Design of joints
to composite columns
for improved fire robustness

To demonstration fire tests

Wald F., Jána T. and Horová K.
Czech Technical University in Prague
September 2011

URL: fire.fsv.cvut.cz/test-veseli-2011

Design of joints to composite columns for improved fire robustness

To demonstration fire tests

Introduction

The aim of the Research fund for coal and steel, RFCS, project Design of joints to composite columns for improved fire robustness, COMPFIRE No RFSR-CT2009-0021, is to provide an integrated approach for the practical application of performance-based fire engineering design of composite structures including joint performance, under natural fire conditions including the cooling phase. By developing methodologies to evaluate the full 3D behaviour of joints between composite floor systems and composite columns, including an assessment of their ductility limits, and incorporating the joint models into global frame analysis, innovative solutions can be achieved which ensure cost-effective design against fire attack and a realistic estimation of real safety levels, and which avoid premature collapse of a composite structure in fire.

The project partners are: Czech Technical University in Prague, DESMO, a. s., Luleå University of Technology, Tata Steel Europe, The University of Manchester, The University of Sheffield a Universidade de Coimbra.

The major objectives of the work package No. 5 Demonstration fire tests are to provide experimental data on complete composite structural response under natural fire and to demonstrate impact of joints with improved detailing on structural fire robustness.

Design of joints to composite columns for improved fire robustness
To demonstration fire tests
Wald F., Jána T. and Horová K.

Česká technika - nakladatelství ČVUT
August 2011
ISBN 978-80-01-04871-9
500 copies, 26 pages, 32 figures

Table of Content

1 Experimental object

The two floor experimental object represents a part of an administrative building of dimension of 10.4 x 13.4 m, with a height of 9 m. The orientation of the wall with two window openings is to the east.

The object is located in PAVUS fire laboratory campus in Veselí nad Lužnicí, Czech Republic, GPS coordinates N49°11'49.686", E14°43'14.48", see Fig. 1. The load-bearing structure is designed according to Eurocodes [1] to [6].

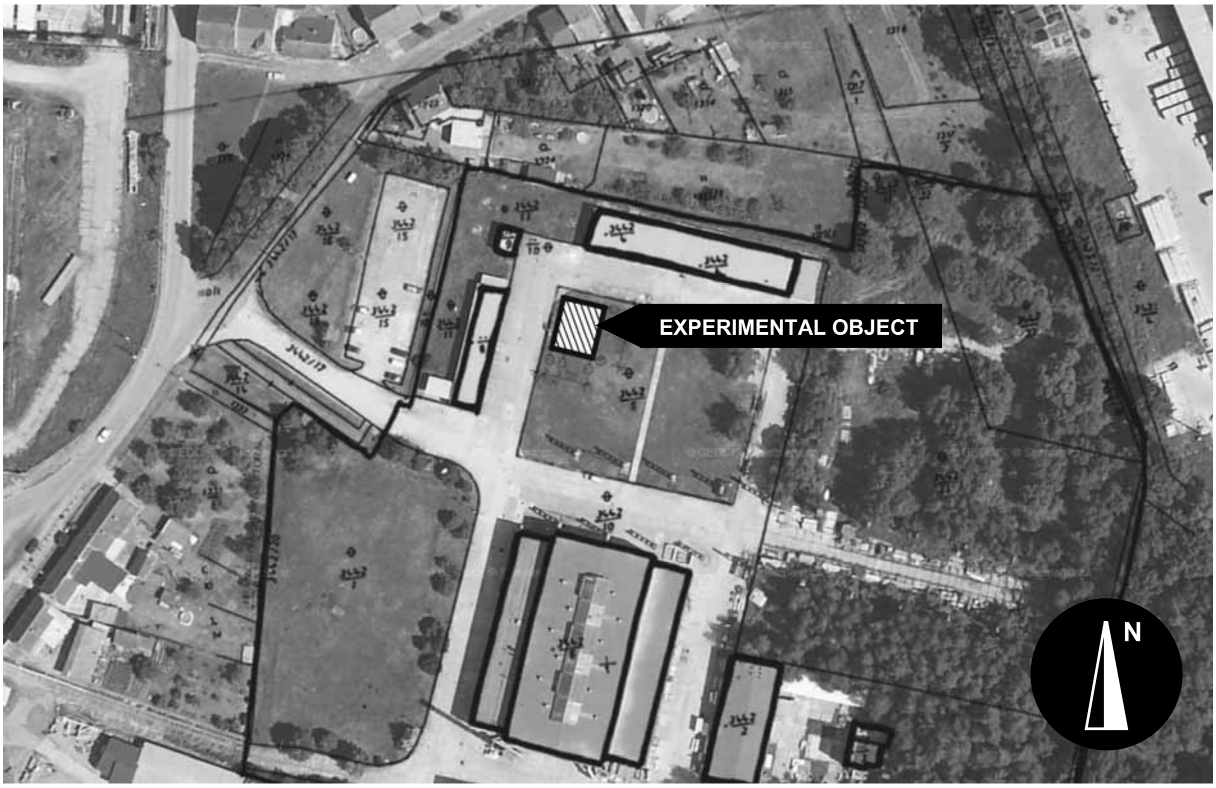


Fig. 1 Location of the experimental object

1.1 Mechanical load for design

The mechanical load was considered consistent with the typical office building design [1]. The variable action is prescribed by the characteristic value of 3.0 kN/m^2. The characteristic values of floorings and partitions are 0.5 kN/m^2 and 0.5 kN/m^2. The dead load of the experimental structure reached the characteristic value of 2.35 kN/m^2.

1.2 Load-bearing structure

The composite slabs of the ceilings are composed of simple trapezoidal sheets Cofraplus 60 (thickness 0.75 mm, steel S350) and concrete C30/37. The height of the concrete slabs is designed 60 mm; the total thickness of the ceilings in lower and upper floor is 120 mm and 100 mm respectively. A ribbed mesh ø 5 mm 100/100 mm was used in the lower concrete slab with the strength of 420 N/mm^2. The upper concrete slab is reinforced with steel wires ø 1 mm length of 60 mm (average tensile strength of 1450 N/mm^2) in quantities 30 kg/m^3.

The beams under the slabs are designed from profile IPE 270, steel S355 and the edge beams from profile IPE 240 steel S355. The lower concrete slab is connected with the beams by Nelson headed shear connectors and the upper concrete slab is connected by X-HVB 110 shear connectors.

The beams are supported by round tube columns (profile TR 245/8, steel S355) filled with concrete C30/37 and columns from sections HEB 200. The horizontal stiffness of the building is carried out by two cross bracings of a tube section 60.3x4 in the both directions. Experimental object is shown in Fig. 2 to Fig. 4.

