

Improving fire resistance of existing concrete slabs by concrete topping

Is EN 1992-1-2 annex E telling the truth, and can it be used?

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STRUCTURES IN FIRE FORUM

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- Introduction; building and problem setting
- Bearing and failure mechanism; some reflections
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- Numerical approach by SAFIR[®]
- Conclusions; answers and an open question

What's up

- Main purpose of existing codes = design of new buildings
- What with existing buildings and in particular their shortcomings?
- Do we need to think on another way or can we just apply the codes?

The most easy way to fix problems in an existing building can be reversed to the solution that we would apply in a new building.

- In this case study; a leak of concrete cover on the bottom can be solved by an extra in situ reinforced topping

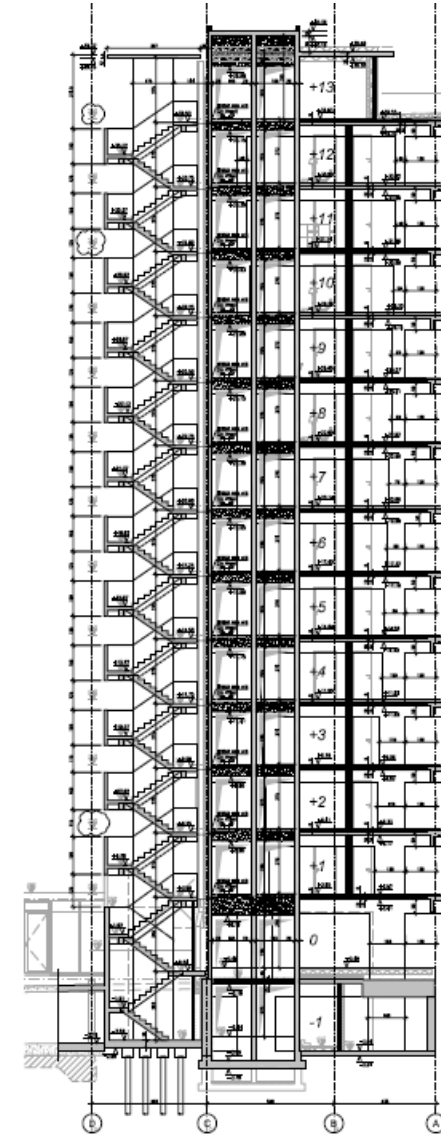
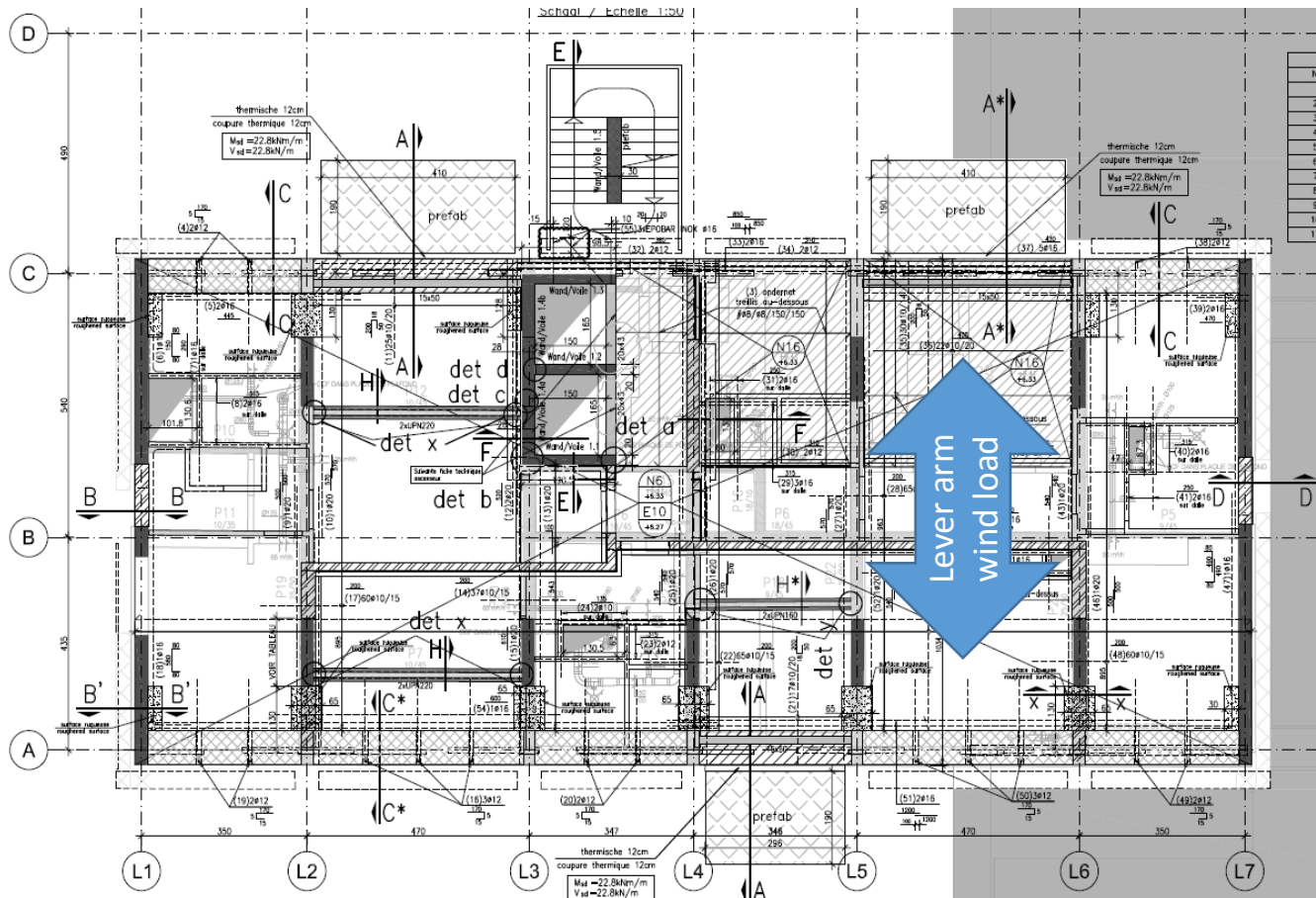
Introduction

