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Finite Element Analysis of Concrete Filled Steel Columns in Fire

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Introduction

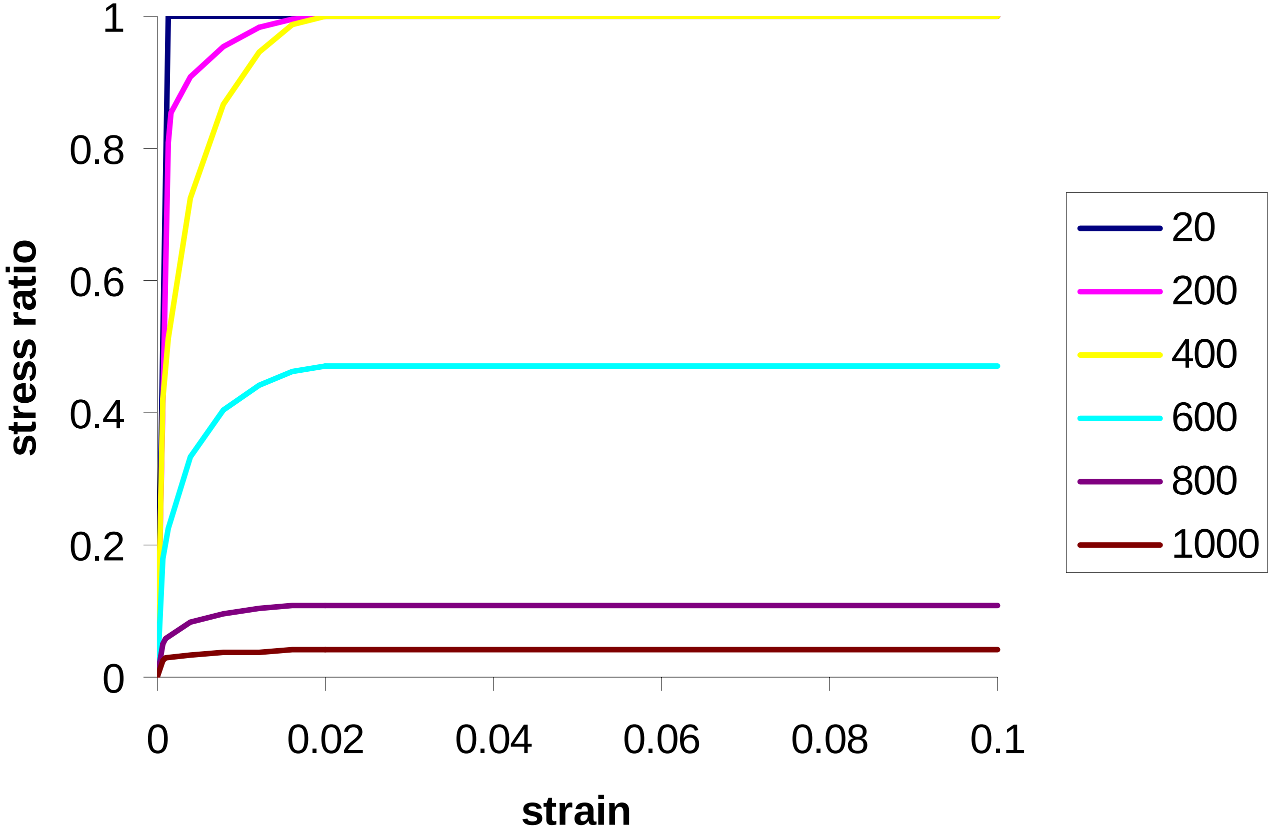
- Concrete filled steel columns take full advantage of the material properties of both steel and concrete.
- Under fire conditions the concrete core works as a heat sink. Thus concrete filled steel columns can reach high fire resistance even without fire protection.

- The current design standards provide only simplified and approximate methods to calculate the fire resistance of these members, but their range of application is limited and there is still a lot of uncertainty over their accuracy.
- Finite element analysis offers the possibility of accurately simulating the behaviour of composite columns in fire.
- ANSYS was used to conduct finite element simulations for both heat transfer and structural analyses.

