Some Information on Eurocode 4 – part 1.2

(mainly from DIFISEK project report)

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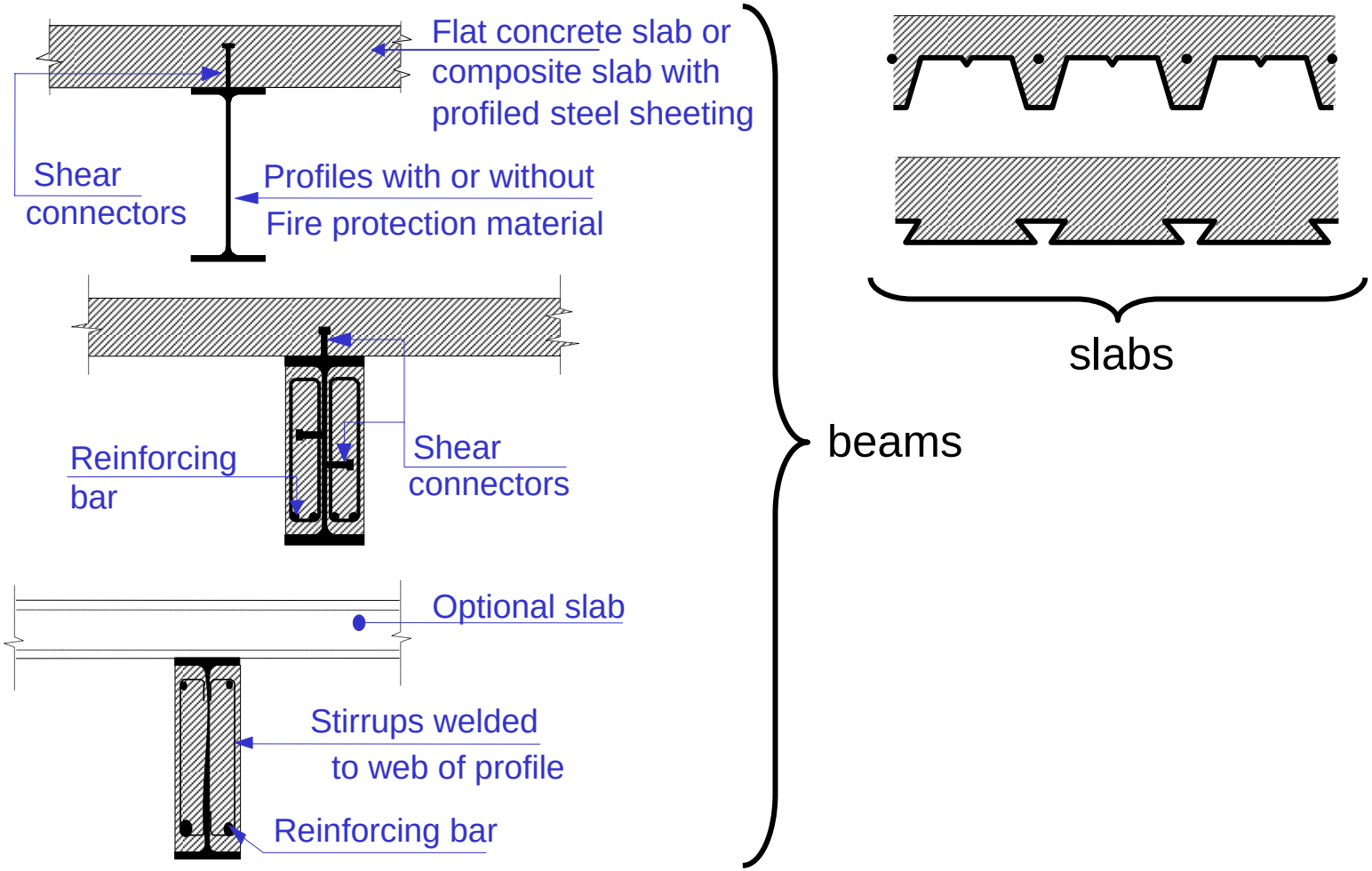
Composite slabs & beams
Options



Composite columns
Options

(a) (b) (c)

a: steel embedded in concrete (traditional approach)

b: concrete between flanges (f.r. dependent on reinforcement)

c: concrete filled SHS

- **without reinforcement (f.r. ca. 30 minutes or less)**
- **with reinforcement (f.r. dependent on reinforcement)**

Calculation procedure thermal response
Composite elements

Non-uniform temperature distribution

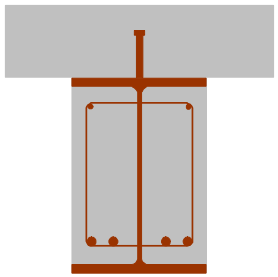
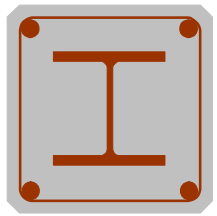
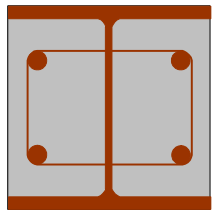
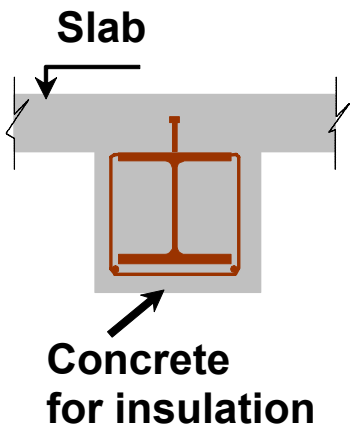
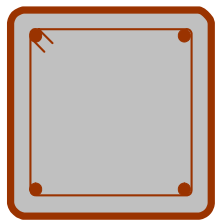
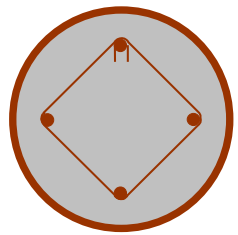
Load bearing and (possibly) separating function

- Load bearing capacity
- Thermal insulation
- Integrity

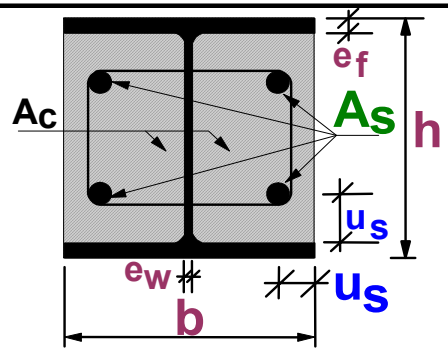
Options

- tabulated data
- simple calculation model
- advanced calculation model

Tabulated data (steel and concrete composite members)

Composite beams	Composite columns
	 
	 

Tabulated data and relevant parameters (composite columns – prEN1994-1-2)



		Standard Fire Resistance			
		R30	R60	R90	R120
	Minimum ratio of web to flange thickness e_w/e_f	0,5			
1	Minimum cross-sectional dimensions for load level	$\eta_{fi,t} \leq 0,28$			
1.1	minimum dimensions h and b [mm]	160	200	300	400
1.2	minimum axis distance of reinforcing bars u_s [mm]	-	50	50	70
1.3	minimum ratio of reinforcement $A_s/(A_c+A_s)$ in %	-	4	3	4
2	Minimum cross-sectional dimensions for load level	$\eta_{fi,t} \leq 0,47$			
2.1	minimum dimensions h and b [mm]	160	300	400	-
2.2	minimum axis distance of reinforcing bars u_s [mm]	-	50	70	-
2.3	minimum ratio of reinforcement $A_s/(A_c+A_s)$ in %	-	4	4	-
3	Minimum cross-sectional dimensions for load level	$\eta_{fi,t} \leq 0,66$			
3.1	minimum dimensions h and b [mm]	160	400	-	-
3.2	minimum axis distance of reinforcing bars u_s [mm]	40	70	-	-
3.3	minimum ratio of reinforcement $A_s/(A_c+A_s)$ in %	1	4	-	-

Standard fire rating

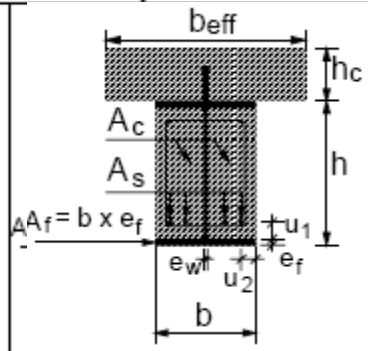
Load level

Section dimension

Reinforcing steel

Concrete cover

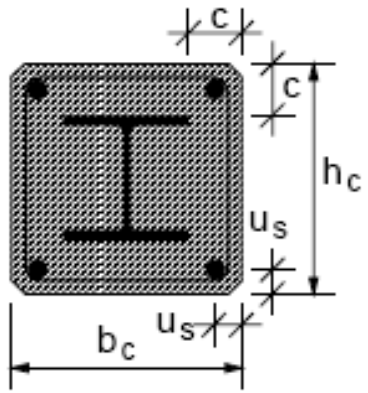
with partial concrete encasement:



Condition for application:
slab: $h_c \geq 120$ mm
$b_{eff} \leq 5$ m
steel section: $b / e_w \geq 15$
$e_f / e_w \leq 2$
additional reinforcement area, related to total area between the flanges:
$A_s/(A_c + A_s) \leq 5\%$

		Standard Fire Resistance				
		R30	R60	R90	R120	R180
1	Minimum cross-sectional dimensions for load level $\eta_{fi,t} \leq 0,3$					
	min b [mm] and additional reinforcement A_s in relation to the area of flange A_s / A_f					
1.1	$h \geq 0,9 \times$ min b	*70/0,0*	*100/0,0*	*170/0,0*	*200/0,0*	*260/0,0*
1.2	$h \geq 1,5 \times$ min b	*60/0,0*	*100/0,0*	*150/0,0*	*180/0,0*	*240/0,0*
1.3	$h \geq 2,0 \times$ min b	*60/0,0*	*100/0,0*	*150/0,0*	*180/0,0*	*240/0,0*
2	Minimum cross-sectional dimensions for load level $\eta_{fi,t} \leq 0,5$					
	min b [mm] and additional reinforcement A_s in relation to the area of flange A_s / A_f					
2.1	$h \geq 0,9 \times$ min b	*80/0,0*	*170/0,0*	*250/0,4*	*270/0,5*	-
2.2	$h \geq 1,5 \times$ min b	*80/0,0*	*150/0,0*	*200/0,2*	*240/0,3*	*300/0,5*
2.3	$h \geq 2,0 \times$ min b	*70/0,0*	*120/0,0*	*180/0,2*	*220/0,3*	*280/0,3*
2.4	$h \geq 3,0 \times$ min b	*60/0,0*	*100/0,0*	*170/0,2*	*200/0,3*	*250/0,3*

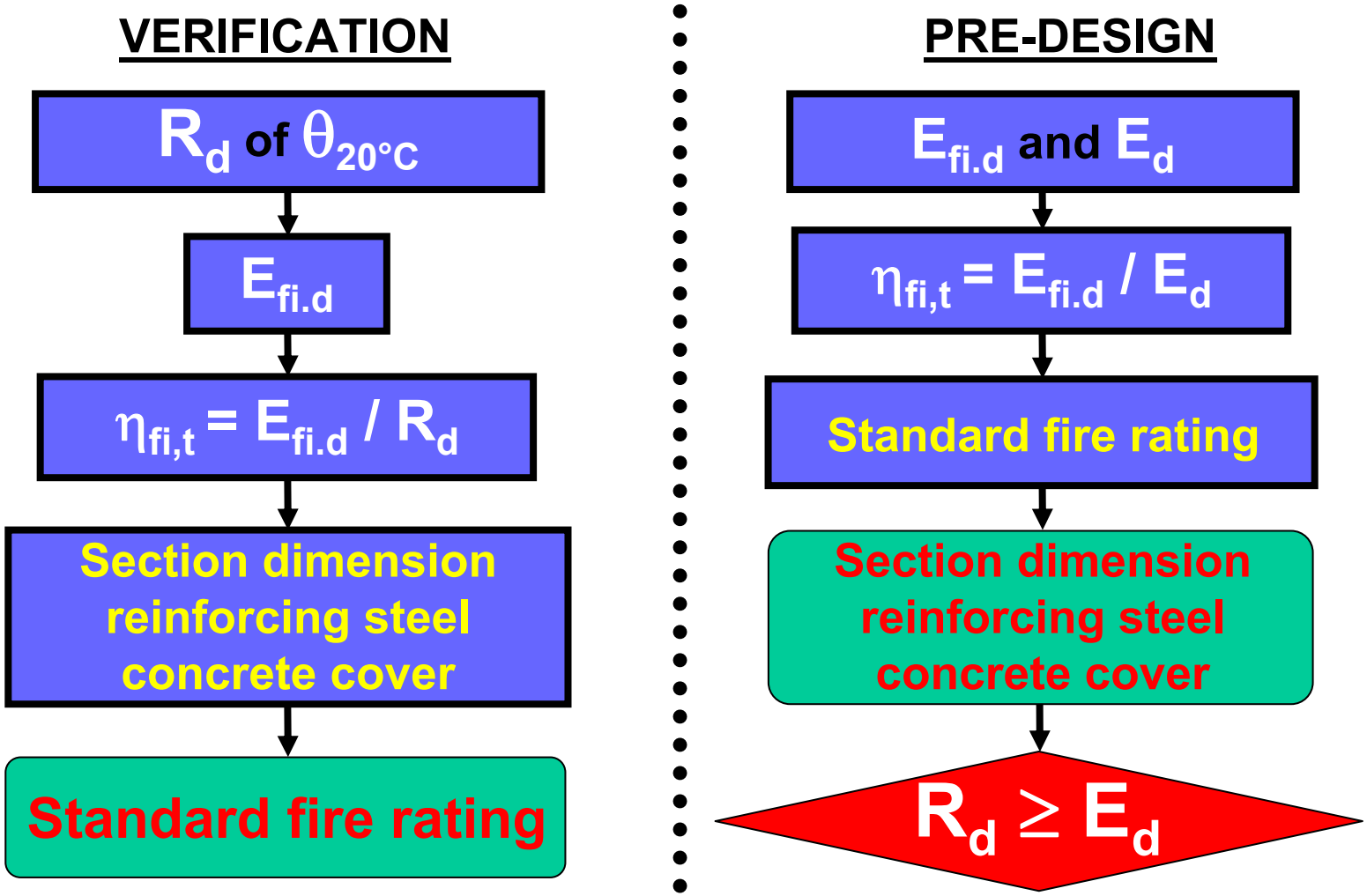
Totally encased steel sections



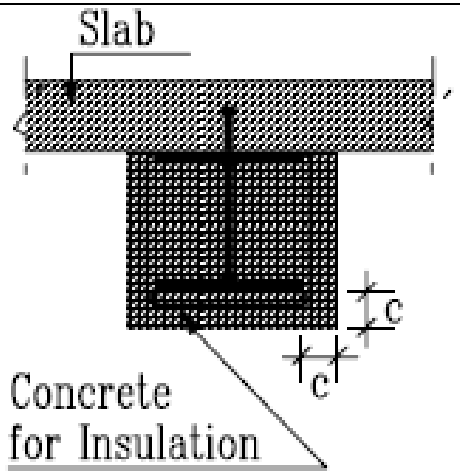
		Standard Fire Resistance					
		R30	R60	R90	R120	R180	R240
1.1	Minimum dimensions h_c and b_c [mm]	150	180	220	300	350	400
1.2	minimum concrete cover of steel section c [mm]	40	50	50	75	75	75
1.3	minimum axis distance of reinforcing bars u_s [mm]	20*	30	30	40	50	50
	Or						
2.1	Minimum dimensions h_c and b_c [mm]	-	200	250	350	400	-
2.2	minimum concrete cover of steel section c [mm]	-	40	40	50	60	-
2.3	minimum axis distance of reinforcing bars u_s [mm]	-	20*	20*	30	40	-

NOTE: *) These values have to be checked according to 4.4.1.2 of EN 1992-1-1

How to apply tabulated data in fire design (two different situations)



Concrete with only insulation function



	Standard Fire Resistance				
	R30	R60	R90	R120	R180
Concrete cover c [mm]	0	25	30	40	50

