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Original scientific paper

DETERMINATION ON FIRE RESISTANCE COMPOSITE BEAMS IN THE FIRE SECTOR

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Abstract

Aim: Unwanted fire is a destructive force that causes thousands of deaths and severe property damage each year. The fire is a spontaneous process of uncontrolled burning with negative effects expressed through the destruction of material goods and endangering human lives. Many of the artificial fires were caused by wars, other weather disasters, lightning, but as well as the poor construction techniques used in the construction of buildings with highly flammable materials. The main factor that motivates us is to design a construction that will have high fire safety with which there will be no great economic and human loss due to its premature collapse. **Method:** Analysis of fire resistance of construction structures according to technical regulations: The action of high temperature on the interlocking structures causes a decrease in the mechanical properties of the two composite components (concrete and steel), and thus drastically reduces their load capacity, then they cause great damage and breakage. The design of fire resistance of construction structures is based on a certain fire scenario. Here are some of the types of fire scenarios that are applied worldwide. In most European countries, a standard fire-time curve is used according to ISO 834 and a parametric curve, the standard curve is very close to the time-temperature curve used in the United States, **ASTM** E119. (American Society for Testing and Materials). The constructive behavior of the composite elements in multi-storey buildings exposed to elevated temperature according to Eurocode 4, part 2.
For the composite beams, the procedure for checking:
- the bearing capacity of the cross-sections of bending,
- vertical shear,
-the load-bearing capacity of the longitudinal shear,
- the bearing capacity of combined bending and vertical shear.
Composite beams are considered, partially and completely concreted, as freely supported, or continuous beams.
Nowadays, several software packages determine the fire resistance of load-bearing elements of a composite structure. One of the most widely used software packages in most European countries is **ArcelorMittal**, which has been used in the analysis of fire resistance of structural elements of a multi-storey building.
Results: The fire resistance of the beams is calculated for three cases/ three types of beams with a span of L = 9.6 m/
- as an unprotected beam only of steel profile;
- protected by gypsum board coating (d = 12.5mm);
- partially concreted.

Fire resistance analysis of composite beams
The room temperature is taken as the initial temperature, and the heating is done gradually according to the standard temperature-time curve (ISO 834) with steps 20°C, 100°C, 500°C, etc., until complete cross-sectional plasticization (beam demolition). For the unprotected beam, a low class of fire resistance of **R 30** was obtained, while for the other two cases the required fire resistance for such objects of **R 120** was obtained.
Conclusion:
The unprotected beam
• In the fire department for the burned steel beam, the following can be concluded:
• -the critical temperature of the beam collapse is **q cr = 805°C**
• -The fire resistance of the beam is **Rpres = 33.95min**
• - the class of fire resistance of the beam is: **R 30**, which is less than that provided for this type of elements **Rmin120**
Protected composite beam with gypsum boards - d = 12.5 mm
-the critical temperature of the beam collapse is **q cr = 783°C**
-the fire resistance of the beam is **R 120min** and is equal to the one provided for this type of element.
The partially concreted joint beam is performed according to the rules provided by Eurocode 4 for welded steel and concrete structures (Part 4). In the fire calculation, the standard temperature-time curve is used as in the previous elements.
• For this type of beams, the program directly determines the class of fire resistance which in this case is equal to the predicted class **R 120**

Keywords: composite constructions, composite inter-floor constructions, fire resistance, steel profile

1. Introduction

Large fires that have occurred over the years have devastated entire areas of history. With this in mind, the first steps towards taking preventive measures to prevent fires, providing fire resistance to structures, evacuating people in the burned building, access to the facility, access to the fire brigade, and several other phenomena are also mentioned major fires.

