Metal Structures

Lecture VII

Corrosion protection and fire protection

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Steel corrosion

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Definition

Corrosion - gradual destruction of materials by chemical reactions (*or physical process*)* from its environment.

* In various sources erosion is treated or as separated proces or as a specific type of corrosion

Photo: wikipedia

Photo: wikipedia

Corrosion – chemical process:

Moisture, water

Oxygen in air and water

$$O_2 + 4e^- + 2H_2O \rightarrow 4OH^-$$

$$O_2 + 4e^- + 4H^+ \rightarrow 2H_2O$$

$$Fe \rightarrow Fe^{2+} + 2e^-$$

Water decomposition, electrolites (pollutions, industry, dirt), sea water, effect of high temperature, secondary effect of high stresses, electric potential difference (contact of various metals)

$$4Fe^{2+} + O_2 \rightarrow 4Fe^{3+} + 2O^{2-}$$

$$Fe^{2+} + 2H_2O \leftrightarrow Fe(OH)_2 + 2H^+$$

$$Fe^{3+} + 3H_2O \leftrightarrow Fe(OH)_3 + 3H^+$$

$$Fe(OH)_2 \leftrightarrow FeO + H_2O$$

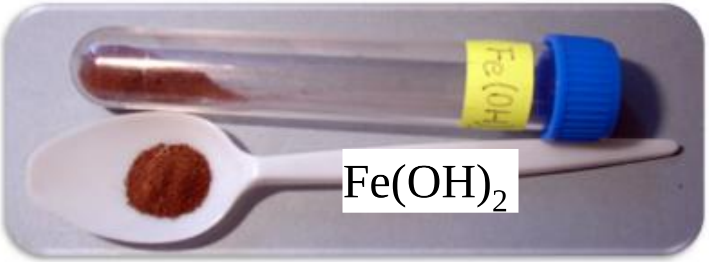
$$Fe(OH)_3 \leftrightarrow FeO(OH) + H_2O$$

$$2FeO(OH) \leftrightarrow Fe_2O_3 + H_2O$$

Photo: wikipedia

Photo: wikipedia

Photo: wikipedia



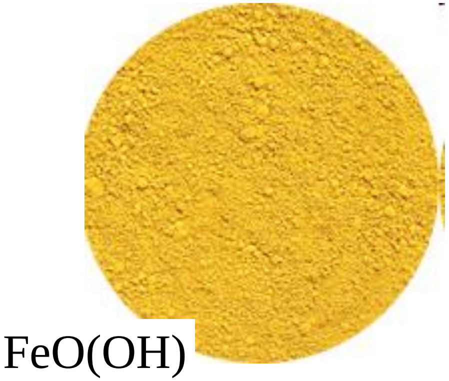


Photo: jpimpex.com

Photo: wikipedia

Corrosion - reasons:

Biological

Chemical

electrochemical (in the presence of electrolyte)

thermo-chemical (no electrolyte, no moisture)

Physical

stress corrosion cracking

fatigue corrosion

erosion-corrosion

*wind erosion**

*abrasion**

*destruction at low temperature**

* In various sources erosion is treated or as separated proces or as a specific type of corrosion

Biological (fungus or algae due to moisture): timber, concrete, masonry structures, but no metal structures:

- eaten by fungi (timber, first of all)
- chemical aggression of metabolic products

Photo: obud.pl

Photo: drewno.pl

Photo: tynki.info.pl

Electrochemical:

- sea water
- rain
- industry pollutions (chlorides and sulfurs first of all)
- chemicals
- soil
- road salt

All types of structure, first of all metal and concrete.

Photo: Author

Photo: korbet.pl

Thermo-chemical:

high temperature + oxygen (mill scale)

Metal structures

Photo: centrevilletrailer.com

Stress corrosion cracking, fatigue corrosion:

differences in stresses → differences in the internal energy → directed motion of electrons → electrochemical potential difference → corrosion → cracking

Metal structures

Photo: nitty-gritty.it

Corrosion-erosion:

corrosion and erosion of corroded part of material (inside pipes with liquids, hydrotechnical structures)

Metal and concrete structures

Photo: drizoro-polska.pl

Photo: amteccorrosion.co.uk

Wind erosion:

grind by wind and grains of sand or cristals of ice

Concrete structures at desert or arctic climate

Photo: wiking.edu.pl

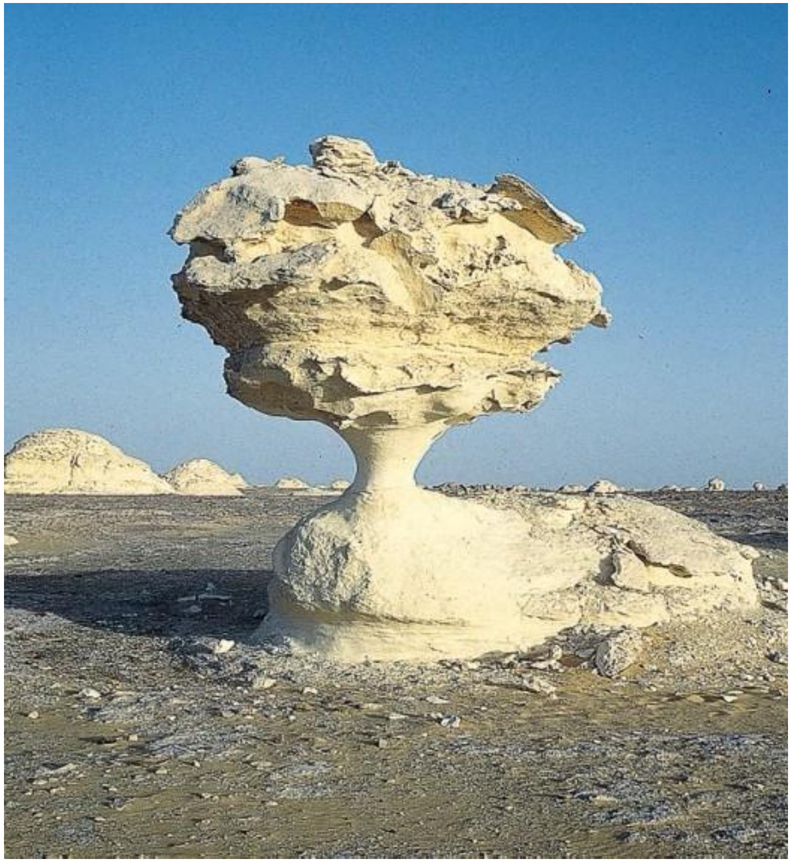


Photo: geomorfologia.w.interiowo.pl

Abrasion:

erosion due rock rubble in river

Concrete hydrotechnical structures, bridge supports

Photo: Author

Attack of rock rubble
during flood

River location
& direction

Destruction at low temperatures

cyclical freezing and thawing of water in pores of masonry or concrete

Masonry and concrete structures

Photo: Mechanizm powstawania uszkodzeń mrozowych zawilgoconych elementów konstrukcji murowych o kapilarno-porowatej strukturze, Partyka J., Przegląd Budowalny 3 / 2015

Photo: civildigital.com

Corrosion (appearance)

Appearance of rusted surface is related to working conditions, type of materials used and technical solutions appied in structure.

Uniform surface
Pitting
Crevice
Contact
Selective
Intergranular

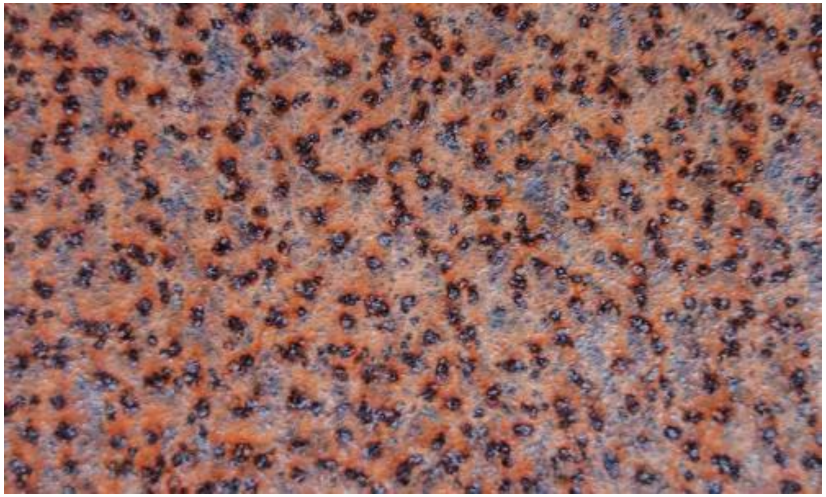
Uniform surface

Photo: Author

Low-aggressive environment, no anti-corrosion protection

Photo: pg.gda.pl

Pitting



Deep corrosion, e.g. in places where anti-corrosion coatings are damaged

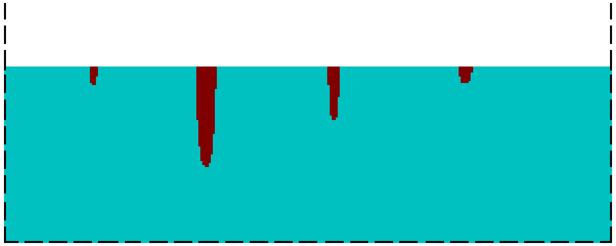


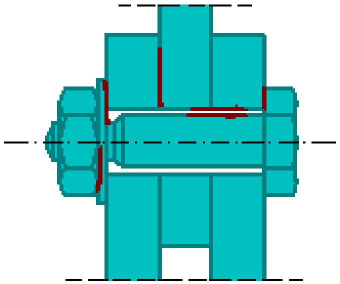
Photo: Author

Photo: efficientplantmag.com

Crevice

Photo: Author

Photo: epg.science.cmu.ac.th



Limited air circulation and limited oxygen access, uneven distribution of sparingly and easily soluble salts on the surface of gap, increased aggressiveness of environment inside gap

Contact (bimetalic): different chemical composition of alloys or contact of different metals. In presence of water/electrolyte, galvanic cell and directed movement of electrons is created. As a result, less noble metal corrodes in the presence of a more noble metal.

Photo: wikipedia

Selective: one of alloying additives corrodes and entire material disintegrates into powder.

Photo: cdcorrosion.com

Photo: wikipedia

Intergranular: as result of technological processes (rolling, welding), specific separation of alloy additives may occurs (they accumulate on steels's grain boundaries). Internal galvanic microcells are created (a sudden change in chemical parameters between additives and iron). Corrosion destroys boundaries between microcrystals and entire material disintegrates into powder.

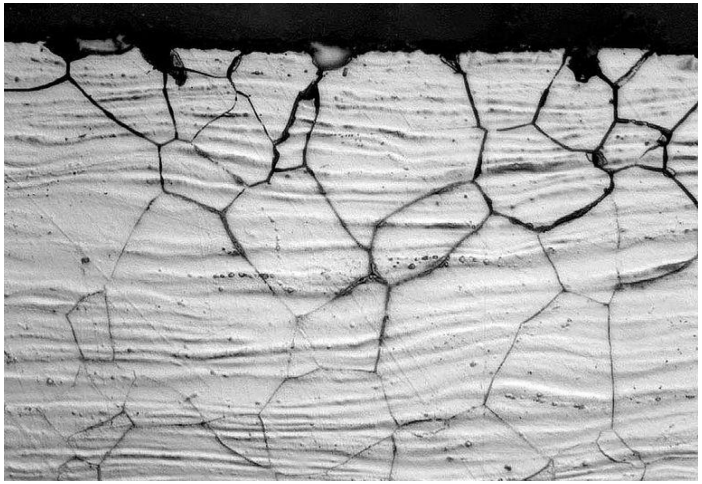


Photo: wikipedia

Protection

Moisture, water

Oxygen in air and water

$$O_2 + 4e^- + 2H_2O \rightarrow 4OH^-$$

$$O_2 + 4e^- + 4H^+ \rightarrow 2H_2O$$

$$Fe \rightarrow Fe^{2+} + 2e^-$$

Water decomposition, electrolites (pollutions, industry, dirt), sea water, effect of high temperature, secondary effect of high stresses, electric potential difference (contact of various metals)

- Formation of structure: preventing accumulation of dirt and moisture (the cheapest way);
- Non-metallic coatings;
- Metallic coatings (passive cathodic protection);
- Duplex coating;

} Barrier between steel and environment (oxygen, moisture, water)

- Active cathodic protection: „controlling movement of free **electrons**" (the most expensive);

Formation of structure

Specific shape of structural members can accelerate or slow down corrosion. Information about right shape of structures is presented in

EN ISO 12 944 - 3

Paints and varnishes - Corrosion protection of steel structures by protective paint systems - Design considerations

In addition, many technical solutions for steel structures are recommended, based on experience.

