



PART 4
SOFTWARE FOR FIRE DESIGN

Fire design objective

R

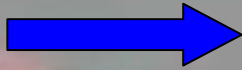
resistance of the structures submitted to fire

>

R_{req}

resistance required to the structures for being safe

R



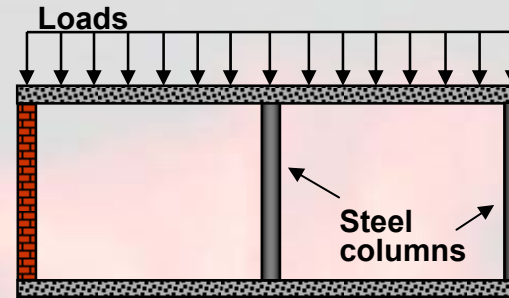
Chain of events during a fire



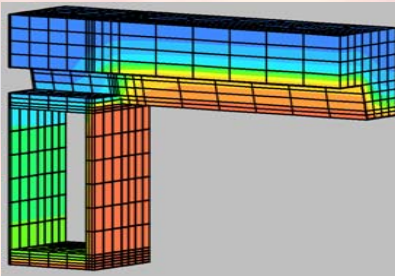
1: Ignition



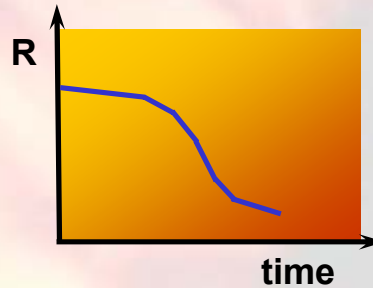
2: Thermal action



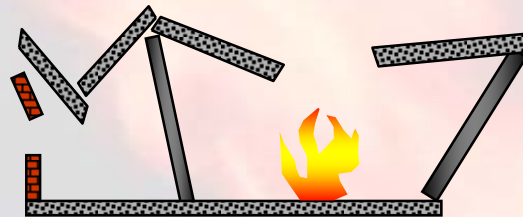
3: Mechanical actions



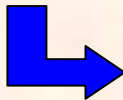
4: Thermal response



5: Mechanical response

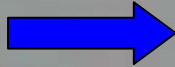


6: Possible collapse



Calculation methodologies - Eurocodes

R_{req}



Safety criterion

$R_{required}$: "R" is assumed to be satisfied where the load bearing function is maintained during the required time of fire exposure.



Prescriptive approach:
national fire regulations

Performance based
approach:
fire safety engineering

Fire design software - Classification

The most common classification of them is broken down in five categories:

- Fire thermal models
- Fire resistance models



R

- Egress models
- Detector response models
- Miscellaneous models



R_{req}
(performance based)

Fire thermal models

Fire thermal models

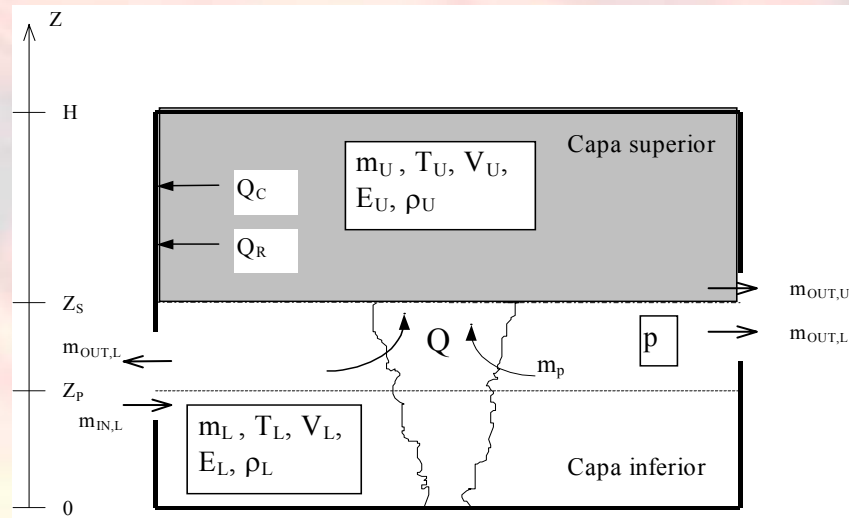
Fire thermal models		
Nominal temperature – time curves (Prescriptive rules)	Standard temperature – time curve	
	External fire curve	
	Hydrocarbon curve	
Natural fires (Performance based rules)	Simplified fire models	Compartment fires
		Localised fires
	Advanced fire models	Zone models
		Field models

Zone models

Zone models

There are two principal types of zone models:

- Two Zone models: fire compartment considered as divided in two zones (hot - cold) with homogeneous properties
- One Zone models: fire compartment considered as a furnace



There are one compartment models (only one compartment) and multi-compartment models (considered several adjoining compartments)

Resolution of equations

- Mass balance
- Energy balance

Zone models - Ozone

Software sheet – general description			
Name	OZone		
Version	2.2.2	Year	2002
Country	Luxembourg	Language	English
System	Windows	Size	5 MB
Authors	J. F. Cadorin, J. M. Franssen (Uni. Liège) L.G. Cajot, M. Haller, J.B. Schleich		
Organisation	Arcelor LCS Research Centre		
Application field	Fire Thermal model - Zone		
Availability	Free – www.ulg.ac.be Free – www.sections.arcelor.com		
Contact	Arcelor ASC: asc.tecom@arcelor.com		
Formulation	Based on mass and energy balance equations		
Short description	Model to predict the thermal action of a defined fire. Heat transfer to simple steel elements and time to collapse (ENV 1993-1-2) incorporated		

Ozone - Main menu

Ozone v2.2 - Restaurante_caso1

File Tools View Help

Name: Restaurante_caso1. Solo abierta la escalera. Vidrio, resistente

Program Flow Chart

- Compartment...
- Fire...
- Zone Temperature
- Steel Profile...
- Heating...
- Steel Temperature
- Element...
- Fire Resistance

Strategy

Parameters

Ozone v2.2

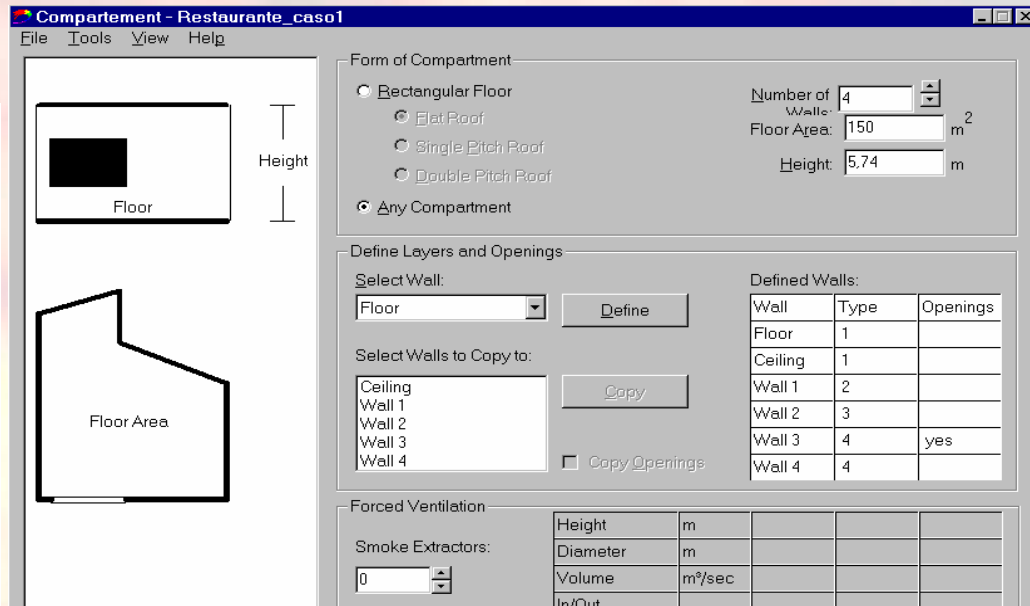
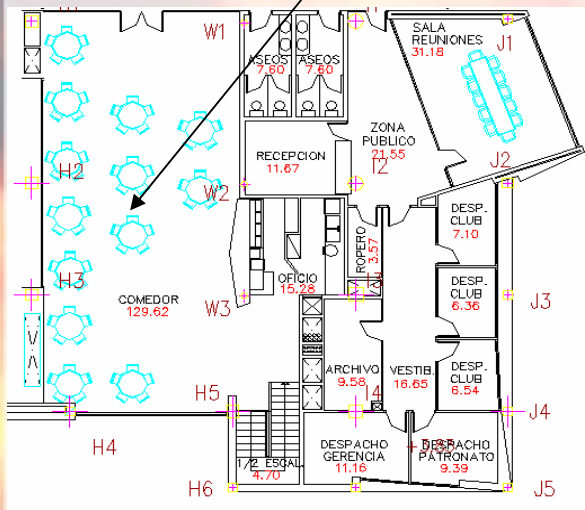


