Fire Safety Design for Building
- Fire Resistance Verification Method-

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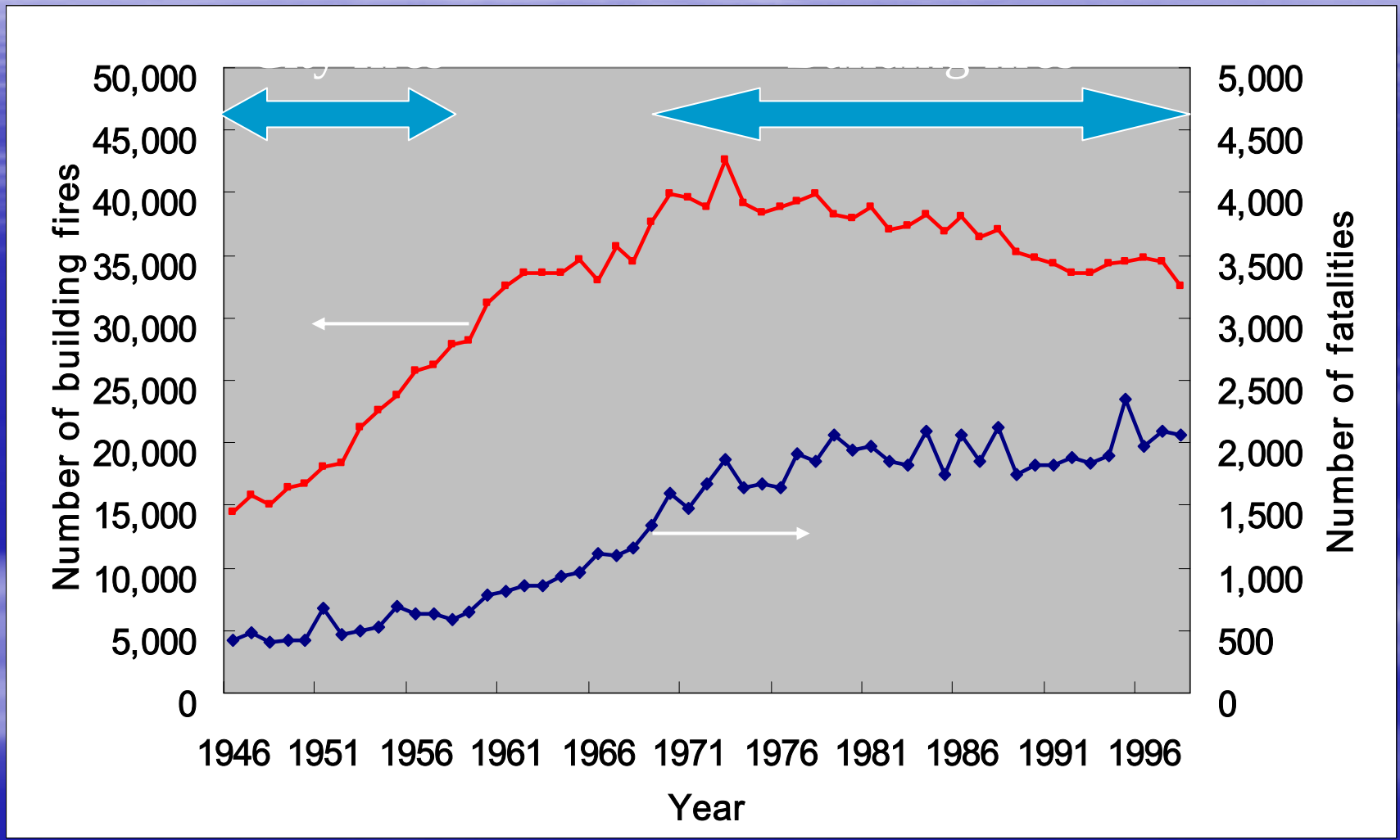
Outline

- Trend of Building Fire in Japan
- Performance Based Code
- Framework of Evaluation on Fire Safety under Performance Based Code
- Fire Safety Verification Methods of Building Standards Law of Japan
- Examples of Design and Research

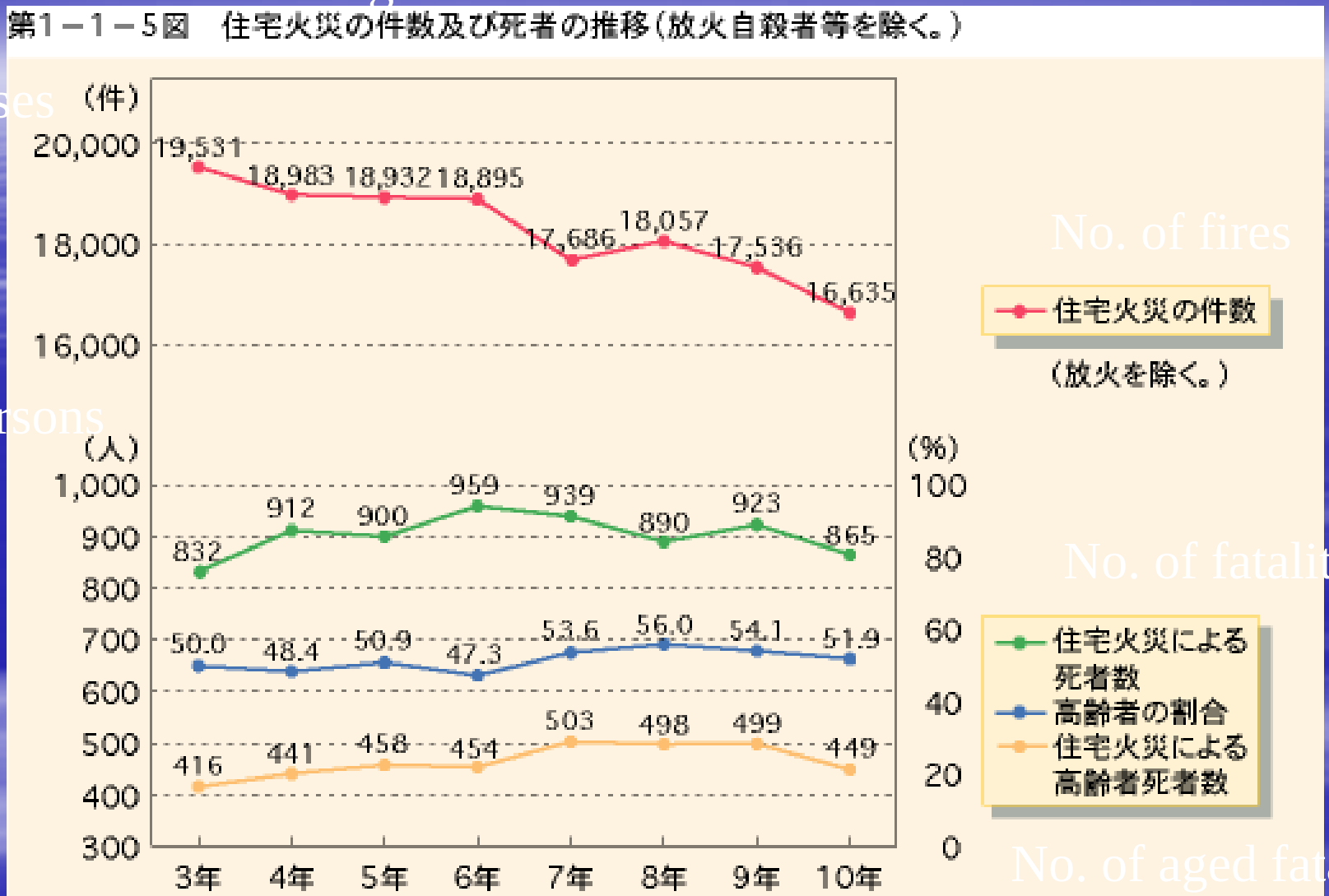
1 . Trend of Building Fire in Japan

- Fire Damage since 1946
- Trends in dwelling fires
- Fatalities by aged groups in dwelling fires
- Major fire causes

