	0,038	3	0,02	31,45	462	0,65	69	73
TUBr-13	0,02	0,3	4,76	0,038	3	0,02	31,45	462	0,74	85	73
TUBr-14	0,01	0,2	4,76	0,038	2	0,02	31,45	462	0,28	49	35
TUBr-15	0,02	0,2	4,76	0,038	2	0,02	31,45	462	0,24	36	38
TUBr-16	0,09	0,3	4,76	0,038	3	0,02	31,45	462	0,46	75	67
TUBr-17	0,15	0,3	4,76	0,038	3	0,02	31,45	462	0,362	65	58
TUBr-18	0,06	0,2	4,76	0,038	2	0,02	31,45	462	0,17	49	42
TUBr-19	0,10	0,2	4,76	0,038	2	0,02	31,45	418	0,13	53	42
TUBr-20	0,03	0,3	2,66	0,038	3	0,02	34,00	458	0,845	111	108
TUBr-21	0,05	0,3	2,66	0,038	3	0,02	34,00	418	0,78	125	94
TUBr-22	0,60	0,3	4,76	0,038	3	0,02	36,55	425	0,06	83	82
TUBr-23	0,02	0,3	4,76	0,038	5	0,025	37,40	436	0,97	114	95
TUBr-24	0,15	0,3	4,76	0,038	5	0,025	36,55	440	0,505	114	91
TUBr-25	0,01	0,2	5,76	0,038	2	0,02	33,15	443	0,208	40	33
TUBr-26	0,02	0,3	3,332	0,038	3	0,02	31,45	433	0,735	160	108
TUBr-27	0.15	0.3	3.332	0.038	3	0.02	44.20	544	0.355	89	86
TUBr-30	0,01	0,3	4,76	0,038	3	0,02	39,10	404	1,224	48	58
TUBr-31	0,01	0,3	3,76	0,038	3	0,02	43,35	452	1,695	57	66
TUBr-37	0,01	0,3	4,7	0,038	3	0,02	35,70	505	1,548	38	47
TUBr-38	0,01	0,3	4,7	0,038	3	0,014	32,30	503	0,97	55	52
TUBr-39	0,01	0,3	4,7	0,038	3	0,02	32,30	526	1,308	57	50
TUBr-40	0,15	0,3	4,7	0,038	3	0,014	32,30	503	0,28	49	47
TUBr-41	0,15	0,3	4,7	0,038	3	0,02	32,30	526	0,465	50	52
TUBr-42	0,10	0,2	5,71	0,03	3	0,014	42,50	480	0,14	31	25
TUBr-43	0,01	0,2	5,71	0,03	3	0,014	42,50	477	0,245	40	25
TUBr-44	0,05	0,2	5,71	0,03	3	0,014	42,50	480	0,172	35	28
TUBr-45	0,01	0,2	5,71	0,03	3	0,014	42,50	482	0,175	49	34
TUBr-46	0,05	0,2	5,71	0,03	3	0,014	42,50	485	0,122	52	37
TUBr-47	0,01	0,2	5,71	0,03	3	0,014	42,50	478	0,128	72	41
RUG-41A	0,02	0,4	3,9	0,033	3	0,016	29,60	576	1,65	93	108
TUBr-21	0,05	0,3	2,66	0,038	3	0,02	34,00	418	0,78	125	93
TUBr-27	0,15	0,3	3,332	0,038	3	0,02	44,20	544	0,355	89	86
NRC-I2	0,00	0,305	1,905	0,061	2	0,0255	36,90	444	1,33	170	161
NRC-III3	0,03	0,305	3,81	0,061	2	0,0255	39,90	444	1	181	96

