9-1. Introduction to fire design

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EQUESTA
Electronic Quality Assured
Steel Training & Assessment

Education and Culture
Lifelong learning programme
LEONARDO DA VINCI

Objectives
Prescriptive approach
Performace approach
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Objectives of the lecture

- The state of art in the fire design
- Recent major fire disasters
- Choice of appropriate procedure
- Eurocodes for fire design
- Educational materials on internet

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Fire safety in buildings

- **Prescriptive based approach**
  - States how a building is to be constructed
- Performance based approach
  - States how a building is to perform under stated criteria

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Set of rules for prescriptive approach

For example :

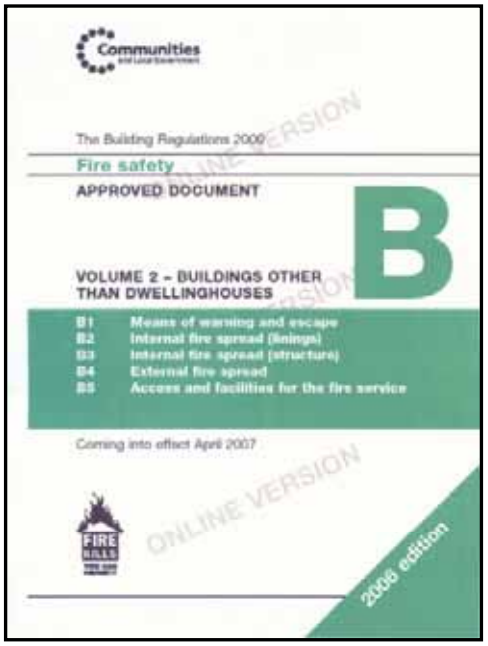
Minimum fire resistance for members

Maximum fire compartment size

Maximum travel distances

Minimum number of exists

Etc.



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Example of prescriptive approach

- Fire resistance periods

	Height of Building (m)			
	<5	<18	<30	>30
Residential (Non Domestic)	30	60	90	120
Offices	30	60	90	klers
Shops, Commercial, Assembly	60	60	90	
Industrial & Storage	60	90	120	
Car Parks - Open	15	15	15	

60 min fire resistance means
that the elements in the building will survive
60 min in a standard fire test

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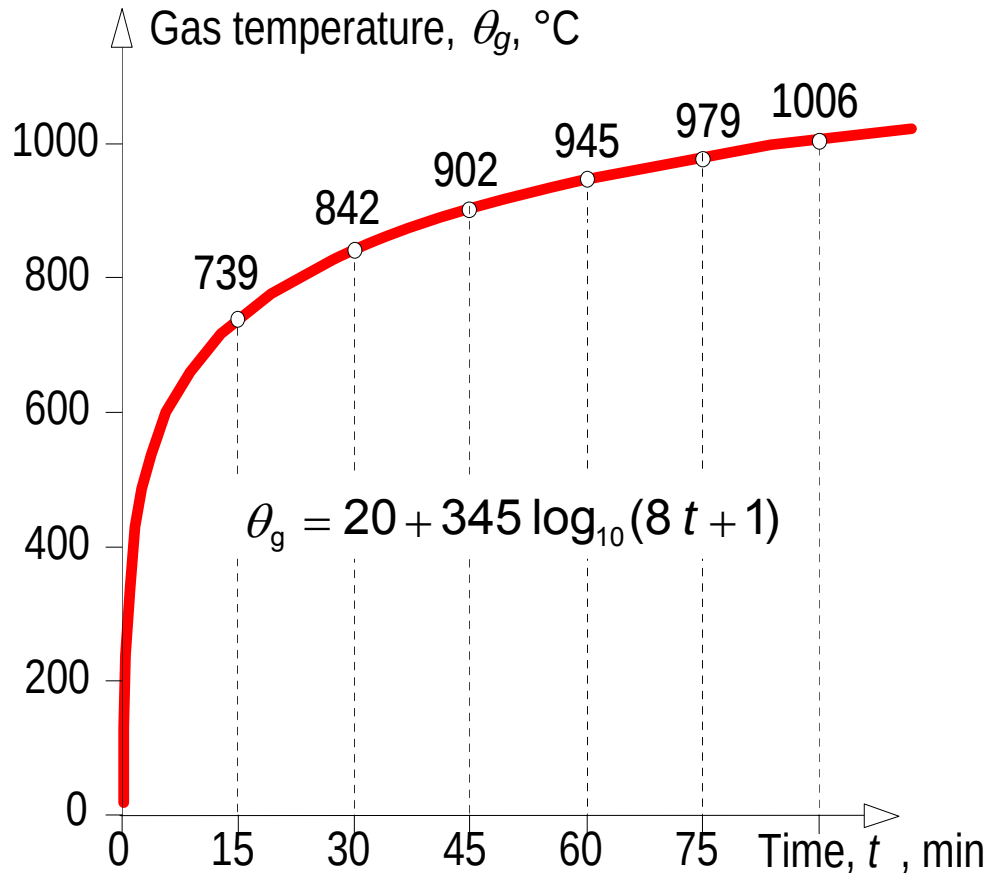
Standard fire resistance

Heating according to
nominal standard fire curve



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Standard fire resistance

Used for

- Load bearing capacity **R**
- Insulation **I**
- Integrity **E**

Marked as

- R15; RE30; REI90

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History of the standard fire test

Over 100 years of testing

- **1890's** early attempts at establishing structural fire behaviour at the behest of **insurance companies**

- **1917** First US Standard produced
- **1932** First Edition of BS476 (UK)
- **1933** E119 (US) produced

- **1985** ISO 834
- **2003** EN 1991-1-2

Fire test of intumescent coating

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Fire protection

- Unprotected steel for limited fire resistance, eg. R15
- Fire protection:
  - Concrete/brick encasing
  - Board protection
  - Intumescent coating
  - Sprayed protection
  - Composite members

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Classified fire protection

Thickness of protection depends on

- Fire resistance class
- Section factor

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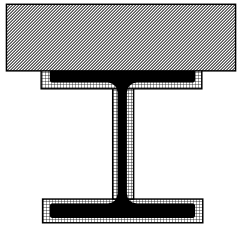
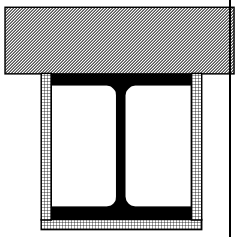
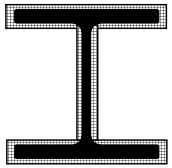
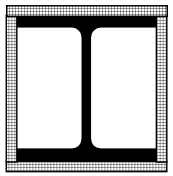
Section factor

$$A_m/V = \frac{\text{the surface area of the member per unit length } [m^2/m]}{\text{the volume of the member per unit length } [m^3/m]} \quad [m^{-1}]$$

Fire exposure	3-sided		All-round	
Type of protection	Contour 	Box 	Contour 	Box 
Section factor $A_m / V =$	$\frac{\text{Steel perimeter} - b}{A}$	$\frac{2h + b}{A}$	$\frac{\text{Steel perimeter}}{A}$	$\frac{2h + 2b}{A}$

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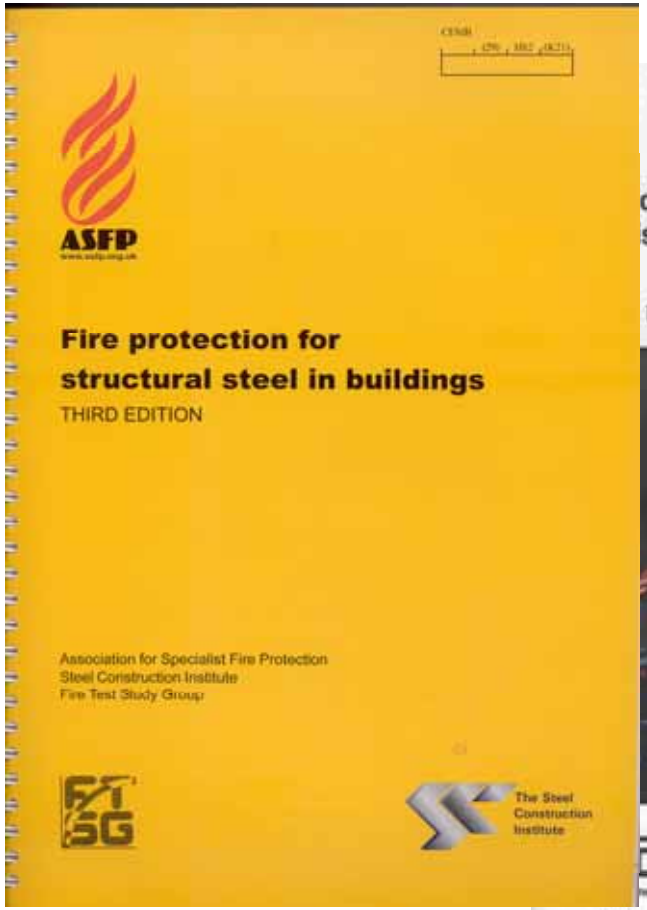
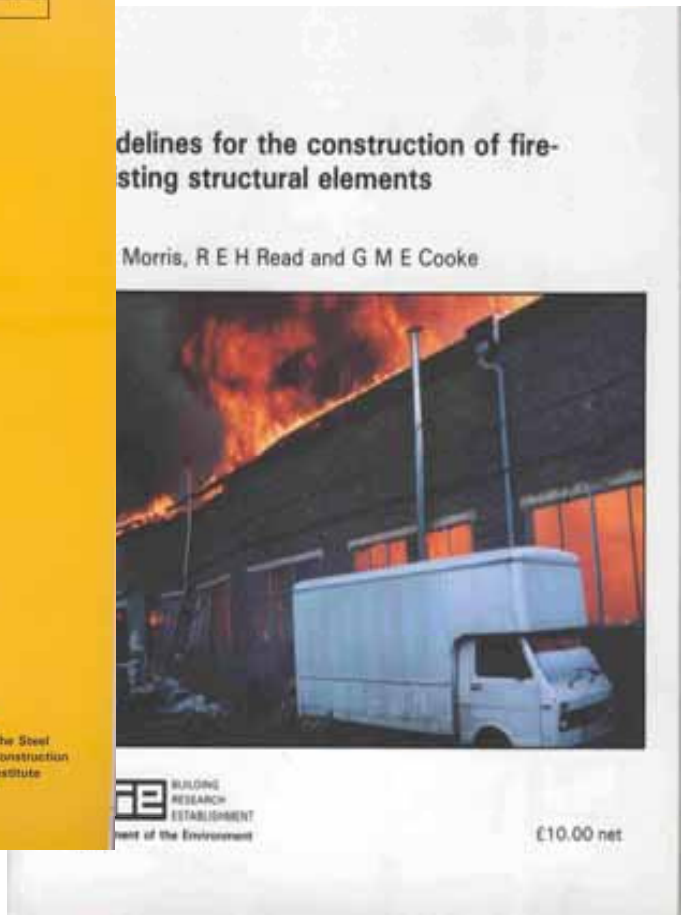
Simple prescriptive rules

– deemed to satisfy





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Generic and proprietary fire protection materials

Thickness specified:
the steel does not exceed
for a given fire resistance period

550°C / 620°C (element exposed from three sides only)

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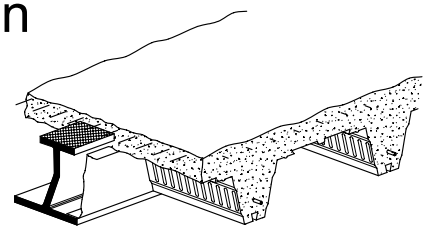
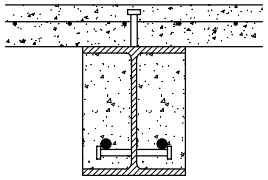
Composite sections

Filled sections till fire resistance 60-90 min
Additional reinforcement 120 min

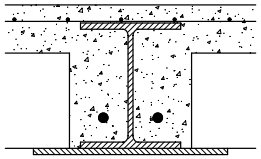


Slab



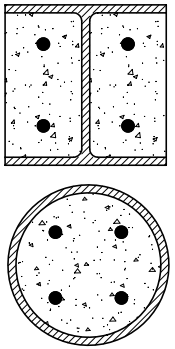
Beams

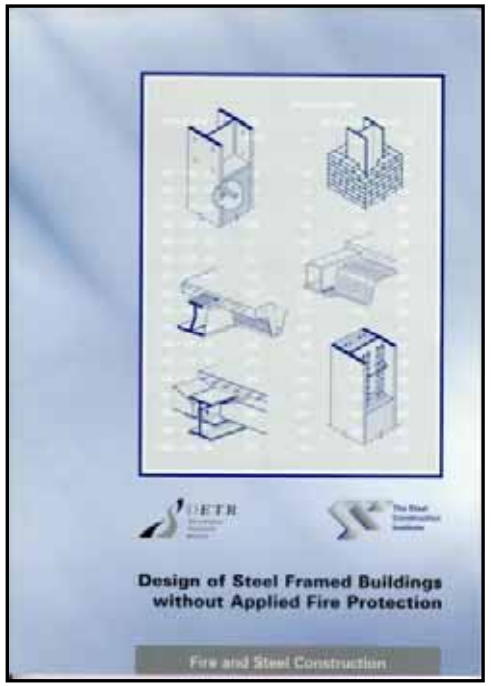
Patially encasses
Slim floor



Columns

Partially encassed
Concrete filled





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Advantages

- Limited design effort
- Experience has shown that approach works
- Approach is easily understood by all parties
- Based on nominal standard fire tests

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Disadvantages

- Actual structural behaviour ignored
- Effect of real fires ignored
- Levels-of-safety and robustness unknown
- Optimum solution in terms of
  - life safety unknown
  - economical impact unknown
  - environmental damage unknown

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- **Performance based approach**
  - States how a building is to perform under stated criteria