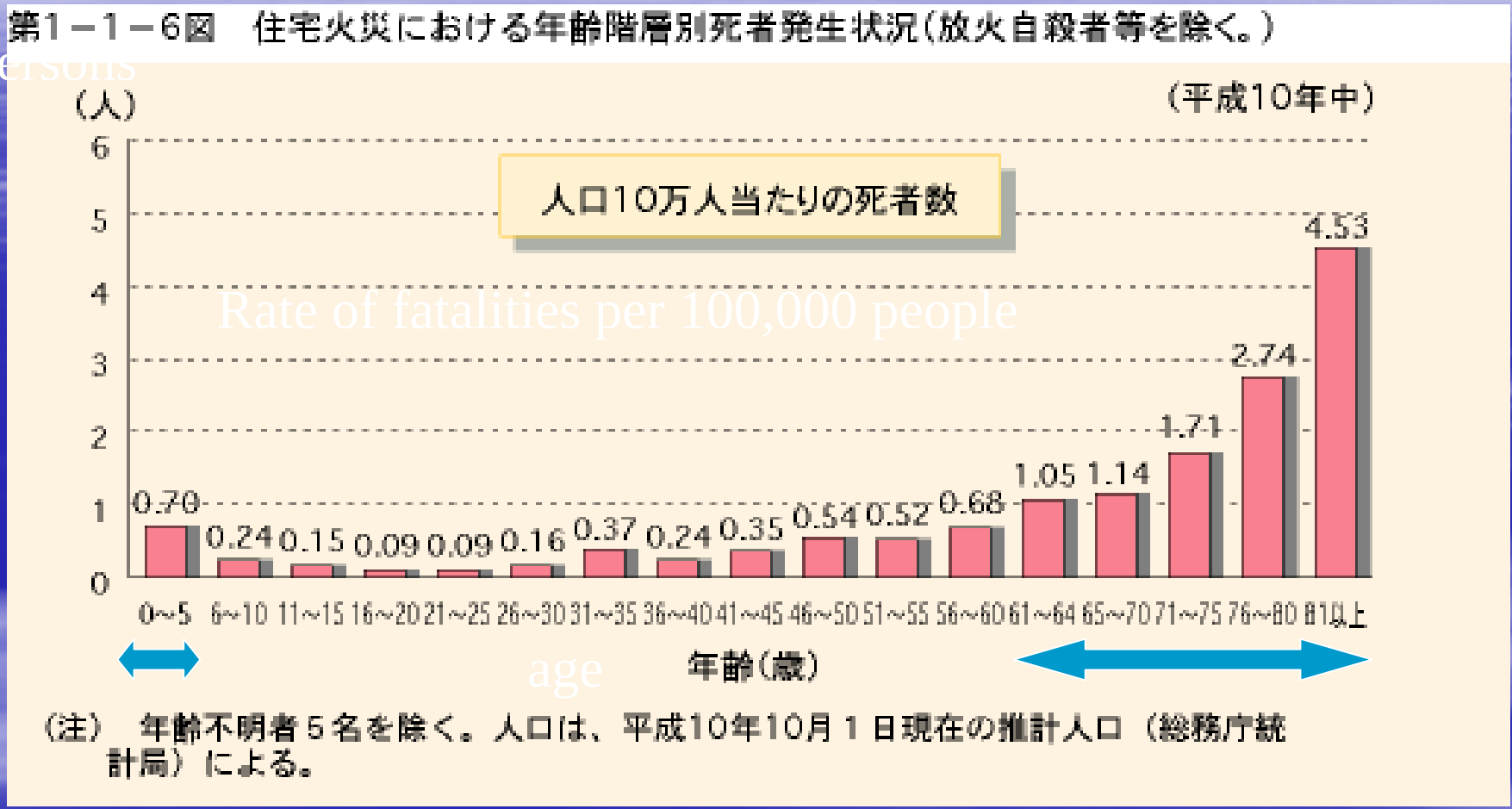
Fire Damage since 1946



Trends in dwelling fires



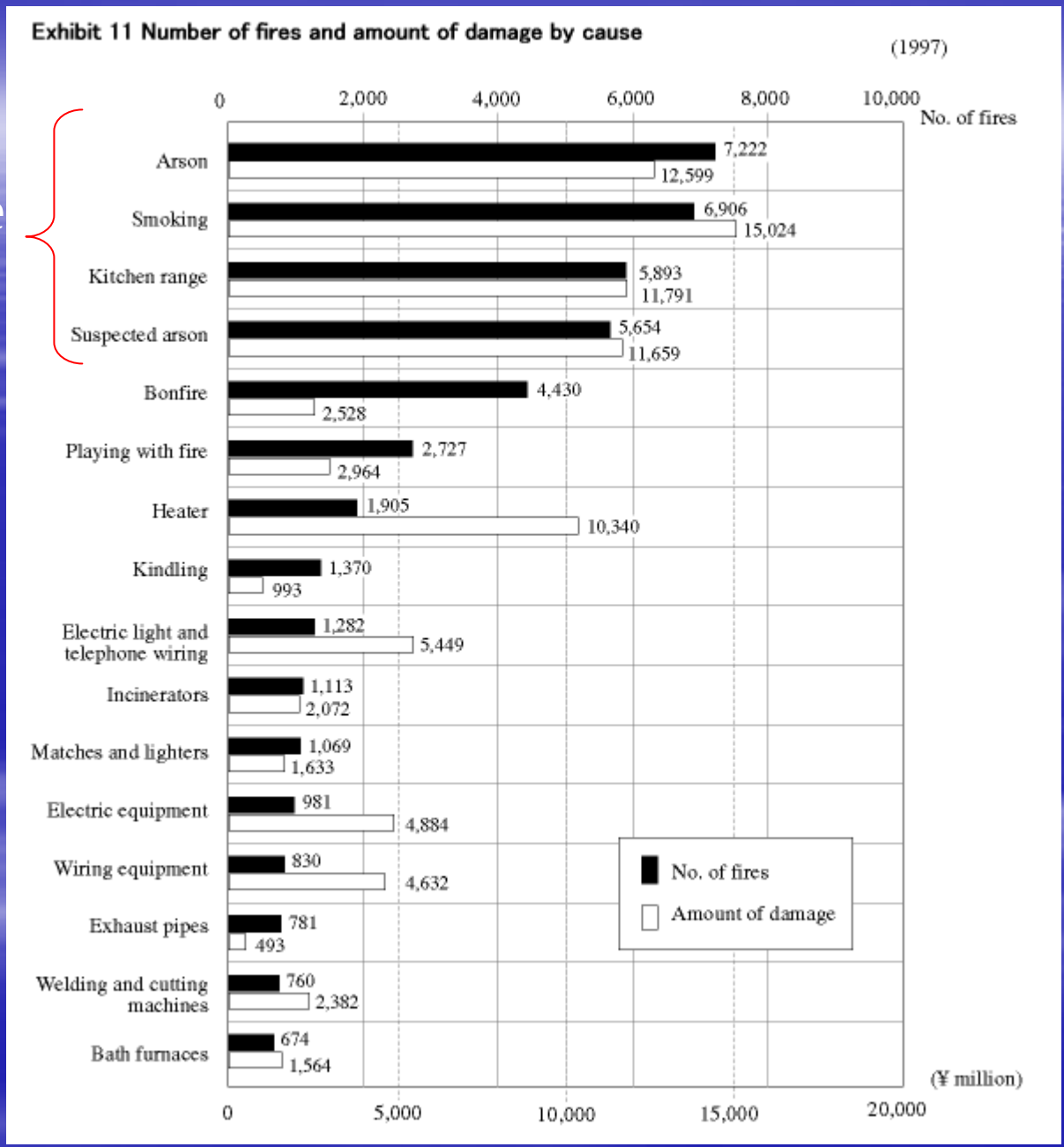
Fatalities by aged groups in dwelling fires



Little children

Aged people

Major fire causes

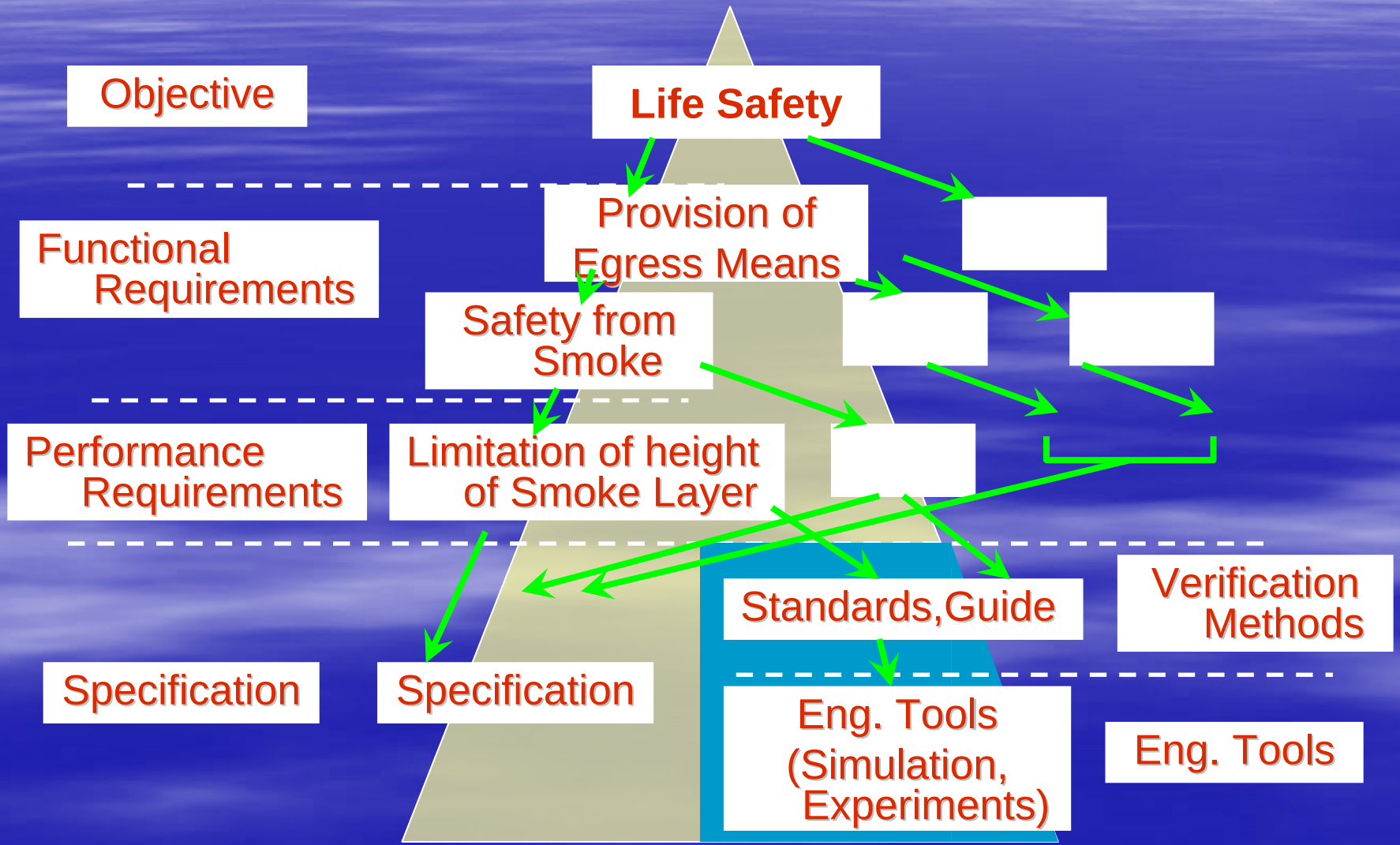


2 . Performance Based Codes

- Performance Based Codes

  (Nordic Committee on Building Regulation 5 Level System)

System of Performance Based Code
(NKB 5 Level System)



3．Framework of Evaluation on Fire Safety under Performance Based Code

- **Framework of evaluation on Fire Safety under performance based code**

Framework of evaluation on Fire Safety under performance based code

Occupancy of Fire Confinement
Performance of envelope

Calculation of design fire

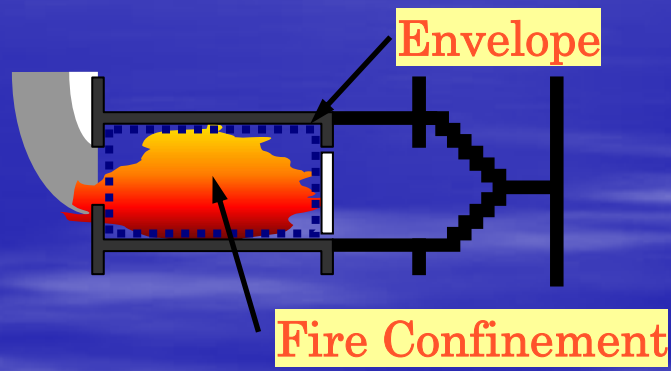
Can envelope endure design fire?

No

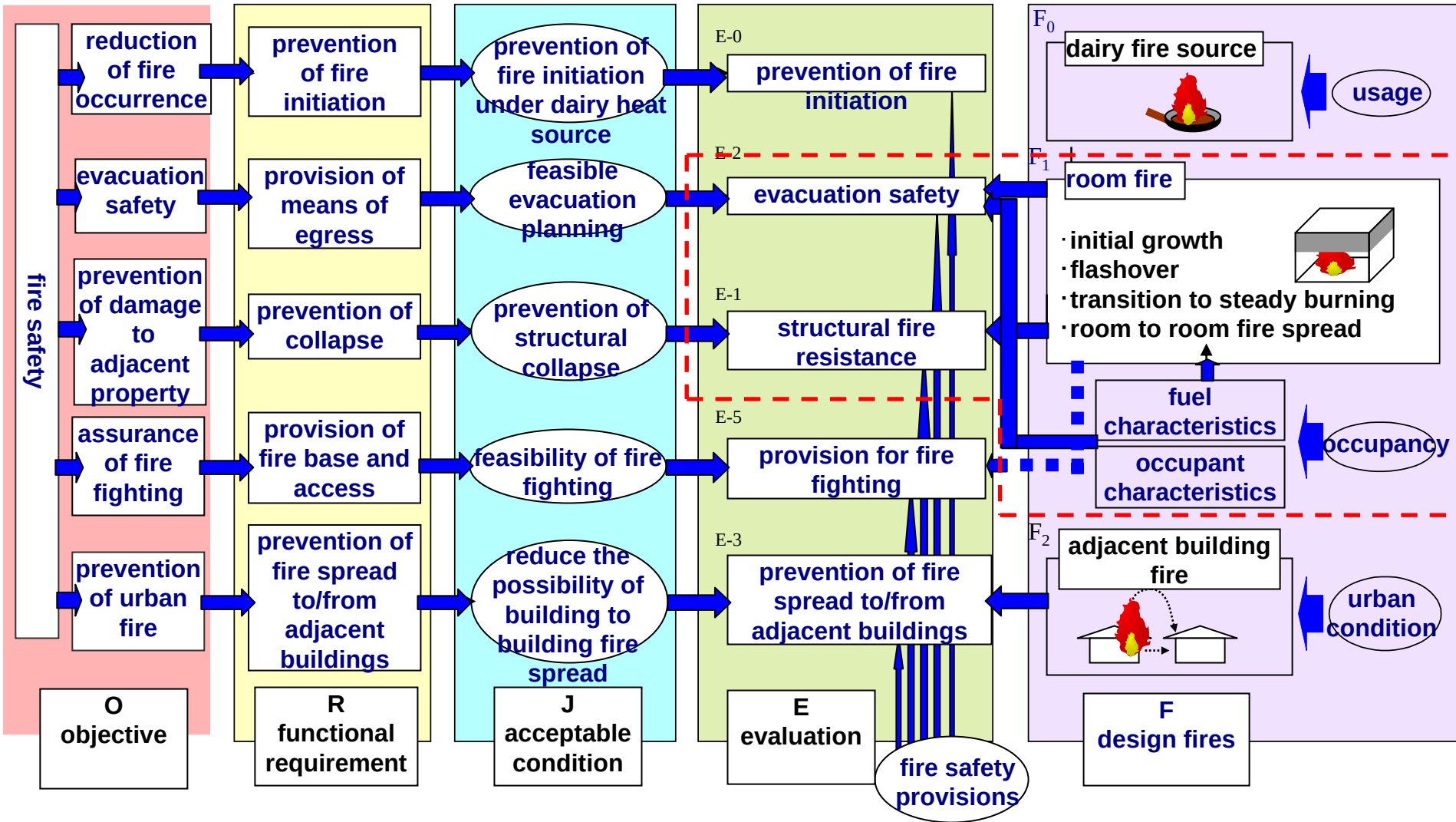
Yes

Objective

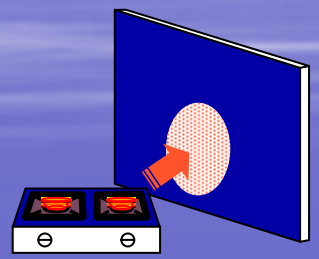
- Reduction of fire occurrence
- Evacuation safety
- Prevention of structural collapse
- Assurance for fire fighting
- Prevention of urban fire