Details recommended according to EN ISO 12 944 - 3

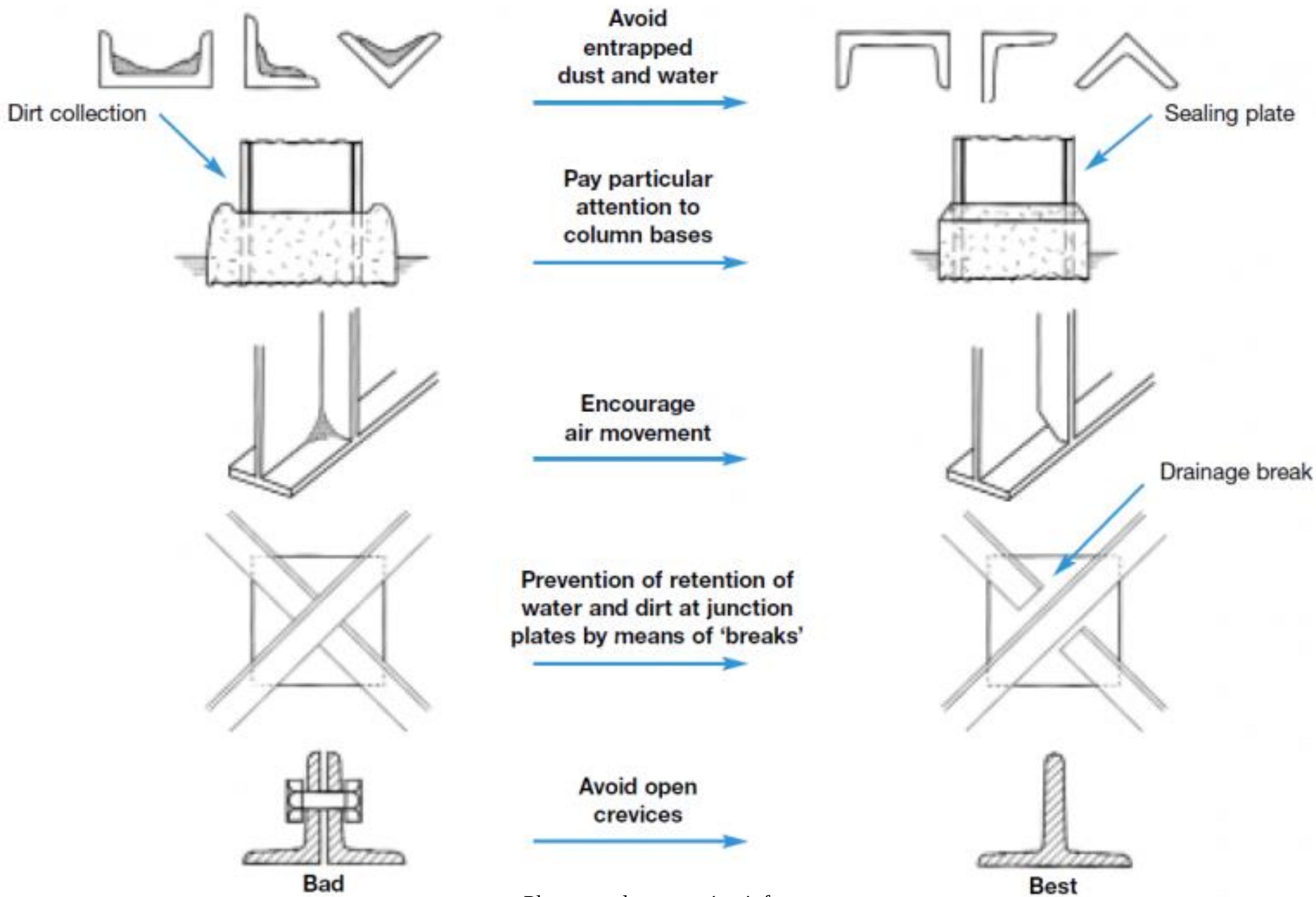


Photo: steelconstruction.info

Whenever we use hollow sections, we must hermetically close the ends by welding to prevent corrosion inside HS. Such type of corrosion can develop without apparent external symptoms and can cause damage of structure without warning signs.

Photo: architectureau.com

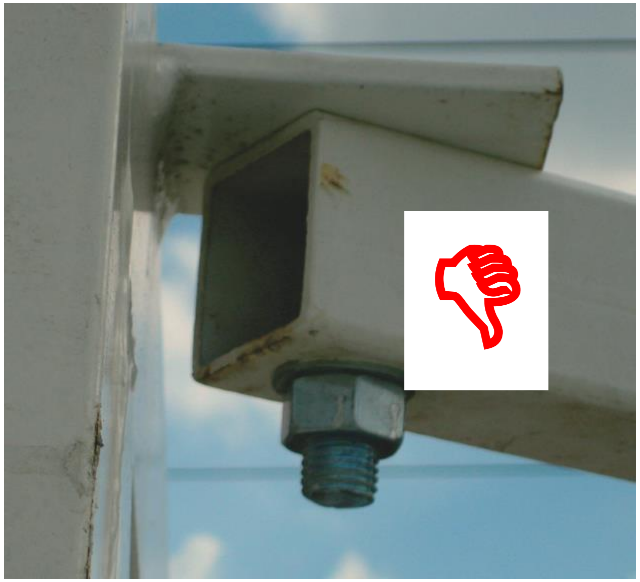


Photo: Błędy wykonawcze podczas realizacji konstrukcji stalowych, Litwin M, Górecki M, *Budownictwo i Architektura 4 (2009) 63-72*

Non-metallic coatings

- anticorrosion paints
- cheap method
- unstable coatings
- periodically to renew

Photo: renowacje.net.pl

Photo: sklep.idachy.com

Metallic coatings

There mus be analised galvanic series (electropotential series), determines the nobility of metals:

less noble: nobler:

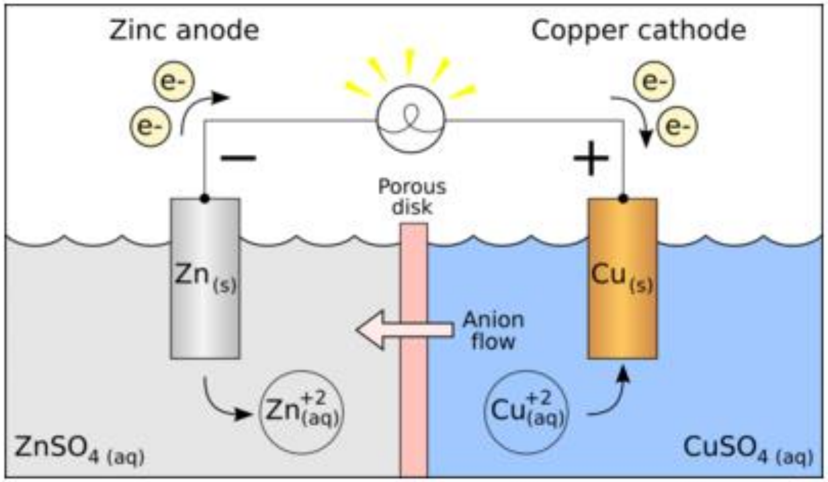
Li K Na Ca Mg Al Zn Cr **Fe** Cd Co Ni Sn Pb **H** Sb Bi Cu Ag Hg Pt Au

Reference level is hydrogen H.

Contact of two different metals + presence of water, moisture, chemicals etc → galvanic cell.

Less noble metal corrodes, nobler not.

Photo: wikipedia



Coating with a less noble metal (for example zinc):

Hermetic, durable, expensive

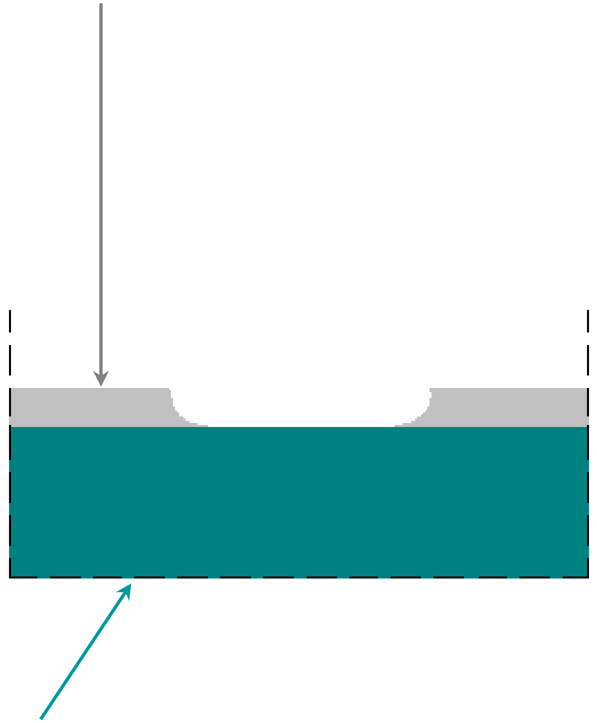


Photo: Author

In case of failure coating → zinc corrodes (less noble), steel didn't corrode. Oxides of zinc makes hermetic layer on surface of zinc → very slow corrosion.

In case of small losses of zinc, steel is still protected. If zinc losses are too large, pitting corrosion of steel may occur.

Coating with a nobler metal (for example copper):

Hermetic, durable, expensive

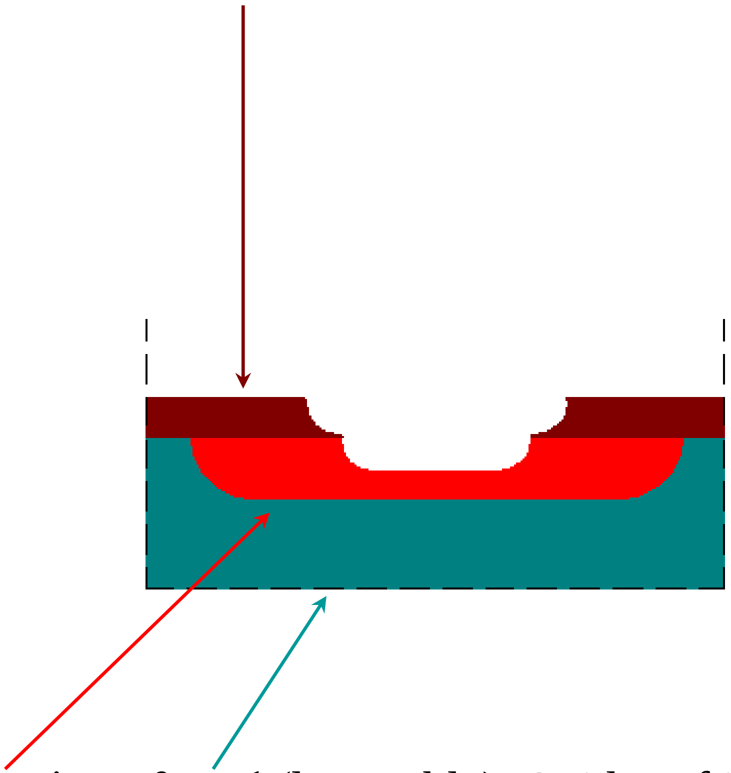


Photo: Author

In case of failure coating → accelerated corrosion of steel (less noble). Oxides of iron are not hermetic.

The most popular method of galvanizing is hot-dip galvanizing: process of coating fabricated steel by immersing it in bath of molten zinc (420 ^{o}C). Surface of element must be properly prepared.

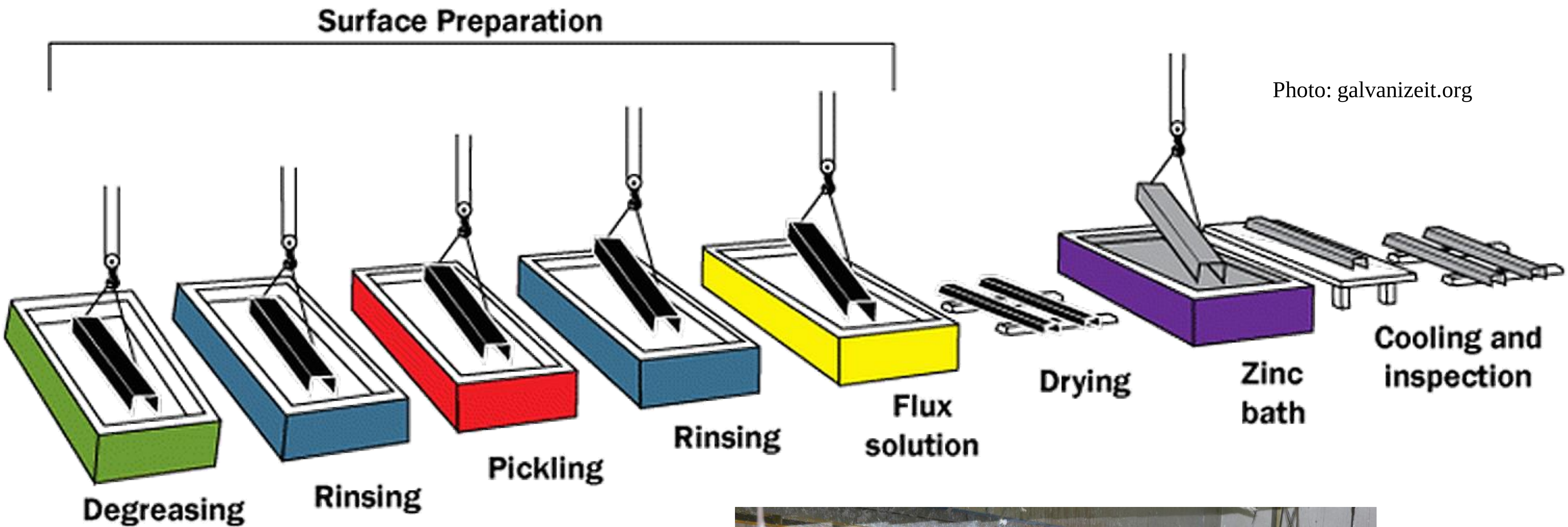


Photo: galvanizeit.org

The most often, thickness of zinc has 50 ÷ 80 μm (0,05 ÷ 0,08 mm)

Photo: ocynkowniadebica.pl

In case of RHS / CHS and welded box sections, galvanizing must be carried out with particular care. Temperature of liquid zinc is 420 ^{o}C. If interior of element is hermetically sealed, temperature will create an internal overpressure of ~45 kPa, related to thermal expansion of air. This must be taken into account in design of cross-section - or element must have holes to allow some air to escape.

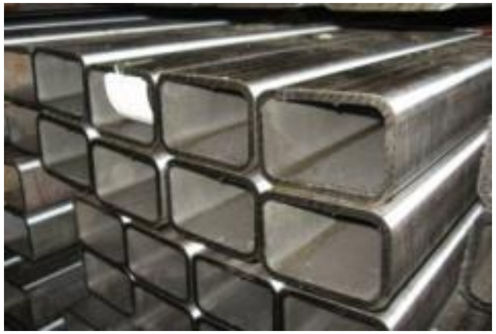


Photo: wggstal.pl

Photo: mtshireandsales.com

Photo: cncinnati-crane.com

Not all steel grades can be galvanized. Stainless steel has a very specific chemical composition. Contact with liquid zinc drastically increases tendency of such steel to crack.

Duplex coating

Coating with zinc + powder coating.
Special powder paint: powder that "sticks" to structure thanks to electrostatic forces. Then element is fired (140-200 ^{o}C) in special owen; powder is sintered into a uniform coating.