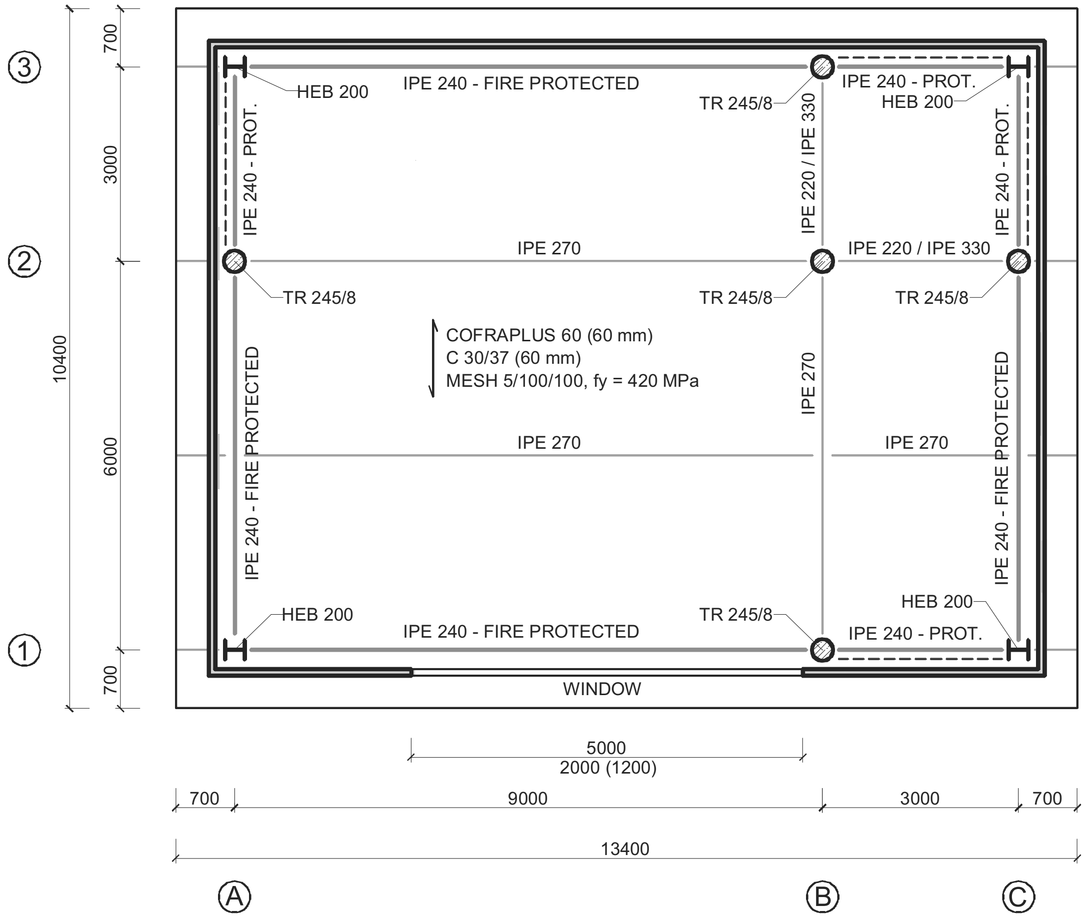


Fig. 2 Ground plan of the experimental object

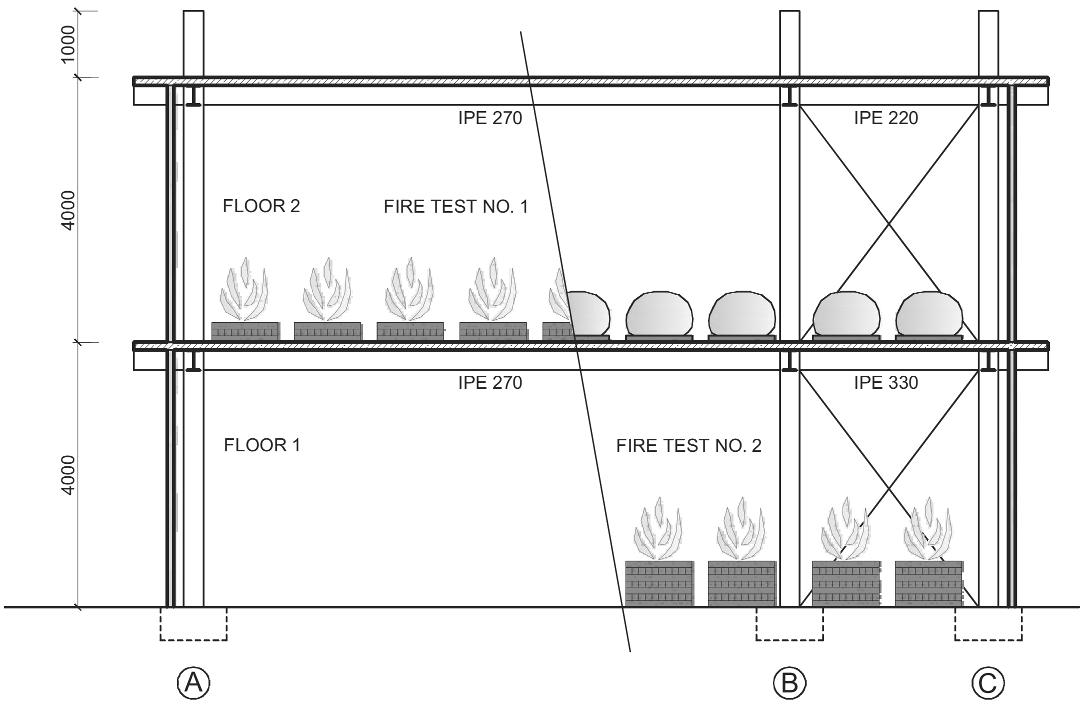


Fig. 3 Vertical section of the experimental object

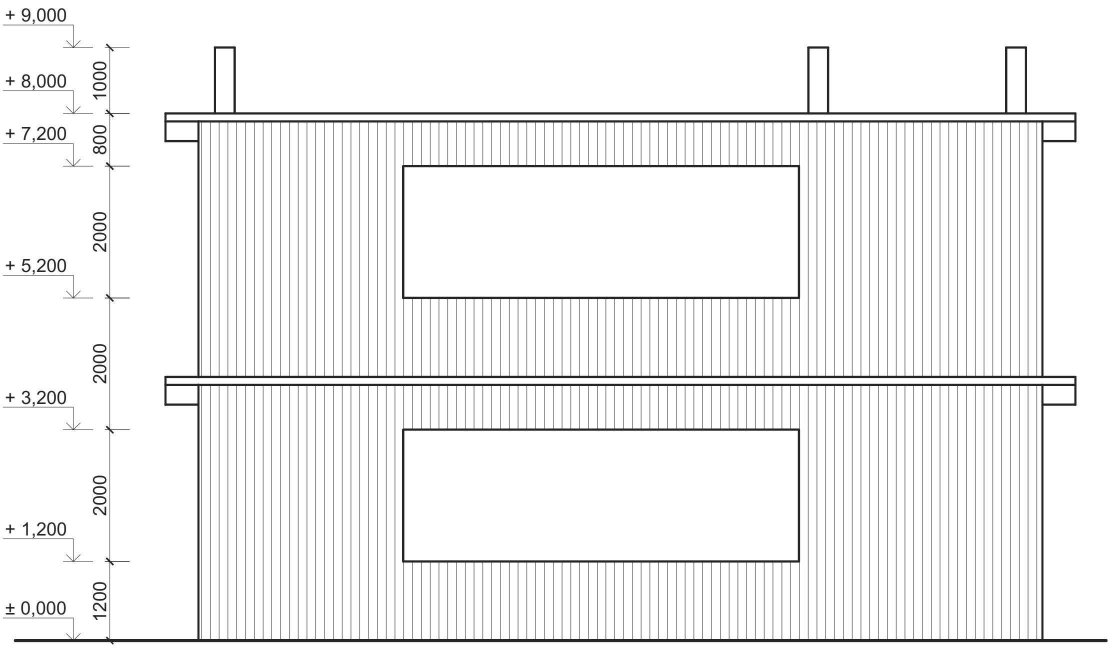
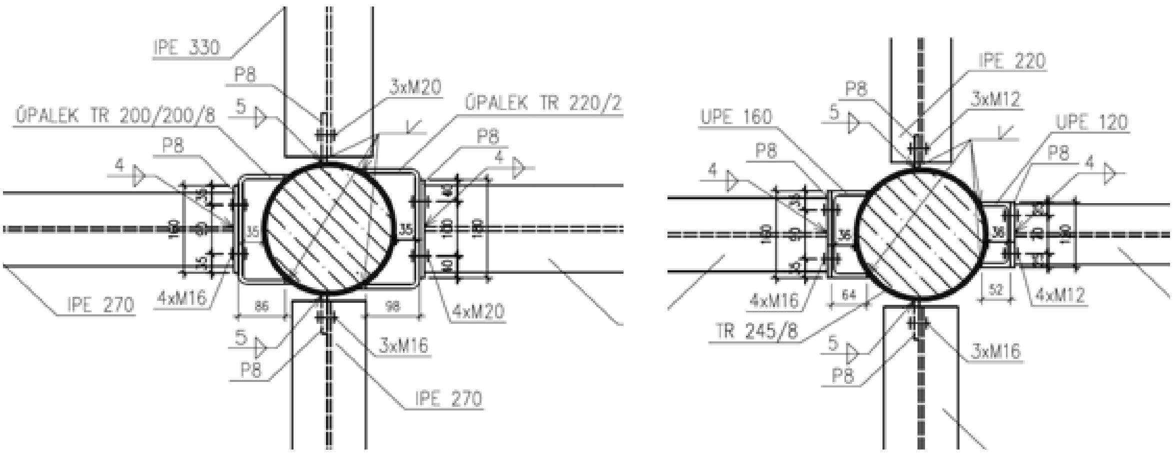


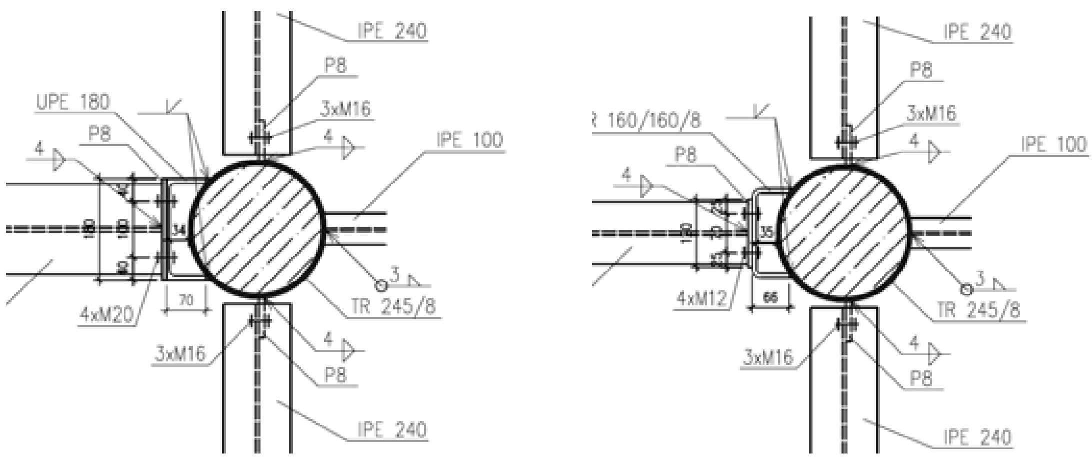
Fig. 4 View of the experimental object

1.3 Connections



a) b)

Fig. 5 Tested reverse channel and fin plate connections (column B2): a) in the 1st floor, b) in the 2nd floor



a) b)

Fig. 6 Tested reverse channel connections (column C2): a) in the 1st floor, b) in the 2nd floor

Fin plate connections and reverse channel connections are designed to resist the shear force only at ambient temperature. The joints design is realized according to Eurocode [4] and checking of connections is performed according to the SCI/BCSA 'Green Book' [7] for fire situation. Some of the connections used in the structure are presented in the Fig. 5 to Fig. 8. All bolts are grade 8.8 and additional material of steel S355.