Ozone - Case study

Fire scenario: fire in a restaurant at third storey
Design fire: fully developed fire - t_{α} growth phase
Objective: fire resistance of steel beams
(Requirement of R90)

Fire compartment definition:

Fire area



Ozone - Input data: Definition of Fire

Fire - difisek_restaurant

File Tools View Help

Fire Curve

NFSC Design Fire User Defined Fire

Max Fire Area: m²

Fire Elevation: m Fuel Height: m

Occupancy	Fire Growth Rate	RHRf [kW/m ²]	Fire Load q _{f,k} 80% Fractile [MJ/m ²]	Danger of Fire Activation
User Defined	150	250	300	1
Description	Fast			Medium

Automatic Water Extinguishing System $\gamma_{n,1} = 1$
 Independent Water Supplies (1 2) $\gamma_{n,2} = 1$
 Automatic Fire Detection by Heat $\gamma_{n,4} = 0,73$
 Automatic Fire Detection by Smoke $\gamma_{n,4} = 0,73$
 Automatic Alarm Transmission to Fire Brigade $\gamma_{n,5} = 1$
 Work Fire Brigade $\gamma_{n,7} = 0,78$
 Off Site Fire Brigade $\gamma_{n,7} = 0,78$
 Safe Access Routes $\gamma_{n,8} = 1$

Design Fire Load

Fire Risk Area: m² $\gamma_{q,1} = 1,42$

Danger of Fire Activation: $\gamma_{q,2} = 1$

Active Measures: $\prod \gamma_{n,i} = 0,8541$

$q_{f,d} = \gamma_{q,1} \cdot \gamma_{q,2} \cdot \prod \gamma_{n,i} \cdot m \cdot q_{f,k} = 291,1 \text{ MJ/m}^2$

Combustion

Combustion Heat of Fuel: MJ/kg

Combustion Efficiency Factor:

Combustion Model:

OK Cancel

Ozone - Input data: Criteria for switching from 2 zones to 1 zone

The screenshot shows a software window titled "Strategy - Restaurante_caso1" with a menu bar (File, Tools, View, Help). On the left, a diagram illustrates the transition from a two-zone fire model to a one-zone model. The top diagram shows a compartment divided into an "Upper Layer" (red) and a "Lower Layer" (white). A downward arrow points to a second diagram where the entire compartment is a single red block, representing a one-zone model.

Transition (2 Zones to 1 Zone) Criteria:

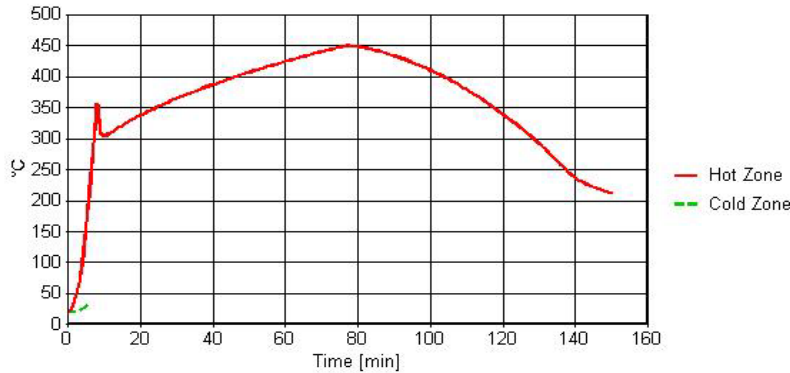
Upper Layer Temperature	≥	500	°C
Combustible in Upper Layer + U.L.	≥	Combustible Ignition Temperature	
		Combustible Ignition Temperature:	300 °C
Interface Height	≤	0,2	Compartment Height
Fire Area	≥	0,25	Floor Area

Select Analysis Strategy

- Combination (default)
- 2 Zones
- 1 Zone

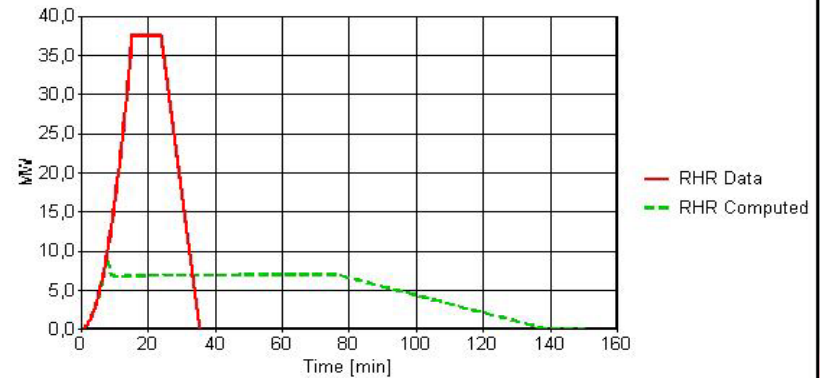
Ozone - Output

Gas Temperature



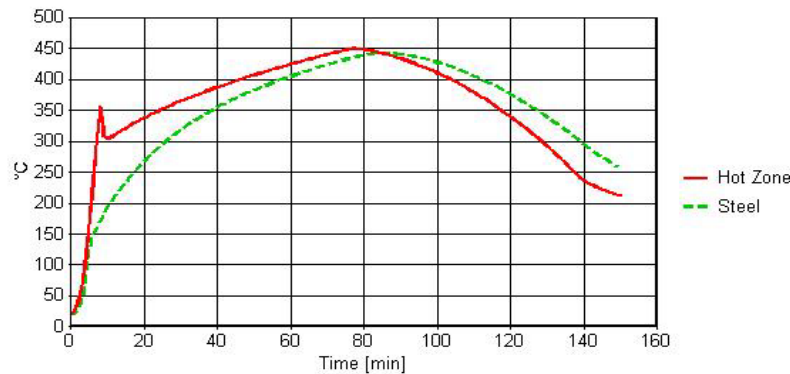
Analysis Name: Restaurante_caso1. Solo abierta la escalera. Vidrio, resisten

Rate of Heat Release



Analysis Name: Restaurante_caso1. Solo abierta la escalera. Vidrio, resisten

Steel Temperature

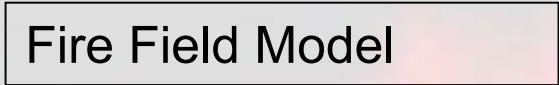
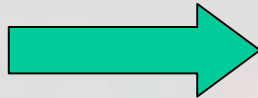
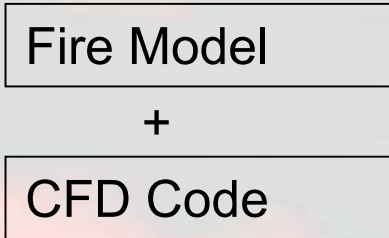


Analysis Name: Restaurante_caso1. Solo abierta la escalera. Vidrio, resisten

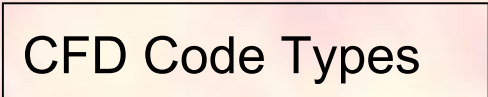
Switch from 2 zones to 1 zone:
120"
(fire governed by ventilation)

Field models

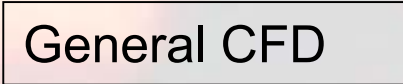
Field models



General description of fire phenomenon.
Physical variables description.



Physical models adjusted to fire problems:
SOFIE, FDS...



More physical models and material properties, selected and adjusted by user to fire modelling: Fluent, CFX, PHOENIX..