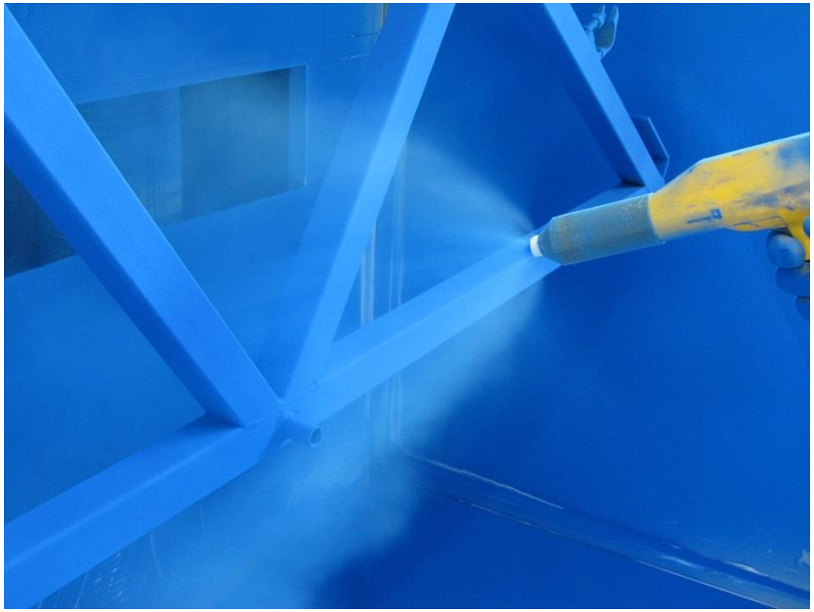


Photo: steelfabservices.com.au

Hermetic, durable, expensive

Photo: malarniacelkab.pl

Active cathodic protection

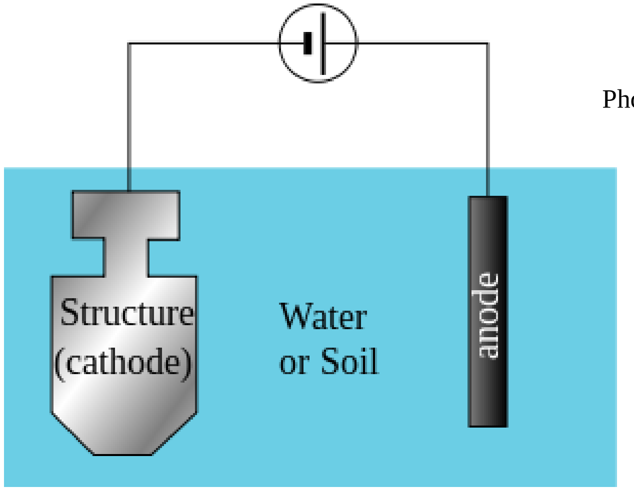


Photo: wikipedia

- for underground pipelines or tanks and for undersea pipelines
- need external power supply
- forced movement of electrons by external power, in the direction opposite to the corrosion (opposite to galvanic cell)
- anodes quickly wear out and must be replaced, structure is protected
- expensive method (external power supply, costs of anodes and their reinstalations)

Environmental classes

There are many different methods of corrosion protection (as, for example, various types of anticorrosion paints), dedicated to various situations. Type of corrosion protection should be applied according to working conditions of structure and its environmental. Environmental classes are presented in

EN ISO 12 944-2

Paints and varnishes - Corrosion protection of steel structures by protective paint systems - Classification of environments

EN ISO 12 944-2 tab. 1 – atmosferic corrosion

Corrosivity category	Mass loss per unit surface / thickness loss (after first year of exposure)				Examples of typical environments	
	Low-carbon steel		Zinc		Exterior	Interior
	Mass loss g / m^2	Thickness loss µm	Mass loss g / m^2	Thickness loss µm		
C1 Very low	≤ 10	≤ 1,3	≤ 0,7	≤ 0,1	-	Heated buildings with clean atmospheres: offices, shops, schools, hotels
C2 Low	10 – 200	1,3 – 25	0,7 – 5	0,1 – 0,7	Atmospheres with low level of pollution; mostly rural areas	Unheated buildings where condensation may occurs: depots, sport halls
C3 Medium	200 – 400	25 – 50	5 – 15	0,7 – 2,1	Urban and industrial atmospheres, moderate sulphur dioxide pollution; coastal areas with low salinity	Production rooms with high humidity and some air pollution: foot-processing plants, laundries, breweries, dairies

EN ISO 12 944-2 tab. 1 – atmosferic corrosion

Corrosivity category	Mass loss per unit surface / thickness loss (after first year of exposure)				Examples of typical environments	
	Low-carbon steel		Zinc		Exterior	Interior
	Mass loss g / m^2	Thickness loss µm	Mass loss g / m^2	Thickness loss µm		
C4 High	400 – 650	50 – 80	15 – 30	2,1 – 4,2	Industrial areas and coastal areas with moderate salinity	Chemical plants, swimming pools, coastal ship- and boatyards
C5 Very high	650 – 1 500	80 – 200	30 – 60	4,2 – 8,4	Industrial areas with high humidity and aggressive atmosphere, and coastal areas with high salinity	Buildings or areas with almost permanent condensation and with high pollution
CX Extreme	1 500 – 5 500	200 – 700	60 – 180	8,4 – 25	Offshore areas with high salinity and industrial areas with extreme humidity and aggressive atmosphere and sub-trop	Industrial areas with extreme humidity and aggressive atmosphere

EN ISO 12 944-2 tab. 2 – water and soil corrosion

Corrosivity category	Environment	Examples
IM1	Fresh water	River installations and hydro plants
IM2	Sea or brackish water	Immersed structures without cathodic protection
IM3	Soil	Buried structures
IM4	Sea or brackish water with cathodic protection	Immersed structures with cathodic protection

EN ISO 12 944-1 4.4 – durability of paint systems

Durability range	Period of time
Low (L)	< 7 years
Medium (M)	7 – 15 years
High (H)	15 – 25 years
Very High (VH)	> 25 years

Corrosion-protection system – tests; EN ISO 12 944-6, EN ISO 12 944-9

Cor. / Env.	Durability			
	L	M	H	VH
C1	No tests needed			
C2	b^{48} ;	b^{48} ;	b^{120} ;	b^{240} ; c^{480} ;
C3	b^{48} ; c^{120} ;	b^{120} ; c^{240} ;	b^{240} ; c^{480} ;	b^{480} ; c^{720} ;
C4	b^{120} ; c^{240} ;	b^{240} ; c^{480} ;	b^{480} ; c^{720} ;	b^{720} ; $c^{1\,440}$; $d^{1\,680}$
C5	b^{240} ; c^{480} ;	b^{480} ; c^{720} ;	b^{720} ; $c^{1\,440}$; $d^{1\,680}$	$d^{2\,688}$
CX	$e^{4\,200}$; $f^{4\,200}$; $g^{4\,200}$			
IM1	Durability not recommended		$a^{3\,000}$; $b^{1\,440}$	$a^{4\,000}$; $b^{2\,160}$
IM2			$a^{3\,000}$; $c^{1\,440}$	$a^{4\,000}$; $c^{2\,160}$
IM3			$a^{3\,000}$; $c^{1\,440}$	$a^{4\,000}$; $c^{2\,160}$
IM4	$e^{4\,200}$; $f^{4\,200}$; $g^{4\,200}$			

(type of test)$^{\text{(how many hours does test take)}}$

4 200 h = 175,0 days

EN ISO 12 944-6	EN ISO 12 944-9
• a – Water immersion, according to ISO 2 812-2 • b – Water condensation, according to ISO 6 270-1 • c – Neutral salt spray, according to ISO 9 277 • d – Cyclic ageing, according to ISO 12 944-6 app. B	• e – Cyclic ageing, according to ISO 12 944-9 app. B • f – Cathodic disbondment, according to ISO 12 711 method A • g – Sea water immersion, according to ISO 2 181-2

Type of test is „in proportion” to corrosivity category or environment;

Period of test’s time is in proportion to durability.

Type of work environment: objective factor.

<table>
<tr><th></th><th>L</th><th>M</th><th>H</th><th>VH</th></tr>
<tr><td>C1</td><td colspan="4" rowspan="10">Coating meets test conditions</td></tr>
<tr><td>C2</td></tr>
<tr><td>C3</td></tr>
<tr><td>C4</td></tr>
<tr><td>C5</td></tr>
<tr><td>CX</td></tr>
<tr><td>IM1</td></tr>
<tr><td>IM2</td></tr>
<tr><td>IM3</td></tr>
<tr><td>IM4</td></tr>
</table>

Durability range: individual designer's decision.

Warranty period <
durability range

Warranty period is defined in contract for erection of stures / make coatings. This is result of negotiations between Investor and Contractor.

Warranty period reffers to quality of coating (99.9% of problems resulting from low-quality work are revealed within 3 years).

Durability range refers to gradual wear of coating during use.

There are no clear guidelines on how to assume durability range depending on type of structure.

Stainless steel

Sometimes there is used stainless steel for specific reason:

- aggresive chemical compounds (internal corrosion: inside tanks, pipelines);
- high corrosivity category (external corrosion);
- aestetic.

Stainless steel is described by specific Eurocode

EN 1993-1-4

Design of steel structures - Supplementary rules for stainless steels.

Photo: exaktglass.com

But "stainless" not means "infinitive corrosion resistance".

Photo: amteccorrosion.co.uk

It means only „bigger resistance than for '*normal*'steel".

Accidents

Silver Bridge, Ohio River, USA;
15 XII 1967 - collapse, fatigue corrosion and stress corrosion cracking in main rope;
killed 46 people, 9 injured

Photo: wikipedia

Photo: appalachianlady.wordpress.com

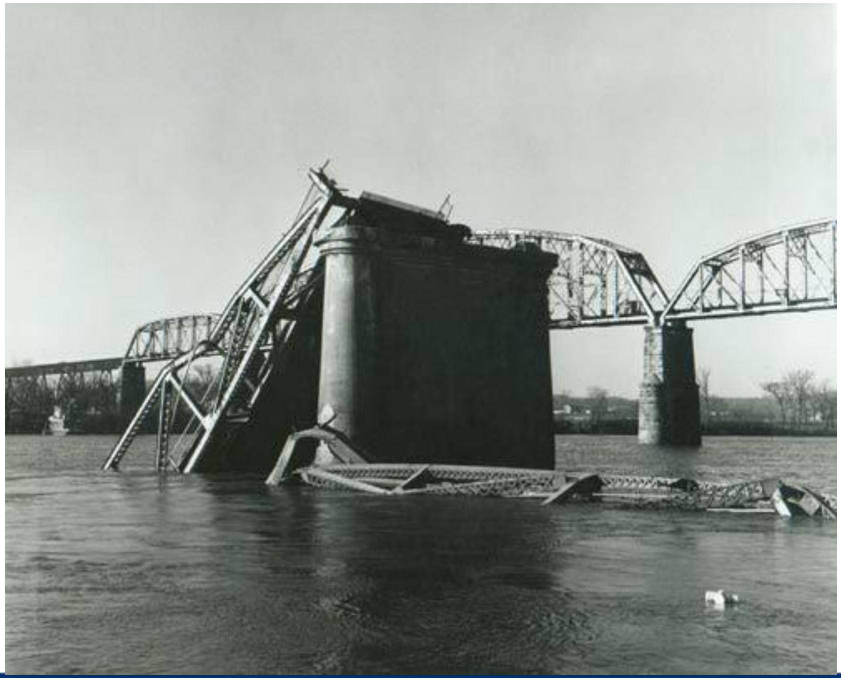


Photo: toledoblade.com

Kinzua Bridge, Kinzua Creek, USA;
21 VII 2003 - collapse, corrosion of bolts and tornado;
no human deaths or injuries

Photo: dailyhike.net

Photo: piximus.net

Photo: stateparks.com

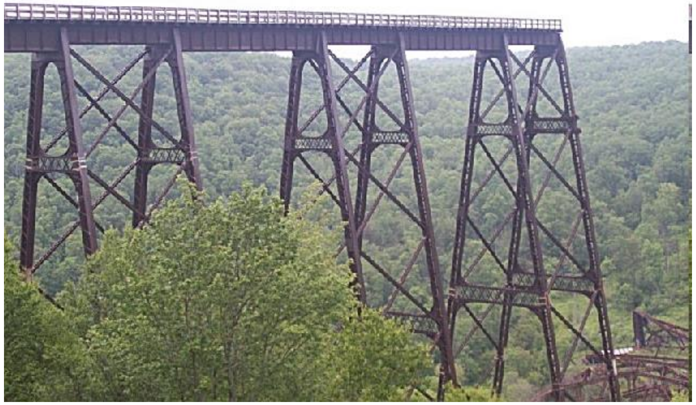
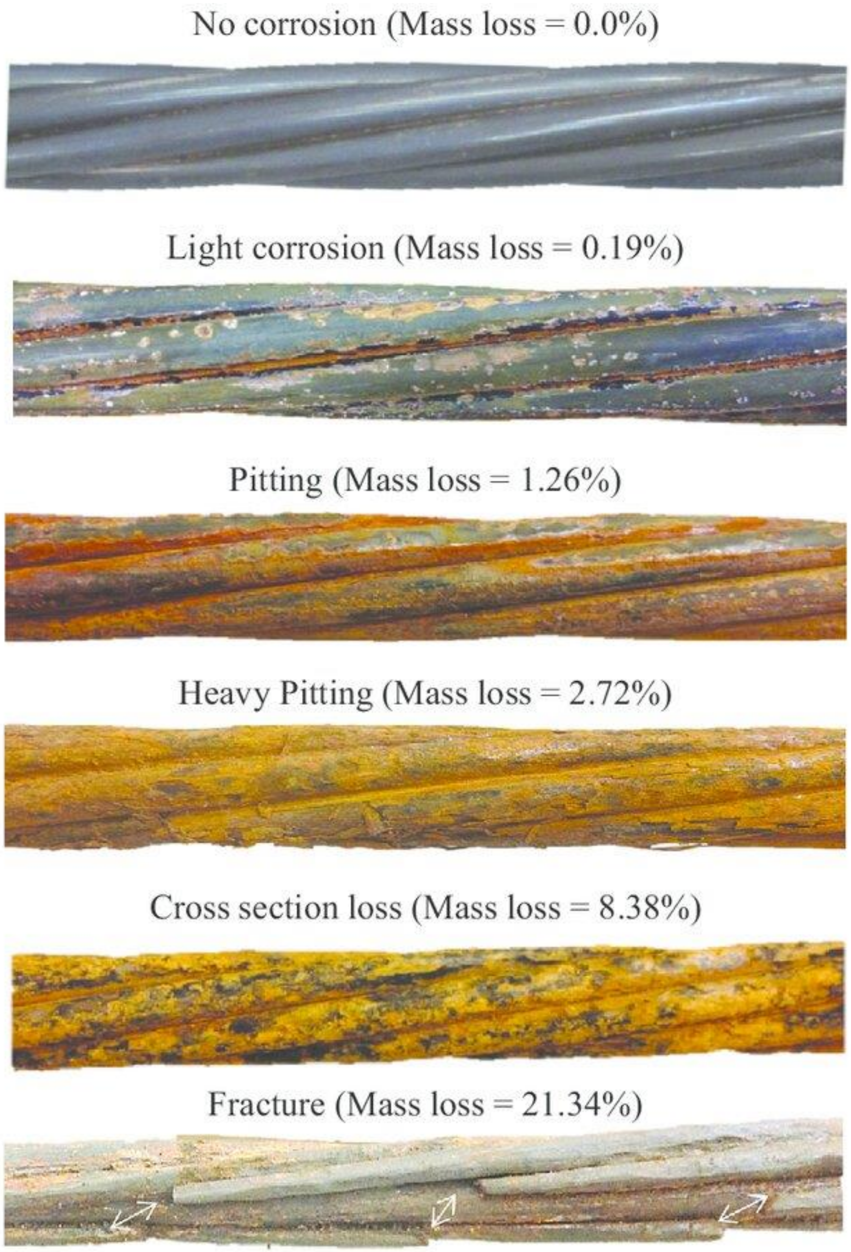


Photo: allwidewallpapers.com



Global annual product of steel (2021):
1 952 mil T

Global annual losses mass due to corrosion (estimated): 25 mil T

Corrosion cost (estimated):
2 500 000 000 000 $

(about 4x gross domestic product of Poland)

Photo: Corrosion damage estimation in multi-wire steel strands using guided ultrasonic waves, A. Farhidzadeh, A. Ebrahimkhanlou, S. Salamone, Structural Health Monitoring and Inspection of Advanced Materials, Aerospace, and Civil Infrastructure, IV 2015

Steel in fire

Calculations according to Eurocodes → #t / 45

Law rules → #t / 57

Fire protection → #t / 69

Accidents → #t / 77

Calculations according to Eurocodes

Three Eurocodes are important for steel structures, exposed to fire:

EN 1990
EN 1991-1-2
EN 1993-1-2

The result of calculations is time form start of fire to collapse the structure. This time must be longer than time for evacuation of people.

