Design
for Fire and Robustness

František WALD

TAN Kang Hai

Jean-Marc FRANSSEN

Jean-François DEMONCEAU

Zdeněk SOKOL

List of Lessons at Seminar

1.	**Fire safety**	FW
2.	Fire and mechanical loading	FW
3.	Thermal response	FW
4.	Steel structures	JMF
5.	Concrete structures	JMF
6.	Composite structures	JMF
7.	Advanced models	JMF
8.	Composite floors	FW
9.	Aluminum structures	FW
10.	Timber structures	FW
11.	After fire and Historical structures	FW
12.	Overview of **Explosion-blast Resistance**	KHT
13.	Response to blast	KHT
14.	P-I diagram	KHT
15.	Equivalent single degree	KHT
16.	Design example	KHT
17.	Definitions of **Design for Robustness**	JMD
18.	Global response of structures	JMD
19.	Design recommendations	JMD
20.	Alternative load path method	JMD

European Erasmus Mundus Master Course

Sustainable Constructions under Natural Hazards and Catastrophic Events

Structures after fire and Historical structures in fire

František Wald

Czech Technical University in Prague

Objectives of the lecture

- The treatment of reconstruction of fire damaged structures
- The particularity of fire safety of historical structures

European Erasmus Mundus Master Course

Sustainable Constructions under Natural Hazards and Catastrophic Events

Structures after fire
Outline of the lecture

- o Principles
- o Assessment procedure
- o Design for repair
- o Case study
- o Summary

European Erasmus Mundus Master Course

Sustainable Constructions under Natural Hazards and Catastrophic Events

Structures after fire

- **In fire design**
  - the structure should resist the required time of fire
  - the structure should survived all fire exposure

Based on rules and models

Structures after fire

- The structural behavior **after fire** is not determined
  - After **compartment fires**
    all the interior is substantially **damaged**
  - Bearing structure is only
    part of the cost of the building
  - Except of special cases, like
    - Tunnels
    - Highrised
    - Towers

After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

Notes

European Erasmus Mundus Master Course
SUSCOS
Sustainable Constructions under Natural Hazards and Catastrophic Events

Assessment procedure

- Site visit
- Desk study
- Detailed collection of evidence
- **Damage assessment**
- Specification of repairs

Site visit

- To gain early scale of damage
- To advise on safety of building
- To recommend protection measures

After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

Notes

European Erasmus Mundus Master Course
Sustainable Constructions under Natural Hazards and Catastrophic Events

Desk Study

- Collect relevant information
  - Original design of building
  - Construction materials, usage before fire, cause of fire
  - Duration of fire
  - Fire spread
  - Contents left unburnt
- Establish a strategy for gathering of more detailed information

After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

Notes

European Erasmus Mundus Master Course
Sustainable Constructions under Natural Hazards and Catastrophic Events

Detailed Assessment Strategy
Demage classification

A. No damage
B. Repairable damages
   – detailed collection of evidences
C. Major damage
   – replacement of structural member
D. Total damage
   – scrap

After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

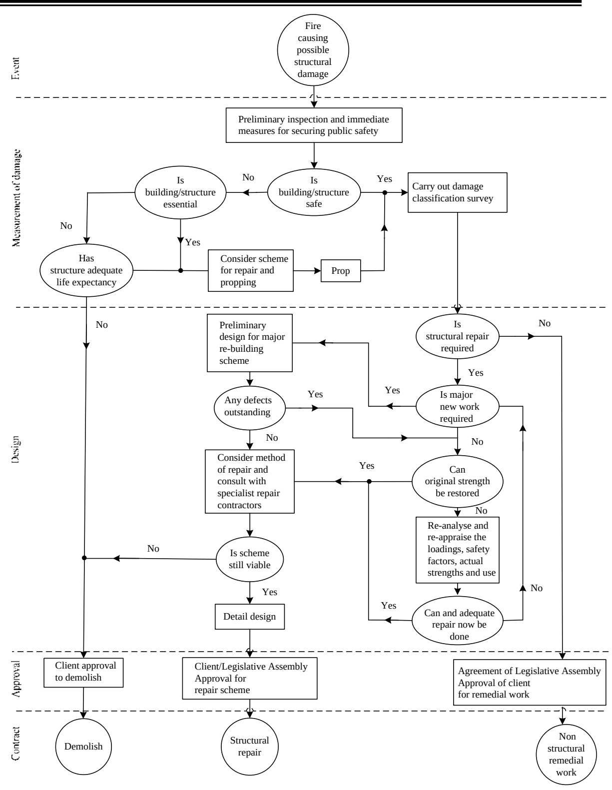
Notes

European Erasmus Mundus Master Course
Sustainable Constructions under Natural Hazards and Catastrophic Events

References to assesment procedure

Concrete structures,

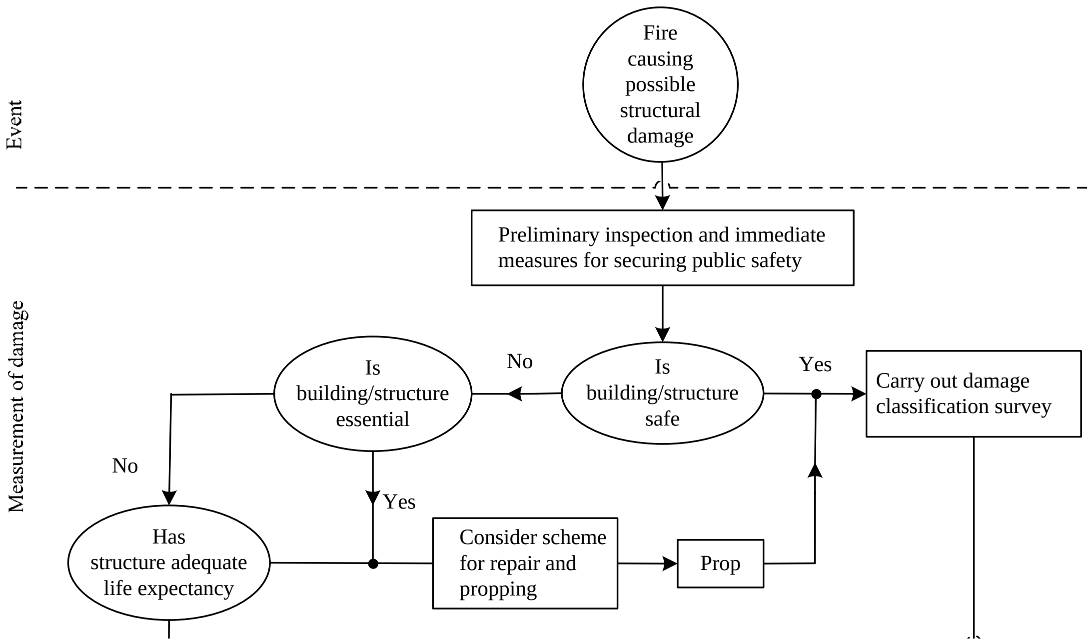
Concrete Soc., 1990



European Erasmus Mundus Master Course
Sustainable Constructions under Natural Hazards and Catastrophic Events

References to assesment procedure

Concrete structures



After fire
Principles
Assessment
› procedure
Design for repair
Case study
Summary