Figure 1. Burned Buildings

In Europe, a standard fire is used, which is given by the temperature-time curve according to **ISO 834**, and a parametric curve, the standard curve is very close to the temperature-time curve used in the United States, **ASTM E119.**

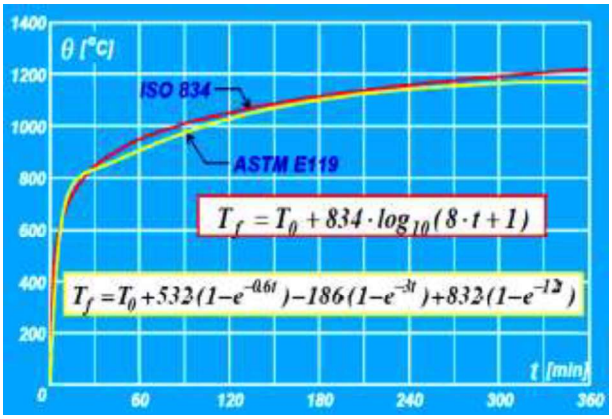

Figure 2. Standard curve-temperature time
(ISO 834 / ASTM E119)

The tested elements of the construction with the standard tests should meet the three most important characteristics:
-capacity (strength) marked as class R,
-the completeness of the examined element (not to fall apart-degraded) marked as class E and
-thermal insulation of the element marked as class I.
For each examined element, its class is determined according to the three characteristics R / E / I.

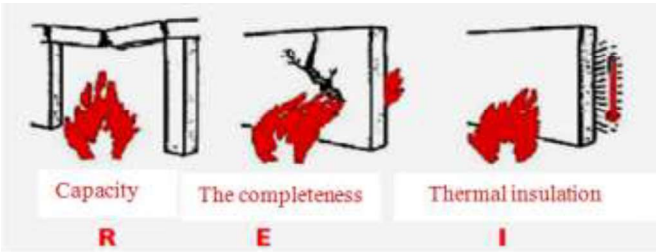

Figure 3. Class Characheristics

2. Materials, calculation procedure and results

2.1 Composite Beams

FIRE SECTOR - FLOOR 1
OZone V 2.2.6 Report File Name: POS 100

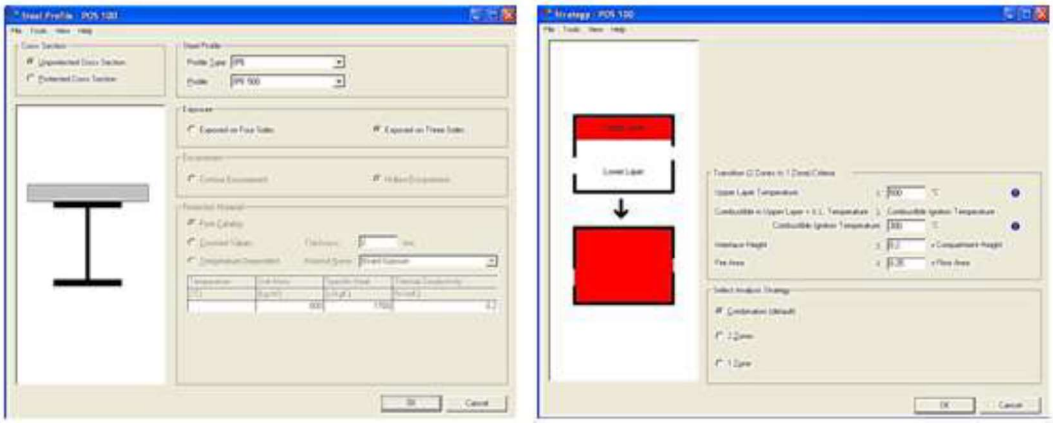

Figure 4.

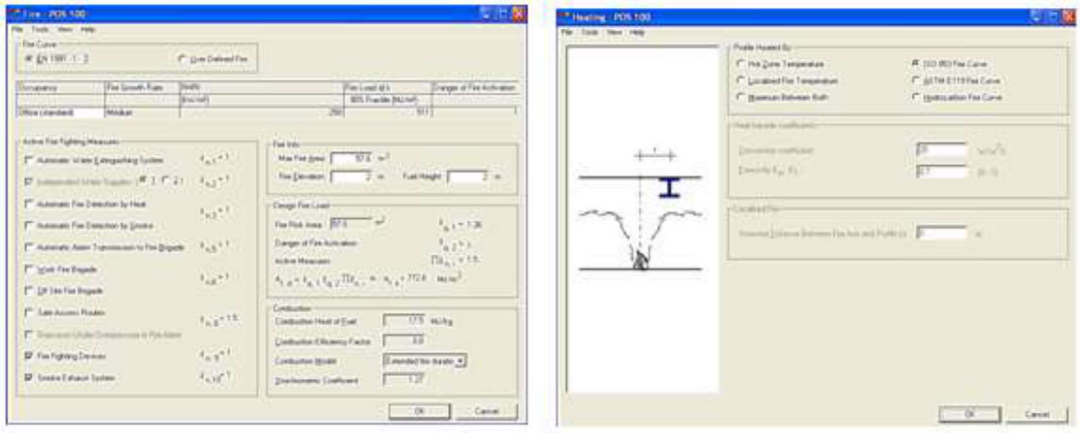

Figure 5.