Calculations include three aspects:

Relationship T(t) (temperature - time) → EN 1991-1-2

Specific combinations of loads for fire action → EN 1991-1-2 4 ; EN 1990 ; EN 1993-1-2 2.2, 2.3 → $E_{fi,\,d}$

Destruction of mechanical characteristics (f_y , E) due to increase of temperature → EN 1993-1-2

Few models of fire (realtionships T(t)) are presented in EN 1991-1-2

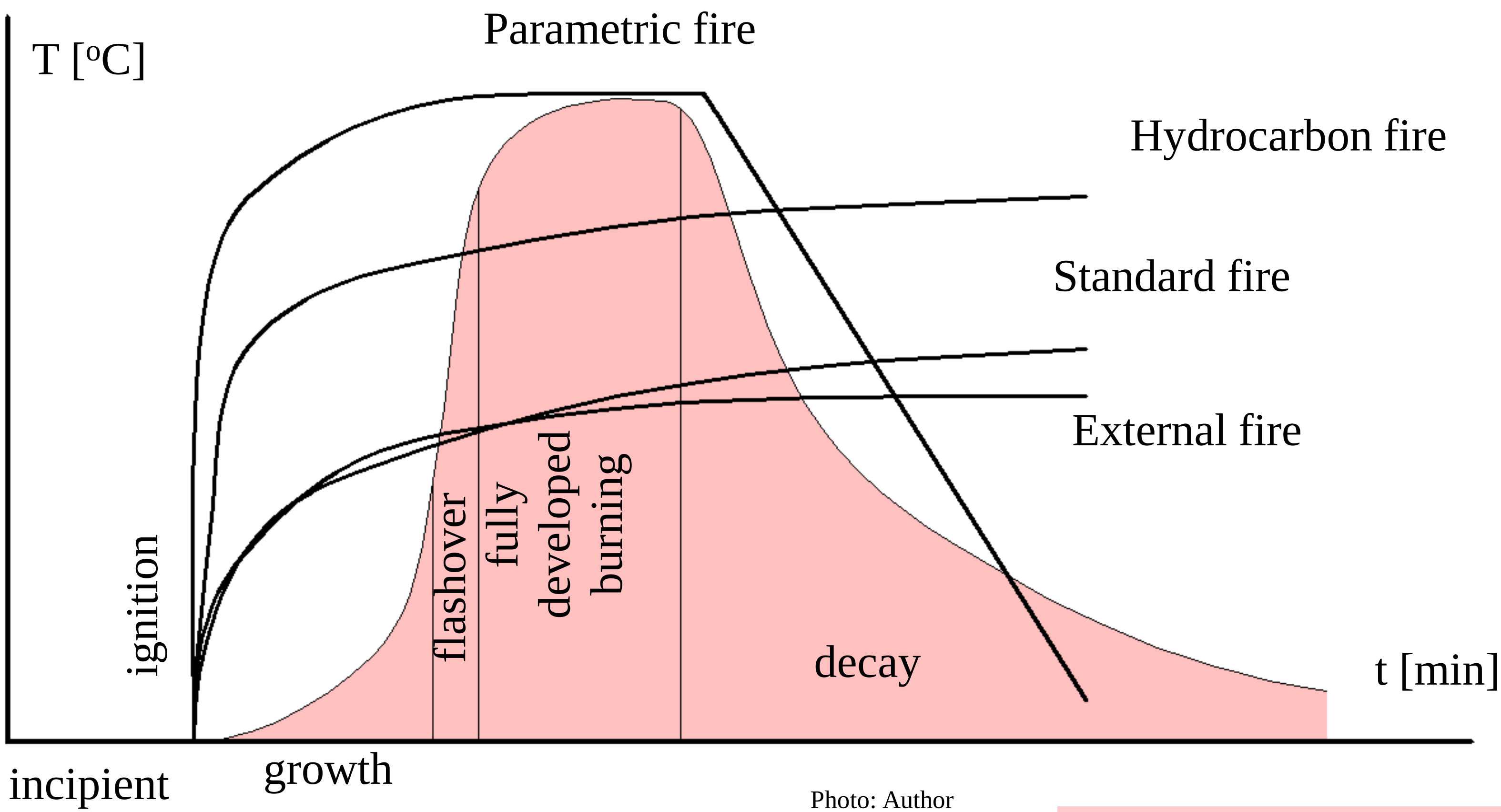


Photo: Author

Real fire (tests, experiments, observations, statistics)

Destruction of material (decreasing of f_y and E due to increasing of temperature) is presented in EN 1993-1-2

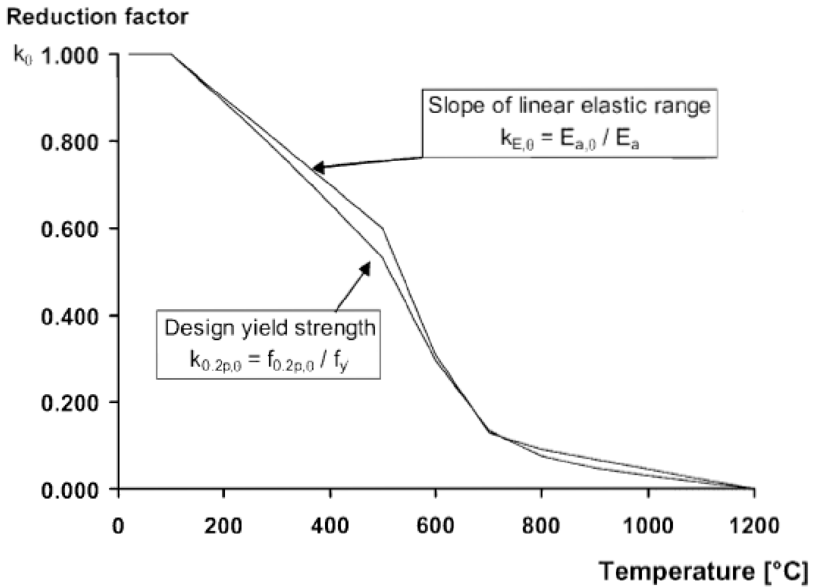
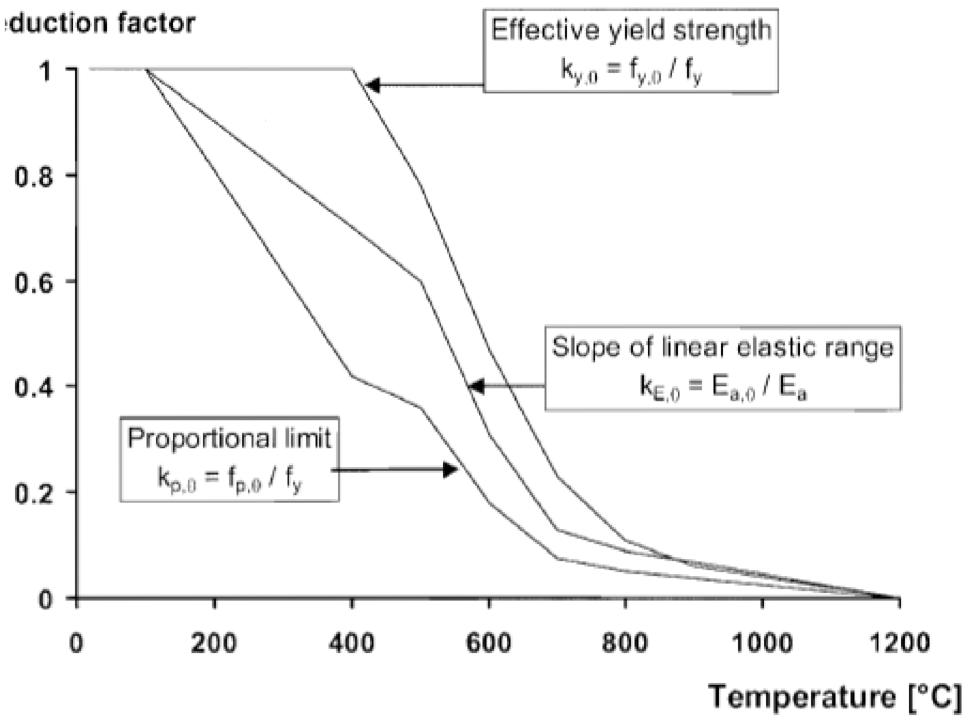


Photo: EN 1993-1-2 fig E.2

Photo: EN 1993-1-2 fig 3.2



→ #3 / 75

Level of cross-sections:

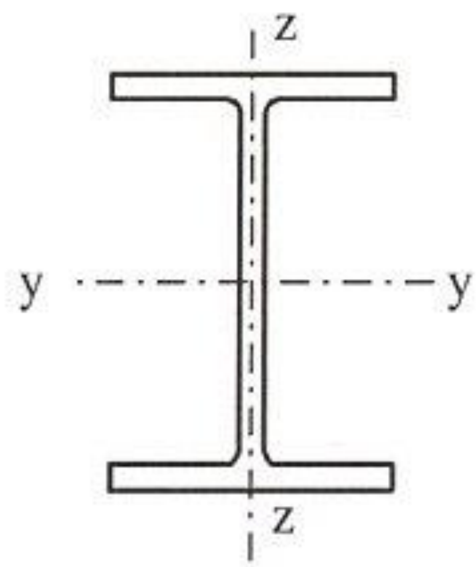


Photo: Author

F - geometry of cross-section

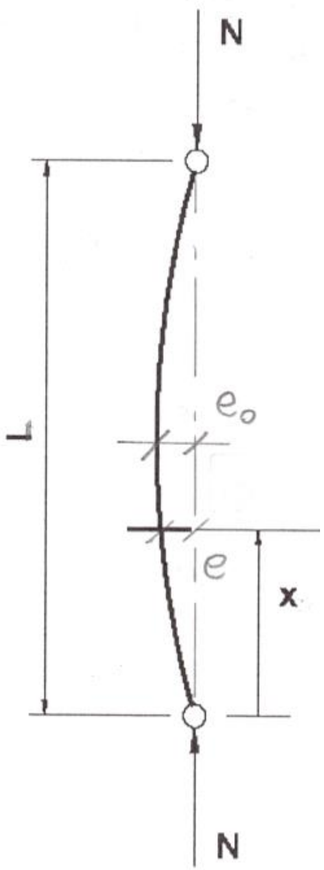
$$R = F\, f_y$$

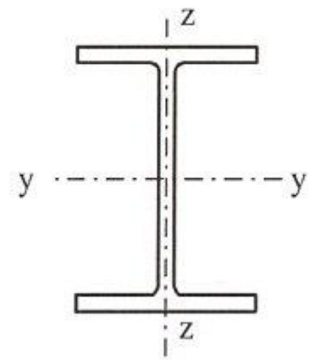
$$E / R \leq 1{,}0$$

Elements, nodes - when instability is not important, bolts, rivets, pins

(~ 40% of calculation's conditions)

Level of elements:





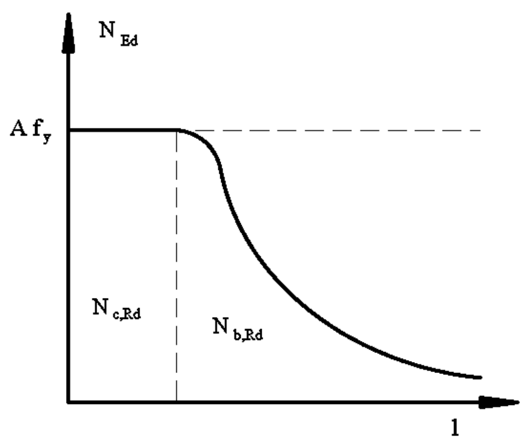


Photo: Author

F - geometry of cross-section

χ - instability coefficient (depends on element geometry)

$$R = \chi\, F\, f_y$$

$$E / R \leq 1{,}0$$

Elements, nodes - when instability is important

(~ 60% of calculation's conditions)

Difference between resistance for cross-section and resistance for element could be presented by two various R:

$$R_{critical} = R\,\chi$$

$$\chi \leq 1{,}0 \;\longrightarrow\; R_{critical} \leq R$$

Instability factor χ depends on, between many others, Young modulus. Resistance of cross-section depends on geometrical characteristis and strength of steel:

$$R = F\,f_y$$

Both factrors: E and f_y decrease with increasing of temperature.