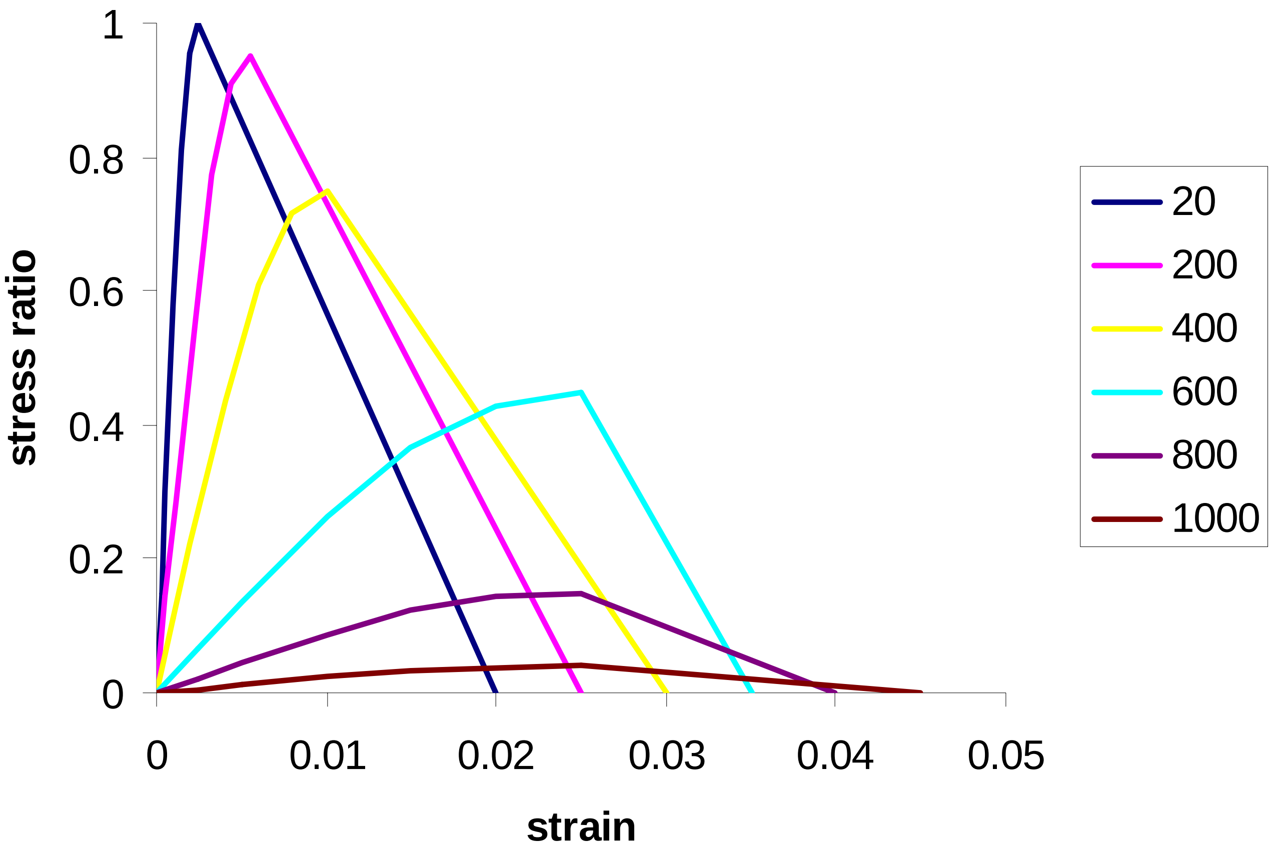
Material Properties

- The material properties recommended in Eurocode 4 Part 1.2 are adopted.
- Creep strains of steel and concrete are considered to be implicitly included in their stress-strain relationships at elevated temperatures.