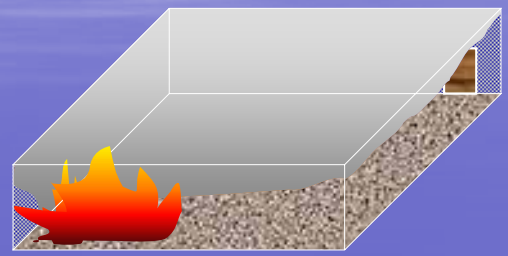


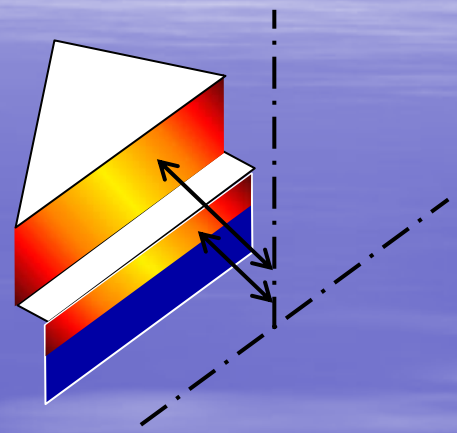
Framework of the evaluation



Design Fire







Design Fire

Reduction of fire occurrence

Prevention of structural collapse

Evacuation safety

Prevention of urban fire

To the Framework of evaluation

Feedback for Design Fire

- **Assume the envelope's insulation and integrity performance**
  - * Fuel load (occupancy dependent)
  - * Lining Materials
  - * Ventilation

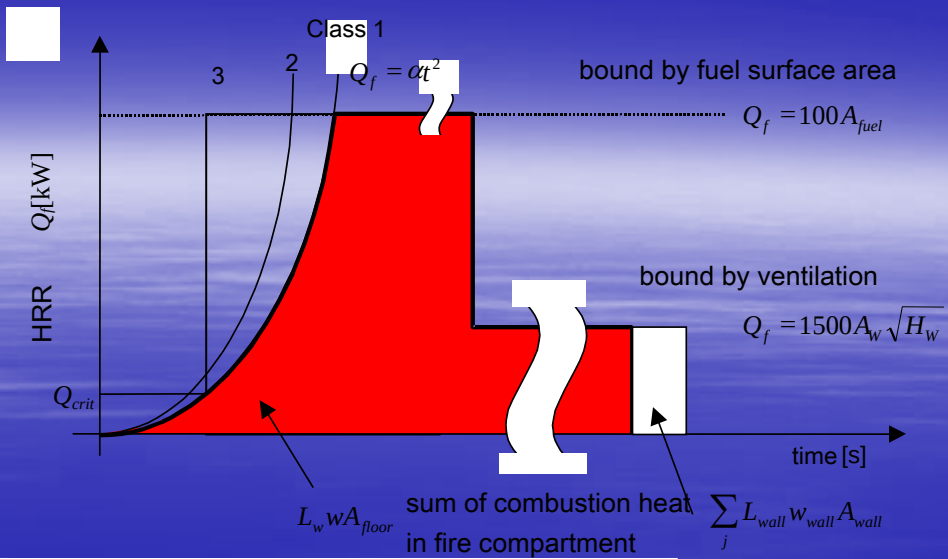
Simulation by Design Fire

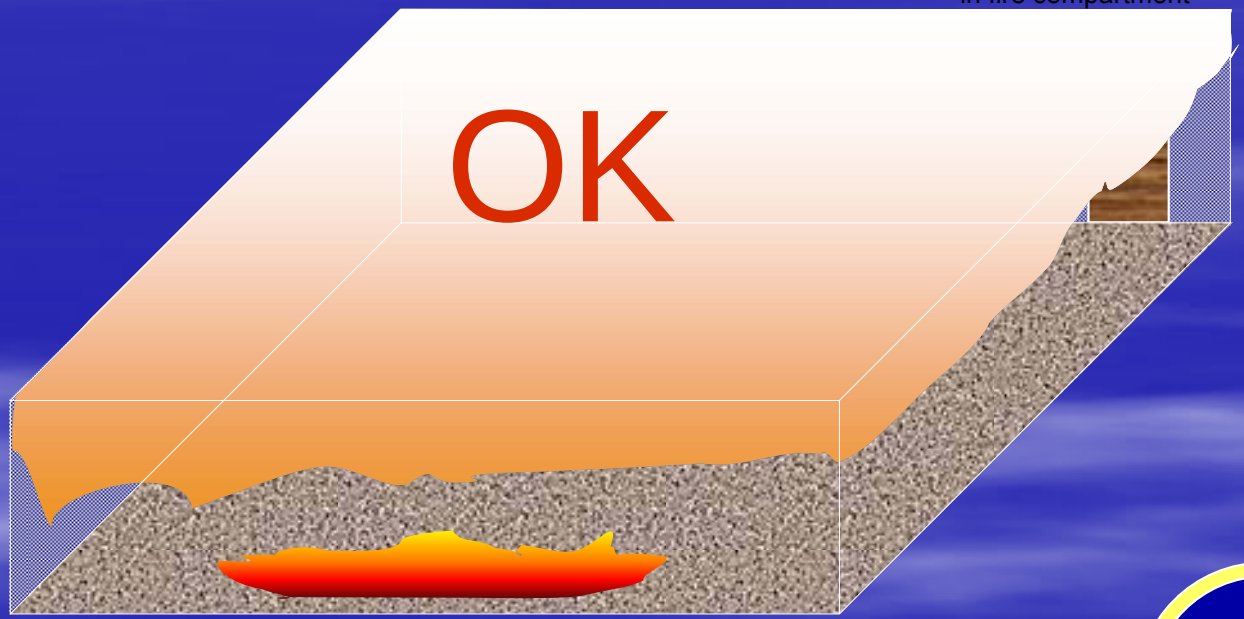
"Heat and/or Flame interruption fails."

Yes

No

Feedback for design fire (returns)





Evaluation of Structural Fire Resistance

- Sufficient Stability of Building Frames during fire

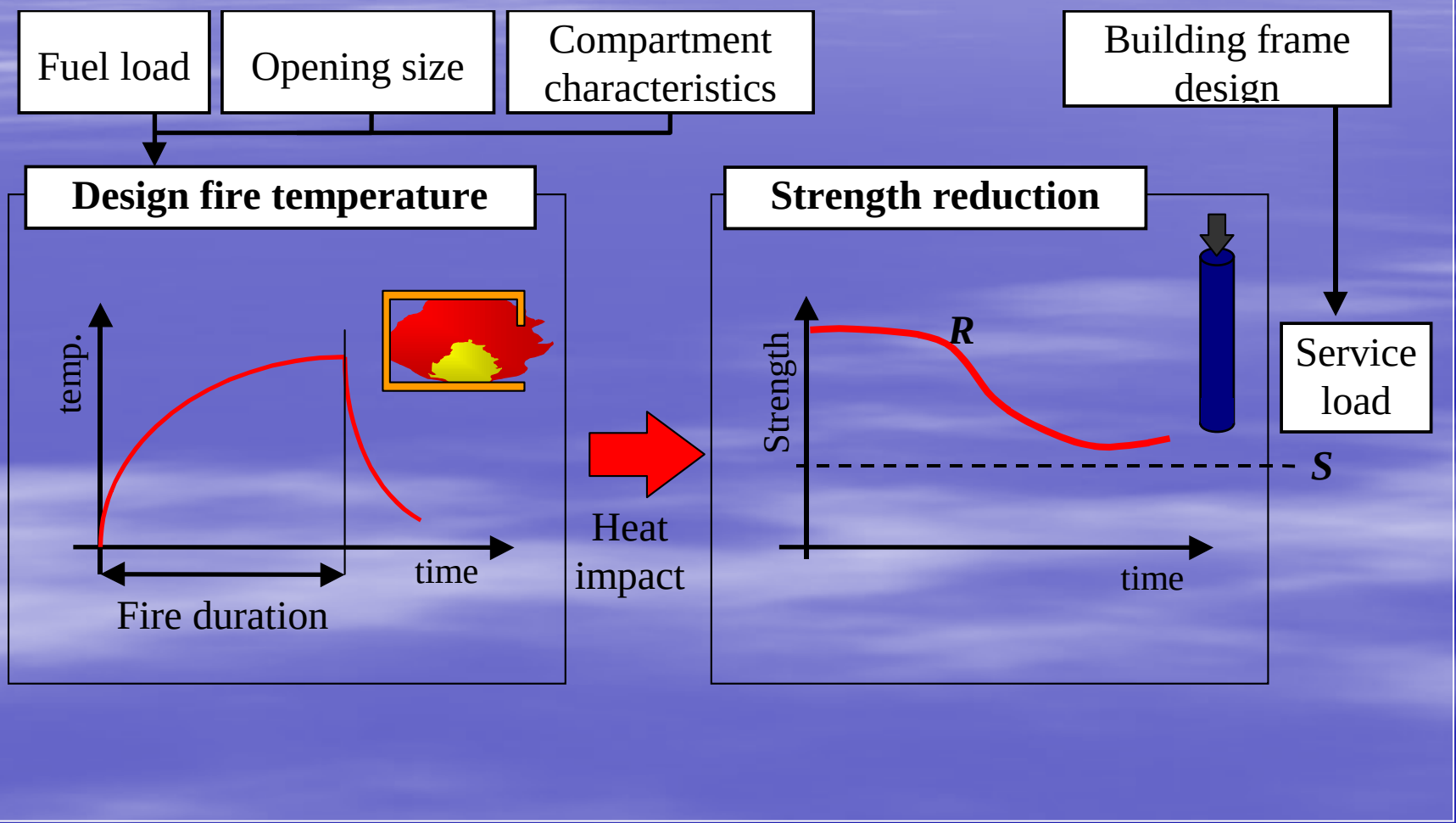
Check by

whole structural frame

or

individual load bearing elements

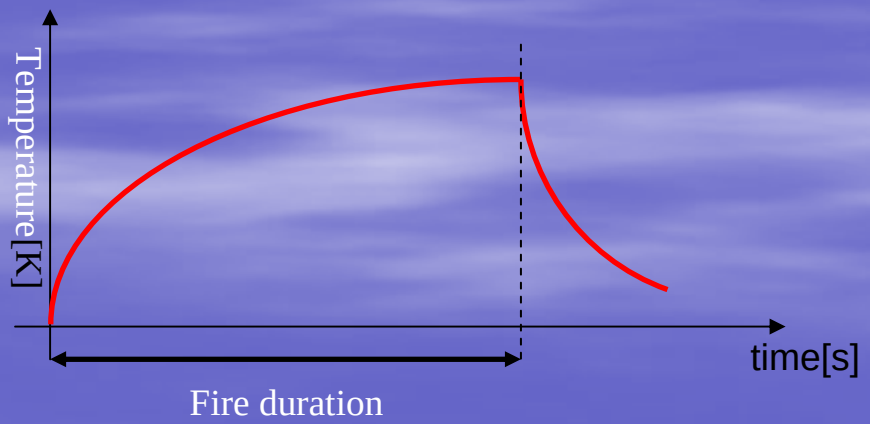
Evaluation Model for Structural Fire Resistance (Load Bearing)