OZone V 2.2.6 Report

ANALYSIS STRATEGY

Selected strategy: Combination 2Zones - 1 Zone Model
Transition criteria from 2 Zones to 1 Zone
Upper Layer Temperature □ 500°C
Combustible in Upper Layer + U.L. Temperature □ Combustible Ignition Temperature = 300 °C
Interface Height □ 0.2 Compartment Height
Fire Area □ 0.25 Floor Area

PARAMETERS

Openings
Radiation Through Closed Openings: 0.8
Bernoulli Coefficient: 0.7
Physical Characteristics of Compartment
Initial Temperature: 293 K
Initial Pressure: 100000 Pa

Parameters of Wall Material

Convection Coefficient at the Hot Surface:	25 W/m²K
Convection Coefficient at the Cold Surface:	9 W/m²K

Calculation Parameters

End of Calculation:	7200 sec
Time Step for Printing Results:	60 sec
Maximum Time Step for Calculation:	10 sec
Air Entrained Model:	Heskestad

Temperature-Dependent Openings

All openings activated at: 400 °C

Stepwise Variation

Temperature [°C]	% of Total Openings [%]
20	10
400	50
500	100

Linear Variation

Temperature [°C]	% of Total Openings [%]
20	10
400	50
500	100

Time Dependent Openings

Time [sec]	% of Total Openings [%]
0	5
1200	100

COMPARTMENT

Form of Compartment:	Rectangular Floor	
Height:	3.3	m
Depth:	6	m
Length:	9.6	m
Roof Type:	Flat Roof	

DEFINITION OF ENCLOSURE BOUNDARIES

Floor

Material (from inside to outside)	Thickness [cm]	Unit Mass [kg/m³]	Conductivity [W/mK]	Specific Heat [J/kgK]
Normal weight Concrete [EN1994-1-2]	14	2300	1.6	1000

Ceiling

Material (from inside to outside)	Thickness [cm]	Unit Mass [kg/m³]	Conductivity [W/mK]	Specific Heat [J/kgK]
Normal weight Concrete [EN1994-1-2]	14	2300	1.6	1000

Wall 1

Material (from inside to outside)	Thickness [cm]	Unit Mass [kg/m³]	Conductivity [W/mK]	Specific Heat [J/kgK]
Gypsum board [EN12524]	1.25	900	0.25	1000
Glass wool & Rock wool	5	60	0.037	1030
Glass wool & Rock wool	5	60	0.037	1030
Gypsum board [EN12524]	1.25	900	0.25	1000

Wall 2

Material (from inside to outside)	Thickness	Unit Mass	Conductivity	Specific Heat

	[cm]	[kg/m³]	[W/mK]	[J/kgK]
Gypsum board [EN12524]	1.25	900	0.25	1000
Glass wool & Rock wool	5	60	0.037	1030
Glass wool & Rock wool	5	60	0.037	1030
Gypsum board [EN12524]	1.25	900	0.25	1000

Wall 3

Material (from inside to outside)	Thickness [cm]	Unit Mass [kg/m³]	Conductivity [W/mK]	Specific Heat [J/kgK]
Gypsum board [EN12524]	1.25	900	0.25	1000
Glass wool & Rock wool	5	60	0.037	1030
Glass wool & Rock wool	5	60	0.037	1030
Gypsum board [EN12524]	1.25	900	0.25	1000

Wall 4

Material (from inside to outside)	Thickness [cm]	Unit Mass [kg/m³]	Conductivity [W/mK]	Specific Heat [J/kgK]
Gypsum board [EN12524]	1.25	900	0.25	1000
Glass wool & Rock wool	5	60	0.037	1030
Glass wool & Rock wool	5	60	0.037	1030
Gypsum board [EN12524]	1.25	900	0.25	1000