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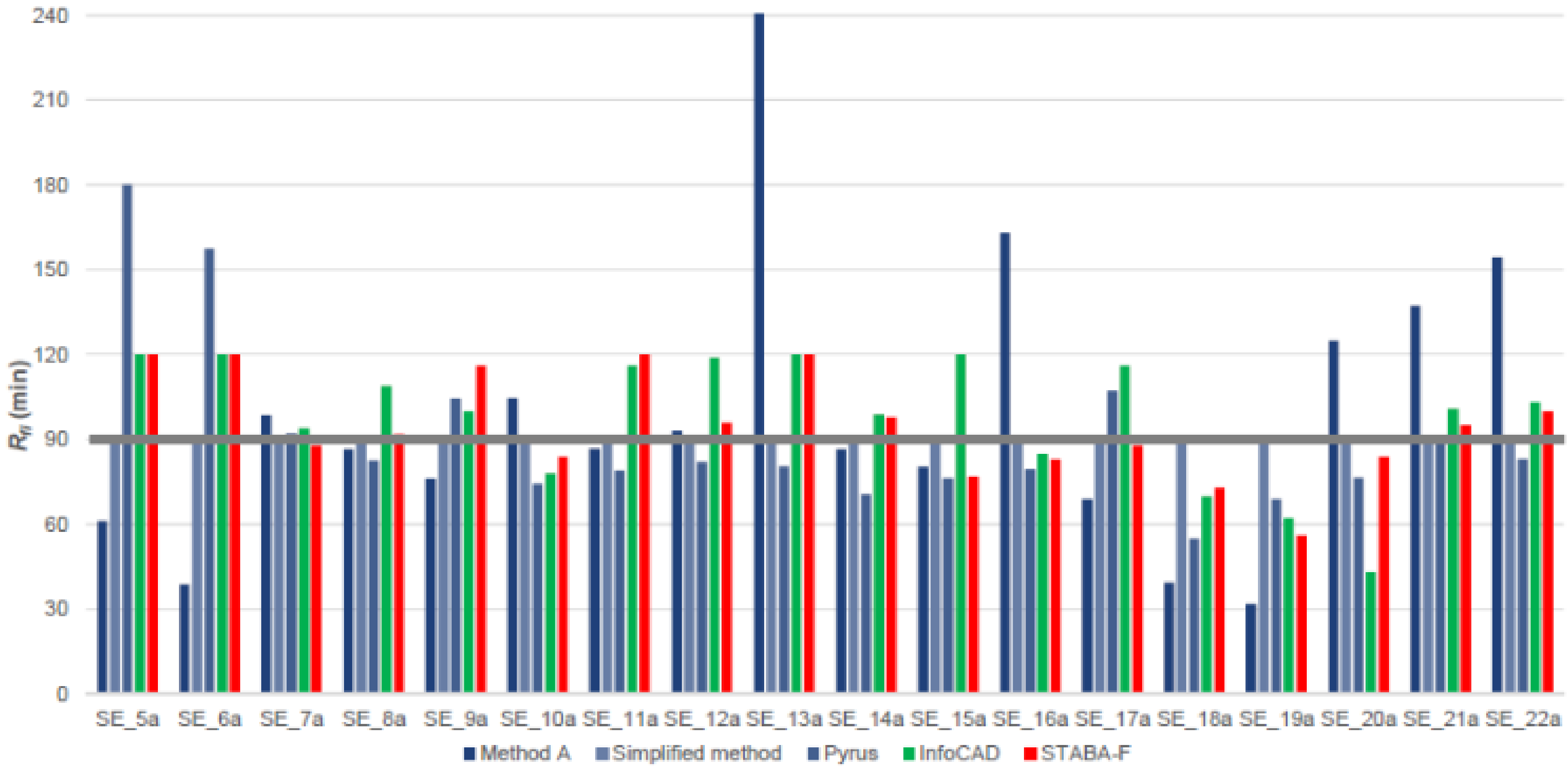