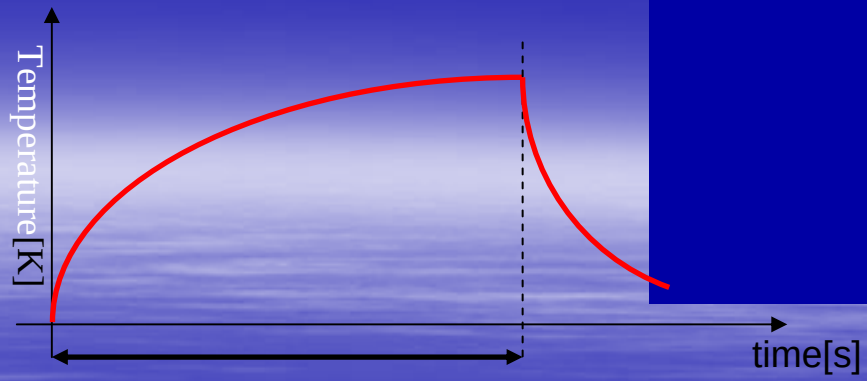
Design Fire → Room Temperature

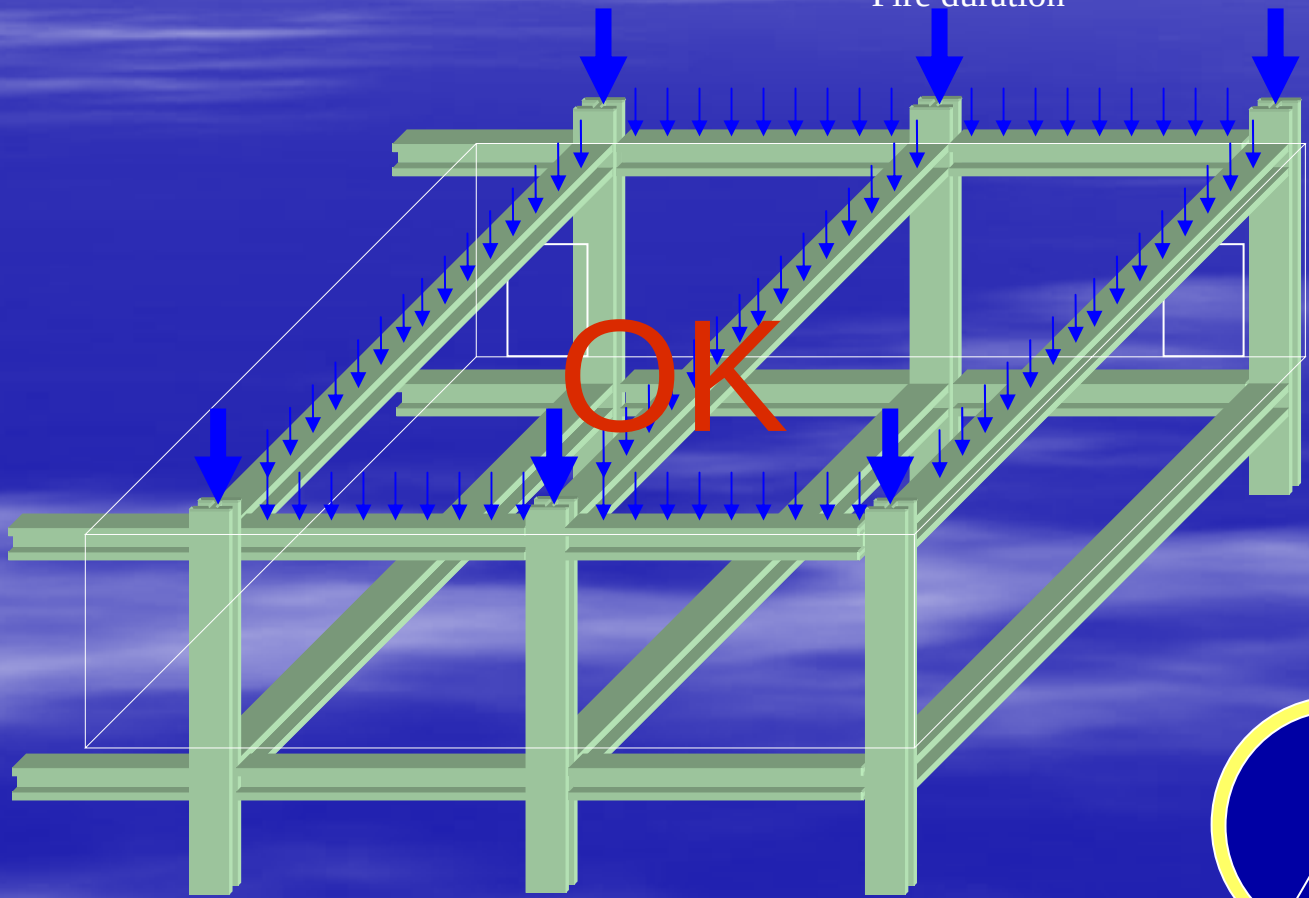
Design fire

Room temperature



Evaluation of Structural Fire Resistance





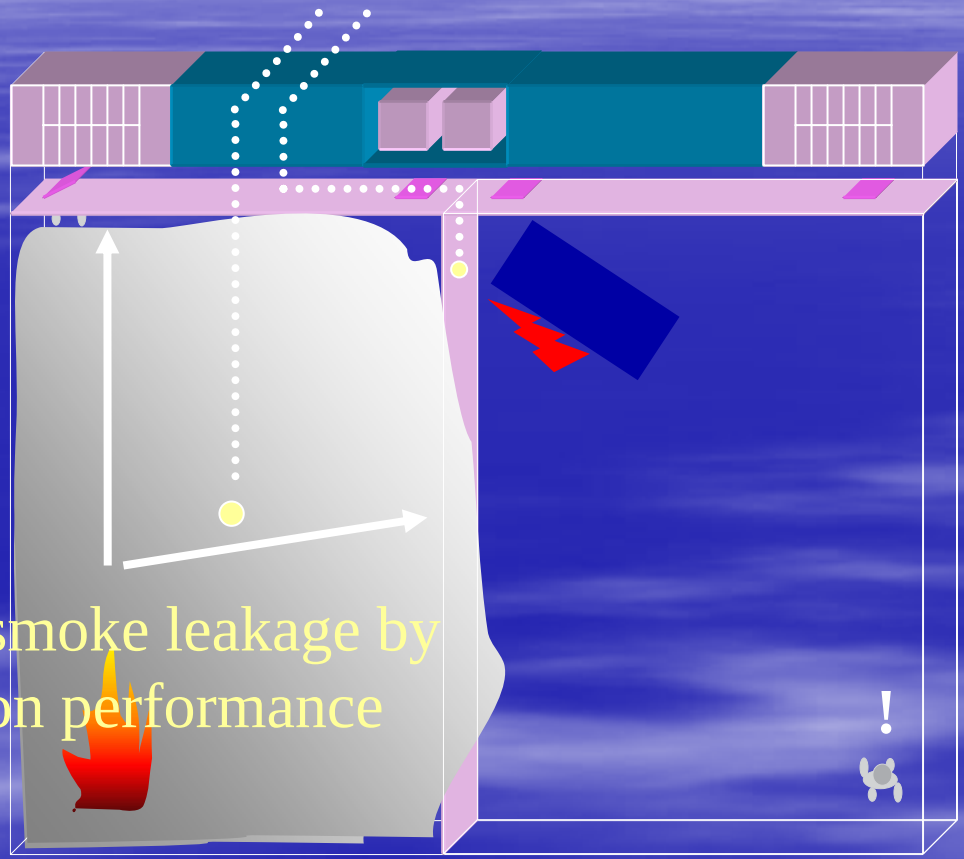
Evaluation of Evacuation Safety

- Evacuation to the staircase

1. Smoke propagation and its control
2. Detection and alarm
3. Reaction (time lug until escape starts)
4. Escape movement

Evaluation of Evacuation Safety

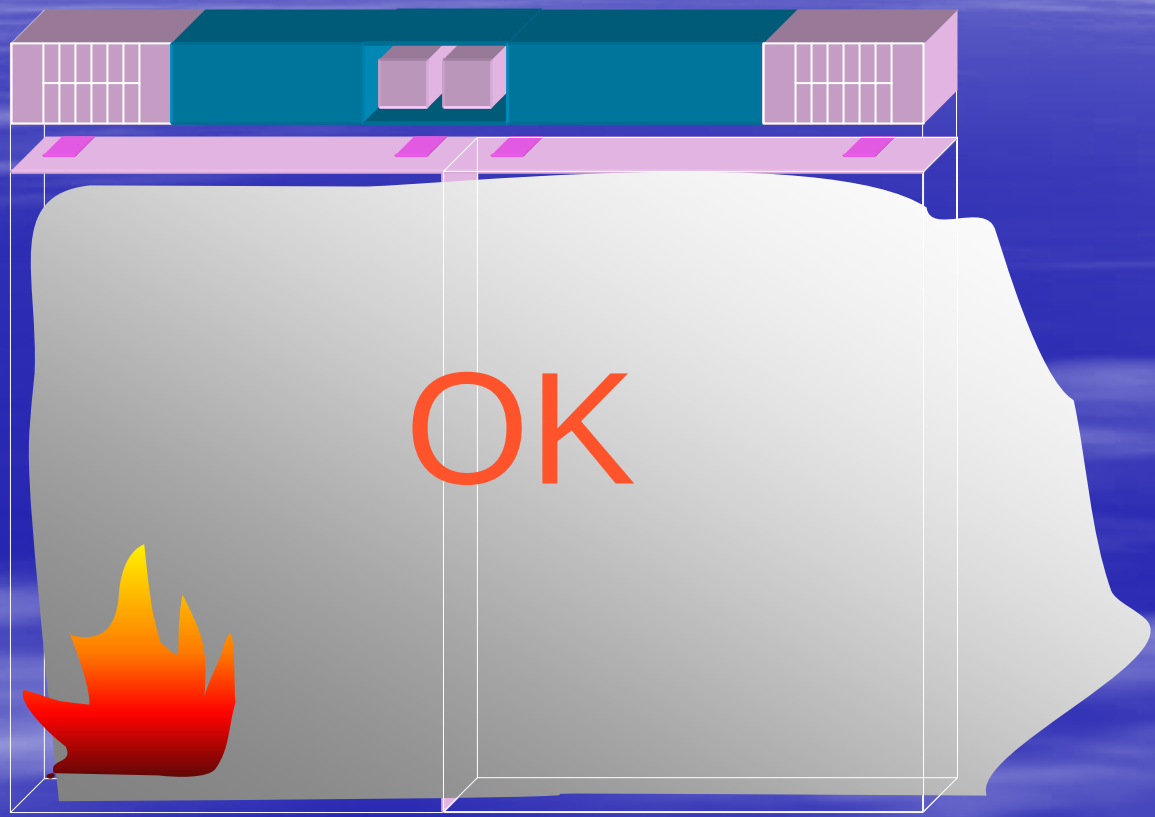
3. Reaction



Estimate smoke leakage by interruption performance

Evaluation of Evacuation Safety

4. Escape movement

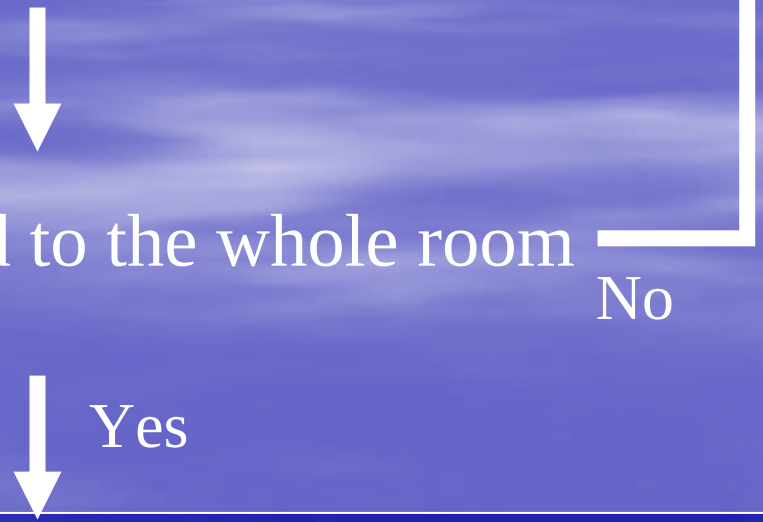


Reduction of Fire Occurrence

- Prevention of fire initiation under daily heat source

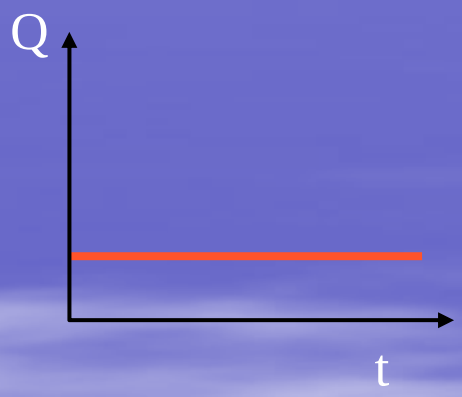
1.Initiation model under daily heat source