- Some images (before the bombs)



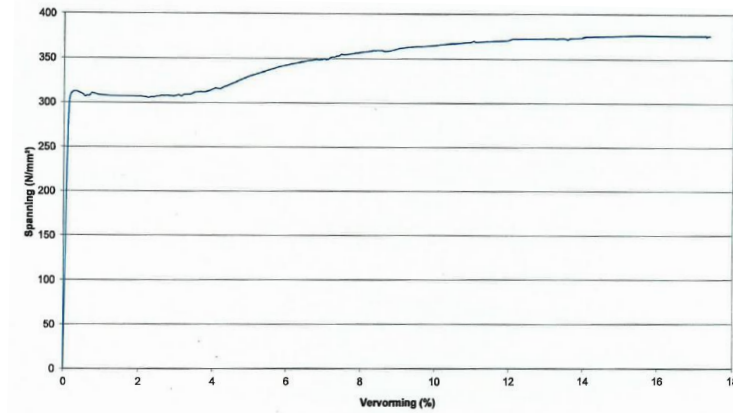
Introduction

- Typical floor layout & section



Introduction

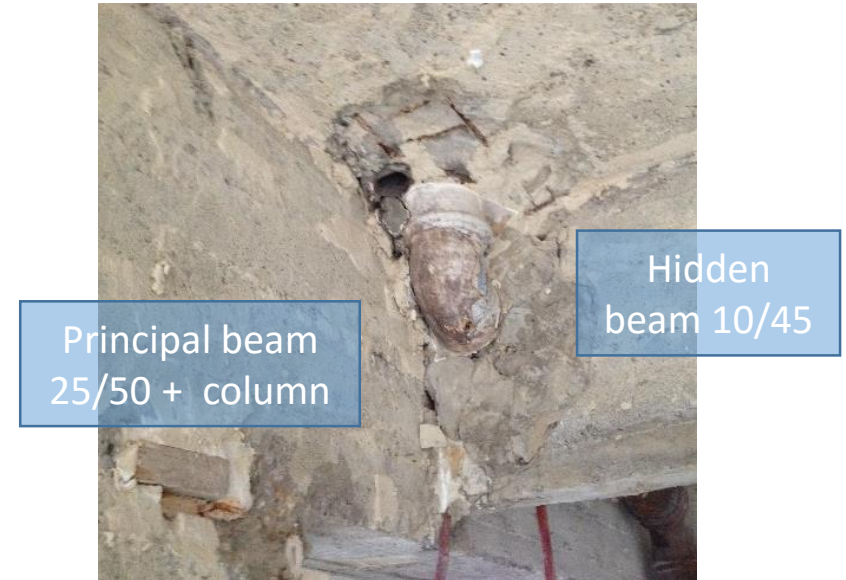
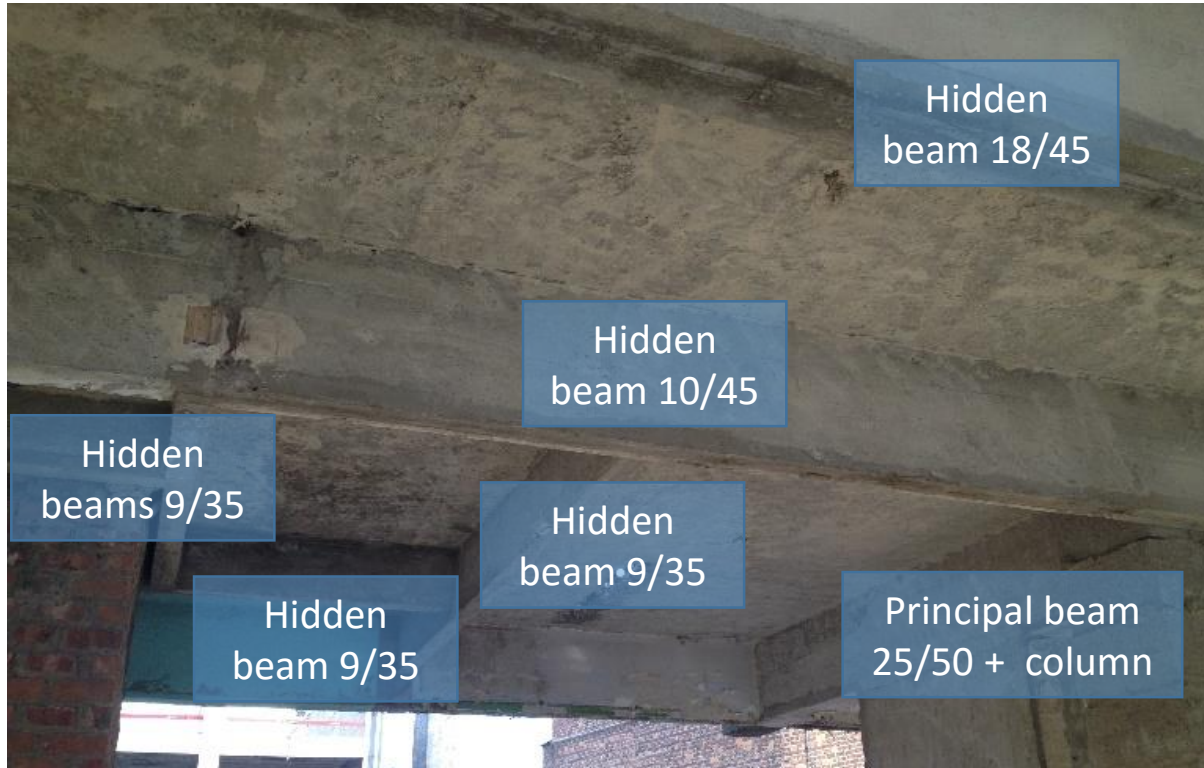
- Preliminary data