Field models - Fluent

Software sheet – general description			
Name	Fluent		
Version	6.1.22	Year	2004
Country	USA	Language	English
System	Windows/UNIX		
Organisation	Fluent Inc.		
Application field	Fire Thermal model - Field.		
Availability	Commercial software		
Contact	www.fluent.com		
Formulation	Based on mass and energy balance equations.		
Short description	General purpose CFD		

Fluent - Input data

Viscous Model

Model

- Inviscid
- Laminar
- Spalart-Allmaras (1 eqn)
- k-epsilon (2 eqn)
- k-omega (2 eqn)
- Reynolds Stress (7 eqn)
- Large Eddy Simulation

k-epsilon Model

- Standard
- RNG
- Realizable

Near-Wall Treatment

- Standard Wall Functions
- Non-Equilibrium Wall Functions
- Enhanced Wall Treatment

Options

- Viscous Heating
- Full Buoyancy Effects

Model Constants

C2-Epsilon: 1.9

TKE Prandtl Number: 1

TDR Prandtl Number: 1.2

Energy Prandtl Number: 0.85

User-Defined Functions

Turbulent Viscosity: none

Prandtl Numbers

TKE Prandtl Number: none

TDR Prandtl Number: none

Energy Prandtl Number: none

OK Cancel Help

Materials

Name: co

Material Type: fluid

Order Materials By: Name Chemical Formula

Chemical Formula: co

Fluid Materials: co

Mixture: pdf-mixture

Database...

Properties

Cp (j/kg-k): piecewise-polynomial

Molecular Weight (kg/kgmol): constant

Standard State Enthalpy (j/kgmol): constant

Standard State Entropy (j/kgmol-k): constant

Change/Create Delete Close Help

Definition of materials, physical models and boundary conditions is required. Some of them shown in this slide

Radiation Model

Model

- Off
- Rosseland
- P1
- Discrete Transfer (DTRM)
- Surface to Surface (S2S)
- Discrete Ordinates

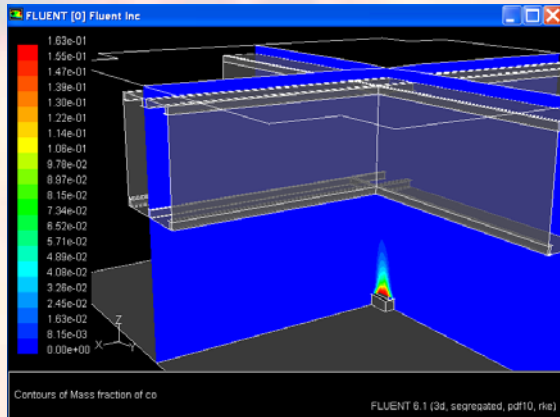
OK Cancel Help

Fluent- Output data

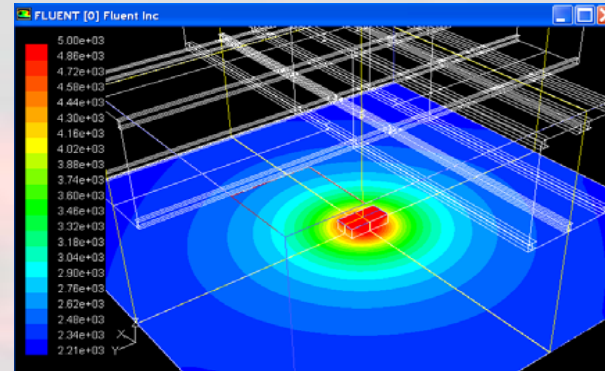
User friendly pre and post processing, but a deep knowledge on fire engineering and CFD is required.

Examples of post processing

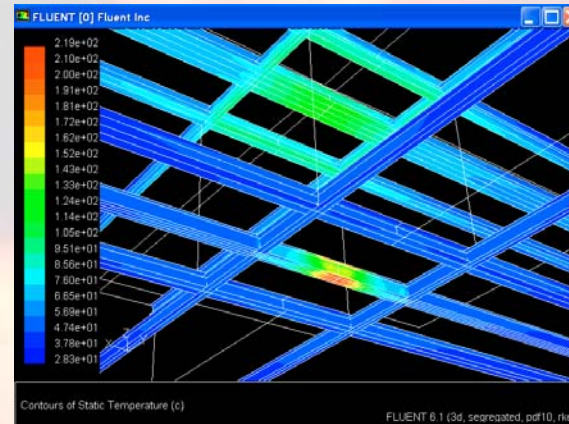
Smoke control: CO concentration



Radiation values



Predicted steel temperatures



Fire resistance models

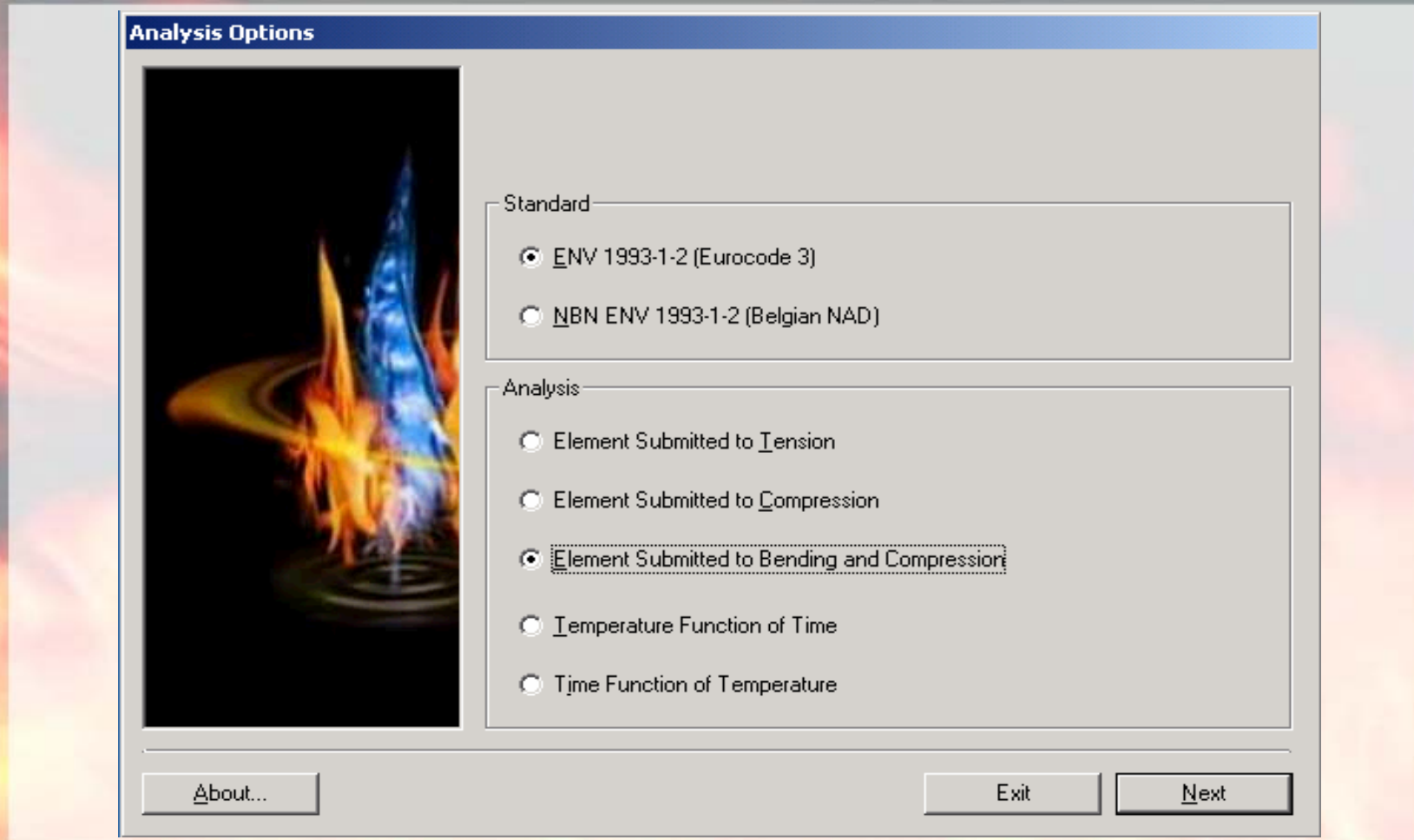
Fire resistance models (FRM)

Structural design procedure			Tabulated data	Simple calculation methods	Advanced methods
Prescriptive based rules	Member analysis	Calculation of mechanical actions and boundaries	YES	YES	YES
	Analysis of part of the structure		NO	YES (if available)	YES
	Analysis of entire structure	Selection of mechanical actions	NO	NO	YES
Performance based rules	Member analysis	Calculation of mechanical actions and boundaries	NO	YES (if available)	YES
	Analysis of part of the structure		NO	NO	YES
	Analysis of entire structure	Selection of mechanical actions	NO	NO	YES

Simplified FRM - Elefir

Software sheet – general description			
Name	Elefir		
Version	2.1	Year	1998
Country	Belgium	Language	English
System	Windows	Size	8 MB
Authors	D. Pintea, L. Mievis, G. Gustin, J. M. Franssen		
Organisation	University of Liege		
Application field	Fire resistance model (simplified)		
Availability	Free – www.ulg.ac.be		
Contact	University of Liege - www.ulg.ac.be		
Formulation	Based on ENV 1993-1-2 (eurocode 3)		
Short description	Software for the calculation of the fire resistance of simple steel elements made of open sections.		