$$f_y = f_y(T) \longrightarrow R = X\,f_y(T)$$

$$E = E(T) \longrightarrow \chi = \chi(E) = \chi[E(T)]$$

$$R_{critical} = X\,f_y(T)\,\chi[E(T)] = R_{critical}\,(T)$$

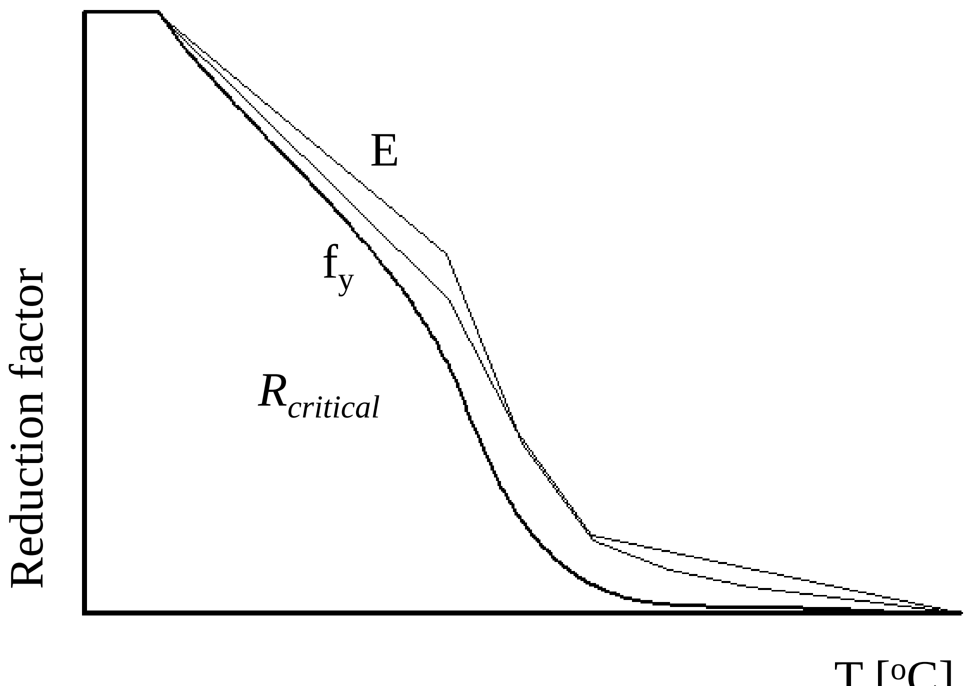


Photo: Author

Decreasing of $R_{critical}$ depends on decreasing of f_y and decreasing E - because of this decreasing of $R_{critical}$ is more rapid than the decreasing of f_y and E analysed separately.

According to Eurocodes, R[(T(t)] is named $R_{fi,\ d,\ t}$

Way of caclulations

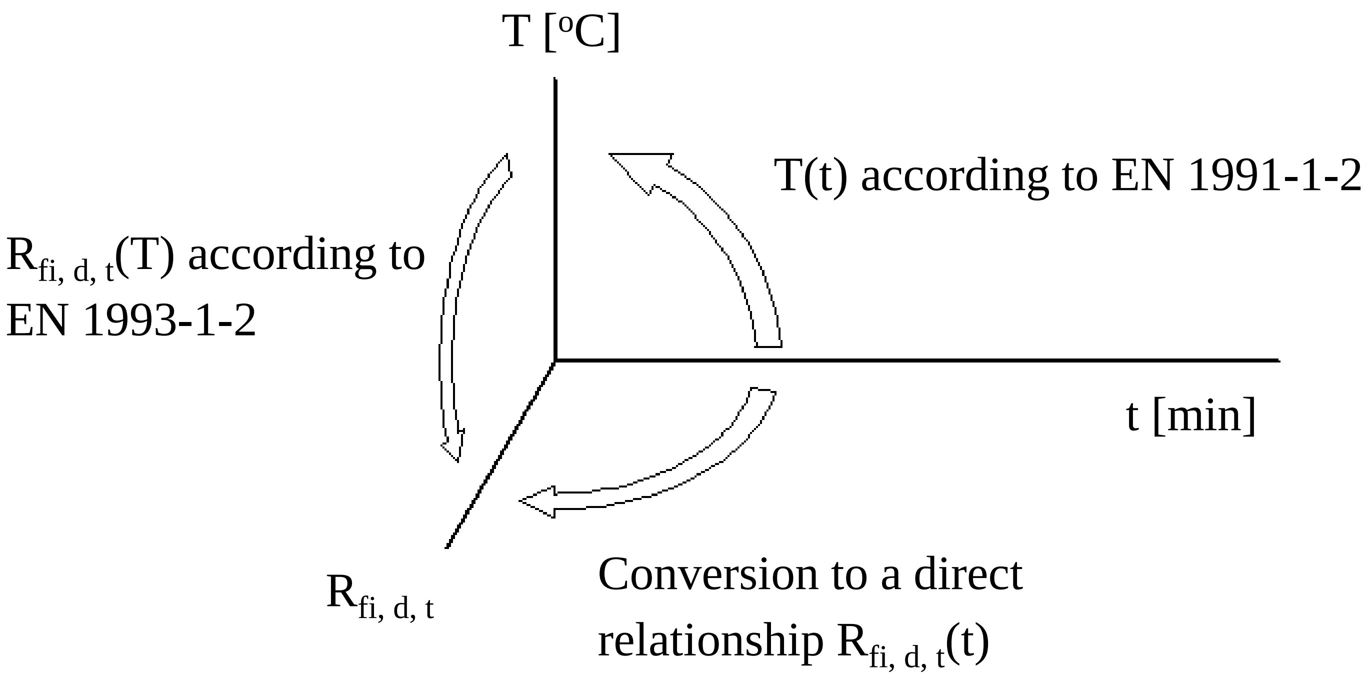
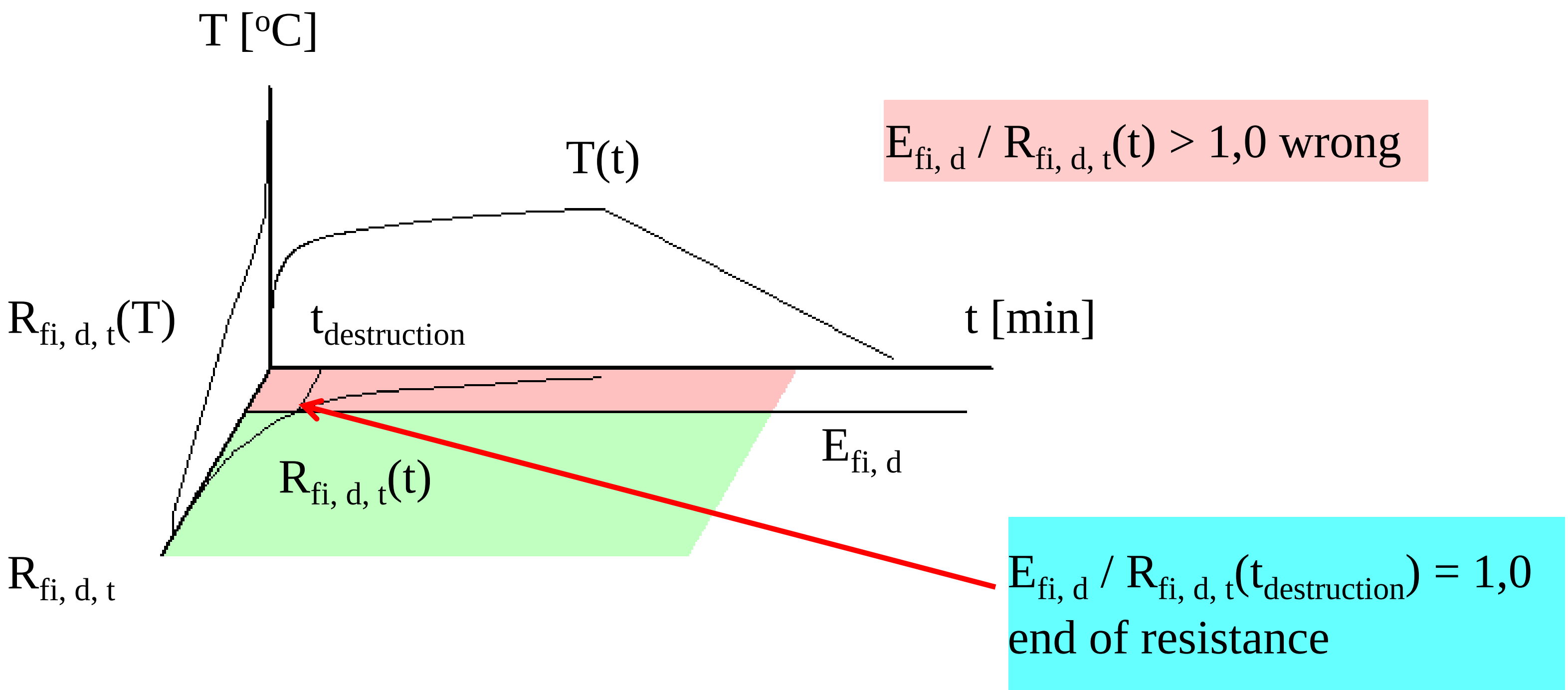


Photo: Author

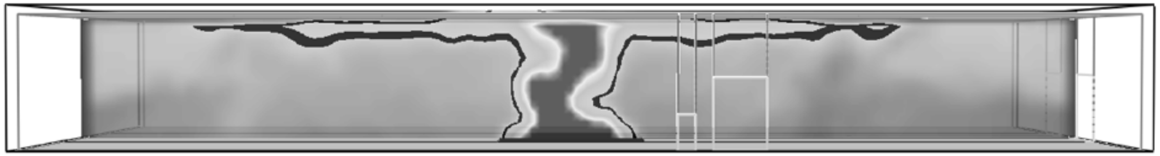


$E_{fi,\,d}$ / $R_{fi,\,d,\,t}(t) < 1{,}0$ ok

$t_{destruction}$ - time from start of fire to destruction; the most important parameter of calculations

Photo: Author

Of course, these calculations are strongly nonlinear and can't be hand-made. It's FEM calculations.



Rys. 4. Model MF1. Rozkład wartości temperatury po 11 minutach trwania pożar. Pogrubioną linią oznaczono izotermę 100°C

Fig. 4. Model MF1. Distribution of temperature values after 11 minutes of fire. 100°C isotherm is marked in bold

Rys. 5. Model MF2. Rozkład wartości temperatury po 11 minutach trwania pożaru. Pogrubioną linią oznaczono izotermę 690°C

Fig. 5. Model MF2. Distribution of temperature values after 11 minutes of fire. 690°C isotherm is marked in bold

Photo: Woźniczka P., Modelowanie komputerowe pożarów w halach wielkopowierzchniowych, Czasopismo Inżynierii Lądowej, Środowiska i Architektury, 3/I/2017

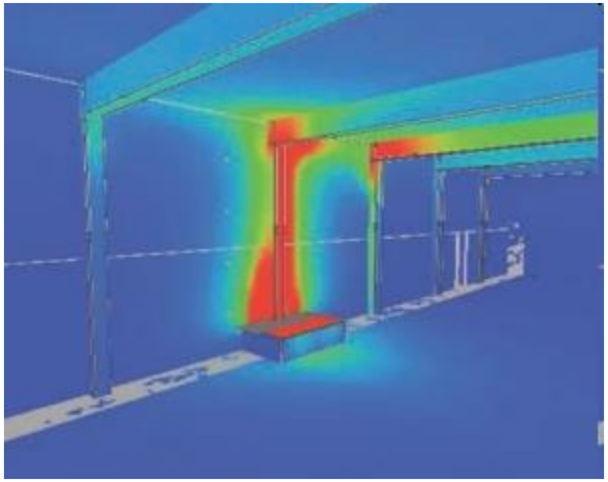


Photo: canadianconsultingengineer.com

Conclusion

- EN 1991-1-2 defines relationship: time ↔ T [^{o}C];
- EN 1993-1-2 defines decreasing of mechanical parameters for T [^{o}C] and resistance in case of fire R_{fire} ;
- Direct dependence R_{fire} (time) is calculated by special computer programmes;
- EN 1991-1-2 4 ; EN 1990 ; EN 1993-1-2 2.2, 2.3 define values of loads in case of fire;
- Statical calculations show results (cross-sectional forces, deformations) for this combination of loads $E_{fire} = E_{fi,\,d}$;
- Condition

$$E_{fi,\,d} / R_{fi,\,d,\,t}(t) \leq 1{,}0$$

is more useful in form:

time of evacuation < time of destruction

- Law rules define minimal time of survival of structures in fire (time of evacuation);

Law rules

$$t_{destruction} > t_{min}$$

$t_{destruction}$ - time from start of fire to destruction;

t_{min} - minimum time of fire resistance (time of evacuation); information about it is not presented in Eurocode. This information is presented in law rules, various for various countries. Generally, time of evacuation concerns evacuation of all people from each parts of building - even if fire occurs in one part. Time to collapse could concern total or even local damage, because local damage can trigger a chain reaction and total collapse of all the structure.

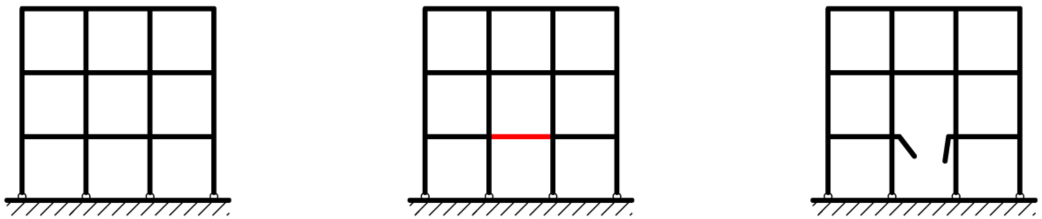
In Poland it is:

Regulation of the Minister of Infrastructure on technical conditions to be met by buildings and their location, 12.04.2002

Rozporządzenie Ministra Infrastruktury z dn. 12 IV 2002 w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie

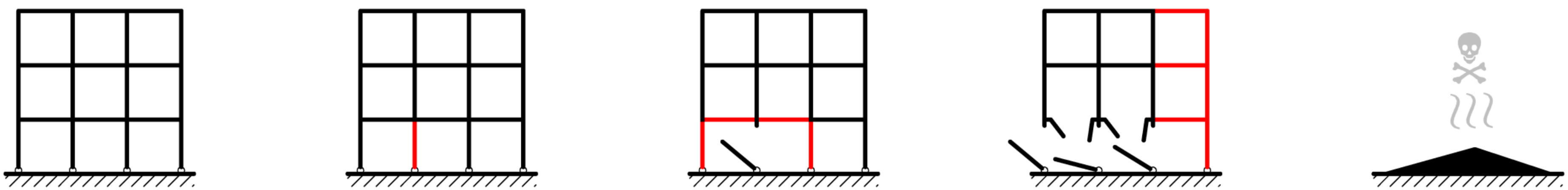
Destruction of one beam

Photo: Autor



Local damage

Destruction of one column



Global collapse

Conclusiom: column - more important for structure, calculation must be more accurate than for beams, few additional phenomenons must be analyzed.

