Numerical analysis of a composite steel-concrete column subjected to fire, using ABAQUS

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Introduction

Methods for evaluation of structural response of elements subjected to fire

- Tabulated data
- Simple calculation models

} Common used cross-sections

- **Advanced calculation models**

} Any model (material, CS, load,etc.)

Verification and Validation

- **By comparison to existing experimental tests**
- **German annex EN1991-1-2**
  - **Comparison examples**

There are 11 examples analyzing :

- **heat transfer for different material properties**
- **elongation of elements**
- **forces and stresses**
- **fire resistance time**

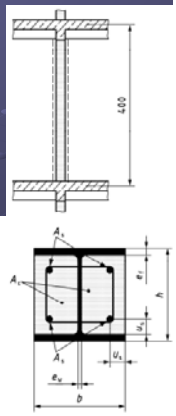
For each example there are given results and their error tolerances

Example 11

Parabolic longitudinal path – midspan imperfection L/1000

Dimensions	l / h / b	cm	400 / 30 / 30
	u_s	mm	50
	e_f	mm	19
	e_w	mm	11
Buckling length	$l_{0,fi}$	cm	200
Load	$N_{fi,Ed,t}$	KN	-1700
Concrete C25/30 (3 % moisture (by mass))	$f_{ck(20°C)}$	N/mm²	25
Reinforcing steel S 500	$f_{sk(20°C)}$	N/mm²	500
Structural steel S 235	$f_{ak(20°C)}$	N/mm²	235
Stress – strain curve	Concrete a.		DIN EN 1994-1-2
	Reinforcing steel b.		
	Structural steel		
Temperature load	ETK (four sides)		DIN EN 1991-1-2
Heat transfer coefficient	α_c	W/(m² × K)	25
Emissivity	ε_m		0.7
Thermal and physical material properties – Concrete	λ, ρ, c_{th}, $\varepsilon_{th,c}$		DIN EN 1994-1-2
Thermal and physical material properties – Steel	λ, ρ_s, c_{th}, $\varepsilon_{th,s}$, $\varepsilon_{th,a}$		DIN EN 1994-1-2

a. Containing mainly quartzite aggregate and density ρ=2400 kg/m³
b. Hot-rolled

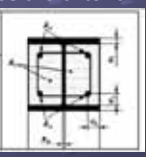


Analysis

Previous verification using SAFIR

- 2D beam elements
- For displacement at 60 minutes the criterion is not fulfilled

Requested results		Reference value		Calculated value	Deviation [%]	Limit [%]
Failure time		92	>	98	-4.35	
Displ. [mm]	30 mm	4.40	<	4.44	-0.82	± 5
	60 mm	5.50	>	5.04	**+8.18**	

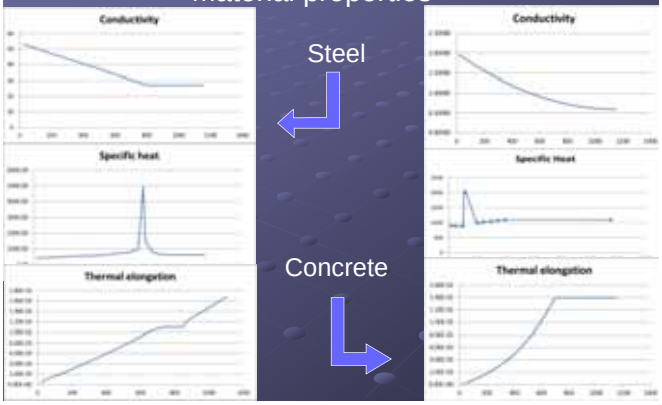


The result is not consistent with the other values:

- at 30min the displacement is bigger than the reference value while for 60 minutes the displacement is smaller than the reference value
- For smaller displacement it is expected longer resistance time; but for this case the fire resistance is smaller