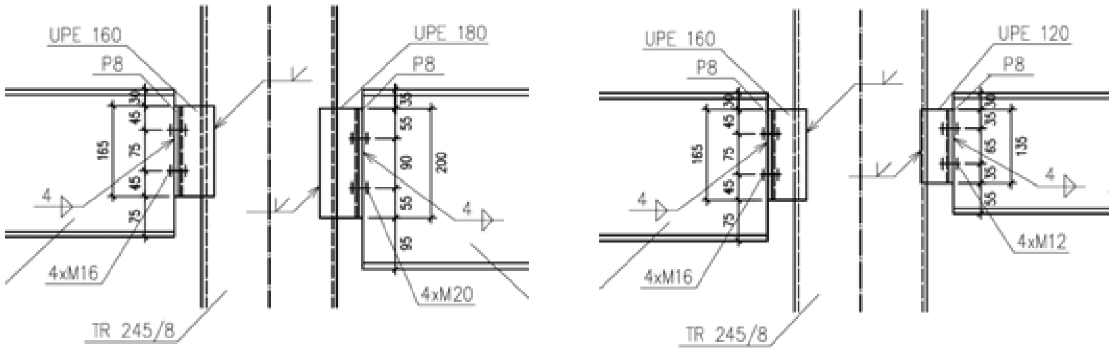


Fig. 7 Tested reverse channel connections (column B2): a) in the 1st floor, b) in the 2nd floor

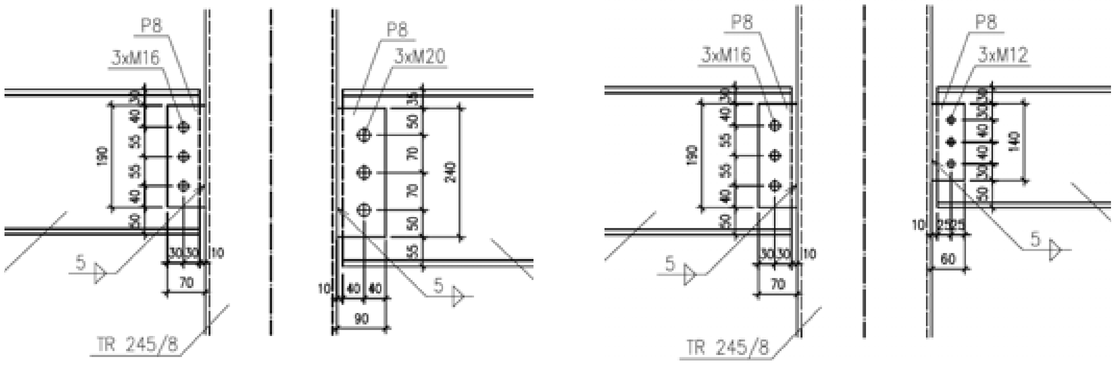


Fig. 8 Tested fin plate connections (column B2): a) in the 1st floor, b) in the 2nd floor

1.4 Cladding

1st floor

Cladding around 1st floor is based on Rockprofil Cassette System with insulation Rockwool Airrock ND for Rockprofil covering noses of linear trays for reduction of thermal bridges. The exterior face is diverse and fixed by special distance screws SFS intec. The arrangement of cladding can be seen in Fig. 9 to Fig. 12.

Field I-7,5m: The basic system of Rockprofil, but for the first time is prepared for testing for span of linear trays L = 7,5m. Therefore linear trays K 130/600/0,88 mm are used + Airrock ND for Rockprofil 165 mm + vertical trapezoidal sheet TR 35/207/0,75 mm fixed by distance screws SFS intec

Field II-3,0m: On linear trays K 120/600/0,75 mm with Airrock ND 155 mm are fixed by distance screws vertical modular clamp profiles carried 300 mm lamella system.

Fields III to VII, IX: Interior part of cladding is the same: linear trays K 120/600/0,75 mm + Airrock ND 155 mm and external face is changing, see below.

Field III-3,0m: Facade cassettes KP-FORM+, width 500 mm are fixed on vertical system of omega profiles, connected to linear trays by distance screws.

Field IV-6,0m: Facade cassettes KP-FORM XL+, width 1000 mm, reinforced on left flank by glued mineral wool plate 30 mm, on right flank by glued gypsum-cardboard 10 mm plate. Cassettes are carried by vertical system of omega profiles again.

Fields V-3,0m, VI-5,4m, VII-3,6m: Vertical trapezoidal sheet TR 35/207/0,63-0,75 mm fixed by distance screws is used.

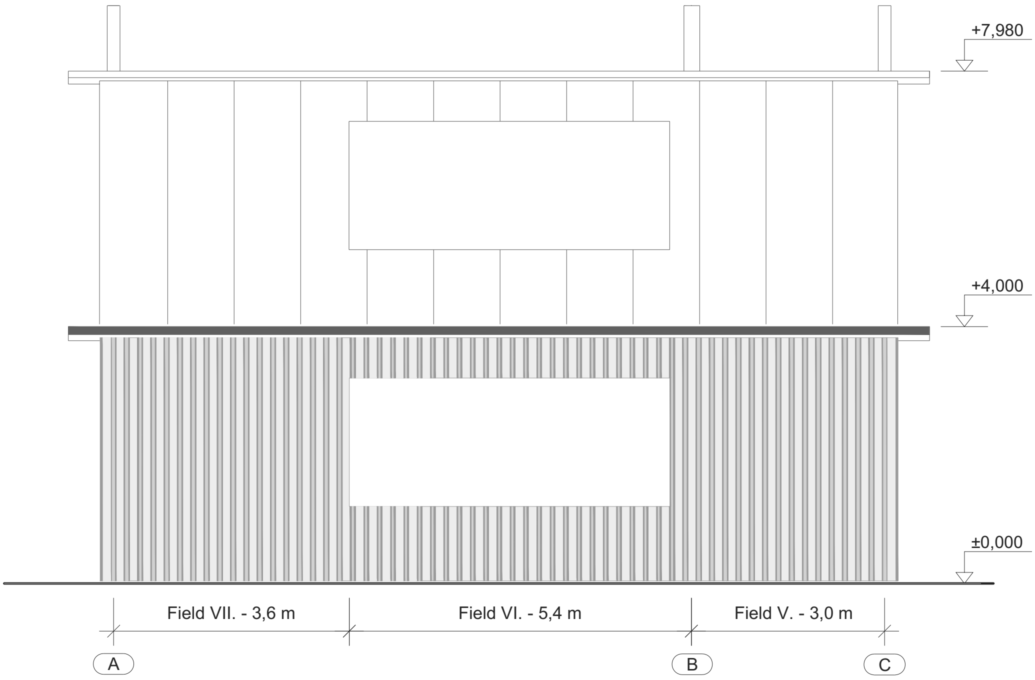


Fig. 9 Wall in axis "1"

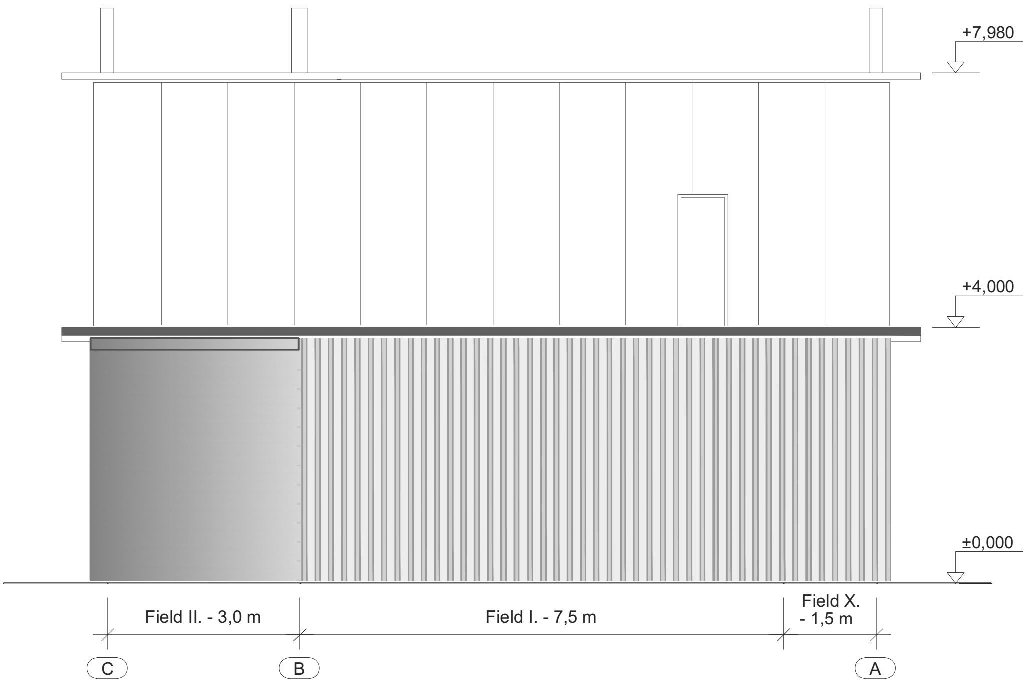


Fig. 10 Wall in axis "3"

Field VIII-6,0m: Linear trays K 120/600/0,75 mm with mineral wool Airrock LD 120. Vertical system of Z-profiles 40 mm, distanced 1000 mm and fixed directly to linear trays. Between Z-profiles are mineral wool Airrock ND plates 40 mm thick. On Z-profiles are horizontally laid sandwich panels with mineral wool core, TRIMO 60mm Invisio, screwed to Z-profiles.

Field IX-3,0m: Vertical system of omega profiles spaced 750 mm and fixed by distance screws. Horizontal cladding of Aluminium composite panels Alpolic®/fr is connected to omega profiles by aluminium rivets.

Field X-1,5m: The same system as Filed I, for complement span 1,5 m only.