Level	Location	h _s mm	h ₁ mm	Principal reinforcement				Transverse reinforcement			
				bar	distance	cover	Rein. R	bar	distance	cover	Rein. R
				mm	mm	mm	mm ² /m	mm	mm	mm	mm ² /m
1	?		102	12	180			8			
0	L2-L3			8	121	14	415	8	141	23	356
9	L2-L3			8	175	8	287	8	185	24	272
	<i>mean</i>						351				351
	L5-L6	194,4		8	175	15	287	6	145	25	195
2	L5-L6	142	101	8	187	14	269	6	160	22	177
6	L5-L6			8	180	2	279	6	155	10	182
7	L5-L6	162	96	8	155	14	324	6	140	22	202
	<i>mean</i>						290				290
3	L6-L7			8	139	14	362	6	156	16	181
5	L6-L7			8	117	17	362	6	108	30	181
	L6-L7			8	157	7	320	6	125	14	226
10	L6-L7			7,6	135	12	336	7	125	24	308
	<i>mean</i>						345				345
mean over all		166	100			12				21	

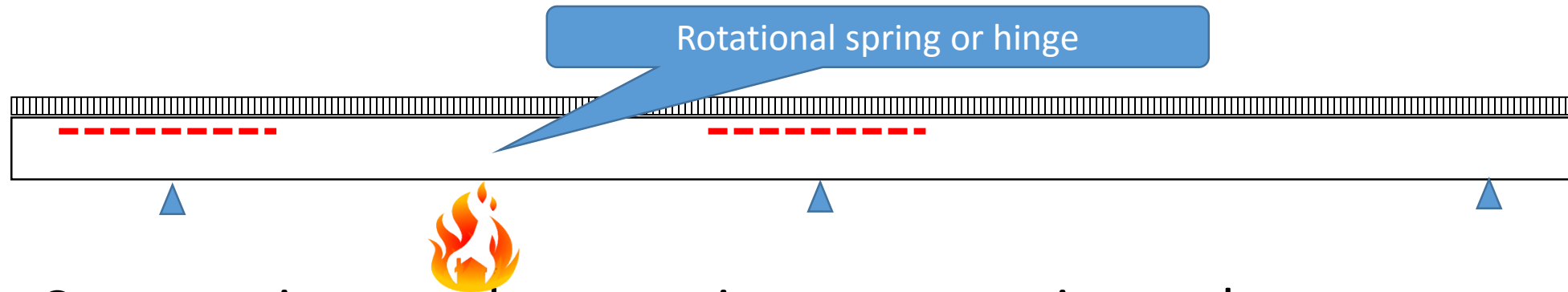
Introduction

- Discoveries during demolishing works

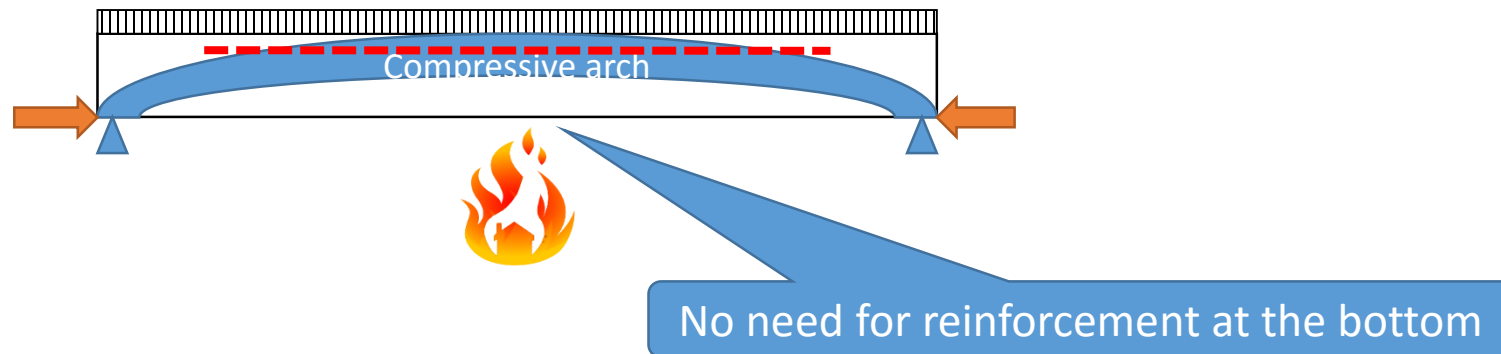


Failure mechanisms; some reflections

- Bending for a continuous slab, deformation $< h/2$ till max h

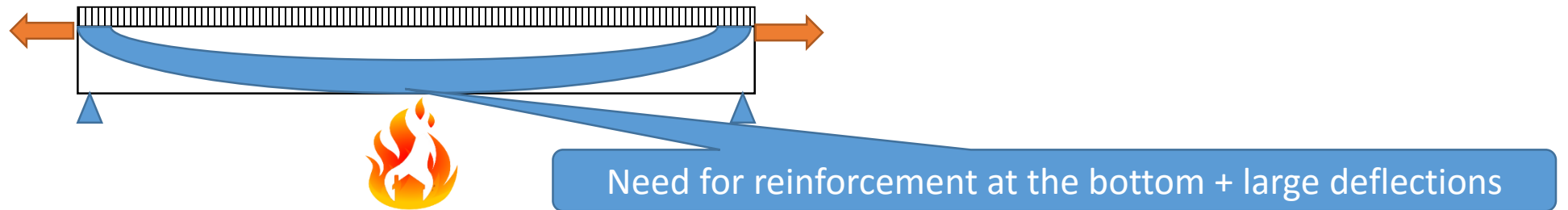


- Compressive membrane action; compression arch



Failure mechanisms; some reflections

- Tensile membrane action, catenary action

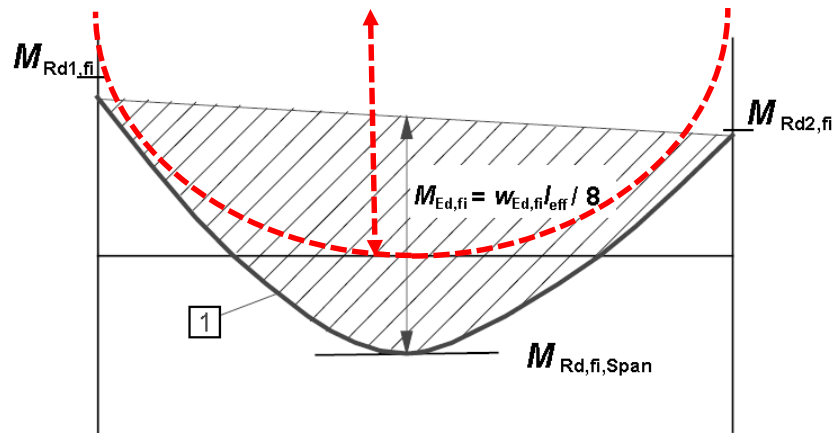


- Tensile membrane action with compressive ring
 - Same issues as for tensile membrane action

=> Some complexities with position reinforcement, analytical design rules, ...