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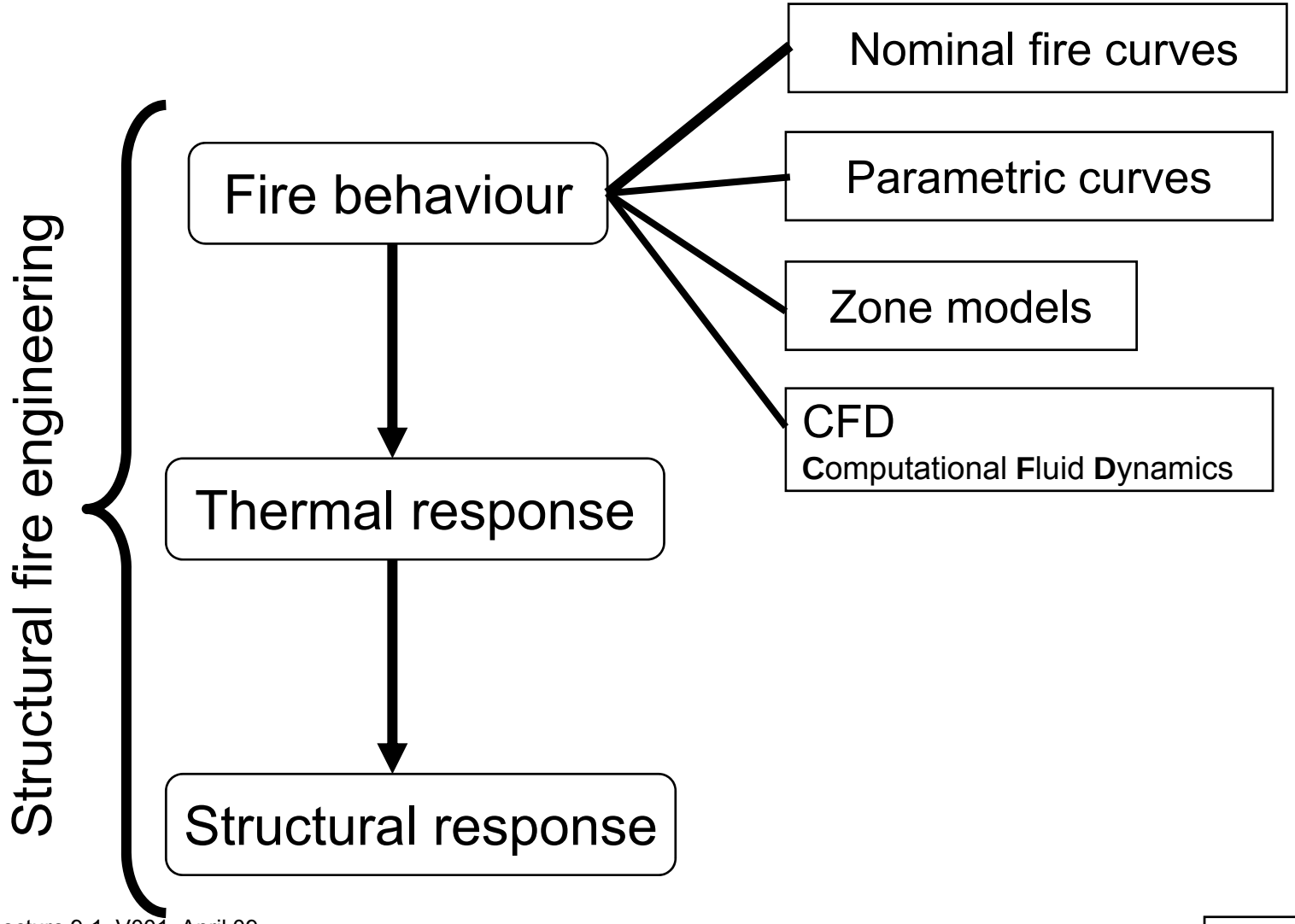
Fire behaviour



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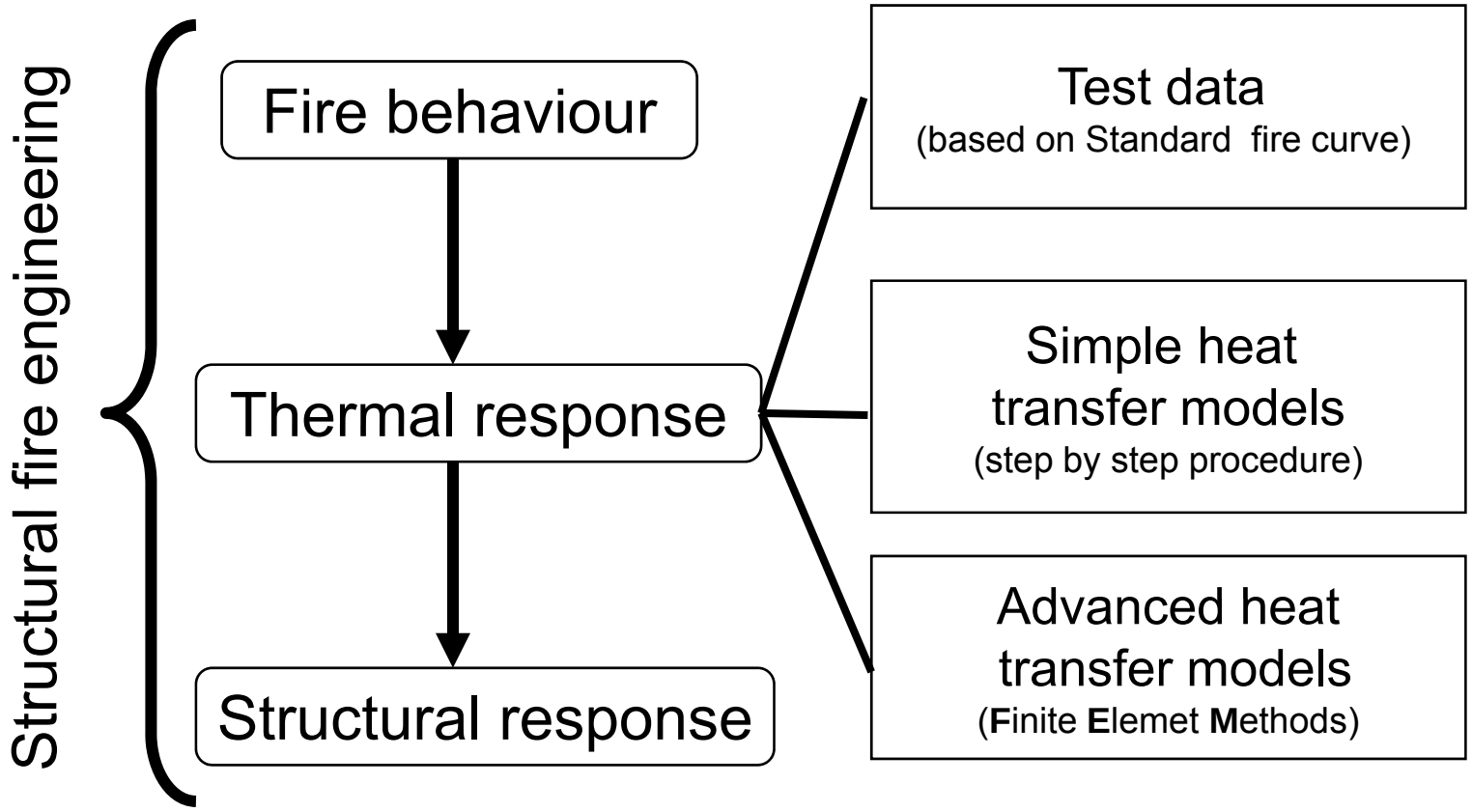
Thermal response



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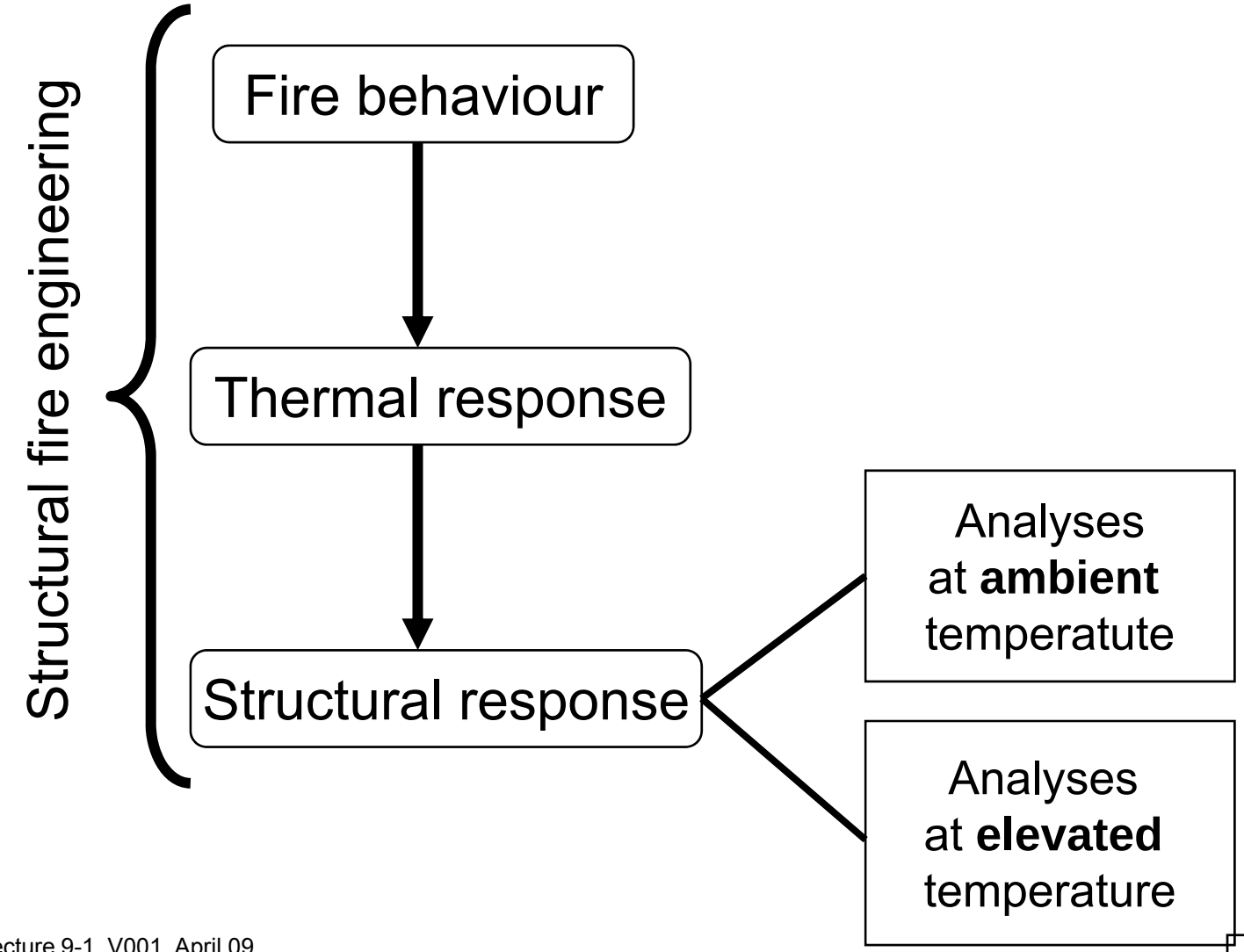
Structural response



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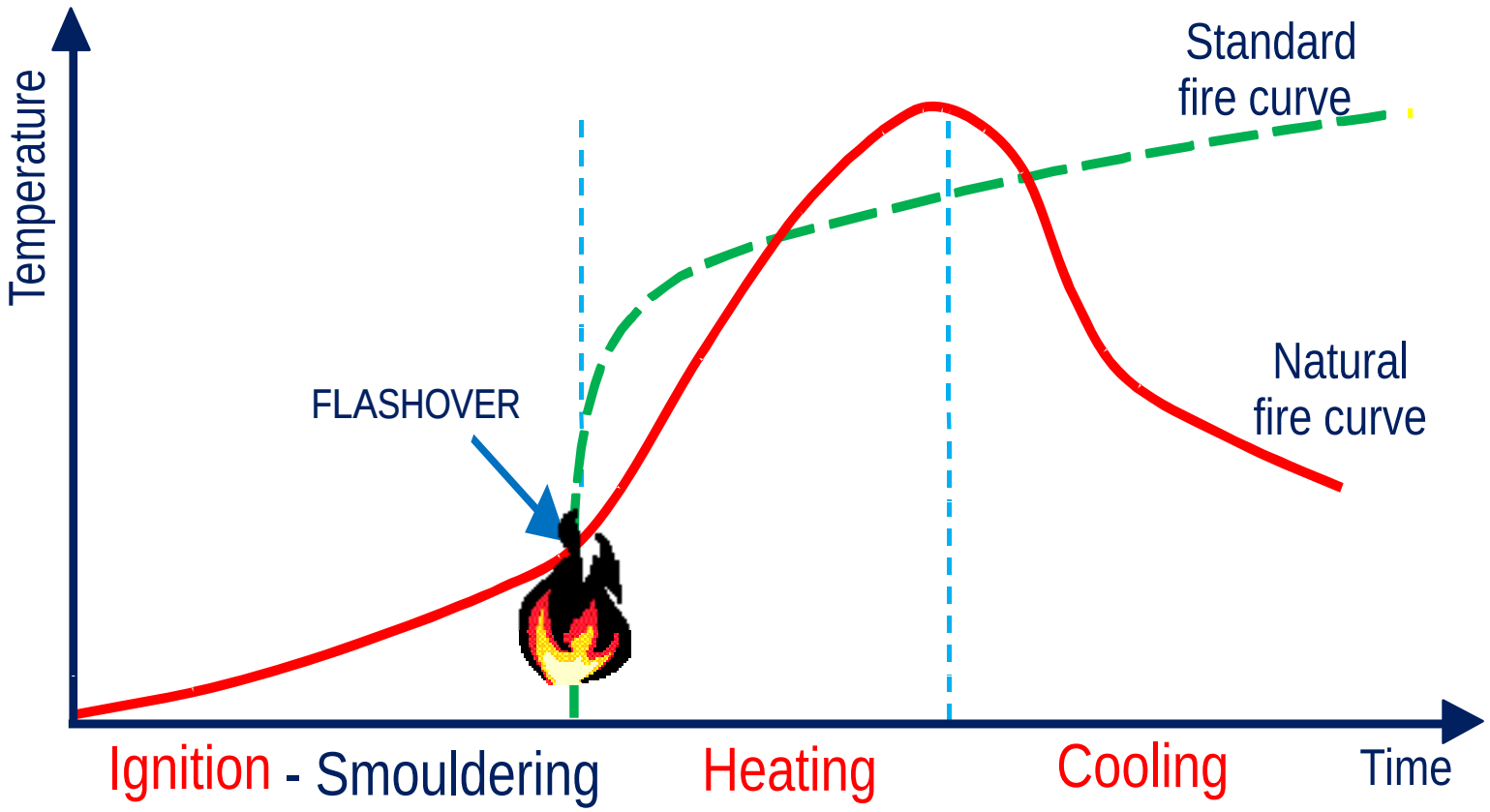
Fire modelling