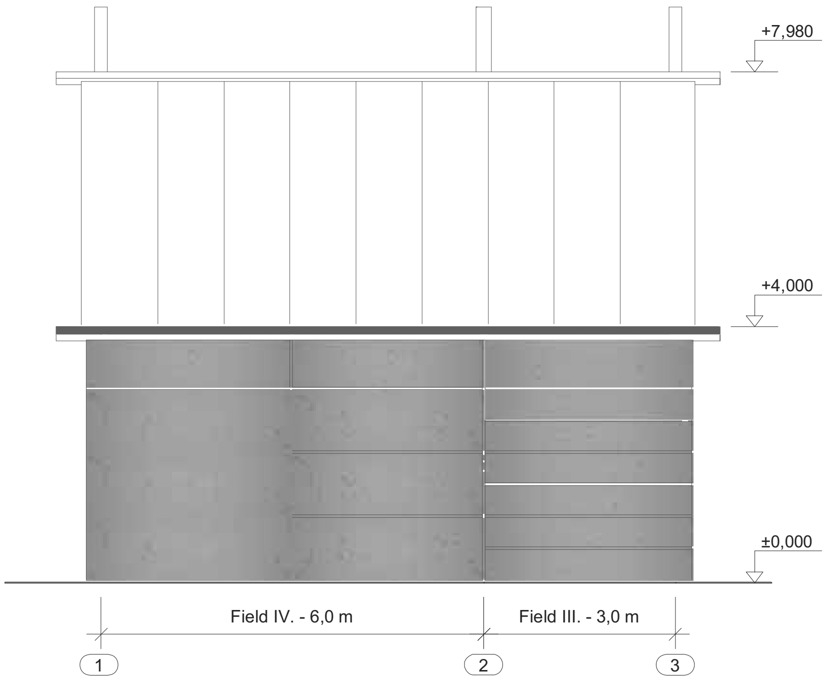


Fig. 11 Wall in axis "C"

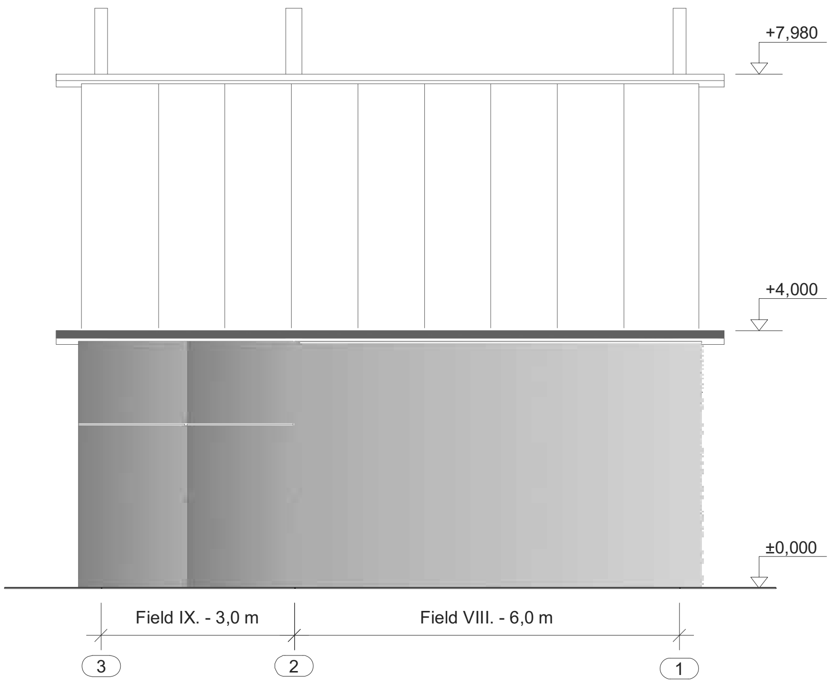


Fig. 12 Wall in axis "A"

2nd floor

Classic and simple assembled cladding is used: linear trays K 120/600/0,75 mm + mineral wool Rockwool 120 mm density ca 40 kg/m3 + trapezoidal sheet TR 35/207/0,63 mm.

The window opening (5 x 2 m) without glass is situated in the front wall in each of two floors. The door with fire resistance is situated in back part of upper fire compartment. This door is placed in the wall of the fire compartment due to the initiation burning of the fire load. During fire tests the door will be closed.

1.5 Fire protection

The bearing steel structure is partially protected by fire spray PROMASPRAY F250. The used protection is a mixture of mineral fibers and cement binder.

On the second floor (the 1st fire test), connections of the central beams with a span of 9 m, cross bracings and cladding columns are fire protected. Spray thickness is 20 mm.

On the first floor (the 2nd fire test), connections of the all three meters beams, cross bracings, cladding columns, corner columns HEB 200 and all edge beams are fire protected. Spray thickness is 60 mm.

1.6 Auxiliary structures

Stair tower for access to the ceiling above the first and second floors and the relocatable frame truss girder for deformation measuring of floor slabs complete structure of the experimental object.

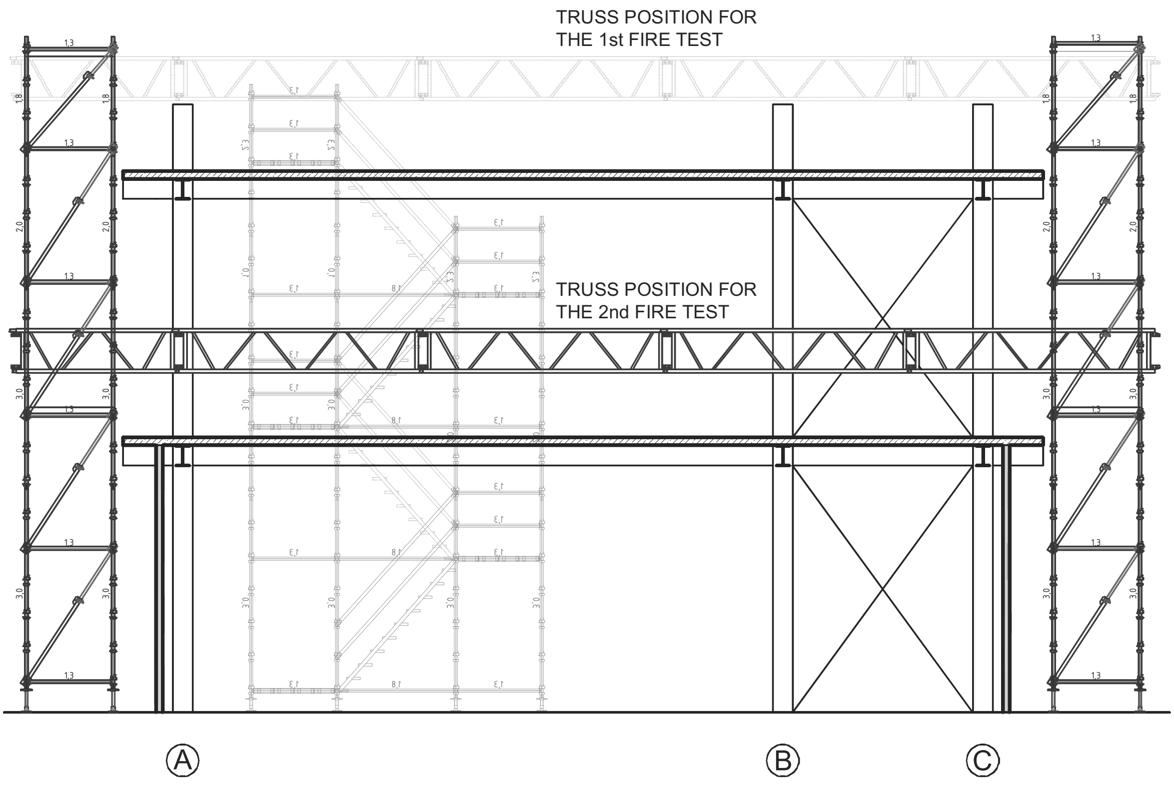


Fig. 13 Auxiliary structures

2 Fire test no. 1

The planned execution date of the 1st fire test is **06/09/2011.**

The main objective of the fire test in the 2nd floor is observation of heat transfer in the steel structure during so-called travelling fire.

2.1 Fire load

The fire load is created by piles from wooden cribs (50 x 50 x 1000 mm). The cribs of softwood are dried to moisture to 12 %. 8 x 3 wooden piles are placed closely together. Each pile consisted of 6 layers with 7 cribs, a total of 42 cribs. Total volume of ligneous mass used is 2,52 m^3, that means 9.9 kg/m^2 or 173.5 MJ/m^2. A linear ignition source is used on the left-hand side by the aid of thin-walled channel filled by mineral wool and penetrated by paraffin in the third layer of cribs.

The opening of size 2.0 x 5.0 m with parapet of 1.20 m will ventilate the fire compartment. To allow a smooth development of the fire no glass will be installed. The door is in the wall of the fire compartment due to the initiation burning of the fire load. During the entire fire test it will be closed.

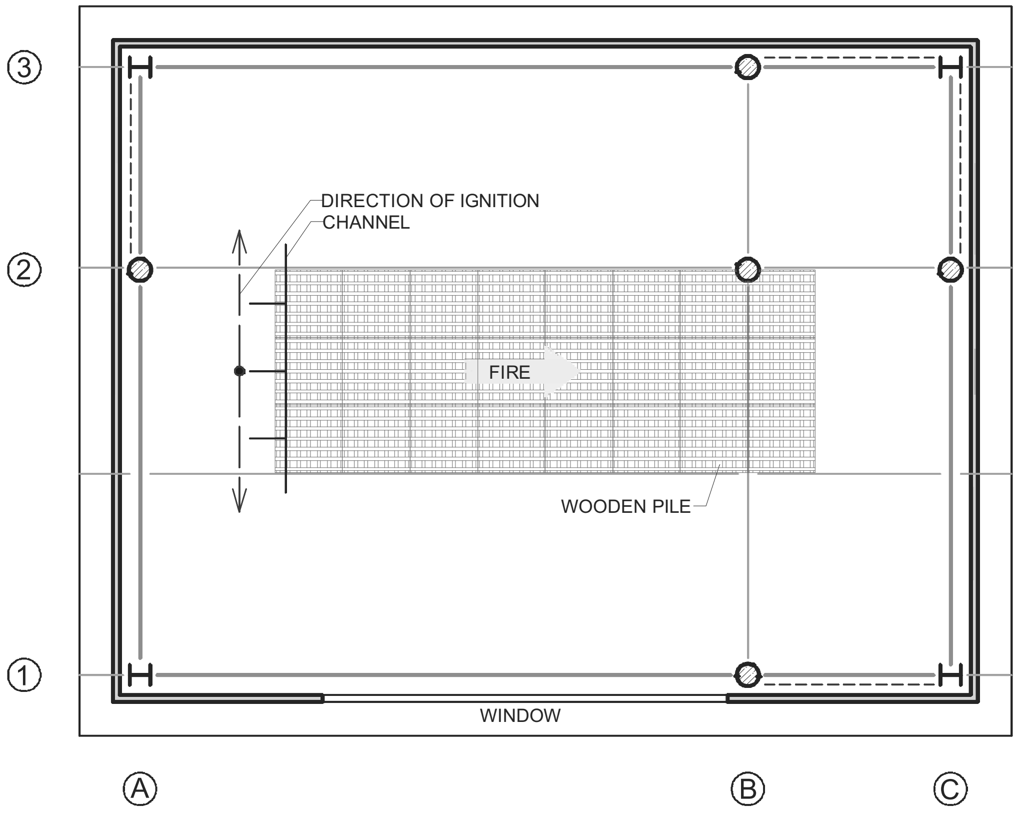


Fig. 14 Position of timber piles in the 2nd floor and fire ignition scheme

2.2 Predicted gas temperature

According to simulate in FDS, the fire travels from left to right. The spread speed is not constant. The maximum temperature of hot smoke of last simulate for the arrangement 7 x 2 piles was about 350 °C, see Fig. 15. For that reason the amount of wooden fuel was increased to 8 x 3 piles (see above). Hot smoke temperature is expected about 500 °C.