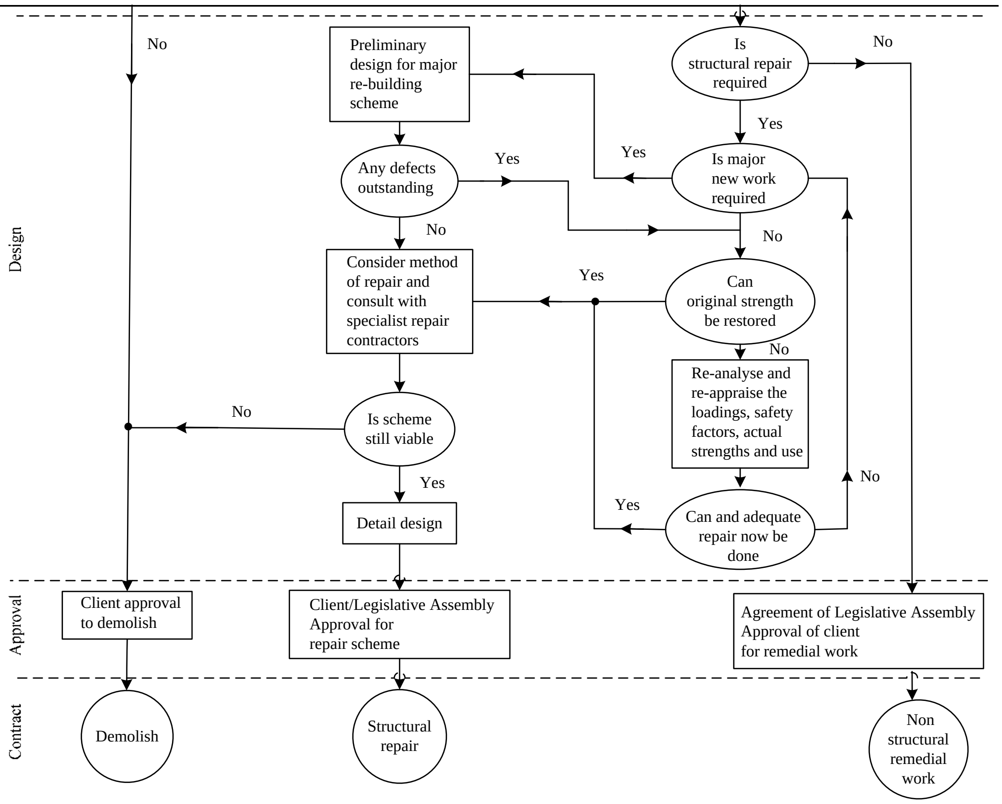
Historical structures
Statistics
Cultural value
Technology
Management
Case studies

Notes

European Erasmus Mundus Master Course
Sustainable Constructions under Natural Hazards and Catastrophic Events

References to assesment procedure

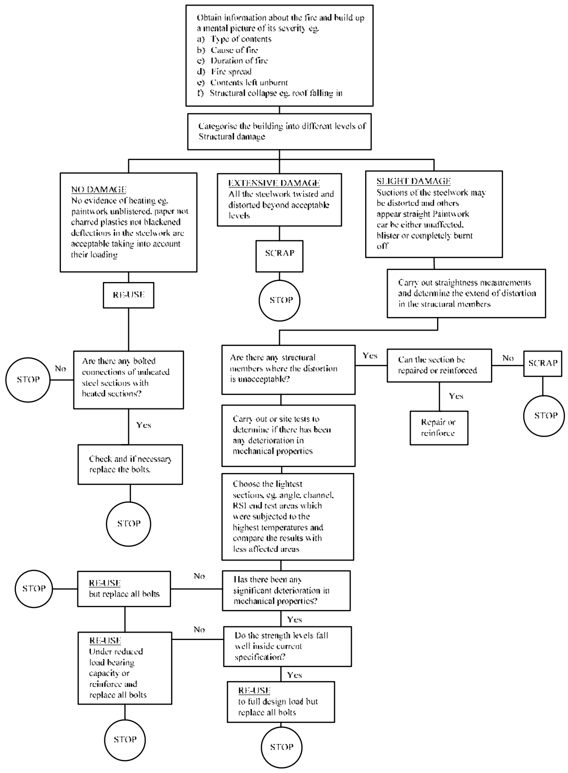
Concrete structures



References to assesment procedure

Steel structures

Kirby et al, 1986



After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

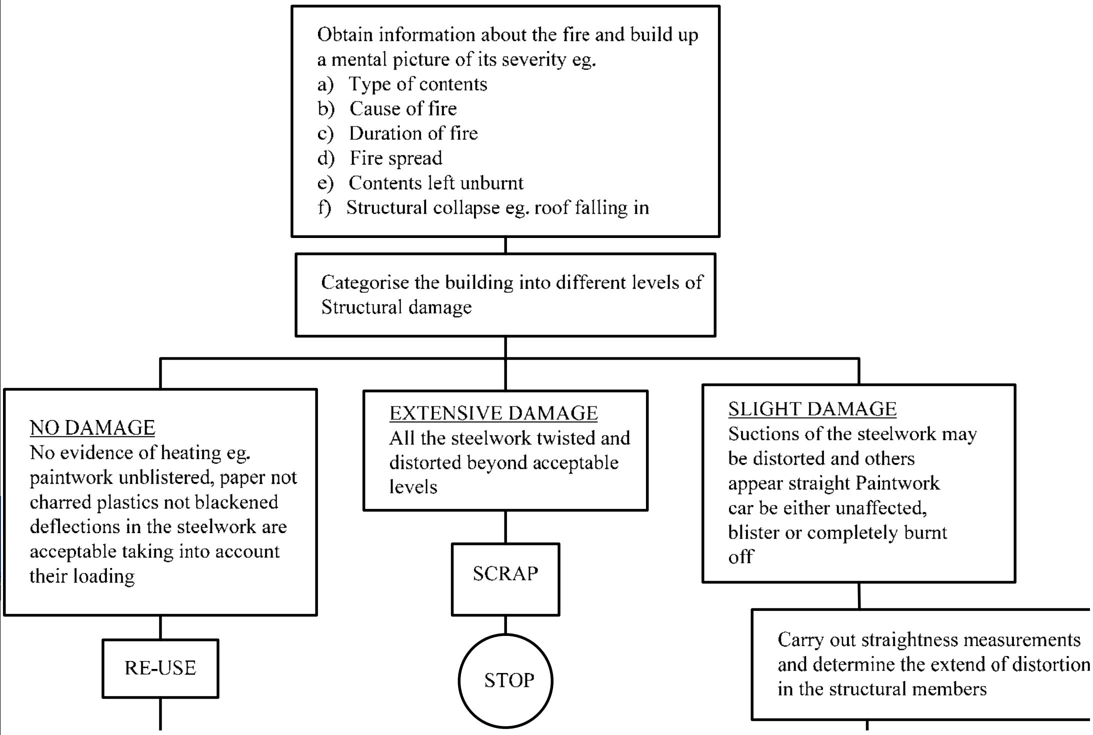
Historical structures
Statistics
Cultural value
Technology
Management
Case studies

Notes

European Erasmus Mundus Master Course
SUSCOS
Sustainable Constructions under Natural Hazards and Catastrophic Events