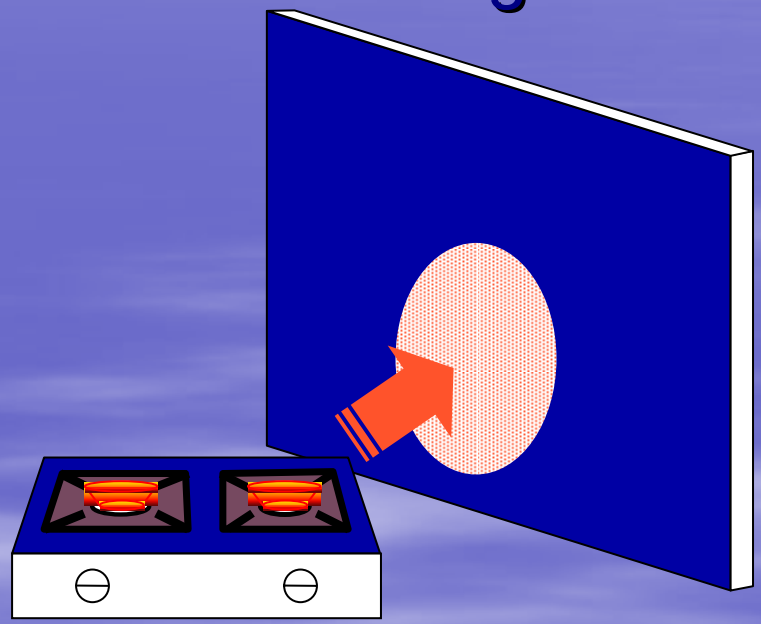
2.Design for interior furnish



Ordinary fire source

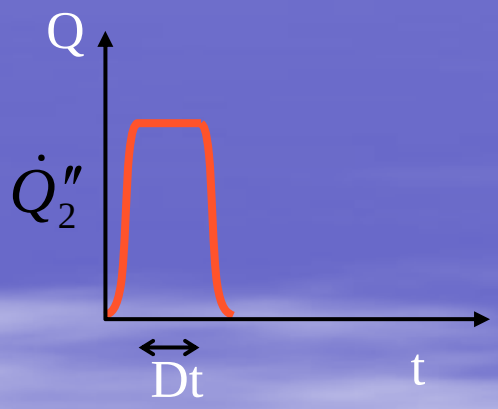
- Example:No materials should be ignited by radiation from a cooking stove

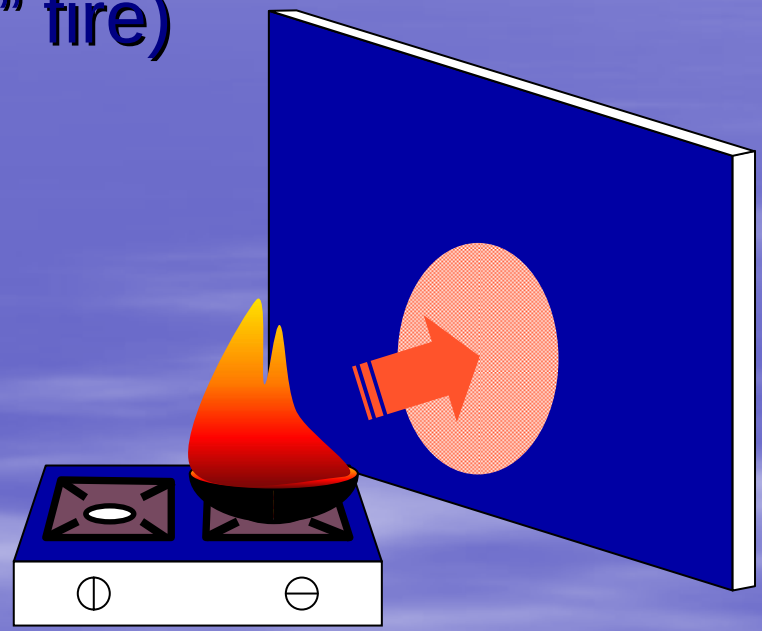




Design fire caused by faults

- Example:Deep fry oil fire cased by over heating ("*Tempura*" fire)





Prevention of fire spread to/from neighbors

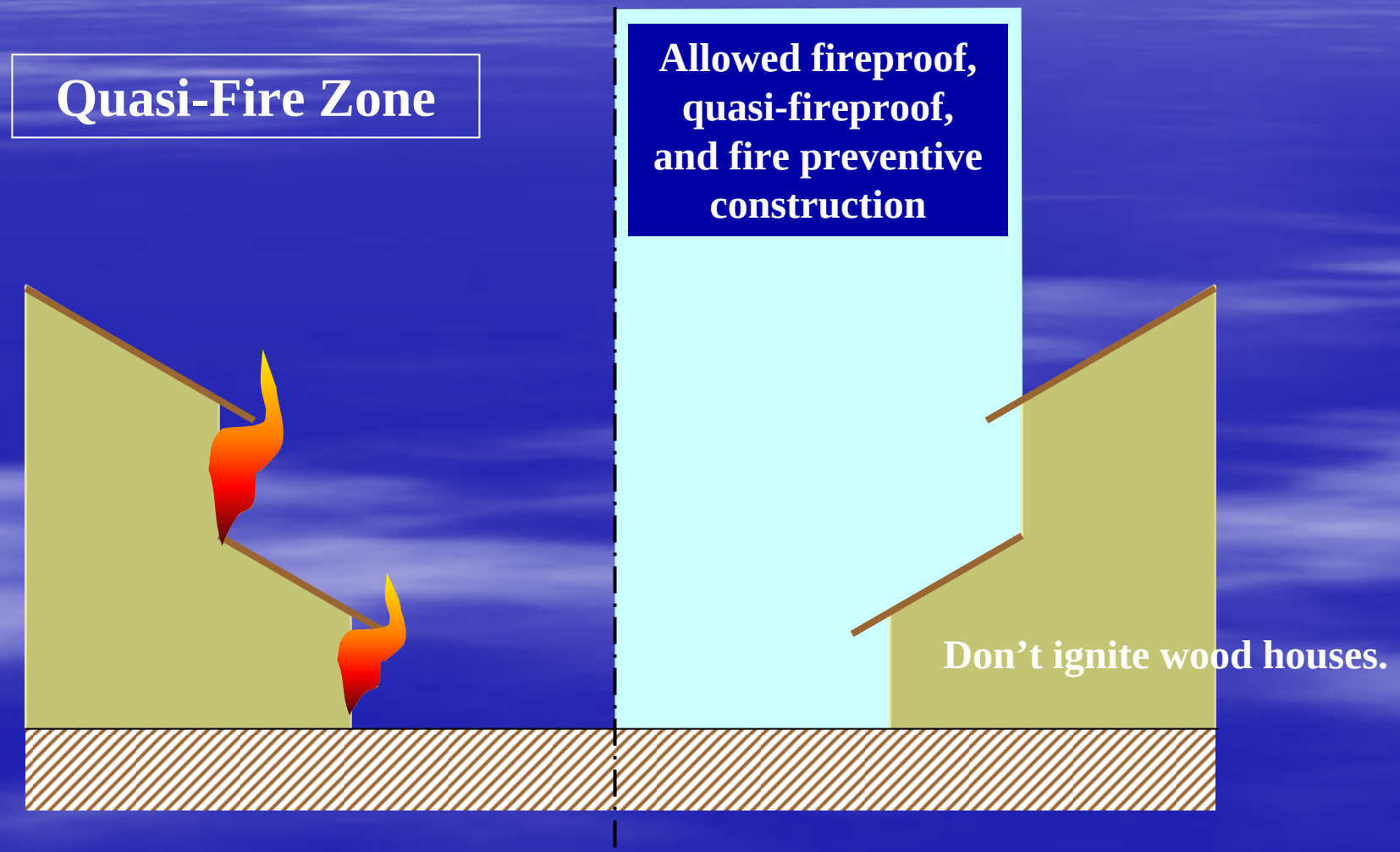
- Prevention of fire spread to/from neighbors

1.Fire model of outspread buildings

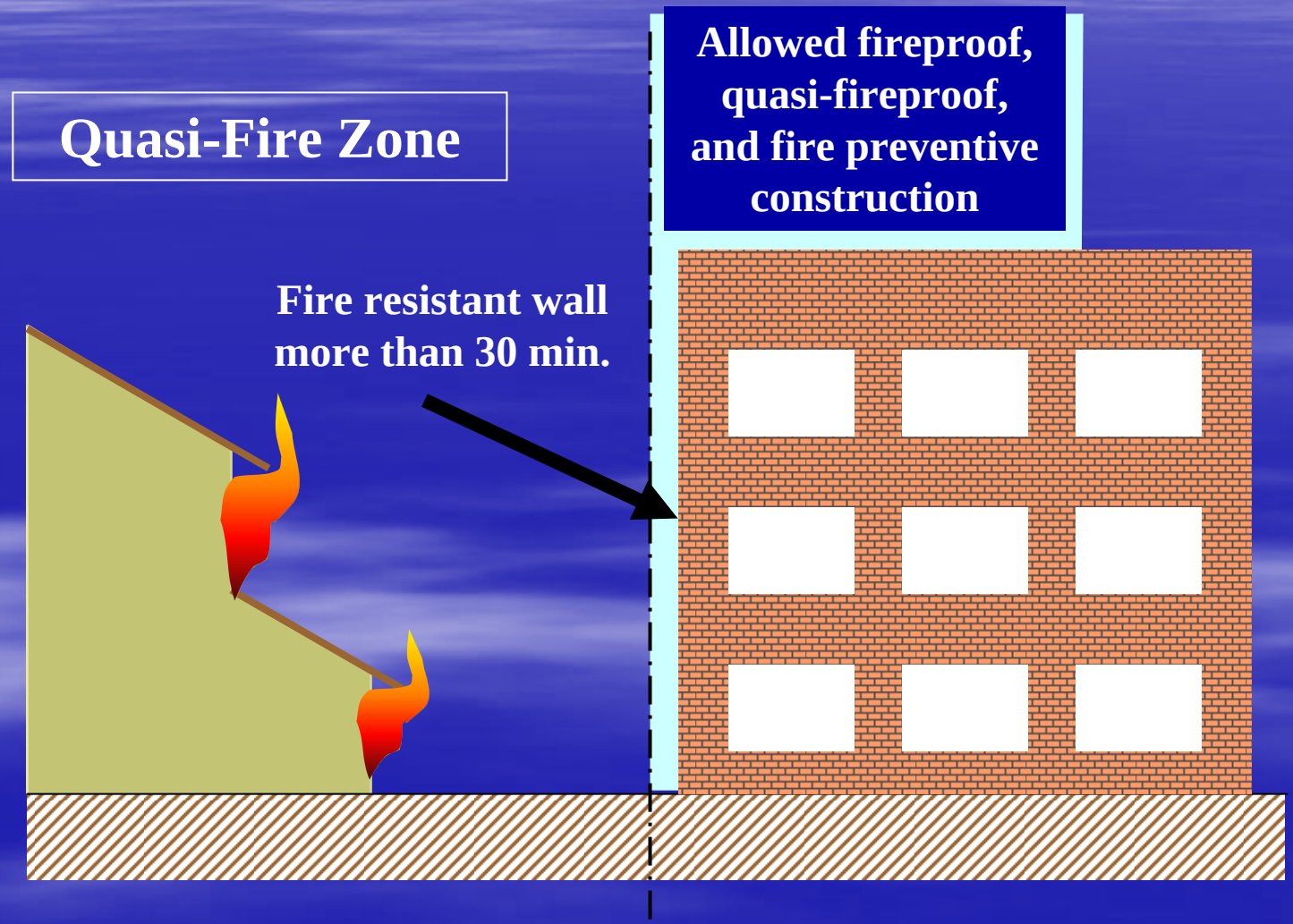
to buildings

2.Design for exterior

Basic concept on Prevention of fire spread



Basic concept on Prevention of fire spread



4 . Fire Safety Verification Methods of Building Standards Law of Japan

- Fire Resistance Verification Method
- Fire Compartment Verification Method
- Verification Method for Floor Evacuation safety
- Verification Method for Building Evacuation safety

Definition of Fire Resistive Building in BSLJ 1/

- (a) Major structural elements of the building are either
  - (1) fire resistant constructions, or

Definition of Fire Resistive Building in BSLJ 2/

- (2) those elements that comply with the following performance requirements:
  - (i) A building shall resist expected indoor fires, corresponding to the construction and service equipment of the building, throughout their duration.
  - (ii) A building should resist ordinary fires occurring in the neighbor of the building throughout their duration.