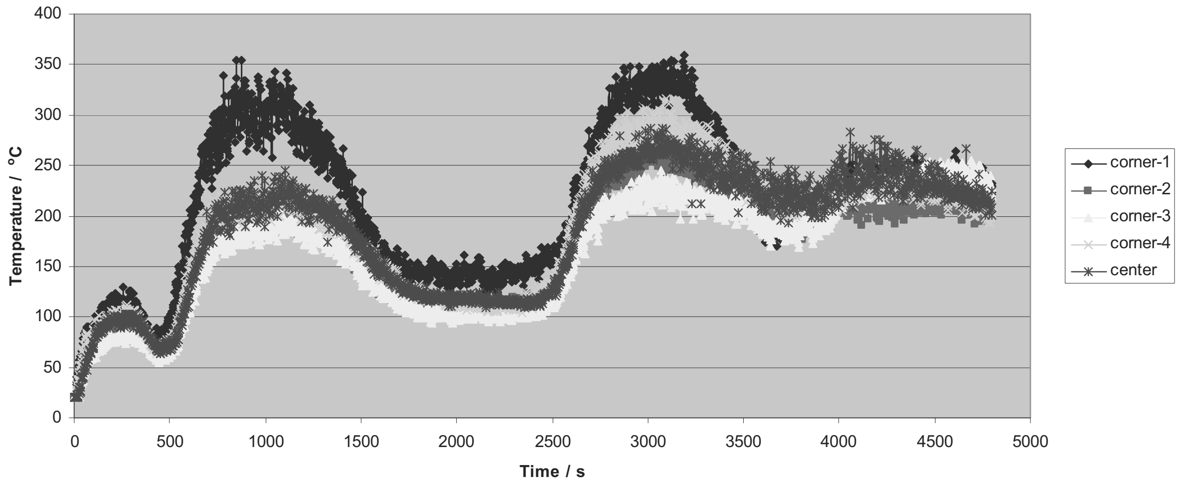


Fig. 15 Predicted gas temperature at the 1st fire test for 7 x 2 wooden piles

2.3 Measurements

Measurements consist of 97 thermocouples to measure gas (20 pcs.), mid-span beams (8 pcs.), reverse channel connections (23 pcs.), fin plate connections (27 pcs.), composite slab (7 pcs.) and column (12 pcs.) temperatures. 7 pieces of plate thermocouples is used to measure adiabatic surface temperatures. Vertical and horizontal deformations of the slab are measured from the scaffold located 1 m above the structure in 5 points. 32 pieces of high temperature strain gauges is located on the round tube columns to predict the forces for connection design. Measurement will be performed by radiometers, pitot tubes, weather station and scan as well. Digital, video and thermo cameras will allow recording the structural behaviour and temperature developments in the structure and walls. Measurements are summarized in Tab. 1, Fig. 16 and Fig. 17.

Tab. 1 List of measurements at the 1st fire test (part 1)

Measurements										
Fire test no. 1										
Meter	**Company**									
Specification	**PAVUS**		**ÚTAM**		**TÚPO**		**VŠB – TUO**		**CTU**	
Thermocouple										
Gas temperatures			11	(TG1 - TG11)						
Gas temperatures					9	(TG12 – TG20)				
Beam temperatures	8	(TB1 - TC8)								
Temp. of reverse channel connection	23	(TC1 - TC23)								
Temp. of fin plate connection	27	(TC24 – TC50)								
Temperatures of the concrete slabs	7	(TS1 – TS7)								
Column temperatures			12	(TSG1 – TSG12)						
Plate thermometer										
Adiabatic surface temperatures	7	(PT1 – PT7)								
Strain gauge										
Relative deformation of columns			32	(SG1 – SG32)						
Pitot tube										
Gas temperature					2	(PTG1 – P2)				
Barometric pressure					2	(PBP1 - PBP2)				

Tab. 1 List of measurements at the 1st fire test (part 2)

Meter	Company									
Specification	PAVUS		ÚTAM		TÚPO		VŠB – TUO		CTU	
Deflectometer										
Vertical deflection of concrete slab			3	(V1 – V3)						
Horizontal deflection of concrete slab			2	(H1 – H2)						
Radiometer										
Radiant flux					2	(R1 – R2)				
Sampling tube										
Chemical gas analysis					1	(ST1)				
Weather station										
Air temperature							1	(WAT1)		
Barometric pressure							1	(WBP1)		
Air humidity							1	(WAH1)		
Wind speed							1	(WWS1)		
Photogrammetry										
Before fire test									1	(PG1)
After fire test									1	(PG2)
Thermocamera										
Structure temperatures									1	(TCM1)
Video camera										
Digital camera										

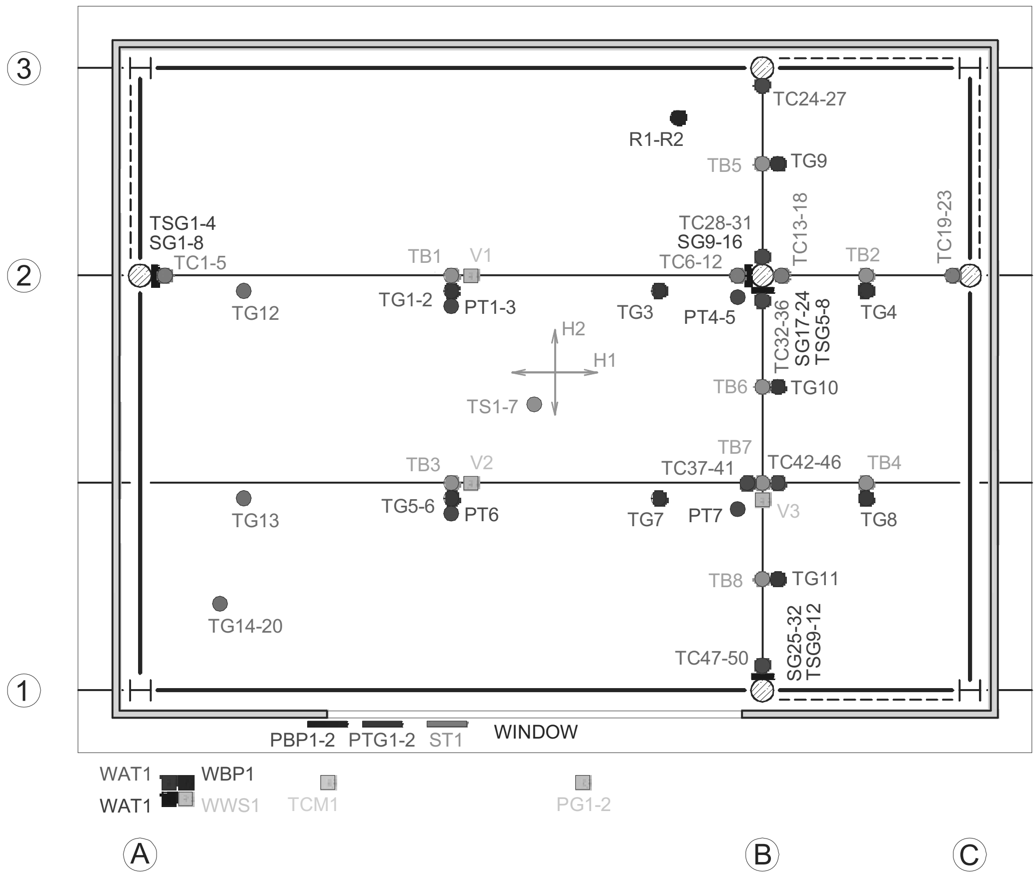


Fig. 16 Diagram of measurements at the 1st fire test (ground plan)