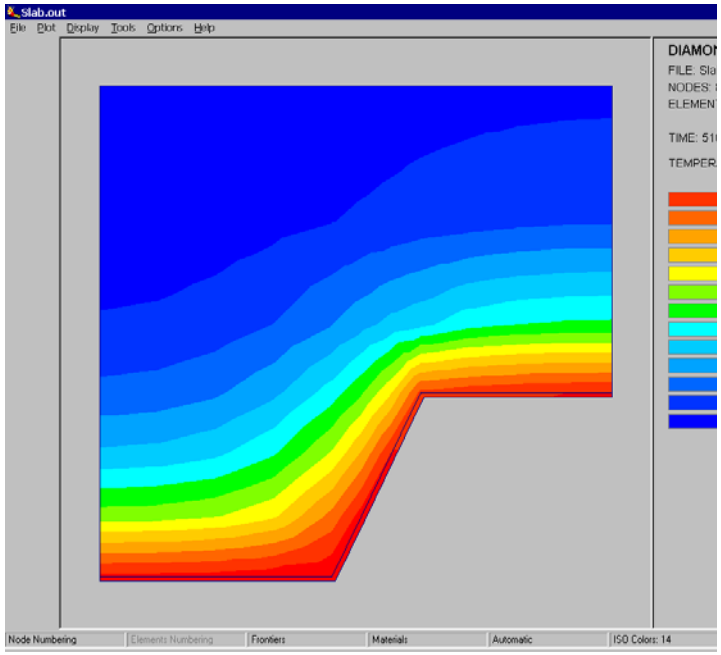
Composite elements
Calculation rules thermal response

Similar to concrete elements

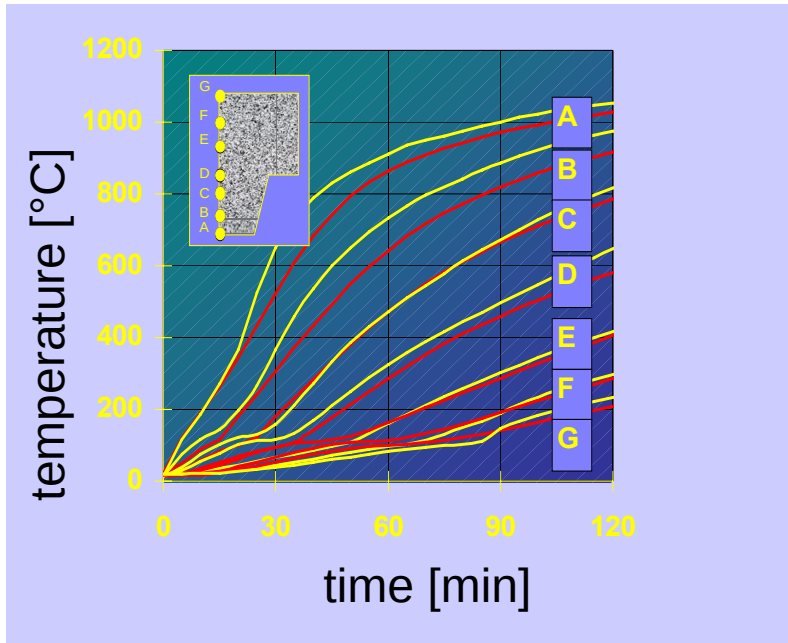
Complications due to shape

Simple calculation rules available

Thermal response composite elements Advanced model (illustration)



computer simulation



test vs. simulation

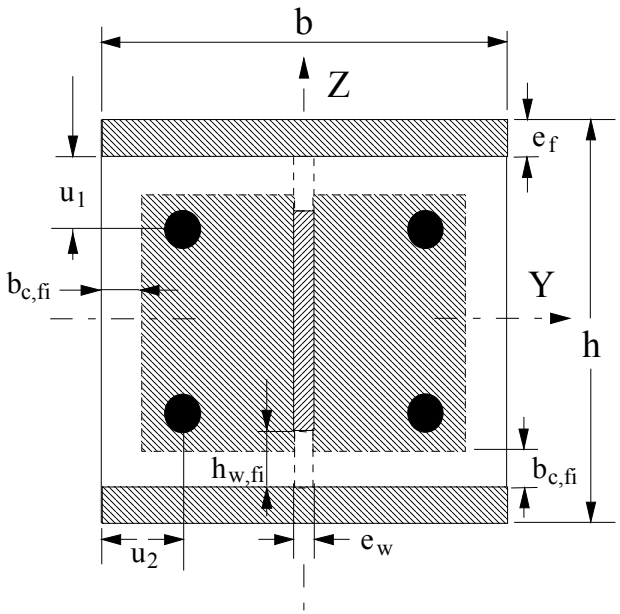
Composite elements
Simple calculation models thermal response

Semi-empirical approach

Parameter study based on systematic calculation with advanced calculation model

Direct application of advanced calculation model

Simple calculation models
Semi-empirical approach



Reduced cross section

Components cross section:
- **flanges steel section**
- **web steel section**
- **concrete**
- **re-bars**

For each component:
reduced strength
and/or
reduced area

Simple calculation models
Parameter study approach

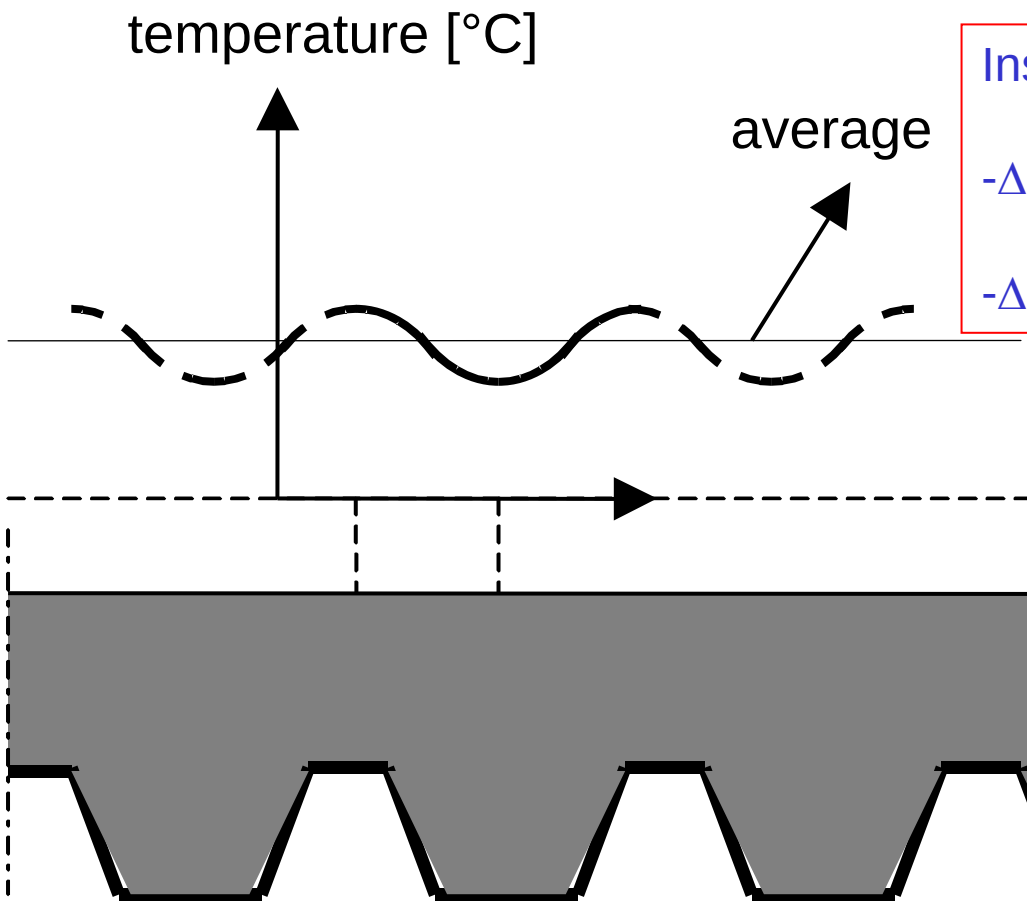
- Composite slabs with profiled steel sheet

Decking type	Concrete depth H_B [mm]	Concrete type
re-entrant (6x)	50, 60, 70, 80, 90, 100, 110, 120	NCW and LWC ENV 1994-1-1
trapezoidal (49x)		

- **standard fire conditions**
- **profiled shape deckings taken into account**
- **thermal properties according to EC**
- **average moisture content: 4% (NWC) and 5% (LWC)**

Note: total number of simulations: 880

Typical temperature distribution at the unexposed side of a composite slab

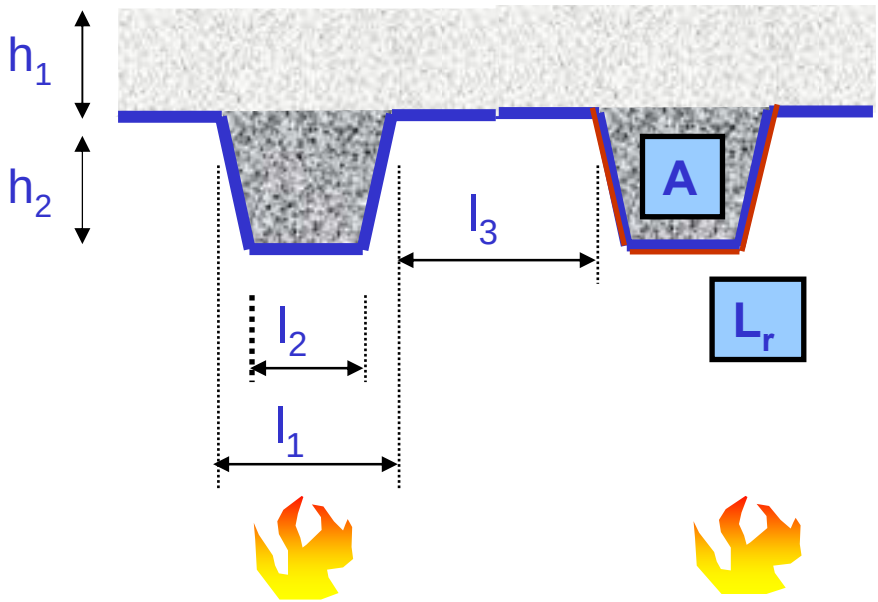


Insulation criterion:

$-\Delta\Theta_{av} \leq 140\ ^{o}C$

$-\Delta\Theta_{max} \leq 180\ ^{o}C$

Composite slabs
Thermal insulation (illustration)



Issues:

$t_f = t_f (l_1, l_2, \ldots, A/L_r, \phi)$

with:

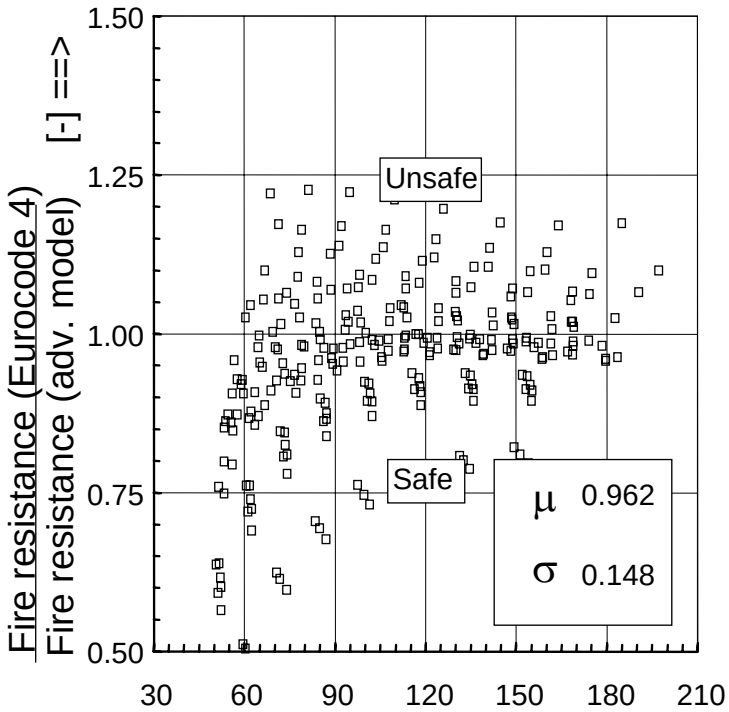
$l_1, l_2, ..$	geometry slab
A	volume rib
L_r	exposed surface rib
ϕ	configuration factor

$$t_f = a_0 + a_1 \cdot h_1 + a_2 \cdot \phi + a_3 \cdot A/L_r + a_4 \cdot 1/L_3 + a_5 \cdot A/L_r \cdot 1/l_3 \quad [\text{min}]$$

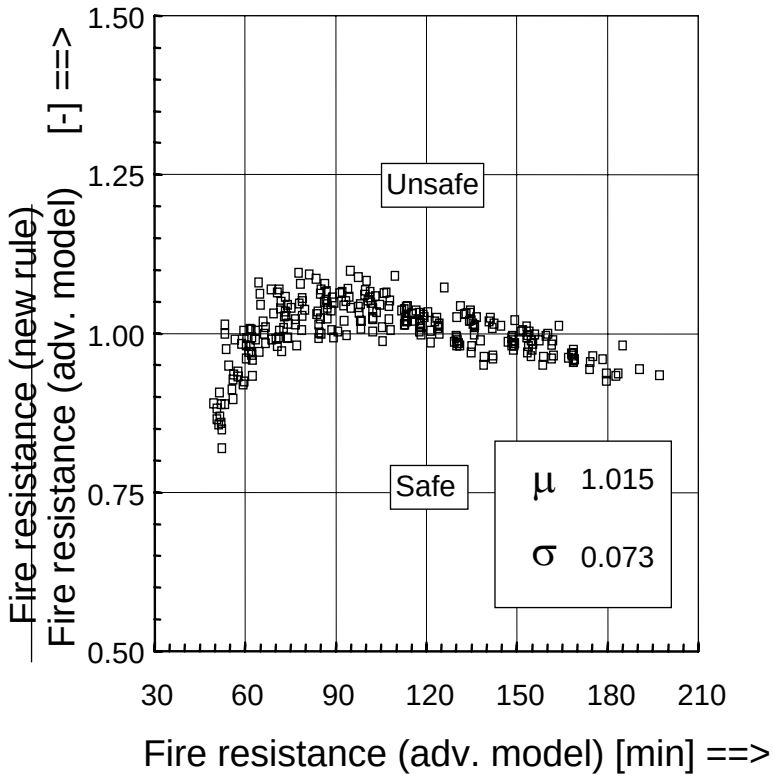
with:

a_i coefficients, depending on duration of s.f.c. exposure

Thermal insulation composite slabs
Verification simple calculation rule

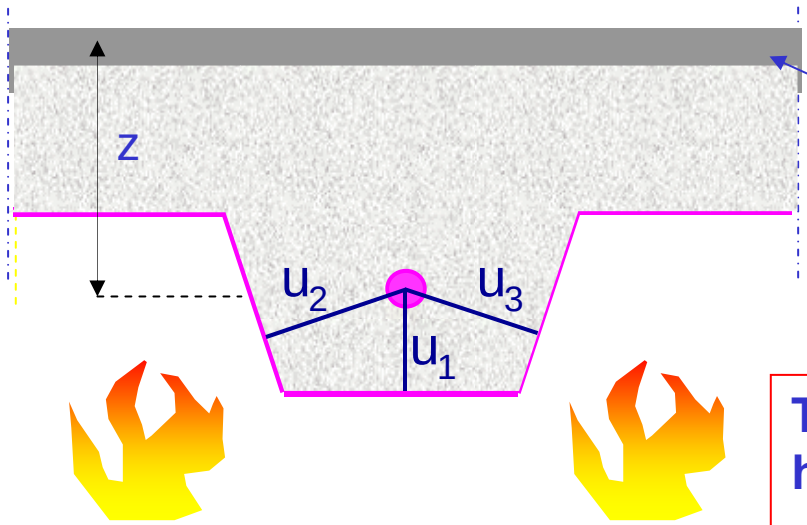


(a) ENV rule



(b) new rule

Composite slabs
Thermal response positive reinforcement



compression zone
concrete (20 °C)