Definition of Fire Resistive Building in BSLJ 3/

- (b) An opening of an exterior wall that is susceptible to the spread of fire from adjacent buildings shall be constructed with a fire door or other fire preventive equipment.

Performance requirements of BSLJ

For indoor fires:

	Ext. Wall	Partition Wall	Column	Beam	Floor	Stairs	Roof
Loadbearing capacity	r*	r*	r	r	r	r	r
Integrity	r						r
Insulation		r			r		

r: required, r*: required only for load bearing walls

For neighbor fires:

	Ext. Wall
Loadbearing capacity	r*
Insulation	r

r: required, r*: required only for load bearing walls

Performance Criteria

- For indoor fires:(expected fire)
  - fire resistance time > = duration of fire.
- For neighbor fires:(standard fire)
  - fire resistance time of an exterior wall >= prescribed time(60 or 30 minutes)

Applicability and Features of the Verification Method

- Applicable to steel, reinforced concrete and wood structured buildings
- Evaluation process of expected indoor fire is common to all types of structures
- Determination process of fire resistance time differs among structures

Steel

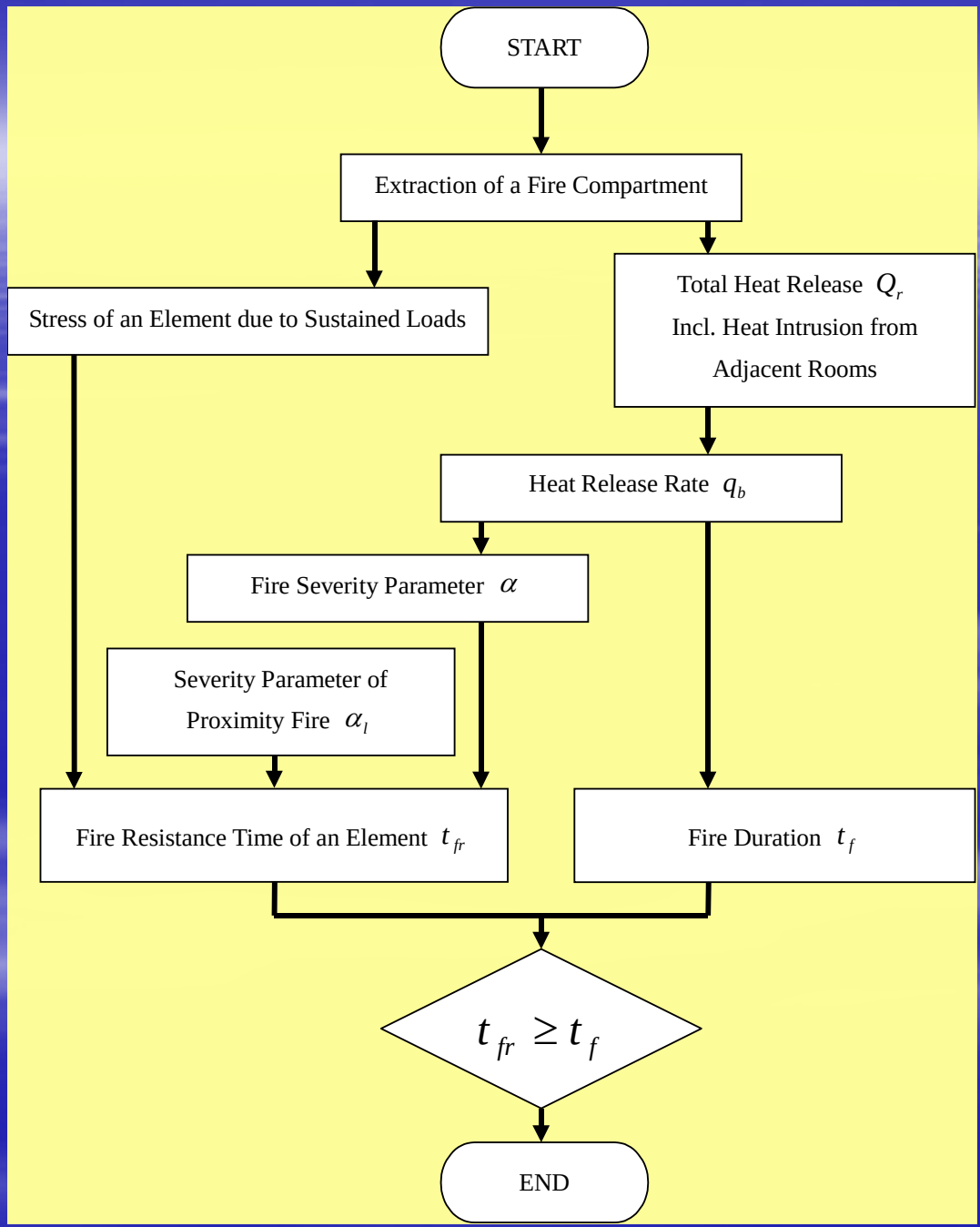
- Applicable only to columns and beams of moment resisting steel frames
- Applicable to unprotected members and members protected with sprayed rockwool or calcium silicate boards
- Only for loadbearing capacity verification

Reinforced Concrete

- Applicable to columns, beams, walls, slabs and roofs
- Ordinary concrete or Class 1 light weight concrete
- Design strength of concrete not exceeding 60 MPa
- Loadbearing capacity, insulation and integrity can be verified

Wood

- Applicable only to columns and beams
- Minimum section size not less than 20 cm
- Only for loadbearing capacity verification


START
Extraction of a Fire Compartment
Stress of an Element due to Sustained Loads
Total Heat Release Q_r
Incl. Heat Intrusion from
Adjacent Rooms
Heat Release Rate q_b
Fire Severity Parameter α
Severity Parameter of
Proximity Fire α_l
Fire Resistance Time of an Element t_{fr}
Fire Duration t_f
$t_{fr} \geq t_f$
END

Fire Duration and Fire Severity

- Total Heat Release (MJ)

$$Q_r = q_l A_r + \sum q_f A_f d_f + \sum f_a \left(q_{la} A_{ra} + \sum q_{fa} A_{fa} d_{fa} \right)$$

Fuel Load

interior surface finishes

heat intrusion factor

Values of Fuel Load

Room Use	q_l (MJ/m^2)
Residential Room	720
Guest Room of Hotel	240
Office	560
Meeting Room	160
Seating Space of Theater or Assembly	240
Stage of Theater or Assembly	480
Classroom	400
Selling Floor of Department Store	480
Seating Space of Restaurant	480
Storage	2,000

Heat Release Per Unit Area, Per Unit Thickness of Interior Finish

Material Classification	Heat Release q_f (MJ/m^2/mm)	Oxygen Consumption Coefficient ϕ
Noncombustible	0.8	0.1
Fire Retardant	1.6	0.2
Slow Burning	3.2	0.4
Others	8.0	1.0

Heat Intrusion Factor

Construction of Wall or Floor	Fire Preventive Equipment	Heat Intrusion Factor f_a
Fire Resistive Construction	Special Fire Preventive Equip.	0.00
	Fire Preventive Equip.	0.07
Specified Quasi Fire Resistive Construction	Special Fire Preventive Equip.	0.01
	Fire Preventive Equip.	0.08
Quasi Fire Resistive Construction	Special Fire Preventive Equip.	0.05
	Fire Preventive Equip.	0.09
Others		0.15

Heat Release Rate

$$q_b = A_{fuel} \cdot \begin{cases} 1.6\chi & (\chi \le 0.081) \\ 0.13 & (0.081 < \chi \le 0.1) \\ 2.5\chi \exp(-11\chi) + 0.048 & (0.1 < \chi) \end{cases}$$

$$\chi = \max\left[\frac{\sum A_{op}\sqrt{H_{op}}}{A_{fuel}}, \frac{A_r\sqrt{H_r}}{70 A_{fuel}} \right]$$

Duration and Temperature of fire

Duration of fire

$$t_f = \frac{Q_r}{60 q_b}$$

Fire temperature curve for the compartment

$$T_f(t) = \alpha t^{1/6} + 20 \quad (0 \le t \le t_f)$$

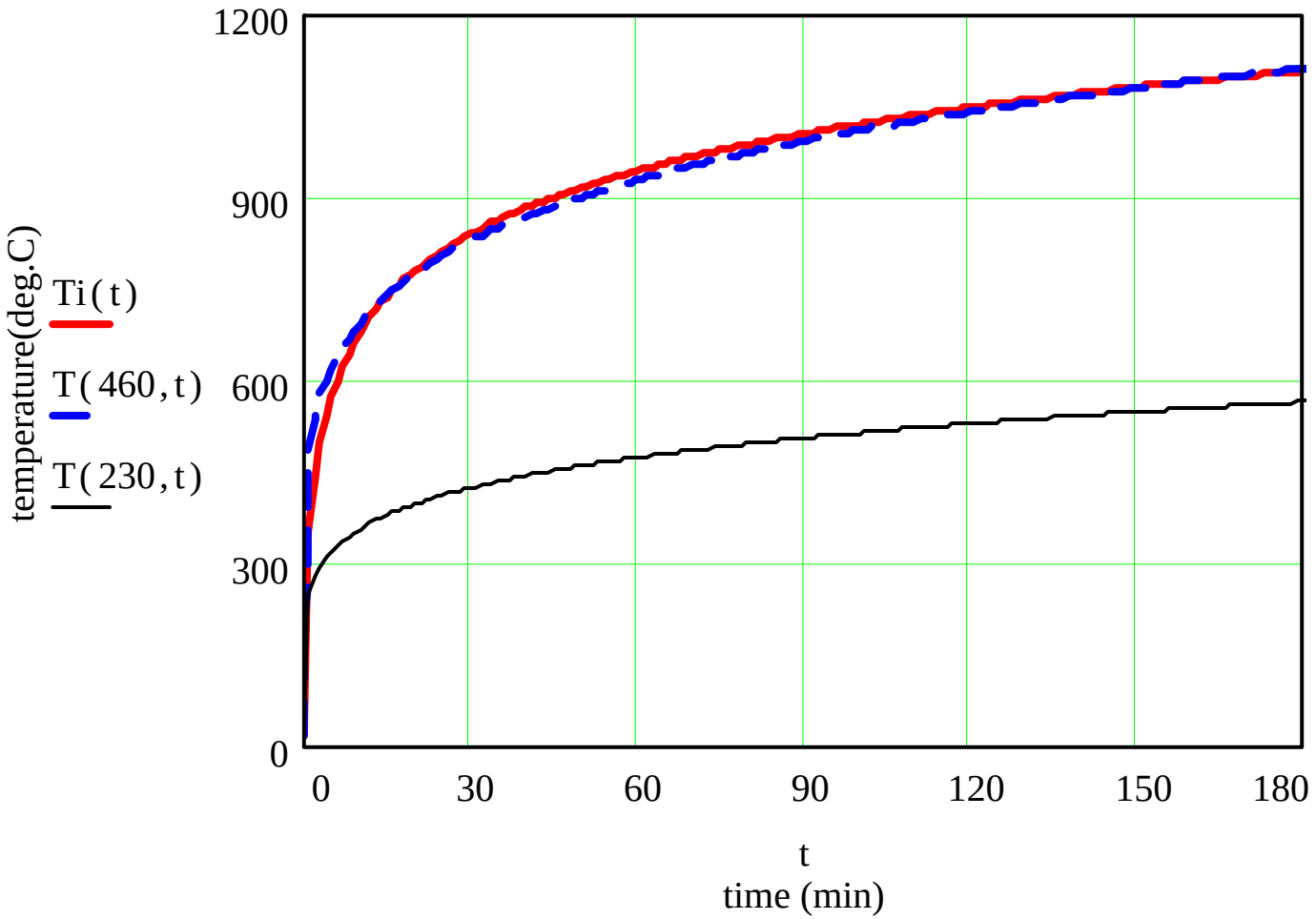
Fire Severity Parameter

Fire severity parameter

$$\alpha = 1280\left(\frac{q_b}{\sqrt{\sum A_C I_h \sqrt{f_{op}}}}\right)^{2/3}$$

Opening factor

$$\sqrt{f_{op}} = \max\left[\sum A_{op}\sqrt{H_{op}}, A_r\sqrt{H_r}/70\right]$$



Fire Temperature Curves ISO-834 vs. BSLJ

Fire Resistance Time of Steel Columns

The critical temperature of a steel column, T_{cr} (°C), is:

$$T_{cr} = \min\{T_B, T_{LB}, T_{DP}, 550\}$$

where

T_B : Temperature of overall buckling (°C)