Model - Abaqus

Material properties



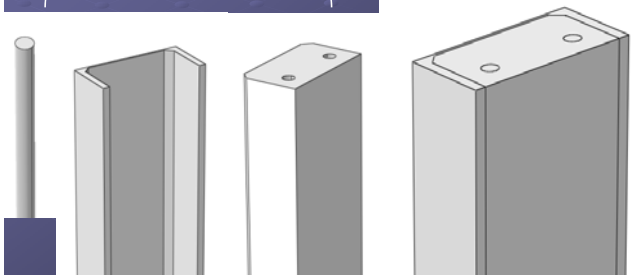
Model

Part definition

Separated parts for each material

-contact problem

One part divided into partitions



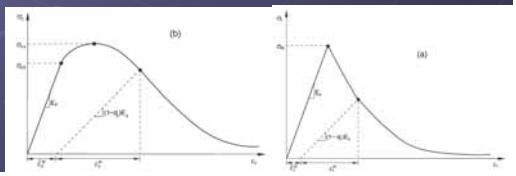
Model

Concrete model

Piecewise stress-strain → Large tensile stress for concrete

Smeared concrete → -elongation & BC problems

Damaged plasticity concrete

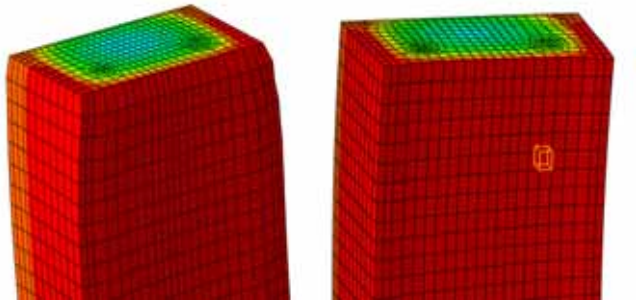


Model

Boundary conditions

Fully fixed -surface

Fully fixed -node

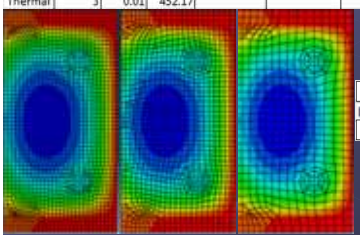


Analysis

Thermal analysis - 2D - verification

Grid Convergence Index (GCI) for temperatures at 90min

ABAQUS (2D)			Temp	refinement ratio (r)	Order of convergence HEB (p)	Asymptotic solution $f_{h=0}$	ε	GCI_{12} [%]	GCI_{23} [%]	$GCI_{23}/r^p GCI_{12}$
	mesh	size	HEB							
	1	0.0025	451.00				-0.0011086			
	2	0.005	451.50	1.414213562	0.844466001	449.5294118		-0.4076	-0.54557	0.998893
Thermal	3	0.01	452.17				-0.0014839			



Temperatures	Abaqus	Safir	DIN
HEB300	452	450	> 447
Reinforcement	512	518	< 535

Analysis

Structural analysis

Sequentially coupled analysis

Thermal analysis

- 3D solid – DC3D8: An 8-node linear heat transfer brick

Mechanical analysis

- 3D solid – C3D8R: An 8-node linear brick, reduced integration, hourglass control

Fully coupled analysis

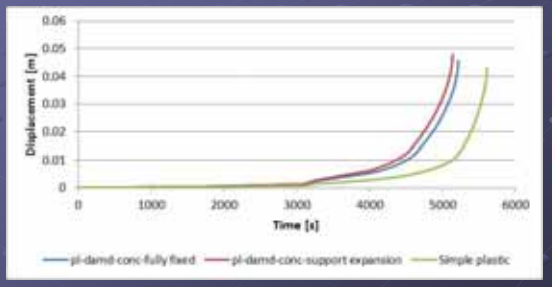
Thermal and mechanical analysis

- 3D solid – C3D8T

An 8-node thermally coupled brick, trilinear displacement and temperature

Results

Fully coupled analysis



Results

The results do not fulfill 2 criterion: fire resistance time and displacement for 60min.

ABAQUS		Reference value X		Calculated value X'	Deviation [%]	Limit [%]
Failure time		92	>	87	-5.43	± 5
Displ. [mm]	30 min	4.40	<	4.56	+3.52	
	60 min	5.50	<	7.82	+42.16	

It can be observed that, as is case of SAFIR analysis, fire resistance time is smaller than the reference value. On the other hand, displacement for 60 minutes is higher than the reference value (still, the Abaqus results are consistent since for a smaller resistance time there is a corresponding larger deflection for the column, with respect to the reference value).

SAFIR		Reference value		Calculated value	Deviation [%]	Limit [%]
Failure time		92	>	88	-4.35	± 5
Displ. [mm]	30 min	4.40	<	4.44	+0.82	
	60 min	5.50	>	5.04	-8.18	

Conclusions

- Extra information needed for the calculation model
- Mechanical interaction between elements - unknown
- Concrete model - difficult to define
- Analysis time – long
- What happens after debonding? –thermal condition

References

1. DIN EN 1991-1-2/NA (2010) National Annex - National determined parameter – Eurocode 1: Actions on structures – Part 1-2: General actions – Actions on structures exposed to fire, Deutsche Norm
2. Raul Zaharia, Thomas Gernay, Validation of the Advanced Calculation Model SAFIR Through DINEN 1991-1-2 Procedure, 10th International Conference on Advances in Steel Concrete Composite and Hybrid Structures Singapore, 2 – 4July 2012
3. Leslaw Kwasniewski, Application of grid convergence index in FE computation, Bulletin Of The Polish Academy Of Sciences, Technical Sciences, Vol. 61, No. 1, 2013
4. Abaqus' Theory Manual

THANK YOU !

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