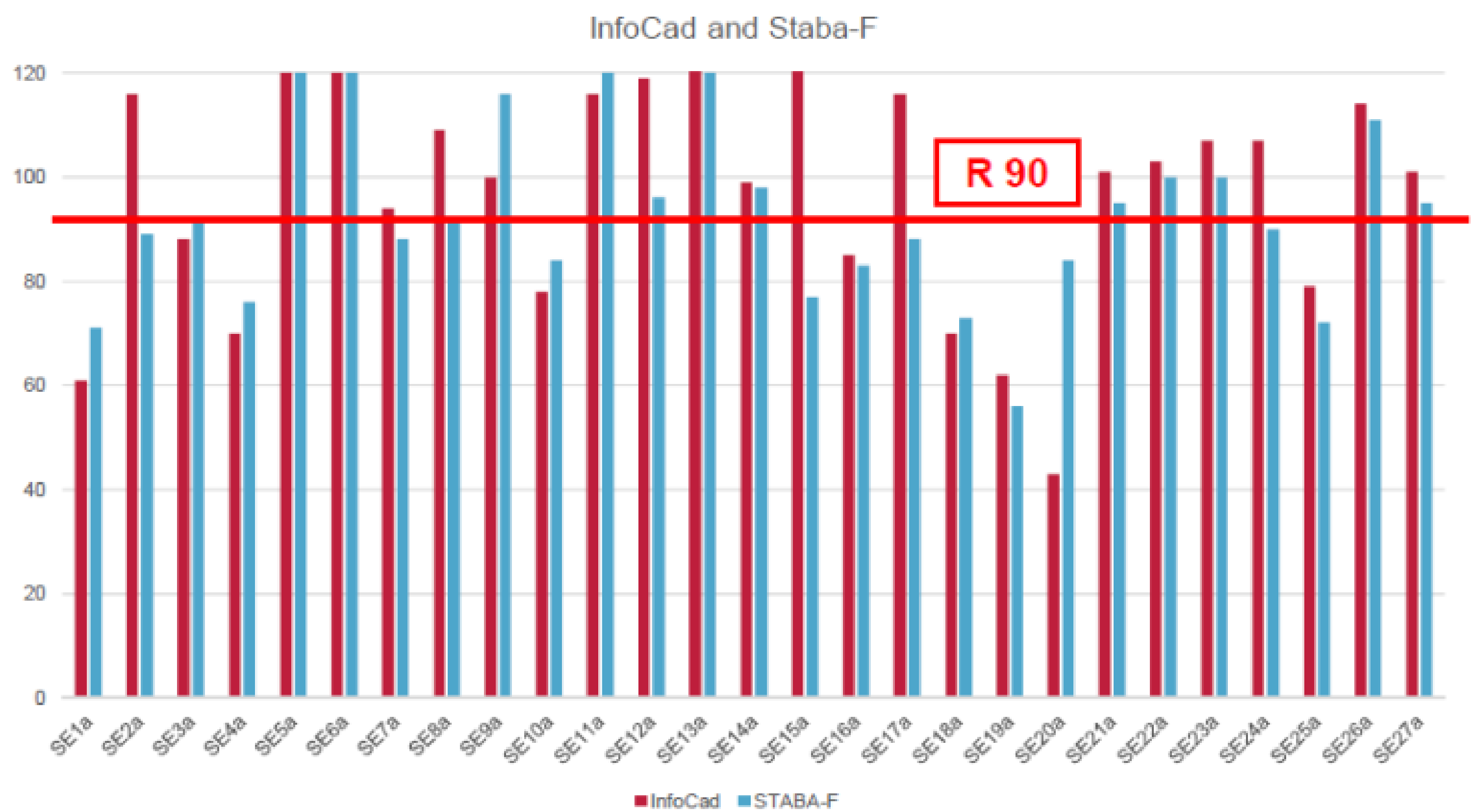
Sensitivity analysis – Second control