Elefir - Main menu

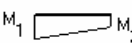



Elefir - Input data

Loads

Select Load:

In-plane lateral loads + end moments

M_1  M_2 +  M_Q

Distributed Load Concentrated Load

M_Q = kN.m

M_1 (can be > or < 0) = kN.m

M_2 (can be > or < 0) = kN.m

Axial Compression

N = kN

Load input window


Protection input window



Select Fire Exposure

Fire on Four Sides

Fire on Three Sides




Select Section Protection

No Protection

Contour Encasement

Hollow Encasement



Elefir - Output data

Results Elefir

Data

Date : 05/08/2004
Time : 13:30:06

Calculation following ENV 1993-1-2
Time function of temperature

Type of Cross-Section : IPE
Profile : IPE 300
Area of the cross-section : 53,81 cm²
Critical Temperature : 486 °C


Exposed to Fire on 3 faces
Temperature-Time Curve : ISO Curve

Type of Protection : Contour Encasement
==> Section factor $\lambda/V = 187.7063 \text{ m}^{-1}$
Type of material : rock/glass wool
Thickness : 10 mm
Specific Heat : 850 J/kg.°K
Thermal Conductivity : 0,04 W/m.°K
Unit Mass : 150 kg/m³

Results

Time/Temperature evolution in the steel section calculated
by ELEFIR using relation 4.22 of ENV 1993-1-2
Time [min.] ; Temperature [°C]

0	20
5	43
10	77
15	112
20	147
25	181
30	215
35	247
40	278
45	308
50	337
55	365
60	391
65	416
70	441
75	464
79,9	486



Temperature Curve

Modify

Profile	IPE 300 Critical time for 468 °C
Configuration	exposed on 3 sides, contour encasement
Protection	rock/glass wool, thickness: 10 mm

Temperature-time curve

ISO Curve Hydrocarbon Curve
 External Fire Curve ASTM Curve
 Other

The profile reaches 468 °C after 75.86 minutes
Section factor : 187.7 m⁻¹

File

The temperature of 486 °C is obtained after 75.86 min.

Simplified FRM - Potfire

Software sheet – general description			
Name	Potfire		
Version	1.11	Year	2001
Country	France	Language	English
System	Windows	Size	15 MB
Authors	G. Fouquet, G. Tabet, B. Zhao, J. Kruppa		
Organisation	CTICM, CIDECT, TNO		
Application field	Fire resistance model (simplified)		
Availability	Free – www.cidect.org		
Contact	CIDECT - www.cidect.org		
Formulation	Based on ENV 1994-1-2 Annex G		
Short description	Fire resistance duration of unprotected filled hollow section columns		

Potfire - Main menu/Input-output data

1°

PotFire

Section

Type of section:

Dimensions of steel section

Diameter: mm

Wall thickness: mm

Material characteristics

Yield strength of steel section: N/mm²

Yield strength of re-bars: N/mm²

Compressive strength of concrete (cylinder at 28 days): N/mm²

Eccentricity of the load

Eccentricity | to buckling axis: mm

Reinforcement bars

By nr of bars By %

Re-bars : # mm

Concrete covering from re-bars axis: mm

Equal to: %

Buckling length

Buckling length: m

Calculation of

Ultimate load Fire resistance duration

Fire duration: min

Result

Non-dimensional slenderness: **4140.0000**

Ultimate load: **1582** kN

2°

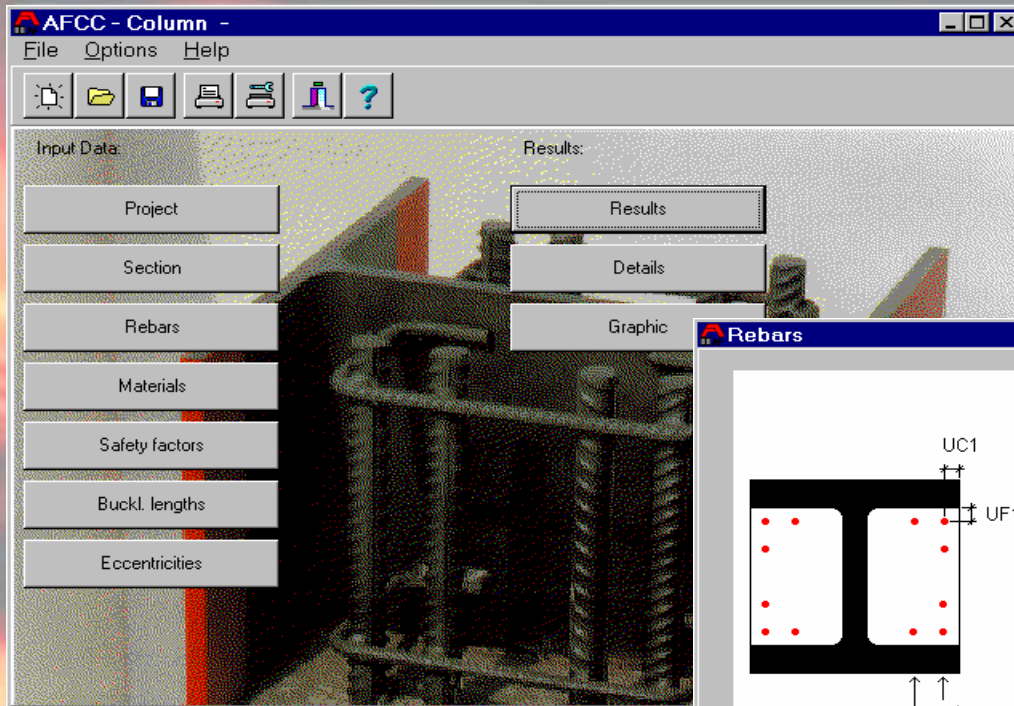
3°

4°

Simplified FRM - AFCC

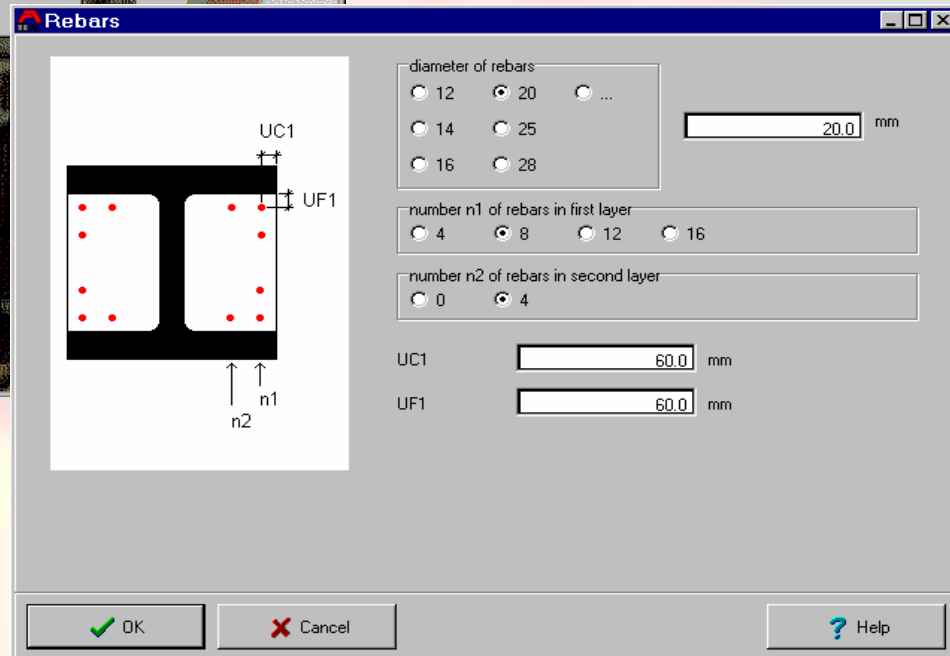
Software sheet – general description			
Name	AFCC		
Version	3.06	Year	2004
Country	Luxembourg	Language	English
System	Windows	Size	2.5 MB
Authors	H. Colbach		
Organisation	Arcelor LCS Research Centre		
Application field	Fire resistance model (simplified)		
Availability	Free – www.sections.arcelor.com		
Contact	Arcelor ASC: asc.tecom@arcelor.com		
Formulation	Based on ENV 1994-1-2		
Short description	Composite columns fire design		

AFCC - Main menu/input data



Panel control.