References to assesment procedure

Steel structures



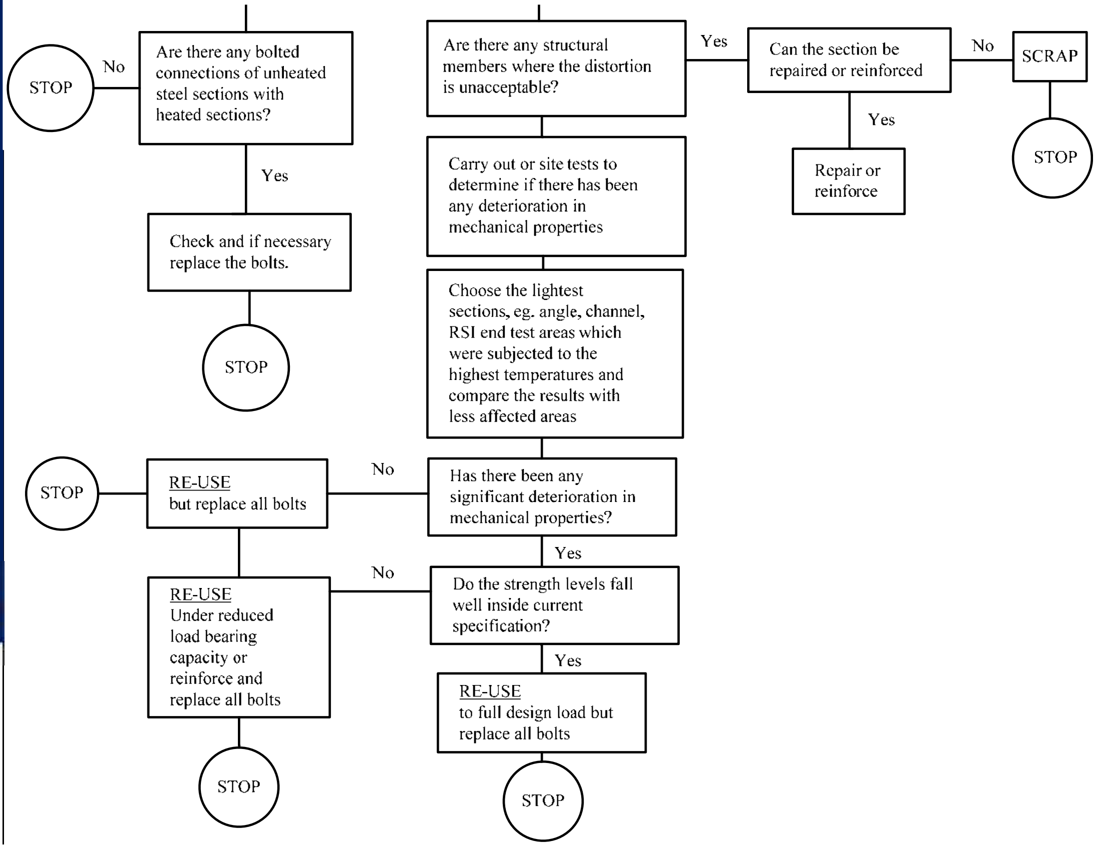
After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

Notes

References to assesment procedure

Steel structures



After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

Notes

Detailed Collection of Evidence

- Residual strength and stiffness of material
- Temperature attained in structure
- Fire development
- Cooling
- **Result of firemen's intervention**
- Correlation of results

After fire
Principles
Assessment procedure
› Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

Notes

European Erasmus Mundus Master Course
SUSCOS
Sustainable Constructions under Natural Hazards and Catastrophic Events

Fire Developments

Depends on

- Burnt combustible materials
- Openings
- Construction materials of enclosure

Should fulfill

- Correlation with physical evidence

After fire
Principles
Assessment procedure
› Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

Notes

European Erasmus Mundus Master Course
SUSCOS
Sustainable Constructions under Natural Hazards and Catastrophic Events

Temperatures Attained in Structural Members

- Fire development + thermal analysis
  - Metallurgy analysis
  - Colour changes in concrete
- More detailed testing: thermoluminescence test
- Physical evidence
- Correlation of results

Mechanical Properties

- Temperatures + residual properties relationships
- Non-destructive testing
  - Schmit Hammer Test
  - Ultrasonic Pulse Velocity Test

- Destructive testing
- Correlation of results

After fire
Principles
Assessment procedure
➤ Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

Notes

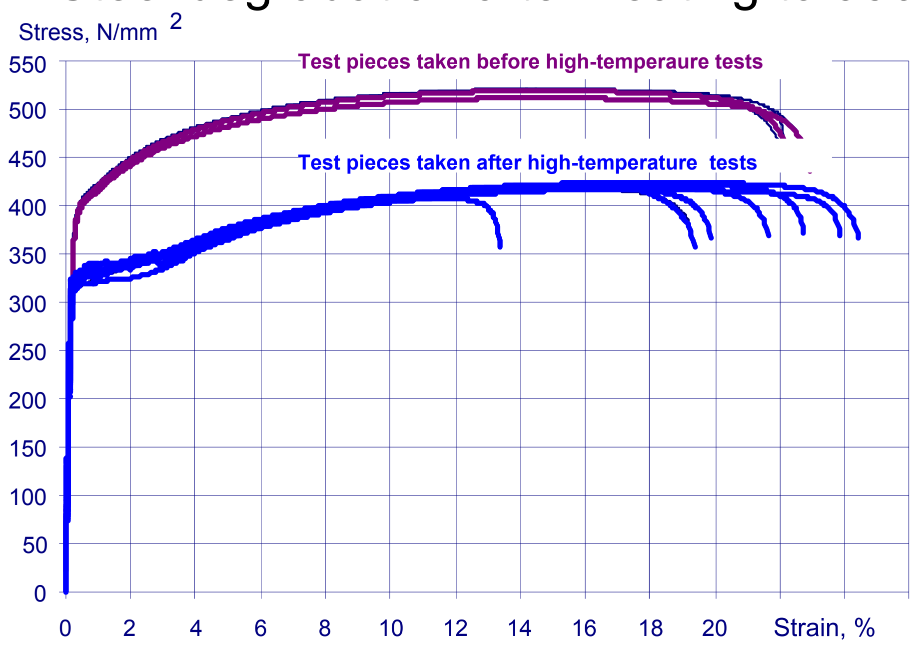
European Erasmus Mundus Master Course
Sustainable Constructions under Natural Hazards and Catastrophic Events

Destructive Tests

- Concrete core test
- Steel coupone test

Steel coupone test

Steel degradation after heating to 950°C



see Outinen and Mäkeläinen, 2004

After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

Notes

European Erasmus Mundus Master Course
Sustainable Constructions under Natural Hazards and Catastrophic Events

Design calculations for repair

Load

- Include extra weight of repair materials
- Temporary support loads
- Reduced material factors

Model

- Treat structure as simply supported
- Complex modelling at elevated temperature

European Erasmus Mundus Master Course
Sustainable Constructions under Natural Hazards and Catastrophic Events

Design calculations for repair of steel structures

Compressed members

- Check of straitness
- Imperfections and tolerances
- Change of deformed compressed members
- Local buckling of plates heated up to 500 °C

Steel connections

- Bolts - change
- Welds - 90 % resistance of heated up to 500 °C

After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

Notes

European Erasmus Mundus Master Course
Sustainable Constructions under Natural Hazards and Catastrophic Events