FIRE

Fire Curve:	NFSC Design Fire	
Maximum Fire Area:	57.6	m²
Fire Elevation:	2.5	m
Fuel Height:	2	m

Occupancy Danger of Fire	Fire Growth Rate	[kw/m²]	RHRf [MJ/m²]	Fire Load qf,k Activation
Office (standard)	Medium	250	511	1

Active Measures Description of	Active	Value
Automatic Water Extinguishing System	No	$\eta_{n,1} = 1$
Independent Water Supplies	1	$\eta_{n,2} = 1$
Automatic Fire Detection by Heat	No	$\eta_{n,3} = 1$
Automatic Fire Detection by Smoke	No	
Automatic Alarm Transmission to Fire Brigade	No	$\eta_{n,5} = 1$
Work Fire Brigade	No	$\eta_{n,6} = 1$
Off Site Fire Brigade	No	
Safe Access Routes	No	$\eta_{n,8} = 1.5$
Staircases Under Overpressure in Fire Alarm	No	
Fire Fighting Devices	Yes	$\eta_{n,9} = 1$
Smoke Exhaust System	Yes	$\eta_{n,10} = 1$

Fire Risk Area:	57.6	m²	$\eta_{q,1} = 1.26$
Danger of Fire Activation:			$\eta_{q,2} = 1$
$q_{f,d} =$	772.6	MJ/m²	
Combustion Heat of Fuel:	17.5	MJ/kg	

Combustion Efficiency Factor: 0.8
Combustion Model: Extended fire duration

Results

Fire Area: The maximum fire area (57.60 m²) is greater than 25% of the floor area (57.60m²). The fire load is uniformly distributed.
Switch to one zone + Fully engulfed fire: Temperature of zone >500.0°C at the time [s] 529.13

STEEL PROFILE

Unprotected Section
Catalog Profile: IPE 500
Exposed to Fire on: 3 sides

HEATING

Profile heated by: ISO 834 Fire
Convection coefficient: 25 W/m²K
Relative emissivity: 0.7

FIRE RESISTANCE

Element Submitted to Bending
Nominal Steel Grade: S 355

A design effect of actions in a fire situation

Plastic Redistribution of the Bending Moment
Loading: Uniform Distributed Load - Continuous Beam (Intermediate Span)
$P_{fi,\,d} = 22.5$ kN
Span = 9.6 m

Adaptation Factors

Non-uniform Temperature Across the Cross-Section: $\square_1 = 0.7$
Non-uniform Temperature Along the Beam: $\square_2 = 0.85$

RESULTS

Critical Temperature: 805 °C
Failure Mode: Flexural Buckling
Class of the Cross Section in Fire: 1
Fire Resistance: 33.95 min

2.1.2 Protected Composite Beams with Gypsum Boards, d = 12.5 mm-POS 100

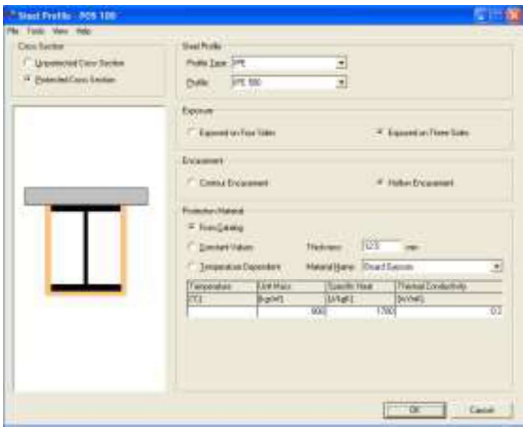

Figure 6.