Three phase of natural fire

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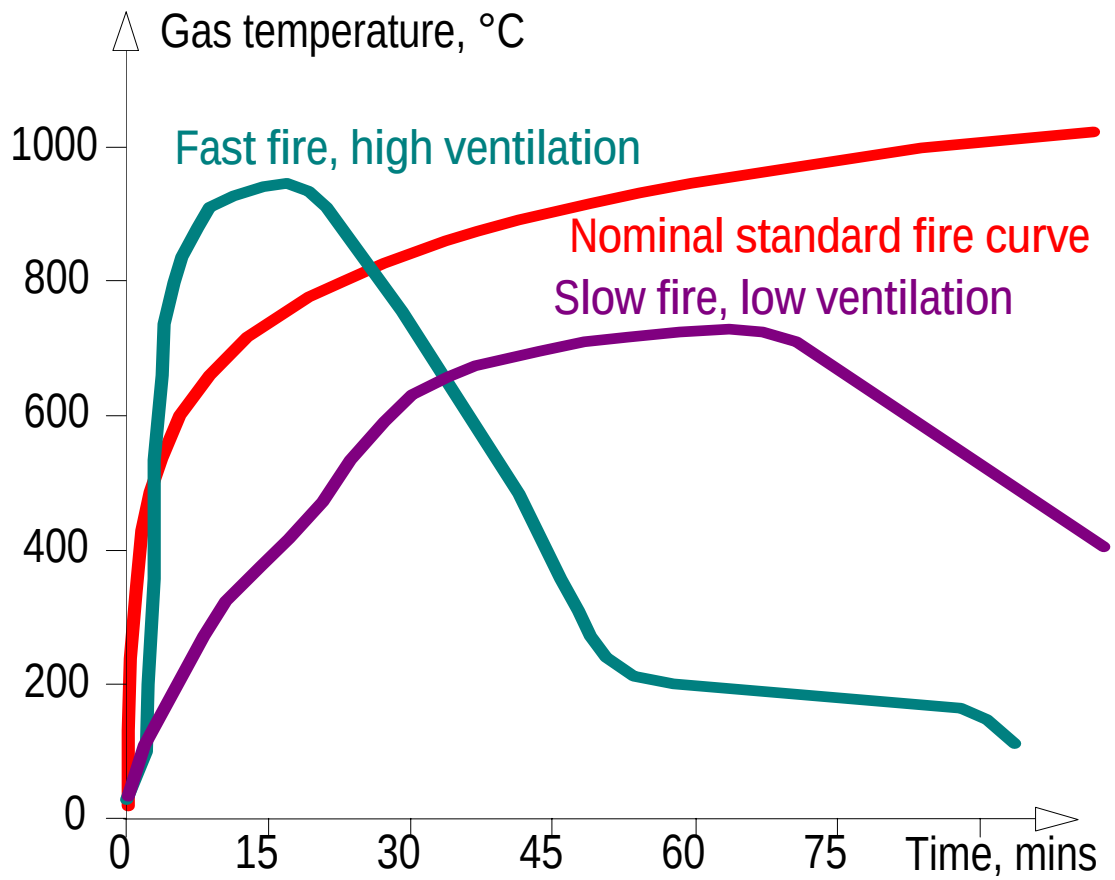
Ventilation and fire load



Standard fire curve is inaccurate

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Fire modelling

- Compartment fire
  - Nominal standard fire curve
  - Parametric fire curve
    - Reached accuracy in case of the Cardington fire test (a widen MS PowerPoint presentation)
  - Zone models
  - **C**omputational **F**luid **D**ynamics CFD
- Localized fire
  - Nominal standard fire curve, very conservative
  - Parametric fires
    - Reached accuracy in case of the Ostrava fire test (a widen MS PowerPoint presentation)
  - **C**omputational **F**luid **D**ynamics CFD

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Real structures

- Today buildings are complex
  - Large spans
  - Mixed building technology
  - New materials

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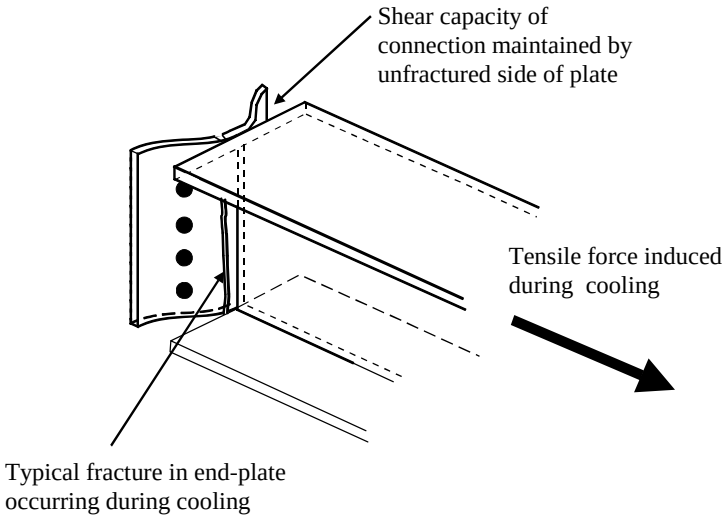
Overall behaviour



- Cooling phase of fire
  - Connection behaviour
  - Mostly collapse of structures

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Advantages

- Actual behaviour and robustness of the building
- Optimum design taking into account
  - Life safety
  - Financial impact
  - Environmental issues
- Part of an assessment of multiple risks
  - Earthquake followed by a fire
  - Explosion followed by a fire

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Disadvantages

- More design effort
- Requires multi-discipline skills
- Design can be complicated
- Change of building use
  may make the fire design invalid

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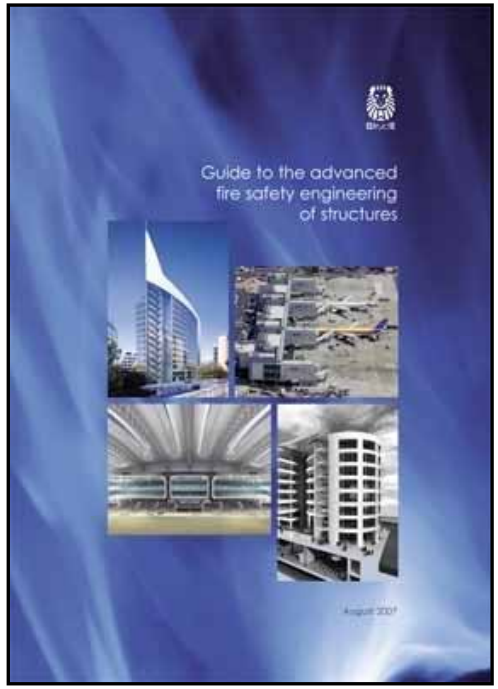
Design methodology

- Simple models
- Based on test of elements
- Advanced structural fire engineering
  - Guidance
  - Modelling
  - Validation
  - Verification
  - Review



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Formative assessment question 1

- What are the advantages of prescriptive based approach for fire safety of buildings?
- How is defined section factor?
- What are the advantages of fire engineering?
- Explain major steps of fire engineering?
- How are divided the models of fire?

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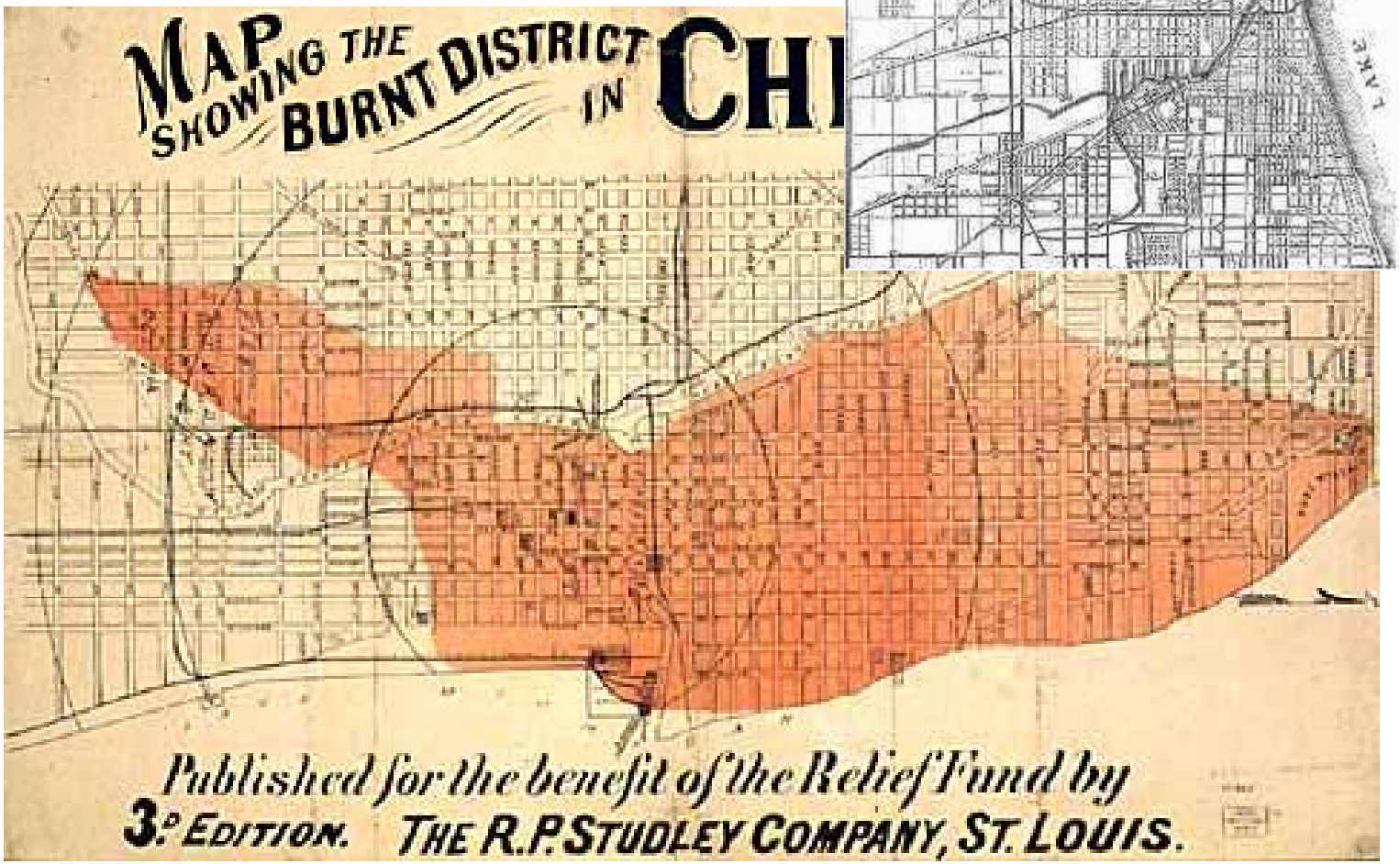
Lecture from major disasters

Great Chicago Fire, 8-10 October 1871



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World Trade Center 11.09.2001

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Other WTC buildings

- 50 buildings were hit by twins
- 17 buildings were demaged
- Source of knowledge

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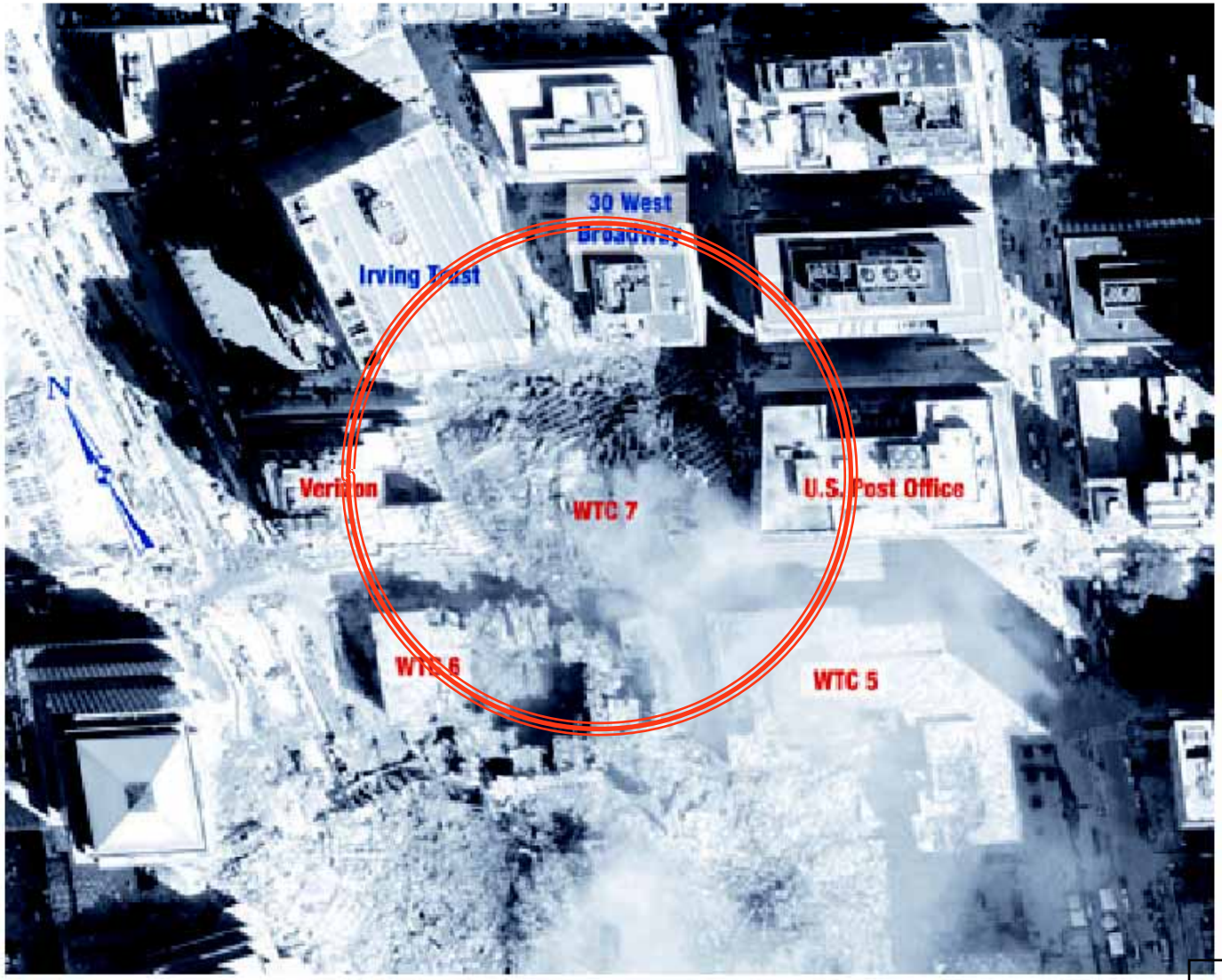
Progresive collapse

