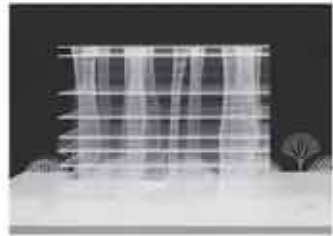


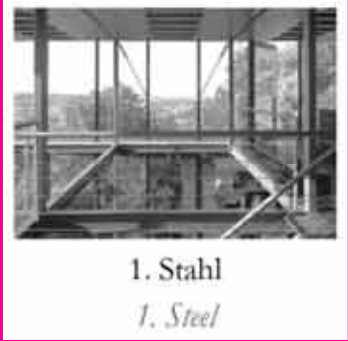
Tragwerksentwurf III

Structural Design III

Joseph Schwartz · Philippe Block



Architektur und Tragwerk
Architecture and Structure



1. Stahl
1. Steel



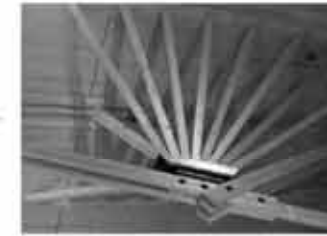
2. Stahlbeton
2. Reinforced concrete



3. Holz
3. Timber



4. Mauerwerk
4. Masonry



5. Konstruktionsdetails
5. Construction details

Tragwerksentwurf III *Structural Design III*

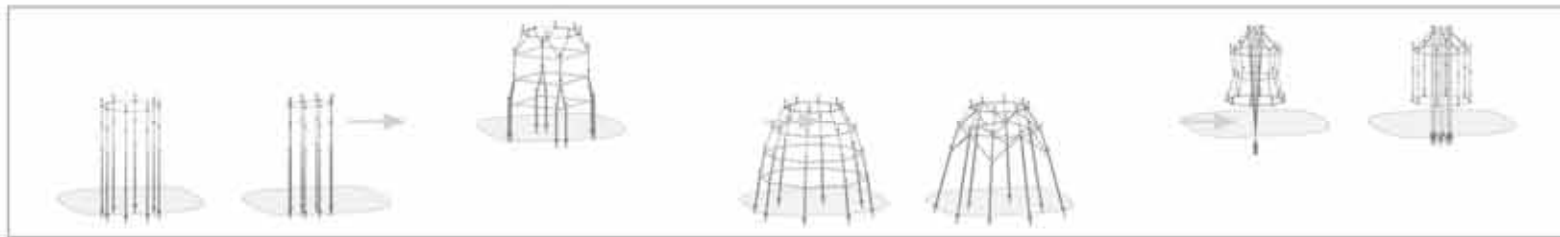
Tragwerksentwurf IV *Structural Design IV*



Entwerfen von Tragwerken I
Design of structures I



Entwerfen von Tragwerken II
Design of structures II



Entwurfsprojekt
Design project



Stahl

Steel

>> Einführung
Introduction

Mechanische Eigenschaften
Mechanical Properties

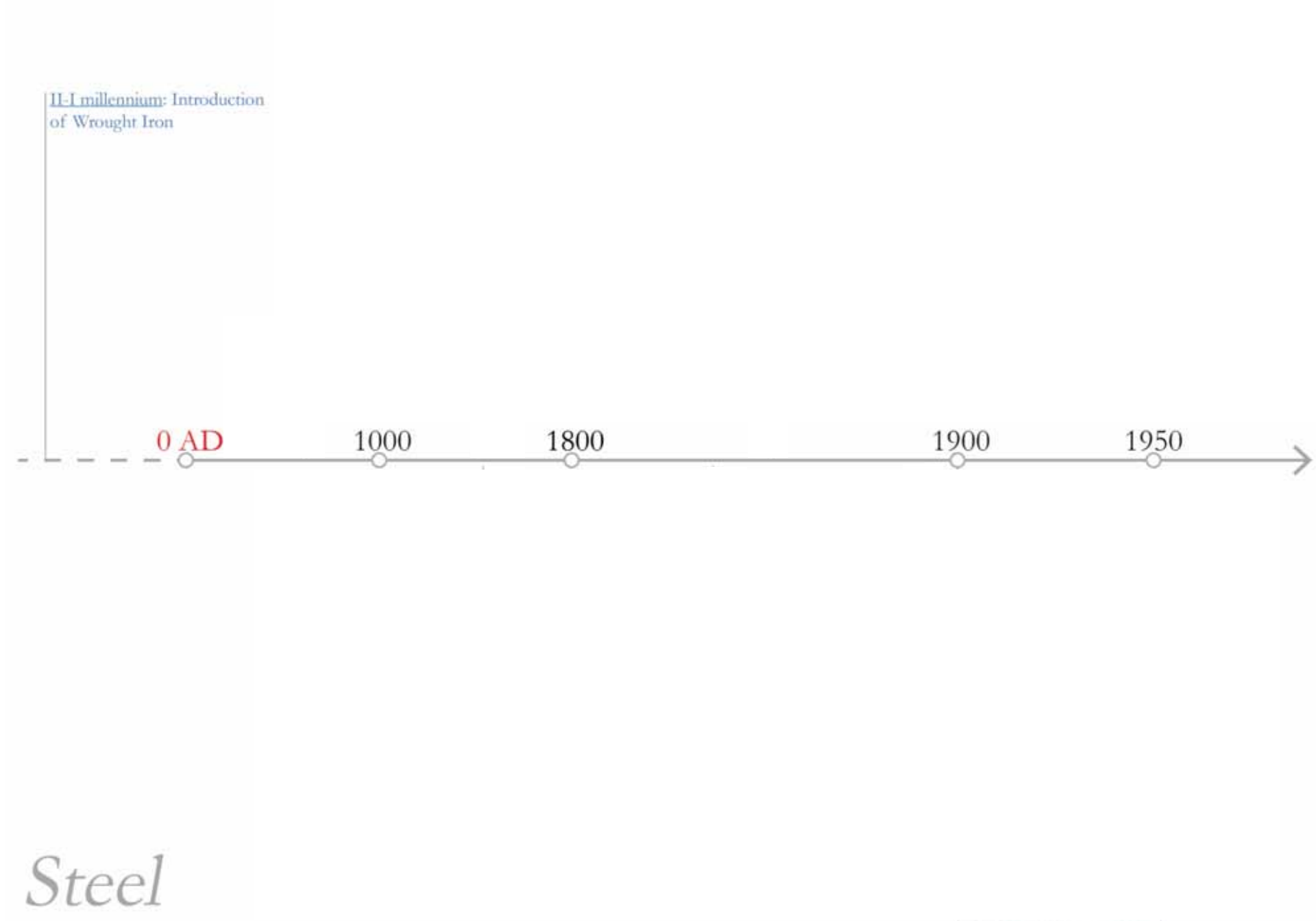
Bautechnologie
Building Technologies

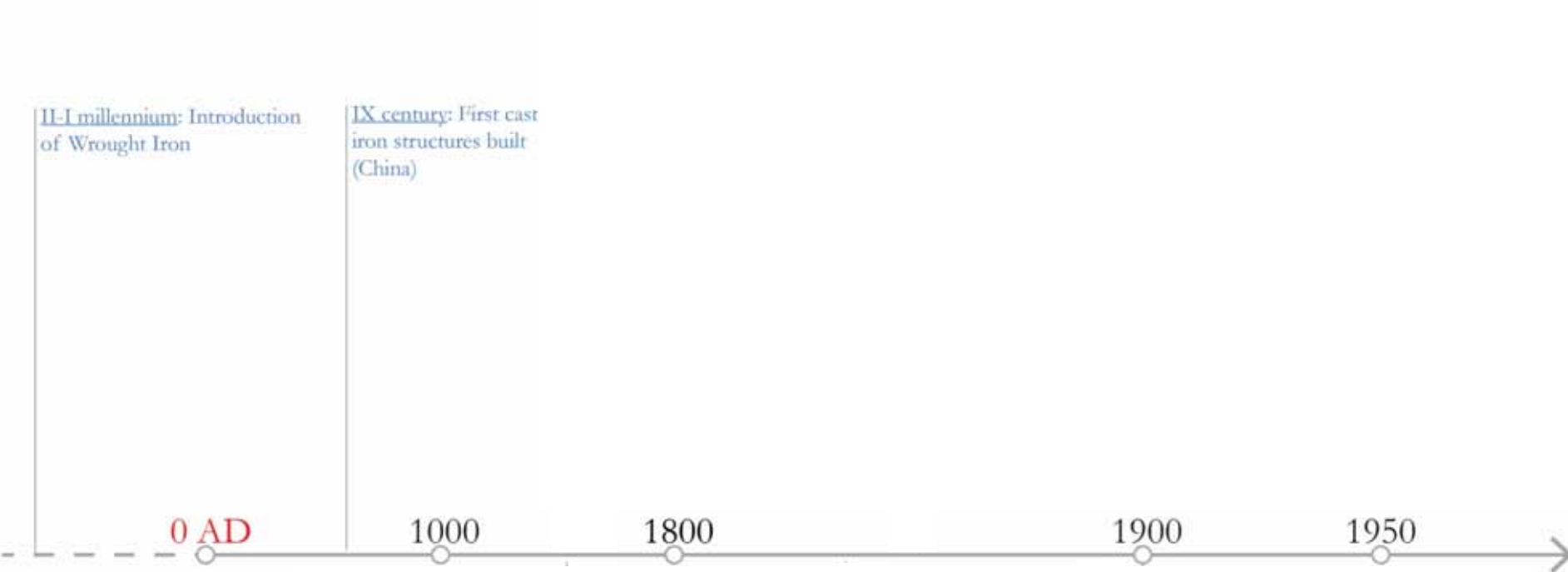
Fallstudie: Haus R128
Case Study: House R128