Steel stress-strain curves at high temperatures



Concrete stress-strain curves at high temperatures

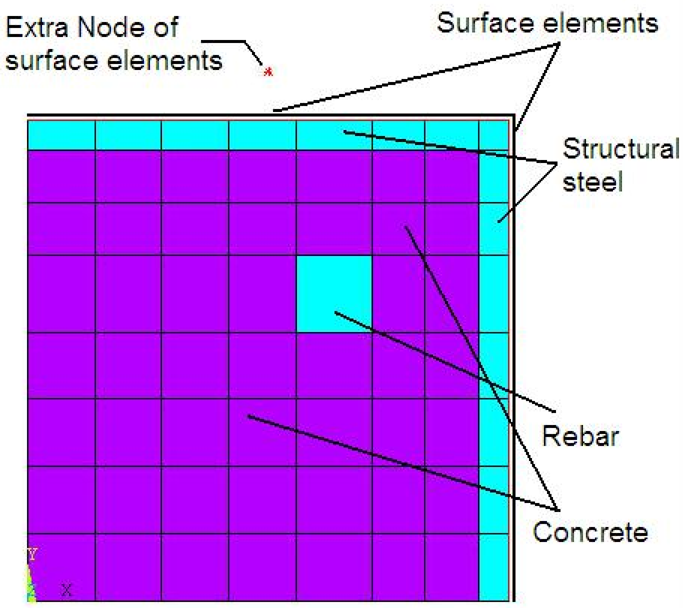


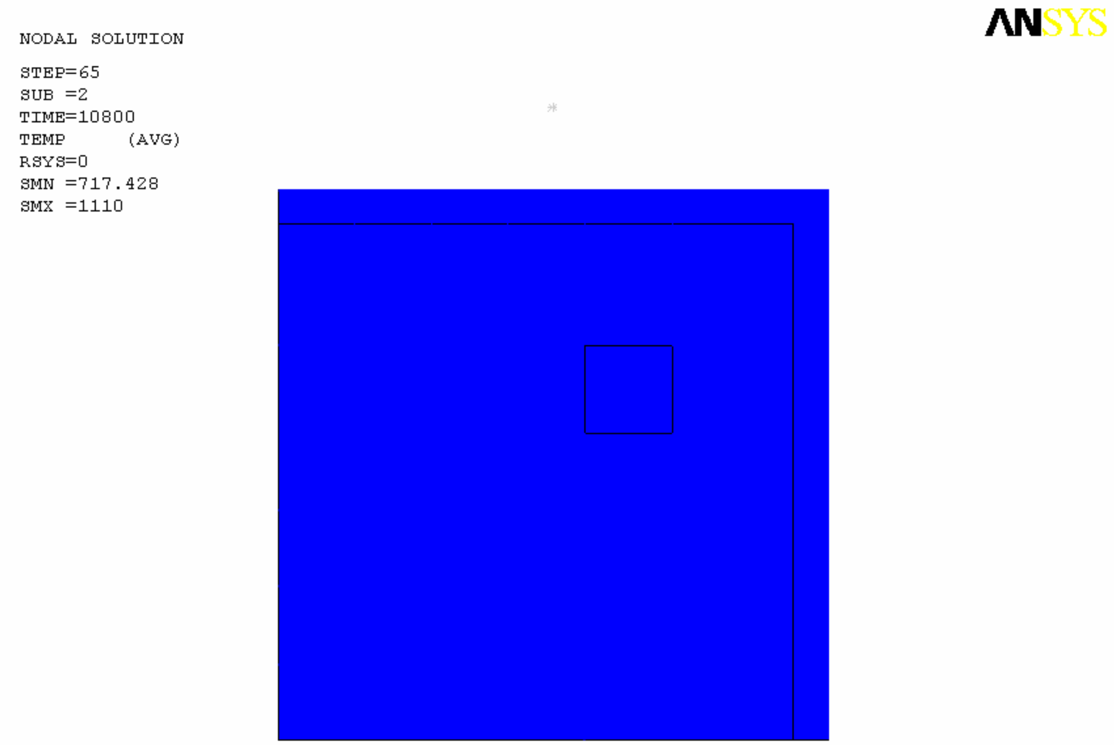
Prediction of temperature field

- It is assumed that the temperature field is constant over the column height.
- Two-dimensional model is created to predict the temperature distribution within a composite column cross section.
- Due to symmetry of the geometry and the boundary conditions, only one quadrant is analyzed.