WTC building 7 only



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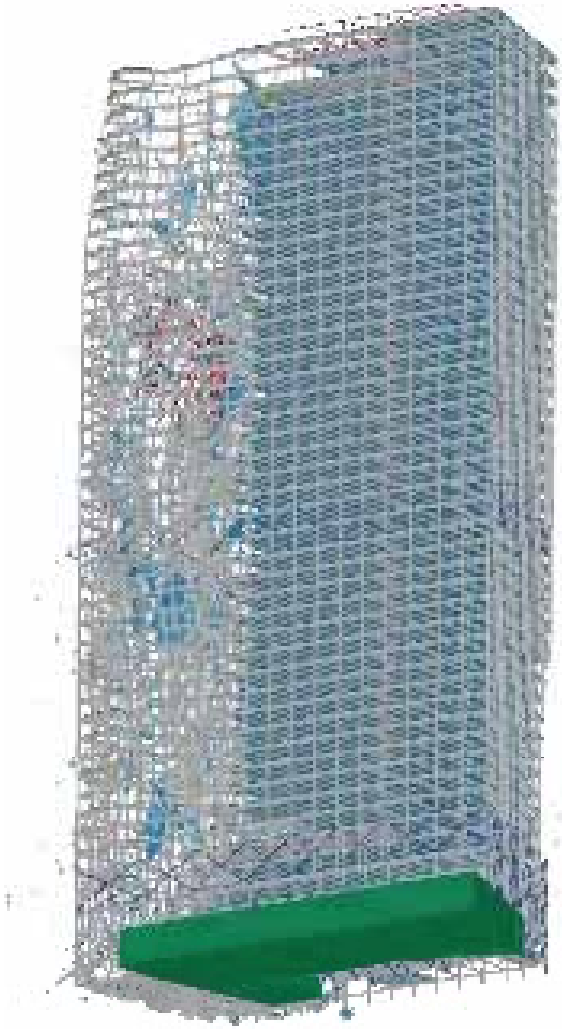
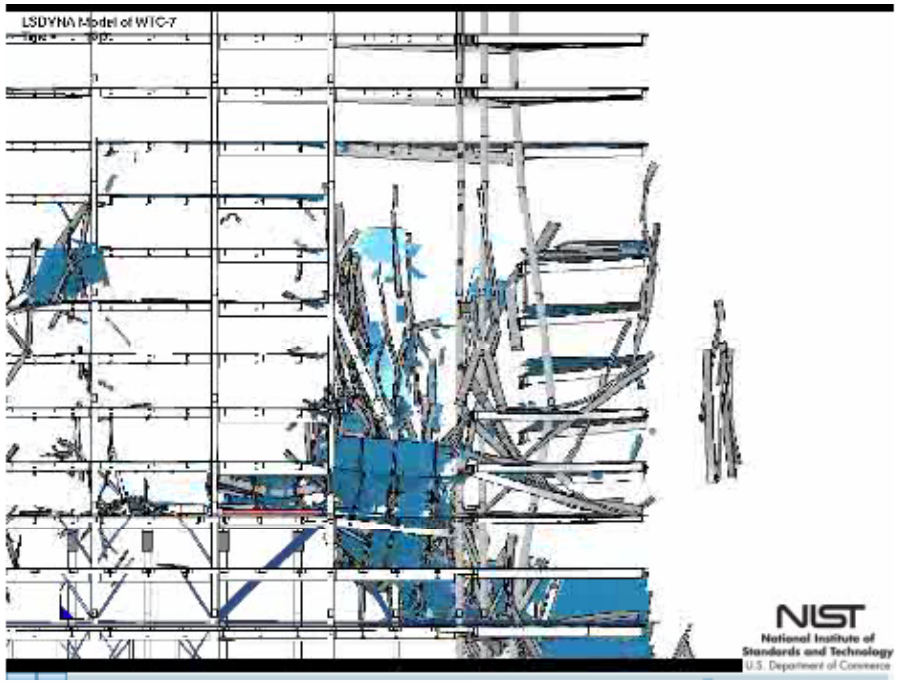
WTC7 – modelling
finished 2008 by NIST





NIST
National Institute of Standards and Technology
U.S. Department of Commerce

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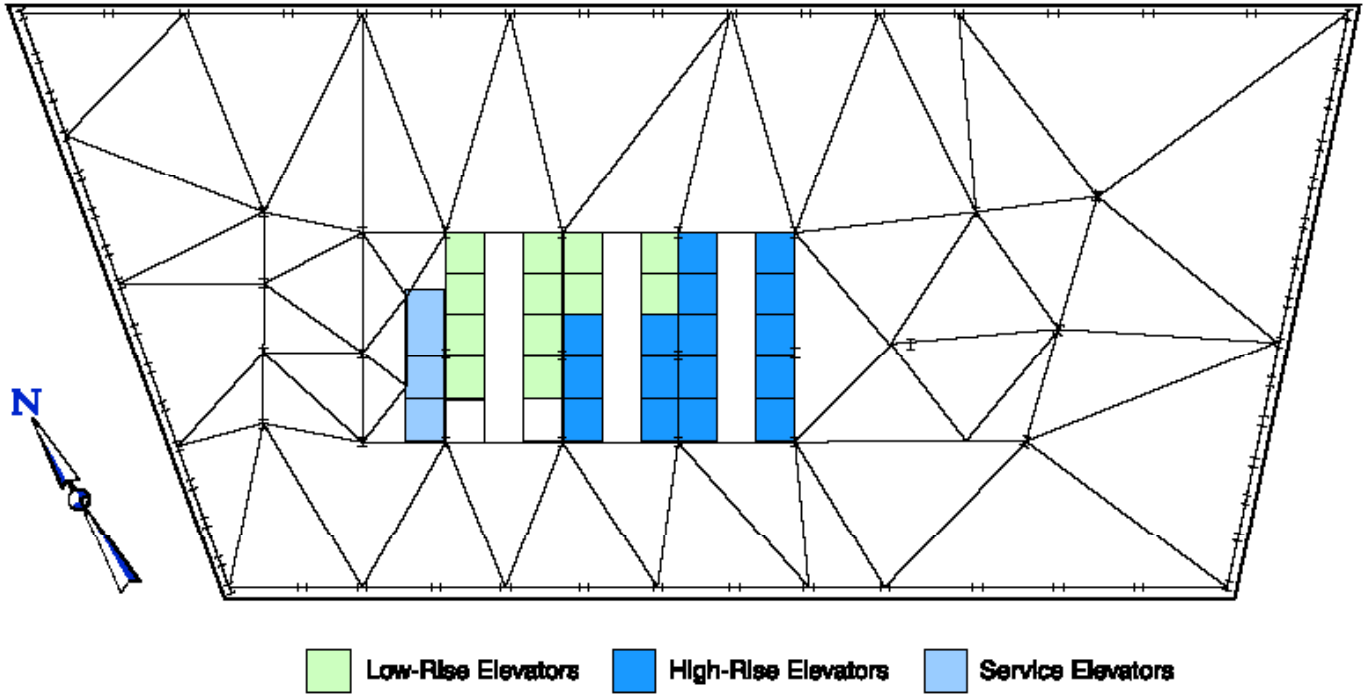
WTC7 plan



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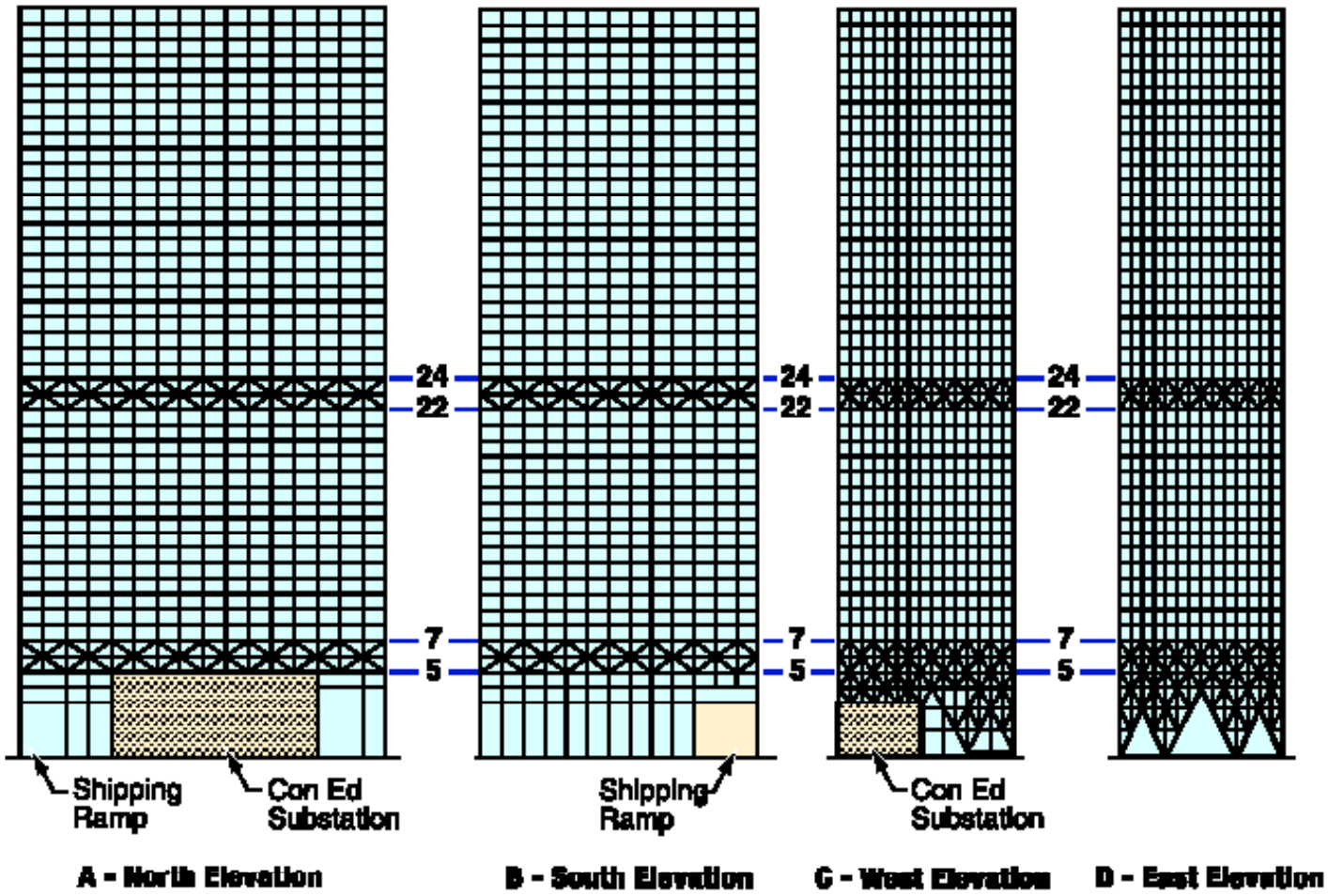
WTC7 view



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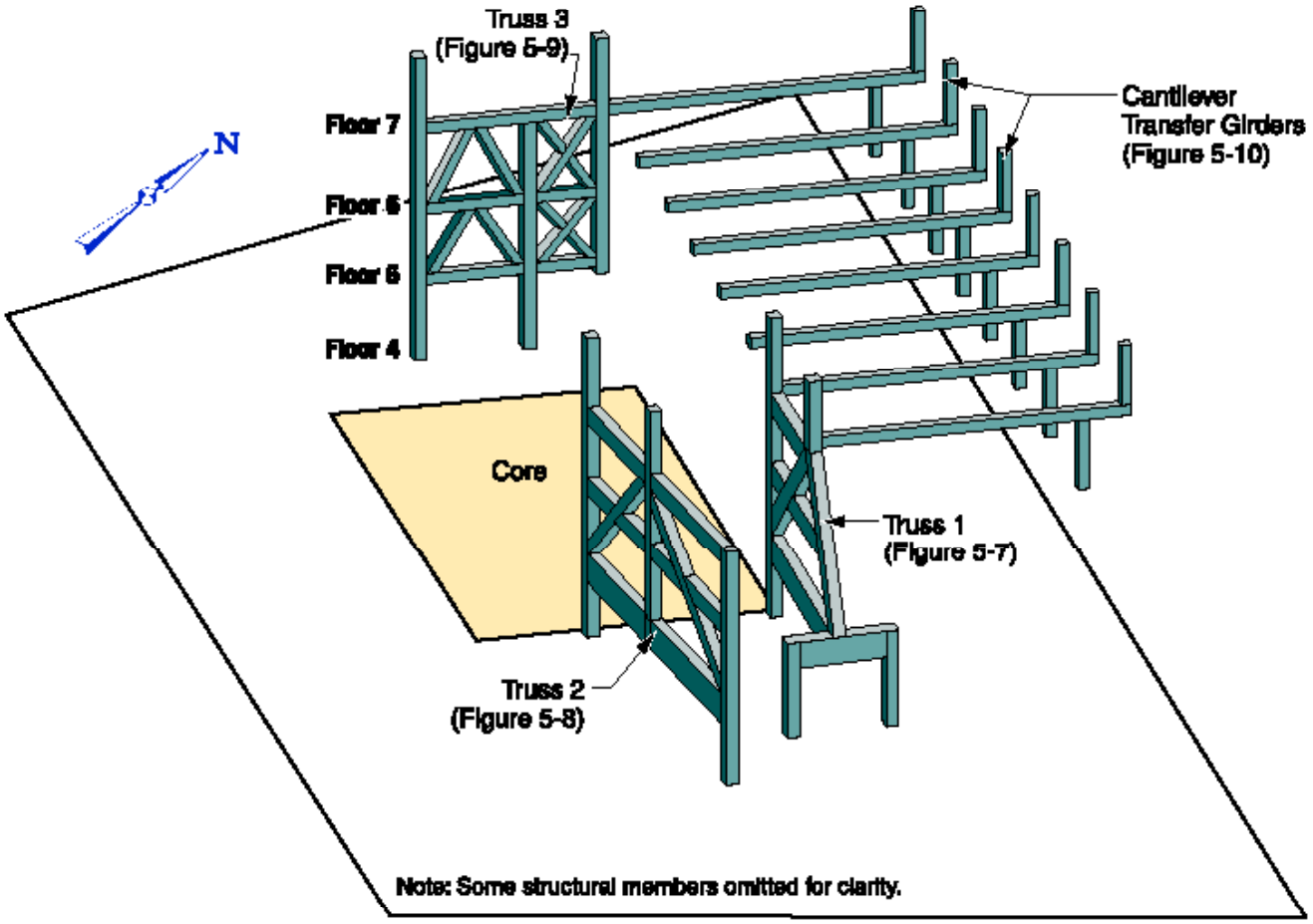
WTC7 bracing in first floor