Ausgewählte Projekte
Selected Projects

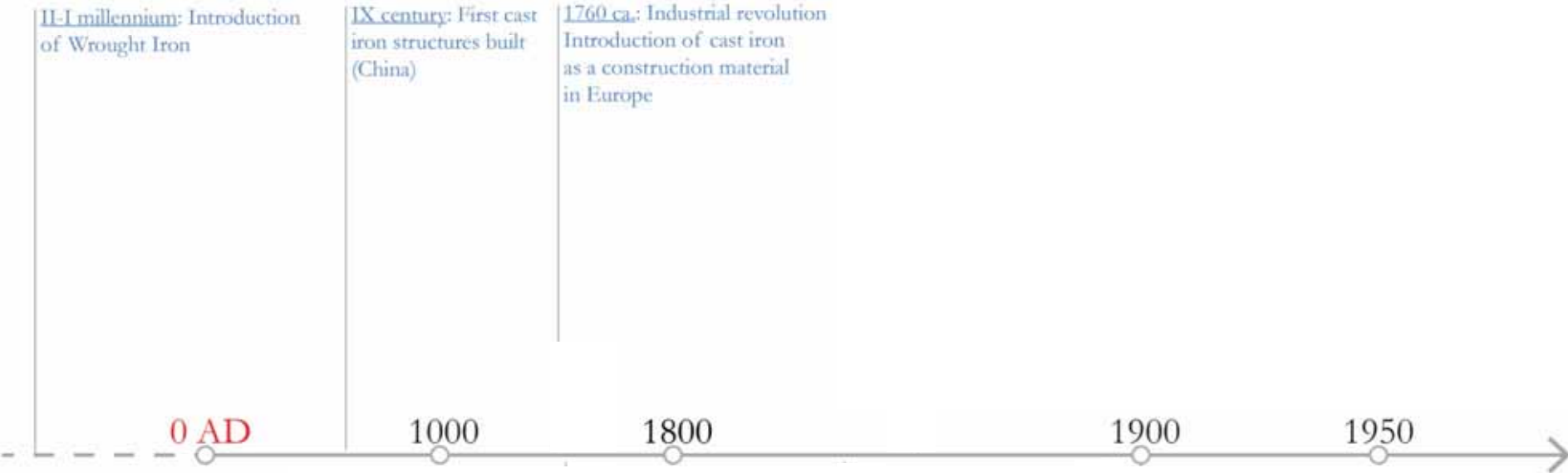


Steel

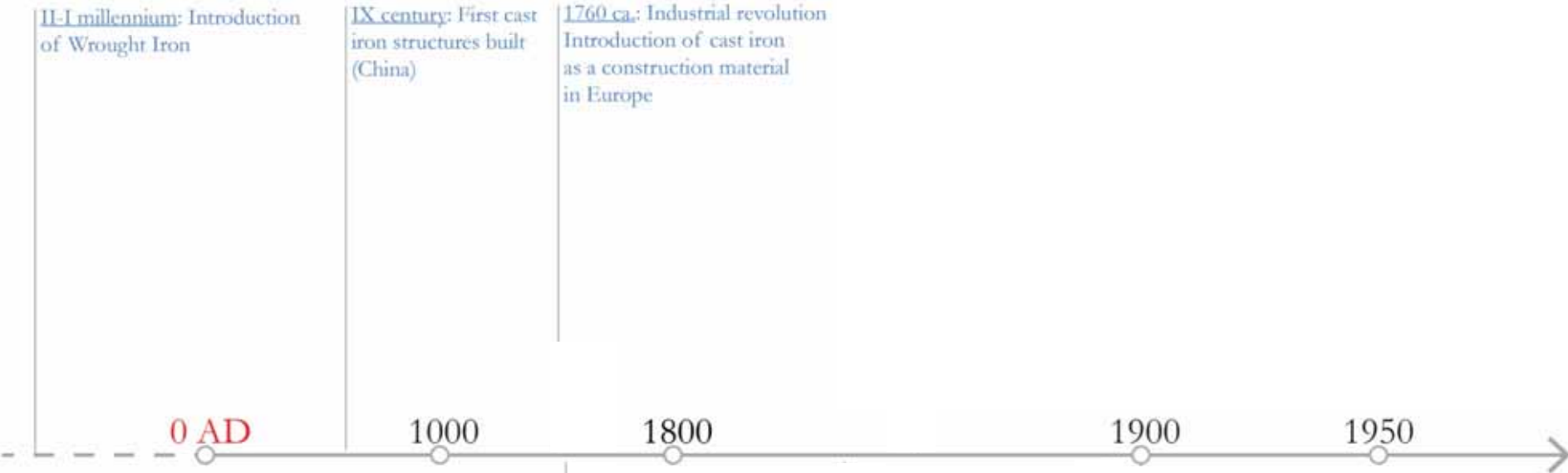




Steel



Steel



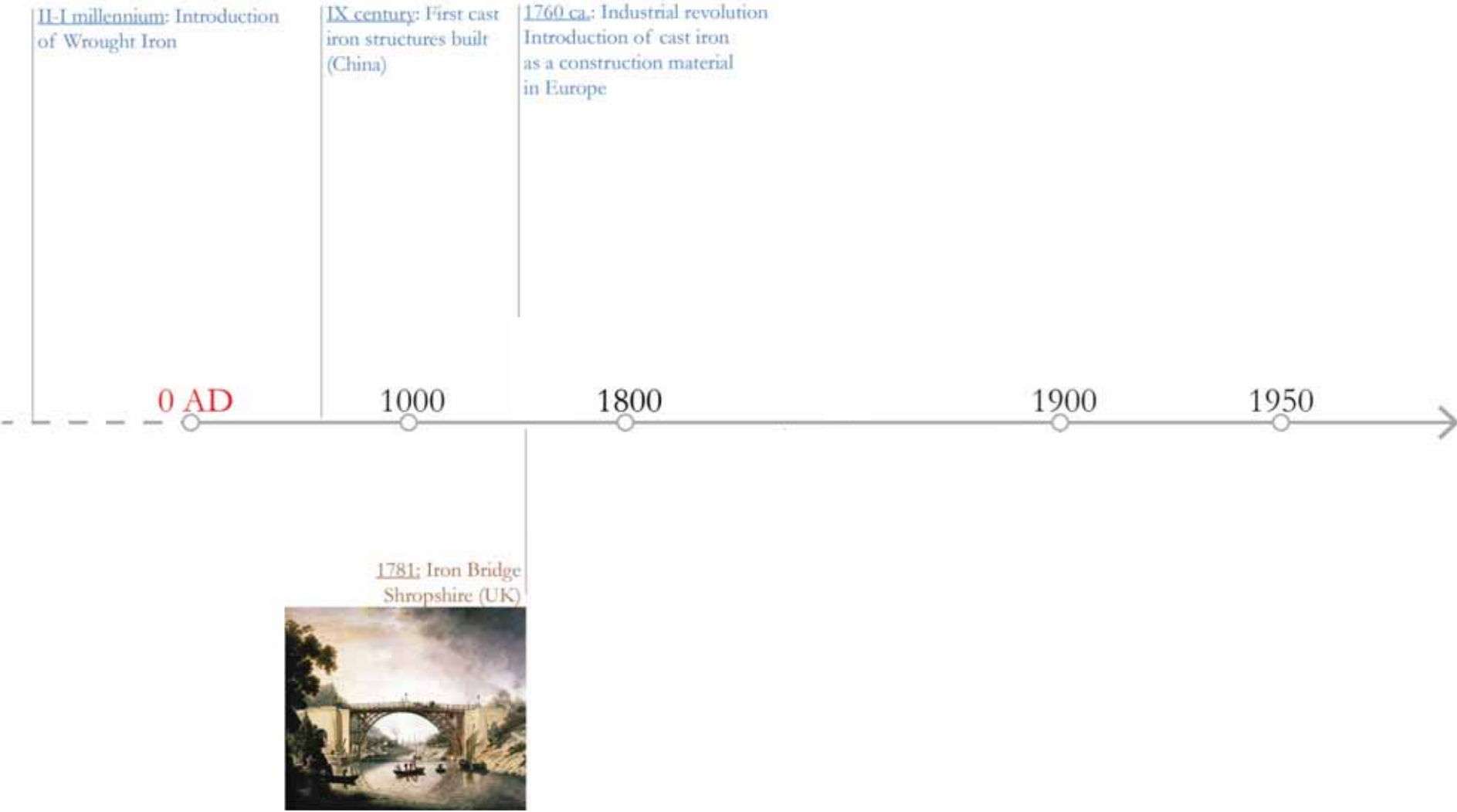
1781; Iron Bridge
Shropshire (UK)



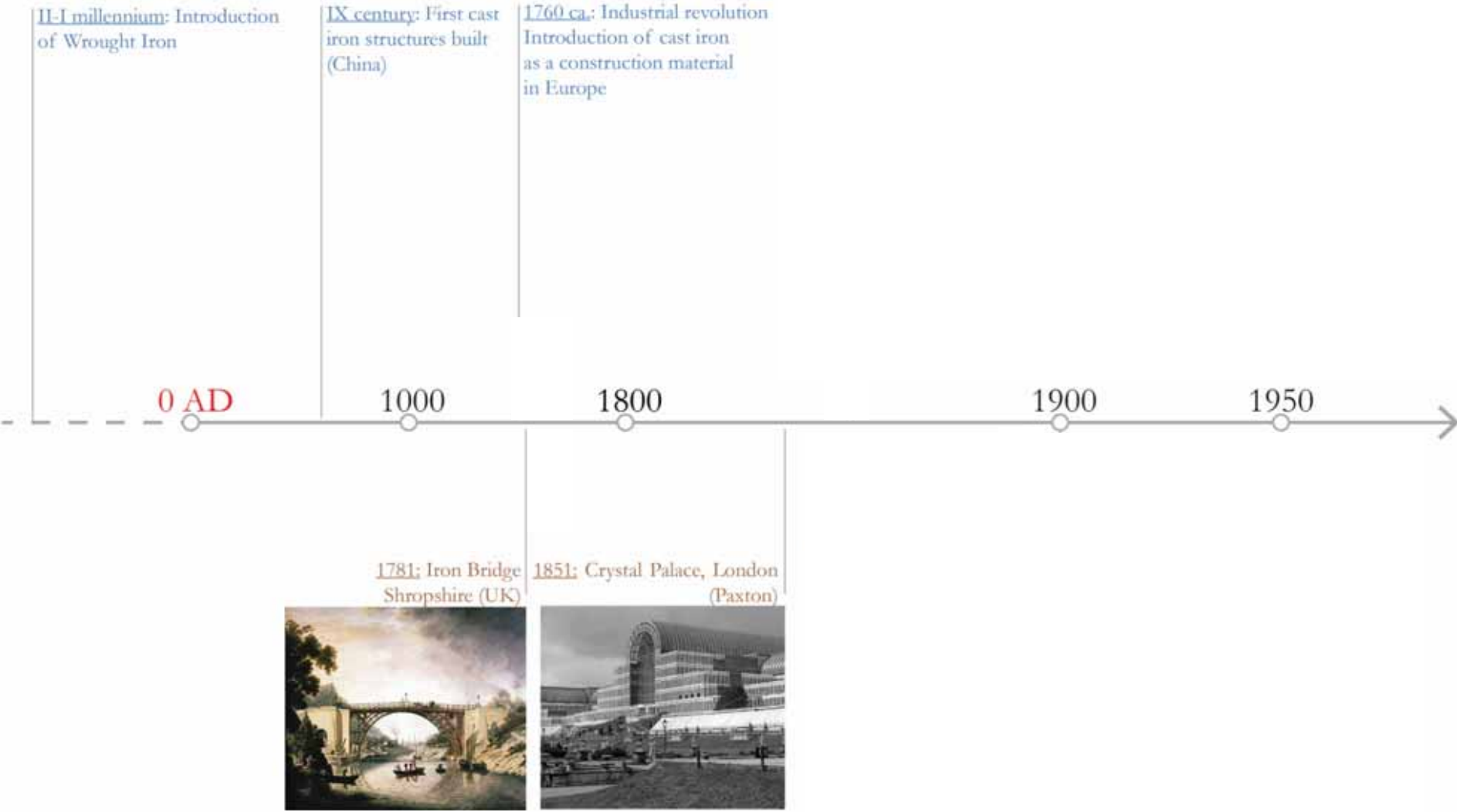
Steel



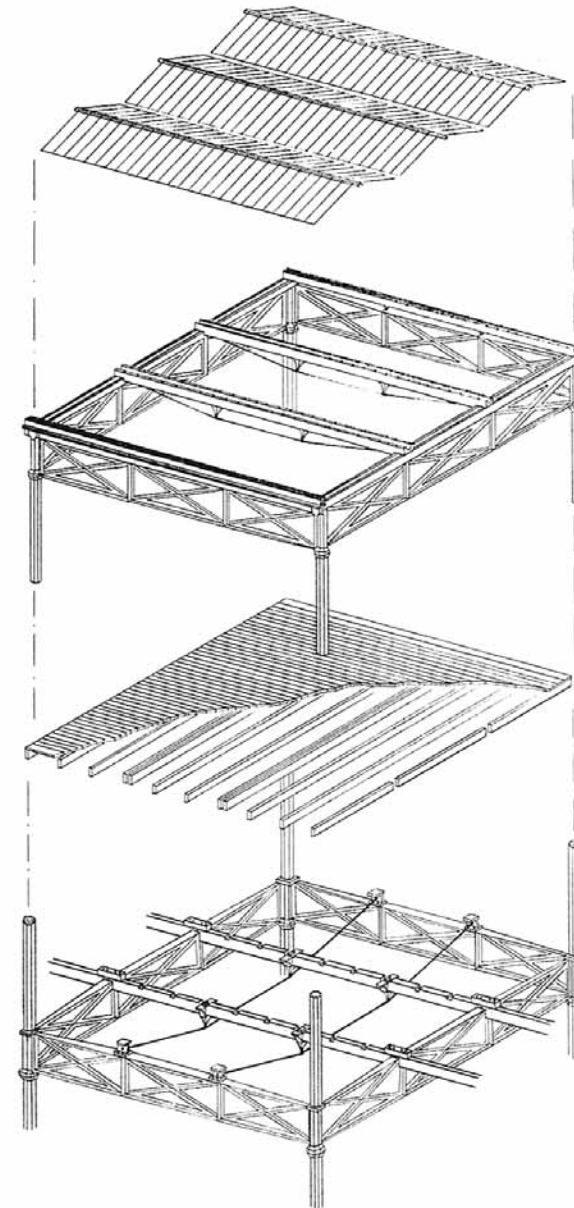
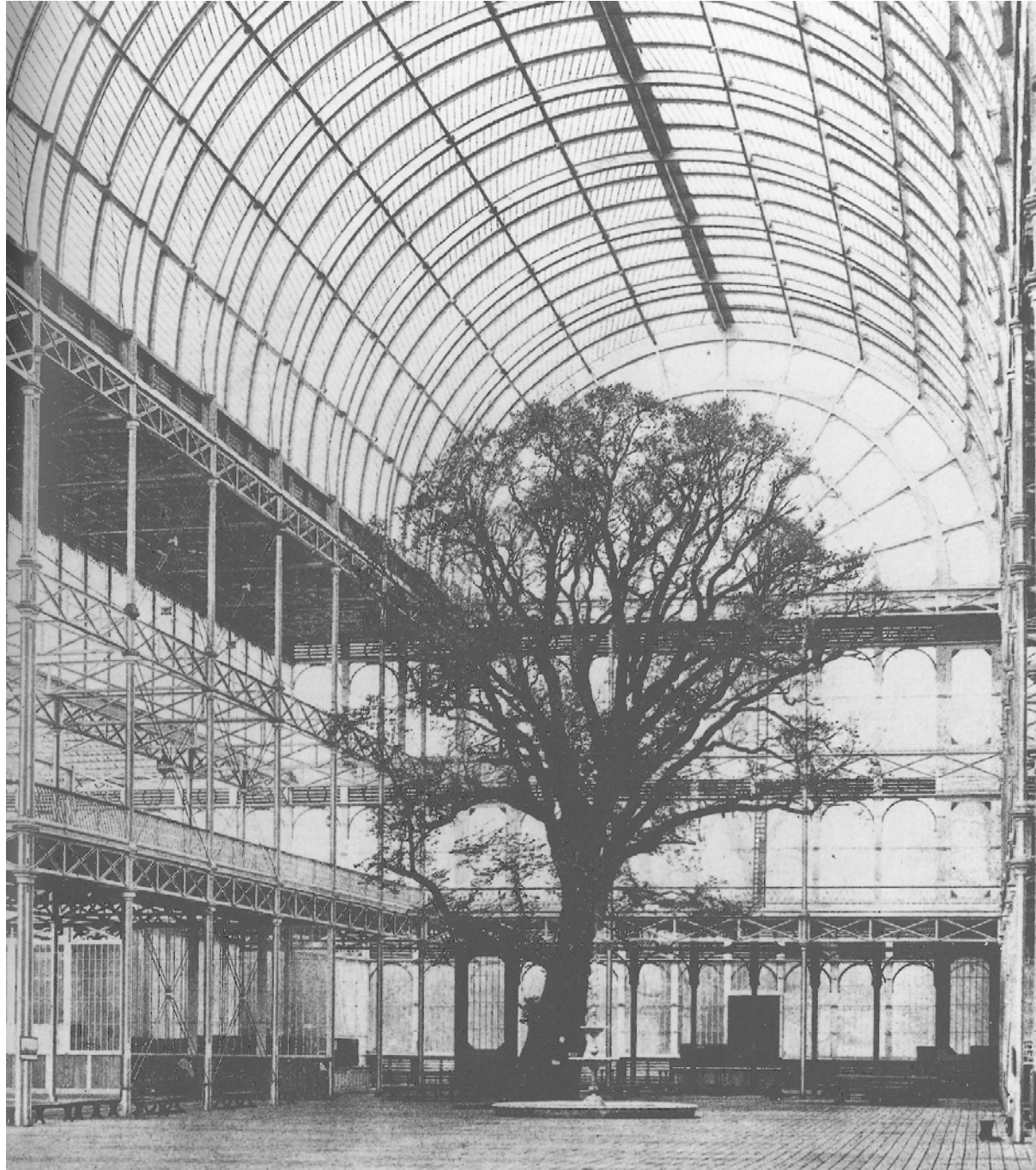
Eisen Brücke, Shropshire, 1781
Iron Bridge, Shropshire, 1781