Design calculations for repair of steel structures

Fireman intervention

- Hardening and los of ductility
- Source fireman reports of fire attack
- Hardeness check by impact hammer

Repair Methods

- Reconstruction
  - Sprayed concrete
  - Resin repair
  - Overcladding
- Others
  - FRP strengthening
  - Change of use
  - Additional supports

After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

Notes

European Erasmus Mundus Master Course
SUSCOS
Sustainable Constructions under Natural Hazards and Catastrophic Events

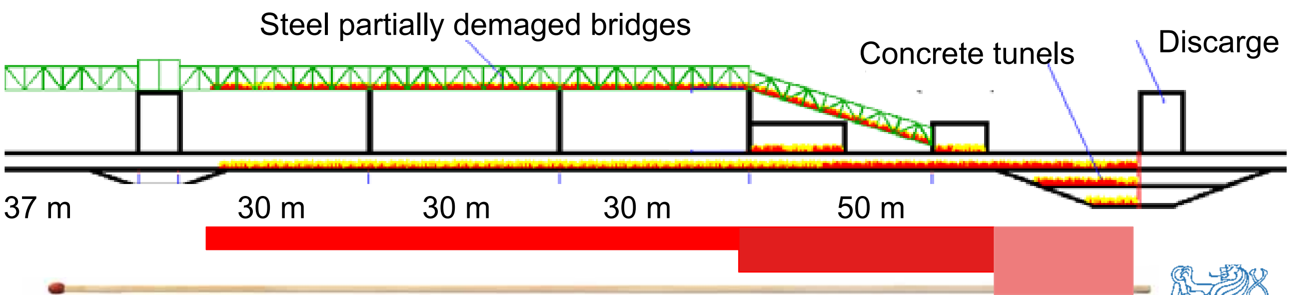
Advanced techniques

- Consideration of **actual fire**
  fire generate non-uniform temperature
  - Fire advanced modelling
  - Thermal deformation measurements
  - Destructive + non-destructive testing
  - Advanced models of damaged structure

Case study
Steel coal feeding bridge

- Fire - September 2005, Opatovice power station, Czech Republic
- Coal belt transport infrastructure completely burned
- Bearing structure noticeably damaged

120 m
of the steel transport bridges attact



Observations

- Geodetic measurements **of major positions of the structure,** joints of the trusses and the rail of the conveyor
- Geometric measurements of **straightness of compressed elements**

- **Mechanical property** by 54 coupon tests - reduction 10 %
- **Microstructure of steel** – changes acceptable

Deformed upper stiffening truss

Reconstruction

Replacing of the end frame

- Elements with excessive deformations were **replaced**
  - Maximum allowed **out of straightness** 10 mm
- Operational test after reconstruction

View into the reconstructed bridge

Replacement

- Horizontal bridges
  - Upper truss stiffeners
  - Upper crossbeams
  - Upper parts of the props of the end stiffeners
- Inclined bridge
  - Also lower cross beams
  - Also lower stiffening trusses

Straightening of riveted connections

Straightening of frame geometry

- Not visibly deformed
- After detailed calculation
  - Assumed 15 % reduction of resistance
  - Unsatisfactory connection

strengthened by welding

Bridge after reconstruction

Uncovered bridge

Reconstruction in three weeks

Summary

- **Assessment differs**
  - from fire resistant design of the structure
  - From structural material
- Steel fire damaged structures **can be mostly repaired**
- Concrete fire damaged structures **have to be damaged**
- Timber fire damaged structures **mostly does not exists**

After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

Notes

European Erasmus Mundus Master Course
SUSCOS
Sustainable Constructions under Natural Hazards and Catastrophic Events

Assessment

- Which structures are designed after fire?
- What are the steps of detailed Assessment Strategy?
- What are the steps Assessment Procedure?
- What is the procedure for compressed members after fire?
- What is the procedure for bolted connections after fire?
- What is the procedure for welded connections after fire?

After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

Notes

European Erasmus Mundus Master Course

Sustainable Constructions under Natural Hazards and Catastrophic Events

Historical structures in fire

Outline of the lecture

- Data, loss statistics and evaluating risks
- Cultural and financial value
- Available and developing technology
- Property management strategies
- Case studies

After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

Notes

European Erasmus Mundus Master Course

Sustainable Constructions under Natural Hazards and Catastrophic Events

15th C Södra RÍda Church, Sweden

15th C Södra RÍda Church, Sweden

After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

Notes

European Erasmus Mundus Master Course
Sustainable Constructions under Natural Hazards and Catastrophic Events

Burns Monument after November 2004 fire, Kilmarnock. Scotland

After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

Notes

European Erasmus Mundus Master Course

Sustainable Constructions under Natural Hazards and Catastrophic Events

Burns Monument after November 2004 fire, Kilmarnock. Scotland

After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

Notes

European Erasmus Mundus Master Course

Sustainable Constructions under Natural Hazards and Catastrophic Events

Historic fire incidents in cities

- London, England 1212 and 1666
- Uppsala, Sweden 1702
- Copenhagen, Denmark 1795
- Edinburgh, Scotland 1824
- Chicago, USA 1871
- Boston, USA 1872
- Jacksonville, USA 1901
- Baltimore, USA 1904
- Alesund, Norway 1904
- Chelsea, USA 1908
- Salem, USA 1914
- Thessaloniki, Greece 1917
- Tokyo, Japan 1923
- Chiado, Lisbon, Portugal 1988
- Edinburgh, Scotland 2002
- Trondheim, Norway 2002

Major European heritage fire losses the mid 1980's to the mid 1990's

- York Minster, England July 1984
- Hampton Court Palace, England March 1986
- Uppark House, England August 1989
- Proveantgarden, Copenhagen, Denmark February 1992
- Odd Fellow Palace, Copenhagen, Denmark April 1992
- Christianborg Palace Church, Copenhagen, Denmark June 1992
- Windsor Castle, England November 1992
- Redoutensal, Hofburg Palace, Vienna, Austria November 1992
- Pont de la Chapelle, Lucerne, Switzerland August 1993