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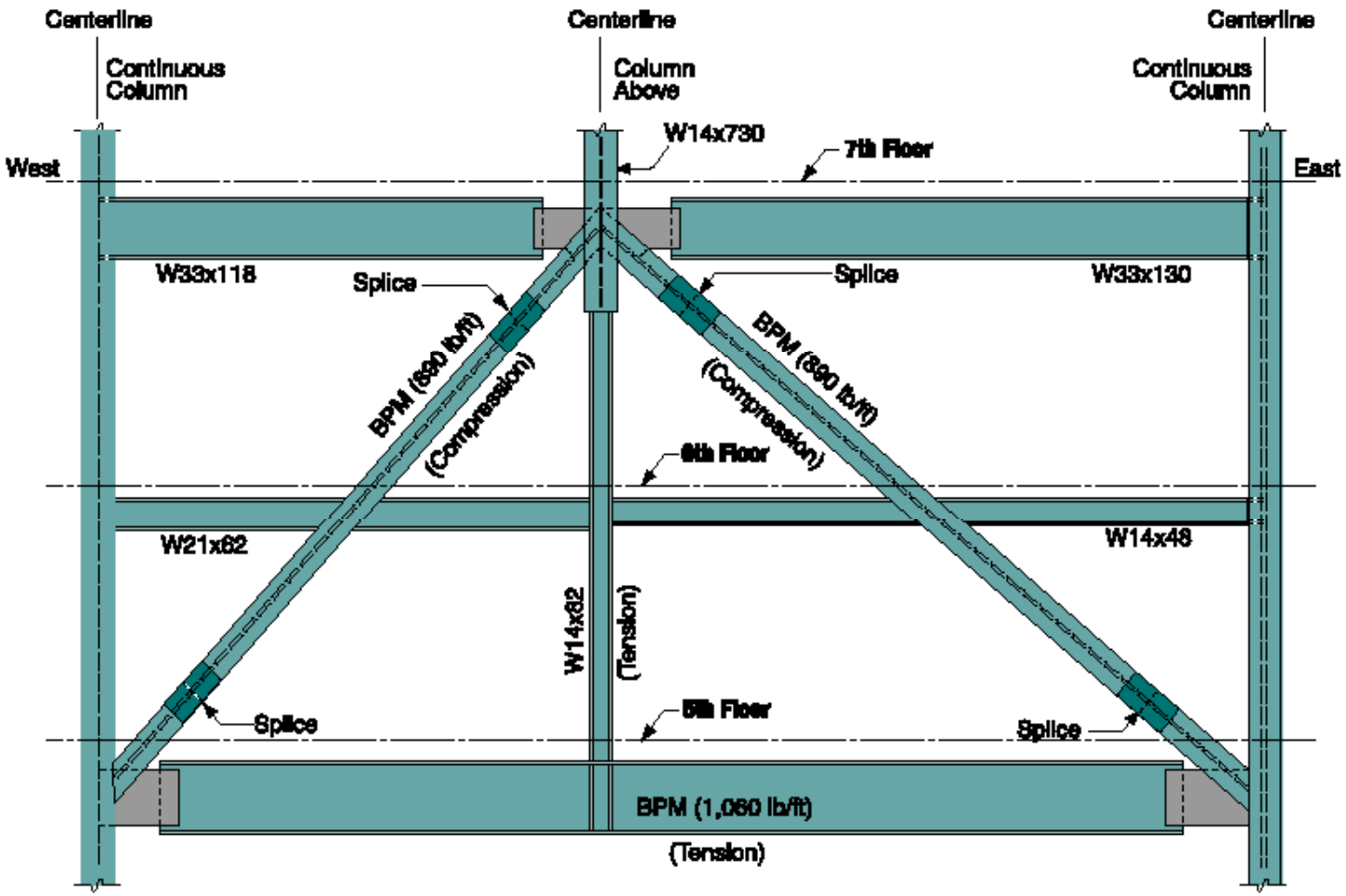
WTC7 truss bracing



EQUESTA
Electronic Quality Assured Steel Training & Assessment

Objectives

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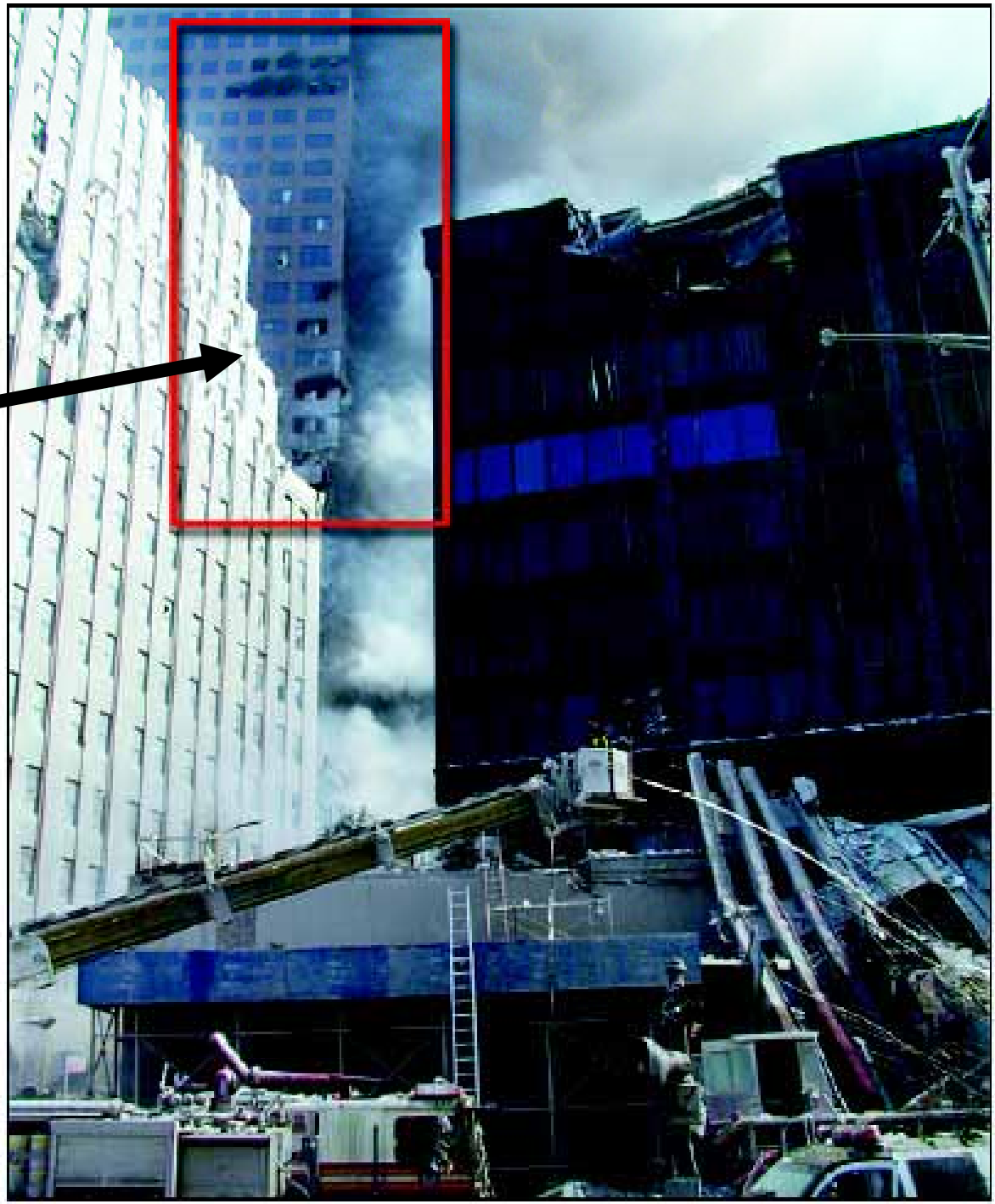
WTC 7

Initiation of crack by part of WTC1's top



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WC7 - large fire

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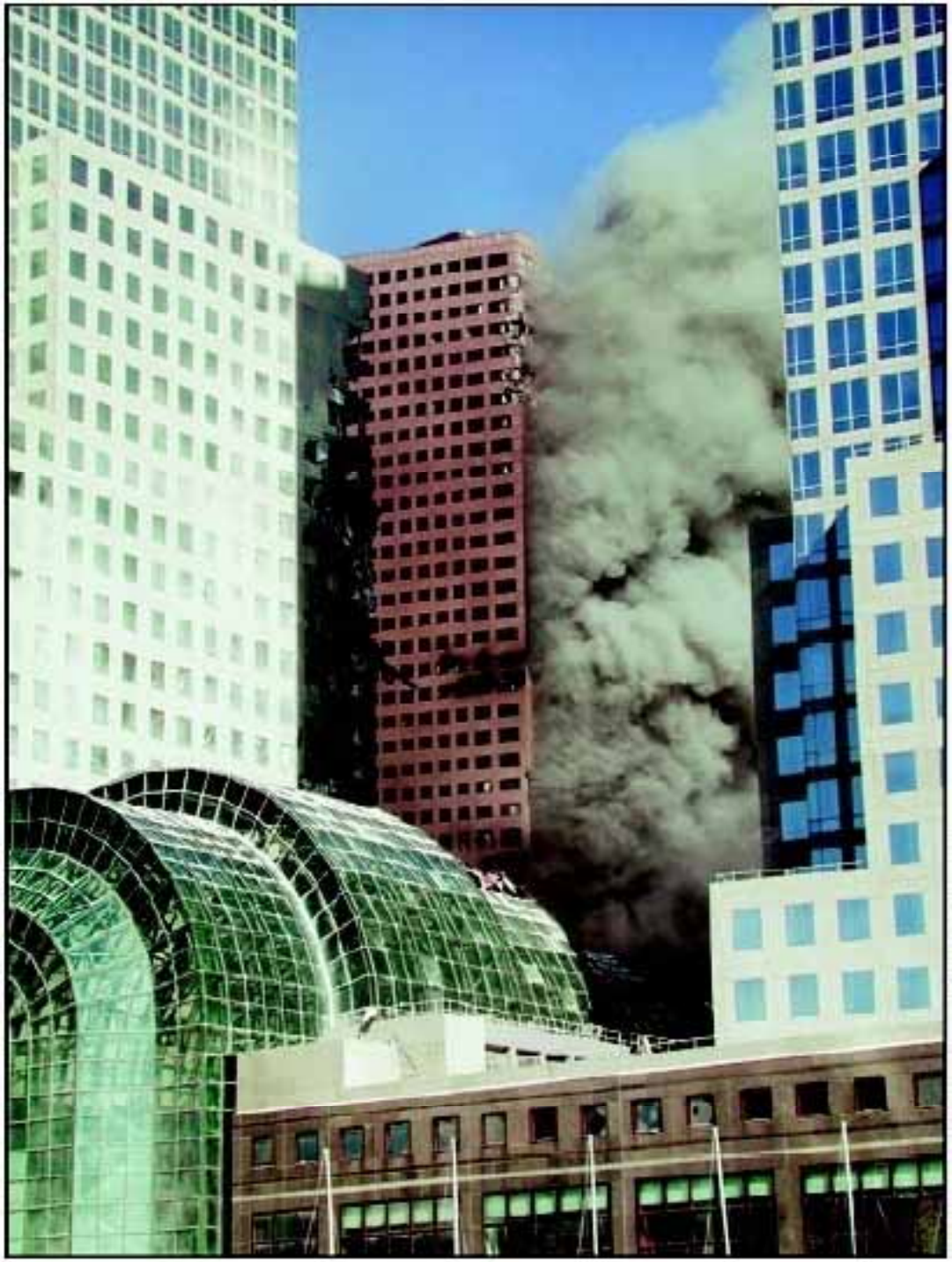
WC7

Fire feed of the fuel oil for the back up sets



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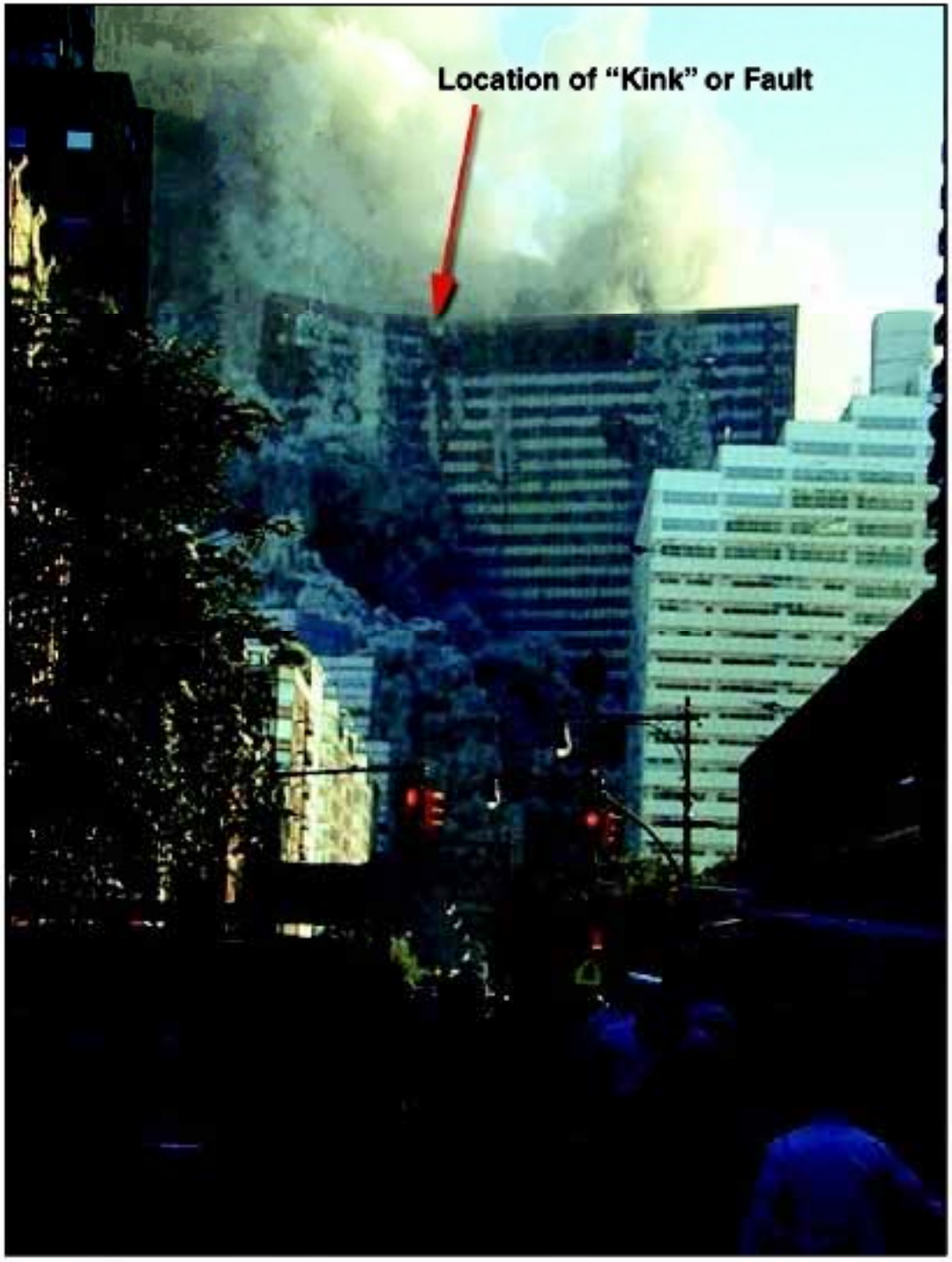
Initial cracking of building