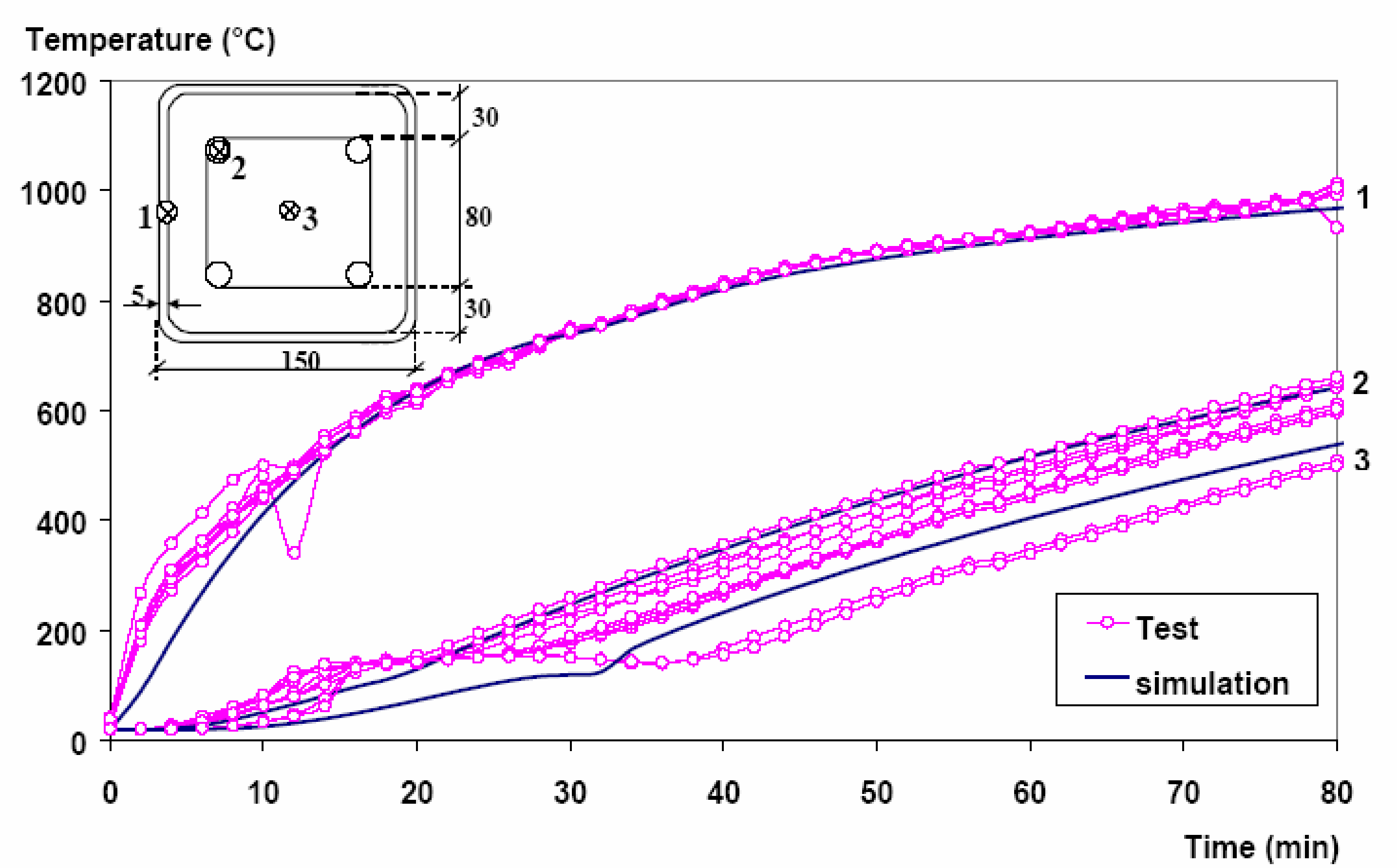
An example of thermal model

RHS 200x200x6.3

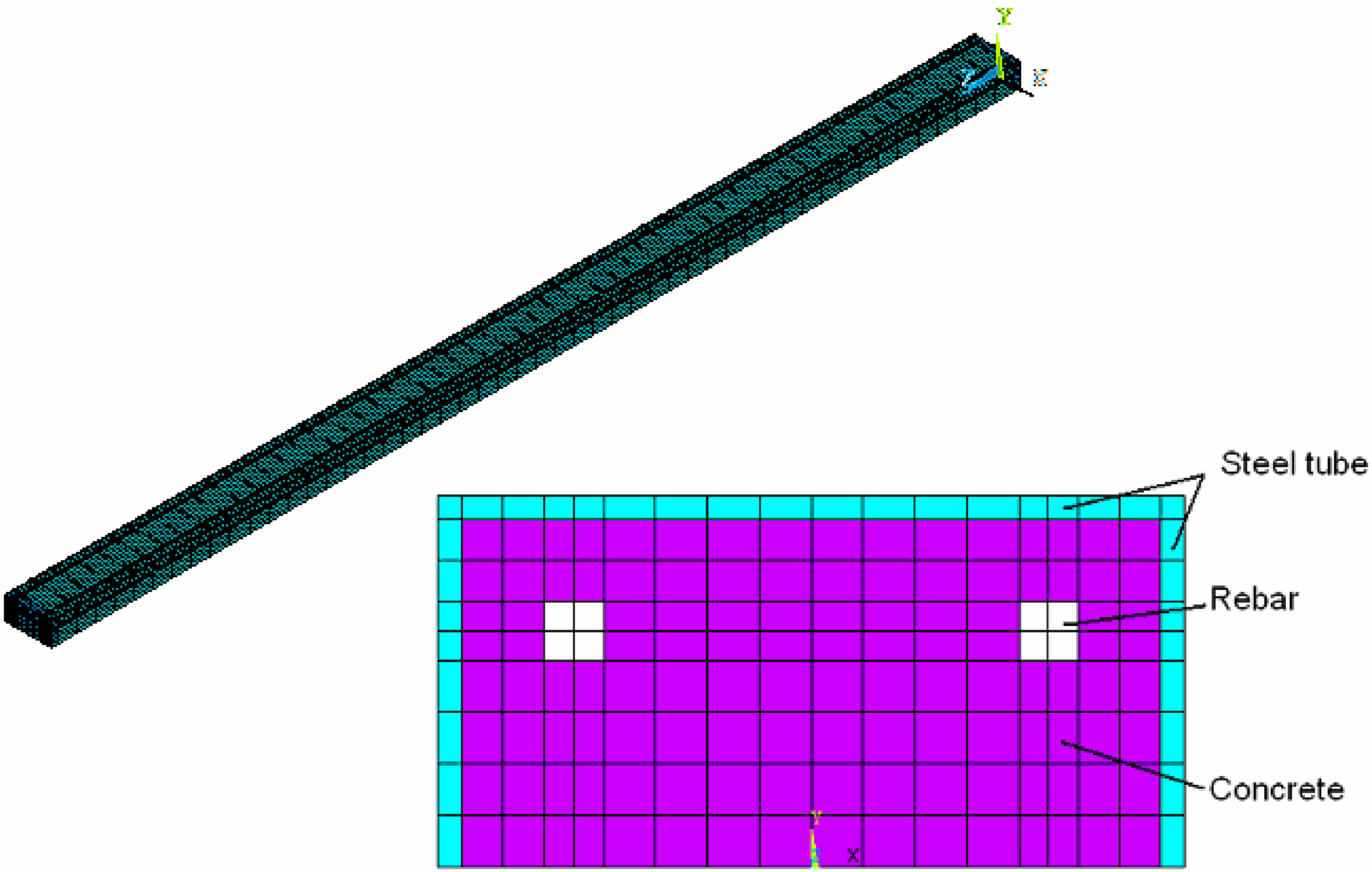




Comparison between calculated and measured temperatures