Reinforced steel



AFCC - Output data

Results

Write report

Results

Ultimate loads [kN]

	axial	axial	eccentrically	eccentrically	eccentrically
	weak axis	strong axis	weak axis	strong axis	biaxial
eccent. [mm]			0.00	0.00	
Service	6403	7256	6403	7256	6403
R 30	5352	5708	5352	5708	5352
R 60	4005	4311	4005	4311	4005
R 90	3019	3277	3019	3277	3019
R 120	1872	2059	1872	2059	1872

Warnings

Number or diameter of the re-bars too high for design at room temperature. Percentage of the reinforcement = 4.16 %
 0.3 % < allowed percentage < 4 % (ENV 1994-1-1, 4.8.3.1 and 4.8.2.5)
 4 % assumed for the calculation at room temperature
 Reduced diameter of re-bars for calculation at room-temperature = 19.62 mm

OK Help

Details

Project

Project-Name: DIFISEK
 Project-Number: Example
 Position-Name: AFCC - Example
 Position-Number: 001
 User: DIFISEK
 Comment: Example of use
 created: 5/8/04
 modified last: 5/8/04

Warnings

Number or diameter of the re-bars too high for design at room temperature. Percentage of the reinforcement = 4.16 %
 0.3 % < allowed percentage < 4 % (ENV 1994-1-1, 4.8.3.1 and 4.8.2.5)
 4 % assumed for the calculation at room temperature
 Reduced diameter of re-bars for calculation at room-temperature = 19.62 mm

Input values:

Steel-Profile: HE 360 A
 h: 350 mm

OK Help

Graphic

Steel-Profile: HE 360 A
 Rebars: 12 x d = 20 mm

OK Help

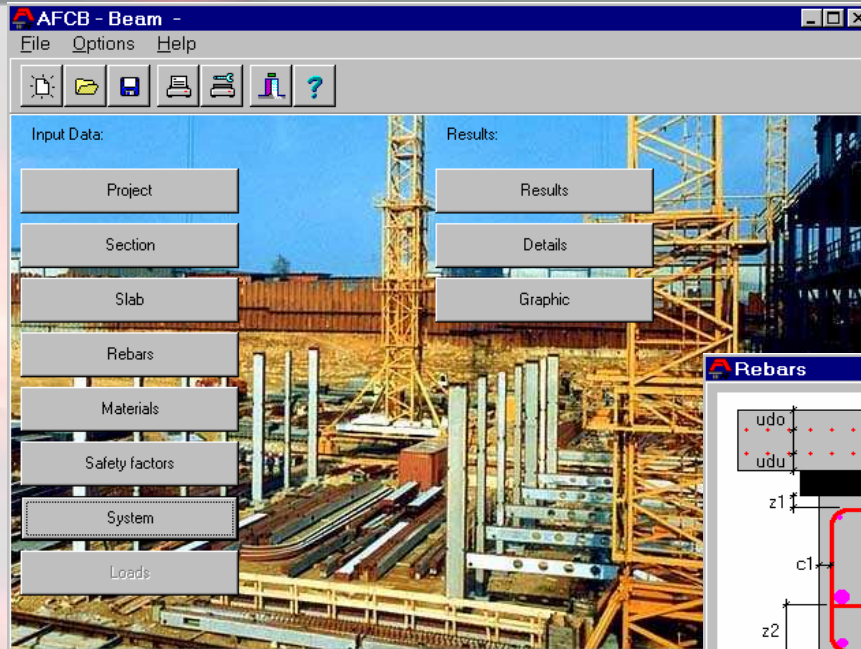
Drawing detail



Simplified FRM - AFCB

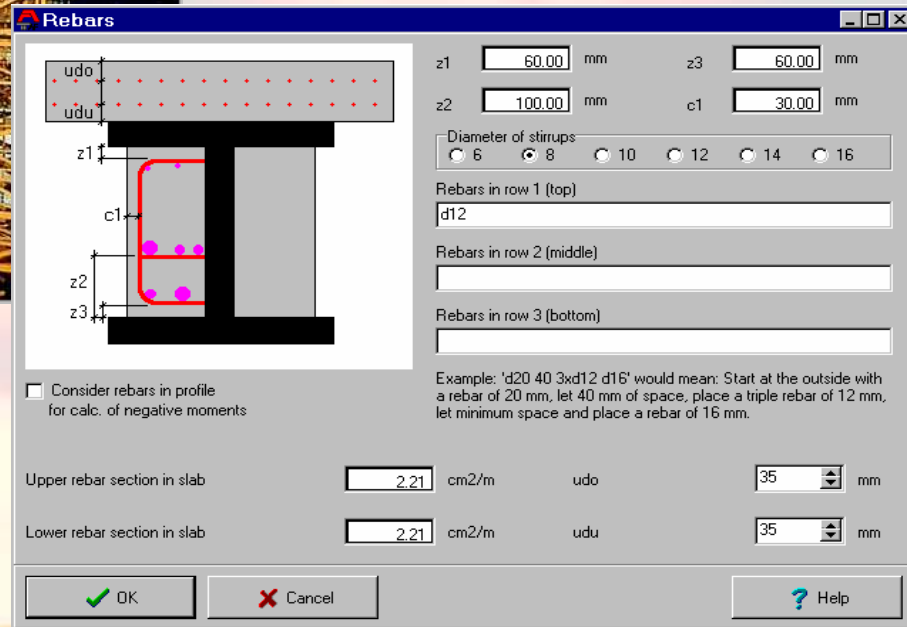
Software sheet – general description			
Name	AFCB		
Version	3.07	Year	2004
Country	Luxembourg	Language	English
System	Windows	Size	3 MB
Authors	H. Colbach		
Organisation	Arcelor LCS Research Centre		
Application field	Fire resistance model (simplified)		
Availability	Free – www.sections.arcelor.com		
Contact	Arcelor ASC: asc.tecom@arcelor.com		
Formulation	Based on ENV 1994-1-2		
Short description	Composite beams fire design		

AFCB - Main menu / input data



Reinforced steel

Panel control.



AFCB - Output data

Results

Write report

Results

Ultimate plastic moments and shear forces

	Ultimate positive	Ultimate negative	Ultimate Shear
	Moments M+ [kNm]	Moments M- [kNm]	Forces T. ult [kN]
cold	1748.31	858.47	1221.19
R60	1376.58	518.56	1211.41

Calculation of fire resistance class under given load
Calculation type: Calculation of section resistance

Warnings

OK Help

Details

Project

Project-Name: DIFISEK
Project-Number: Example
Position-Name: 001
Position-Number: 001
User: DIFISEK
Comment: Example of use
created: 5/8/04
modified last: 5/8/04

Input values:

Steel-Profile: IPE 600
h: 600 mm
b: 220 mm
t.w: 12 mm
t.f: 19 mm
r: 24 mm
b*: 220 mm

Concrete slab : Cast in place slab
Type of slab : Cast in place slab
Orientation of joints or ribs : perpendicular to beam-axis

OK Help

Graphic

Steel-Profile: IPE 600
Cast in place slab
Orientation of joints or ribs : perpendicular to beam-axis