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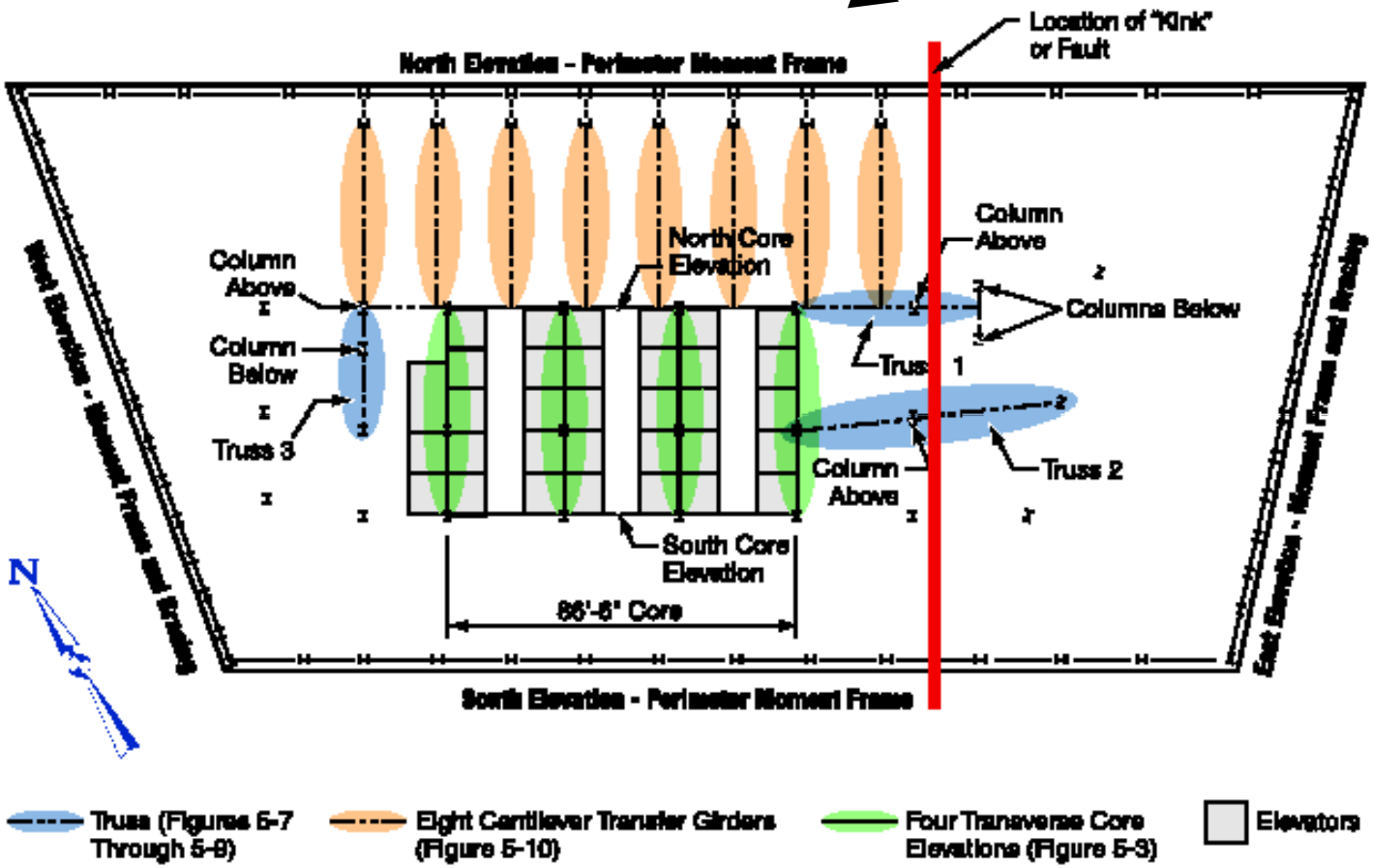
WTC 7

Position of crack



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WTC7 progresive colapse at 17:25

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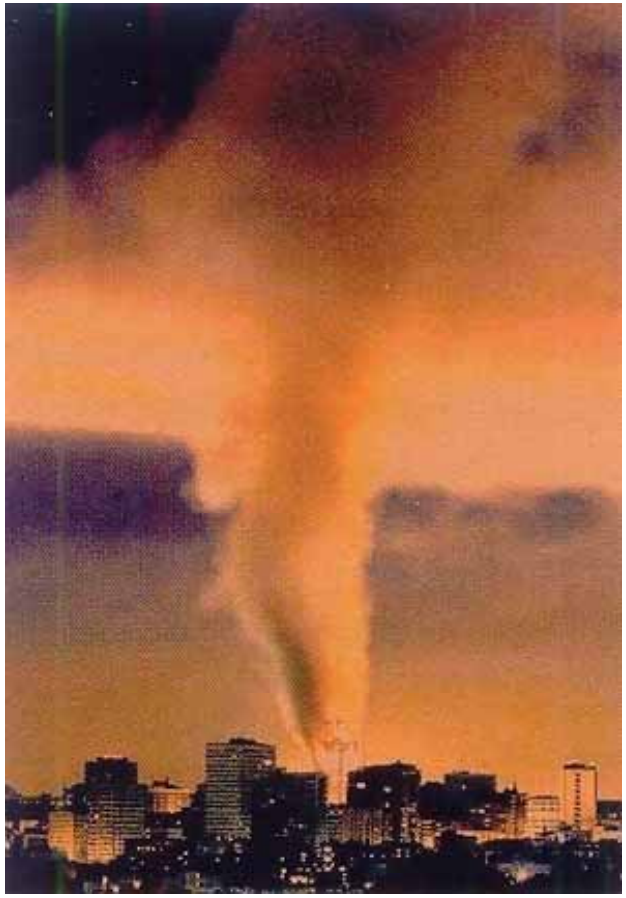
Windsor Tower Madrid

large fire 13.02.2005



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Windsor Tower Madrid

collapse of concrete floors

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Windsor Tower Madrid

buckling of steel external columns

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Lecture from last disasters

- New materials and new structural solutions needs performance based design
- Robustness and behaviour of the building
- In fire design should be integrated
  - Life safety
  - Financial impact
  - Environmental issues
- Multiple risks
  - Earthquake followed by a fire
  - Explosion followed by a fire

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Principles of fire safety

The primary fire safety requirements of national regulations are to:

- Permit safe evacuation of the occupants
- Control fire development
- Prevent fire spread
  E.g.there may be specific boundary conditions when a building is close to its boundary.
- Permit effective fire fighting
- Prevent building collapse

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Requirements for fire safety

Regulations specify the following requirements for design of the multistorey building:

- Minimum fire resistance
  - generally in 15 min increments
  - the fire resistance period is the nominal time a building will withstand a nominal standard fire without
    - collapse,
    - the breach of the compartment perimeter, or
    - excessive deformation
- Maximum compartment areas
- Maximum travel distance for means of escape

From AccessSteel Fire safety strategy for multi-storey buildings for commercial and residential use

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Active and pasive fire measurements

In office buildings, fire engineering may be used effectively in the following design cases, where:

- Sprinklers or other active systems reduce the risk and severity of a fire
- Detection and alarm systems achieve more rapid evacuation
- An atrium or other large internal enclosure influences effective compartmentation in fire
- A reduction in fire resistance can be argued based on fire load and ventilation conditions
- Means of escape and smoke control in protected escape routes is good

From AccessSteel Fire safety strategy for multi-storey buildings for commercial and residential use

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Forms of passive fire protection

There are five forms of passive fire protection:

- Spray protection – applied around the profile
- Board protection – applied as a ‘box’
- Intumescent coating – applied around the profile
- Concrete encasing – forms a rectangular encasement around the member
- Composite member – for example in-filling of tubular columns

From AccessSteel Fire safety strategy for multi-storey buildings for commercial and residential use

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EU legislation

- **Construction Products Directive**, Council Directive 89/106/EEC, from 21.12. 1988, see ANNEX I: Essential requirements
- The Regulations relating to fire cover:
  - Load-bearing capacity
  - Spread of fire and smoke
  - Spread of the fire to neighbouring construction
  - Occupants can leave
  - Safety of rescue teams

Covers life safety only

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Direct fire loss
example in % of GDP

• Slovenia	0,07
• Poland	0,07
• Czech Republic	0,10
• Japan	0,10
• USA	0,10
• United Kingdom	0,13
• Finland	0,15
• Germany	0,16
• Sweden	0,17
• Canada	0,17
• Italy	0,18
• France	0,19
• Denmark	0,20
• Norway	0,25

Average of 2002 – 2004

Source: www.data360.org

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Number of deaths in fires

example, per 100,000 inhabitants

• Switzerland	0,51
• Spain	0,61
• New Zealand	0,96
• United Kingdom	0,97
• Canada	1,15
• Norway	1,27
• Czech Republic	1,29
• Austria	1,31
• Sweden	1,32
• USA	1,39
• Denmark	1,55
• Japan	1,79
• Finland	2,08
• Hungary	2,10

Average of 2002 – 2004

Source: www.data360.org

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Eurocodes for fire design

- **EN 1991-1-2:2002** Actions on structures exposed to fire
  - Concept of fire design
  - Fire behaviour
  - Mechanical loading during fire
- **EN 199x-1-2:2005** Structural fire design
  - Thermal response
  - Material behaviour
  - Structural response

Eurocode 2: Design of concrete structures

Eurocode 3: **Design of steel structures**

Eurocode 4: **Design of composite steel and concrete structures**

Eurocode 5: Design of timber structures

Eurocode 9: Design of aluminium structures

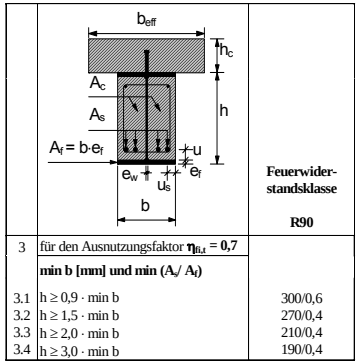
Verification methods

Example

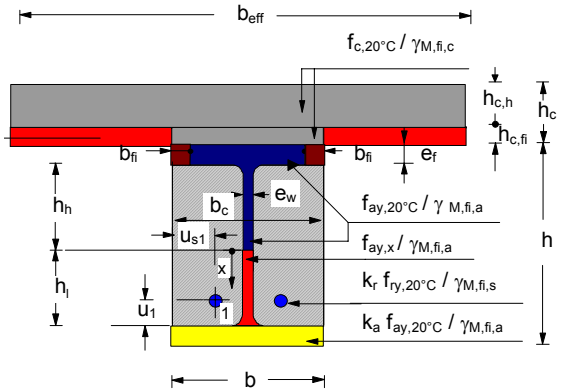
Eurocode 4: Composite steel and concrete structures

Level 1

Tabulated data

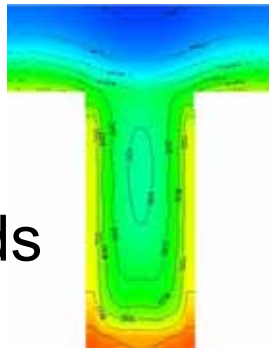


		Feuerwider-standsklasse R90
3	für den Ausnutzungsfaktor $\eta_{fi,t} = 0,7$	
	min b [mm] und min (A_c/ A_f)	
3.1	$h \geq 0,9 \cdot$ min b	300/0,6
3.2	$h \geq 1,5 \cdot$ min b	270/0,4
3.3	$h \geq 2,0 \cdot$ min b	210/0,4
3.4	$h \geq 3,0 \cdot$ min b	190/0,4



Level 2

Simplified calculation methods



Level 3

General calculation methods

From: Prof. Peter Schaumann
Institute for Steel Construction
Leibniz Universität Hannover

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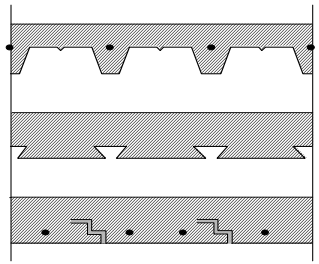
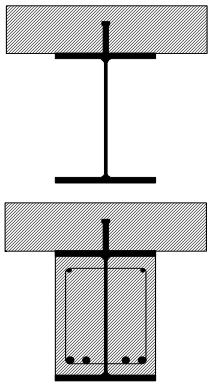
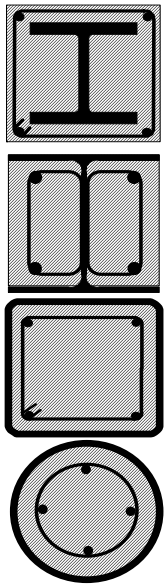
Scope of application Eurocodes

Example
Eurocode 4: Composite steel and concrete structures

Tabulated data

Composite slabs	Composite beams	Composite columns
		

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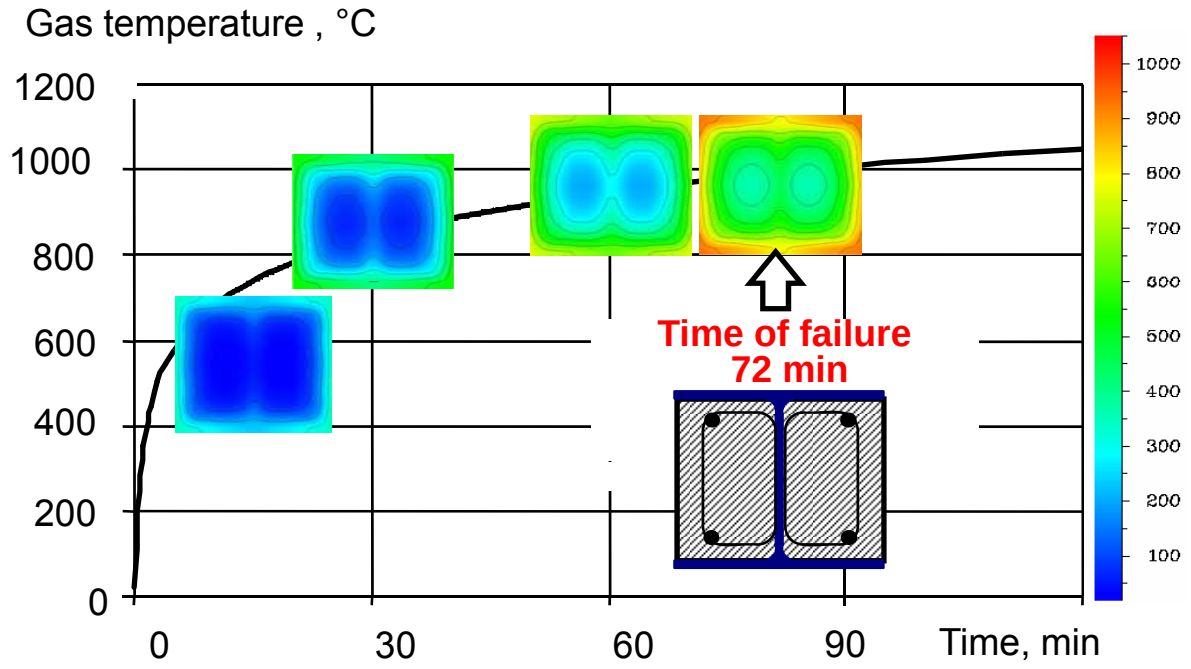
Accuracy of temperature modelling