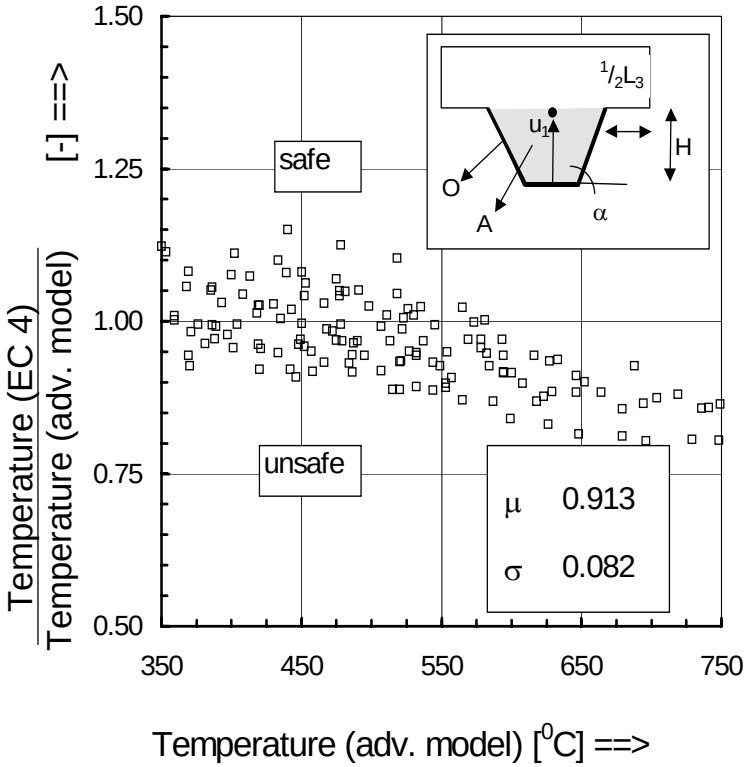
Temperature reinforcement has significant impact on $M^{+}_{p,\Theta}$

$$\Theta_r = \Theta_r (u_1 , A/O, l_3, z \ldots)$$

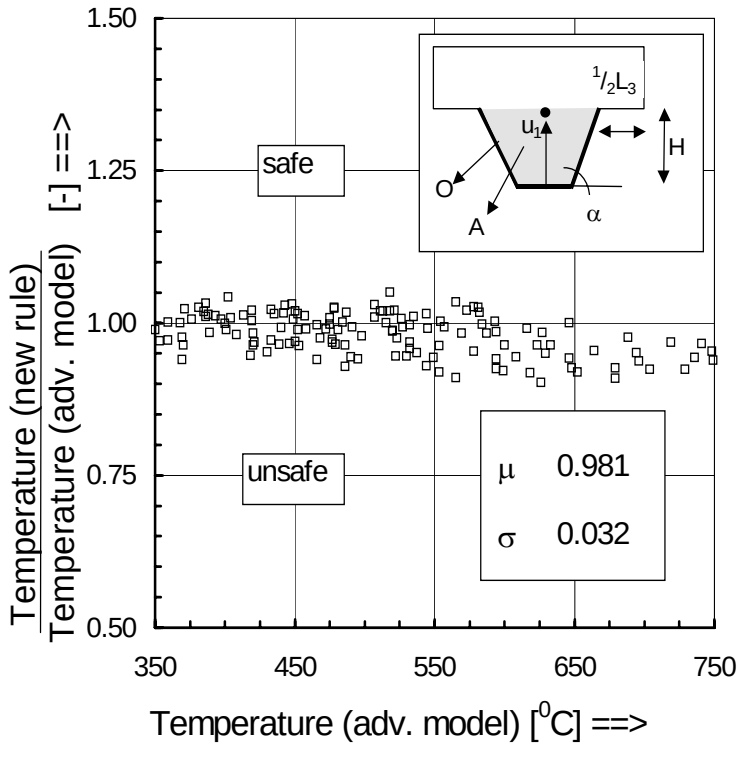
$$z = z(u_1, u_2, u_3)$$

Note: steel sheet may significantly contribute to the load bearing capacity!

Thermal response positive reinforcement
Simple calculation rule

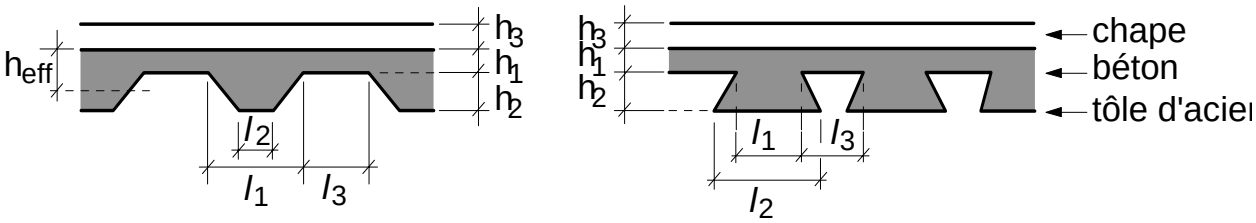


(a) ENV rule



(b) new rule

Composite slabs



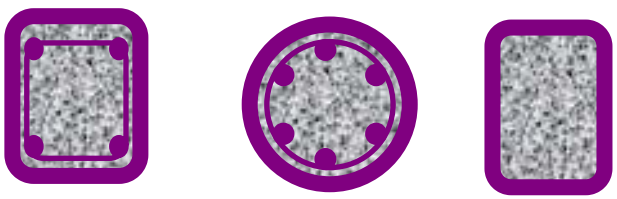
Thermal Insulation (ISO fire)	Equivalent thickness h_{eff}[mm]
I 30	$60 - h_3$
I 60	$80 - h_3$
I 90	$100 - h_3$
I 120	$120 - h_3$

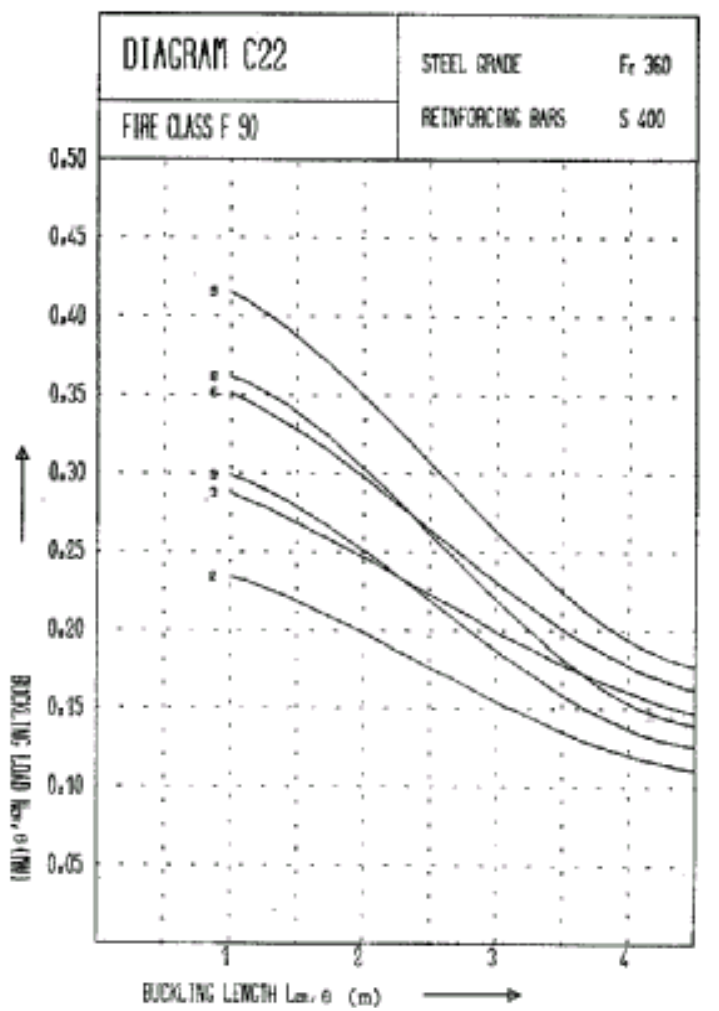
Concrete filled SHS columns
Resistance to fire (traditional approach)

Design charts available
Unpractical
Need for "user friendly" design tool

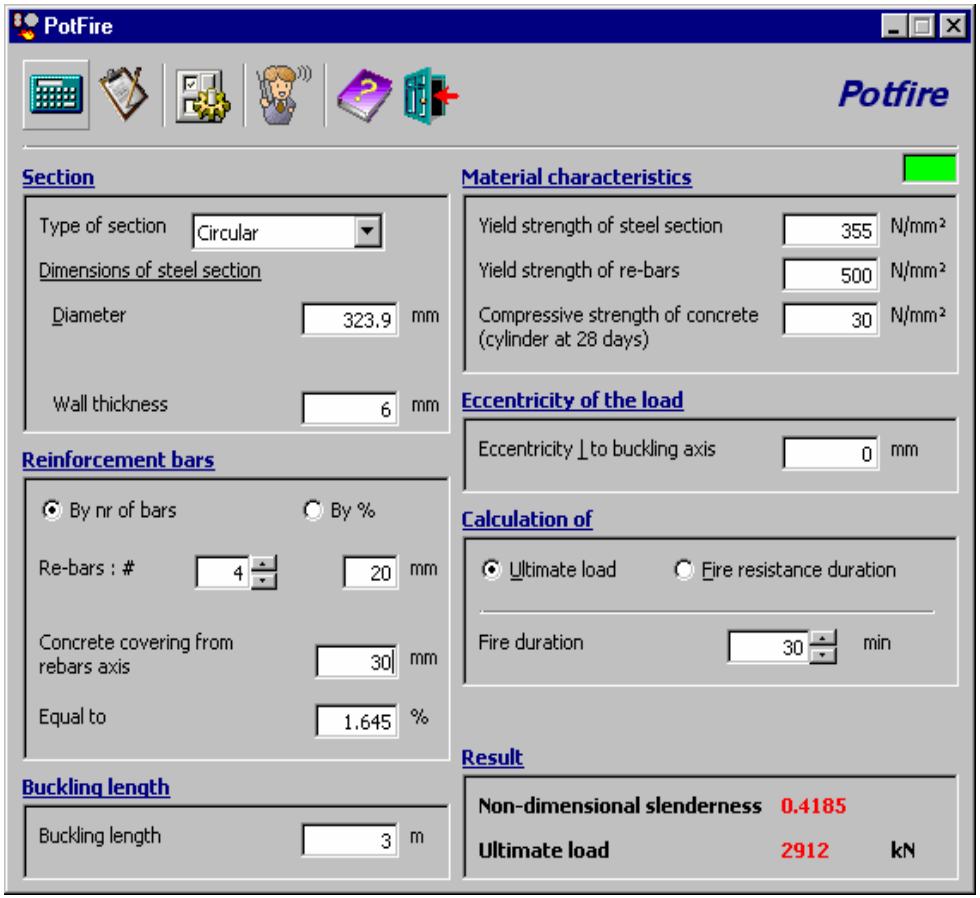
⇒ e.g. POTFIRE

no.	concrete quality	rebar %
1	C20	1.0
2	C20	2.5
3	C20	4.0
4	C30	1.0
5	C30	2.5
6	C30	4.0
7	C40	1.0
8	C40	2.5
9	C40	4.0



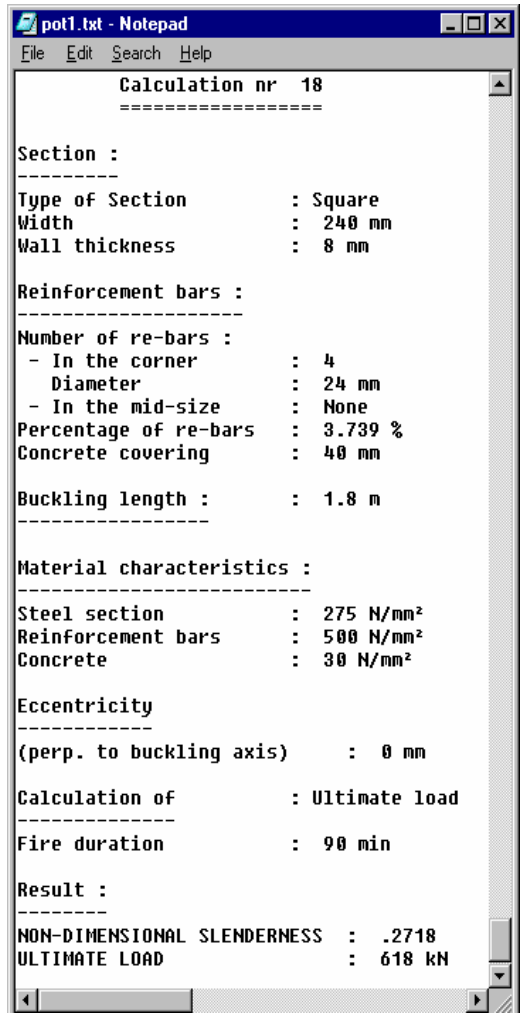


POTFIRE
In- & output

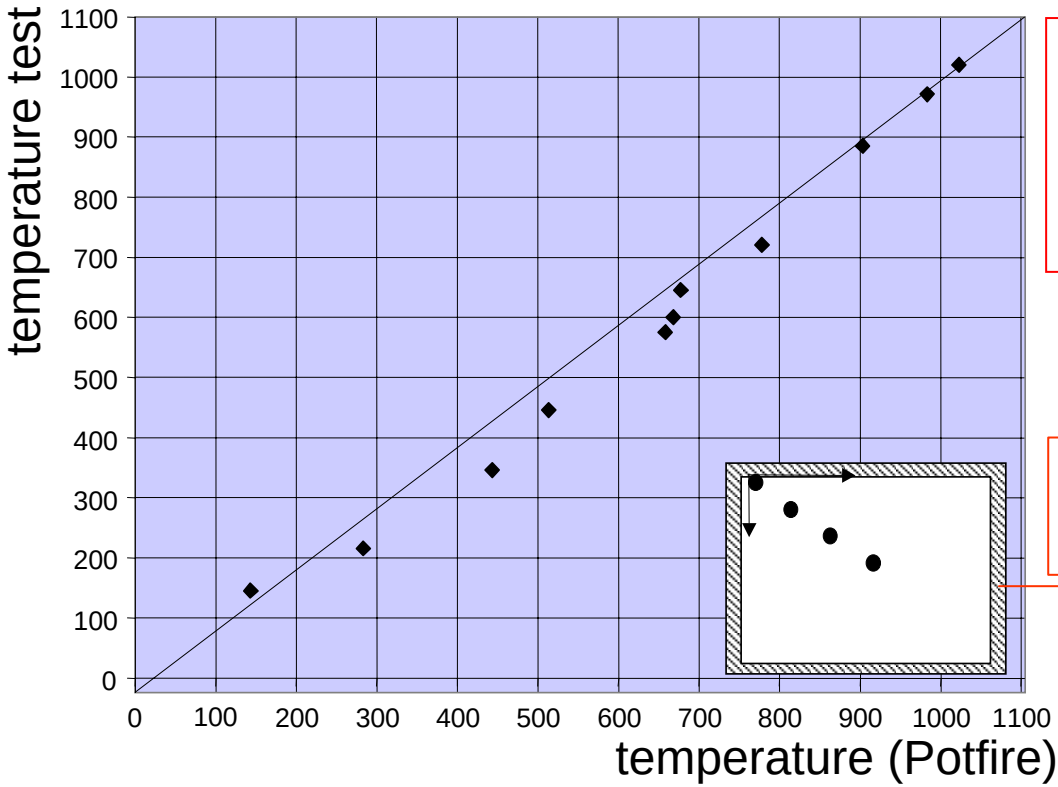


input

output



Validation POTFIRE



assumptions:

- α_{conv} = 25 W/m²k
- ε_{res} = 0.7

Concrete Filled
Steel Hollow Section

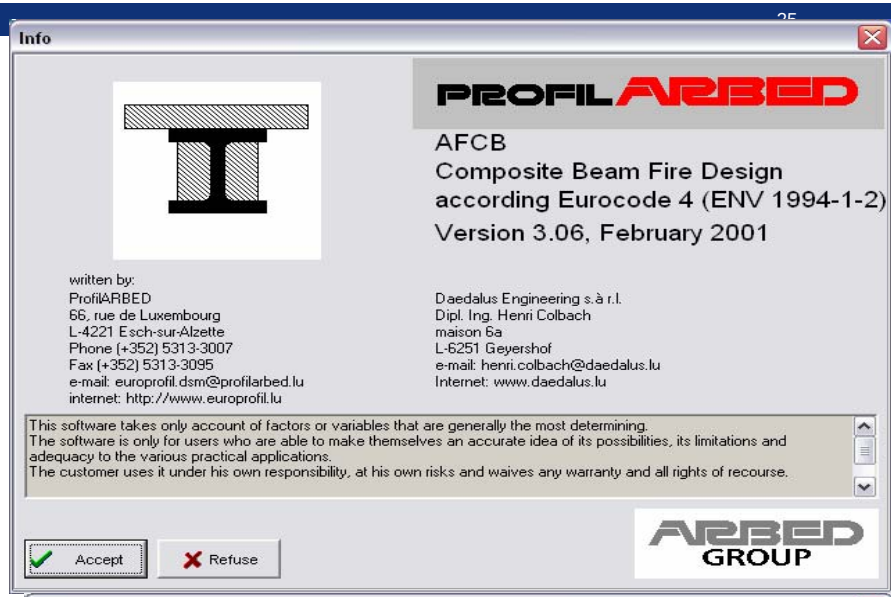
Logiciels de calcul

Logiciels « AFcolumn » et « AFbeam »