OZone V 2.2.6 Report

Analysis Name:
File Name: POS 100.ozn

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Calculation Parameters
End of Calculation: 7200 sec
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Temperature Dependent Openings
All openings activated at: 400 °C
Stepwise Variation
Temperature % of Total Openings

[°C]	[%]
20	10
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500	100

Linear Variation

Temperature	% of Total Openings
[°C]	[%]
20	10
400	50
500	100

Time Dependent Openings

Time	% of Total Openings
[sec]	[%]
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COMPARTMENT

Form of Compartment:	Rectangular Floor	
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Material (from inside to outside)	Thickness [cm]	Unit Mass [kg/m³]	Conductivity [W/mK]	Specific Heat [J/kgK]
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Glass wool & Rock wool	5	60	0.037	1030
Glass wool & Rock wool	5	60	0.037	1030

Gypsum board [EN12524]	1.25	900	0.25	1000

Wall 4

Material (from inside to outside)	Thickness [cm]	Unit Mass [kg/m³]	Conductivity [W/mK]	Specific Heat [J/kgK]
Gypsum board [EN12524]	1.25	900	0.25	1000
Glass wool & Rock wool	5	60	0.037	1030
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Switch to one zone + Fully engulfed fire: Temperature of zone >500.0°C at the time [s] 529.13

STEEL PROFILE

Protected Section	
Catalog Profile:	IPE 500
Exposed to Fire on:	3 sides
Hollow Encasement	
Protection Material:	From Catalog
Protection Thickness:	12.5 mm

Material Name:	Board Gypsum	
Unit Mass	Specific Heat	Thermal Conductivity
[kg/m³]	[J/kgK]	[W/mK]
800	1700	0.2

HEATING

Profile heated by: ISO 834 Fire
Convection coefficient: 25 W/m²K
Relative emissivity: 0.7

FIRE RESISTANCE

Element Submitted to Bending
Nominal Steel Grade: S 355

Design effect of actions in fire situation

Plastic Redistribution of the Bending Moment
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Adaptation Factors

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Non-uniform Temperature Along the Beam: $\square_2 = 0.85$

RESULTS

Critical Temperature: 783 °C
Failure Mode: Flexural Buckling
Class of the Cross Section in Fire: 1
Fire Resistance: 120.00 min at least