For example

Eurocode 4: Composite steel and concrete structures

Calculation - Nominal standard fire curve exposure



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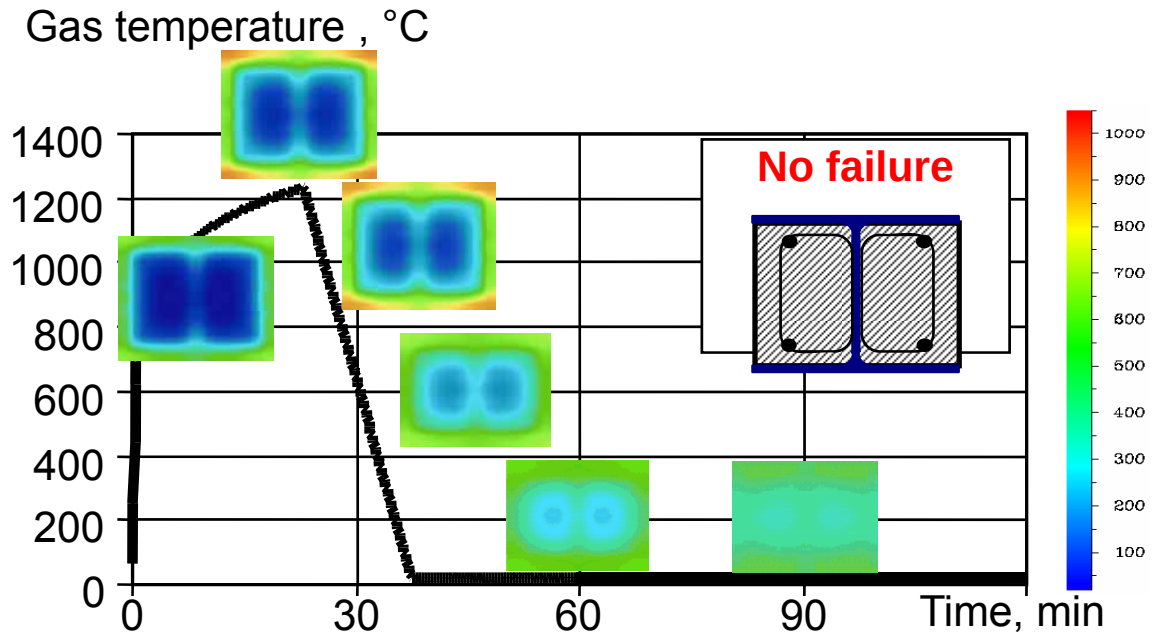
Accuracy of temperature modelling

Example

Eurocode 4: Composite steel and concrete structures

Calculation – Parametric fire curve exposure



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Formative assessment question 2

- What passive fire protection is used for steel members?
- Please list the major topics related to fire in EU Construction products directive.
- Which parts of Eurocodes are focussed for fire design?
- Where is described the fire loading?
- Please specify the levels of verification method in Eurocodes.

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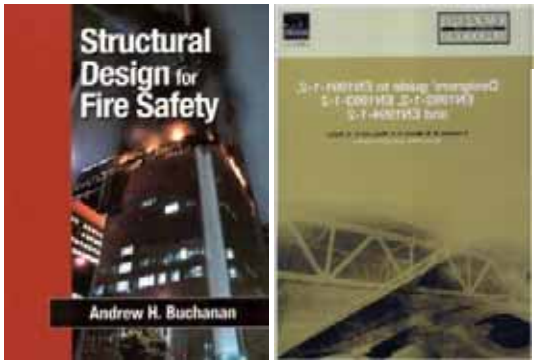
Educational materials

- Text books
  - Designers' Guide to EN 1991-1-2, EN 1993-1-2 and EN 1994-1-2: Handbook for the Fire Design of Steel, Composite and Concrete Structures to the Eurocodes, D. Moore, T. Lennon, C. Bailey, Y. Wang, Thomas Telford, 2007, ISBN 0727731572.
  - Structural Design for Fire Safety, A.H.Buchanan, Wiley, 2001, ISBN 0471889938.
  - Others at www.steelconstruct.com
- Internet
  - AccessSteel
  - Difisek+



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Tools on internet

URL: www.access-steel.com

- **AccessSteel** a hypertext engine for structutral steel
- Support EC3, EC4
  - Case studies
  - Design procedures
  - Flow charts
  - NCCI's
  - Worked examples
  - Tables
- Tables and simplifed fire design
  - 30 % of lectures

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Tools on internet

URL: www.difisek.eu

DIFISEK+ lectures and text

- Thermal & Mechanical Actions
- Thermal Response
- Mechanical Response of Structures in Fire
- Software for Fire Design
- Worked Examples
- Illustration of Completed Projects

Simplified and advanced design

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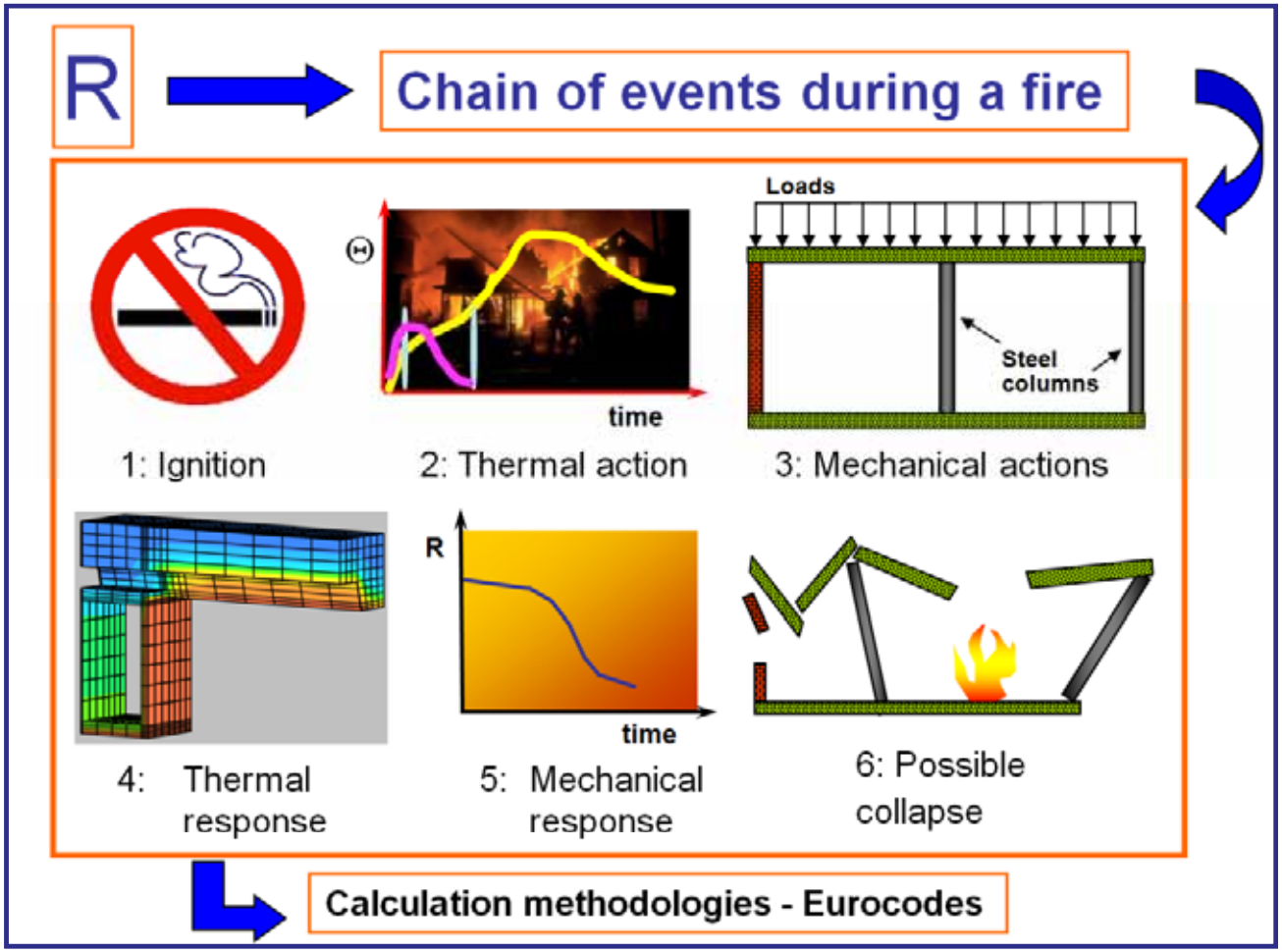
DIFISEK+

Example - Basic design procedure



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Case studies

- The case studies for fire design may be found on web
  - Difisek+

    URL: www.difisek.eu

  - AccessSteel

    URL: www.access-steel.com

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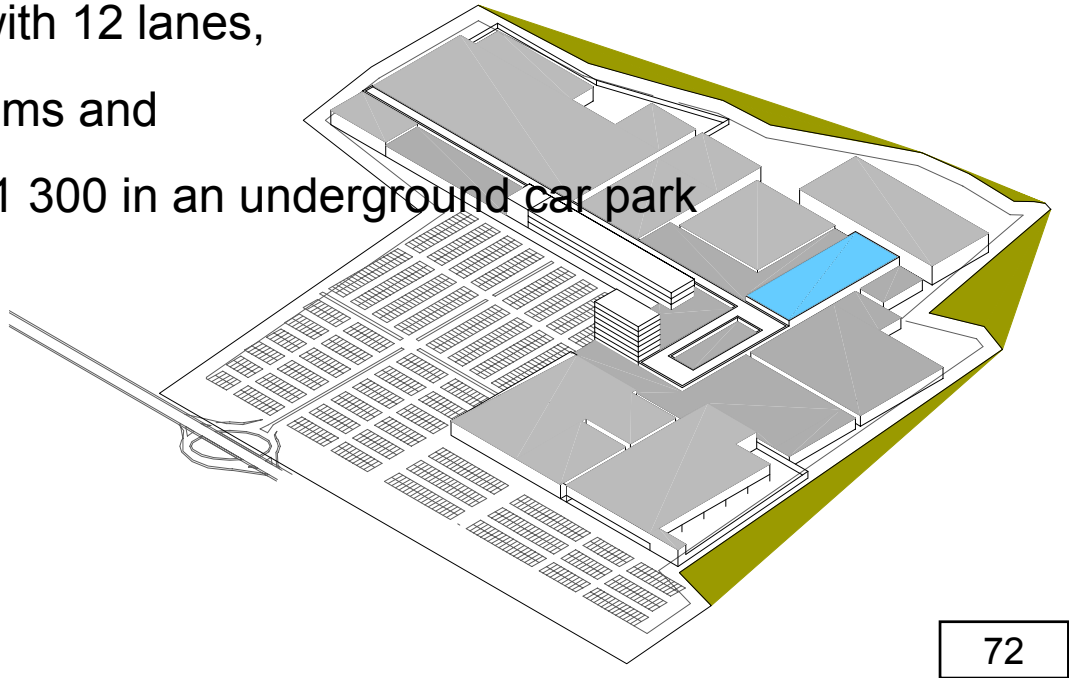
Case study

from AccessSteel - Fire Engineering of "Las Cañas" Shopping Centre, Viana, Spain

A major shopping centre, providing 65 000 m^2 floor area for a variety of uses:

- 80 shops (including a supermarket),
- 12 cinemas,
- 1 discotheque,
- 1 bowling centre with 12 lanes,
- 1 hotel with 75 rooms and
- 3 130 car places, 1 300 in an underground car park



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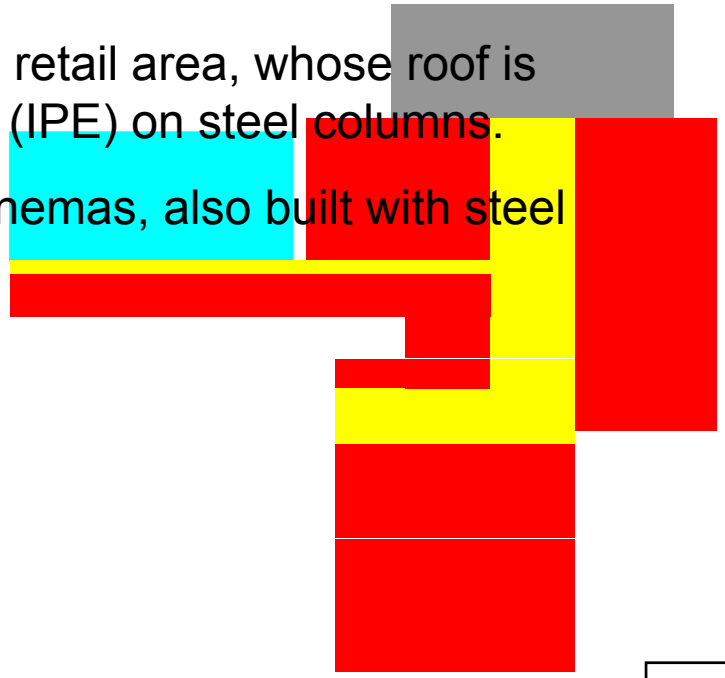
Case study

the shopping centre layout

- The yellow area corresponds to the main corridor, built with IPE columns and trusses (HEB profiles with welded joints) which support the beams and purlins of the roof structure.
- The blue area is a supermarket, attached to the corridor on one side. Its roof is supported by timber beams resting on steel columns.
- The red area corresponds to the retail area, whose roof is supported by continuous beams (IPE) on steel columns.
- The grey area corresponds to cinemas, also built with steel columns.