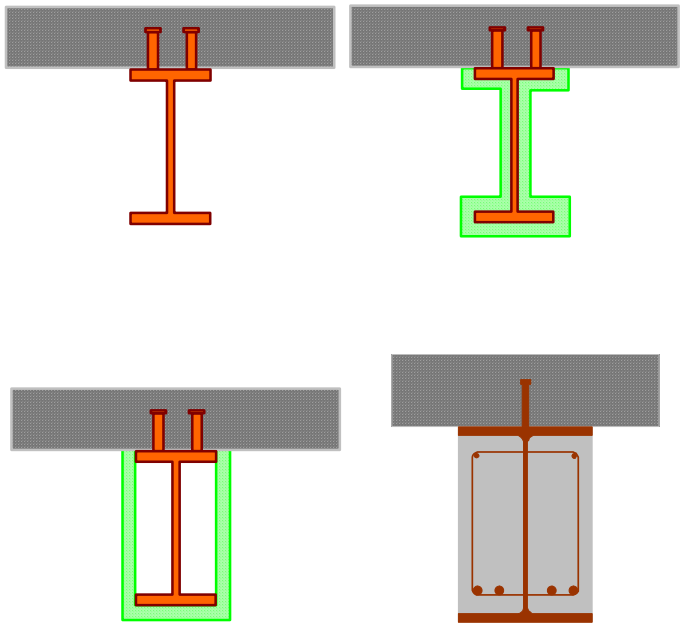
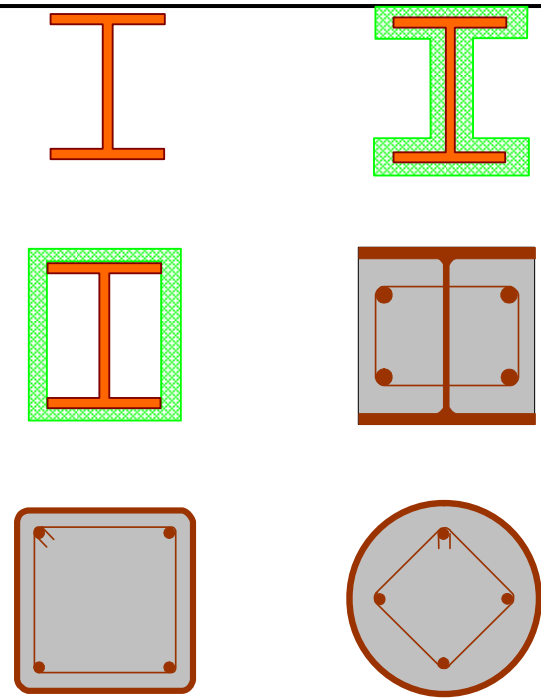
Développés par ProfilARBED

Peuvent être obtenus sur le site

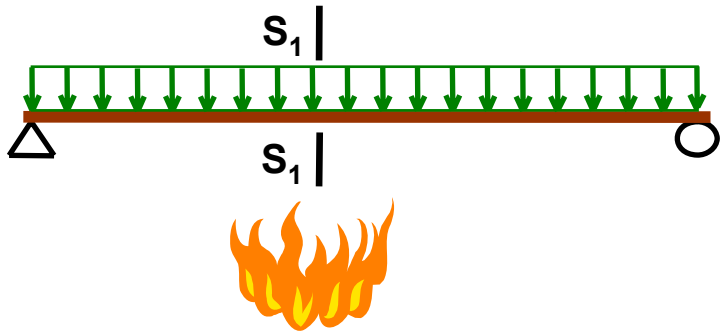
www.arcelormittal**.com**

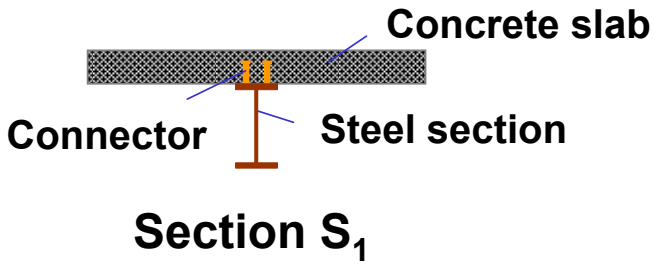


Simple calculation model (steel and composite members)

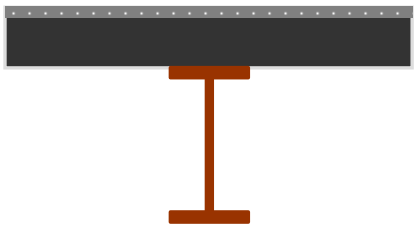
Beams (steel or composite)	Columns
	

Simple calculation model (composite beam) - plastic resistance theory



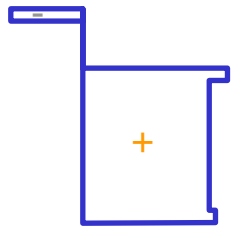


Section S_1

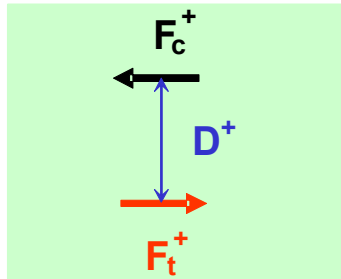


Section geometry

Temperature distibution



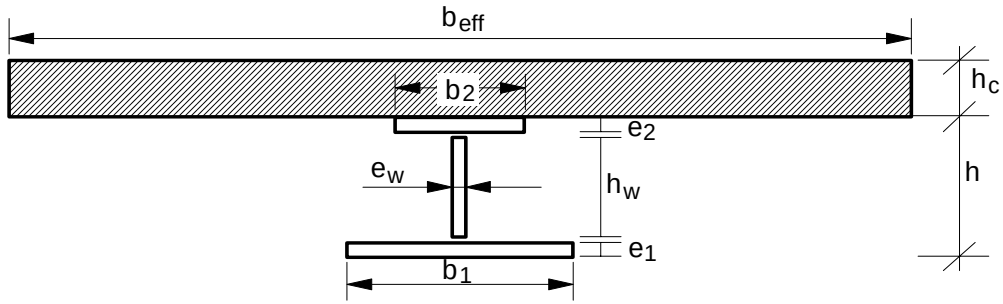
Stress distribution



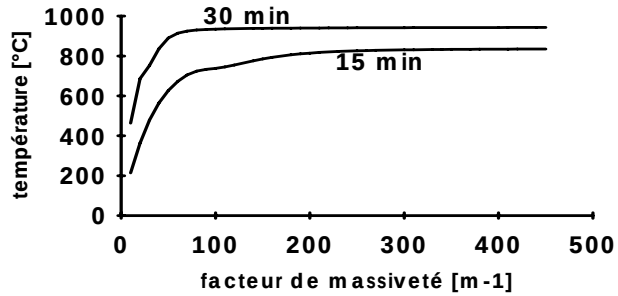
Moment resistance

$$M_{fi,Rd^+} = F_t^+ \times D^+$$

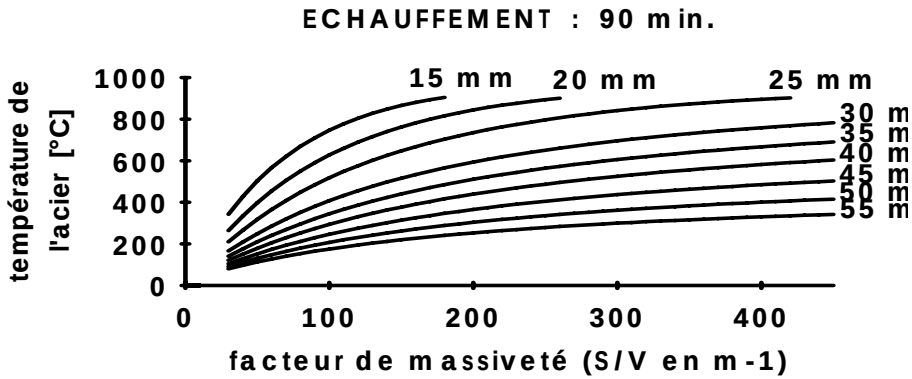
Composite beams



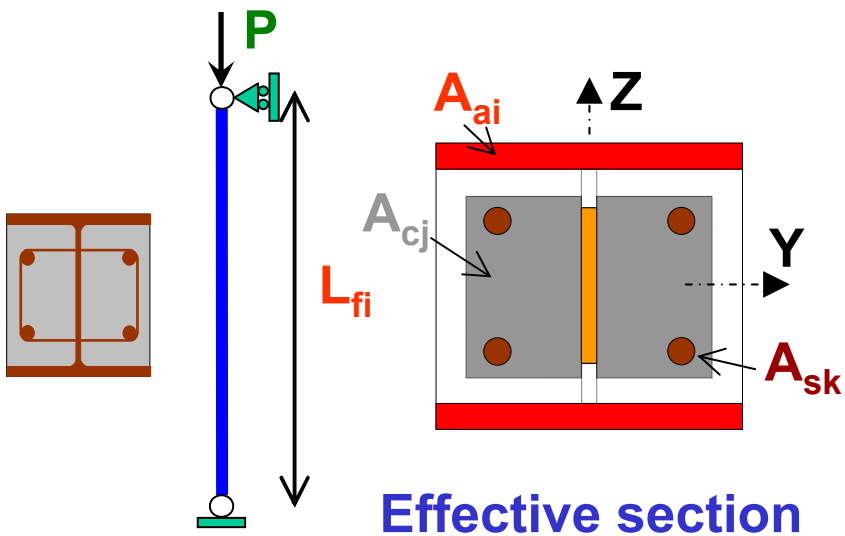
- bare



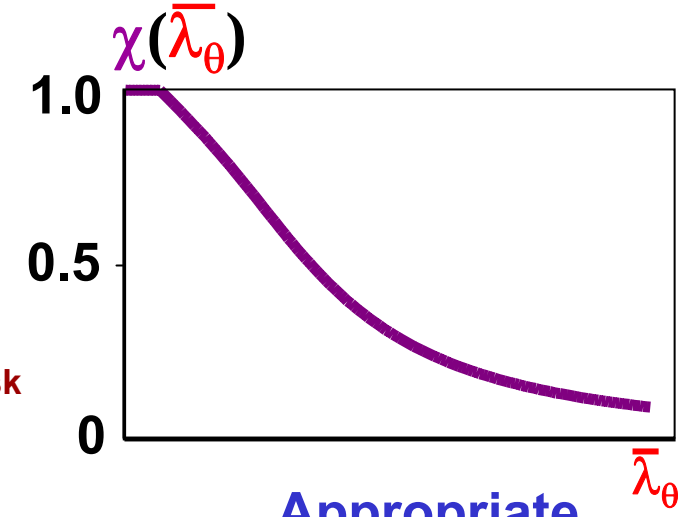
- insulated



Simple calculation model (composite column) - buckling curve



Effective section



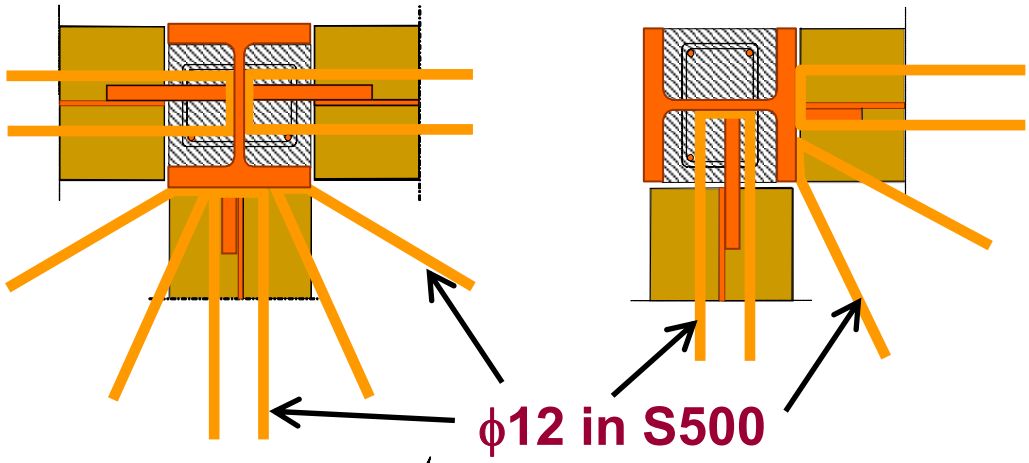
Appropriate buckling curve

Load capacity: $N_{fi.Rd} = \chi(\bar{\lambda}_\theta)\, N_{fi.pl.Rd}$

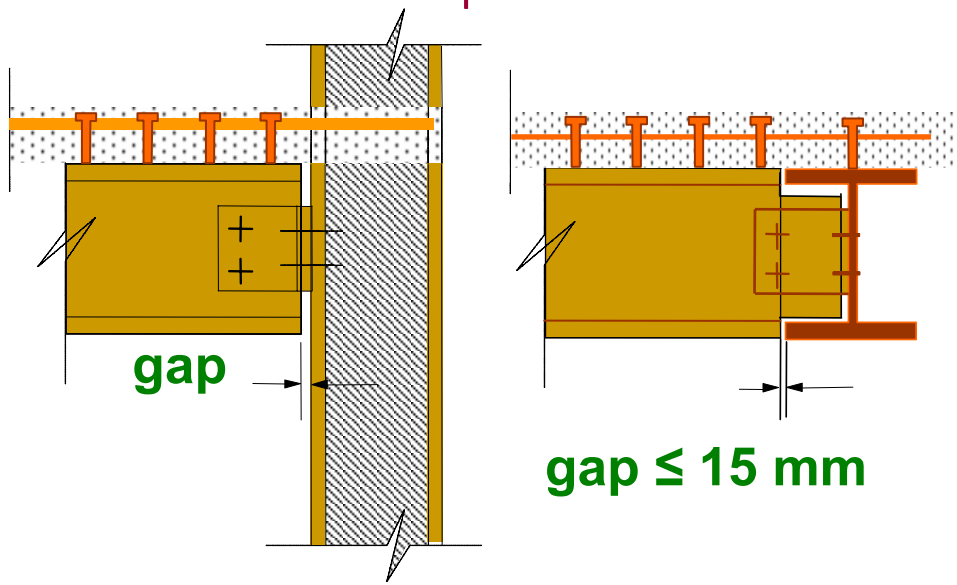
$\chi(\bar{\lambda}_\theta) \Leftarrow$ **strength and rigidity of effective section + column buckling length** L_{fi}

Construction details shall be respected in order to consistent with numerical models

Reinforcing bars between slab and edge columns

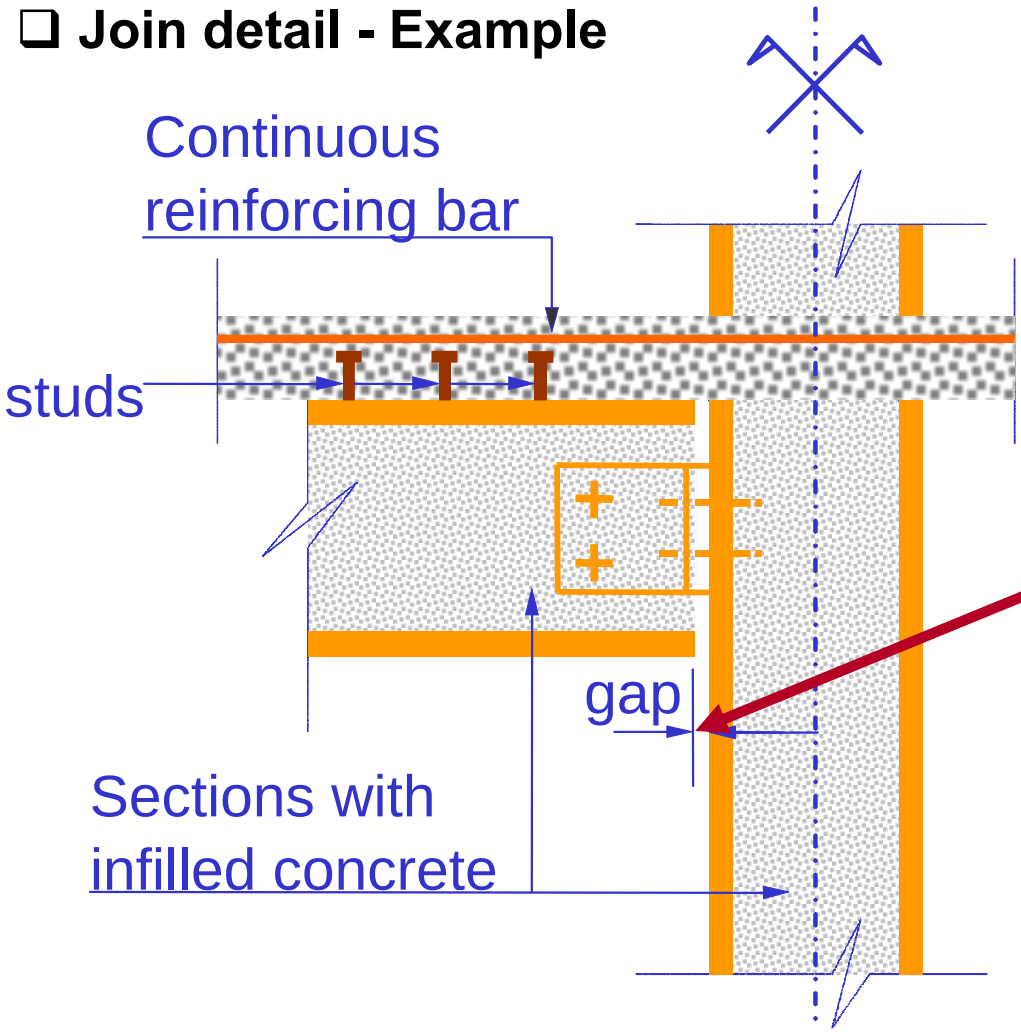


Maximum gap of 15 mm between beam and column and between lower flange of the beam