Structural model



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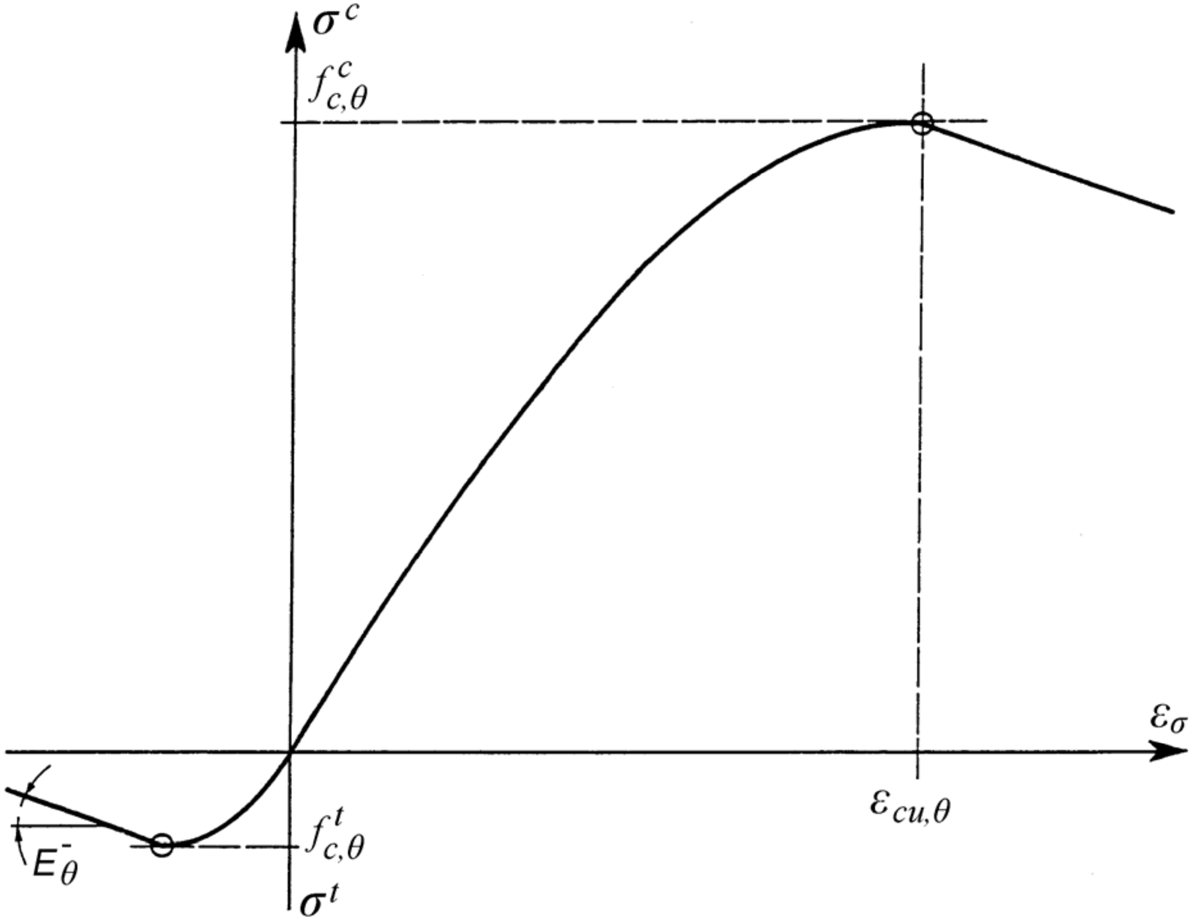
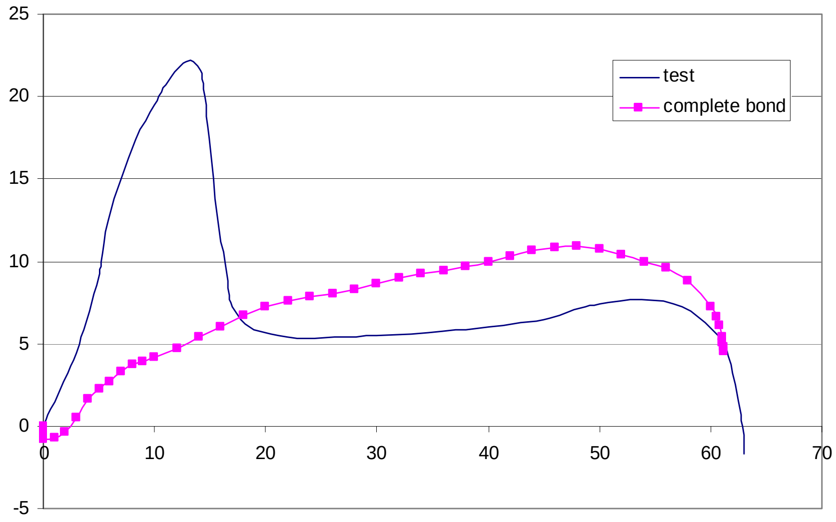
Concrete tension

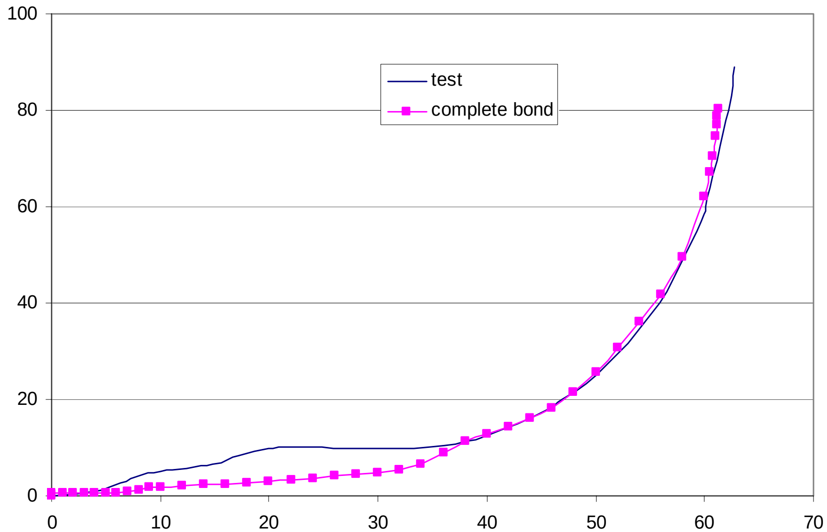


Validation of FEA Results

- Initial displacement = L/1000
- $f_{c,\theta}^{t} = f_{c,\theta}^{c} / 10$
- $E_{\theta}^{-} = 0$
- Complete bond between steel and concrete