First, further and third control:
InfoCad vs. Staba-F results



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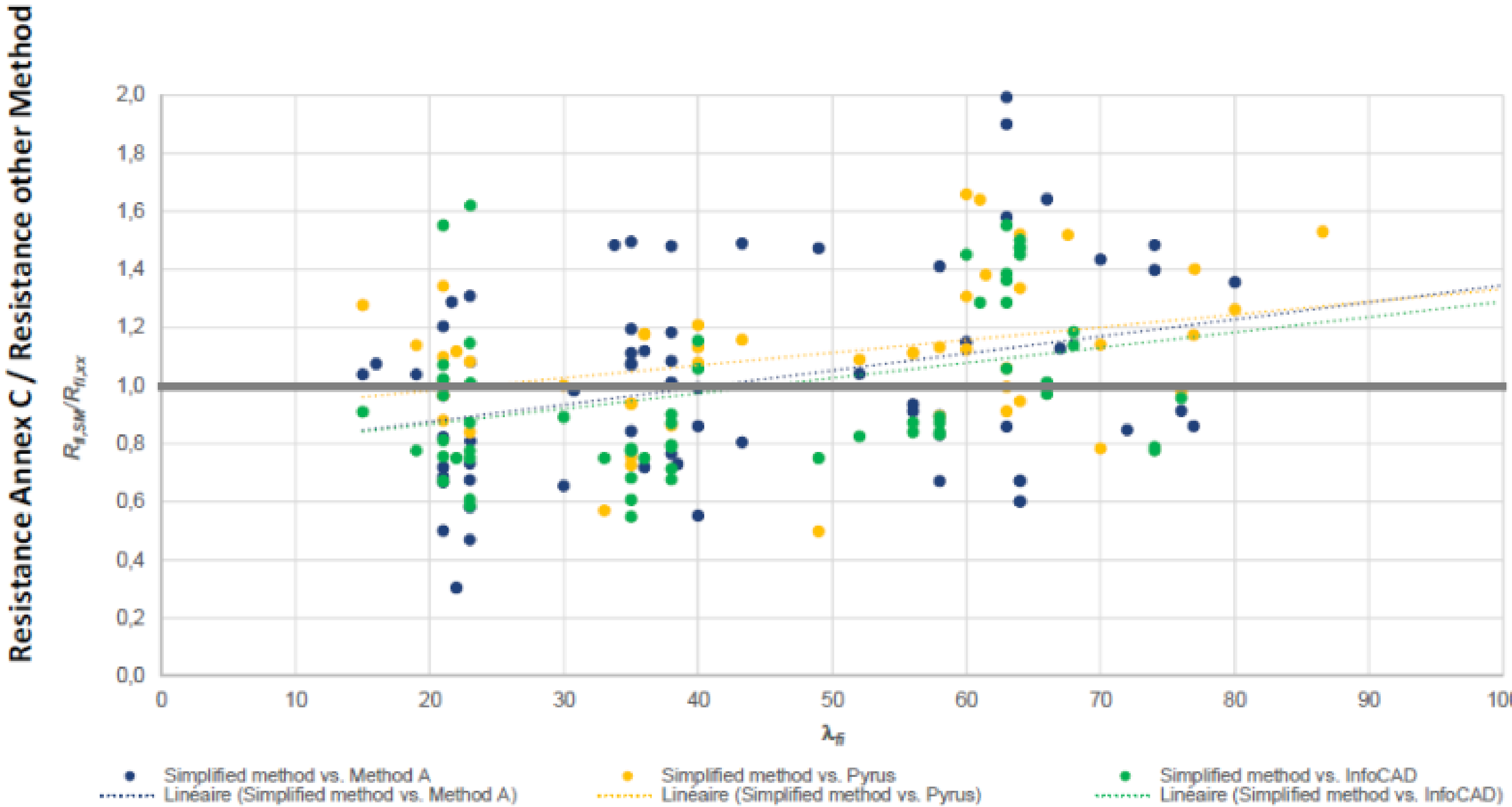
Sensitivity analysis –
Parameter study: slenderness λ_{fi}