Construction details to get hogging moment resistance in fire situation

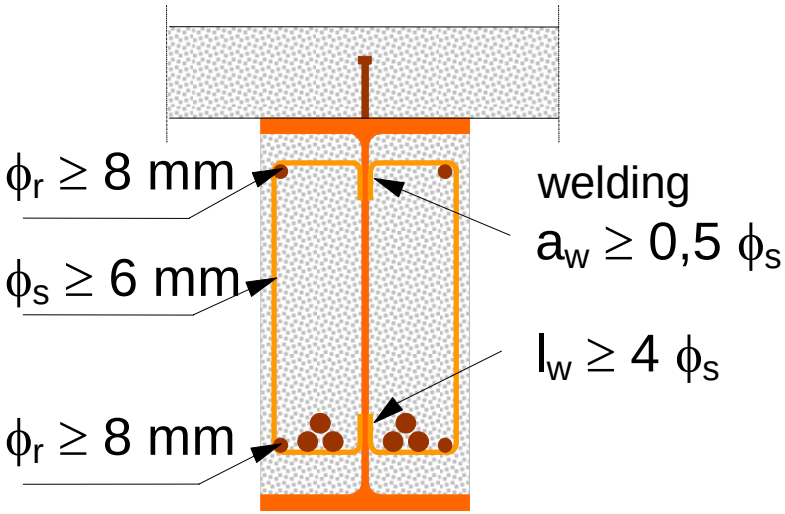
❑ **Join detail - Example**



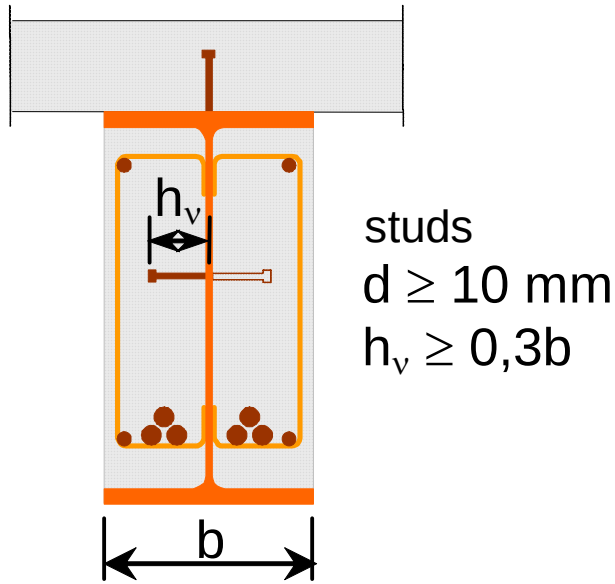
A limited gap allowing to develop a hogging moment in the fire situation

Construction details for connection between concrete and steel

❑Connection between steel profile and encased concrete



Welding of stirrups to the web

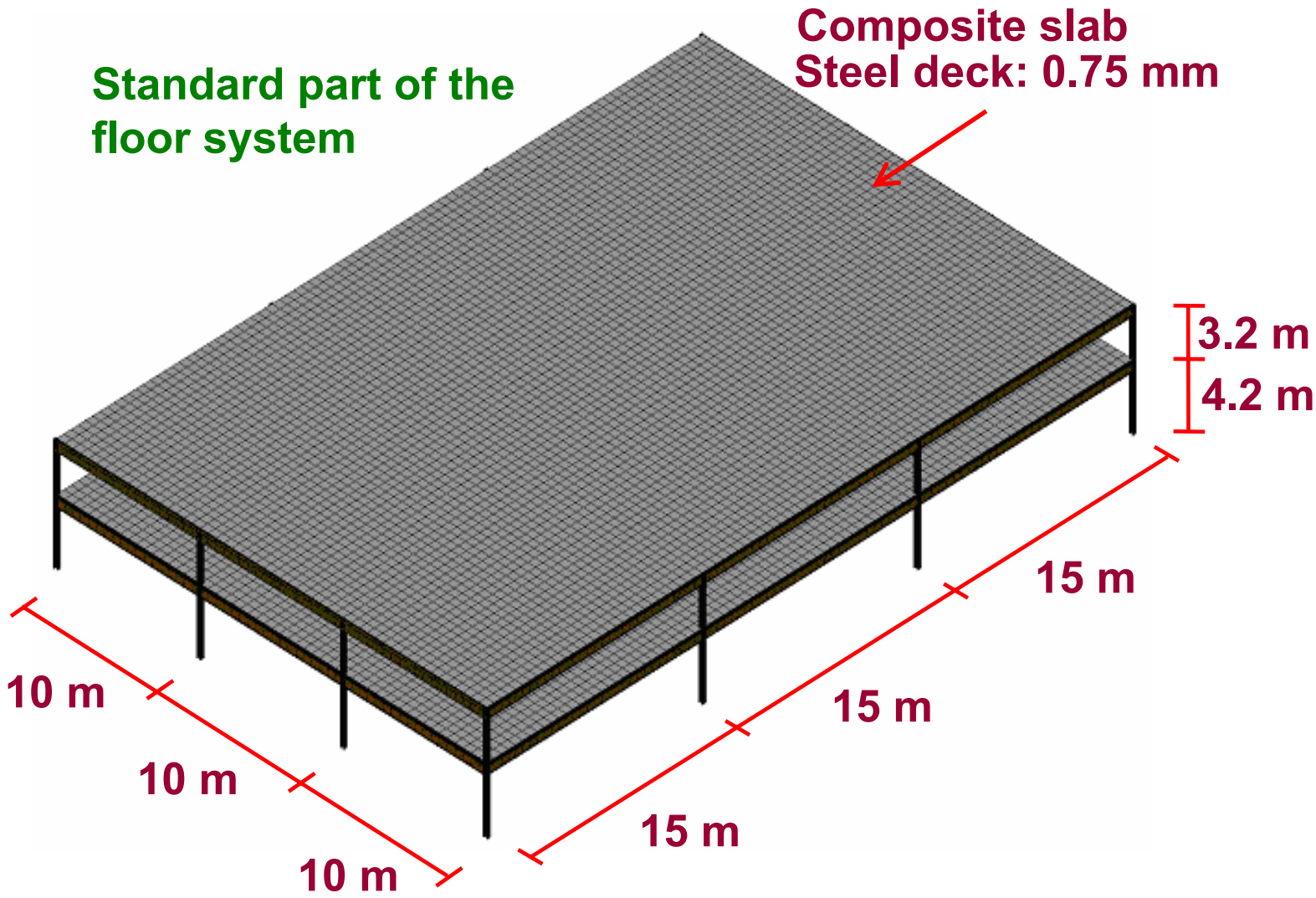


Welding of studs to the web

Fire design by global structural analysis

- **Application requirement of advanced calculation models**
  - **requirement on material models**
    - **strain composition**
    - **kinematical material model**
    - **strength during cooling phase**
  - **step by step iterative solution procedure**
  - **check of possible failure untreated in direct analysis**
    - **rupture due to excessive steel elongation**
    - **cracking and crushing of concrete**

Global analysis of steel and concrete composite floor under localised fire



Choice of structural model

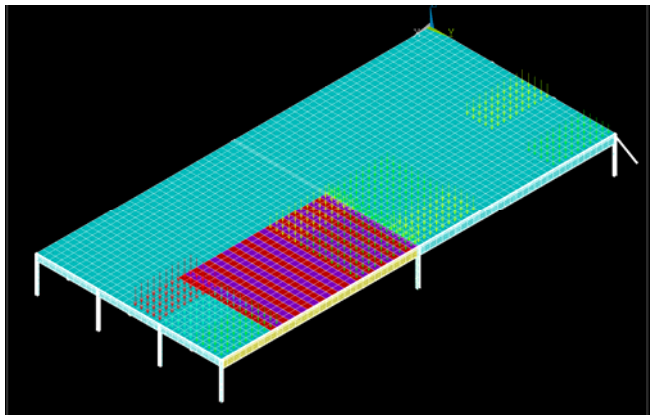
Two different structural models may be adopted

- **2D composite frame model (beam elements)**
  - **membrane effect is limited to one direction due to 1D effect slab model**
  - **load redistribution is not possible between parallel beams**
- **3D composite floor model (multi-type element)**
  - **membrane effect over whole floor area**
  - **load redistribution becoming possible with help of shell elements**

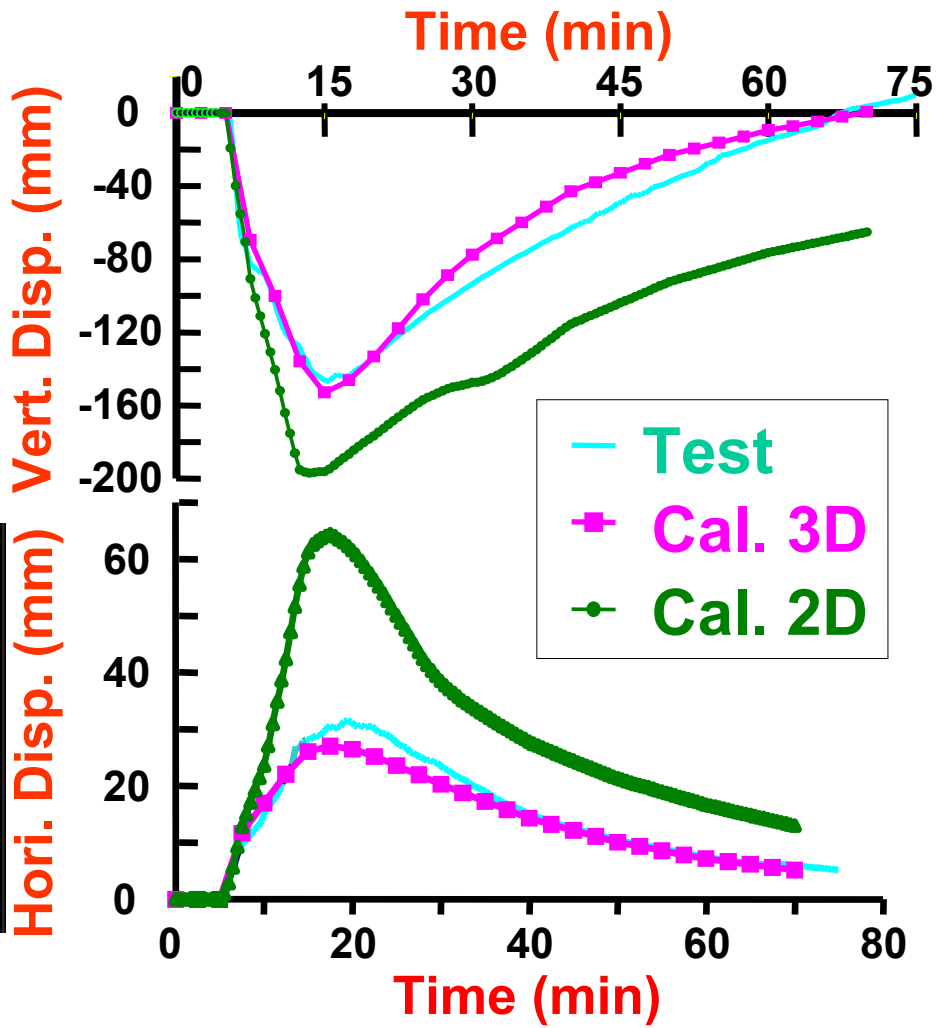
More realistic to apply 3D composite floor model