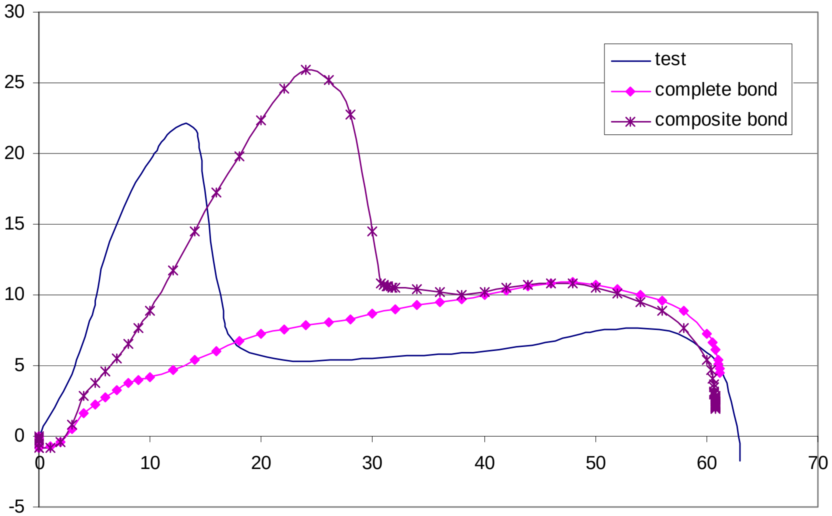
Vertical displacement at the top of the column



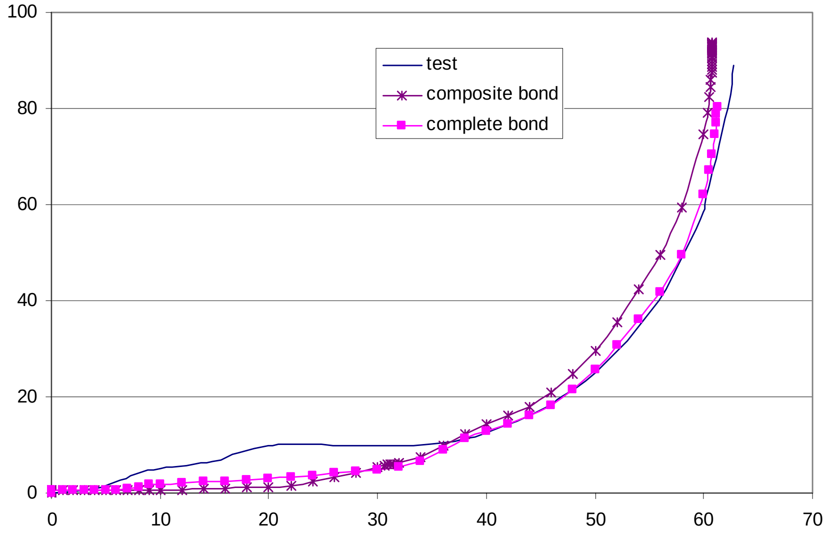
Transverse deflection at mid-height of the column

Effect of Composite Action

- Initial displacement = L/1000
- $f_{c,\theta}^{t} = f_{c,\theta}^{c}/10$
- $E_{\theta}^{-} = 0$
- Coefficient of friction = 0.2