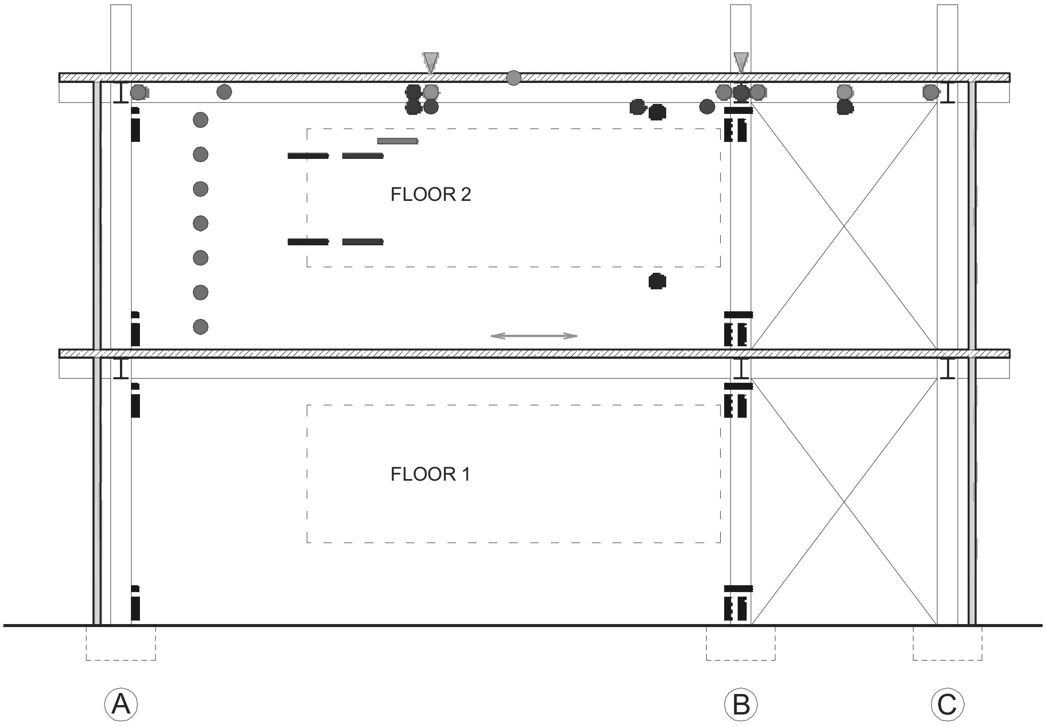


Fig. 17 Diagram of measurements at the 1st fire test (vertical section)

3 Fire test no. 2

The planned execution date of the 2nd fire test is 15/09/2011. Development of fire in the 1st floor should correspond to fire scenario in a regular administrative building.

The main objectives of the fire test are observations of heat transfer in the steel structure, identifying temperature influence between the protected and unprotected steel members and verification ductility of the connections to allow membrane action of the composite slab.

3.1 Fire load

The fire load is created by piles from wooden cribs. The cribs of softwood are dried to moisture to 12 %. In the compartment 28 wooden piles are placed and total volume of ligneous mass used is 7,653 m^3, see Fig. 18. Each pile consisted of 11 layers with 10 cribs, a total of 110 cribs. Total fire load is 30.1 kg/m^2, that means 525.0 MJ/m^2. Due to simultaneous ignition of the piles, they are joined together by thin-walled channels filled by mineral wool and penetrated by paraffin in the third layer of cribs.

The opening of size 2.0 x 5.0 m with parapet of 1.20 m will ventilate the fire compartment. To allow a smooth development of the fire no glass will be installed.

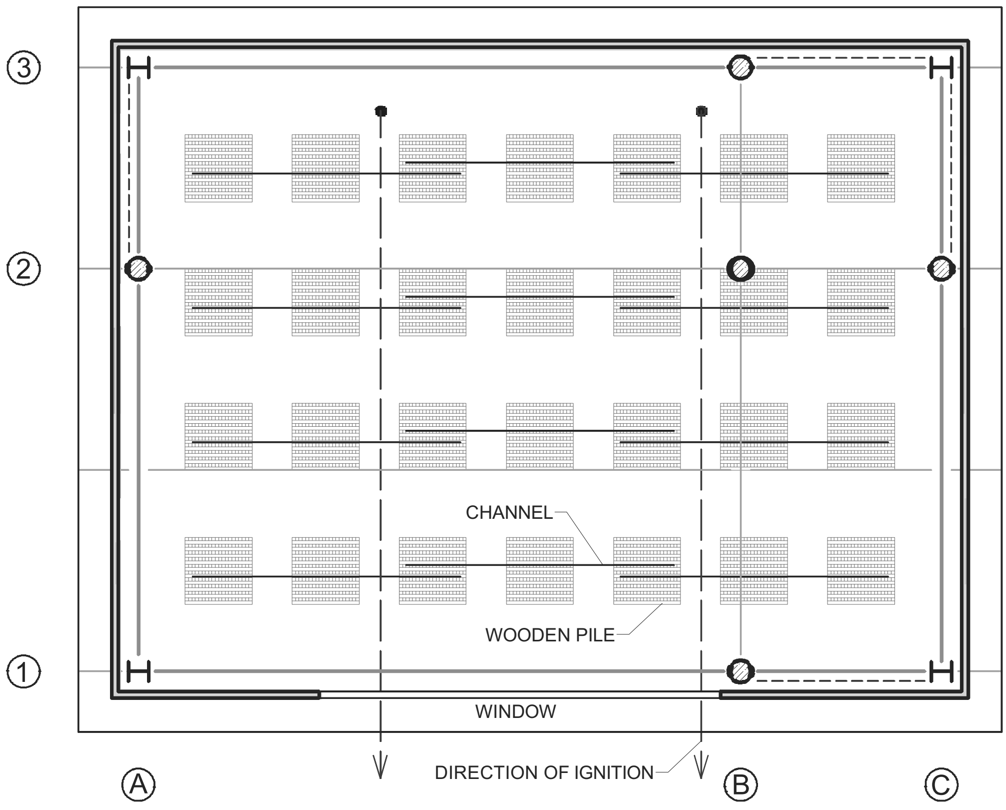


Fig. 18 Position of timber piles in the 1st floor

3.2 Predicted gas temperature

Maximum temperature 1046 °C is predicted at 60th min of the fire test in the 1st floor. Tools Ozone V2.2 [8] was used to predict the temperature curve. Graphical output is shown in Fig. 19.

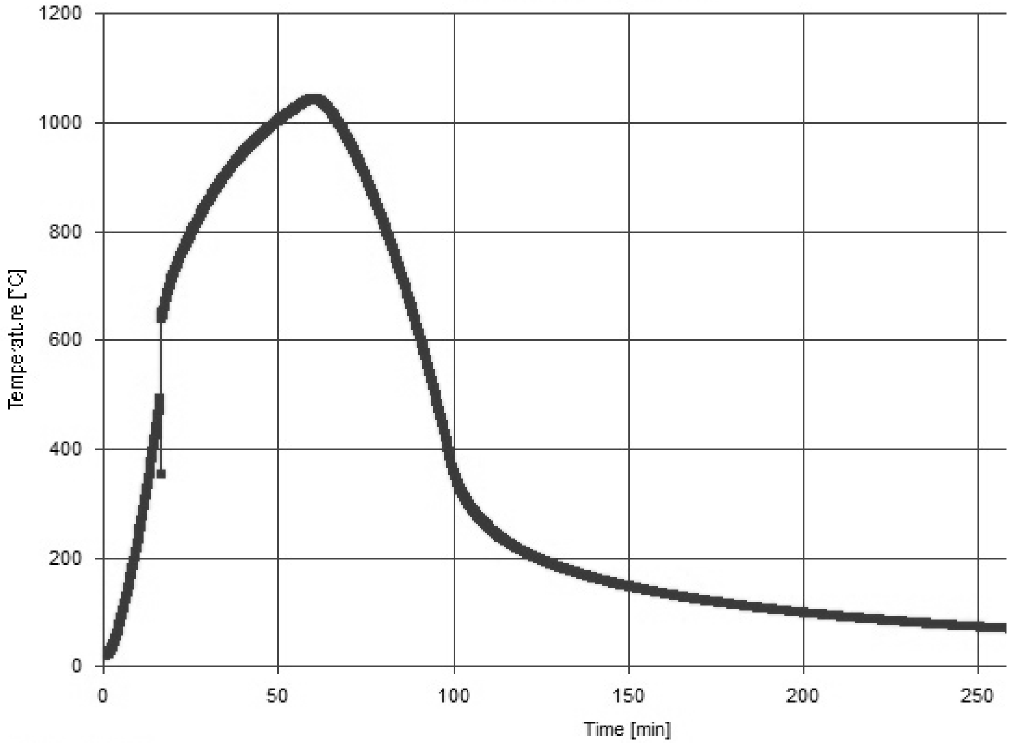


Fig. 19 Predicted gas temperature at the 2nd fire test

3.3 Mechanical load

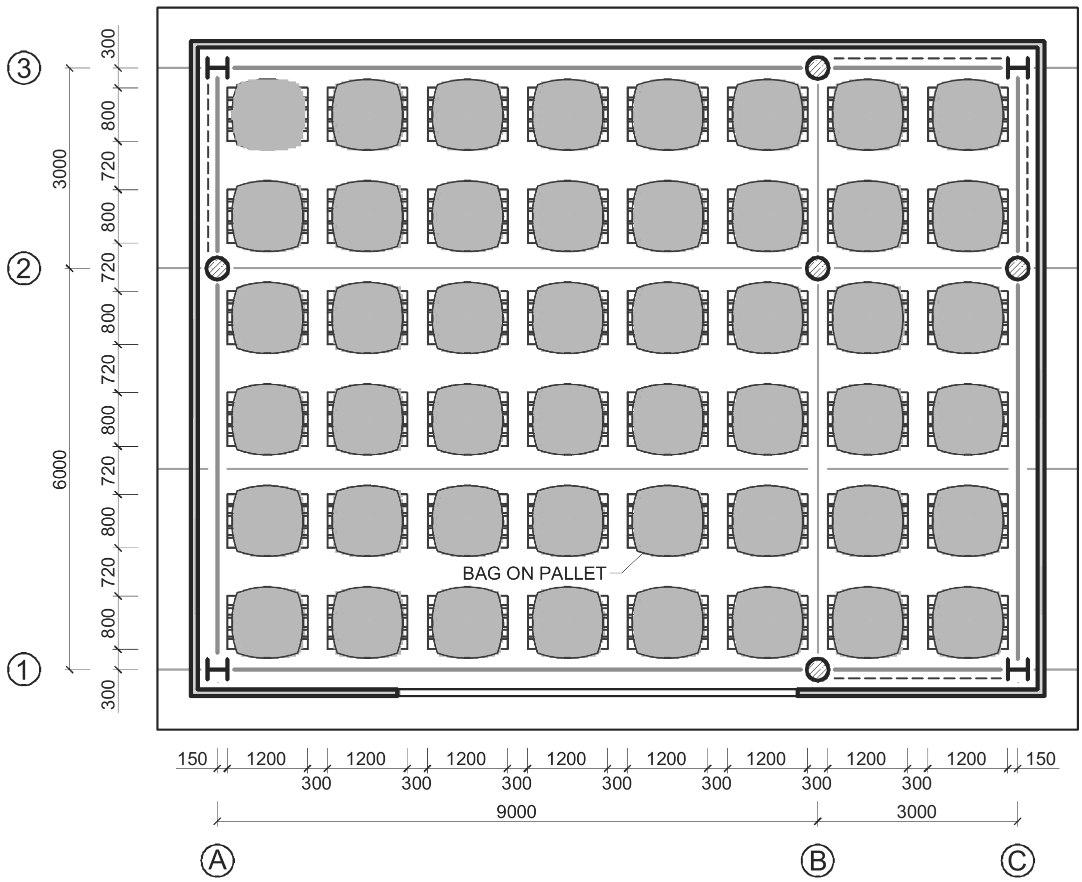


Fig. 20 Position of pallets and bags with road metal

The mechanical load for the 2nd fire test is simulated by plastic bags filled with road-metal. During the fire situation, the mechanical load is below the maximum value. The applied load represented the characteristic value of the variable action for an elevated temperature 1.5 kN/m2, the characteristic value of floorings of 0.5 kN/m2 and the characteristic value of partitions of 0.5 kN/m2.