Validity of 3D composite floor model

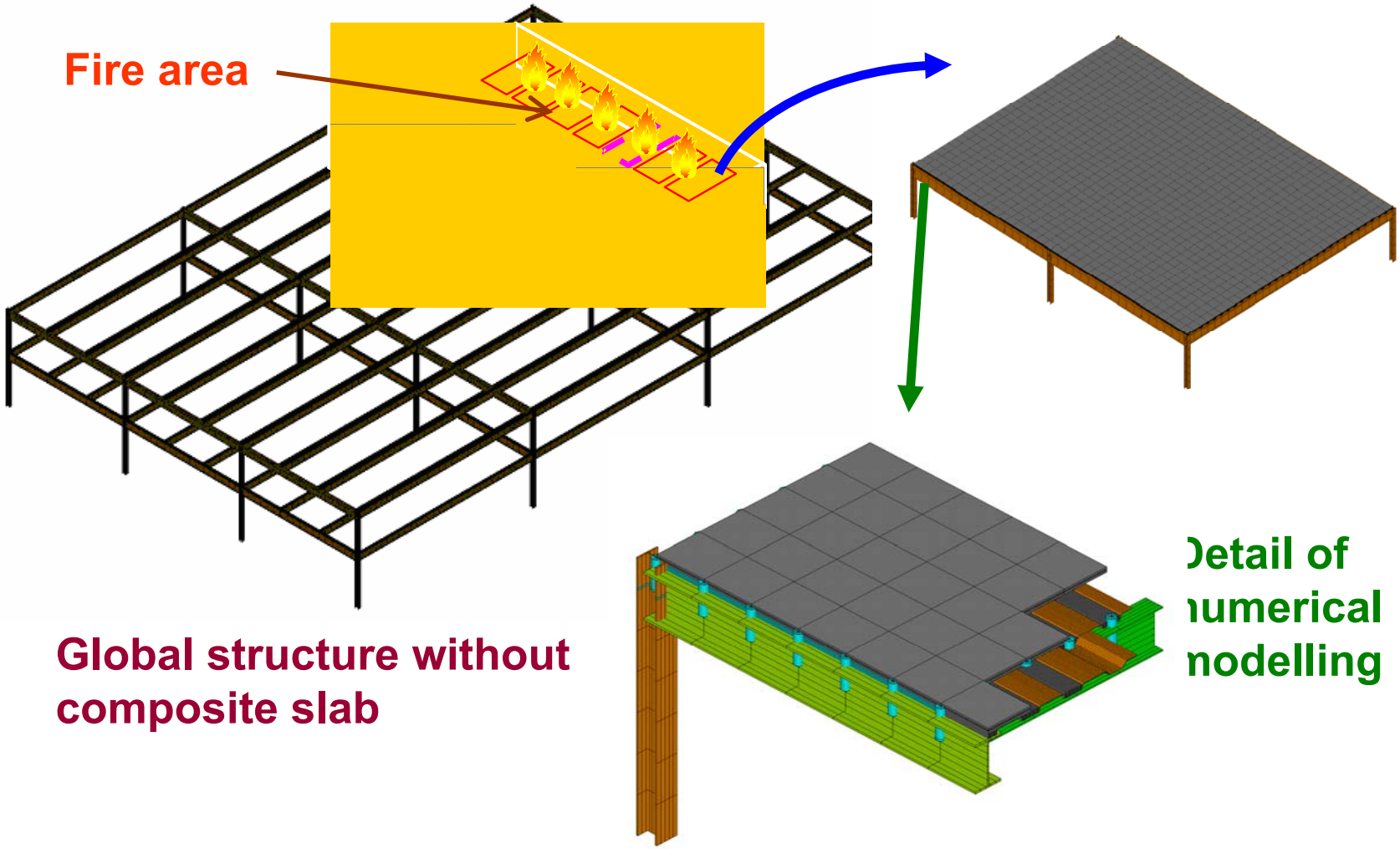
Test



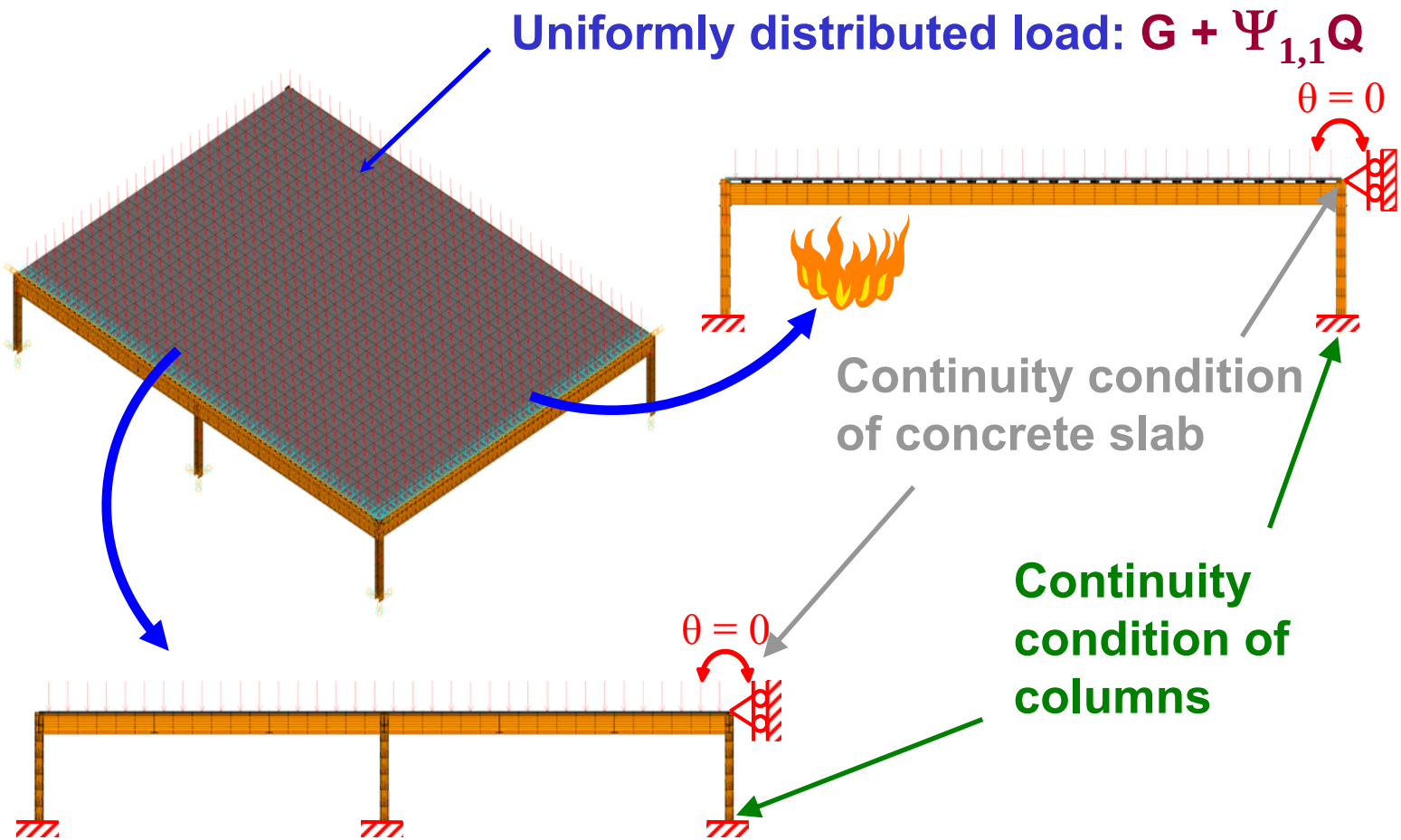
3D calculation model



Strategy of 3D composite floor modelling

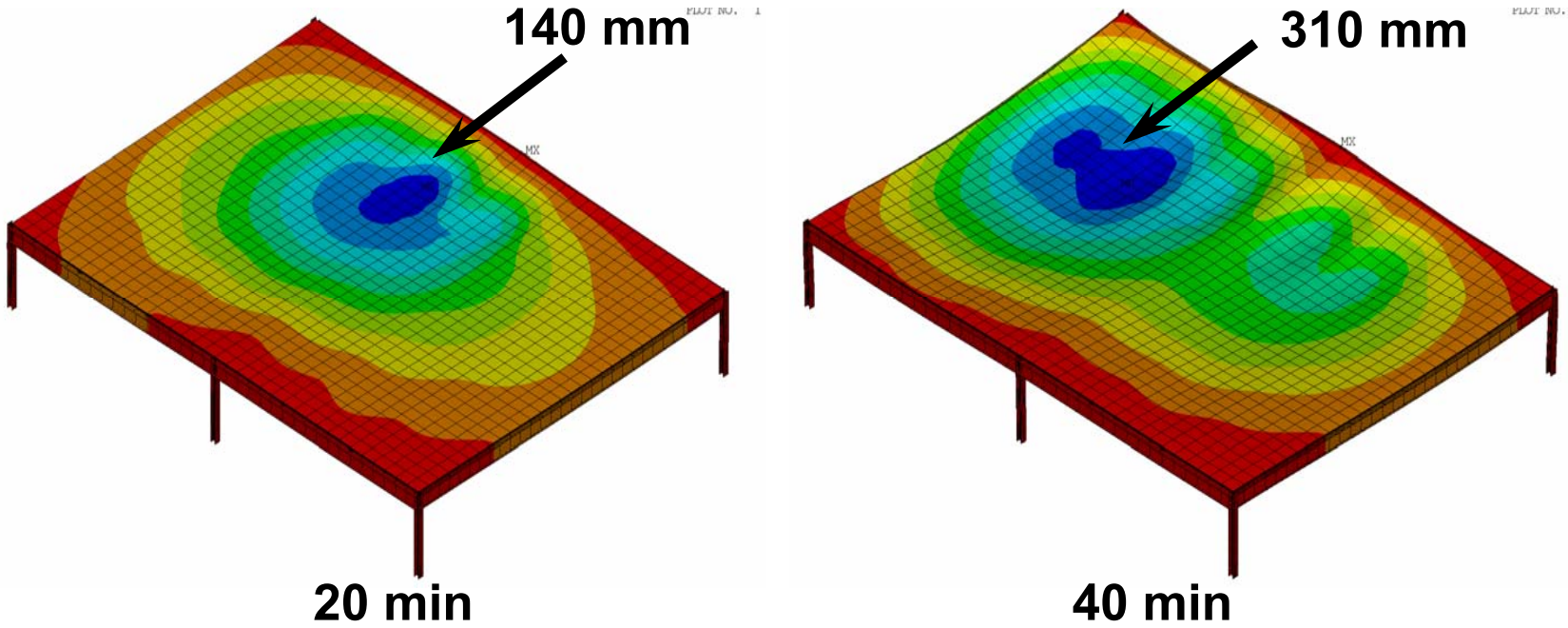


Mechanical loading and boundary conditions



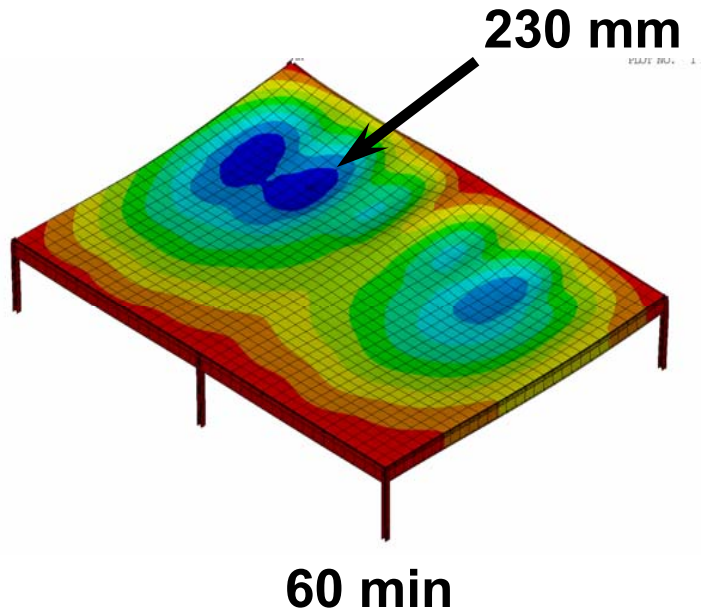
Mechanical response of the structure

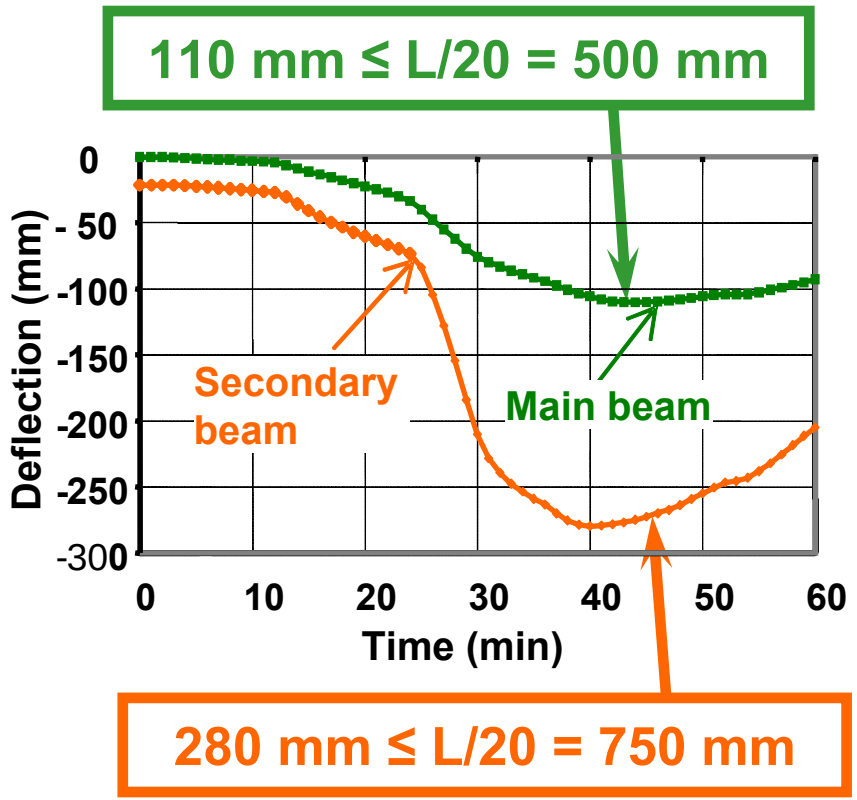
- **Total deflection of the floor and check of the corresponding failure criteria**



Mechanical response of the structure

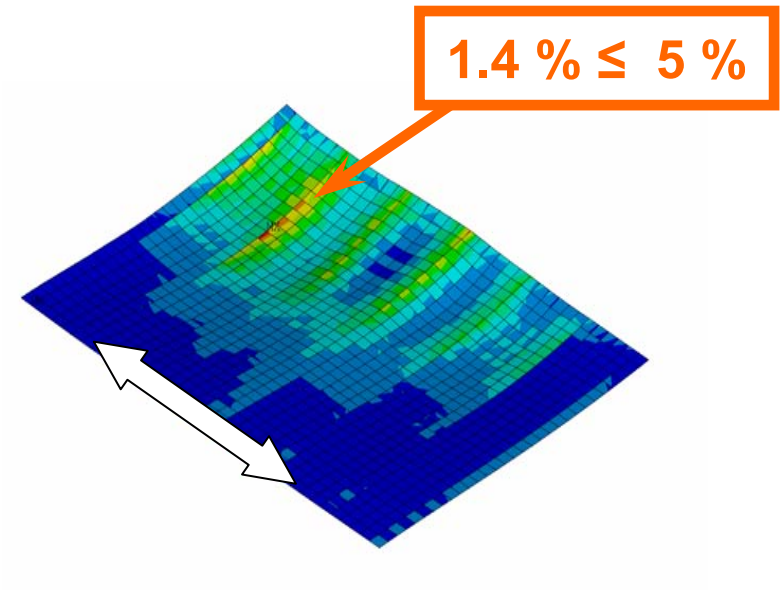
- **Total deflection of the floor and check of the corresponding failure criteria**



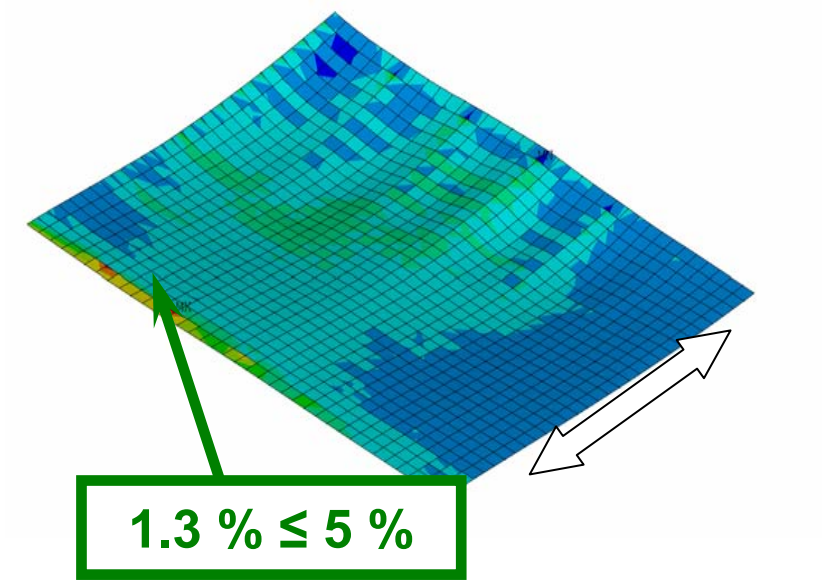


Mechanical response of the structure

➢Check of failure criteria: elongation of reinforcing steel



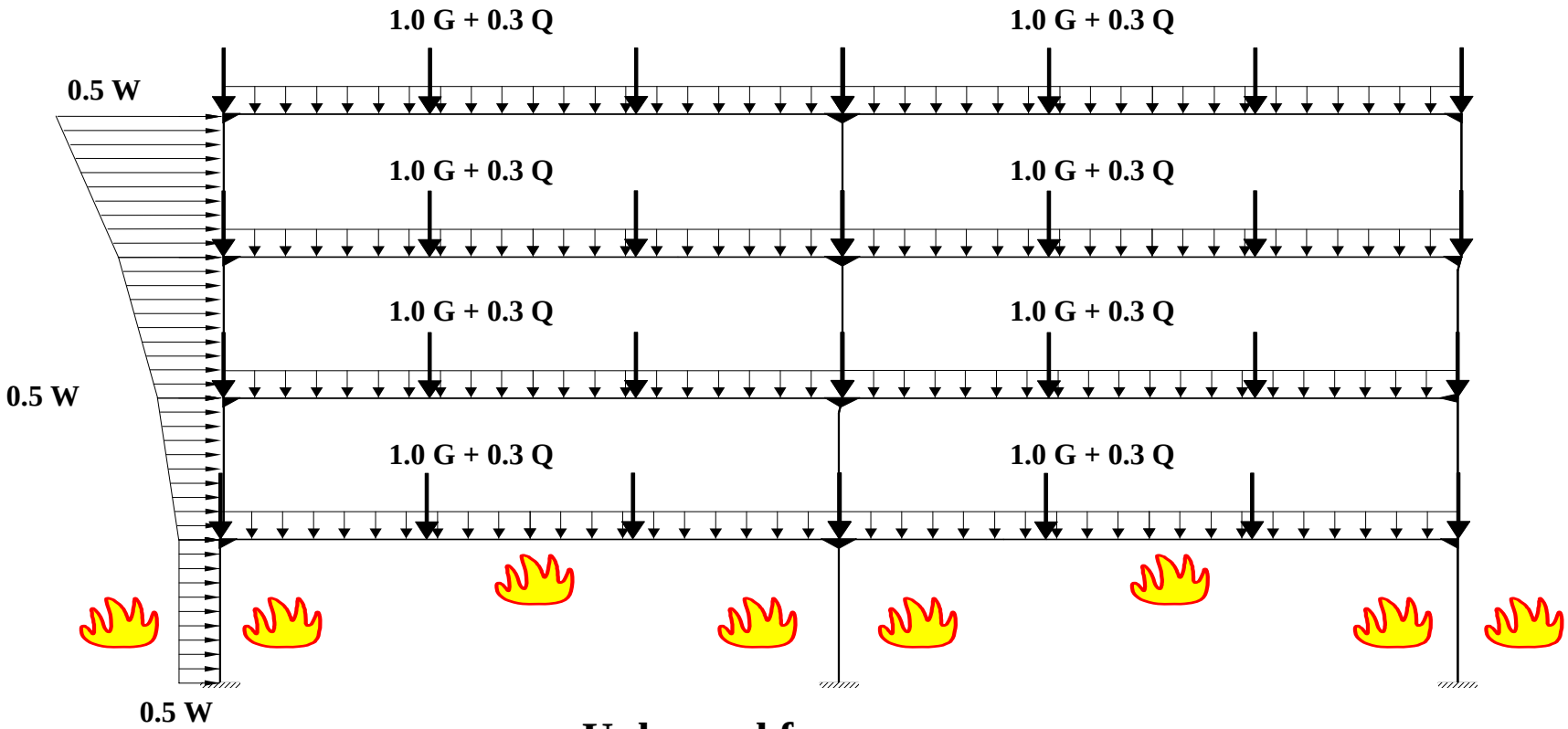
Strain of reinforcing steel
// slab span