After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

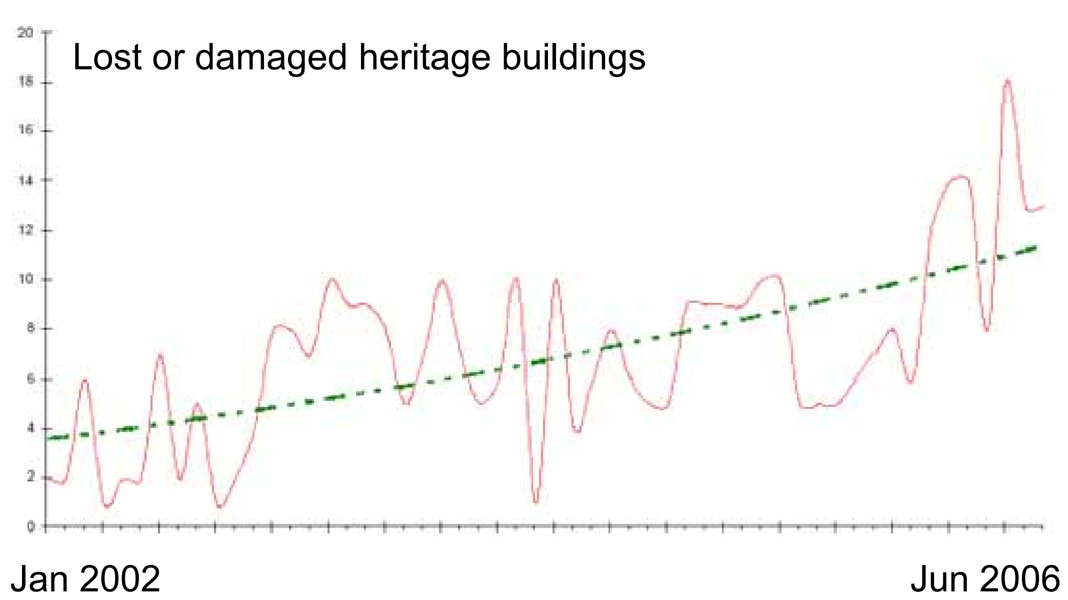
Notes

European Erasmus Mundus Master Course

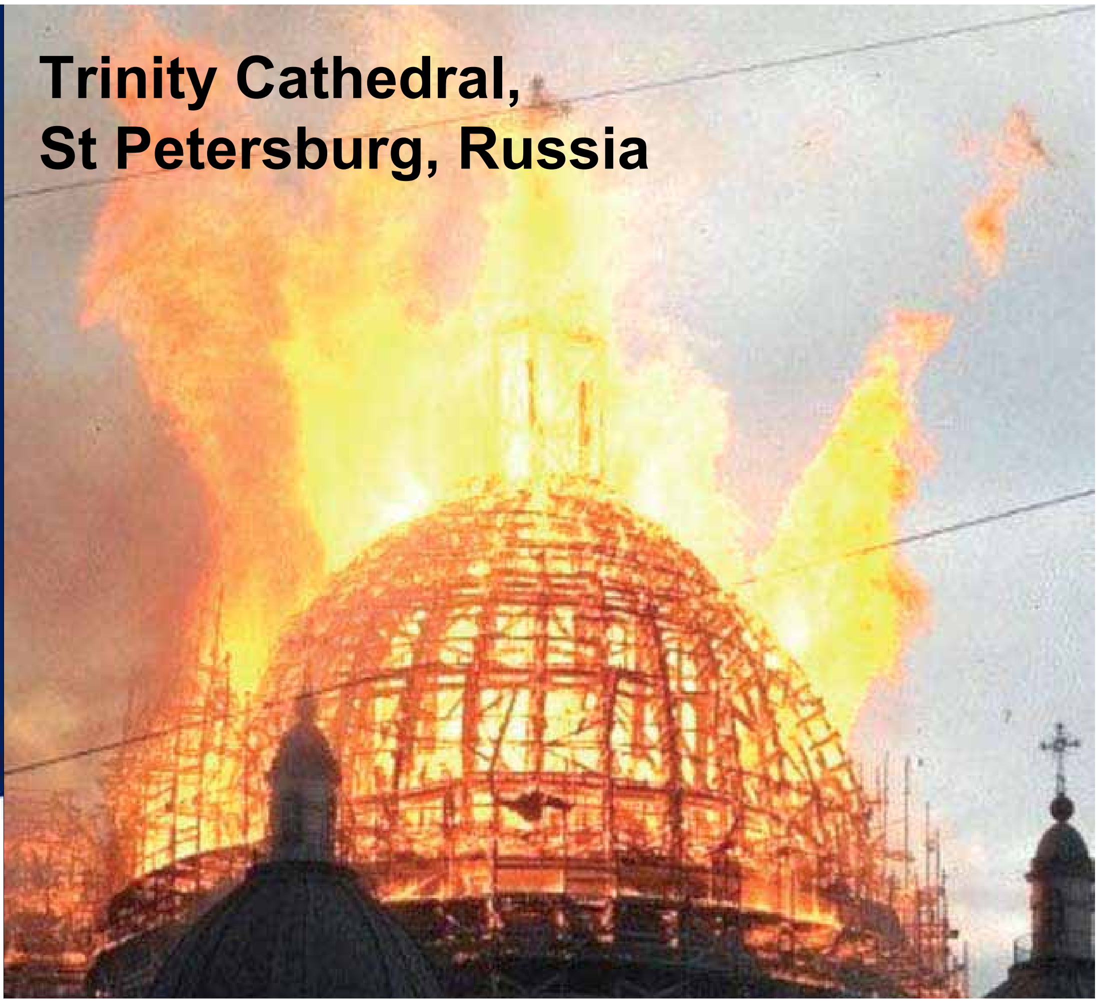
Sustainable Constructions under Natural Hazards and Catastrophic Events

Example
Fire Loss to Historic Buildings

- Monthly and Cumulative in UK Historic Buildings



Trinity Cathedral, St Petersburg, Russia



After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

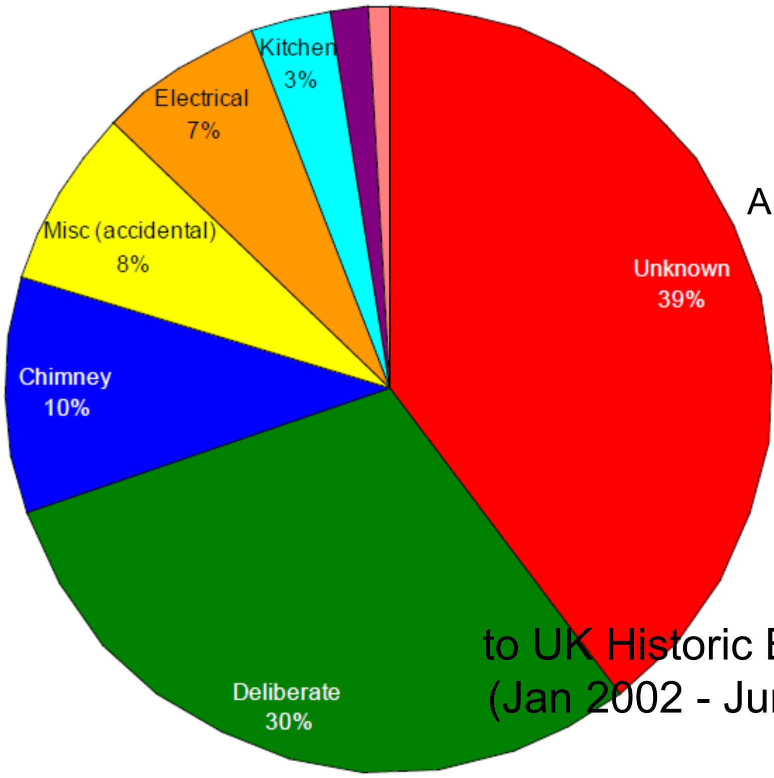
Notes

European Erasmus Mundus Master Course
SUSCOS
Sustainable Constructions under Natural Hazards and Catastrophic Events

Most common causes of fire in historic buildings

1. Arson
2. Electrical fault
3. Match
4. Smoking Materials
5. Candle
6. Heating equipment
7. Natural causes (lightning)
8. Hot works

Causes of Fire Loss



to UK Historic Buildings
(Jan 2002 - June 2006)

Hofburg Palace, Vienna December 1992

After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

Notes

European Erasmus Mundus Master Course

Sustainable Constructions under Natural Hazards and Catastrophic Events

Thatched Cottage, Stanford in the Vale, Oxford, England August 2005 fire

After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

Notes

European Erasmus Mundus Master Course

Sustainable Constructions under Natural Hazards and Catastrophic Events

Bower Building, Glasgow University, Scotland

Evaluation of risks:
measures for historic buildings

Considering the consequences of the loss of a historic building, the risk analysis should include:

- loss of economic value (in terms of providing a modern replacement of premises of the same quality as the building which has been lost)
- loss of historic cultural and emotional value
- loss of a positive image for the local community
- loss of economic impact on the tourist industry
- additional costs for reconstruction

Evaluation of risks:
special measures for historic buildings

The special characteristics of historic buildings should be described and analysed in the risk analysis to recognise the:

- particular vulnerability of the building
- activities taking place in the building
- fabric of the building and its structural features
- surroundings of the building, and the activities that take place there
- probability of fire ignition
- length of time required for the fire brigade to arrive

Fire risk from spot lamp

Introducing technology into historic and cultural buildings

- **Essential**
  - The fire systems should be central to meeting the objectives of the protection of life, buildings and contents.
- **Appropriate to Risk**
  - Any system that is installed should be apposite to the risks being considered.
- **Compliant with legislation**
  - Systems should be installed according to demonstrable performance-based and other legislatively prescribed standards of safety.
- **Minimally invasive**
  - The retrospective fitting of fire systems should involve minimal degrees of physical intervention on the historic structure.
- **Sensitively integrated**
  - Installed systems should be designed to be integrated sympathetically with the historic fabric and its detail.
- **Reversible**
  - Fire systems should be installed according to a reversible, ‘plug-in, plug-out’ installation philosophy.

Inserted intumescent door sealing strip

After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

Notes

European Erasmus Mundus Master Course
Sustainable Constructions under Natural Hazards and Catastrophic Events

Sprinkler

After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

Notes

European Erasmus Mundus Master Course

Sustainable Constructions under Natural Hazards and Catastrophic Events

Technical solution Example - pull fire escape

Museo diocesano Santa Chiara di Sulmona

After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

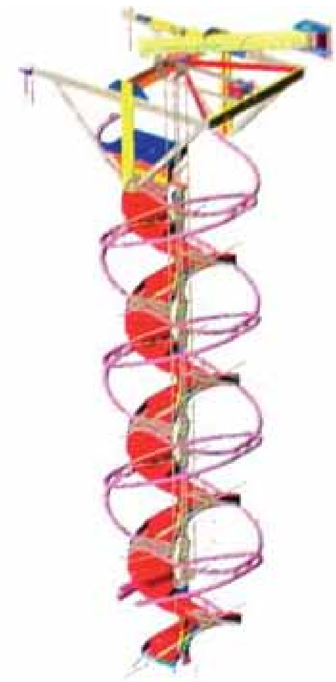
Notes

European Erasmus Mundus Master Course

Sustainable Constructions under Natural Hazards and Catastrophic Events

Technical solution Example - pull fire escape

Museo diocesano Santa Chiara di Sulmona



After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

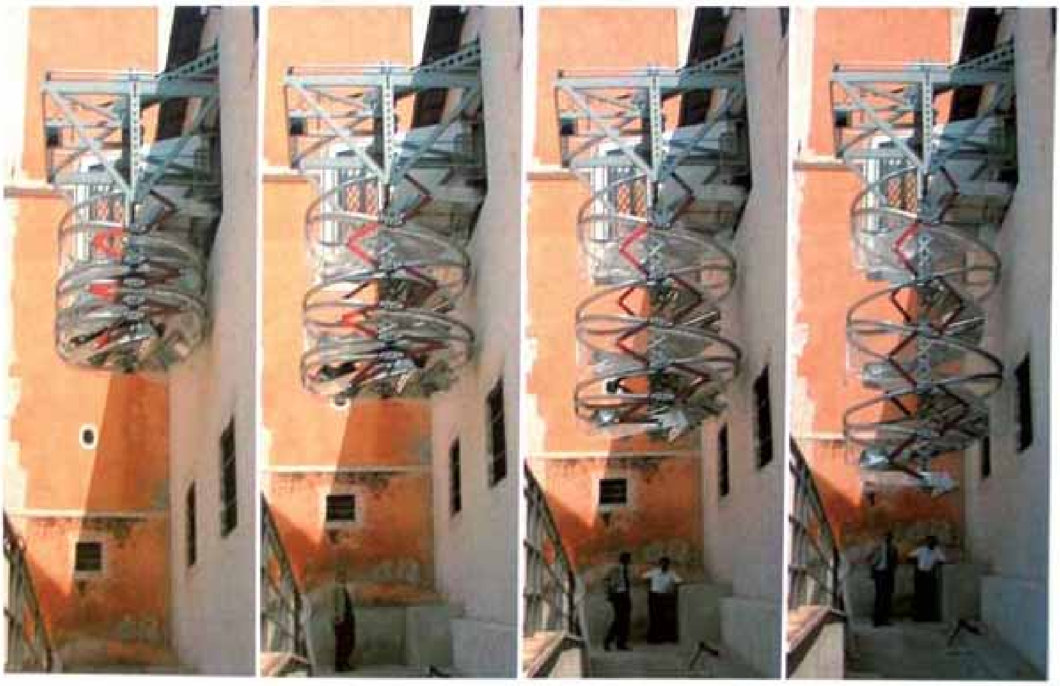
Historical structures
Statistics
Cultural value
› Technology
Management
Case studies

Notes

European Erasmus Mundus Master Course
Sustainable Constructions under Natural Hazards and Catastrophic Events

Technical solution
Example - pull fire escape

Museo diocesano Santa Chiara di Sulmona



After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
› Management
Case studies

Notes

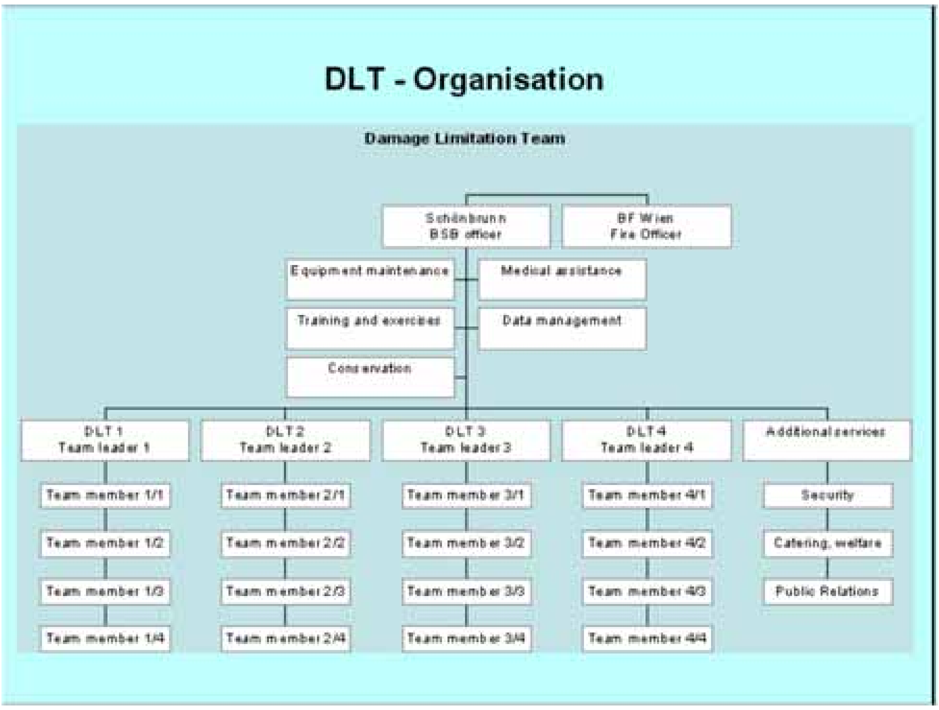
European Erasmus Mundus Master Course
Sustainable Constructions under Natural Hazards and Catastrophic Events

Improvements by records/rules

A Fire Safety Log Book

- Fire training sessions
- Fire drills undertaken
- Inspections
  - by the insurance company, fire brigade or other persons including brief details of any observations made
- Full details of all fire equipment
  - fire systems maintenance, including
  - emergency lighting
  - fire detection or alarm systems
- Details of any fire incidents, false alarms or other matters of interest, together with the responses or remedial action taken.