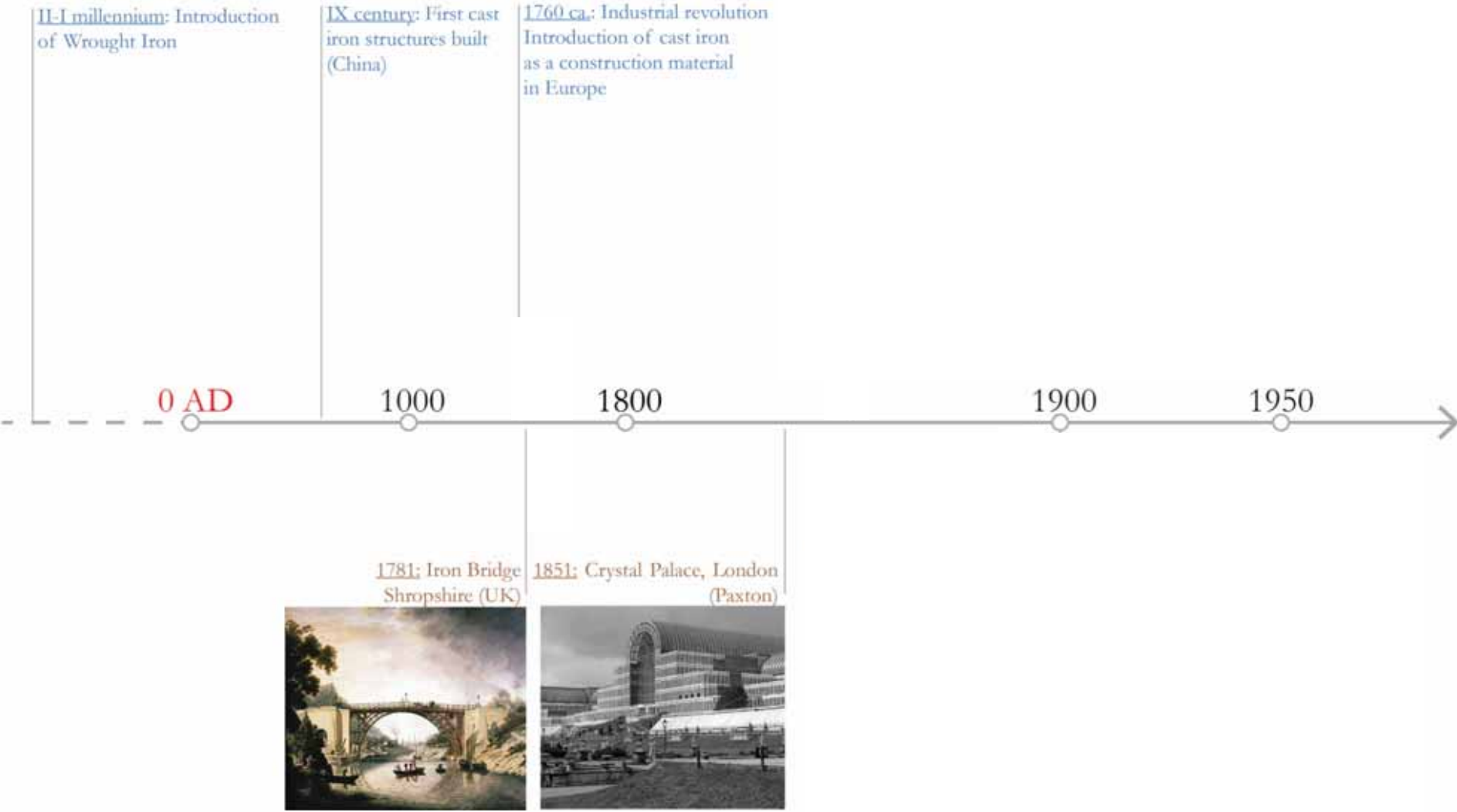
Steel



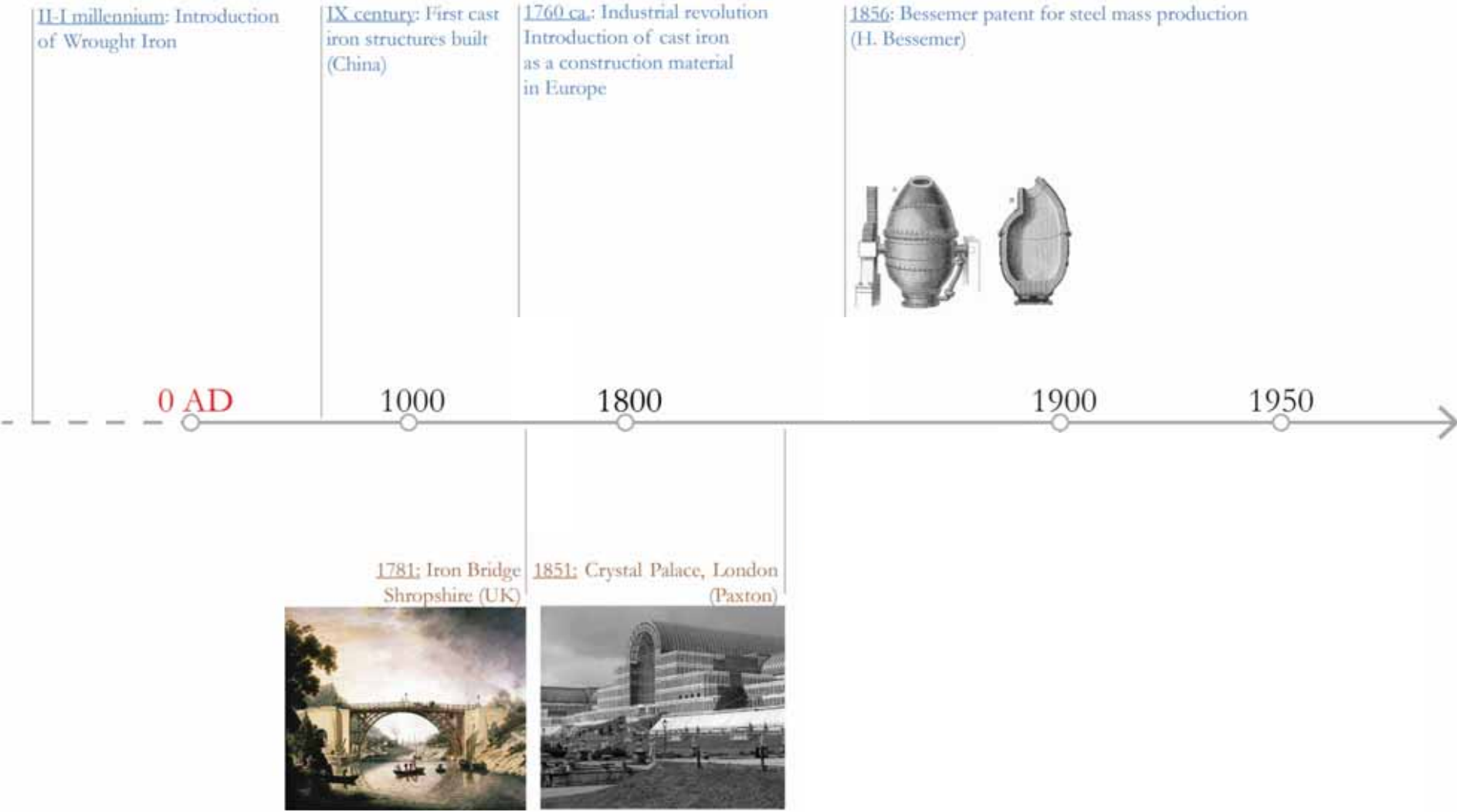
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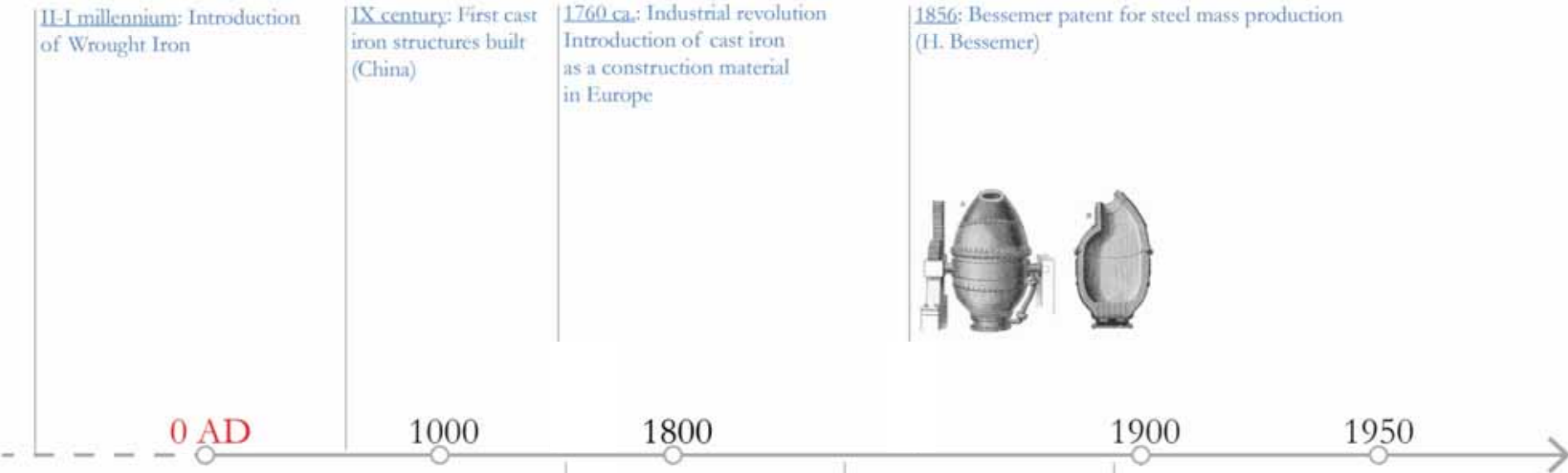
Crystal Palace, London, 1851, arch. Joseph Paxton



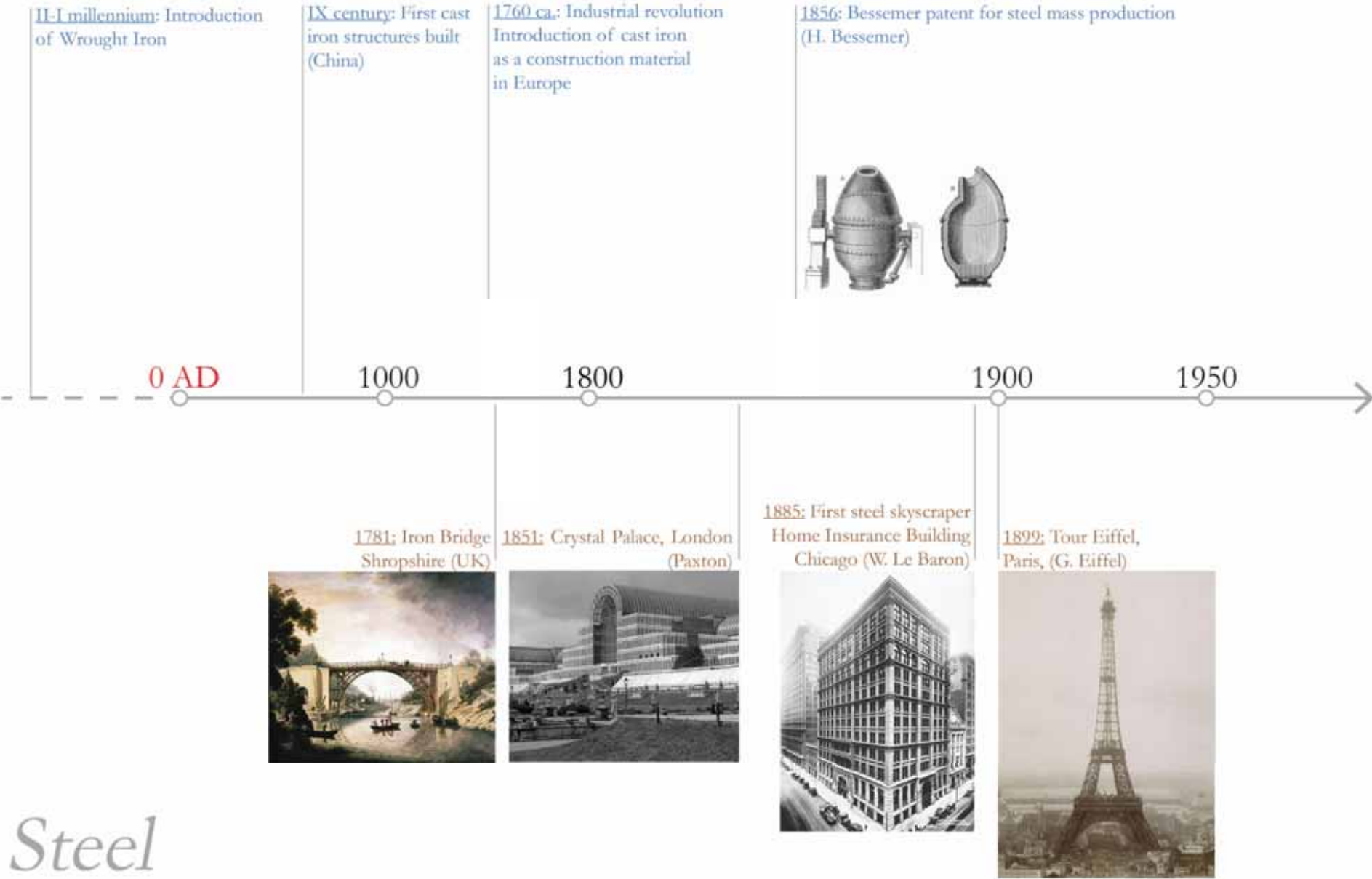
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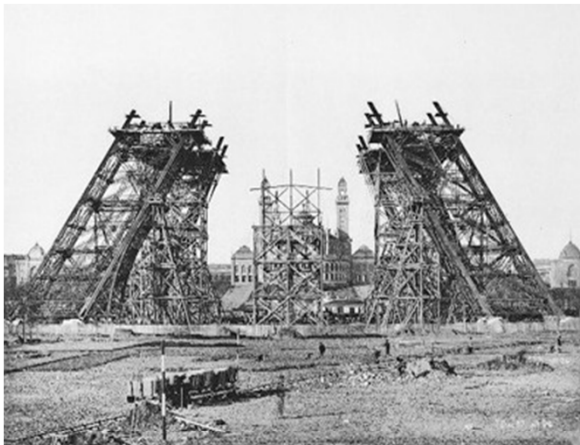