Annex E of Eurocode EN 1992-1-2

- Shifting the moment line for continuous slabs



$$M_{Ed,fi} = \frac{w_{Ed,fi} l_{eff}^2}{8} = \frac{w_{Ed,fi} \left(\frac{l_{eff}}{2}\right)^2}{2}$$

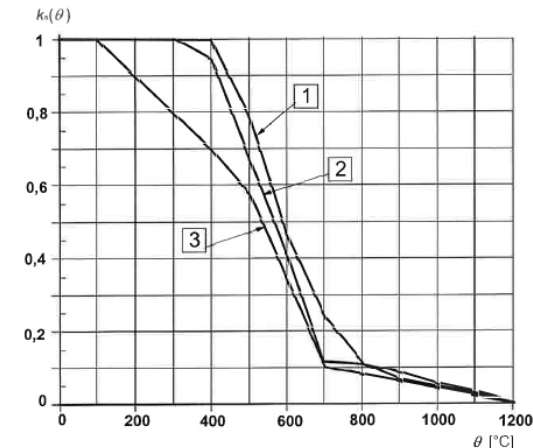
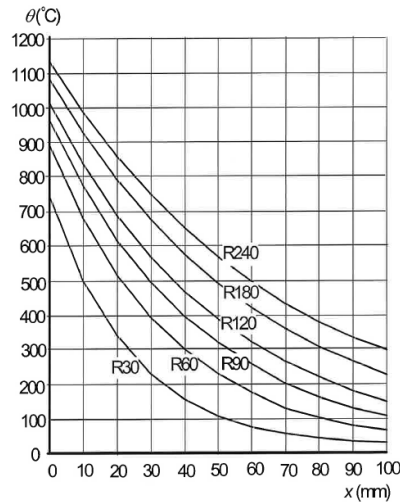
$$M_{Rd,fi} = A_s b f_{y,\theta} \left(h_1 - c - \frac{\emptyset}{2} - \frac{A_s b f_{y,\theta}}{2 b f_{ck}} - i_\theta \right)$$

- Issue of interface not covered

Case study for the Linné-Plantes building

Slab; $M_{Ed,fi} = (2,5+1,5+1,2+0.3 \cdot 2.0) \cdot 4.7^2/8 = 16.02 \text{ kNm}$

- $M_{Rd,fi,span} = 0.87 \text{ kNm}$ with $k_s(\theta) = 0.07$, $x = 2+8/2 = 6 \text{ mm} \Rightarrow 900^\circ\text{C}$
- $M_{Rd1,fi} = M_{Rd2,fi} = 16.02 - 0.87 > 15.15 \text{ kNm}$ with #150/6+Ø10/150mm?
- EN 1992-1-2 graphs:



Curve **1**: Tension reinforcement (hot rolled) for strains $\epsilon_{s,fi} \geq 2\%$
 Curve **2**: Tension reinforcement (cold worked) for strains $\epsilon_{s,fi} \geq 2\%$
 Curve **3**: Compression reinforcement and tension reinforcement for strains $\epsilon_{s,fi} < 2\%$

\Rightarrow Equilibrium guaranteed

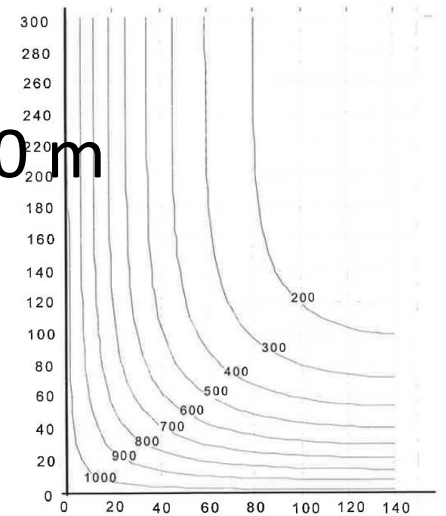
$$M_{Rd1,fi} = M_{Rd2,fi} = (262 + 188) \cdot 1 \cdot 500 \left(100 + 6 + \frac{10}{2} - \frac{450 \cdot 1 \cdot 500}{2 \cdot 1000 \cdot 30} - 36 \right) = 16.03 \text{ kNm}$$

Case study for the Linné-Plantes building

Beam of TT-frame; $M_{Ed,fi} = (23.78+3.13) \cdot 6.75^2/8 = 153 \text{ kNm}$

- With $(3.5+4.7)/2 \cdot (2.50+1.50+1.2+0.3 \cdot 2) = 23.78 \text{ kN/m}$
- New façade + inner wall + beam =
 $(3.5+4.7)/2 \cdot [3.93+(0.12 \cdot 0.43+0.2 \cdot 0.7) \cdot 25] = 35.75 \text{ kN @1.20 m}$
- Principal beam = $0.25 \cdot 0.50 \cdot 25 = 3.13 \text{ kN/m @1.60 m}$
- $M_{Rd1,fi,max} = M_{Rd2,fi,max} = 35.75 \cdot 1.2 + 3.13 \cdot 1.6^2/2 = 47 \text{ kNm}$
- $M_{Rd,fi,span} > M_{Ed,fi} - M_{Rd1,fi,max} = 153 - 47 = 106 \text{ kNm ?}$

=> Equilibrium not guaranteed with one level; need for push down

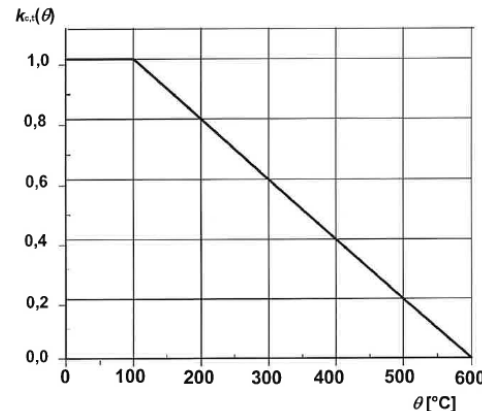


$$M_{Rd,fi,span} = (5 \cdot 380 \cdot 0.25) \cdot 300 \left(560 - 18 - \frac{22}{2} - \frac{5 \cdot 380 \cdot 0.25 \cdot 300}{2 \cdot 250 \cdot 30} \right) = 74 \text{ kNm}$$

Interface between topping and existing slab

Some engineering judgement based on a combination of EN 1992-1-1 paragraph 6.2.5. and EN 1992-1-2.