2.1.3 Partially Concreted Composite Beam - Pos 100

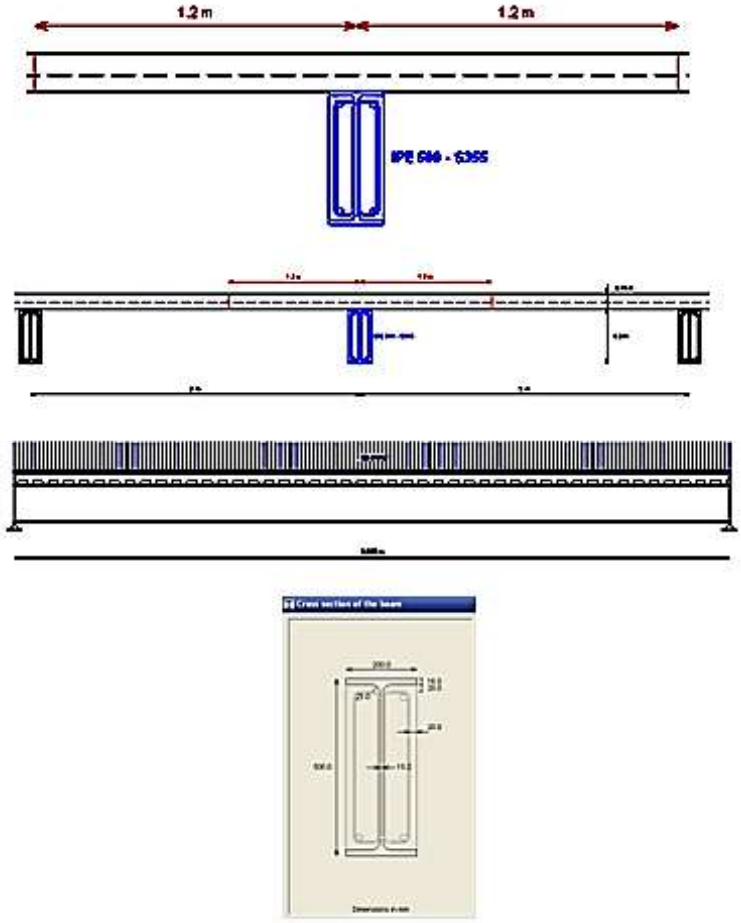
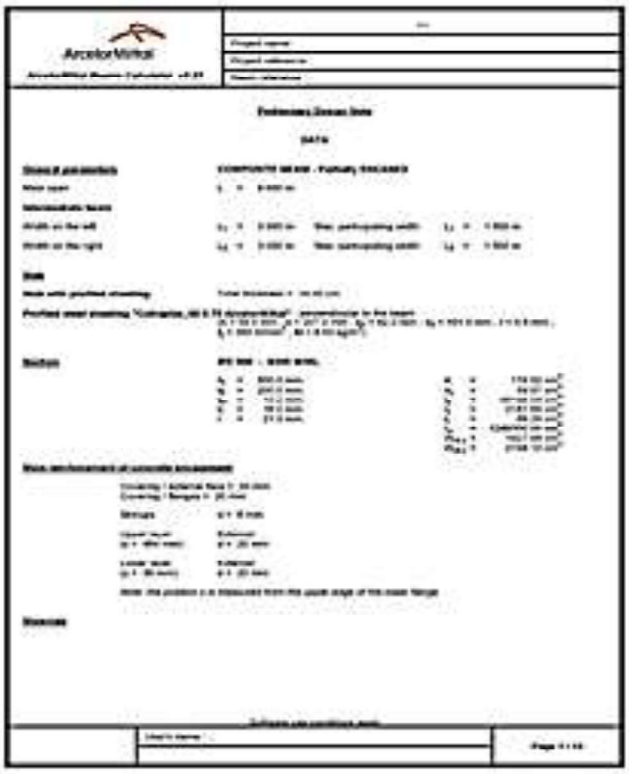
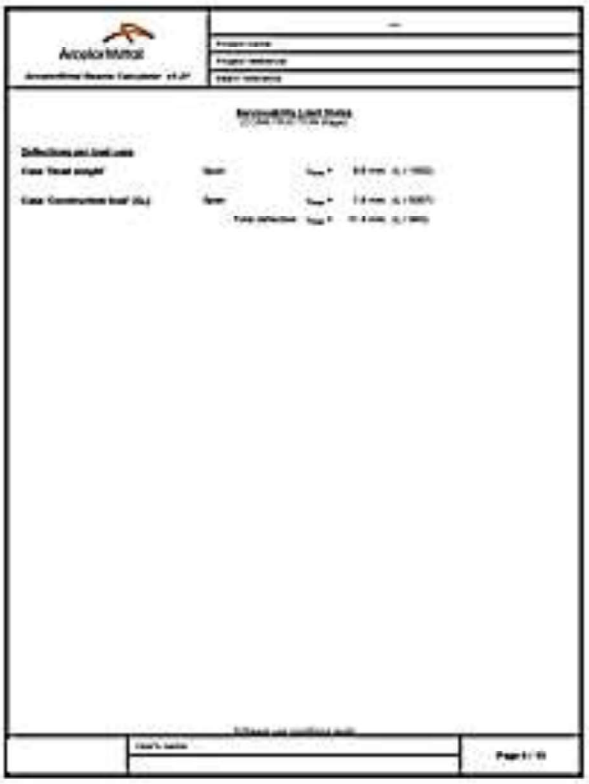
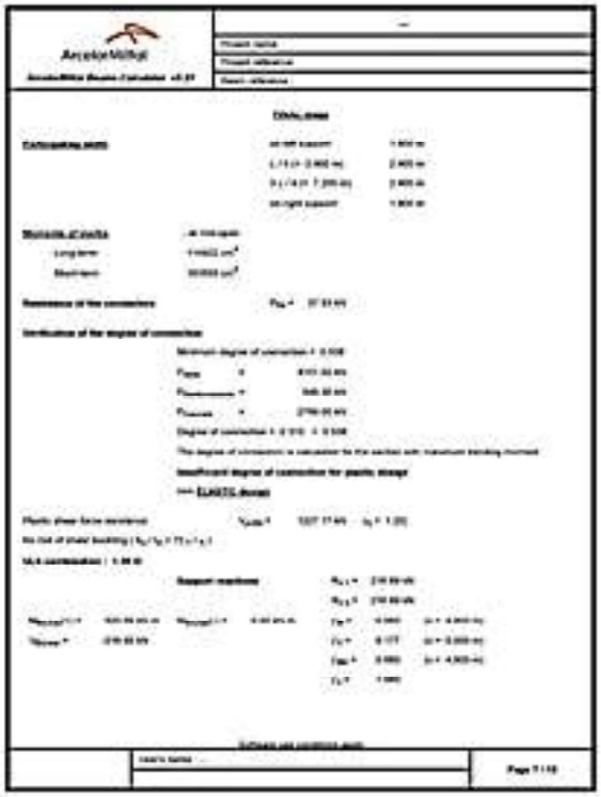