Schloss Schonbrunn Damage Limitation Team structure



After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

Notes

European Erasmus Mundus Master Course
Sustainable Constructions under Natural Hazards and Catastrophic Events

Herzogin Anna Amalia Library in Weimar

- Built in 1565 as a palace for Duke Johann Wilhelm
- In 1766, the Duchess Anna Amalia converted to Library
- Goethe the librarian (1797 – 1832)

After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

Notes

European Erasmus Mundus Master Course
Sustainable Constructions under Natural Hazards and Catastrophic Events

Engraving

After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

Notes

European Erasmus Mundus Master Course
Sustainable Constructions under Natural Hazards and Catastrophic Events

Fire

- Evening of 2 September 2004 severely demages
  - The fire started in the attic and spread to the rococo hall
  - Automatic fire report
  - Fire compartmentation, fire walls and doors
- 50,000 books were completely destroyed
- 62,000 suffered fire and/or water damage
  - saved as the fire blazed by staff and the public, who organised hand-to-hand chains.
  - included the 'Luther Bible' from 1534

Library on fire: 2 September 2004

After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

Notes

European Erasmus Mundus Master Course
Sustainable Constructions under Natural Hazards and Catastrophic Events

Post fire situation

The interior after the fire

After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
› Case studies

Notes

European Erasmus Mundus Master Course
SUSCOS
Sustainable Constructions under Natural Hazards and Catastrophic Events

The interior after the fire

Book salvage

European Erasmus Mundus Master Course
SUSCOS
Sustainable Constructions under Natural Hazards and Catastrophic Events

Historic books do burn

Book salvage

After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

Notes

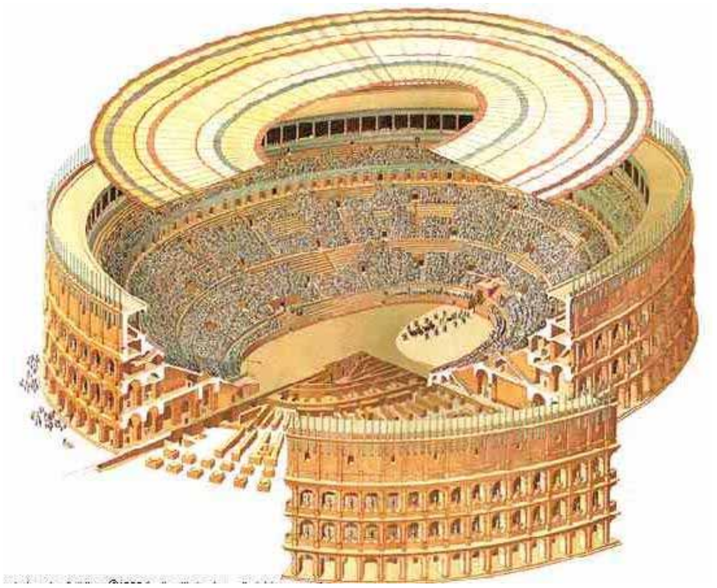
European Erasmus Mundus Master Course
Sustainable Constructions under Natural Hazards and Catastrophic Events

The Colosseum fire 217 AD

- According to study of Prof. Enzo Cartapati

The Colosseum fire 217 AD

- For up to 45 000 viewers
- Timber stands and equipment



After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

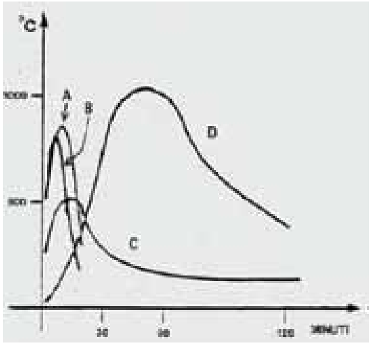
Notes

The Colosseum fire 217 AD

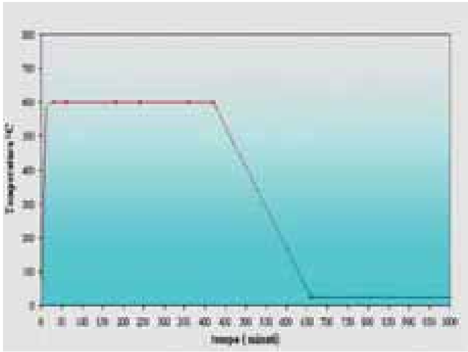
- Construction from 69 AD under Emperor Vespasian
- Open hand 80 AD at emperor Titus
- Fire in 217, 23 August??
- Earthquakes year August-October 223
- Reconstruction in 230
  Under the Emperor of Alexander Severus
- Abandoned in 523

The Colosseum fire 217 AD

- Fire simulation by prof. Enzo Cartapati



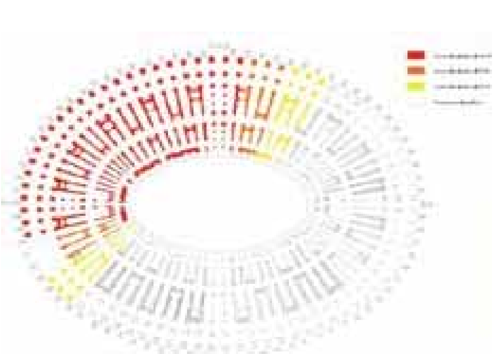
Temperature of fire

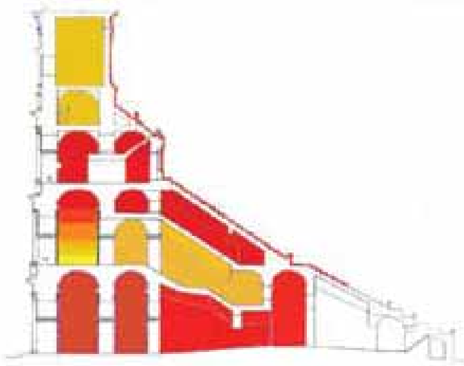


Temperature of structure

The Colosseum fire 217 AD

- Fire simulation by prof. Enzo Cartapati



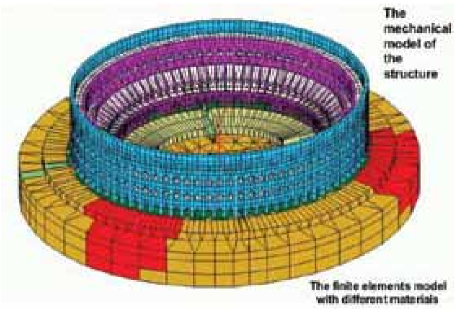


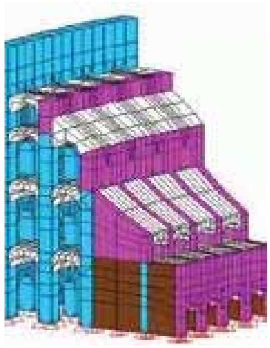
Transfer of heat

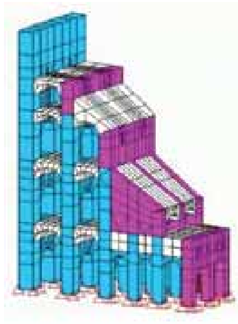
European Erasmus Mundus Master Course
Sustainable Constructions under Natural Hazards and Catastrophic Events