Steel



Steel





December 1887



March 1888



May 1888



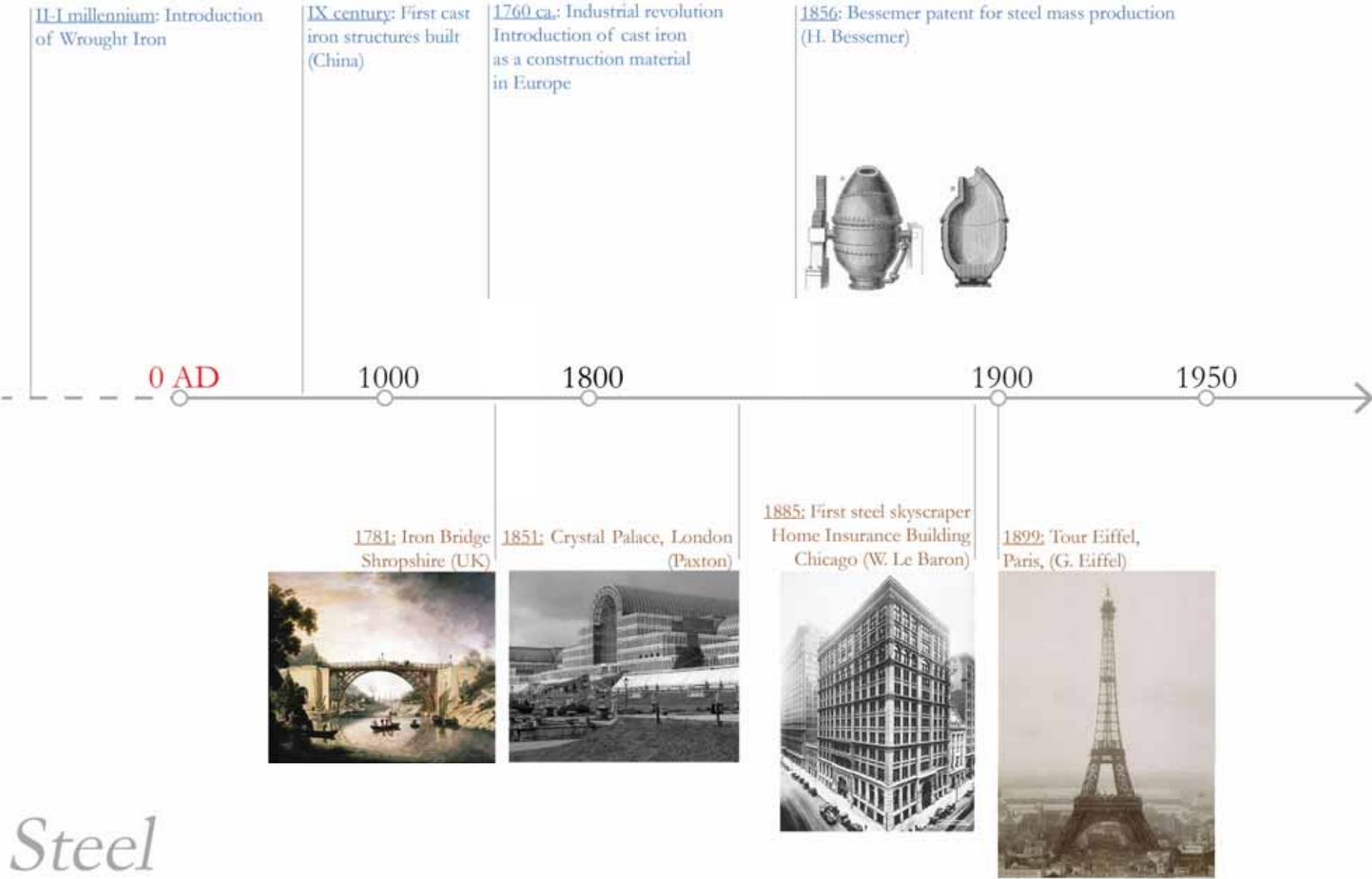
August 1888



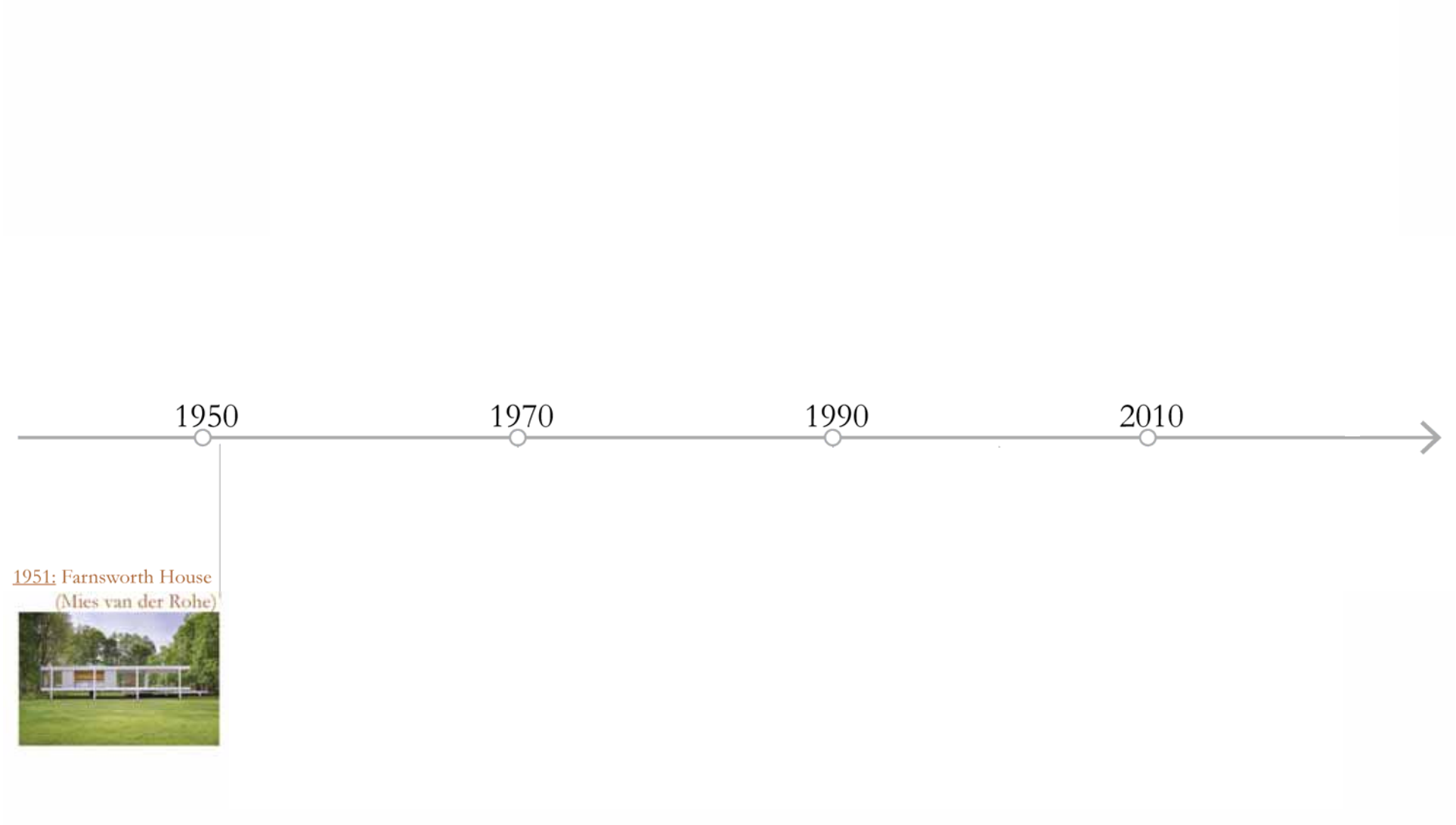
December 1888



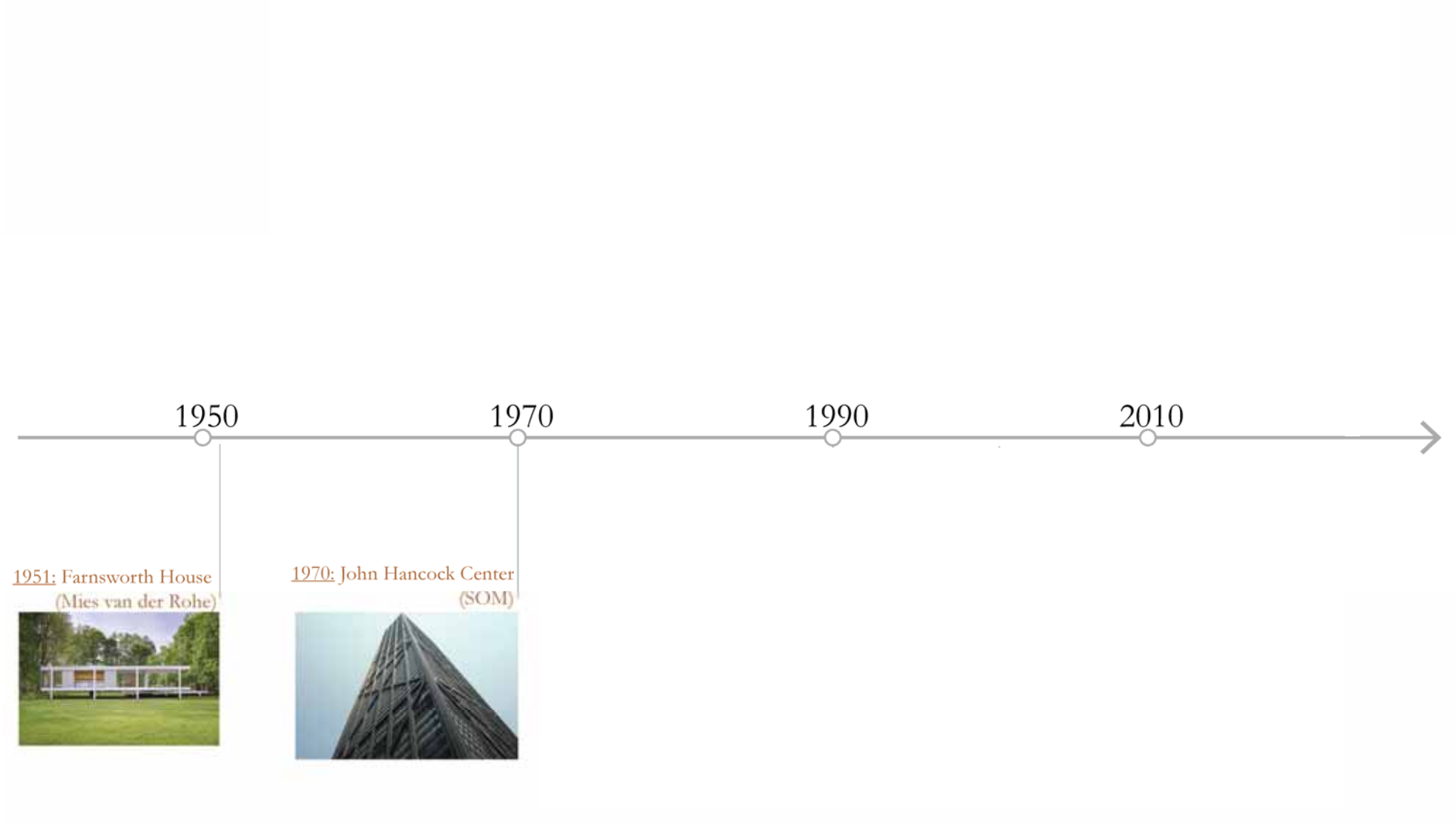
March 1889



Steel



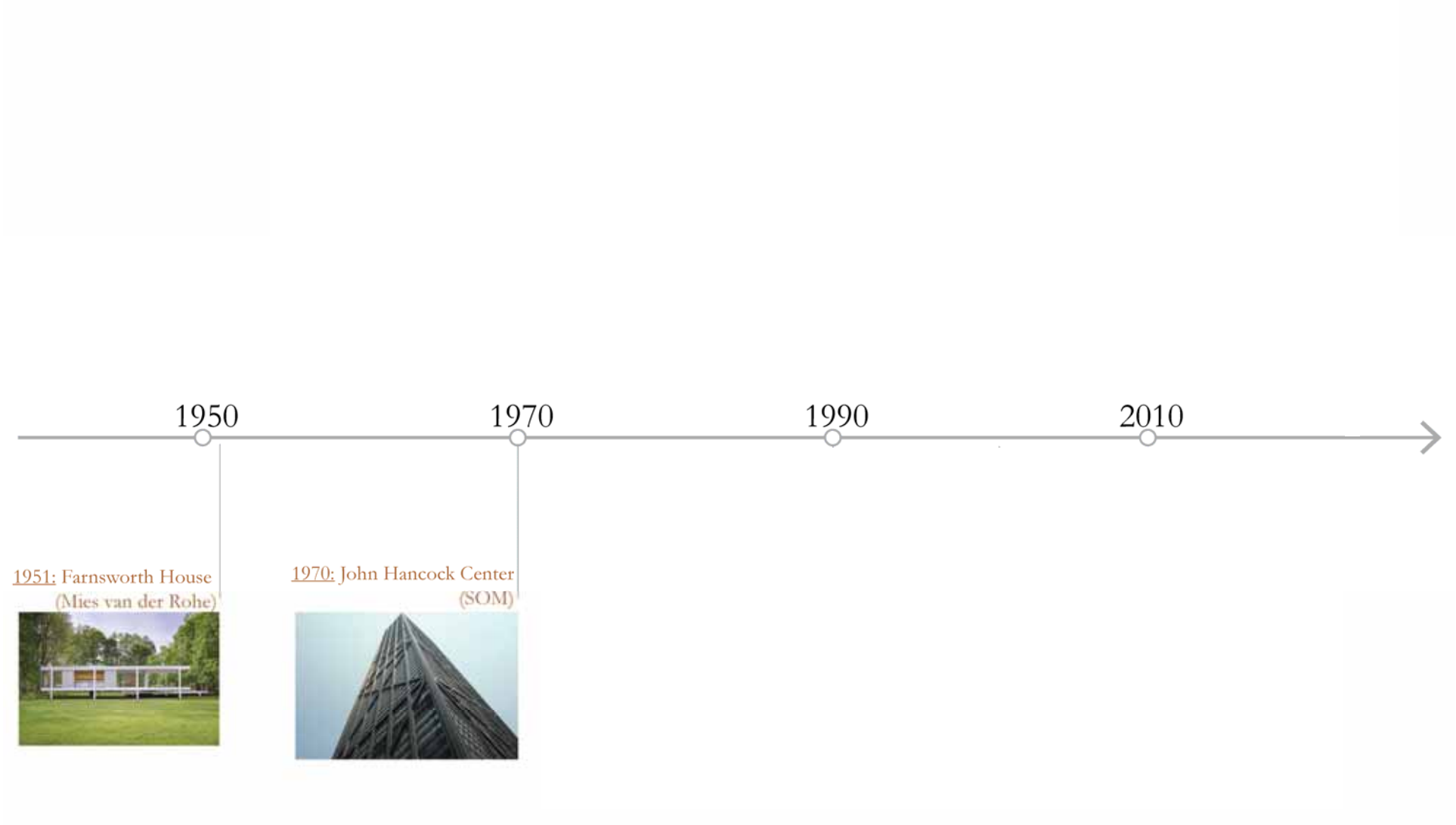
Steel



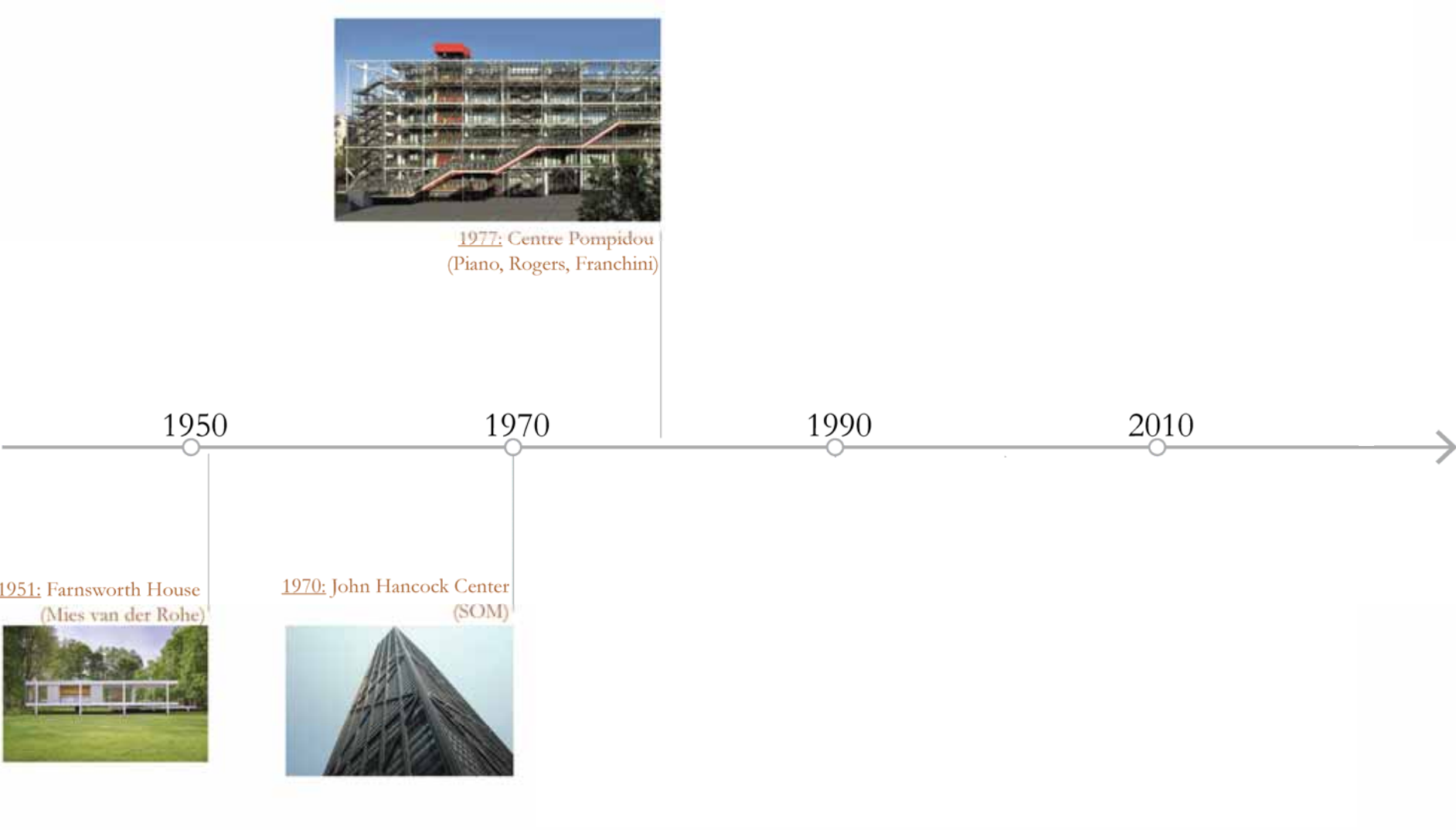
Steel



John Hancock Center, Chicago, 1970, eng. SOM



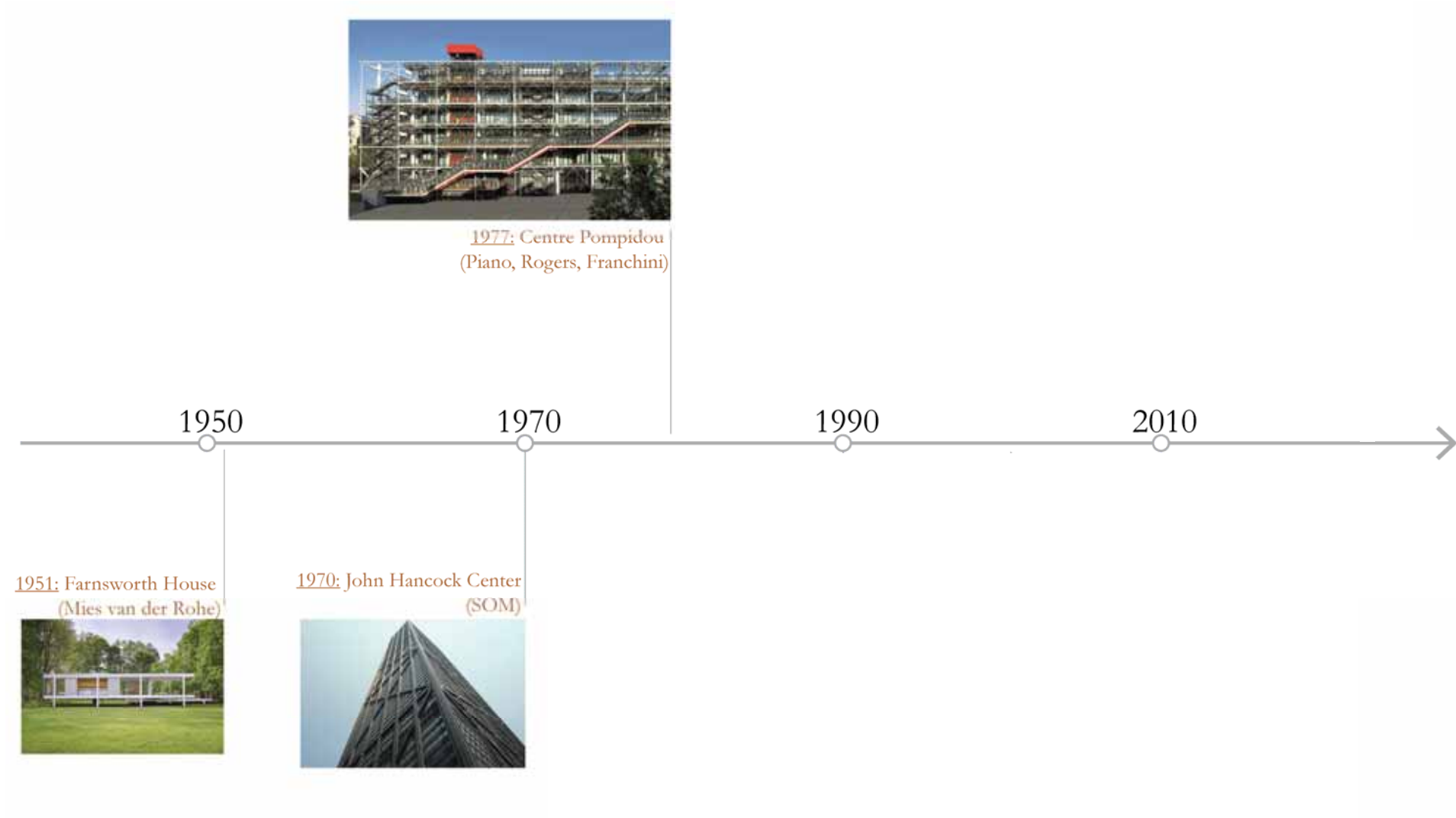
Steel



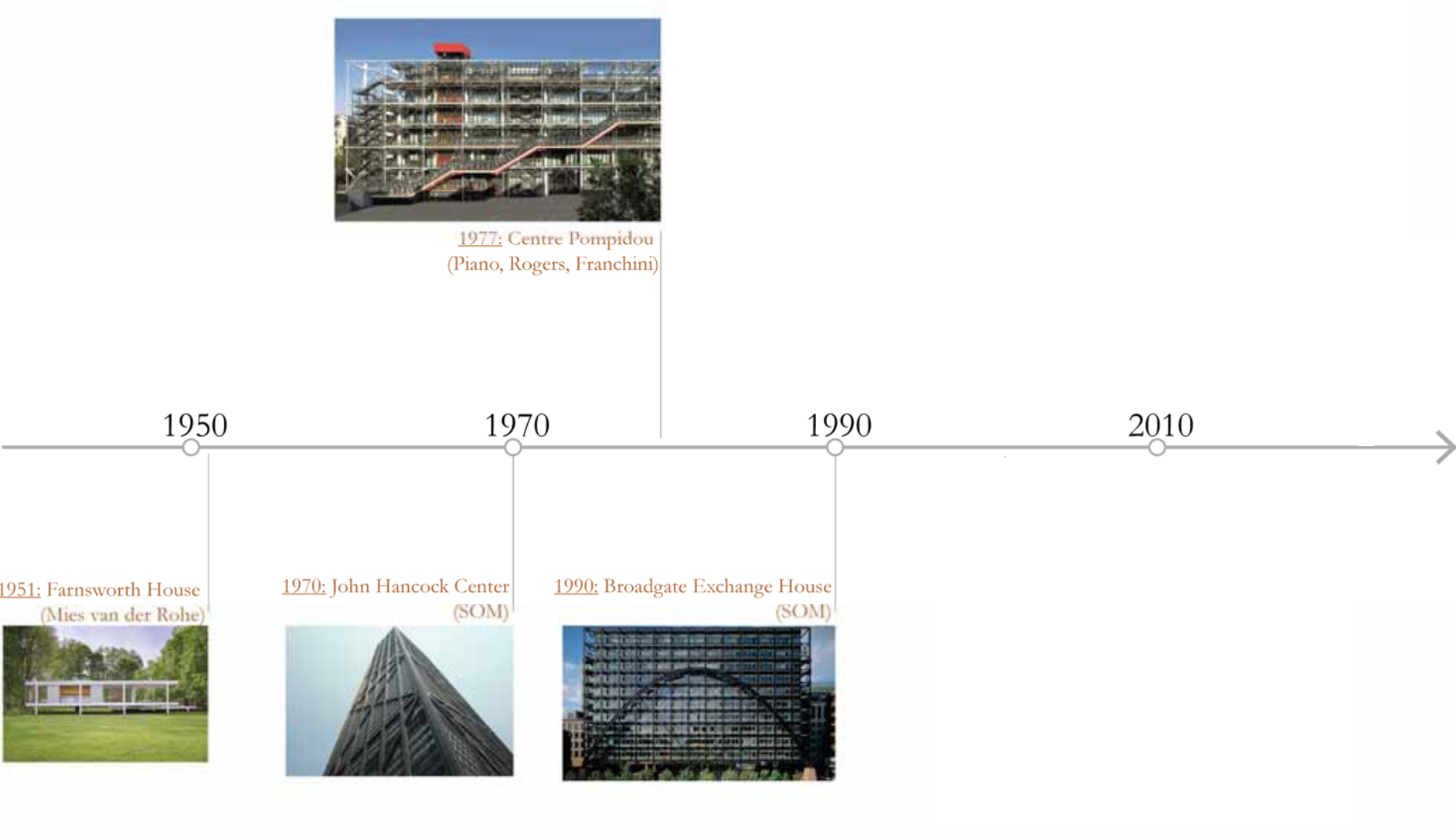
Steel



Centre Pompidou, Paris, 1977, arch. Renzo Piano, Richard Rogers, Gianfranco Franchini



Steel



Steel



Steel



Guggenheim Museum, Bilbao, 1997, arch. Frank Gehry



Steel



Steel