The bags on the composite slab above the first floor are organized into matrix 8 x 6, see you Fig. 20. They are placed on wooden pallets to ensure uniform distribution of the mechanical load on the ceiling structure. The weight of each bag is approximately 550 kg (excluding pallet).

3.4 Simple mechanical analysis

The mechanical analysis of the composite slab above the first floor during the second fire test has been done by simple model software FRACOF [9]. The model includes the membrane action of the slab by enhancement factor of bending resistance. According to the simple model, load capacity utilization rate of the ceiling structure at the 60. min of the fire test is 99 %. The results are summarized in Tab. 2. Fig. 21 and Fig. 22 show the graphical output from the software FRACOF.

Tab. 2 Table output of software FRACOF

Time	Beam	Mesh	Slab top	Slab bottom	Beam capacity	Maximum allow able deflection	Slab yield	Enhance ment	Slab capacity	Total capacity	Unity factor
mins	°C	°C	°C	°C	kN/m²	mm	kN/m²		kN/m²	kN/m²	
0	20	20	20	20	10,22	174	0,64	2,76	1,78	12,00	0,42
10	78	23	20	76	10,22	206	0,64	3,09	1,99	12,21	0,41
20	525	47	26	377	8,19	372	0,64	4,82	3,10	11,30	0,44
30	799	106	47	648	1,46	512	0,64	6,28	4,04	5,50	0,91
40	894	167	77	792	0,82	577	0,64	6,96	4,48	5,30	0,95
50	958	246	110	882	0,63	600	0,64	7,20	4,63	5,27	0,95
60	1005	321	145	945	0,51	600	0,64	7,19	4,57	5,09	0,99
61	1009	328	148	951	0,50	600	0,63	7,19	4,56	5,06	0,99
62	1013	335	151	956	0,49	600	0,63	7,19	4,54	5,03	1,00
63	1017	341	161	961	0,48	600	0,63	7,19	4,52	5,00	1,00
64	1020	348	168	965	0,47	600	0,63	7,19	4,50	4,97	1,01
65	1022	354	175	968	0,47	600	0,62	7,19	4,48	4,95	1,01
66	1021	360	180	969	0,47	600	0,62	7,19	4,47	4,93	1,02
76	958	411	221	931	0,63	574	0,59	6,90	4,06	4,69	1,07
86	835	438	248	832	1,20	503	0,54	6,14	3,34	4,54	1,10
96	680	441	266	699	3,58	418	0,54	5,27	2,84	6,42	0,78
106	500	423	274	546	8,73	327	0,57	4,34	2,47	11,19	0,45
116	349	390	274	424	10,21	259	0,61	3,64	2,22	12,44	0,40
126	274	354	266	356	10,22	225	0,62	3,29	2,05	12,27	0,41
136	230	322	255	309	10,22	205	0,64	3,08	1,96	12,18	0,41
146	200	296	241	274	10,22	193	0,64	2,96	1,90	12,12	0,41
150	190	287	235	263	10,22	190	0,64	2,92	1,88	12,10	0,41

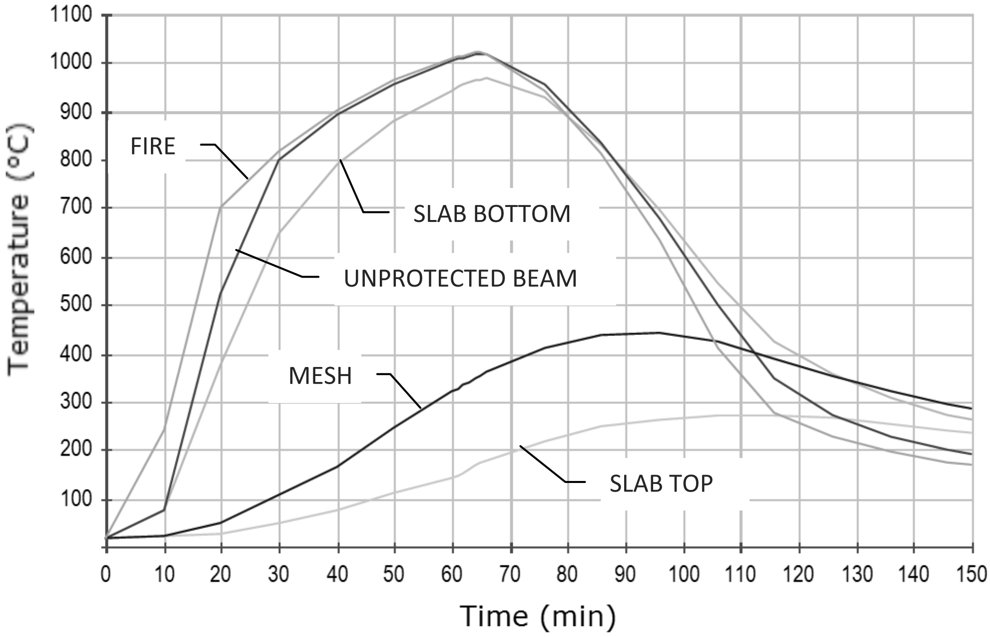


Fig. 21 Predicted temperatures in the ceiling structure at the 2nd fire test (soft. FRACOF)

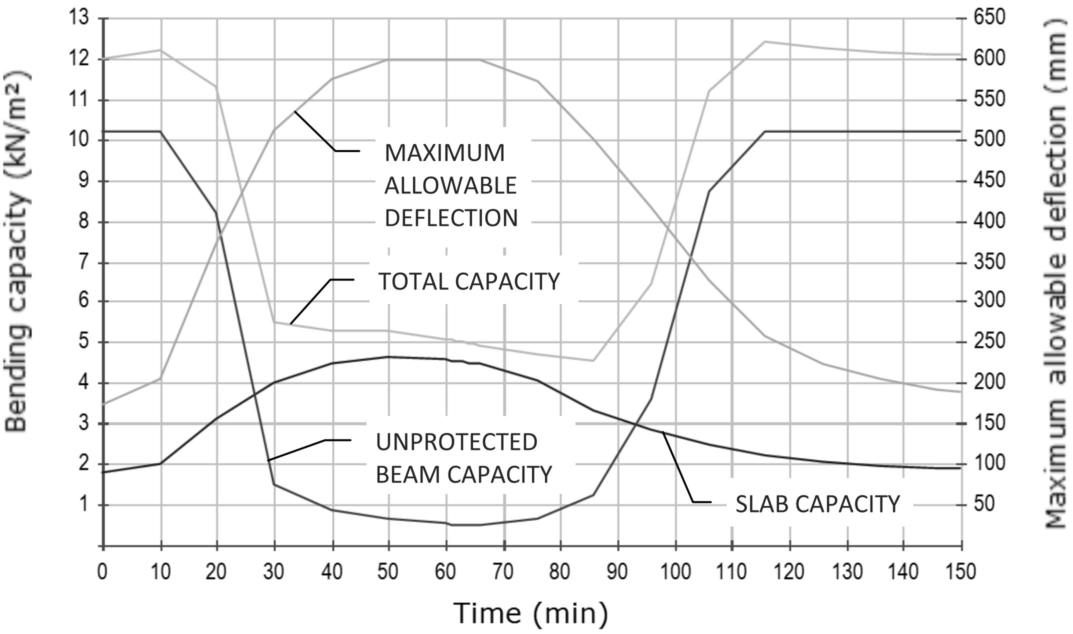


Fig. 22 Bearing capacity of the ceiling structure at the 2nd fire test (software FRACOF)

3.5 Measurements

Measurements consist of 126 thermocouples to measure gas (20 pcs.), mid-span beams (8 pcs.), reverse channel connections (21 pcs.), fin plate connections (29 pcs.), composite slab (14 pcs.), partially protected structure (16 pcs.), zinc coated members (6 pcs.) and column (12 pcs.) temperatures. 7 pieces of plate thermocouples is used to measure adiabatic surface temperatures. Vertical and horizontal deformations of the slab are measured from the scaffold located 1 m above the structure in 5 points. 32 pieces of high temperature strain gauges is located on the round tube columns to predict the forces for connection design. Measurement will be performed by radiometers, pitot tubes, weather station and scan as well. Digital, video and thermo cameras will allow recording the structural behaviour and temperature developments in the structure and walls. Measurements are summarized in Tab. 3, Fig. 23 and Fig. 24. The separate measurement of cladding temperatures is not included in the list.