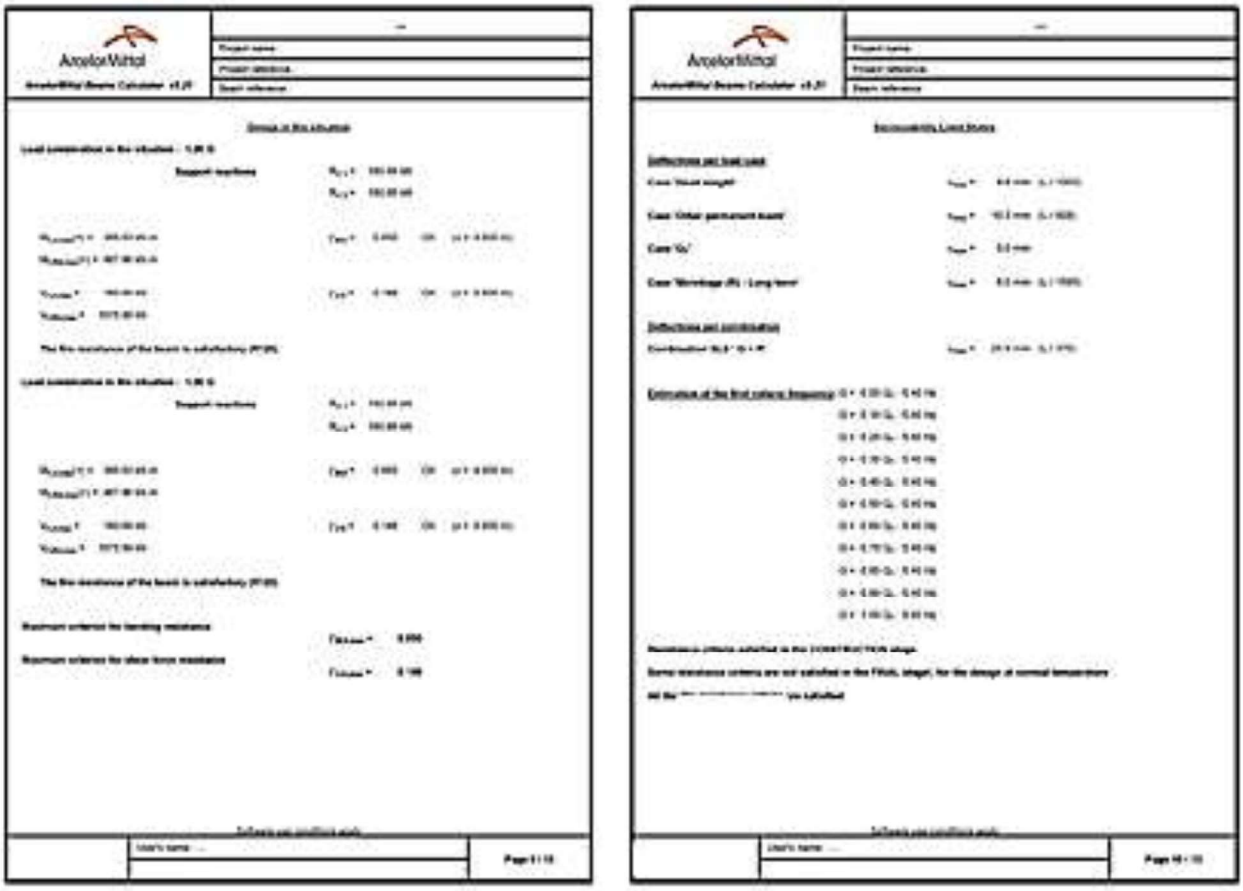
Figure 7.