Sendai Mediateque, Sendai, 2001, arch. Toyo Ito



Steel



Steel



Metal 3D-printed bridge, MX3D and Arup, 2017



Steel

Stahl

Steel

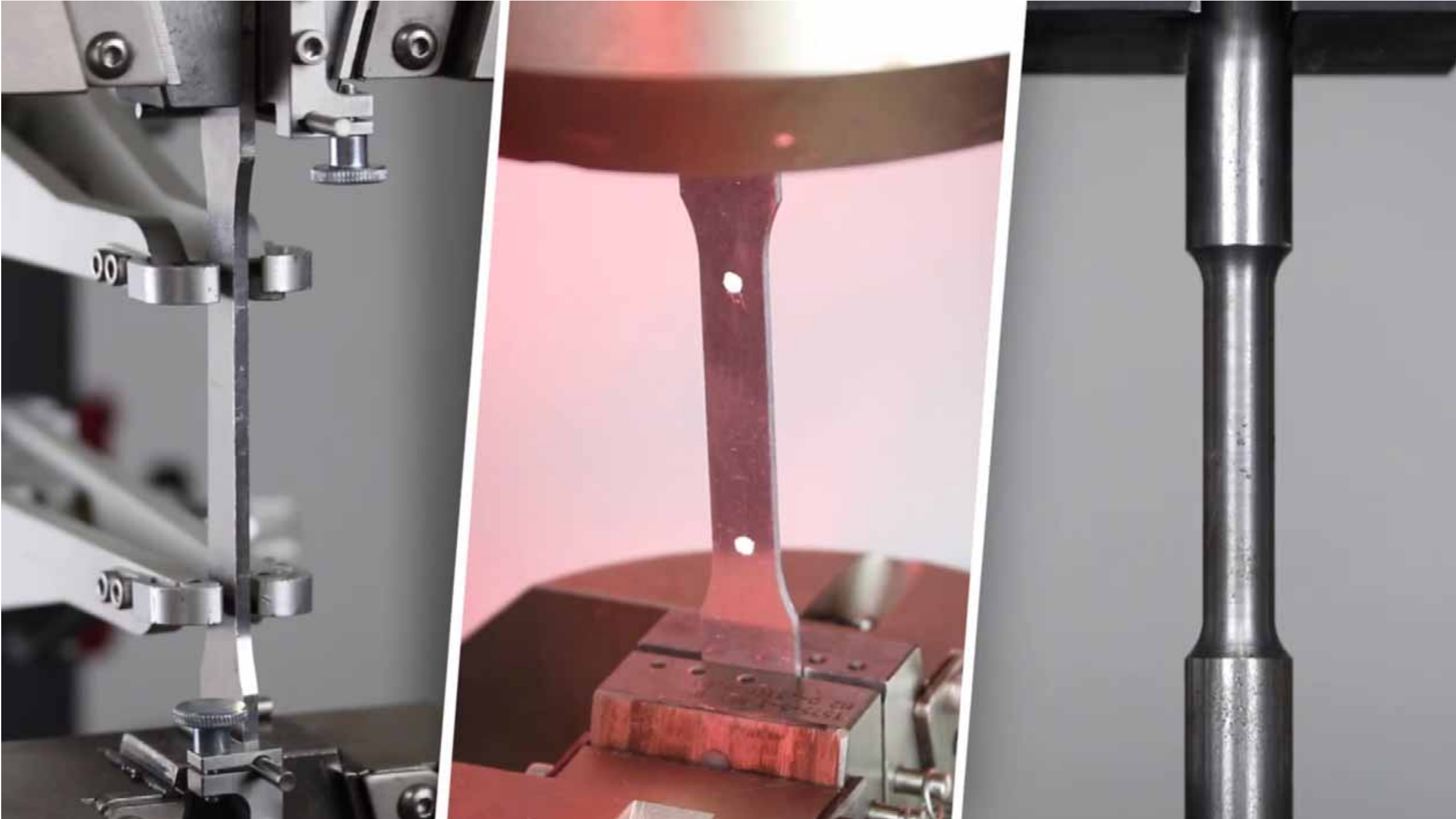
Einführung
Introduction

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Mechanical Properties

Bautechnologie
Building Technologies

Fallstudie: Haus R128
Case Study: House R128

Ausgewählte Projekte
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Zugversuch

Tensile Test

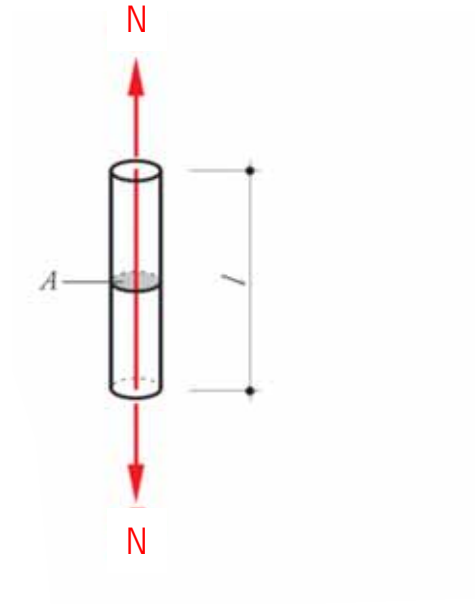


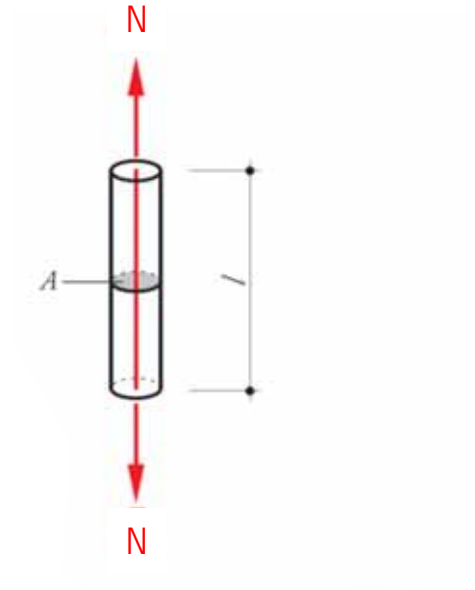
Zugversuch

Tensile Test



Zugversuch
Tensile Test

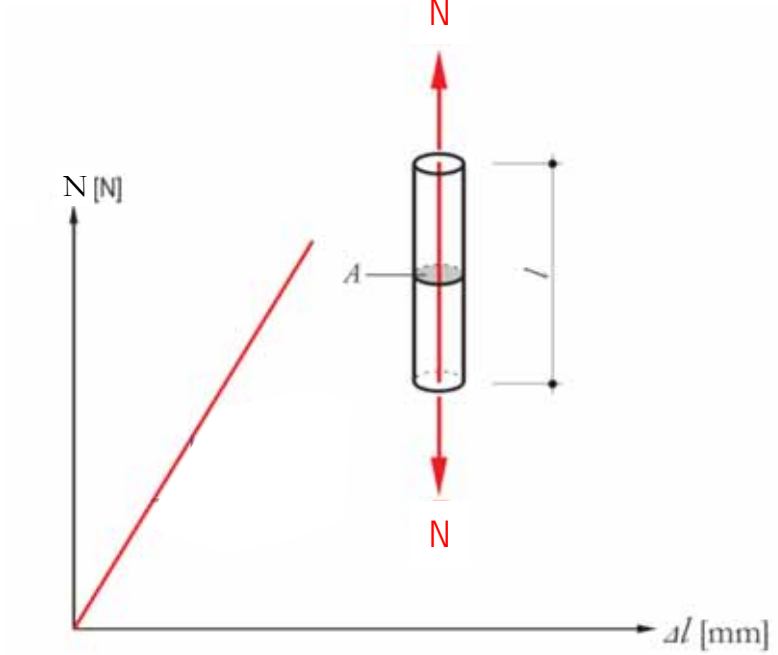




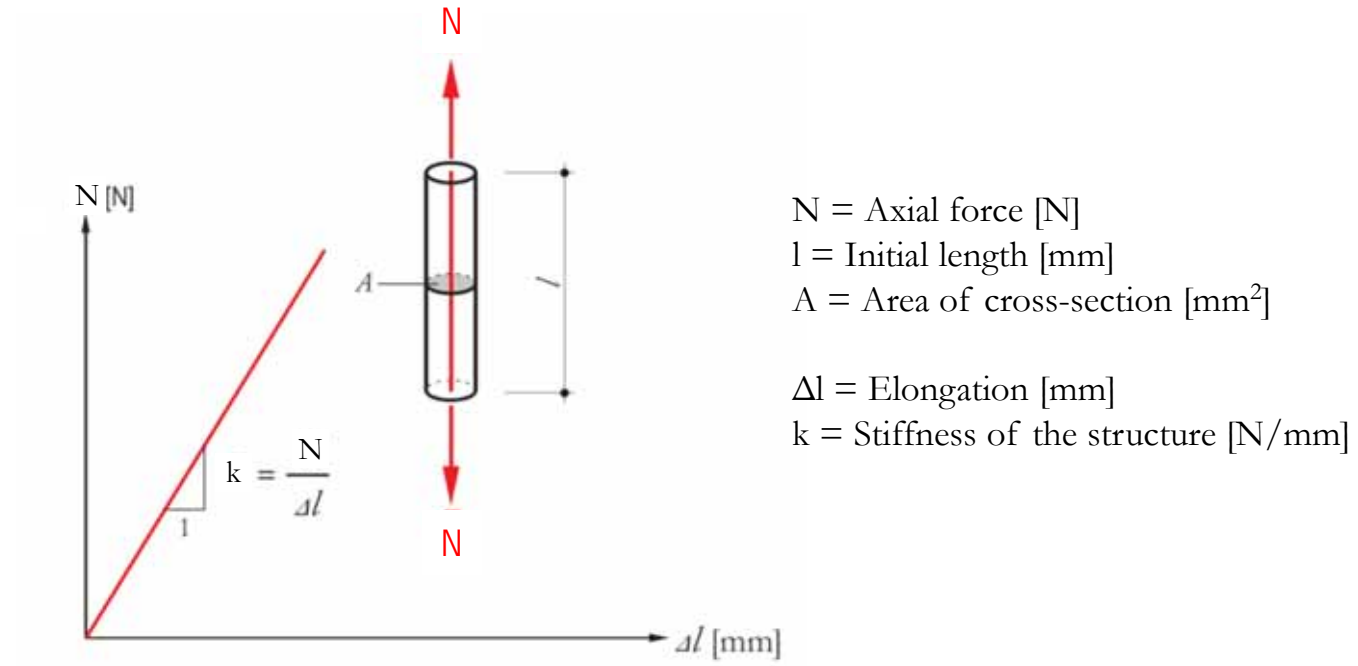
N = Axial force [N]