- Reciprocal theorem of shear stresses; we consider that the shear stress perpendicular to the surface is equal to the tensile stress
- So the reduction of the shear stress at this interface has the same behavior as the reduction of the tensile stress.

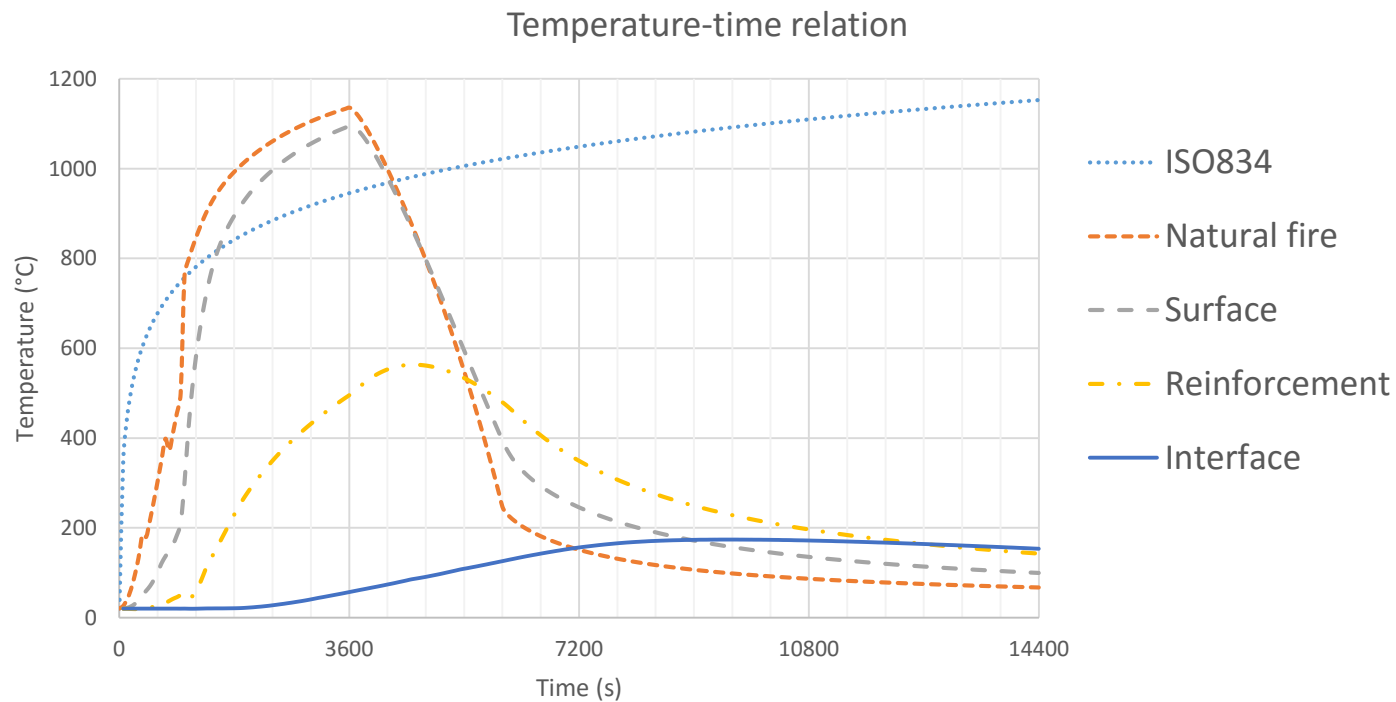


$$V_{Edi,fi} = (2.5 + 1.5 + 1.2 + 0.3 \cdot 2) \cdot \frac{4.7}{2} = 13.63 \frac{kN}{m}$$

$$\begin{aligned} V_{Rdi,fi} &= k_{ct}(\theta) \cdot c \cdot \frac{f_{ctk,0.05}}{\gamma_c} \cdot z \cdot b_i \\ &= 0.9 \cdot 0.2 \cdot \frac{2.0}{1} \cdot 0.9 \cdot (100 + 6 + \frac{10}{2}) \cdot 1000 = 35.96 kN/m \end{aligned}$$