The Colosseum fire 217 AD

- Fire simulation by prof. Enzo Cartapati





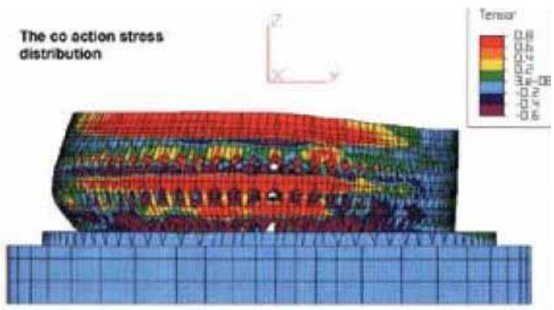


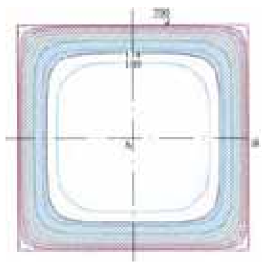
Mechanical model

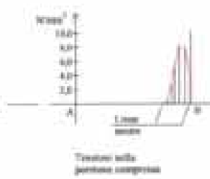
European Erasmus Mundus Master Course
Sustainable Constructions under Natural Hazards and Catastrophic Events

The Colosseum fire 217 AD

- Fire simulation by prof. Enzo Cartapati







Temperature of structure

After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

Notes

European Erasmus Mundus Master Course
SUSCOS
Sustainable Constructions under Natural Hazards and Catastrophic Events

The Colosseum fire 217 AD

- Fire simulation by prof. Enzo Cartapati

Colosseum today

After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

Notes

European Erasmus Mundus Master Course
SUSCOS
Sustainable Constructions under Natural Hazards and Catastrophic Events

The Colosseum fire 217 AD

- Virtual fire show 17.-19.9.2010

European Erasmus Mundus Master Course

Sustainable Constructions under Natural Hazards and Catastrophic Events

List of Lessons at Seminar

1.	**Fire safety**	FW
2.	Fire and mechanical loading	FW
3.	Thermal response	FW
4.	Steel structures	JMF
5.	Concrete structures	JMF
6.	Composite structures	JMF
7.	Advanced models	JMF
8.	Composite floors	FW
9.	Aluminum structures	FW
10.	Timber structures	FW
11.	After fire and Historical structures	FW
12.	Overview of **Explosion-blast Resistance**	KHT
13.	Response to blast	KHT
14.	P-I diagram	KHT
15.	Equivalent single degree	KHT
16.	Design example	KHT
17.	Definitions of **Design for Robustness**	JMD
18.	Global response of structures	JMD
19.	Design recommendations	JMD
20.	Alternative load path method	JMD

Thank you for your attention

František WALD

wald@fsv.cvut.cz

After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

Notes

European Erasmus Mundus Master Course

Sustainable Constructions under Natural Hazards and Catastrophic Events

Sources

- Chan D., 2009. Fire damage assessment of structural steel in a school, *The Structural Engineer*, 87 (19) 6 October, pp. 18-20.
- Concrete Society, 1990. *Assessment and Repair of Fire-Damaged Concrete Structures,* Technical Report No. 15, The Concrete Society, UK.
- Construction Industry Research and Information Association (CIRIA), 1986, *Testing Concrete in Structures, A Guide to Equipment for Testing Concrete in Structures,* Technical Report 143, CIRIA, UK.
- Dias W. P. S., 1992. Some properties of hardened cement paste and reinforcing bars upon cooling from elevated temperatures, *Fire and Materials*, 16 (1), pp. 29-35.
- Hajpál M. 2008. Heat effect by natural stones used by historical monuments, 11th International Congress on Deterioration and Conservation of Stone (STONE 2008).

After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

Notes

European Erasmus Mundus Master Course

Sustainable Constructions under Natural Hazards and Catastrophic Events

Sources

- Hajpál M., Török Á. 2004. Physical and mineralogical changes in sandstones due to fire and heat. *Environmental Geology*, 46, 3, 306-312.
- Kirby, B.R., Lapwood, D.G. & Thomson, G., 1986. *The Reinstatement of Fire Damaged Steel and Iron Framed Structures,* British Steel Corporation (now Corus), London, p. 46
- Outinen, J., Mäkeläinen, P., 2004. Mechanical properties of structural steel at elevated temperatures and after cooling Fire and Materials, 28 (2-4), pp. 237-251.
- Pang P. T. C., 2006. Fire engineering design and post fire assessment, *The Structural Engineer* 84, (16) 6 October, pp.23-29.
- Steel Construction Industry Forum (SCIF), 1991. Structural Fire Engineering*: Investigation of Broadgate Phase 8 Fire,* Steel Construction Institute, UK.

Sources

- The Institution of Structural Engineers (ISE), 1996. *Appraisal of Existing Structures,* Institution of Structural Engineers, London, UK.
- Török Á., Hajpál M. 2005. Effect of Temperature Changes on the Mineralogy and Physical properties of Sandstones. A Laboratory Study. International Journal for Restoration of Buildings and Monuments, 11, 4, Freiburg, 211-217.
- Vácha, J., 2006. Reconstruction of coal feeding bridge after fire. in Czech Rekonstrukce zauhlovacích mostů po požáru, *Konstrukce*, 01, pp. 22-24. ISSN 1803-8433.
- Wang Y.C., Wald F., Török A., Hajpál M., 2008. Fire damaged structures, in *Technical sheets – Urban habitat constructions under catastrophic events,* Print Pražská technika, Czech Technical University in Prague, ISBN 978-80-01-04268-7.
- Yan, X., Li, H., Wong, Y. L,. 2007. Assessment and repair of fire-damaged high-strength concrete: Strength and durability *Journal of Materials in Civil Engineering* 19 (6), pp. 462-469.

After fire
Principles
Assessment procedure
Design for repair
Case study
Summary

Historical structures
Statistics
Cultural value
Technology
Management
Case studies

Notes

European Erasmus Mundus Master Course
SUSCOS
Sustainable Constructions under Natural Hazards and Catastrophic Events

Sources

- Ingval Maxwell I:. COST Action C17, Built Heritage: Fire Loss to Historic Buildings - Executive Summary of Recommendations, Historic Scotland, Edinburgh 2007, ISBN 978 1 904966 53 1.
- Cartapati E., Cerone M., The Colosseum fire: 217 AD, COST Action C17: Built Heritage: Fire Loss to Historic Buildings: Conference Proceedings - Part 4, Rome, 2006.