Tab. 3 List of measurements at the 2nd fire test

Measurements										
Fire test no. 2										
Meter	**Company**									
Specification	**PAVUS**		**ÚTAM**		**TÚPO**		**VŠB – TUO**		**CTU**	
Thermocouple										
Gas temperatures			11	(TG21 – TG31)						
Gas temperatures					9	(TG32 – TG40)				
Beam temperatures	8	(TB9 – TB16)								
Temp. of reverse channel connection	21	(TC51 – TC71)								
Temp. of fin plate connection	29	(TC72 – TC100)								
Temperatures of the concrete slabs	14	(TS8 – TS21)								
Temp. of partially protected structure			16	(TP1 - TP16)						
Temperatures of zinccoated members	6	(TZ1 – TZ6)								
Column temperatures			12	(TSG1 – TSG12)						
Plate thermometer										
Adiabatic surface temperatures	7	(PT8 – PT14)								
Strain gauge										
Relative deformation of columns			32	(SG1 – SG32)						
Pitot tube										
Gas temperature					2	(PTG3 – P4)				
Barometrický tlak					2	(PBP3 - PBP4)				
Deflectometer										
Vertical deflection of concrete slab			3	(V4 – V6)						
Horizontal deflection of concrete slab			2	(H3 – H4)						
Radiometer										
Radiant flux					2	(R3 – R4)				
Sampling tube										
Chemical gas analysis					1	(ST2)				
Weather station										
Air temperature							1	(WAT2)		
Barometric pressure							1	(WBP2)		
Air humidity							1	(WAH2)		
Wind speed							1	(WWS2)		
Photogrammetry										
Before fire test									1	(PG3)
After fire test									1	(PG4)
Thermocamera										
Structure temperatures			1	(TCM4)					2	(TCM2 - TCM3)
Video camera										
Digital camera										

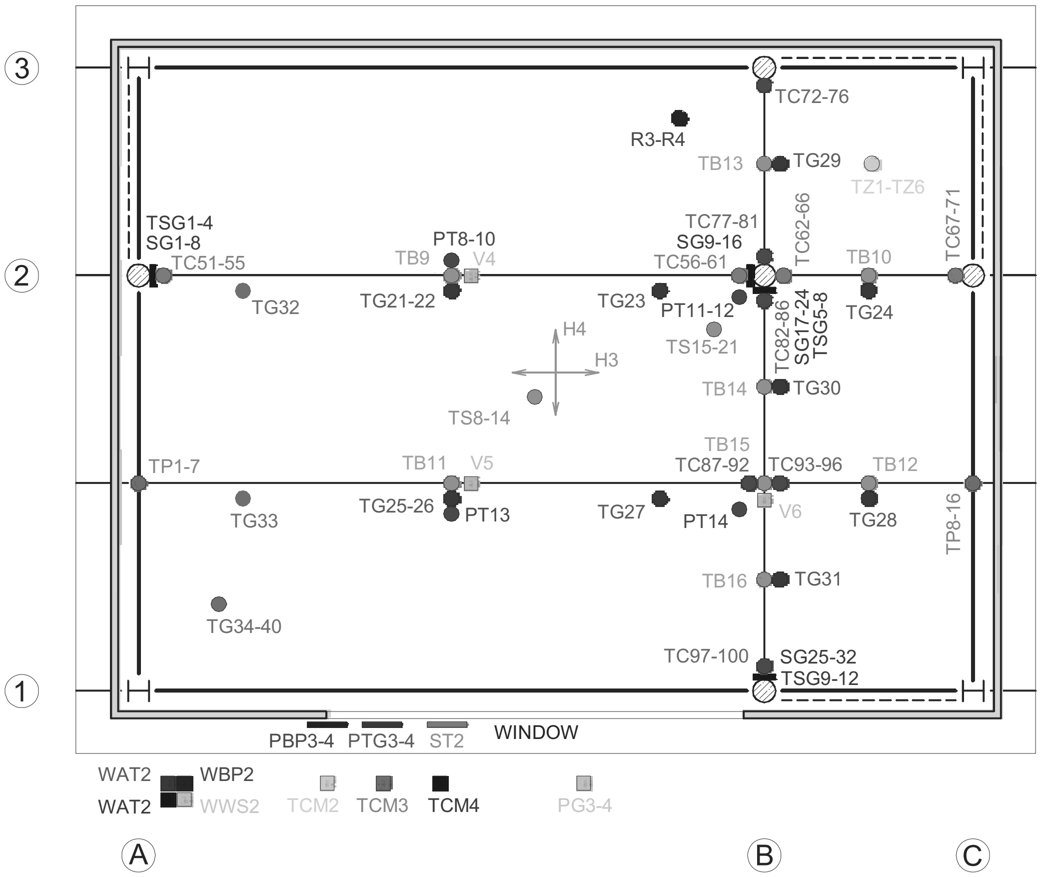


Fig. 23 Diagram of measurements at the 2nd fire test (ground plan)

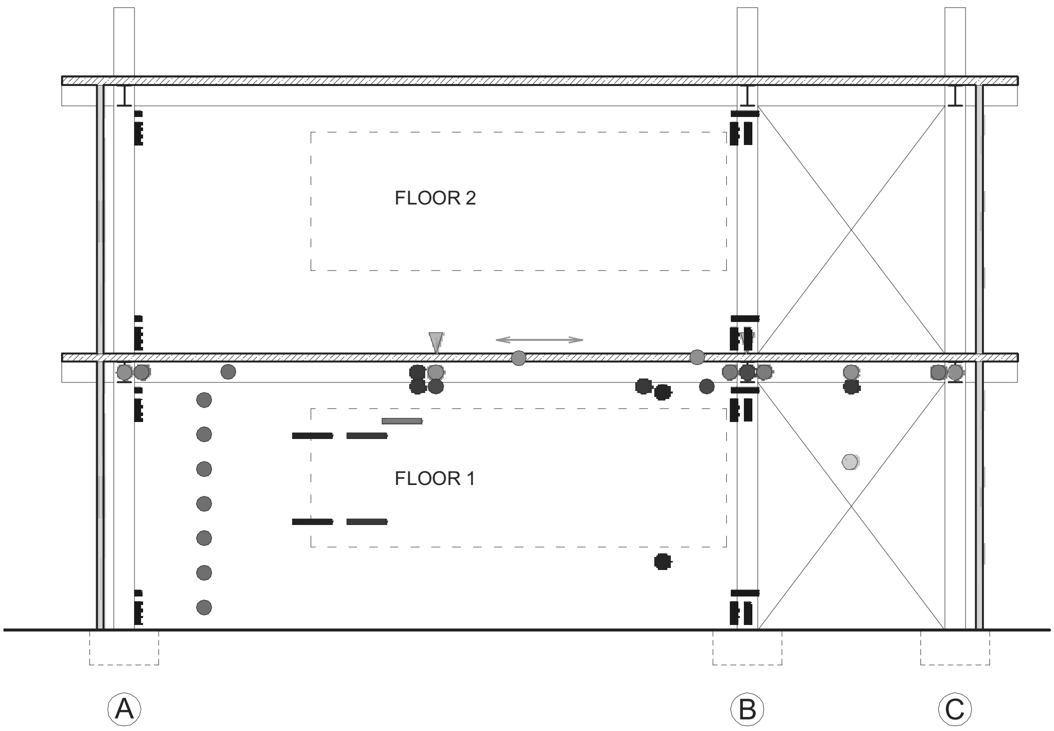


Fig. 24 Diagram of measurements at the 2nd fire test (vertical section)

4 Photos from the construction

Fig. 25 Erection of the steel structure

Fig. 26 The complete steel structure

Fig. 27 Reverse channel and fin plate connections

Fig. 28 The steel structure with the composite slabs

Fig. 29 Temporary covering of the composite slabs

Fig. 30 Installation of the cladding

Fig. 31 Application of the fire protection

Fig. 32 Frame for measurements and stair tower

5 References

[1] EN 1991-1-1: Actions on structures - Part 1-1: General actions - Densities, self-weight, imposed loads for buildings. 2004.

[2] EN 1993-1-1: Design of steel structures - Part 1-1: General rules and rules for buildings. 2006.

[3] EN 1993-1-2: Design of steel structures - Part 1-2: General rules - Structural fire design. 2006.

[4] EN 1993-1-8: Design of steel structures - Part 1-8: Design of joints. 2006.

[5] EN 1994-1-1: Design of composite steel and concrete structures - Part 1-1: General rules and rules for buildings. 2005.

[6] EN 1994-1-2: Design of composite steel and concrete structures - Part 1-2: General rules - Structural fire design. 2006.

[7] Joints in steel construction: Simple connections, SCI P212, London 2002, ISBN 1-859420-72-9.

[8] Cadorin J. F., Franssen J. M.: OZone V2.2.5, University of Liege, 2004.

[9] Fire resistance assessment of partially protected composite floors (FRACOF): Engineering background, The Steel Construction Institute, 2010.

Notes

The project partners are: Czexch Technical University in Prague, DESMO, a. s., Luleå University of Technology, Tata Steel Europe, The University of Manchester, The University of Sheffield a Universidade de Coimbra as contractor.

The experiment was prepared in cooperation with MV-GŘ HZS ČR, PAVUS, a. s., TÚPO and ÚTAM AV ČR, v. v. i.

To the erection of experimental building contributed: ARCHaPLAN, s. r. o., ArcelorMittal Construction CZ, s. r. o., Hilti ČR, spol. s r. o., Kovové profily, spol. s r. o., Metrostav, a. s., Morávek CZ, s. r. o., Promat, s. r. o., HARSCO Infrastructure CZ, s. r. o., ROCKWOOL, a. s. a SKÁLA & VÍT, s. r. o.

Media partner is journal KONSTRUKCE.

Design of joints to composite columns for improved fire robustness
To Demonstration fire tests
Wald F., Jána T. and Horová K.

Česká technika - nakladatelství ČVUT
August 2011
ISBN 978-80-01-04871-9
350 copies, 26 pages, 32 figures