T_{LB} : Temperature of local buckling (°C)

T_{DP} : Limit temperature for deformation (°C)

550: Limit temperature for joint stability (°C)

Overall Buckling

For $\lambda < 0.1$:

$$T_B = 700 - 375p$$

and for $0.1 \le \lambda \le 1$:

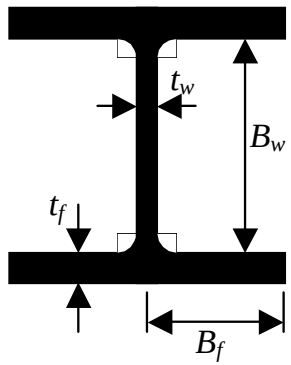
$$T_B = \max\left\{700 - 375p - 55.8\left(p + 30p^2\right)(\lambda - 0.1),\ 500\sqrt{1 - \frac{p\left(1 + 0.267\lambda^2\right)}{1 - 0.24\lambda^2}}\right\}$$

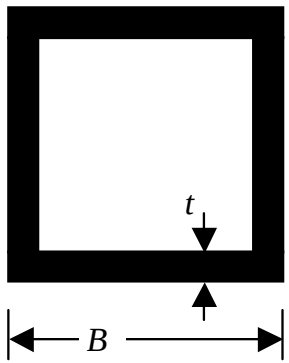
Local Buckling

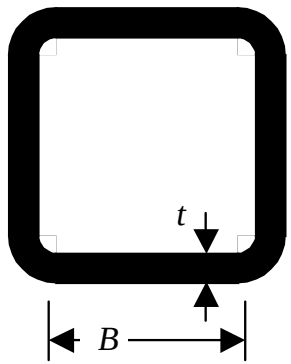
$$T_{LB} = 700 - \frac{375\ p}{\min\left(R_{LBO},\ 0.75\right)}$$

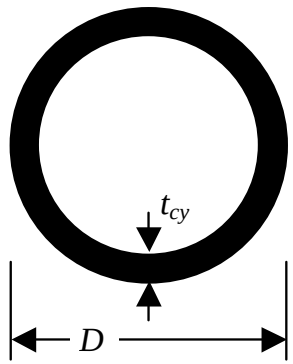
Section Shape	R_{LBO}
Wide Flange	$\min\left\{\dfrac{7}{0.72\dfrac{B_f}{t_f}+0.11\dfrac{B_w}{t_w}},\quad 21\dfrac{t_w}{B_w}\right\}$
Square or Rectangular Tubing (Hot-formed or Weld Built-up)	$21\dfrac{t}{B}$
Cold-formed Square or Rectangular Tubing	$17\dfrac{t}{B}$
Pipe	$\dfrac{35.6}{D/t_{cy}\ +\ 10.6}$

$B_f, B_w, t_f, t_w, B, t, D$ and t_{cy} are measured in mm.









Deformation Limit

$$T_{DP} = 20 + \frac{18000}{\sqrt{A_r}}$$

Fire Resistance Time

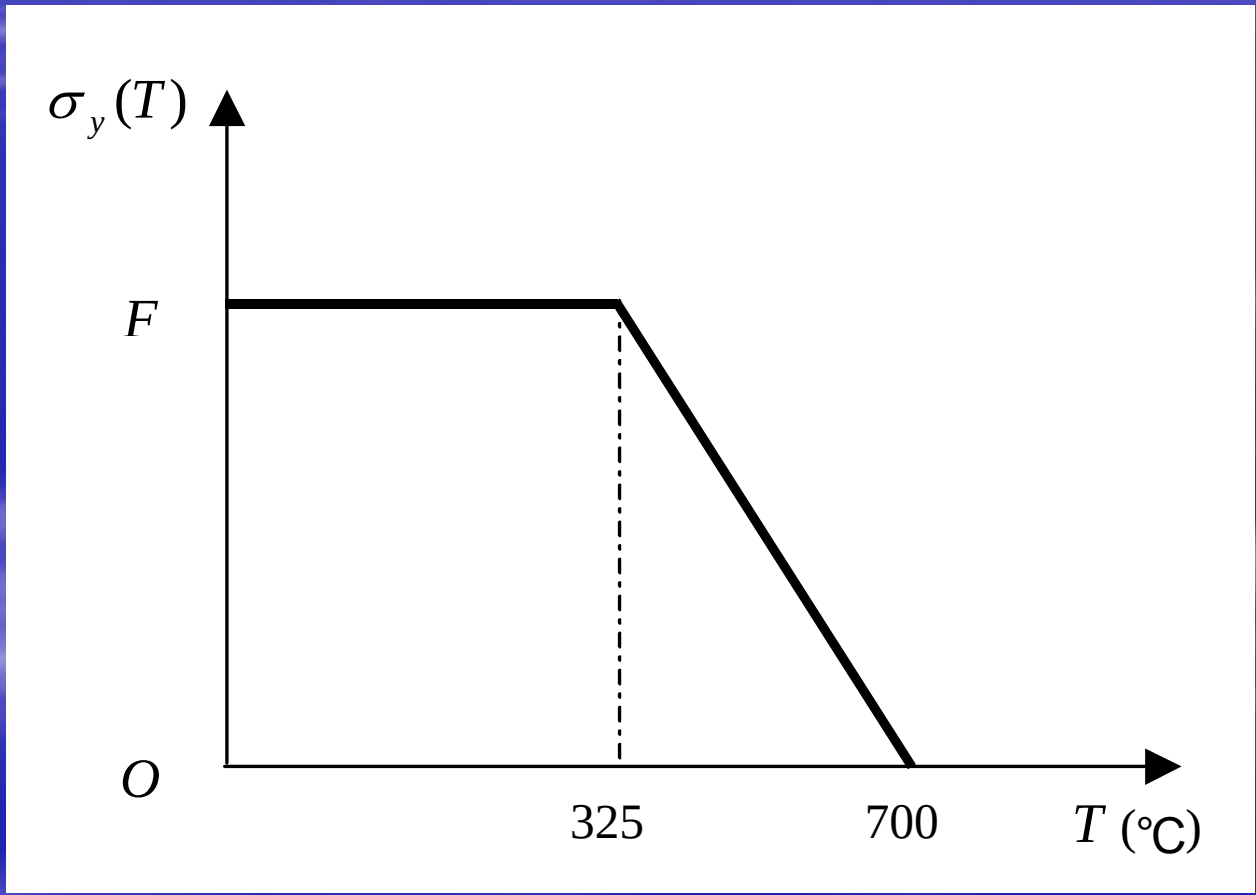
$$t_{fr} = \max\left\{ \begin{array}{l} \dfrac{9866}{\alpha^{3/2}} \left\{ \dfrac{2}{h} \left\{ \dfrac{1}{\log_e \{h^{1/6}(T_{cr} - 20)/1250\}} \right\}^2 + \dfrac{a_w}{\left(H_i / A_i\right)^2} \right\} \\ \left(\dfrac{T_{cr} - 20}{\alpha} \right)^6 \end{array} \right.$$

Temperature Rise Parameter

For protected steel sections the temperature rise parameter of the sections, h , is:

$$h = \frac{\psi K_0 (H_s / A_s)}{\left\{1 + \frac{\psi R}{H_i / A_i}\right\}\left\{1 + \frac{\psi}{2}\frac{H_s / A_s}{H_i / A_i} C\right\}}$$

Yield Strength of Steel at Elevated Temperature



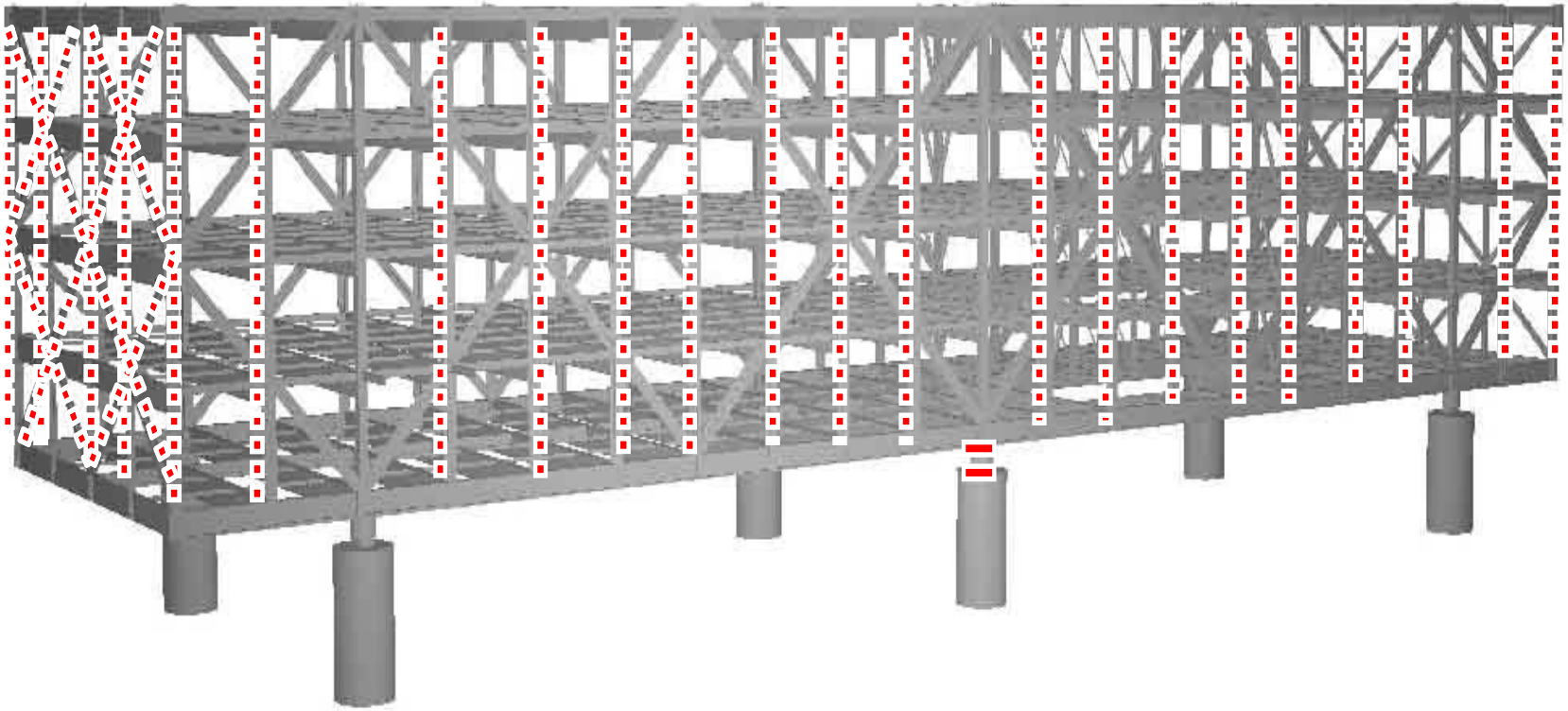
5. Examples of Design and Research

- Fire Safety Measures Applied to New Office of Shimizu Institute of Technology
- Fire Resistance Test of Steel Colmun