Vertical displacement at the top of the column



Transverse deflection at mid-height of the column

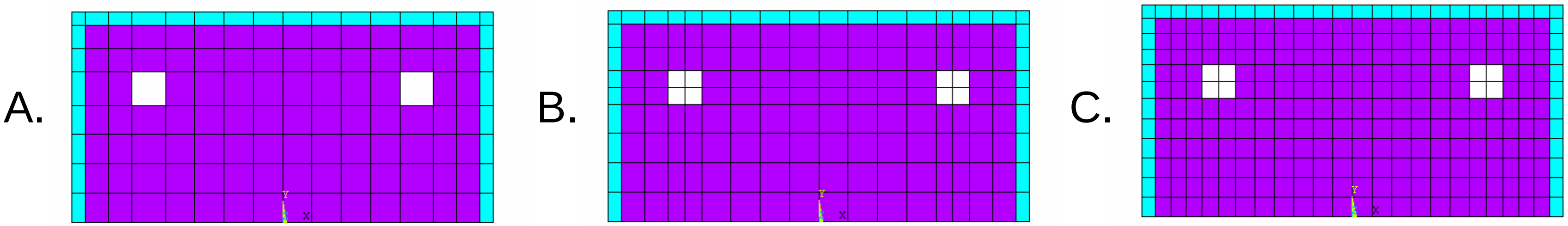
Tested columns with calculated results

No.	Profile Type[a]	Dimensions	Rebar (mm)	Length (mm)	End[b]	Load (kN)	*e* (mm)	Material properties (N/mm^2)			Failure time (min)	
								Steel	Rebar	Concrete	Measured	Calculated
1	R	200×6.3	4ϕ18	4200	p-f	429	20	277	475	45.9	63	62.6
2	R	200×6.3	4ϕ18	4200	p-f	315	50	277	475	45.9	58	56.9
3	R	200×6.3	4ϕ18	4200	p-f	534	5	291	475	42.9	61	56.5
4	R	200×6.3	-	4200	p-f	397	20	279	-	55	22	20.3
5	R	200×6.3	4ϕ18	3700	p-f	646	20	265	475	75	56	55.6
6	R	200×6.3	4ϕ18	4200	p-f	547	5	274	475	55	59	59.5
7	R	200×6.3	4ϕ18	3700	p-f	294	20	281	469	35	82	78.8
8	R	200×6.3	4ϕ18	4200	p-f	375	22	287	469	35	68	65.5
9	R	200×12.5	4ϕ18	4200	p-f	453	50	234	475	45.9	34	32.4
10	R	150×5.0	4ϕ12	3810	p-p	140	0	416	596	37.8	82	75.6
11	C	273.1×6.35	4ϕ20	3810	p-p	1050	0	350	400	46.7	188	150.2
12	C	273.1×6.35	4ϕ20	3810	p-p	1900	0	350	400	47.0	96	90.8
13	C	219.1×4.78	-	3810	f-f	492	0	350	-	31.0	80	73.7
14	R	254×6.35	4ϕ20	3810	f-f	1440	0	350	400	48.1	113	97.8
15	C	273.1×5.56	-	3810	f-f	525	0	350	-	29.0	133	127.0
16	C	355.6×12.7	-	3810	f-f	1050	0	350	-	25.4	170	144.2

Initial displacement

Column No.	Initial displacement (L = column length)							
	L/2000		L/1000		2L/1000		3L/1000	
	FEA	EC4	FEA	EC4	FEA	EC4	FEA	EC4
1	64.0	*63.9*	62.6	*63.2*	61.3	*61.7*	60.1	*60.1*
2	57.5	*61.7*	56.9	*60.9*	55.7	*59.4*	54.4	*57.9*
3	59.0	*61.1*	56.5	*59.9*	55.0	*57.9*	53.8	*56.1*
4	21.2	*45.2*	20.3	*44.5*	20.2	*43.2*	20.2	*41.6*
5	57.0	*55.9*	55.6	*55.0*	54.5	*53.3*	53.3	*51.6*
6	61.1	*63.0*	59.5	*61.9*	57.3	*59.8*	55.5	*58.0*
7	79.8	*80.3*	78.8	*79.3*	77.5	*77.8*	76.1	*76.5*
8	66.2	*65.1*	65.5	*64.3*	64.1	*62.9*	63.0	*61.6*

Meshing of the cross-section



Meshing	A	B	C
Failure time (min)	62.9	62.6	62.5

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Concrete tension curve

- Using user defined material subroutine, different concrete tension curves can be determined by two values: $f_{c,\theta}^{t}$ and E_{θ}^{-}

$f_{c,\theta}^{t}$		0	0	$f_{c,\theta}^{c}/10$	$f_{c,\theta}^{c}/10$	$f_{c,\theta}^{c}/10$
E_{θ}^{-}		0	$E_{\theta}/100$	-880	0	$E_{\theta}/100$
Column No.	1	58.2	59.0	43.2	62.6	62.7
	2	53.3	55.1	34.5	56.9	56.9
	3	52.8	53.6	31.2	56.5	56.5

Conclusions

- Both the thermal model and the structural model are verified by comparing the simulation results with a number of fire tests.
- The bond between steel and concrete has little effect on the ultimate capacity of composite columns.
- The structural model which includes contact elements at the surface between steel and concrete gives better results of displacement, but doesn’t effect the fire resistance of the column much.

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- The parametric study shows that initial displacement and meshing of the cross-section have little effect on the fire resistance of concrete filled steel columns.
- Also different tension strength and tangent stiffness of concrete have minor effect on the calculated column failure time, unless the tangent stiffness after crack is negative.

Thank you!

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