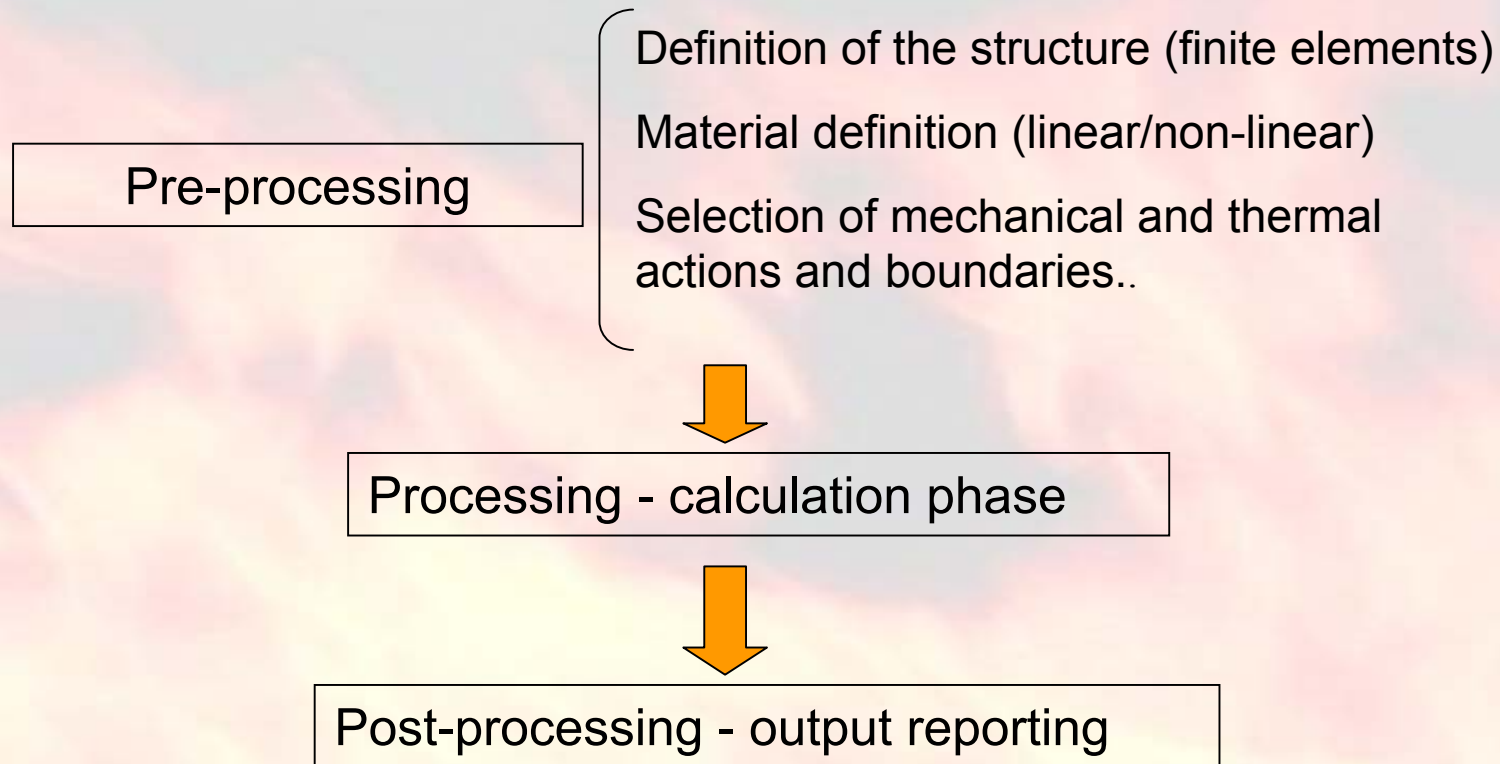
OK Section Moments Hogging-cold Hogging-fire Sagging-cold Sagging-fire Help

Drawing detail



Advanced calculation methods

The advanced calculation methods have three principal phases



Advanced FRM - Safir

Software sheet – general description			
Name	Safir		
Version	9.8	Year	2002
Country	Belgium	Language	English
System	Fortran/Visual Basic	Size	----
Authors	J. M. Franssen		
Organisation	University of Liege		
Application field	Fire resistance model (advanced)		
Availability	Commercial software		
Contact	JM.Franssen@ulg.ac.be		
Formulation	Finite element code		
Short description	Finite element model for the behaviour of the structures in fire.		

Advanced FRM - Ansys

nSoftware sheet – general description			
Name	Ansys		
Version	8.1	Year	2003
Country	U.S.A	Language	English
System	-----	Size	----
Authors	-----		
Organisation	ANSYS Inc.		
Application field	Fire resistance model (advanced)		
Availability	Commercial software		
Contact	Ansys – www.ansys.com		
Formulation	Finite element code		
Short description	General purpose software		

Advanced FRM - Example: Abaqus

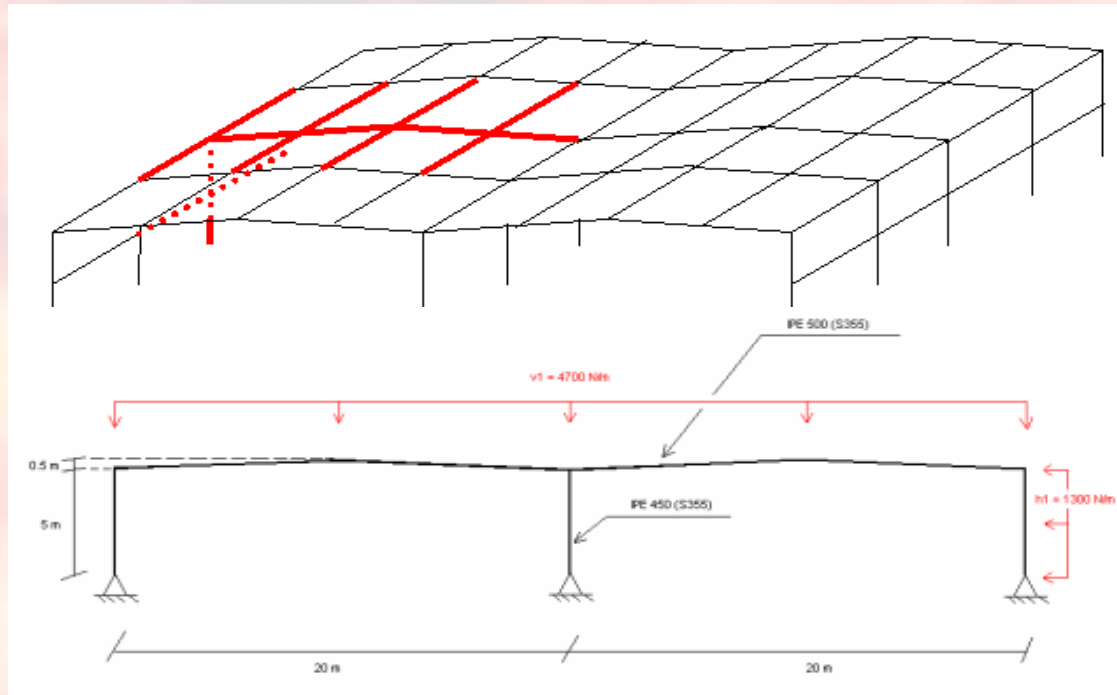
Software sheet – general description			
Name	Abaqus		
Version	6.3	Year	2003
Country	U.S.A	Language	English
System	MS-DOS	Size	----
Authors	Hibbitt, Krlsson and Sorensen		
Organisation	ABAQUS Inc.		
Application field	Fire resistance model (advanced)		
Availability	Commercial software		
Contact	Abaqus – www.abaqus.com		
Formulation	Finite element code		
Short description	General purpose software		

SAFIR/ANSYS/ABAQUS - Case study

Fire scenario: fire in an industrial building

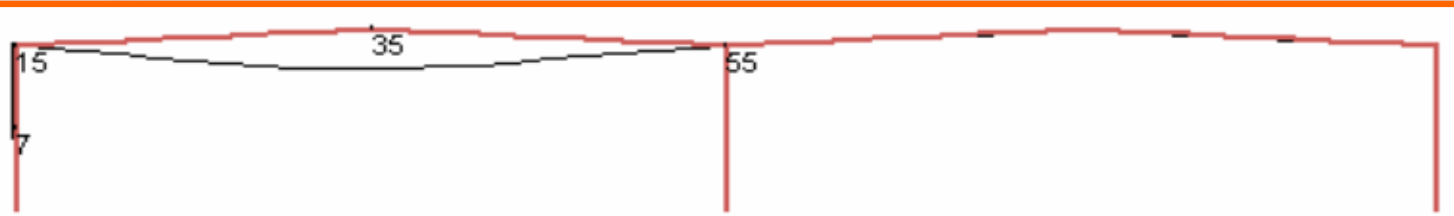
Design fire: ISO curve

Objective: definition of fire resistance of the whole structure and the influence of the affected zone on the rest of the structure.