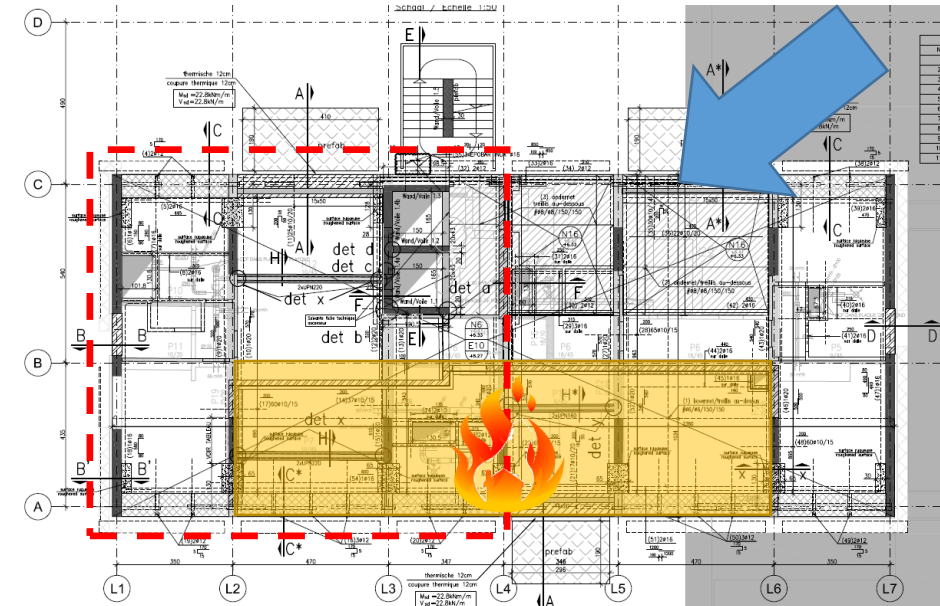
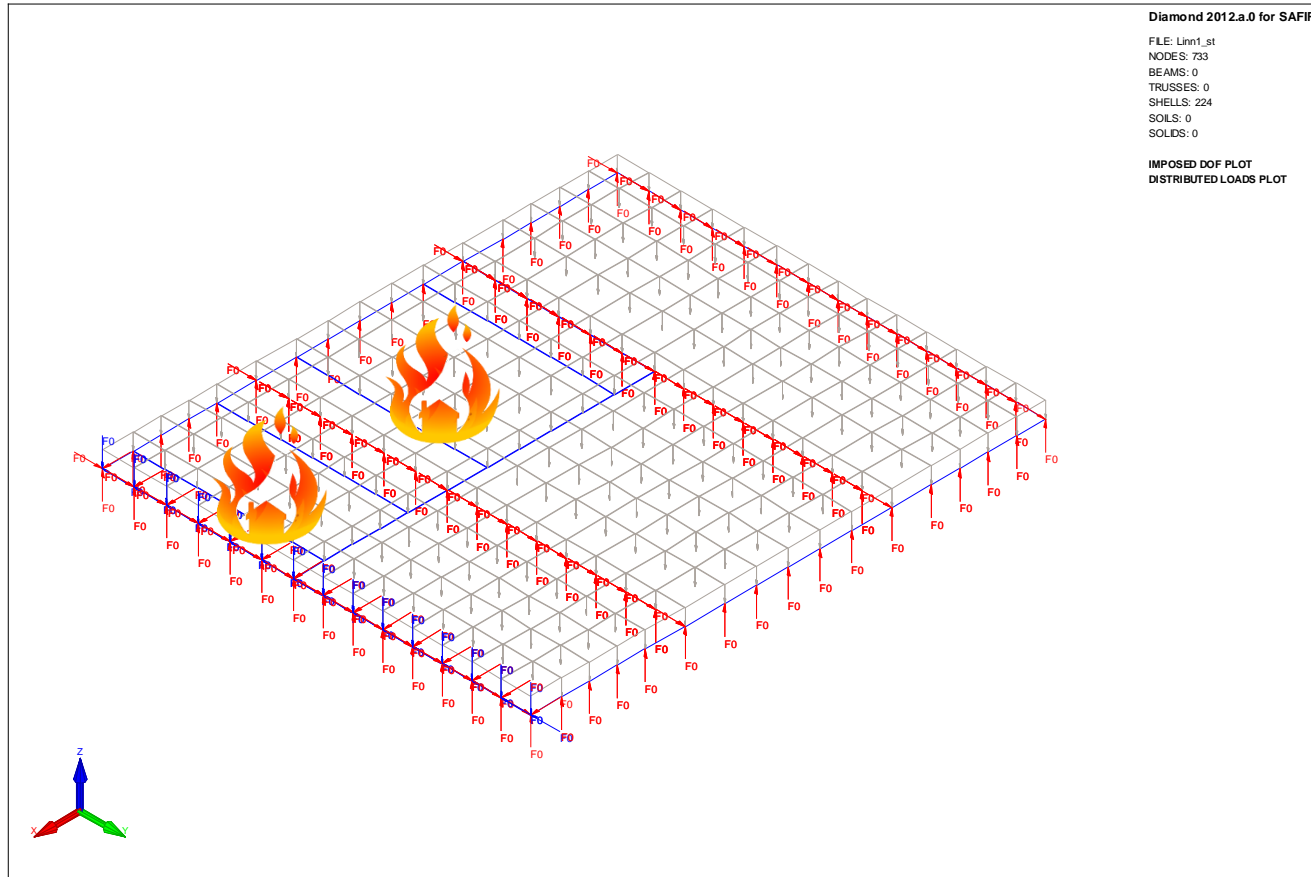
Interface between topping and existing slab

- Is an ISO fire representative enough to deal with this problem?
- What happens in a real fire (with gas peak temperature @ 60 min.)?