11 IX 2001 - example of local damage, which trigger a chain reaction and total collapse of all the structure:

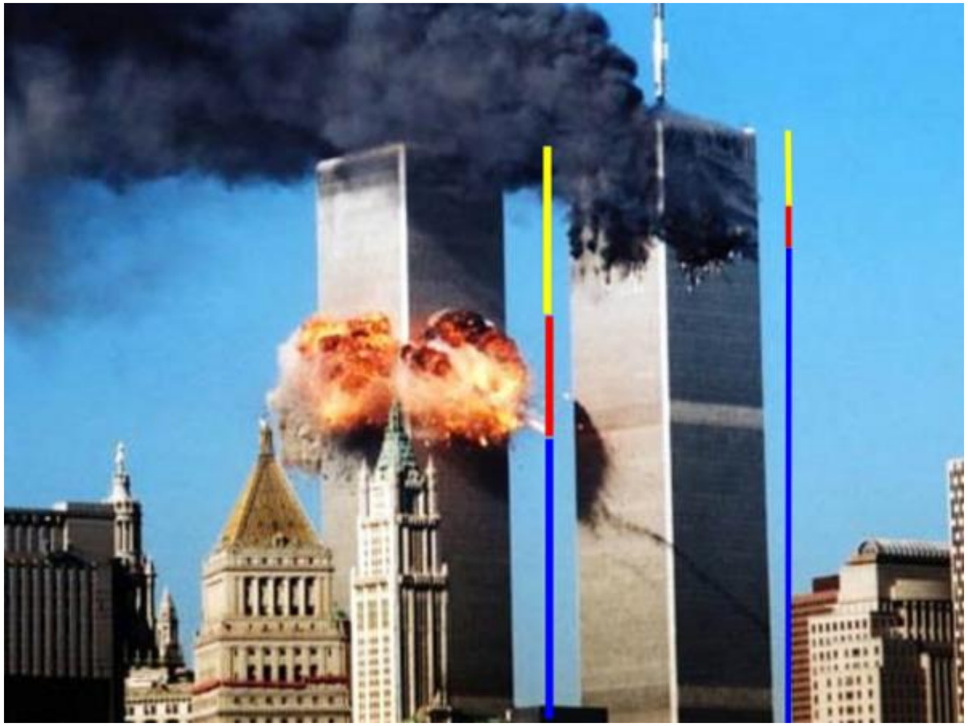


Photo: chronologia.pl

1. Within an hour, initial explosion and the fire locally destroyed structure in red part (few levels of tower);

2. Yellow part (few - several levels, many thousands of tones) crushed weakened red part, run down and hit blue one;

3. Dynamic axial force due to collision both parts was about 30 times greater than resistance of blue part for axial force;

4. Dynamic force crushed all the blue part.

According to Polish Law Rules, time of fire resistance of building depends on two parameters: height of building and type of using. Fire resistance of sub-part are defined based on these two parameters.

Height	Symbol
< 12 m; < 4 levels	N
12 - 25 m; 4- 9 levels	SW
25 - 55 m; 9 - 18 levels	W
> 55 m; > 18 levels	WW

Use of	Symbol
Accomodations for the simultaneous presence of > 50 people who do not have trouble with mobility (cinema, theater, shopping center)	ZL I
For people who have trouble with mobility (nursery, hospital, kindergarten, old age home)	ZL II
Other public buildings	ZL III
Residential buildings	ZL IV
Collective residential buildings, apart ZLI and ZL II	ZL V
Production, storage	PM
Livestock building	IN

A = the best fire protection is needed.

The minimum requirements for fire resistance class of the building (OP)		Use of: ZL				
		ZL I	ZL II	ZL III	ZL IV	ZL V
Height	N	B	B	C	D	C
	SW	B	B	B	C	B
	W	B	B	B	B	B
	WW	A	A	A	B	A

The minimum requirements for fire resistance class of the building (OP)		Use of: PM, IN				
		Maximum fire load density in the building Q [MJ / m^2]				
		< 500	500 - 1000	1 000 - 2 000	2 000 - 4 000	> 4 000
Height	Single-storey	E	D	C	B	A
	N	D	D	C	B	A
	SW	C	C	C	B	A
	W	B	B	B	Not accepted by Regulation	
	WW	B	B	B		

According to this Regulation, buildings are divided into six sub-parts:

main structures;
roof girders;
ceilings;
external walls;
internal walls;
roofings;

There is information about the minimum time resisting fire for each type of sub-patrs. Symbols of this resistance is

F number

F - specific type of resistance (R, E, I);
number - minimum time of fire resistance in minutes.

R - load-bearing capacity (ULS + SLS);

End of limit states not earlier than after 60 minutes since start of fire → R 60

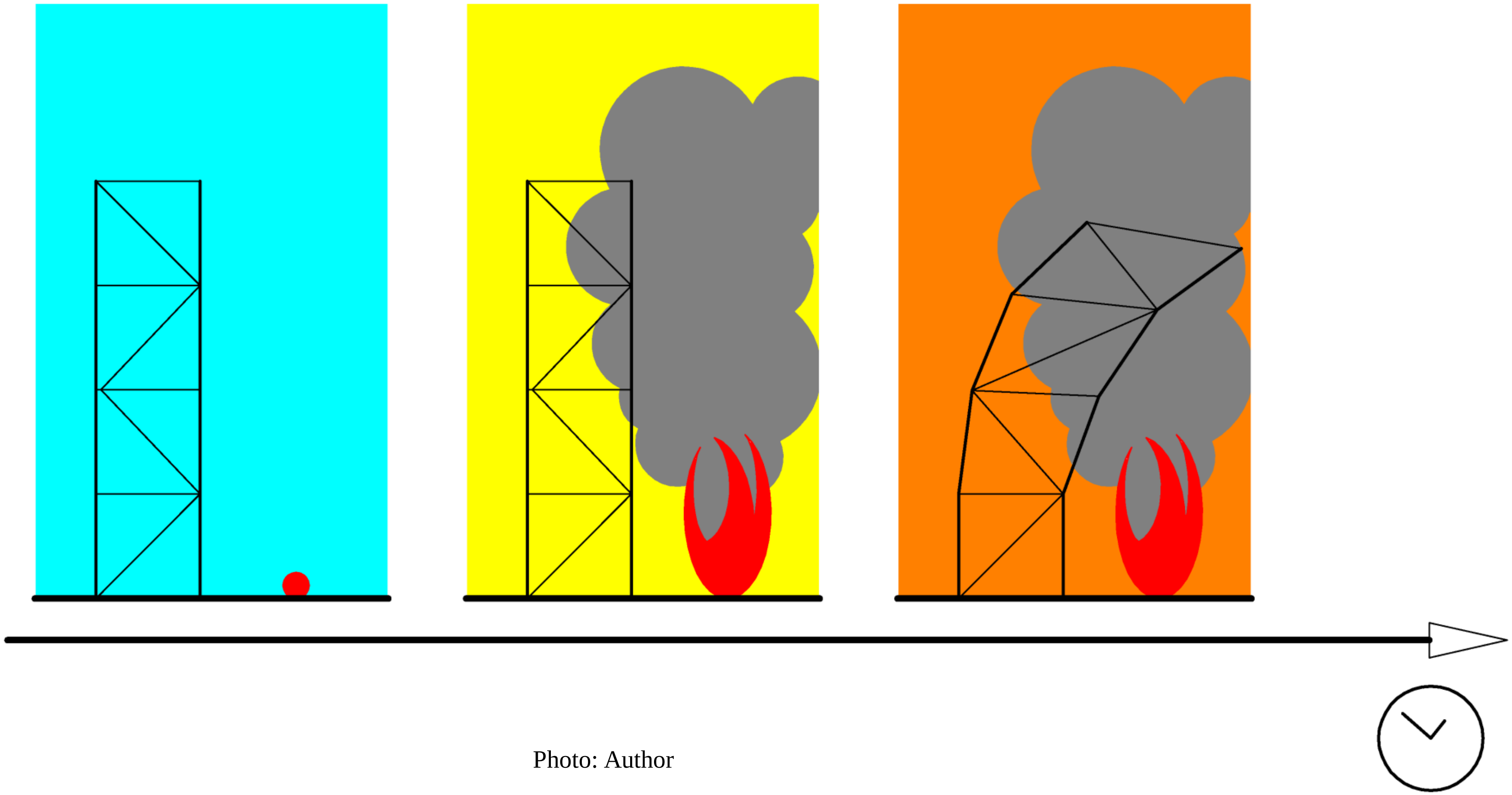


Photo: Author

E - integrity;

Penetration by fire or smoke not earlier than after 30 minutes since start of fire → E 30

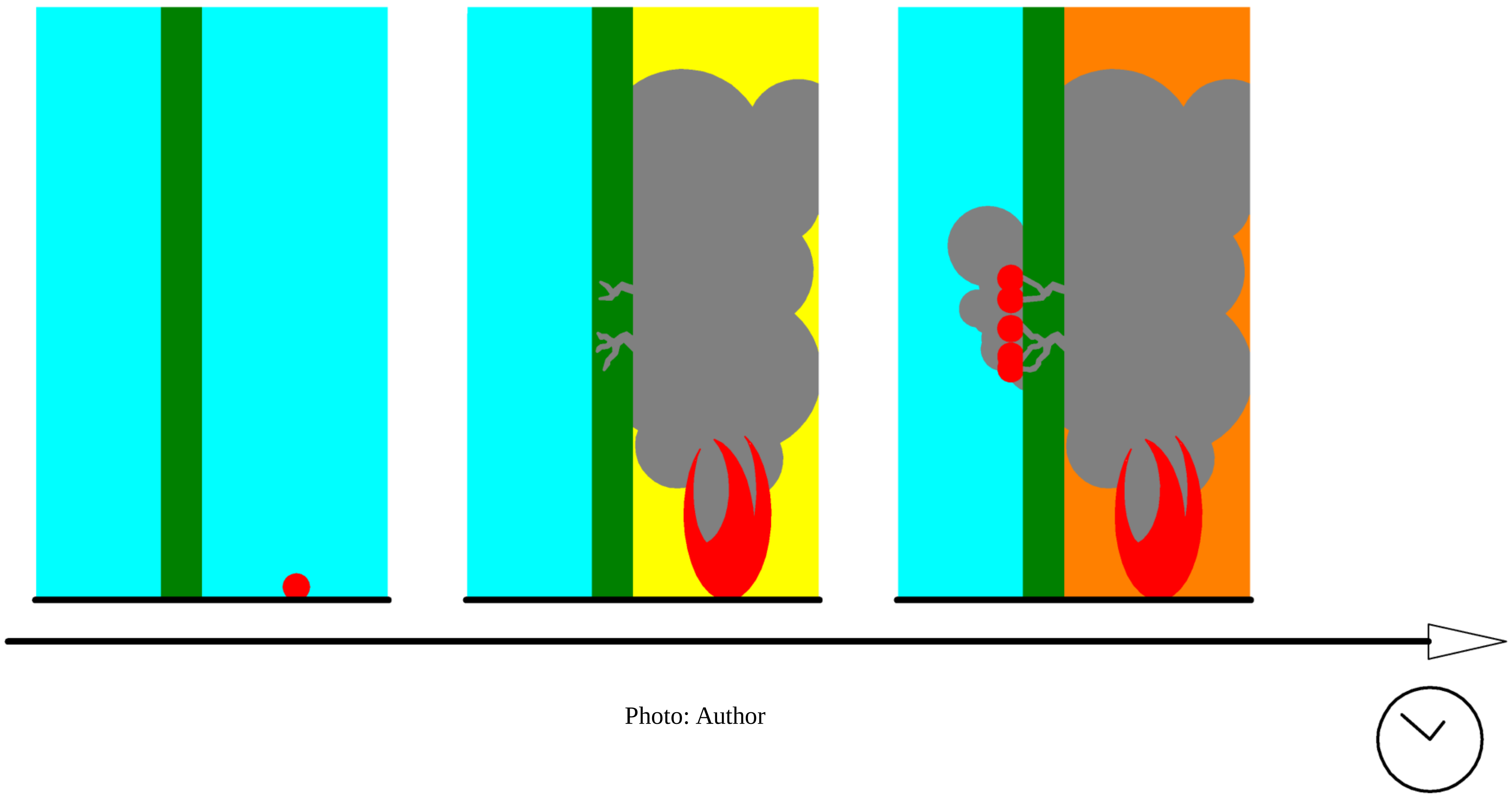


Photo: Author

I - insulation;

Too high temperature at the opposite surface of wall / ceiling not earlier than after 30 minutes since start of fire → I 30