Fire Safety Measures Applied to New Office of Shimizu Institute of Technology

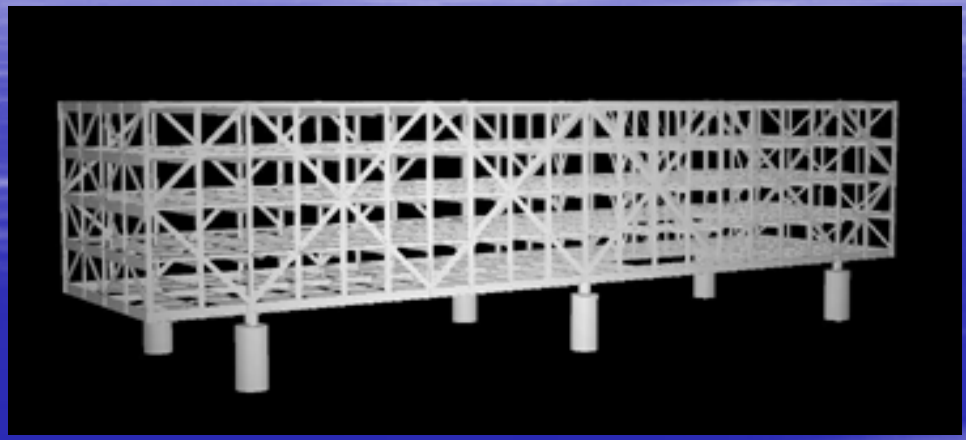
External Appearance

Fire Safety Measures Applied to New Office of Shimizu Institute of Technology

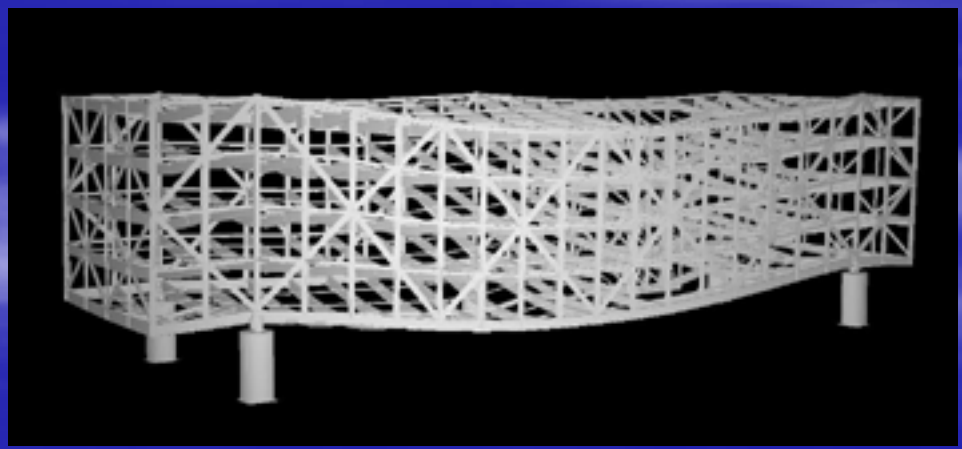


Elements without Fire Protection Covering

Fire Safety Measures Applied to New Office of Shimizu Institute of Technology



Before Fire



After Fire

Fire Safety Measures Applied to New Office of Shimizu Institute of Technology

Frame without Fire Protection Covering Compartment of Elevator Hall using Water Curtain

Fire Safety Measures Applied to New Office of Shimizu Institute of Technology

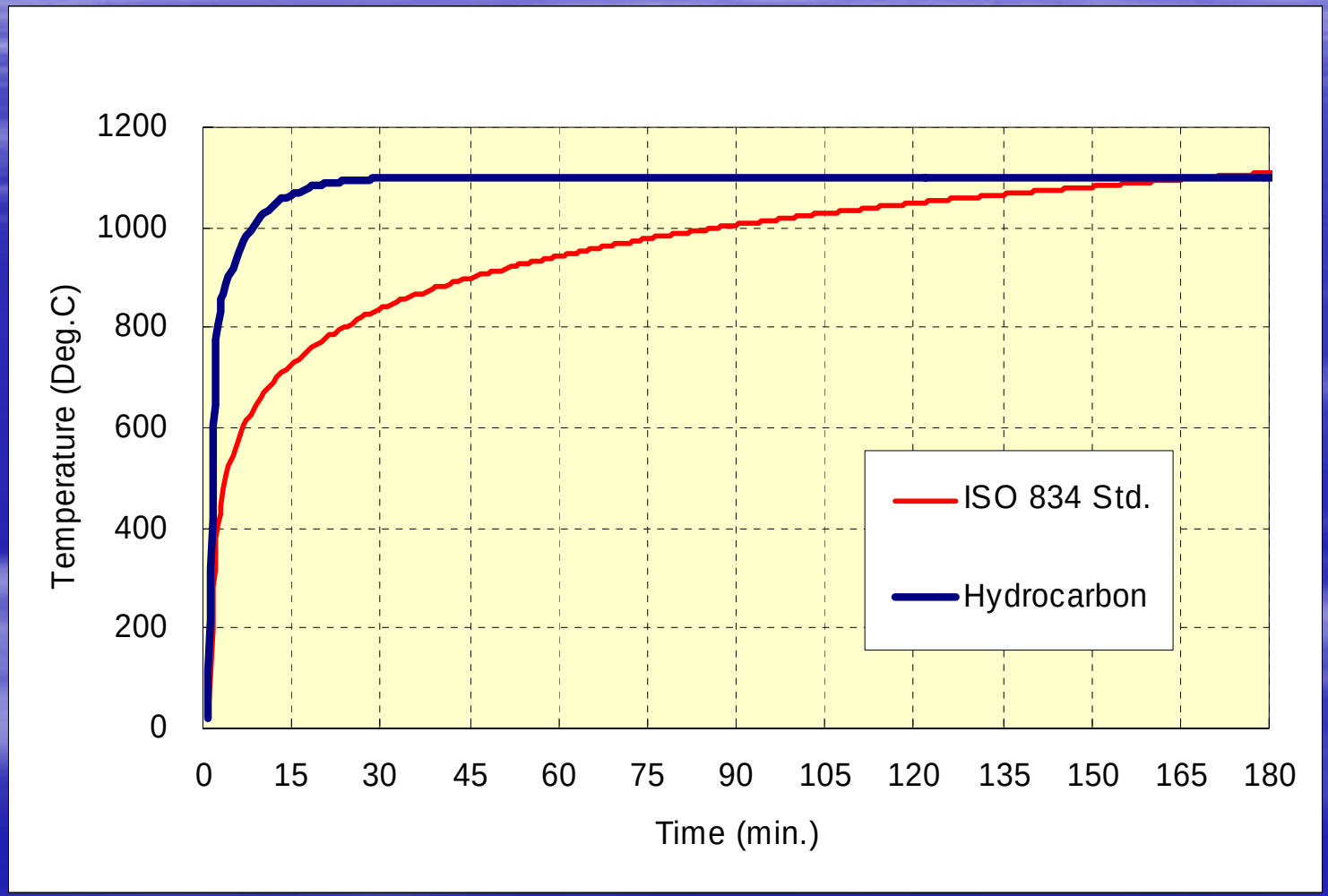
Seismic Isolation Device without Fire Protection Covering

Fire Resistance Test of Steel Column

Column Furnace

Test Specimen

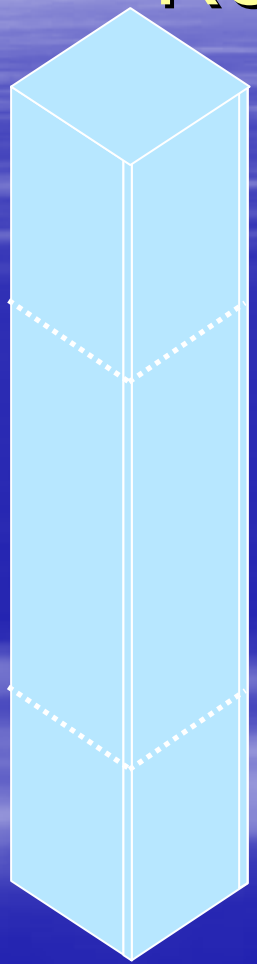
Fire Resistance Test of Steel Column Heating Curves



Fire Resistance Test of Steel Column
Summary of Experiments

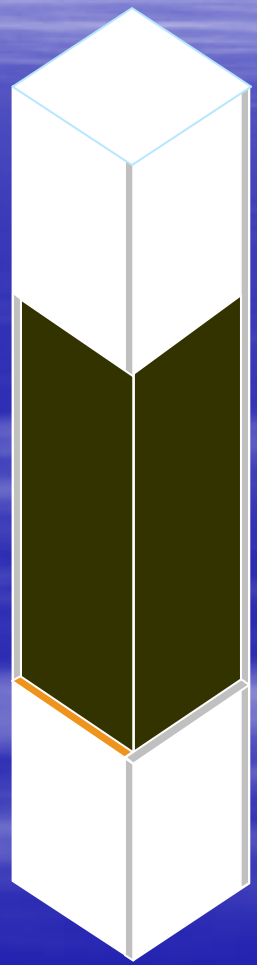
Exp.	Grade	Protection (Fireguard®)	Load Load ratio	heating	End of the Exp.
1	SN490C	80 mm (3-hour-rated)	10.1 MN (0.5)	Hydrocarbon	3 hours
1A	SN490C	80 mm (3-hour-rated) 25% unprotected	10.1 MN (0.5)	Hydrocarbon	Deformation reversal (27.5 min.)
2	SN490C	30 mm (1-hour-rated)	9.8 MN (0.49)	ISO-834	Deformation reversal (330min.)
3	NSFR490C	30 mm (1-hour-rated)	12.9 MN (0.6)	ISO-834	4 hours
3A	NSFR490C	30 mm (1-hour-rated) 25% unprotected	6.5 MN (0.3)	ISO-834	Deformation reversal (105min.)

Fire Resistance Test of Steel Column
Removal of Protection

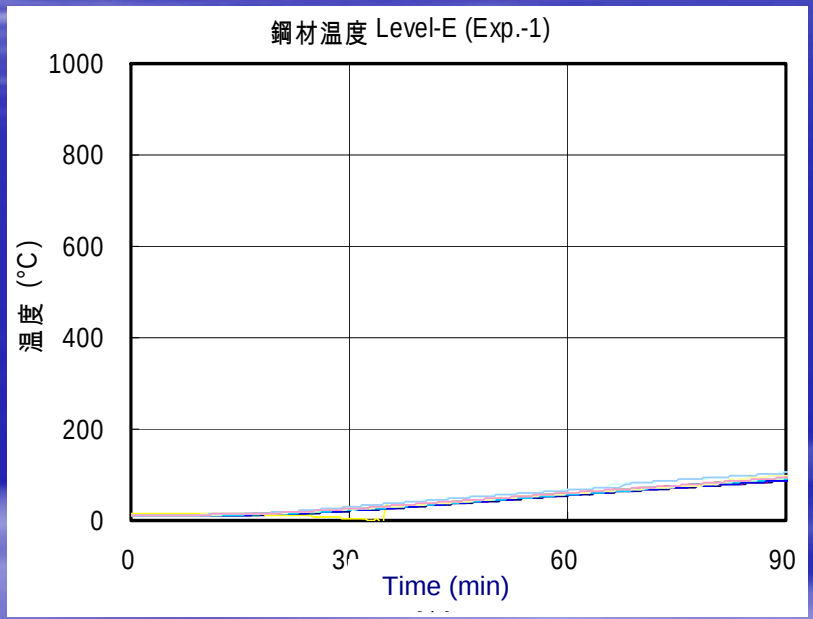


Fully protected

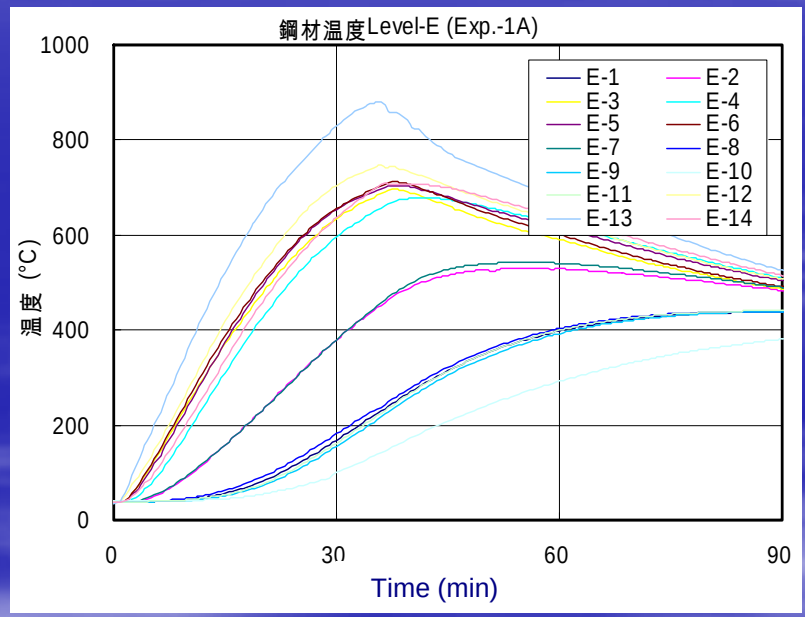
→ 25% Unprotected



Fire Resistance Test of Steel Column
Comparison of Steel Temperatures



Fully protected



25% unprotected

Fire Resistance Test of Steel Column

Column Elongations vs. Time