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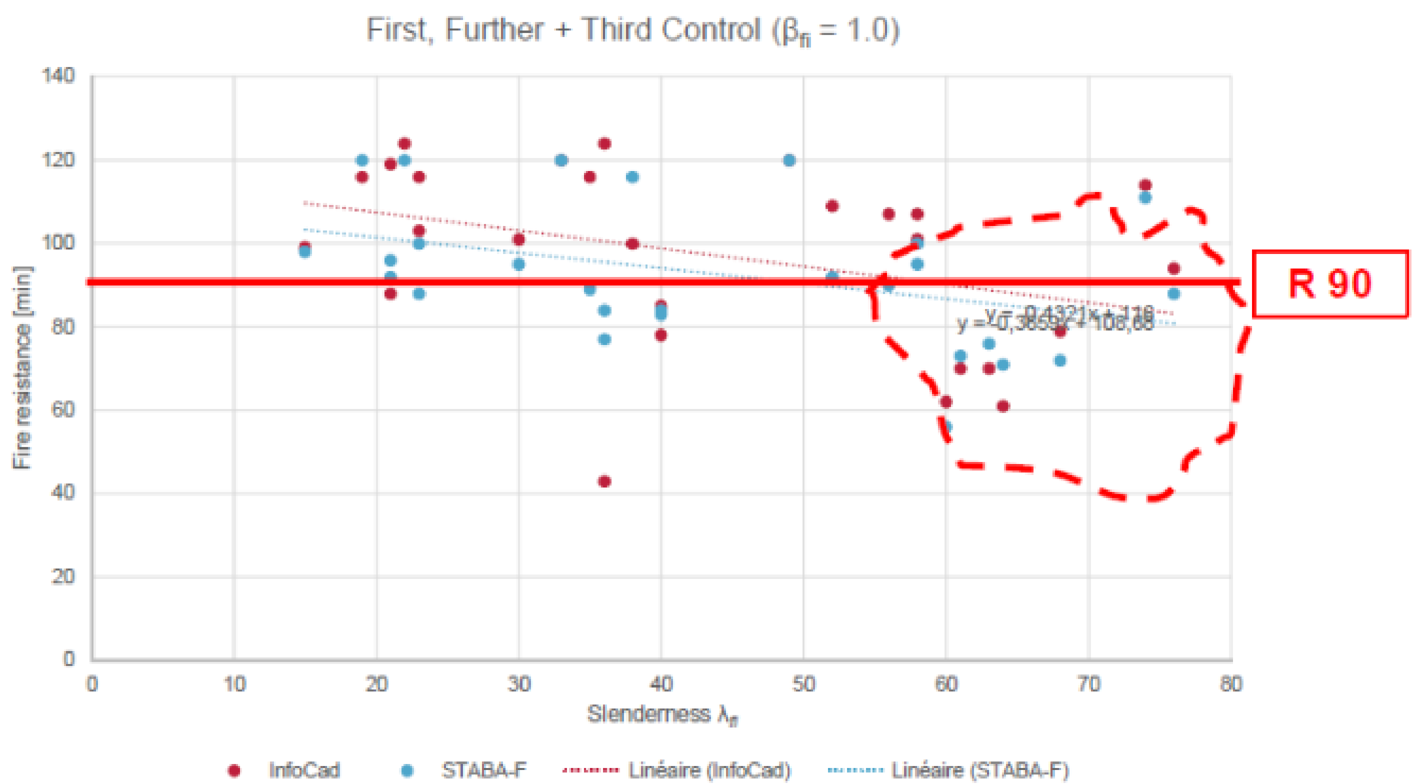
Correlation of the fire resistance and the slenderness



Results from the validation

The new tables show good agreement with the different methodologies

With regard to experimental results, on 47 results, 39 columns on the safe side, 8 columns on the unsafe side but 5no. < 5 min, 3no. < 10 min → OK !

- Good agreement with the advanced models except for high slenderness ratio for which it appears that higher discrepancy may be observed.
- Proposal to limit the slenderness λ_{fi} to 55

Next Steps

- Production of finalised background document
- Agreement by CEN/TC250 and CEN/TC250/SC2