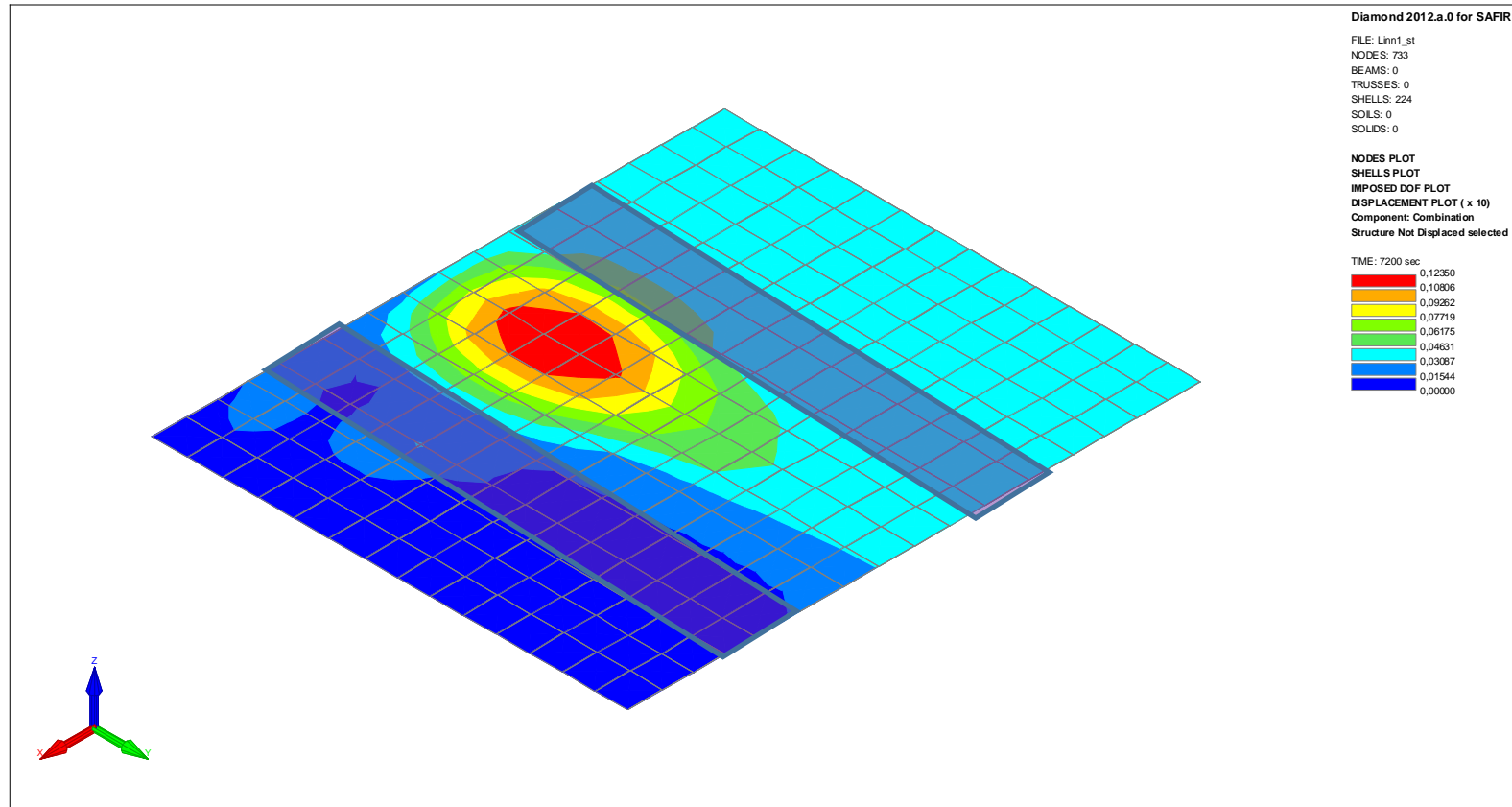
Numerical approach by SAFIR®

- Model = half part



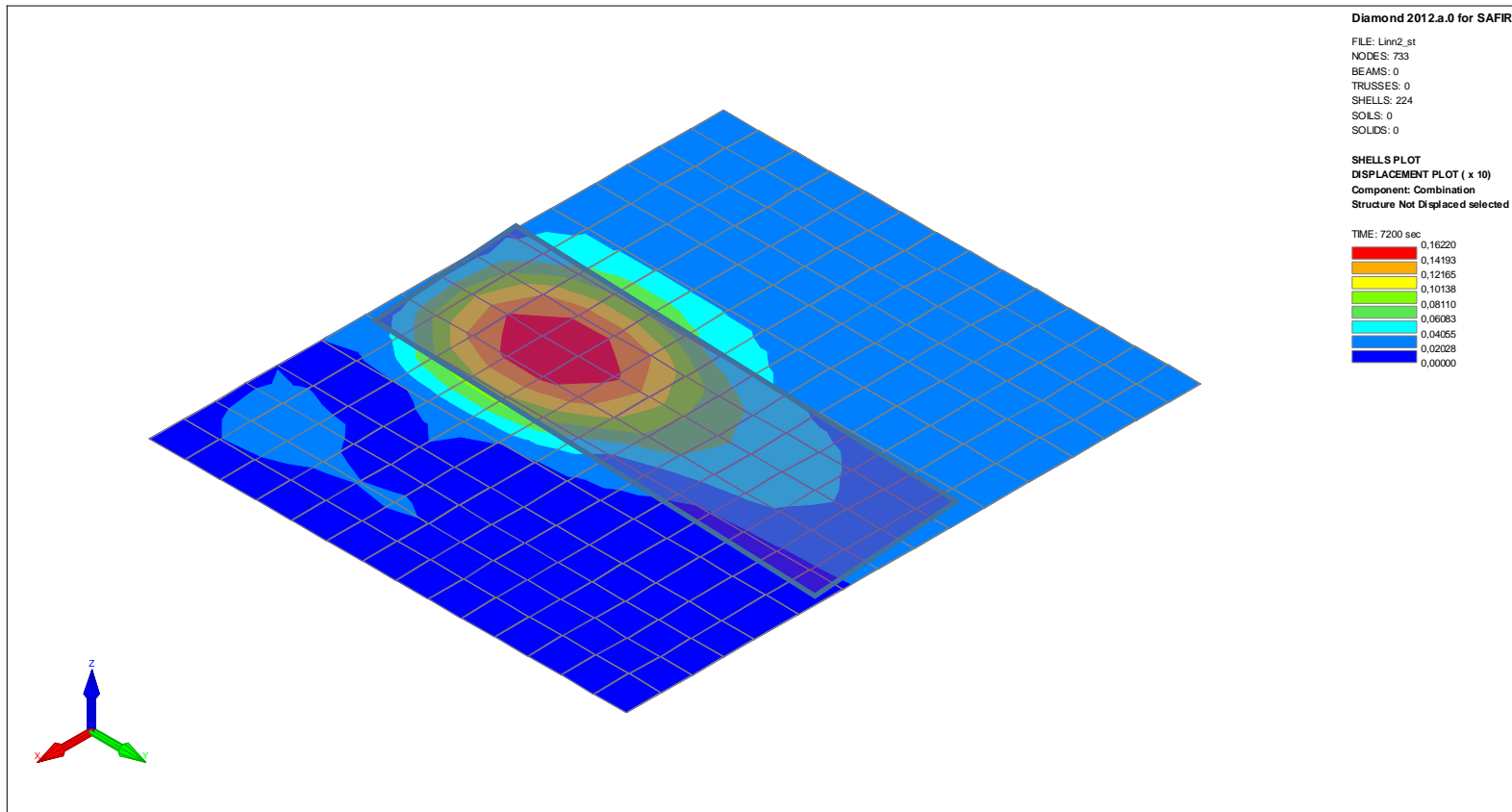
Numerical approach by SAFIR[®]