Strain of reinforcing steel
⊥ slab span

Unbraced frame – R + 3

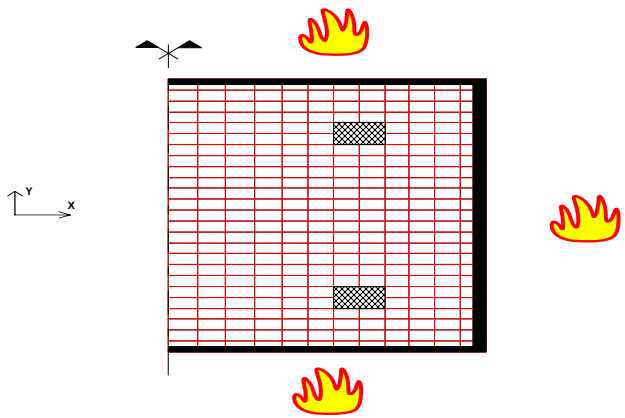
Design



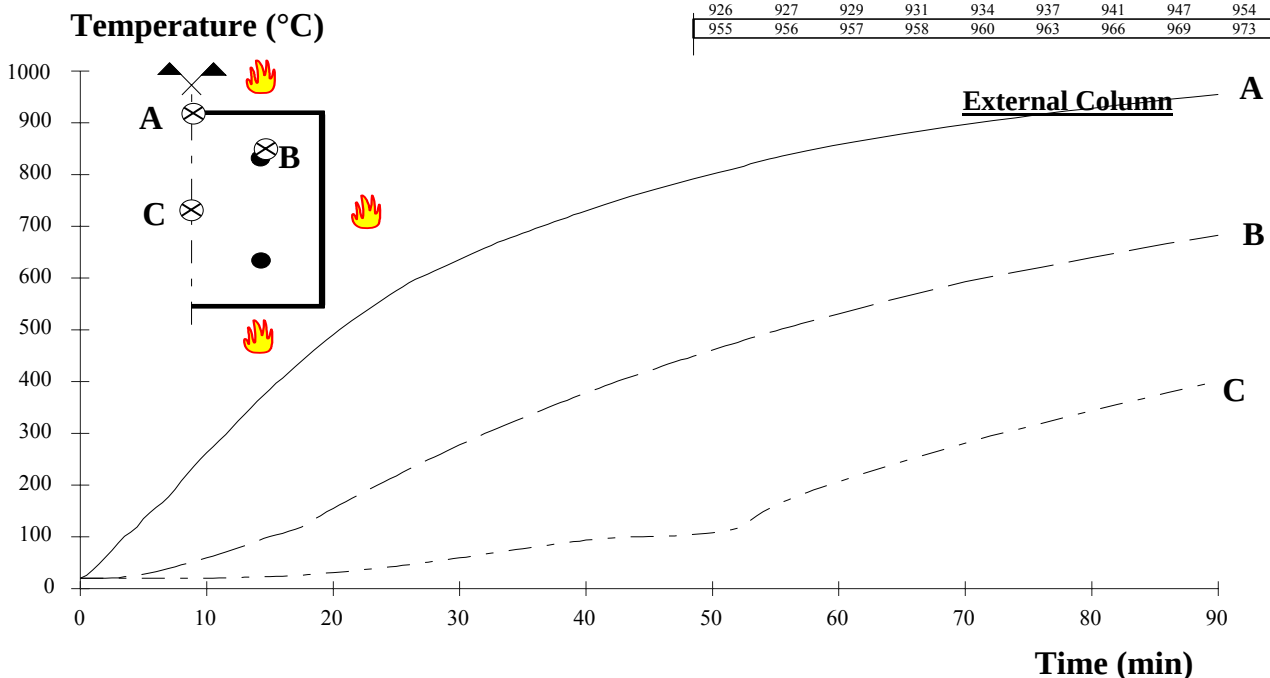
Unbraced frame

Edge column temperature

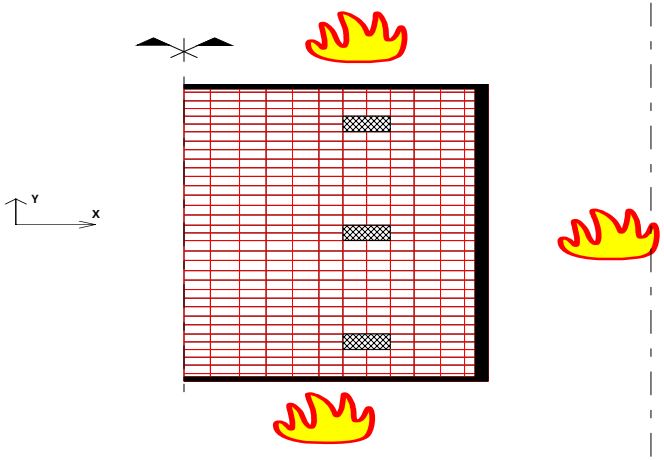
Time : 90 minutes



955	956	957	958	960	963	966	969	973	977	981	983	983
926	927	929	931	934	937	941	947	954	963	972	980	983
845	847	851	855	860	866	873	884	901	923	950	972	981
750	753	759	767	775	782	791	807	835	875	923	963	977
671	675	683	694	707	714	718	729	770	835	901	954	973
606	611	621	636	655	674	683	686	729	807	884	947	969
553	558	570	589	614	654	680	683	718	791	873	941	966
510	516	529	550	578	619	654	674	714	782	866	937	963
475	482	496	517	546	578	614	655	707	775	860	934	960
448	455	469	491	518	551	590	637	695	767	855	931	958
428	435	449	471	498	532	573	623	685	760	851	929	957
413	420	435	457	485	519	561	613	677	755	848	927	956
405	412	426	448	477	511	554	607	672	751	846	926	955
403	409	423	446	474	509	552	606	671	750	845	926	955
405	412	426	448	477	511	554	607	672	751	846	926	955
413	420	435	457	485	519	561	613	677	755	848	927	956
428	435	449	471	498	532	573	623	685	760	851	929	957
448	455	469	491	518	551	590	637	695	767	855	931	958
475	482	496	517	546	578	614	655	707	775	860	934	960
510	516	529	550	578	619	654	674	714	782	866	937	963
553	558	570	589	614	654	680	683	718	791	873	941	966
606	611	621	636	655	674	683	686	729	807	884	947	969
671	675	683	694	707	714	718	729	770	835	901	954	973
750	753	759	767	775	782	791	807	835	875	923	963	977
845	847	851	855	860	866	873	884	901	923	950	972	981
926	927	929	931	934	937	941	947	954	963	972	980	983
955	956	957	958	960	963	966	969	973	977	981	983	983



Central column temperature



954	955	956	957	959	962	965	968	972	976	980	983	983
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842	844	847	852	858	863	871	882	899	922	949	972	980
745	748	753	762	770	778	787	803	832	872	922	962	976
663	667	675	687	700	708	712	723	765	832	899	953	972
595	600	610	627	647	666	676	679	723	803	882	945	967
538	544	556	576	603	645	673	676	712	785	869	939	963
487	494	508	530	561	604	640	663	705	774	860	933	960
443	451	465	488	519	553	592	637	692	763	852	929	957
407	415	430	453	483	518	560	611	674	751	844	925	954
378	386	401	425	455	491	535	590	657	739	837	921	951
354	362	378	402	432	469	516	573	643	728	830	917	948
335	343	359	384	415	453	500	559	631	718	824	913	946
320	328	344	369	401	440	488	547	620	709	817	910	943
308	316	333	359	392	431	478	536	609	699	811	907	941
300	309	327	354	389	427	472	526	596	687	804	903	939
296	305	324	353	391	439	478	507	570	673	796	900	938
294	303	323	353	395	451	487	492	549	664	792	899	937
294	303	323	353	395	451	487	492	549	664	792	899	937
296	305	324	353	391	439	478	507	570	673	796	900	938
301	309	327	354	389	427	472	526	596	687	804	903	939
308	317	333	359	392	431	478	536	609	699	811	907	941
320	328	344	369	401	440	488	547	620	709	817	910	943
335	343	359	384	415	453	500	559	631	718	824	913	946
354	362	378	402	433	470	516	573	643	728	830	917	948
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745	748	754	762	770	778	787	803	832	872	922	962	976
843	845	848	853	858	864	871	883	899	922	949	972	980
925	926	927	930	933	936	940	946	953	962	972	980	983
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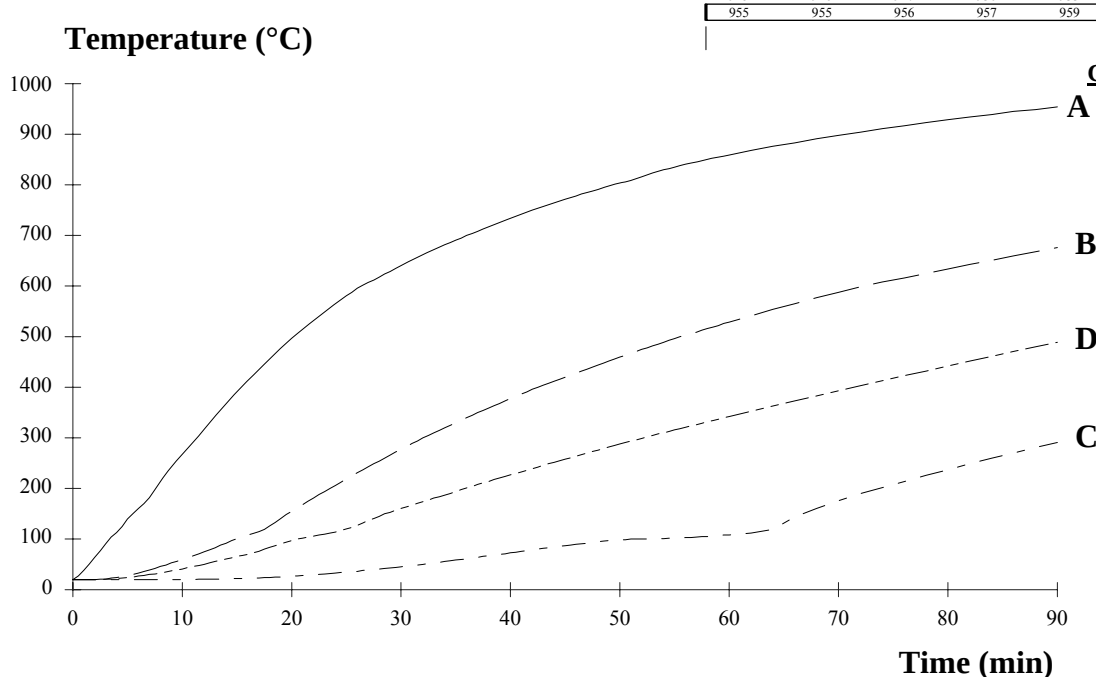