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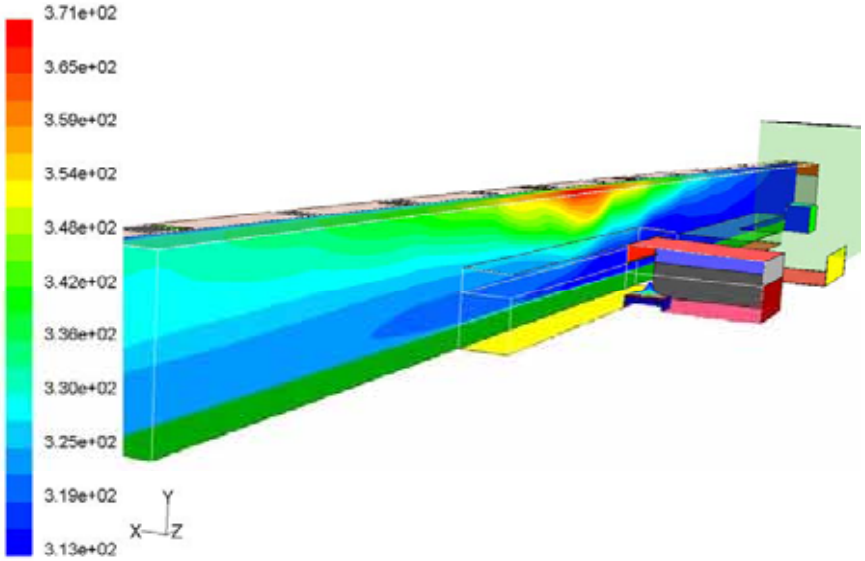
Case study

Smoke control

Smoke control is a major concern in this kind of buildings, for the following reasons:

- A high number of people.
- Occupants do not know the building.
- The egress routes can be affected by smoke coming from a fire.
- A smoke control system was verified by simulations, using analytical methods.



Hot gases in the main corridor due to a fire in a shop.
Temperature contours in K

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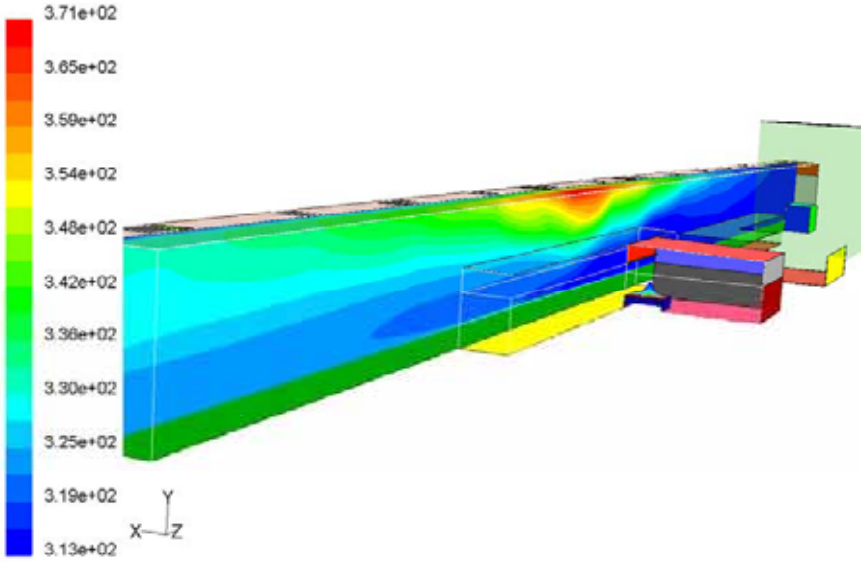
Case study

Fire scenarios

Several fire scenarios were studied to cover different three main fire safety goals:

- Structural stability of the shops adjacent to the main corridor.
- Structural stability of the supporting elements of the corridor.
- Verification of the smoke control system formed by smoke vents and draft curtains.



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Case study
final conclusions

- The stability of the steel structure of the corridor was maintained without passive protection.
- The beams inside the shops adjacent to the corridor could also remain unprotected.
- Some columns embedded in masonry walls were recommended not to be protected.
- It was recommended to increase the size and number of smoke curtains in the main corridor to improve the smoke control and users' safety.

For more see at www.access-steel.com

Fire Engineering of "Las Cañas" Shopping Centre, Viana, Spain

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Assessment

- What are the advantages of performance based approach for fire safety of buildings?
- In which part of Eurocode is described te thermal response?
- Which level of verification is covered in internet tool AcessSteel?

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Conclusions

- The prescriptive based approach brought a high safety
  for today's buildings
- The performance based approach offers a higher level of
  safety,
  economy, and
  protection of fireman

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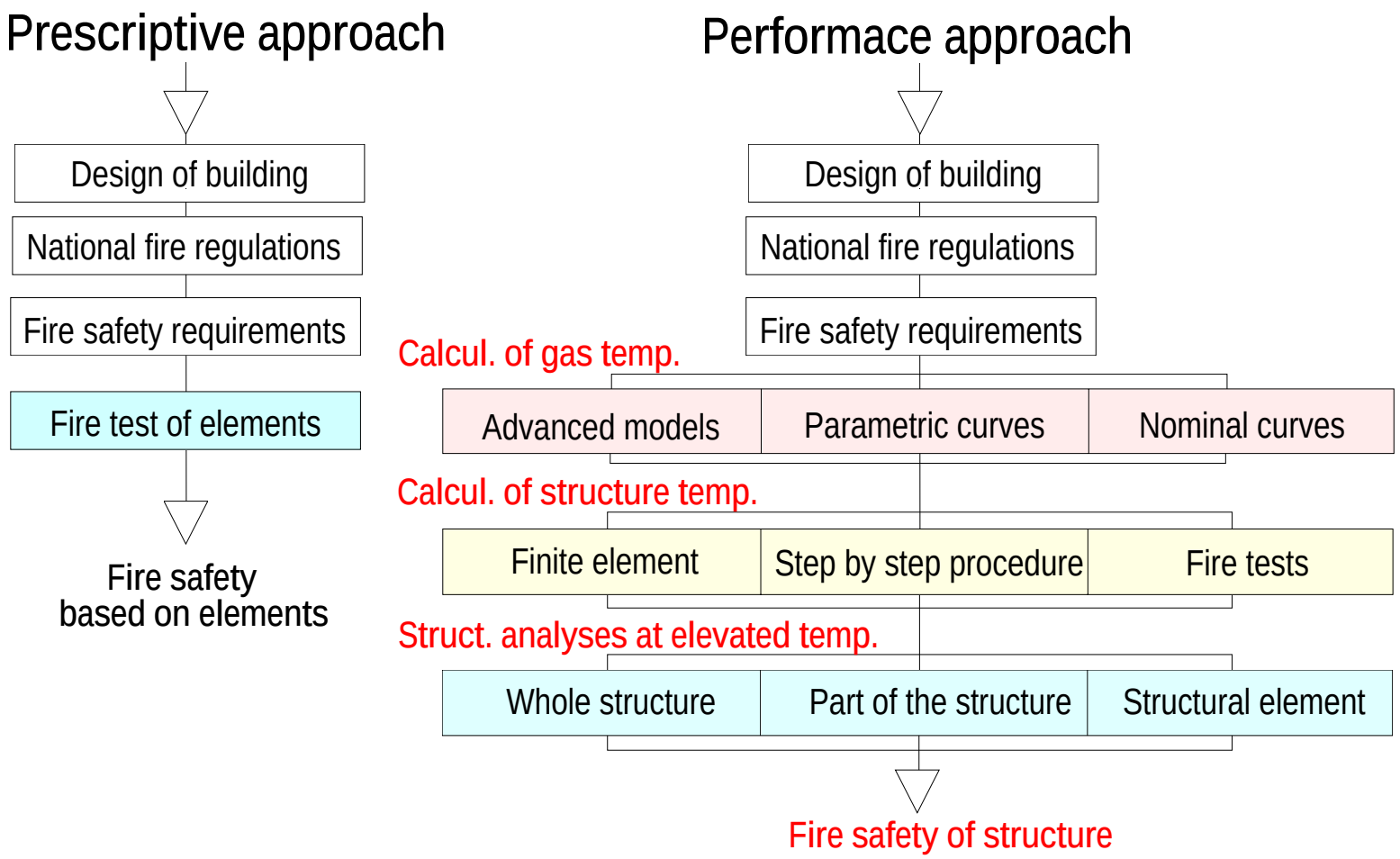

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Conclusions

- Conceptual choice of appropriate fire solution may bring a high economical subsequence
- On internet are avaliable educational materials in fire design

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- The structural design codes, Eurocodes, have a parts related to fire design EN199x-1-2
- These codes describe design by tables, analytical models and advanced model

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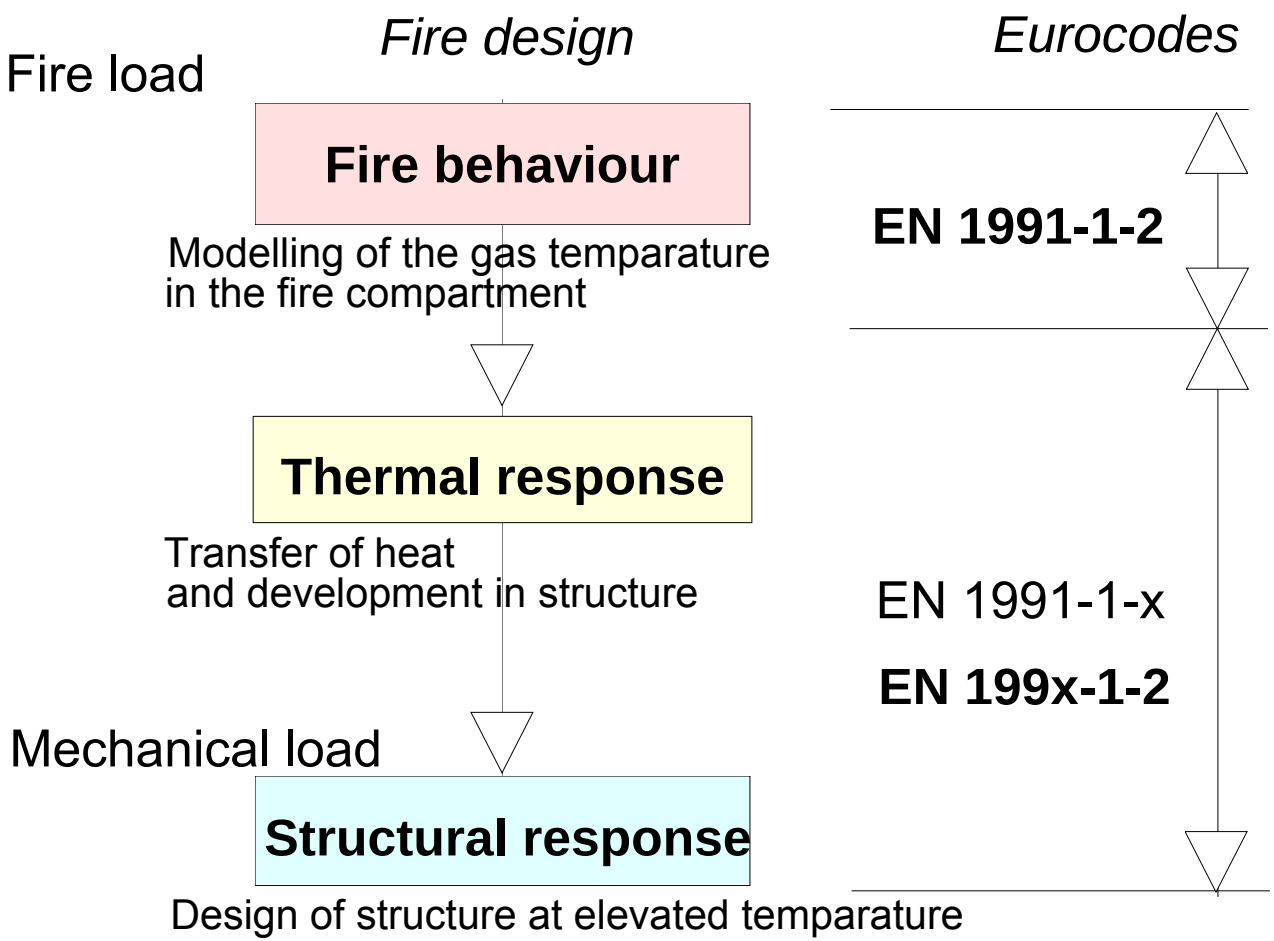

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Thank you for your kind attention

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Notes to users of the lecture

- This session is a basic information about the fire design and requires about 60 min lecturing.
- Further readings on the relevant documents from website of www.access-steel.com and www.difisek.eu.
- The use of relevant standards of national standard institutions are strongly recommended.
- Formative questions should be well answered before the summative questions completed within the tutorial session.
- Keywords for the lecture:

  fire design, prescriptive approach, performance approach, fire protection, Eurocodes.

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Text documents of advanced fire design of the completed buildingsin Difisek+ case studies at URL: www.difisek.eu are offering:

- Indoor Football Arena, Rauma, Finland
- State Street Bank, Luxembourg, Luxembourg
- Administrative Building of ProfilARBED, Esch/Alzette, Luxembourg
- Köln-Arena, Cologne, Germany
- Bilbao Exhibition Centre, Bilbao, Spain
- City Gate Düsseldorf, Düsseldorf, Germany
- Charles de Gaulle Airport, Paris, France
- Shopping Centre Cactus, Esch/Alzette, Luxembourg
- Shopping Centre Las Cañas, Viana, Spain
- Airbus Hall, Toulouse, France
- Rembrandt Tower, Amsterdam, Netherlands
- Airport Hangar M2, Mošnov, Czech Republic

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Text documents of fire design of the completed buildings in AccessSteel case
at URL: www.access-steel.com are offering:

- Köln Arena, Germany
- Rembrandt Tower, Amsterdam, Netherlands
- Fire Engineering of "Las Cañas" Shopping Centre, Viana, Spain
- Airbus halls, Toulouse, France
- Indoor Football Arena, Finland
- Office building AOB, Luxembourg
- Terminal 2F, Charles de Gaulle airport, Paris

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Selection of fire engineering strategy may be find at AcceSteel

- Client guide on the key issues for structural fire resistance
- Scheme development
  - Fire safety strategy for multi-storey buildings for commercial and residential use
  - Selection of appropriate fire engineering strategy for multi-storey commercial and apartment buildings
  - Checklist for fire design of multi-storey office buildings
  - Checklist for fire design of multi-storey apartments
  - Fundamentals of structural fire design
  - Ensuring fire safety

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Notes to users of the lecture

The description of features of different pasive fire protection in AccessSteel materials:

- Board fire protection
- Intumescent coatings
- Sprayed fire protection
- Shielded members in fire
- Slim floor systems

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Notes for lecturers

- Subject: Bases of fire design
- Lecture duration: 60 min
- Keywords: fire design, prescriptive approach, performance approach, fire protection, Eurocodes
- Aspects to be discussed: advantages and disadvantages of prescriptive and performance approach
- Within the lecturing, the introduction of Eurocode fire design is explained
- Further reading: relevant documents from website of www.access-steel.com and www.difisek.eu
- The reached accuracy in prediction of compartment fire is shown on the prediction of the seveth large scale Cardington fire test
- The reached accuracy in prediction of localized fire is shown on the prediction of Ostrava fire test.