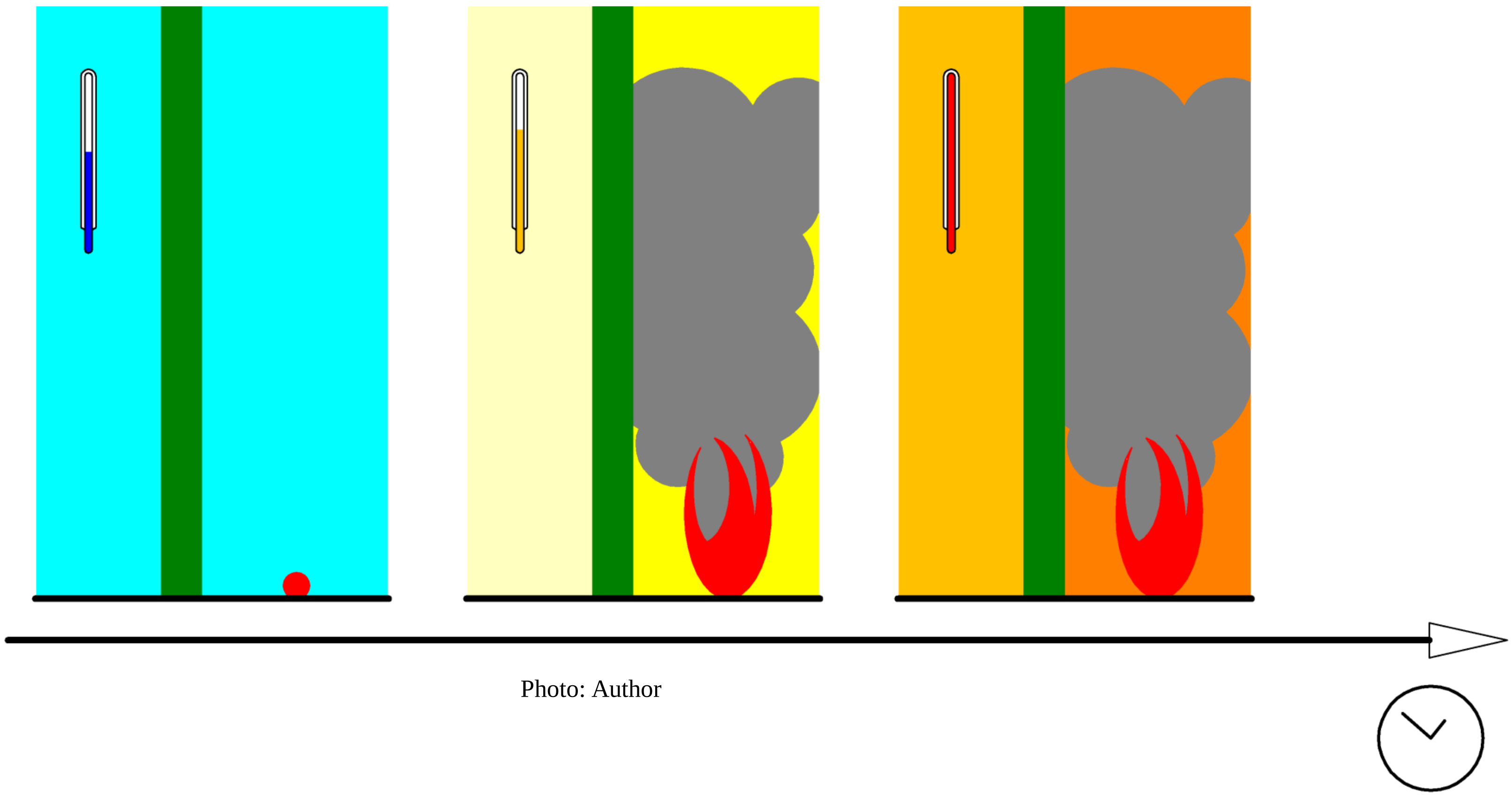


Photo: Author

Fire resistance class for building Klasa odporności pożarowej budynku (OP)	Fire resistance class for sub-part Klasa odporności ogniowej (OO) elementów budynku					
	Main structures	Roof girders	Ceilings	External walls	Internal walls	Roofings
A	R 240	R 30	REI 120	EI 120	EI 60	EI 30
B	R 120	R 30	REI 60	EI 60	EI 30	EI 30
C	R 60	R 15	REI 60	EI 30	EI 15	EI 15
D	R 30		REI 30	EI 30		
E						

Green part of table is important for steel structures: main structures and roof girders

Photo: traskostal.pl

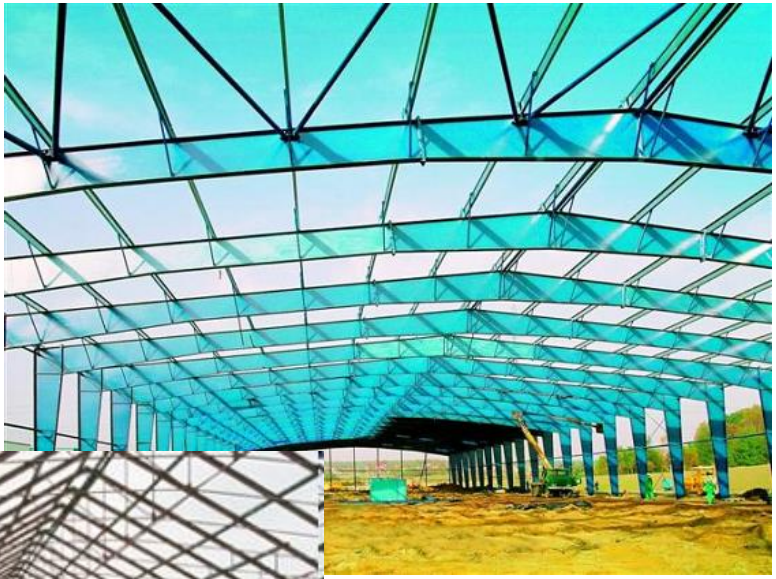


Photo: metroland.com.au

Photo: buildingconservation.com

Roofing and housing

Sandwich panels, cladding panels or corrugated sheets; steel or aluminum

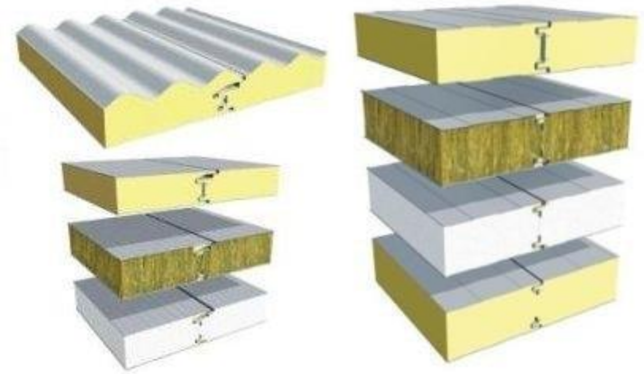


Photo: steelprofil.pl

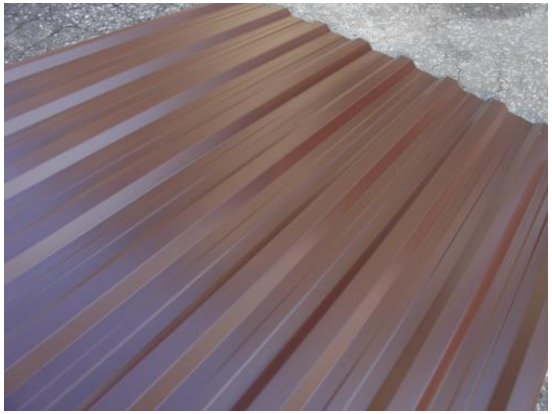


Photo: amarodachy.pl

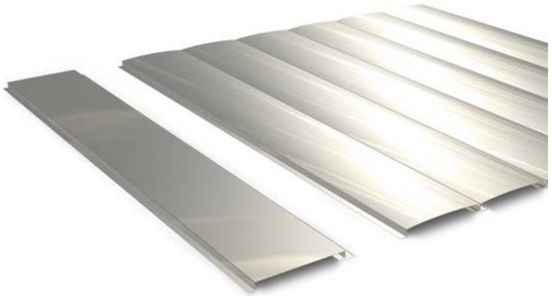


Photo: pruszynski.com.pl

Photo: elewacje-stalowe.pl

Fire protection

Active

- fire sprinkler systems;
- fire monitoring;

Shorter time between starting of fire and starting of firefighting action

Passive

- reduction of the ratio A_m / V (perimeter / area);

"Control" rate of element's temperature increase

- enclosure of the steel structure;
  - by concrete;
  - by thermal isolation;
- coating by intumescent paint;

Longer time of structure's temperature increasing

Fire sprinkler systems

Fire suppression or, at least, significant extension of time from notice of fire to collapse of structure.

Photo: fireguardllc.net

Photo: cofirepro.com

Fire monitoring

Smoke detectors calling the fire brigade.

Photo: interfach.com.pl

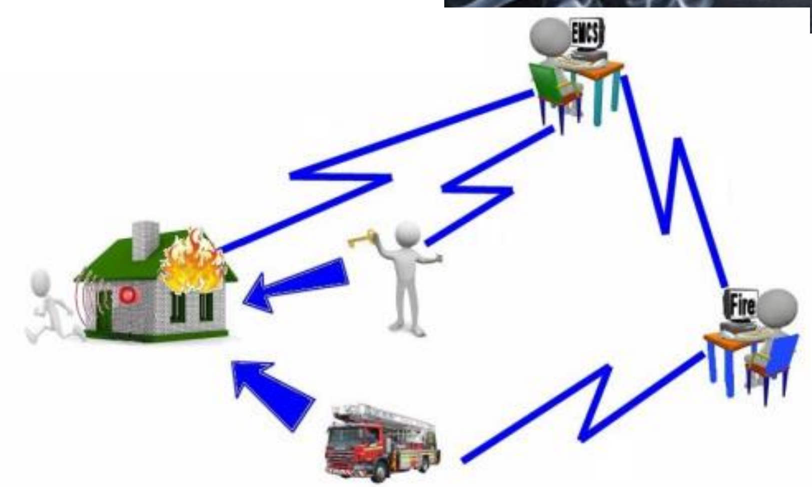


Photo: tsng.co.uk

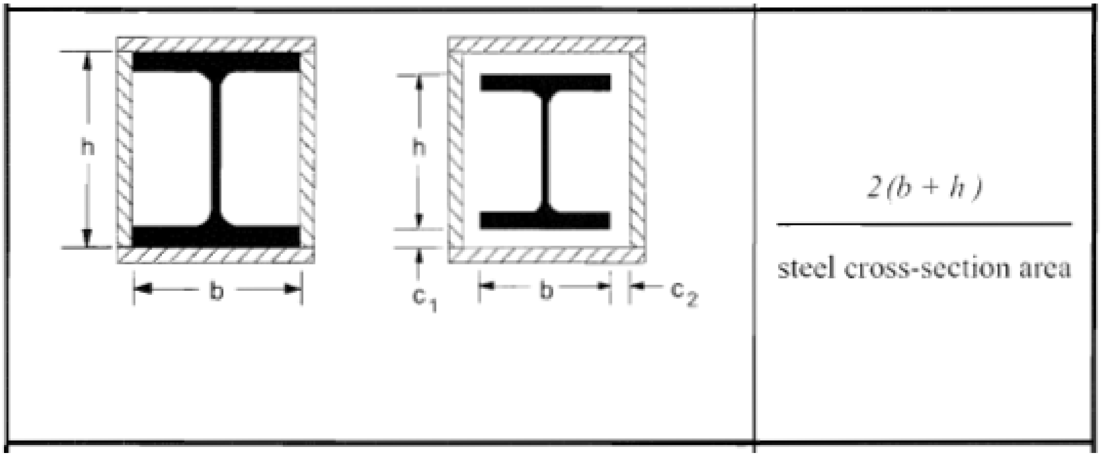
Photo: fire-monitoring.com

Reduction of the ratio A_m / V

The rate of heat transfer into element depends on the cross-sectional perimeter A_m. Small A_m means long time of „heat attack" without significant amount of energy transferred into element.

The rate of temperature rise depends on the cross-sectional area V. Big V means small increasing of temerature even under big amount of energy transported into element.

The reduction ratio A_m / V slows down the heat penetration and temperature rise of the element.



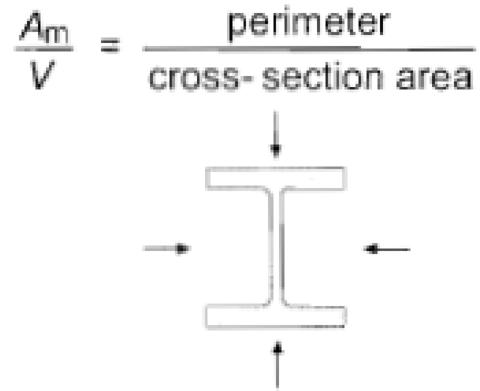


Photo: EN 1993-1-2 tab 4.2, tab. 4.3

Reduction of the perimeter
and inccreasing of the area:

Reduction of the perimeter
(and enclosure of structure):

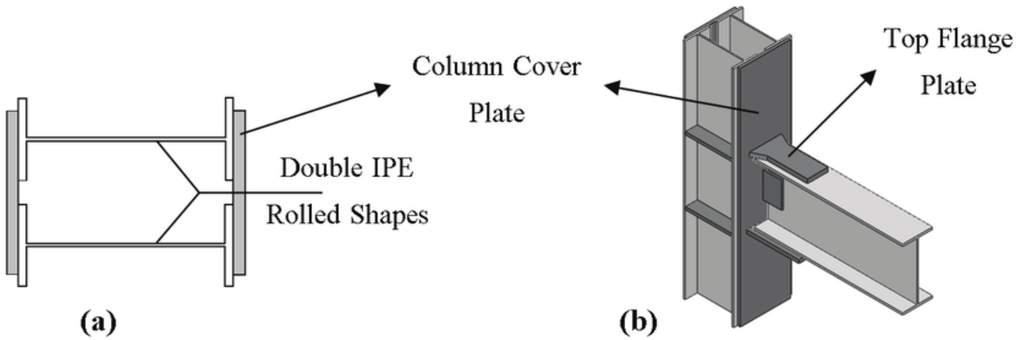


Photo: Ardeshir Deylami, Retrofitting of Moment Connection of Double-I Built-Up Columns using Trapezoidal Stiffeners, December 2011Procedia Engineering 14:2544-2551

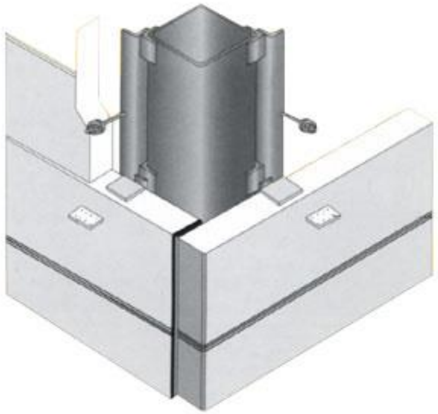
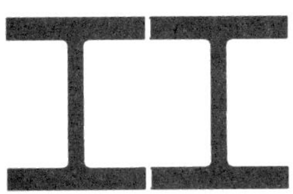


Photo: ytong.asia

Photo: Author



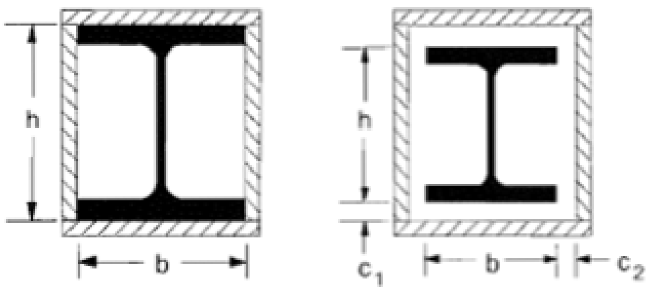
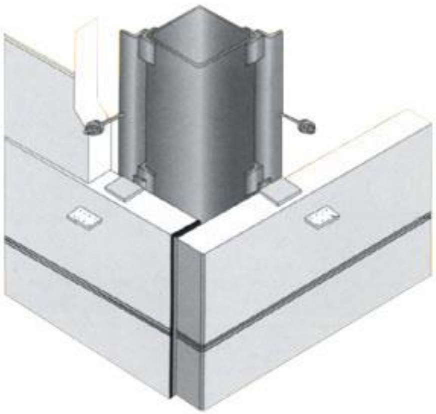


Photo: EN 1993-1-2 tab 4.2

Photo: ytong.asia



Enclosure of the steel structure by concrete or by thermal isolation - elongation of the time required to raise the temperature of the structure.