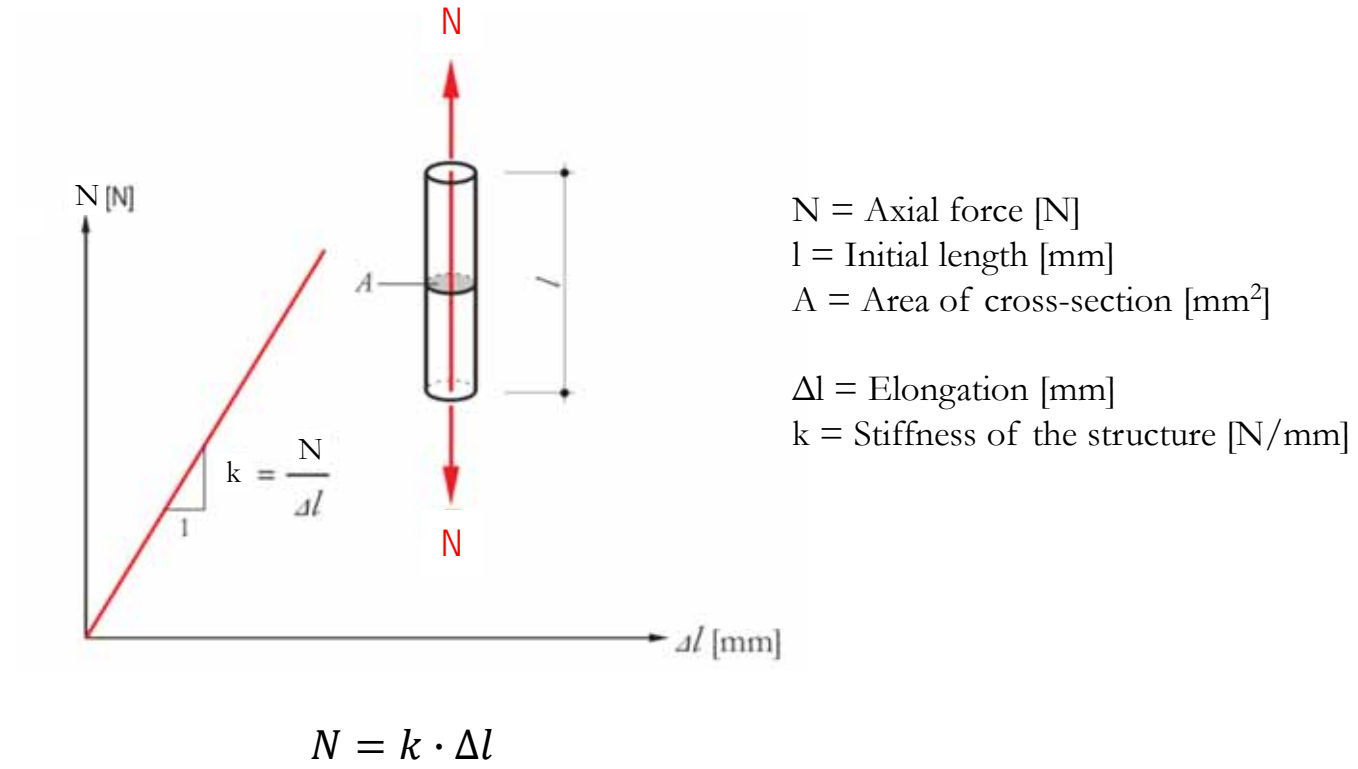
l = Initial length [mm]

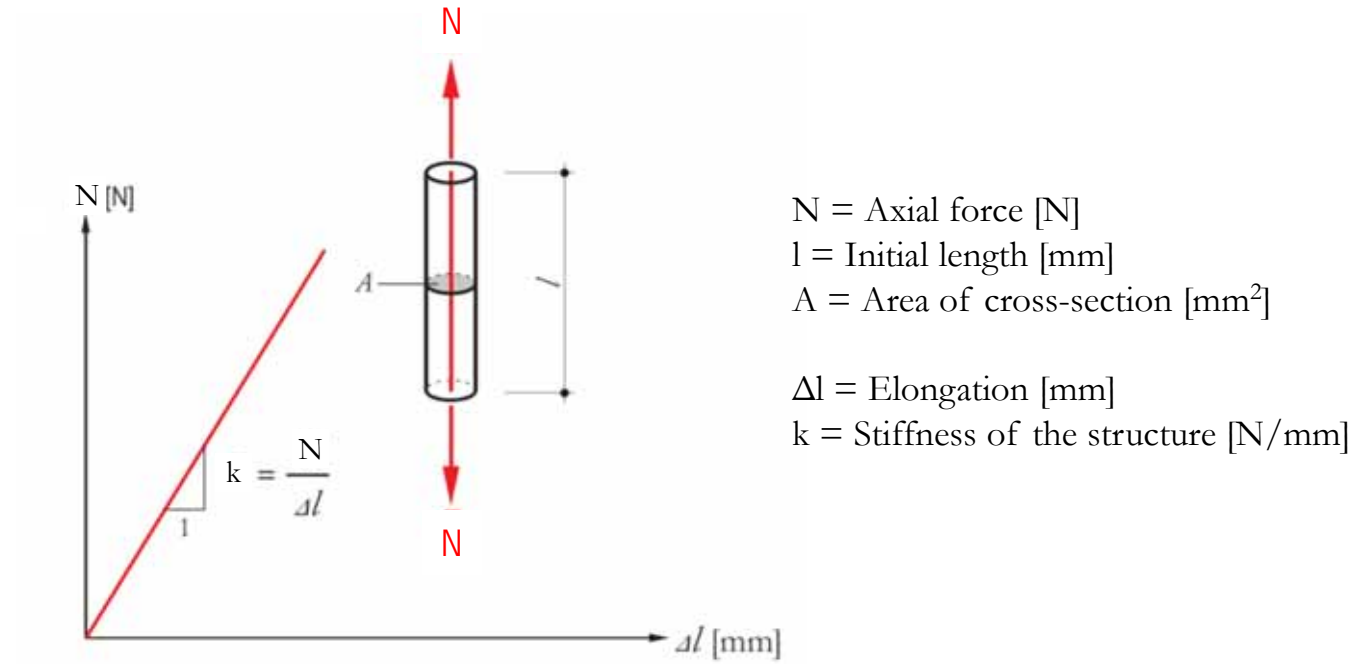
A = Area of cross-section [mm²]



N = Axial force [N]
 l = Initial length [mm]
 A = Area of cross-section [mm²]
 Δl = Elongation [mm]

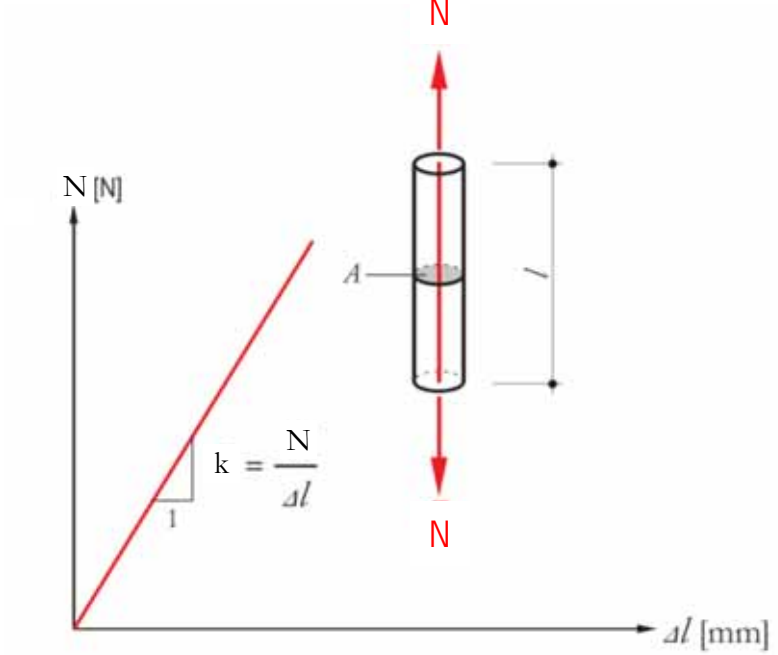






$$N = k \cdot \Delta l$$

$$k = \frac{E \cdot A}{l}$$



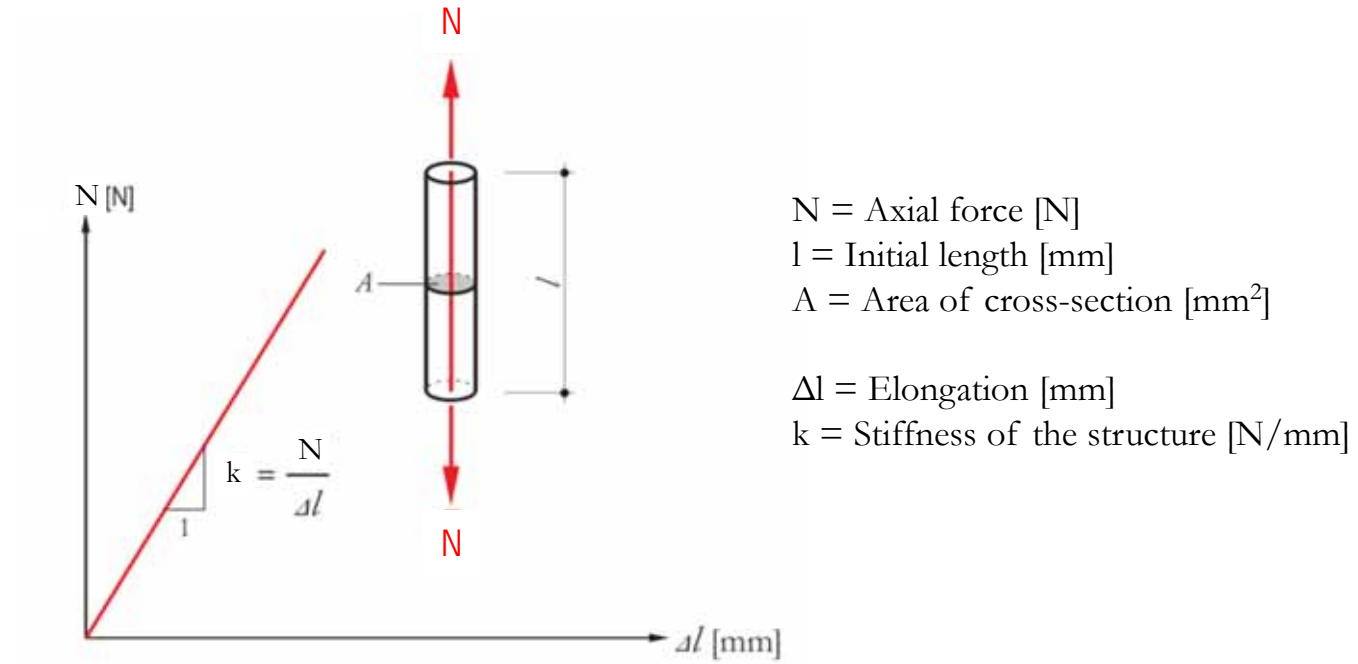
N = Axial force [N]
 l = Initial length [mm]
 A = Area of cross-section [mm²]

Δl = Elongation [mm]
 k = Stiffness of the structure [N/mm]

$$N = k \cdot \Delta l$$

$$k = \frac{E \cdot A}{l}$$

Young's modulus [N/mm²]
 Stiffness of the material

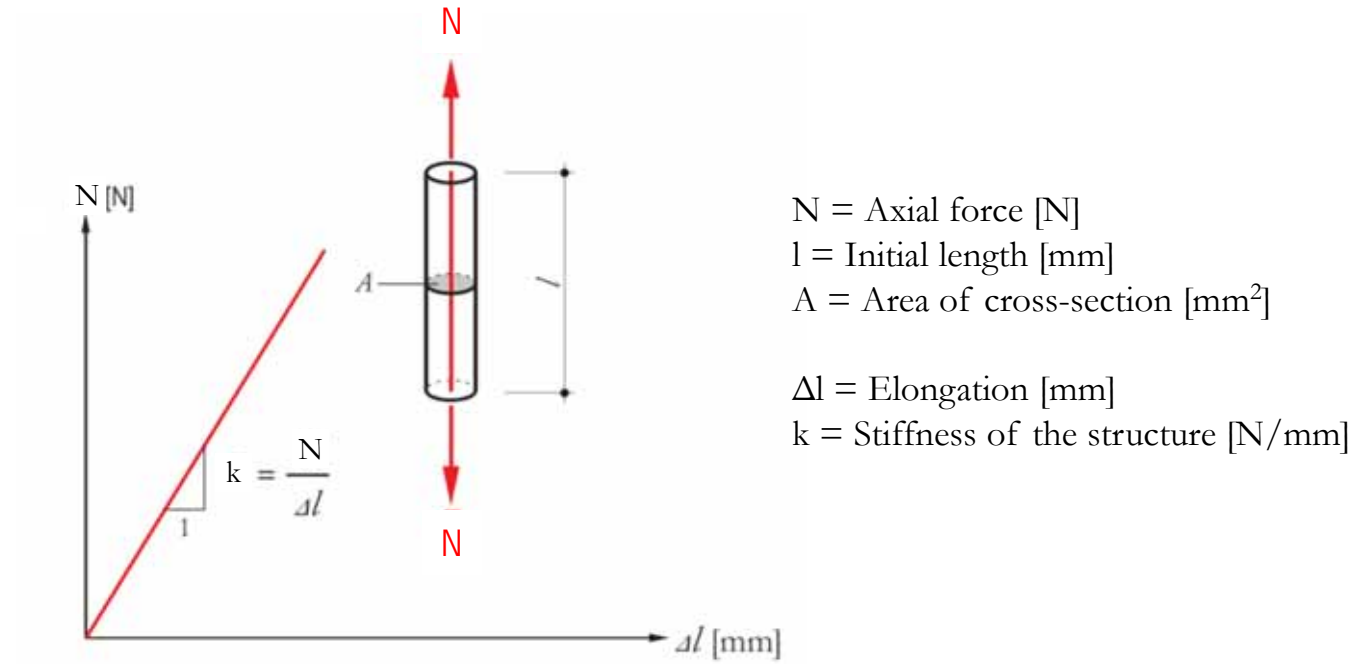


$$N = k \cdot \Delta l$$

$$k = \frac{E \cdot A}{l}$$

Young's modulus [N/mm²]
Stiffness of the material

$$N = \frac{E \cdot A}{l} \cdot \Delta l$$



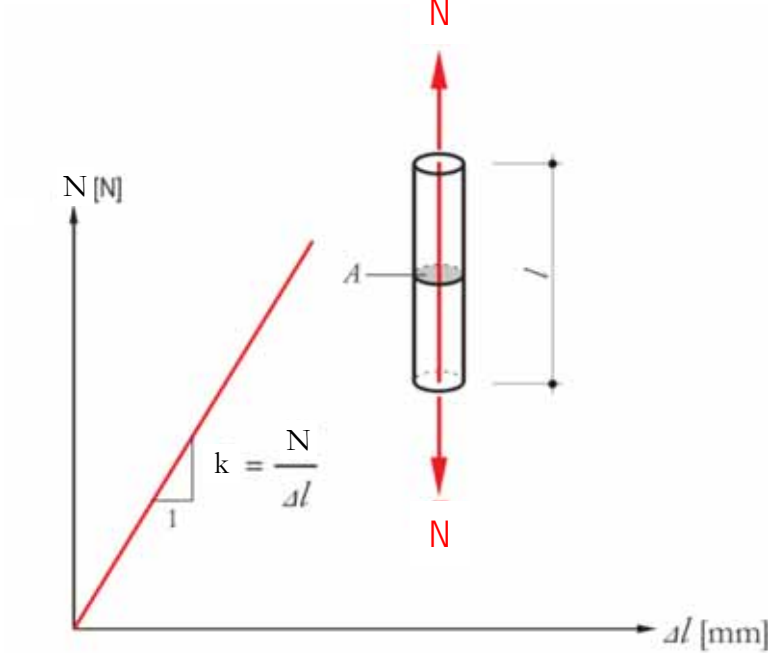
$$N = k \cdot \Delta l$$

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Young's modulus [N/mm²]
Stiffness of the material