- Cantilever reinforcement: 0.124 m @ 7200s



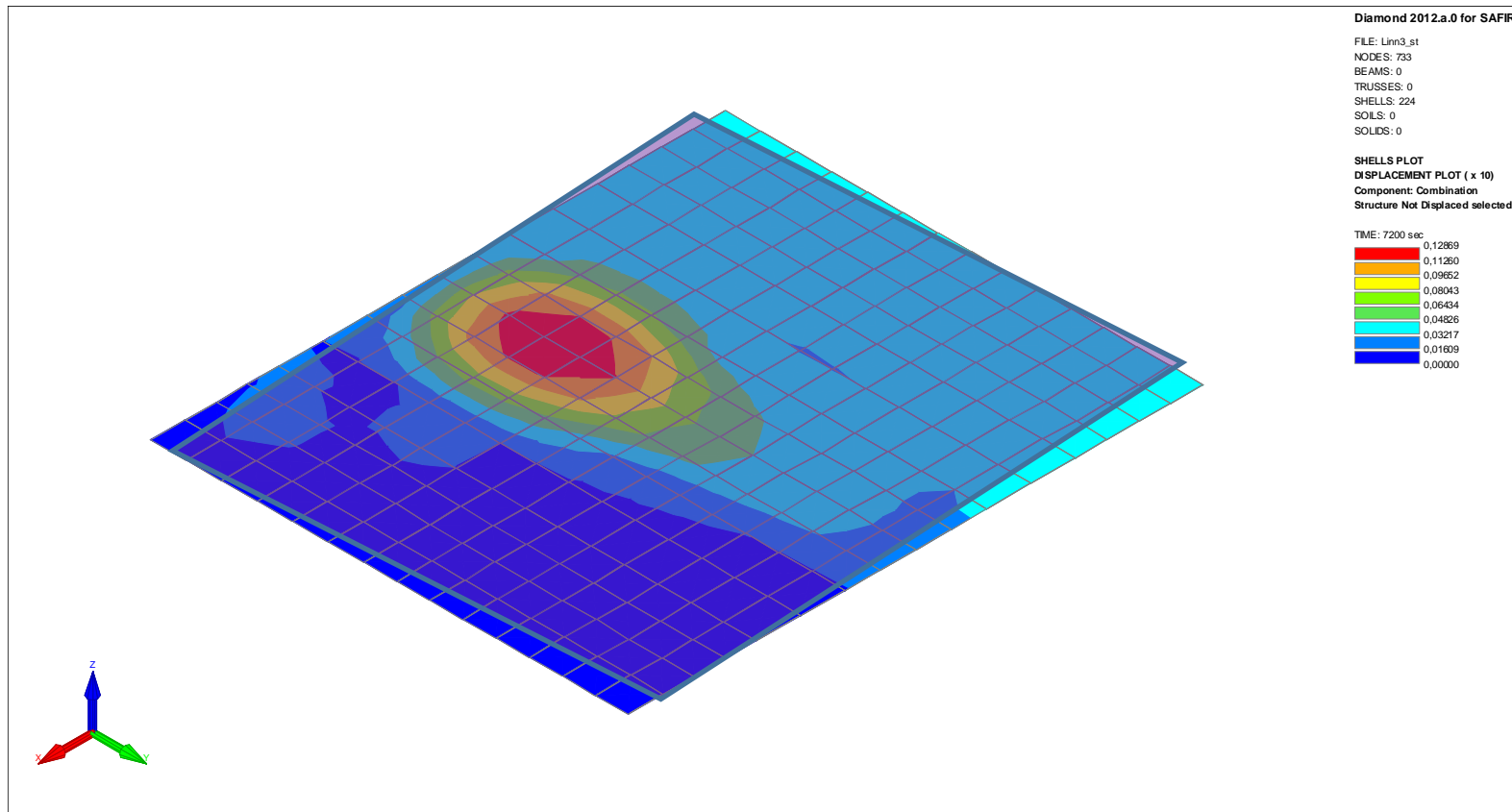
Numerical approach by SAFIR®

- Compressive membrane action reinforcement: 0.164 m @ 7200s



Numerical approach by SAFIR[®]

- Full option, shutting with a gun is not even better: 0.129 m @ 7200s

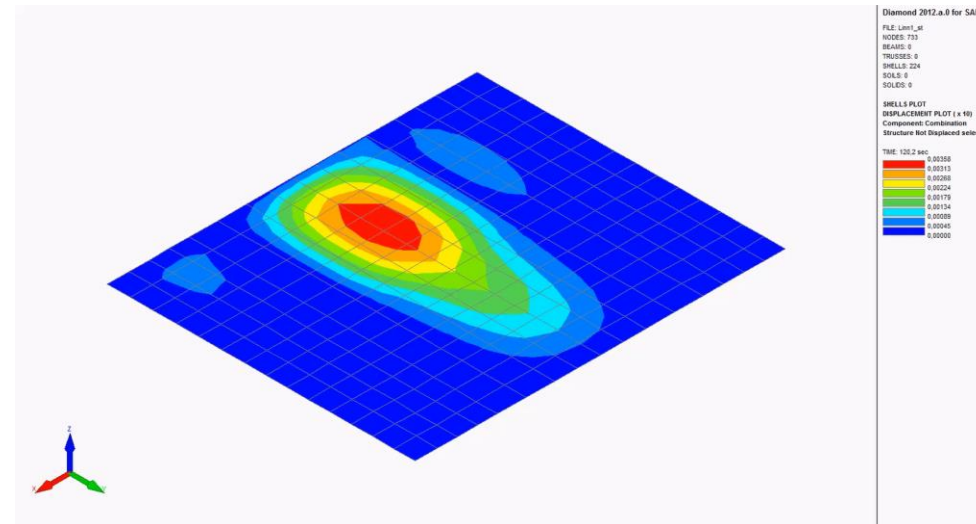


Conclusions

- Missing bearing capacity in case of fire can be solved by adding an extra upper reinforcement in a new in situ concrete topping.
- The question that an ISO fire would be representative enough to judge the bearing capacity of the interface, couldn't be answered.
- Location or concentration of the extra upper reinforcement seems to be of lesser importance. Due to the still limited deformations handling as a cantilever moments seems to be the best fit. But also other distributions react well.
- Model uncertainties still to investigate => without vertical support,...

Questions, answers, suggestions ?

Anyway thanks for the opportunity to deal this information.



Just for information; StuBeCo operations will be very soon integrated in Sweco Belgium