Photo: sharpfibre.com

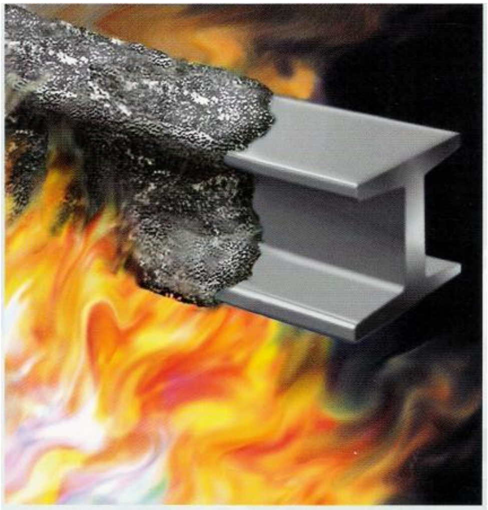


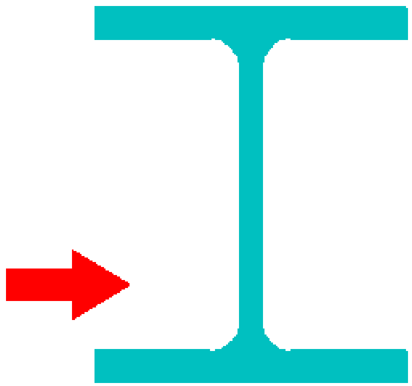
Photo: techno-poz.pl

Comparison of steel column protected and unprotected by concrete.

Photo: metabunk.org

Coating by intumescent paint

All the energy raises the temperature of steel structure.



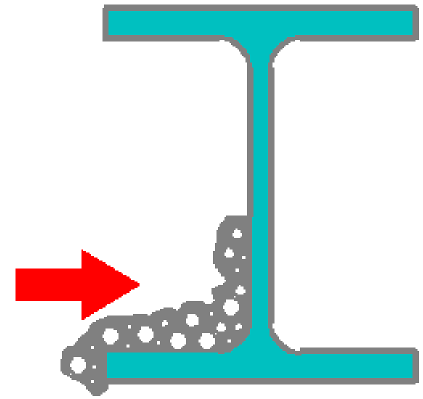


Photo: Author

Energy acts gradually:

- pore formation,
- evaporation of water from the pores,
- evaporation of cover,
- raising the temperature of steel structure.

Photo: propaintersnorthants.co.uk

Temperature of structure increases slower than without cover.

Accidents

28 V 2003 "Gigant" Shopping Center

Kraków

Arson by unknown perpetrators, defective fire sprinkler system.

Photo: rmf24.pl

No human deaths or injuries.

Photo: b.aplus.pl

Photo: psp.krakow.pl

Photo: psp.krakow.pl

Photo: psp.krakow.pl

Photo: wiadomosci.wp.pl

Steel structure in fire: enormous large deformations after even short time of exposure on fire.

Photo: psp.krakow.pl

Photo: psp.krakow.pl

Photo: psp.krakow.pl

Photo: wiadomosci.wp.pl

Photo: 911research.wtc7.net

Photo: 911research.wtc7.net

Enormous big deformations are characteristic for steel in fire.

Photo: 911research.wtc7.net

Photo: homelandsecuritynewswire.com

Aluminum

Photo: isel.com

Second metal, used as construction material, has different corrosion and fire characteristics than steel.

Photo: tradekorea.com

<table>
<tr><th></th><th>☺</th><th>☹</th></tr>
<tr><td>Steel</td><td rowspan="2">◆ High tensile strength
◆ High degree of prefabrication
◆ Easy to enhance facilities
◆ Possibility of demountable structures
◆ Full recycling of alloy used for building structures
◆ Lightweight</td><td>◆ Susceptibility to corrosion
◆ No fire resistance</td></tr>
<tr><td>Aluminum</td><td>◆ High cost of material
◆ No fire resistance
◆ Susceptibility to thermal destruction
◆ Low fatigue strength</td></tr>
</table>

→ #1 / 32

Aluminum is much more resistant to corrosion than steel. On the aluminum surface, an hermetic layer of oxides is formed, protecting against corrosion. Contact corrosion (other metals) and aggressive (very strongly acid or very strongly alkaline) chemicals are dangerous for aluminum.

Photo: aluteam-alumeco.com.pl

A side effect of the formation of a hermetic layer of aluminum oxides may be extensive stains and discoloration. This effect is unfavorable in the case of window frames. That is why aluminum finishing elements are protected against corrosion.

Photo: bramsec.pl

Each uncontrol action of temperatures (welding process, fire actions) completely devastates effects of precipitation hardening and decreases mechanical properties of aluminum alloys.

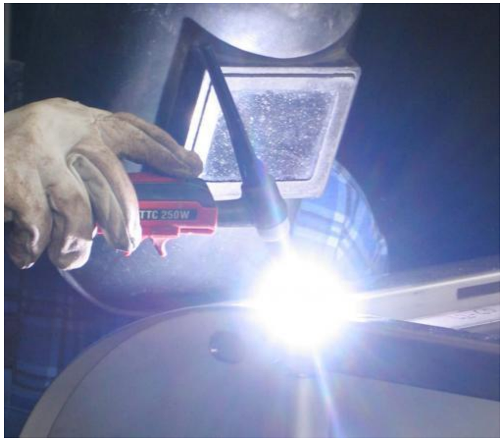


Photo: stelmet.net

Photo: easternontarionetwork.com

Relationships between strength of material and its temperature during fire are presented:

- for steel: EN 1993-1-2 fig E.2;
- for aluminum: EN 1999-2 tab. 1.a.

Photo: easternontarionetwork.com

„Normal” calculations, not in case of fire:

$$E / R \leq 1{,}0$$

Fire – separate load combinations in accordance with EN 1991-1-2:

$$E_{fire} / R_{fire} \leq 1{,}0$$

$E_{fire} \approx$ 40-70% E

Therefore, as long as $R_{fire} \geq$ 40-70% R, structure could be in safe situation.

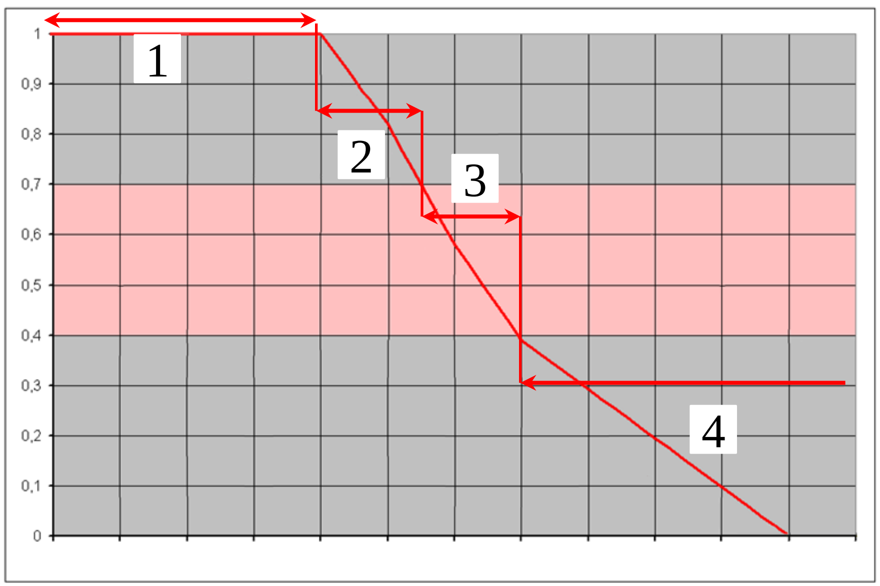


Photo: Author

1 – no impact of temperature on resistance;

2 – impact of temperature, but resistance higher than external action in case of fire;

3 – impact of temperature, resistance could be smaller than external action in case of fire;

4- imparc of temperature, resistance for sure smaller than external action

Relationships R↔T for steel and aluminum can be presented on one diagram:

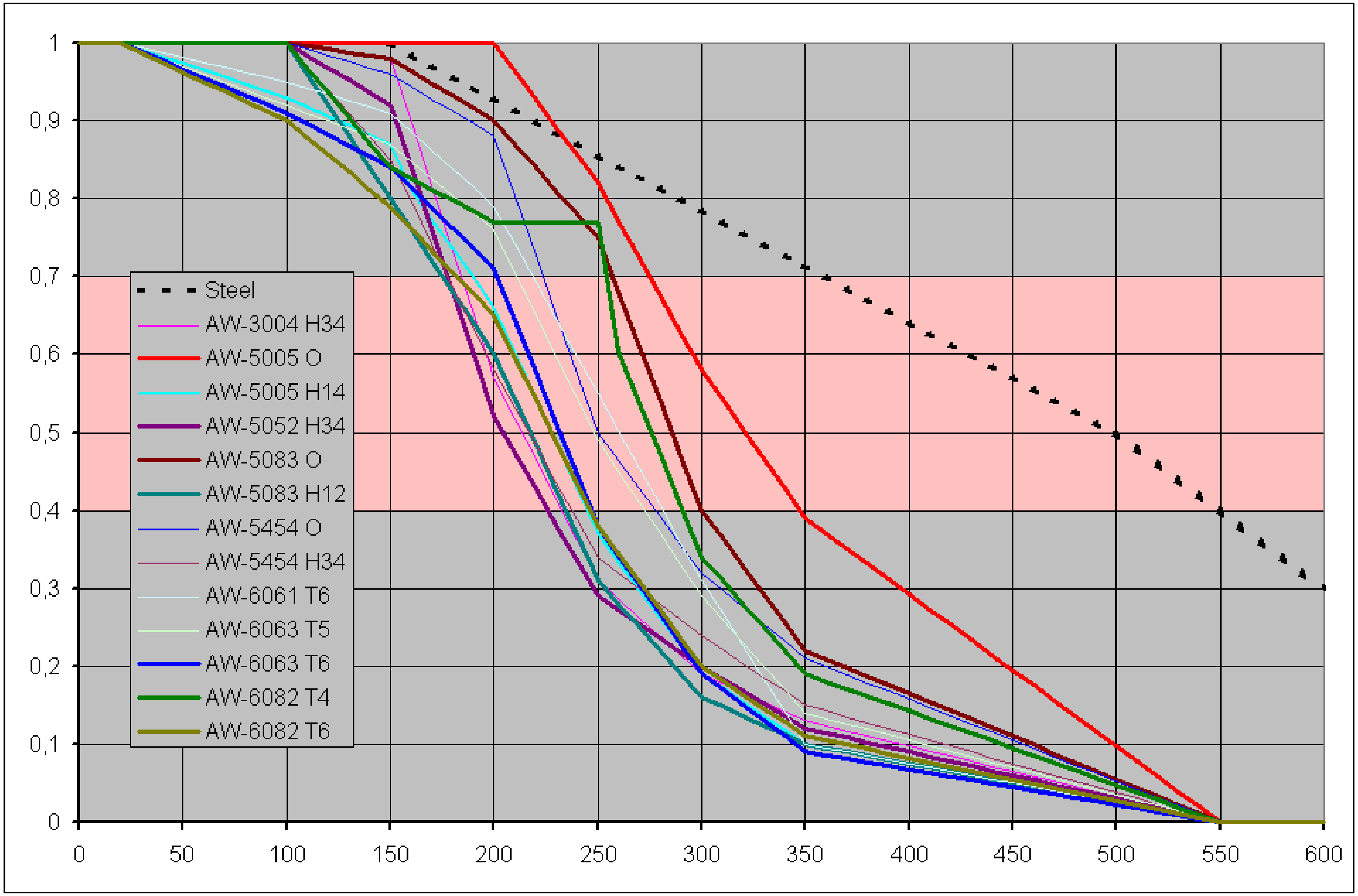


Photo: Author

Conclusion: in case of fire, temperature 300 ^{o}C (collapse of aluminum structure) will be reached much faster than 550 ^{o}C (collapse of steel structure).

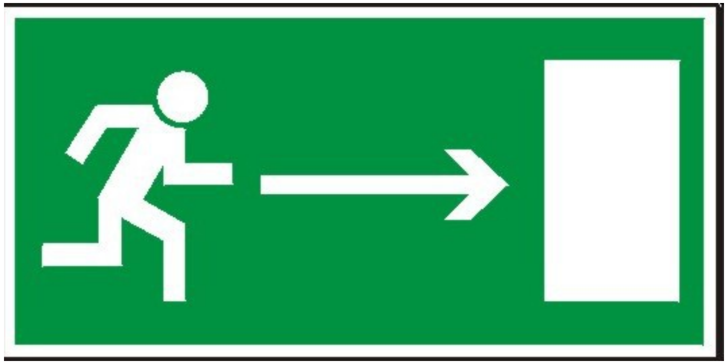


Photo: heron.waw.pl

Time to evacuate of people (from notice of fire to collapse) is much more shorter for aluminum structures than for steel structures.

Aluminum structures are, in this regard, more dangerous than steel.

<u>Examination issues</u>

Reasons of corrosion

Ways of corrosion protection

Way of calculation for steel structure exposed to fire

Resistances R, E, I - definitions

Ways of fire protection

Impact of temperature on steel and aluminium – silimiarities and differences

Uniform surface corrosion - powierzchniowa
Crevice - szczelinowa
Pitting - wżerowa
Contact - kontaktowa, galwaniczna
Selective - selektywna
Intergranular - międzykrystaliczna
Scale - zendra, zgorzelina
Intumescent paint - farba pęczniejąca

Thank you for attention

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