$$N = \frac{E \cdot A}{l} \cdot \Delta l$$

$$\frac{N}{A} = E \cdot \frac{\Delta l}{l}$$



N = Axial force [N]
 l = Initial length [mm]
 A = Area of cross-section [mm²]
 Δl = Elongation [mm]
 k = Stiffness of the structure [N/mm]

$$N = k \cdot \Delta l$$

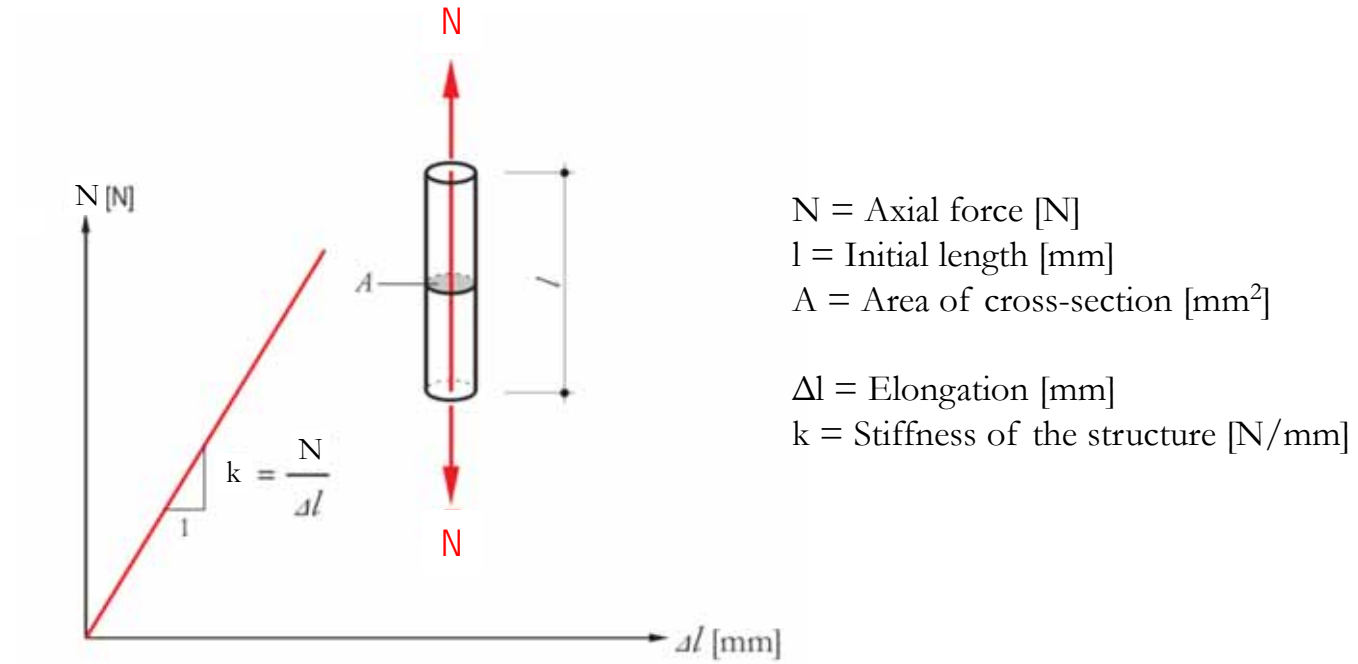
$$k = \frac{E \cdot A}{l}$$

E = Young's modulus [N/mm²]
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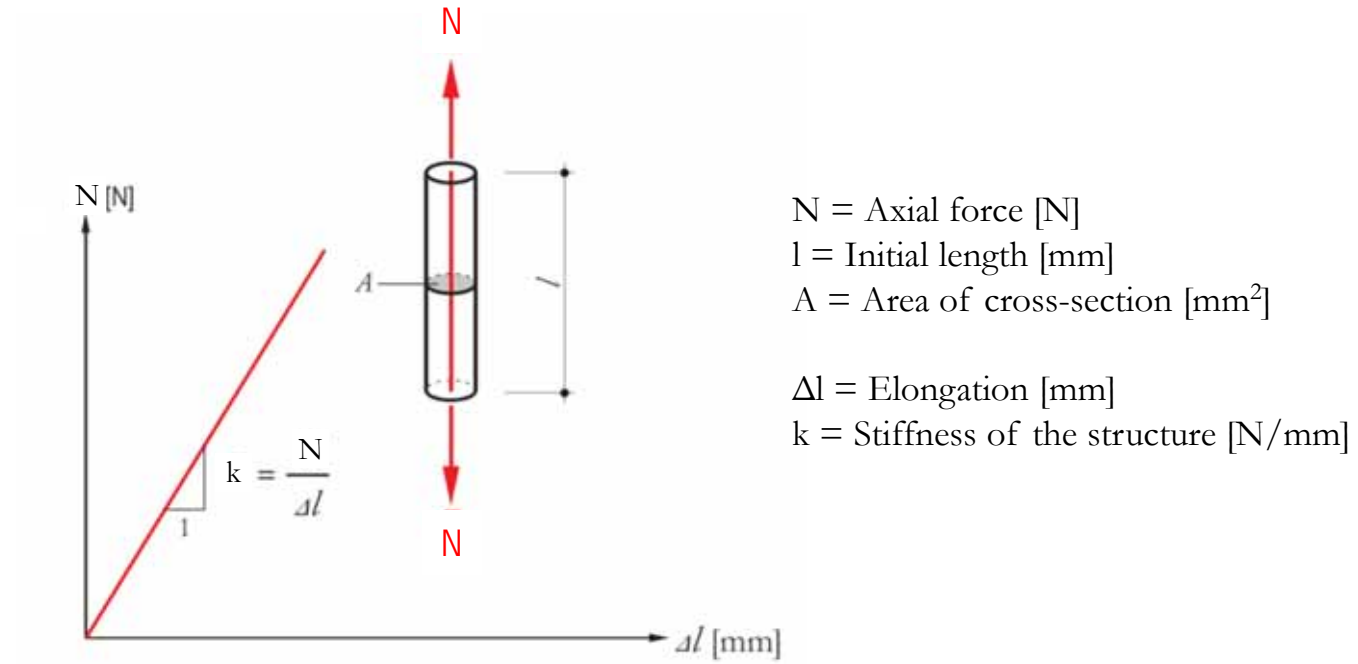
$$N = \frac{E \cdot A}{l} \cdot \Delta l$$

$$\frac{N}{A} = E \cdot \frac{\Delta l}{l}$$

$\frac{\Delta l}{l}$ = Strain ϵ [%]
 $\frac{N}{A}$ = Stress σ [N/mm²]



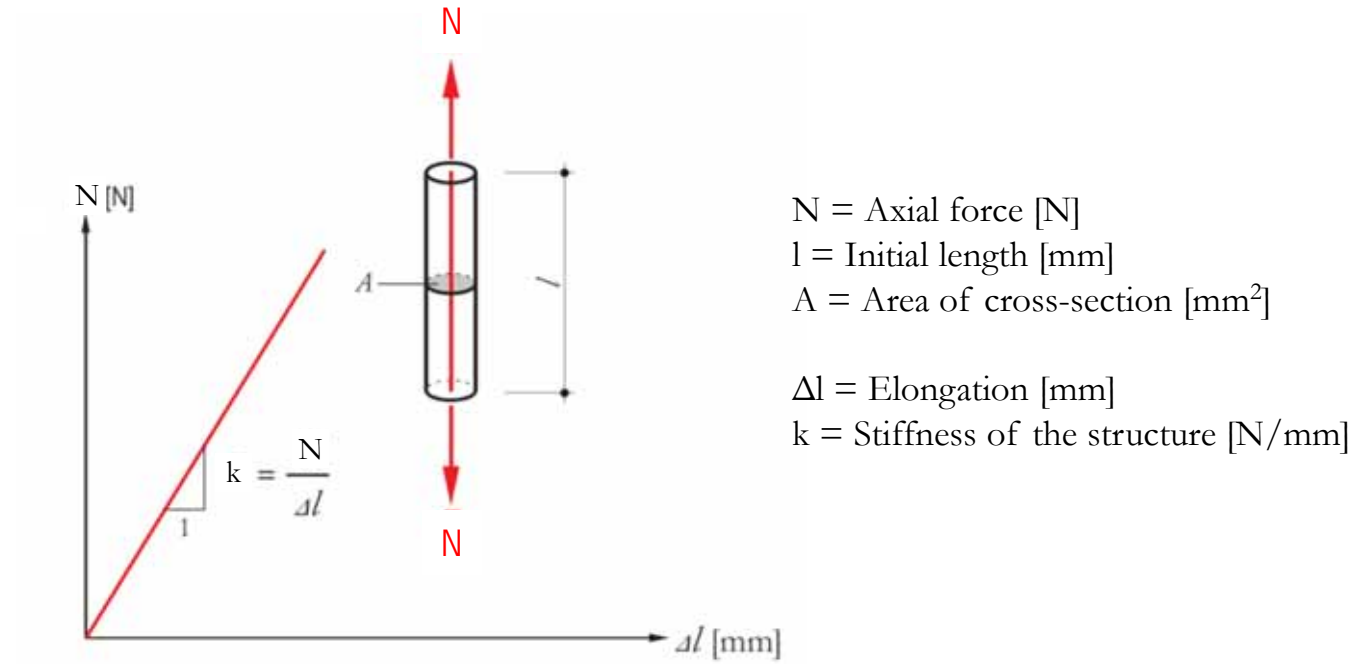
$$\frac{N}{A} = E \cdot \frac{\Delta l}{l}$$



$$\frac{N}{A} = E \cdot \frac{\Delta l}{l}$$

$$\frac{N}{A} = \sigma \text{ ————— Stress } \sigma \text{ [N/mm}^2\text{]}$$

$$\frac{\Delta l}{l} = \varepsilon \text{ ————— Strain } \varepsilon \text{ [\%]}$$

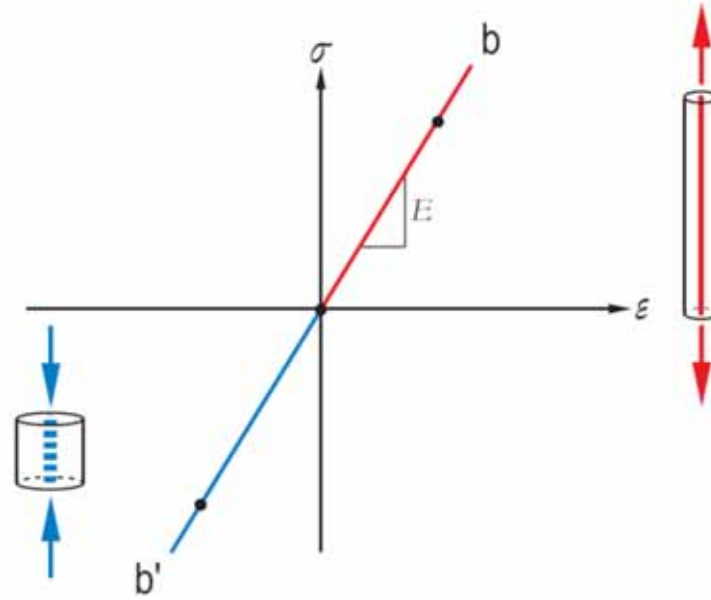


$$\frac{N}{A} = E \cdot \frac{\Delta l}{l}$$

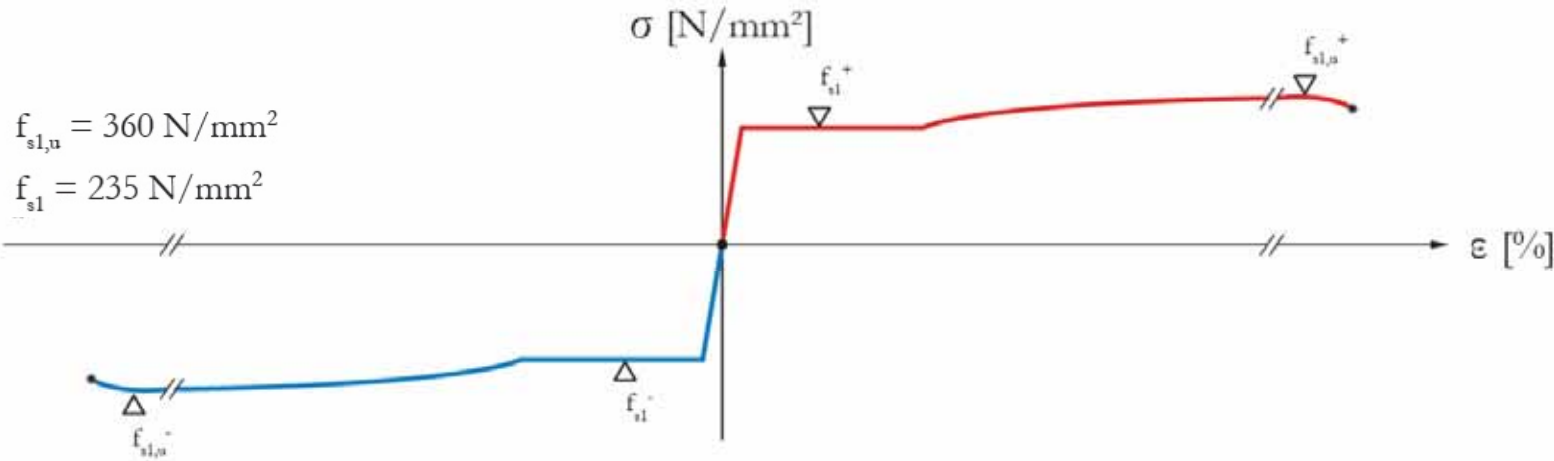
$$\frac{N}{A} = \sigma \text{ ————— Stress } \sigma \text{ [N/mm}^2\text{]}$$

$$\frac{\Delta l}{l} = \varepsilon \text{ ————— Strain } \varepsilon \text{ [\%]}$$

$$\sigma = E \cdot \varepsilon$$

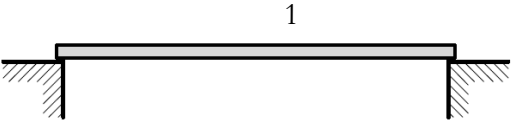
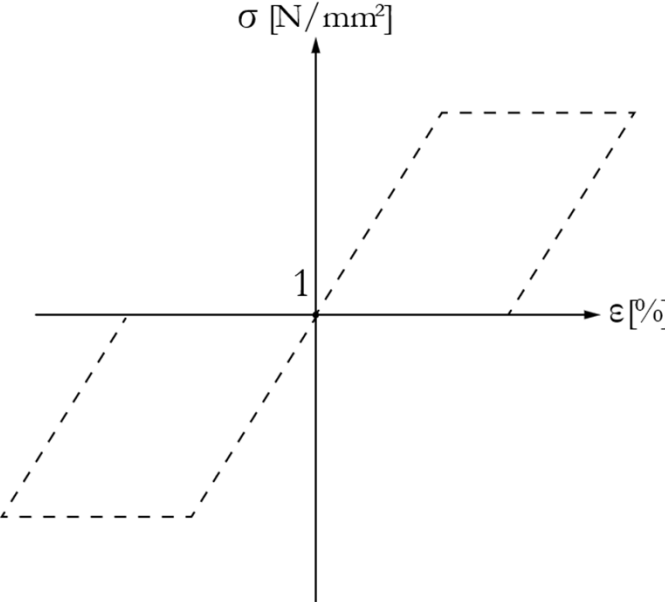