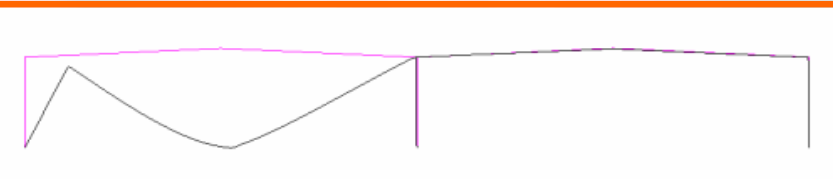
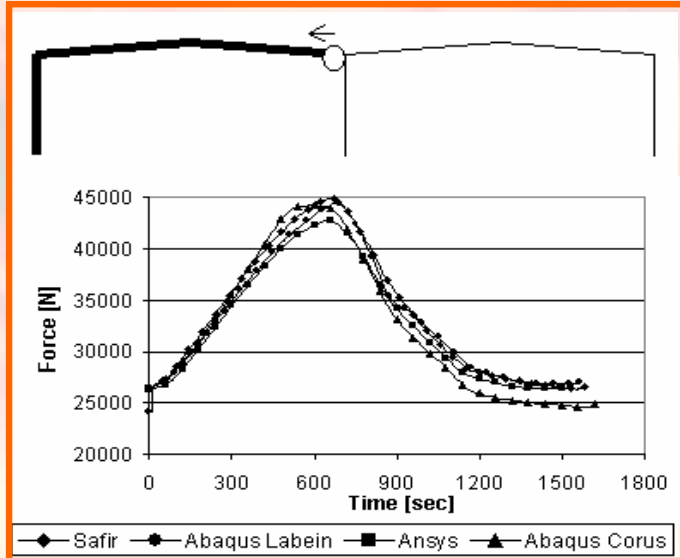


SAFIR/ANSYS/ABAQUS - Case study

2D



Deformed shape without amplification (static mode)

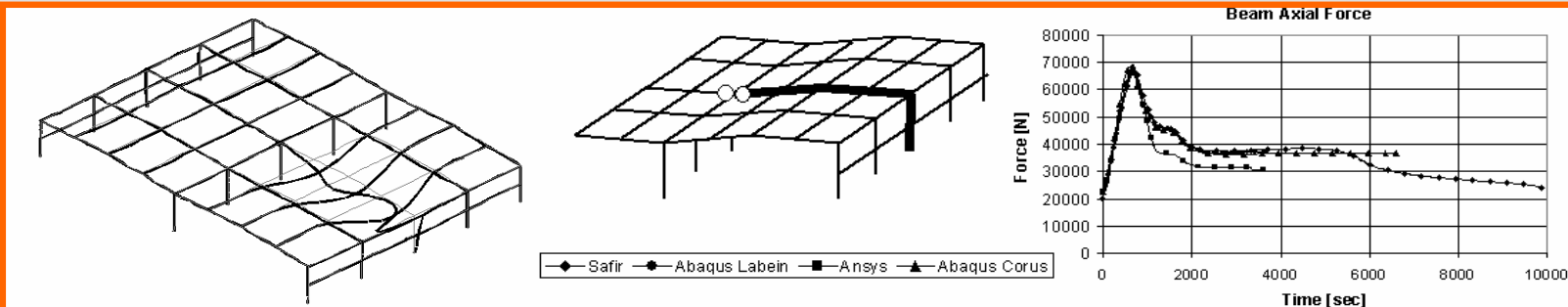


Deformed shape without amplification (dynamic mode)
Left frame collapse towards inside of the building.

Axial force - No bigger than the effect of the wind in service condition.

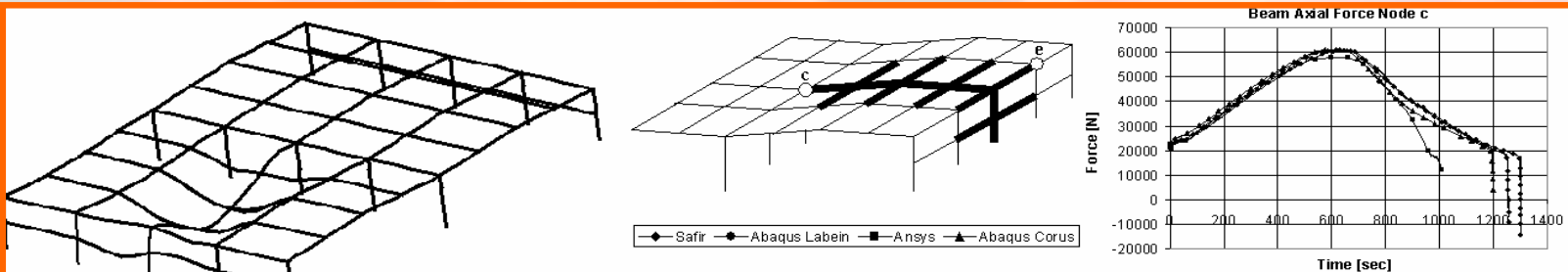
SAFIR/ANSYS/ABAQUS - Case study

3D - With more than one frame without hot purlins



Deformed shape(x10) - The purlins support the frame submitted to fire

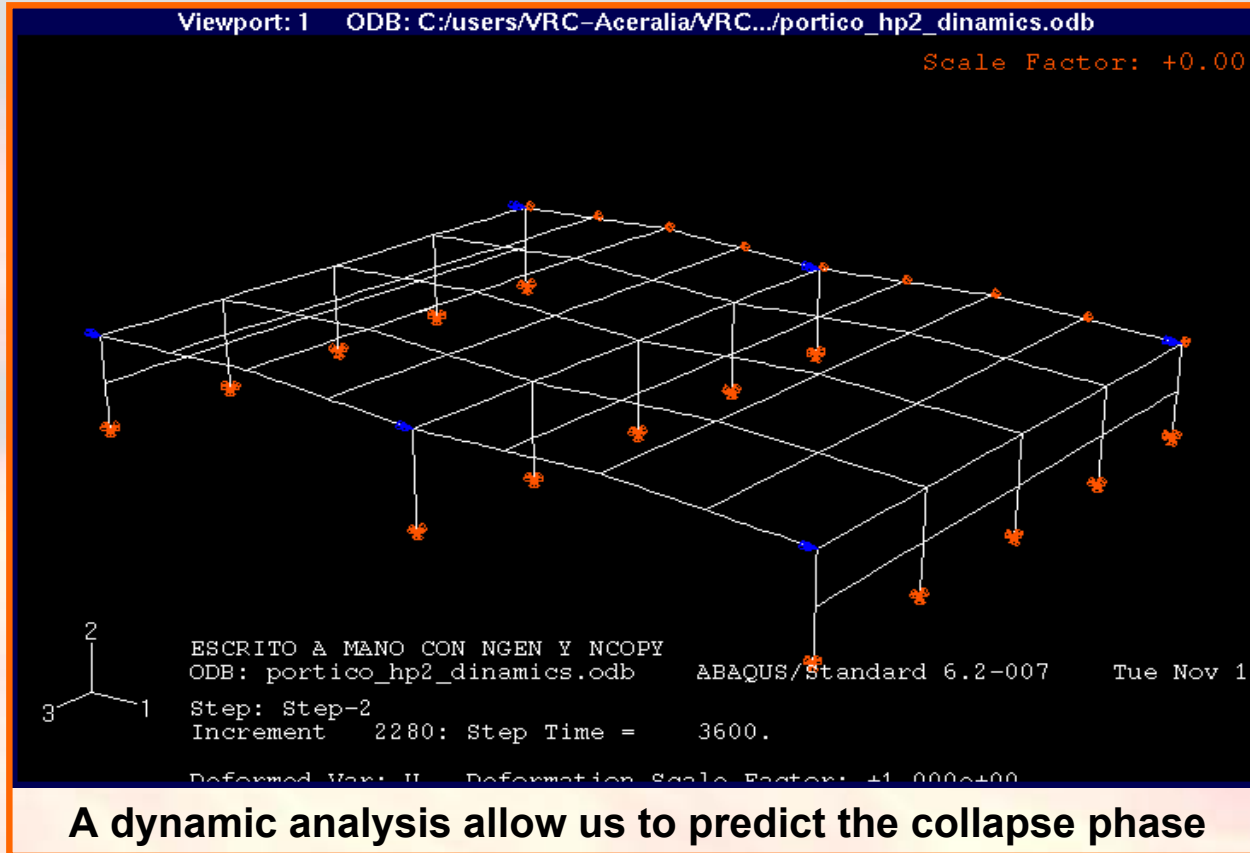
3D - With more than one frame with hot purlins



Deformed shape without amplification
Axial load

SAFIR/ANSYS/ABAQUS - Case study

3D - With more than one frame with hot purlins (Dynamic)