Report









3. Conclusions and recommendations

The main conclusions that can be drawn from this paper are: In the last ten years, the burning/ fire of a large number of buildings and multi-story buildings, the question arises that which materials it is best to perform. The option of these materials should be, so they do not skip each other in case of fire but help each other in such cases/situations. One of the main problems with multi-story buildings is the existence of load-bearing structural elements in fire conditions. The structural elements are the ones that determine, to a large extent, the fire behavior of the structure. Thermal insulation measures significantly improve the fire resistance of the structural elements of the building. According to the analysis of the calculated calculations for the various combinations of projected fire protection, or without proper protection, we conclude that special attention should be paid to the structural elements of the beams that are exposed to fire risk. In this context, appropriate solutions are proposed for the most optimal protection of these structural elements without disturbing the functional and aesthetic effects of the building. Based on the performed calculations of the fire resistance of unprotected, protected composite elements of a multi-storey building, the following conclusions can be - **Drawn**.

1. The unprotected steel alloy beam (IP 500) only with a plate exposed to fire on all three sides according to the standard curve (ISO 834), has low fire resistance for loads and is R 30 less than the standards provided by several European countries **R 120**.

2. Protected steel beam with gypsum boards (d = 12.5mm), as well as partially concreted beam, meet the required class **R 120**, exposed to the fire according to the standard curve.

Based on the given conclusions about the fire resistance of the interlocking elements of a multi-storey building, I give the following recommendations:

Recommendations

1. We must carry the supporting elements in the combined multi-storey buildings protect with a suitable refractory material, completely concreting the beams

2. Such fire protection must be foreseen the design of buildings by making a fire project resistance of the load-bearing elements of the building.

3. Many countries in the world have their own standards for fire protection using materials for which their characteristics are experimentally tested and validated, as needed to be done in our country as well.

4. The use of fire protection of the structural elements during multi-storey buildings will certainly make the building more expensive, but always will be neglected given the safety of people's lives working in the building.

References

[1]. Zarić B., Vlajčić Z., Buđevac D.: Analitičke metode za utvrđivanje otpornosti protiv požara čeličnih konstrukcija, Razvojno istraživački projekt-Spratne zgrade od čelika, IMK-*Građevinski fakultet u Beogradu*, Beograd, 1985.
[2]. R. P. Johnson: Composite structures of Steel and Concrete, Vol. 1., *Collins London*, 1986
[3]. R. P. Johnson: Composite structures of Steel and Concrete, Vol. 2., Bridges, *Collins London*, 1986
[4]. Wainman, W. and Kirby, B., Compendium of UK standard fire test data, No.1- Unprotected structural steel, British Steel, *Swinden Technology Centre*, 1987.
[5]. ENV1994-1-1:1992: Design of composite steel and concrete structures – Part 1-1: General rules and rules for buildings
[6]. Evrokod 4: Proračun spregnutih konstrukcija od čelika i betona, Deo 1.1: Opštapravila i pravila za proračun zgrada, *Građevinski fakultet Univerziteta u Beogradu* (editori M. Milićević i M. Aćić), Beograd 1996
[7]. Lennon, T., 'Cardington fire tests: instrumentation locations for large compartment fire test.', Building Research Establishment Report N100/98, June 1996.
[8]. Lennon, T., 'Cardington fire tests: instrumentation locations for corner fire test.', Building Research Establishment Report N152/95, June 1996.
[9]. ENV 1993- (Eurocode 3) : Design of Steel structures,Part 1-1(General rules and rules for Building), Part 1-2 (Fire) ,Part 1-3(Could formed sheting), Part 1-4 (Stainless steel), Part 1-5 (Plate stability) , Part 3-1 (Towers and masts), Part 3-2 (Chimneys) , Part 6 (Cranes) , CEN- Brusseles (1992-1998).
[10]. 'The behaviour of Multi-storey steel framed buildings in fire', A European joint research programme, British Steel Swinden Technology Centre, 1999.
[11]. ECCS – Technical Committee 11, the Group Authors: Design of Composite Joints for Buildings, First Edition, ECCS Publications No. 109, Brusseles 1999.
[12]. Buđevac D.,Zarić B., Stipanić B, Čelične konstrukcije u građevinarstvu,Građevinska knjiga Beograd, 2000
[13]. Brandschuzt Atlas, Baulicher Brandschutz Band 1, Josef Mayr (gl. urednik), Wehner GmbH Verlag von Brandschutzpublikation, 2000.