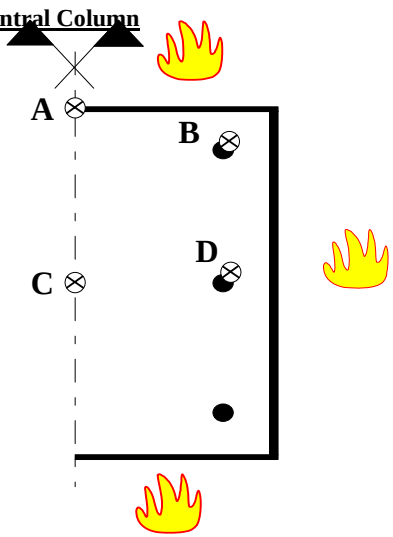

Bean-slab temperature

38	39	41	46	55	68	87	115	143	168	195	230	270	294	300	302	303	303	303
41	41	44	49	59	74	94	127	162	191	224	266	315	344	352	354	354	354	354
44	45	47	52	63	80	103	144	187	222	262	315	374	407	416	418	418	418	418
49	49	51	56	67	86	116	166	217	260	310	378	449	485	494	496	496	496	496
54	54	56	60	72	92	130	192	251	307	373	461	546	582	590	592	592	592	592
61	61	62	64	76	99	144	218	289	361	454	575	673	703	709	710	711	711	711
66	66	66	67	80	110	163	247	329	419	570	753	849	861	865	865	865	865	865
66	66	66	67	83	122	182	274	367	471	645								
68	68	68	71	89	132	200	300	400	512	679								
72	71	72	79	98	144	220	327	432	546	721								
76	75	76	86	109	159	242	354	463	576	745								
81	80	81	92	120	176	265	385	495	603	762								
86	85	86	97	129	193	289	424	534	624	771								
92	91	92	102	138	209	314	473	627										
99	97	97	107	148	225	339	525	750										
107	103	101	114	159	240	363	568	815										
118	111	104	123	173	255	384	598	836										
131	120	110	133	186	269	402	617	847										
147	135	125	146	199	283	417	630	855										
165	154	145	163	213	297	430	641	860										
185	175	165	182	229	311	443	650	864										
209	199	188	202	246	327	456	659	868										
236	225	212	224	266	343	469	668	872										
266	254	240	249	288	363	485	678	876										
301	287	271	278	314	385	503	690	881										
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383	367	346	349	380	444	551	721	894										
433	416	393	395	424	483	583	741	902										
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552	536	516	518	543	591	671	797	925										
624	612	598	603	625	666	732	835	940										
705	701	700	709	729	760	808	881	957										
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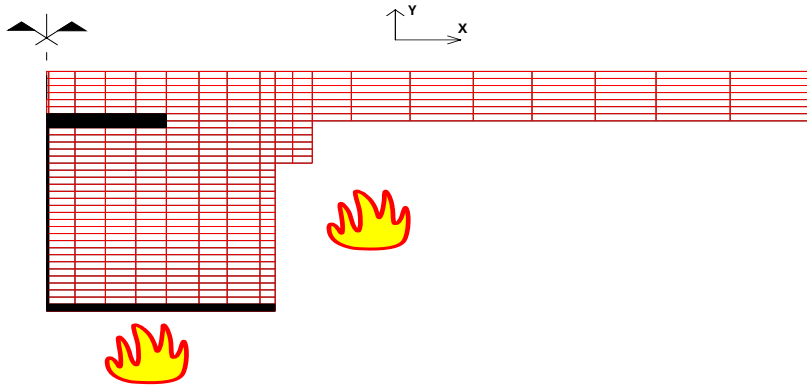
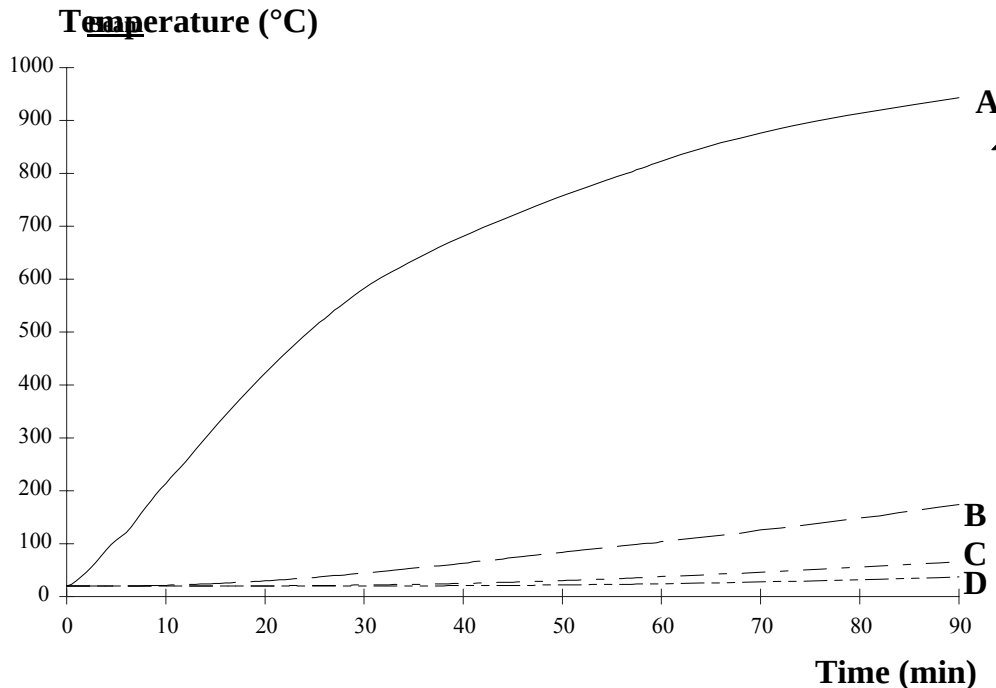
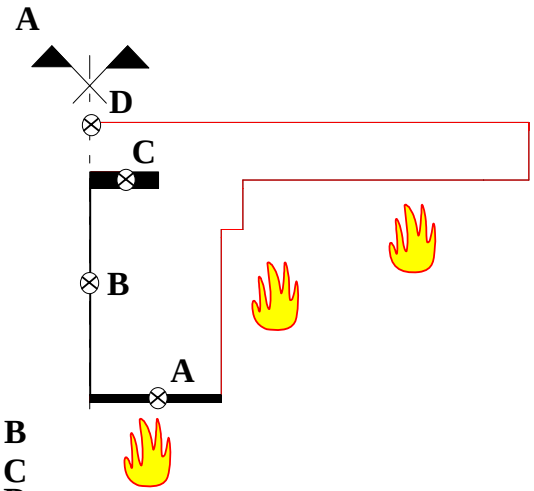
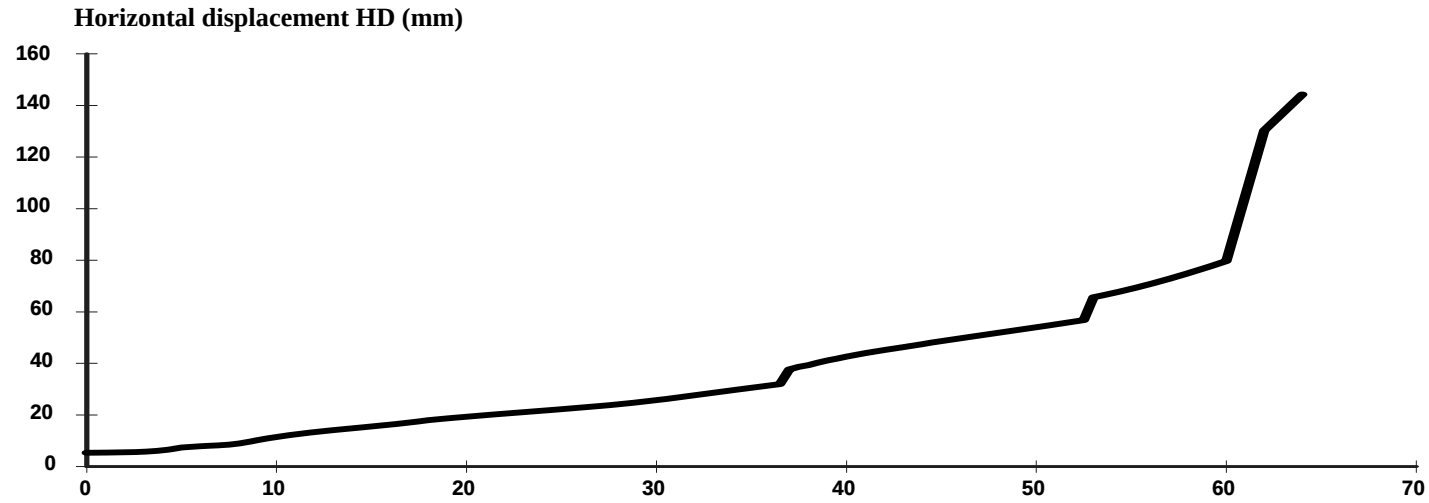
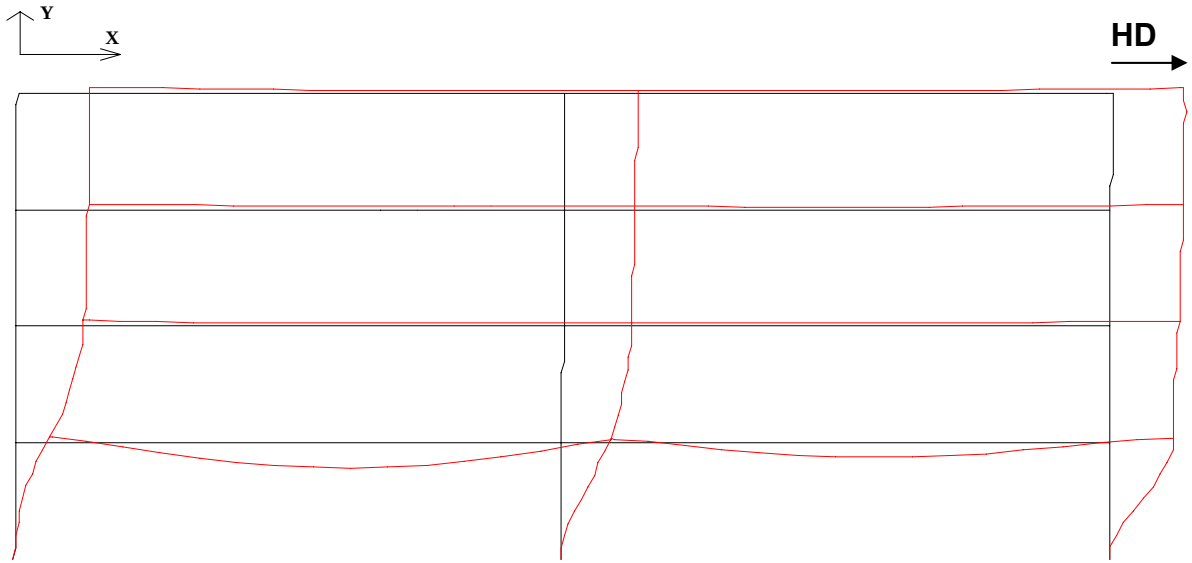




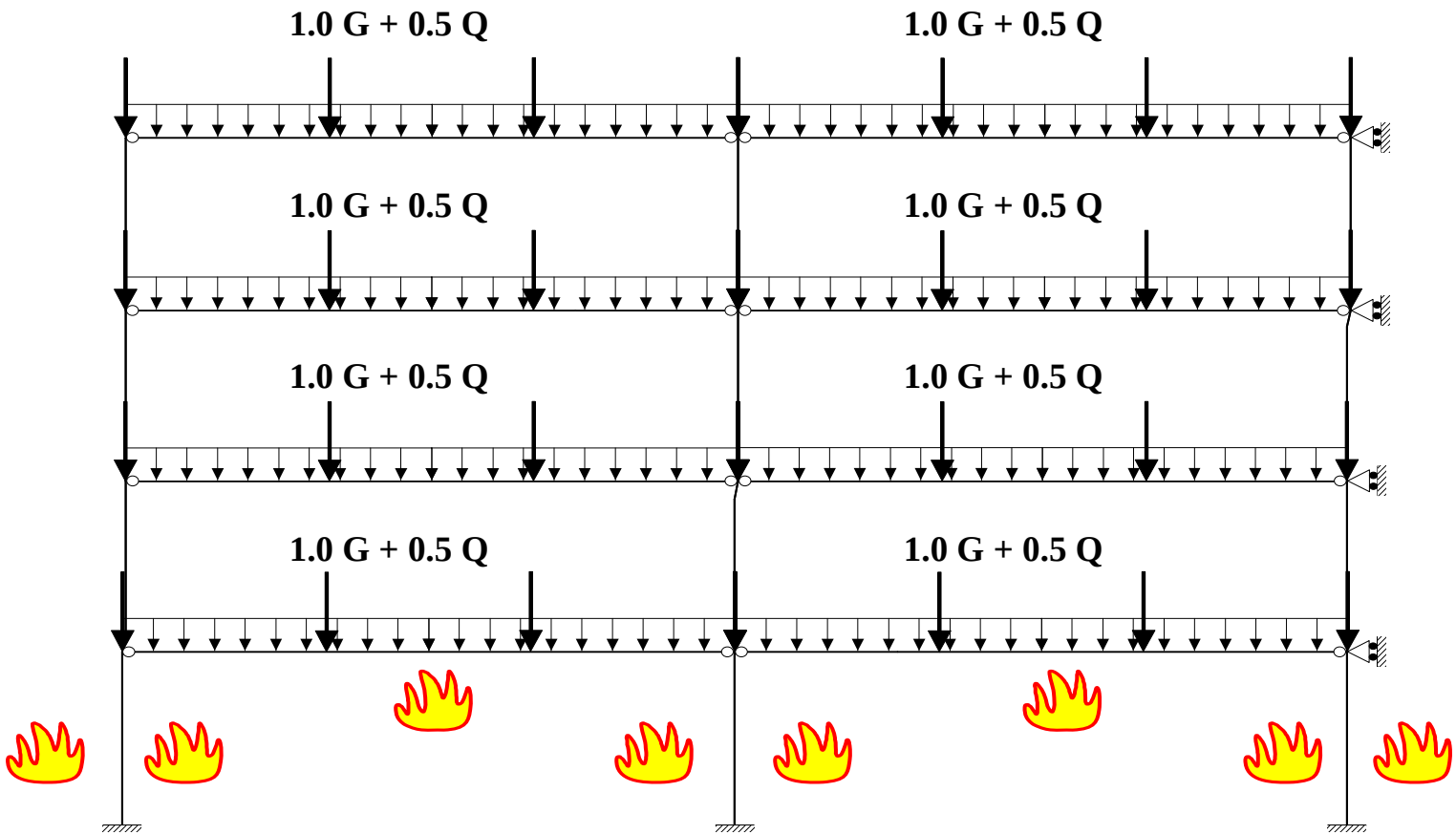


Deformations of the frame



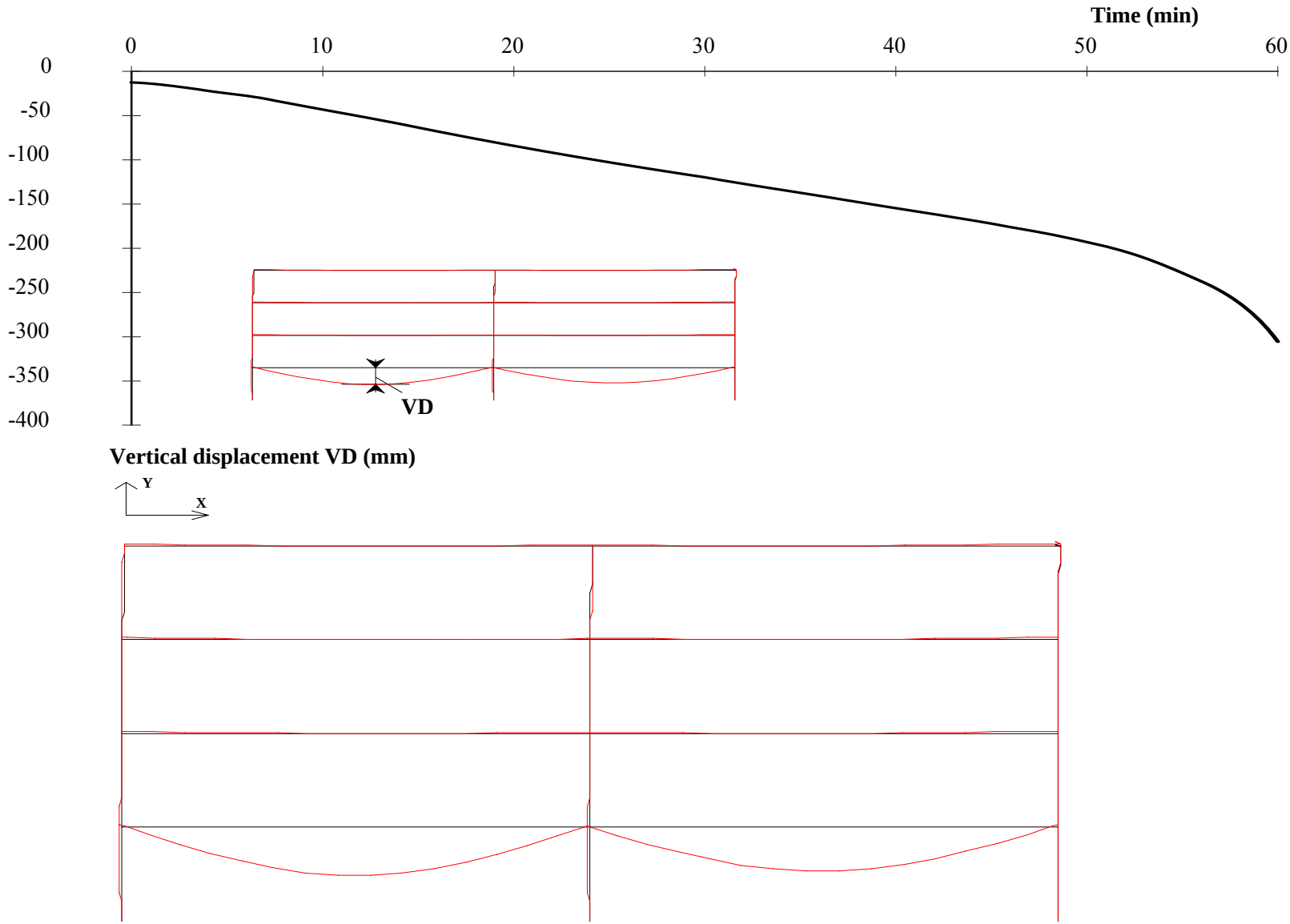


Braced frame

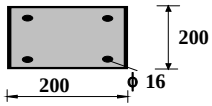
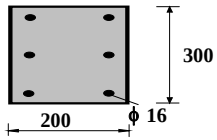
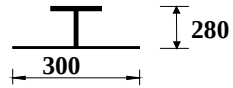
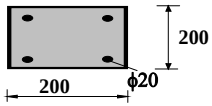
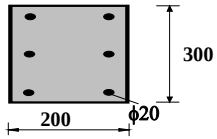
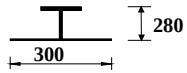
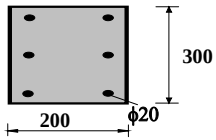
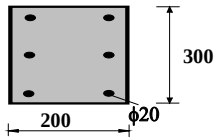
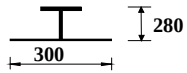
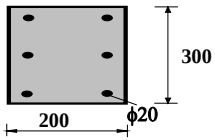
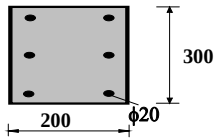
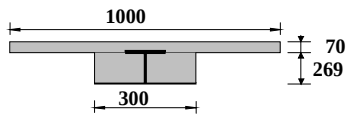
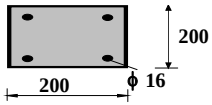
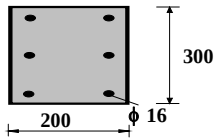
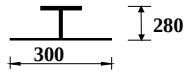
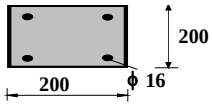
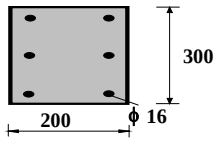
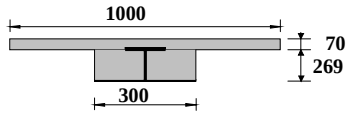


Braced frame

Deformation of frame



Comparison

° of ase	Restraint condition	dimension of external column	dimension of central column	dimension of beam	Fire resistan of the fram
ase 1	unbraced				37.5 minutes
ase 2	unbraced				44.5 minutes
ase 3	unbraced				60.5 minutes
ase 4	unbraced				64.0 minutes
ase 5	braced				47.5 minutes
ase 6	braced				60.0 minutes