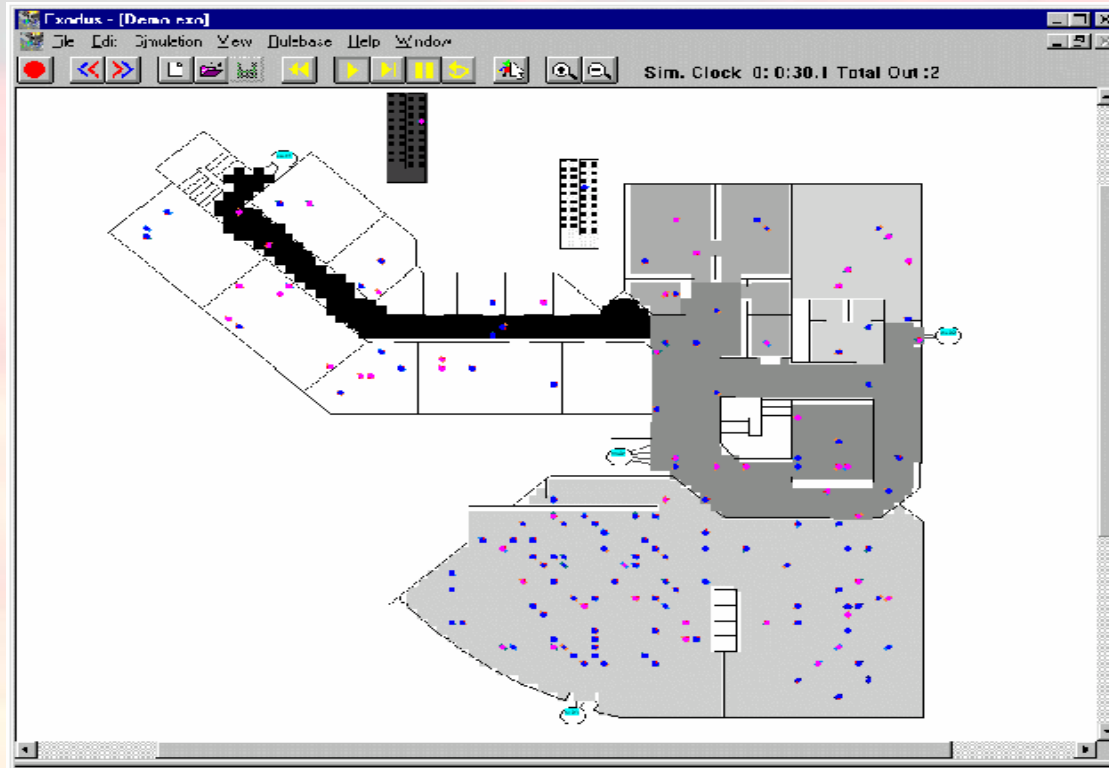
Egress and detector response models

Egress models - Exodus

Software sheet – general description			
Name	Exodus		
Version	4.0	Year	2004
Country	England	Language	English
System	Windows	Size	-----
Authors	E. Galea, St. Gwyne, S. Blake, L. Filippidis		
Organisation	University of Greenwich		
Application field	Egress model		
Availability	Commercial – www.fseg.gre.ac.uk		
Contact	E.R.Galea@greenwich.ac.uk		
Formulation	-----		
Short description	Egress model based on human behaviour		

Egress models - EXODUS

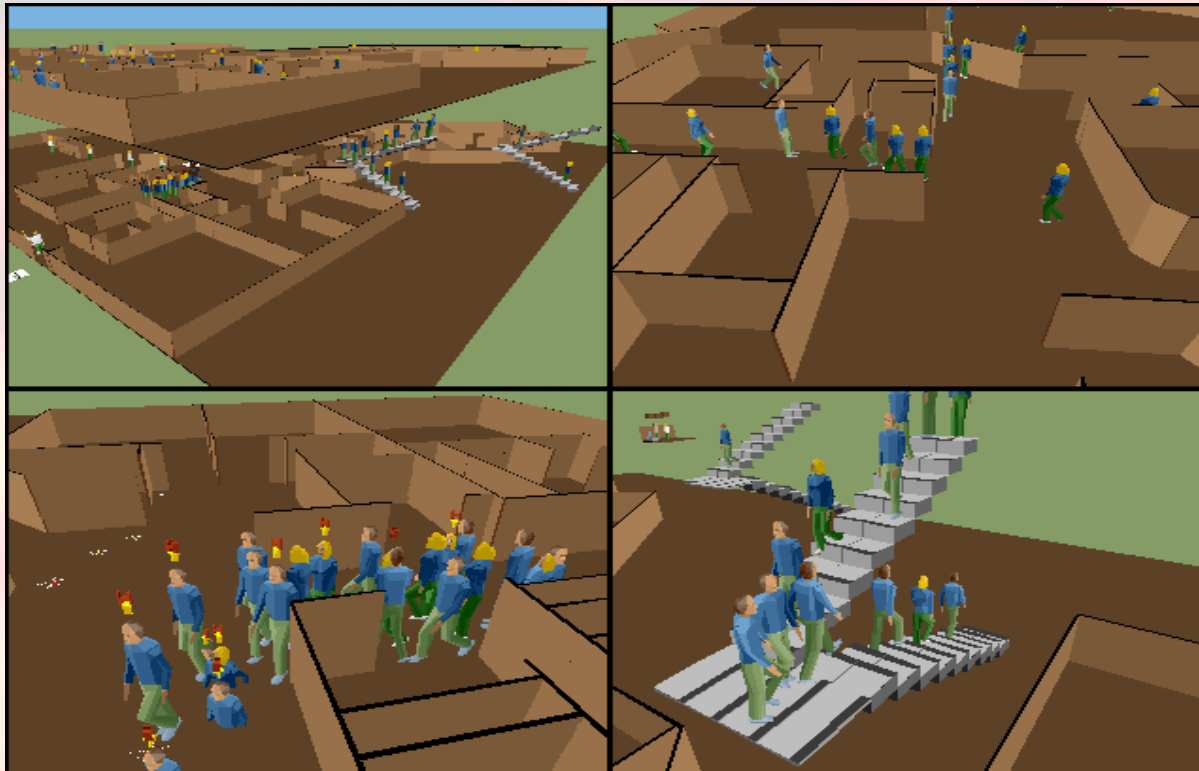
- Simulation allow user to asses the level of safety along the evacuation.



Egress models - EXODUS

Results:

Simulations can be viewed with the post-processing tool
VR-EXODUS



Detector response models - Jet

Software sheet – general description			
Name	Jet		
Version	1.0	Year	1999
Country	U.S.A	Language	English
System	Windows	Size	4 MB
Authors	W. D. Davids		
Organisation	NIST (National Institute of Standards and Technology)		
Application field	Detector response models		
Availability	Free – www.fire.nist.gov		
Contact	NIST - www.fire.nist.gov		
Formulation	Zone model based on code LAVENT Algorithm for plume centerline temperature Algorithm for ceiling jet depending on smoke layer depth		
Short description	Sprinkler response – Time to activation		

Jet - Main menu / input data

jet

vents fire links

Open File Unit Convert Save File Run Jet End

JET

Compartment

Room Geometry (m)

Room Length (m)	11,52
Room Width (m)	9,35
Ceiling Height (m)	5,12
Curtain Length (m)	1,50
Curtain Height (m)	2,00

Ceiling Properties

INSULATED METAL DECK	
Th. Cond. (W/(m °C))	1,50E-01
Ht. Cap. (J/kg °C)	1,16E+03
Density (kg/cu m)	1,05E+03
Ceiling Thickness (m)	0,10

Sprinkler properties

Sprinkler Links

Link #	Rad. Dist. (m)	RTI sqrt(m s)	Fuse Temp (°C)	Below Ceiling	C-factor sqrt(m/s)
1	1,75	350,00	79,00	0,62	1,00
2	1,75	350,00	79,00	0,62	1,00
3	3,20	350,00	79,00	0,62	1,00
4	3,20	350,00	79,00	0,62	1,00

Vents

Vent Properties

Vent #	Vent Area (sq m)	Link #

Forced Ventillation

Air Flow (m3/s)	Temp °C	Time s
0,00	20,00	20,00

Design fire

Fire Properties

Ambient Temp (°C)	20,00
Fire Height (m)	1,00
Fire Diameter (m)	255,00

HRR/Area for selected fuels

Seg. #	Time (s)	HRR (kW)	Rad. Frac. (<1.0)
1	0,00	0,00	0,33
2	0,00	40,00	0,33
3	0,00	160,00	0,33
4	120,00	640,00	0,33
5	180,00	1.440,00	0,33
6	300,00	4.000,00	0,33

Parameters

Program Times (s)

Output Time	25,00
End Time	300,00

Solver Inputs

DDrive Tol.	1,00E-06
SOLVER Type	1
Flux Update Int. (s)	2,00
Smallest Value	1,00E-06
# Ceiling Seg.	6