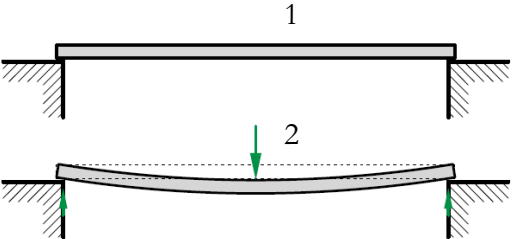
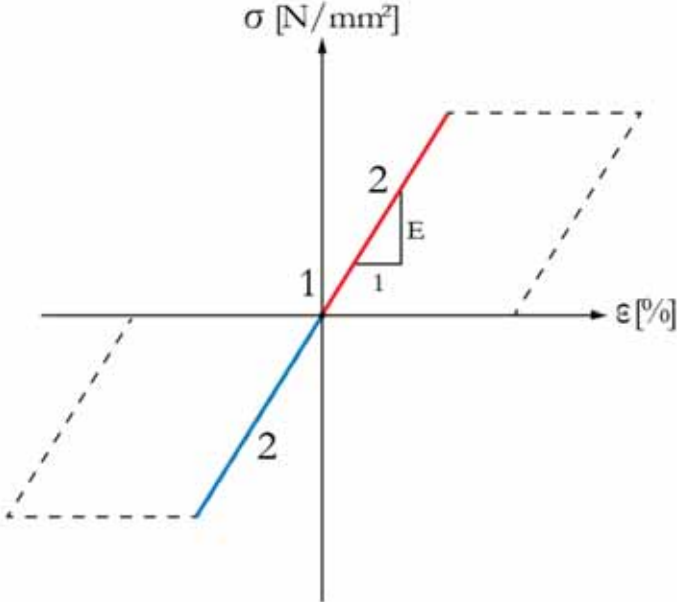
$$\sigma = E \cdot \varepsilon$$

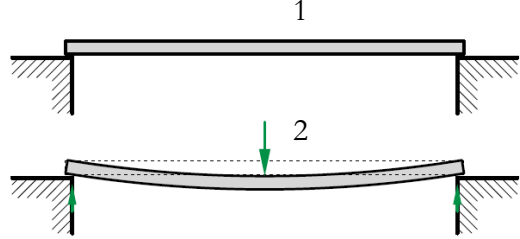
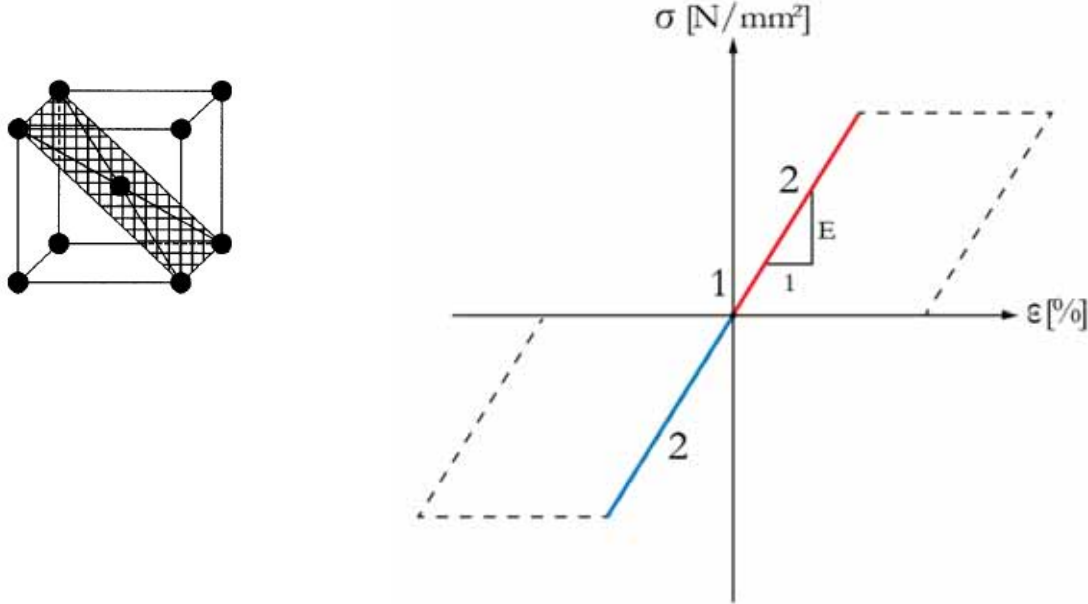


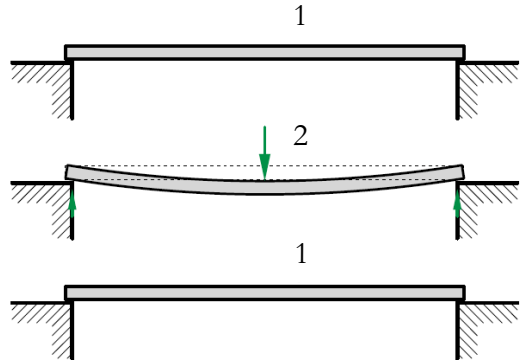
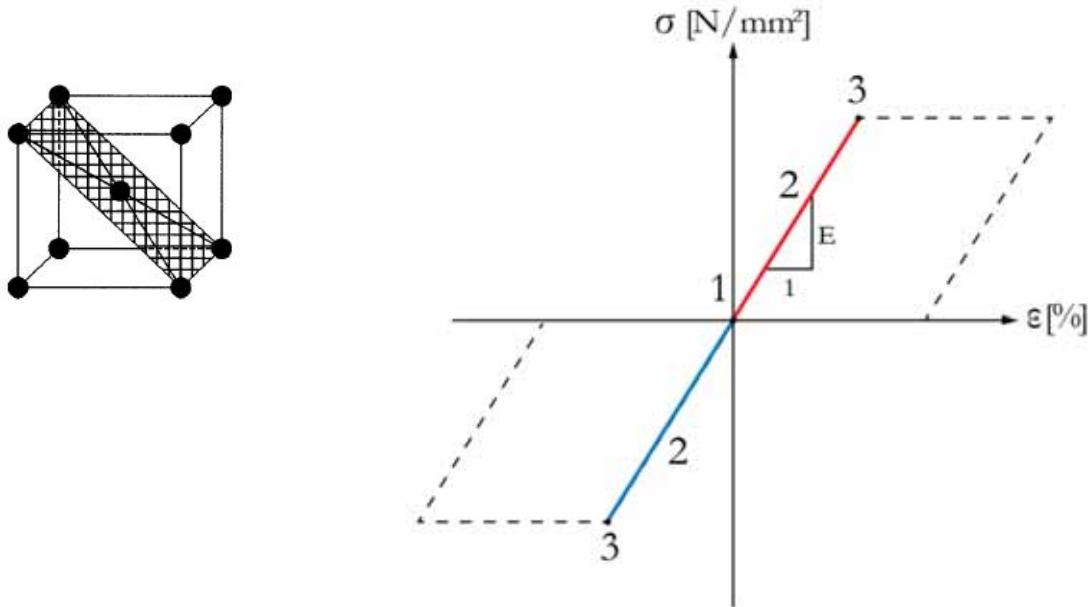
Stahl S235, Spannungs-Dehnungs-Diagramm

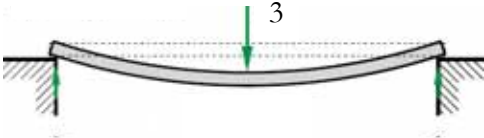
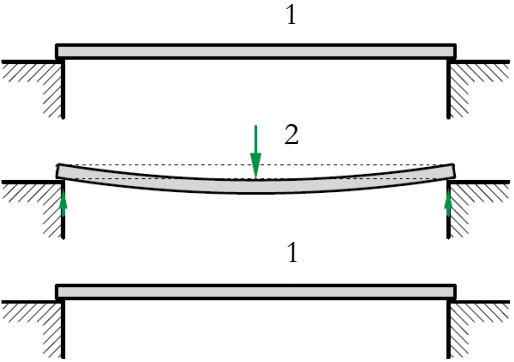
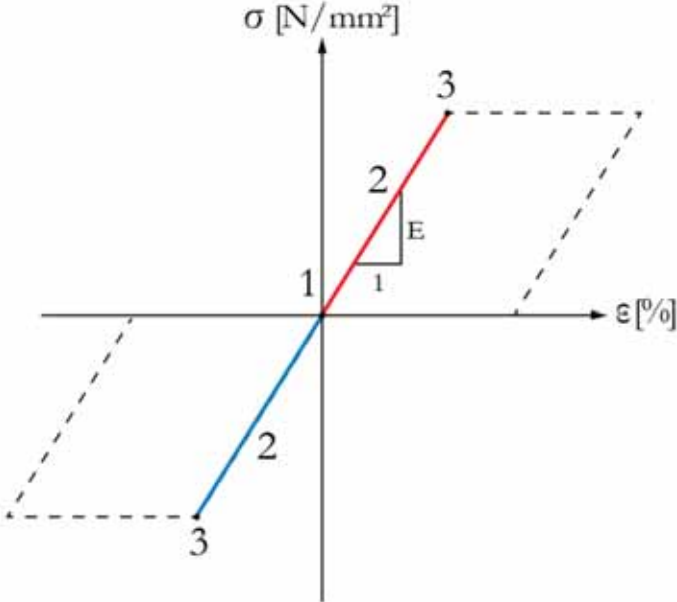
Steel S235, stress-strain diagram

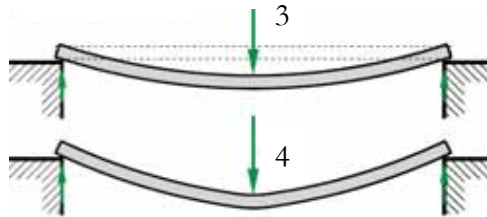
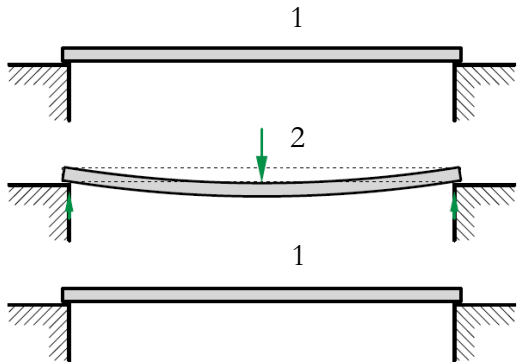
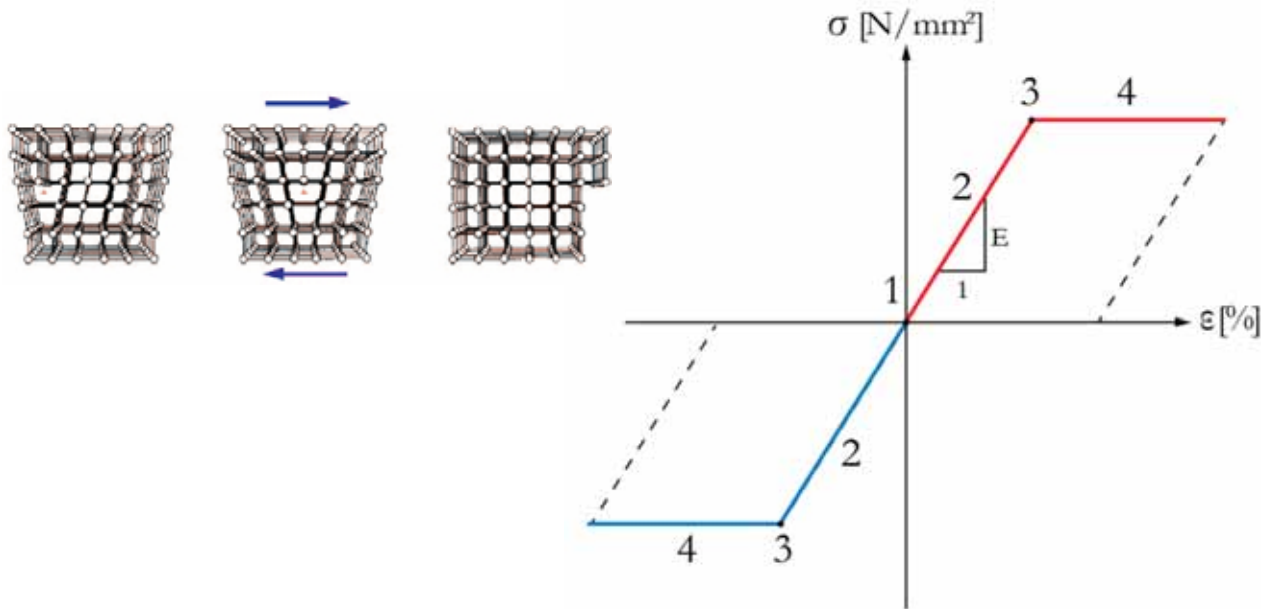


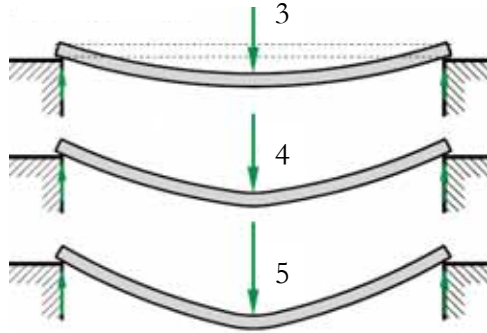
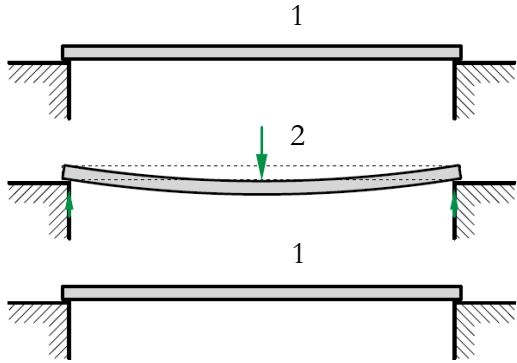
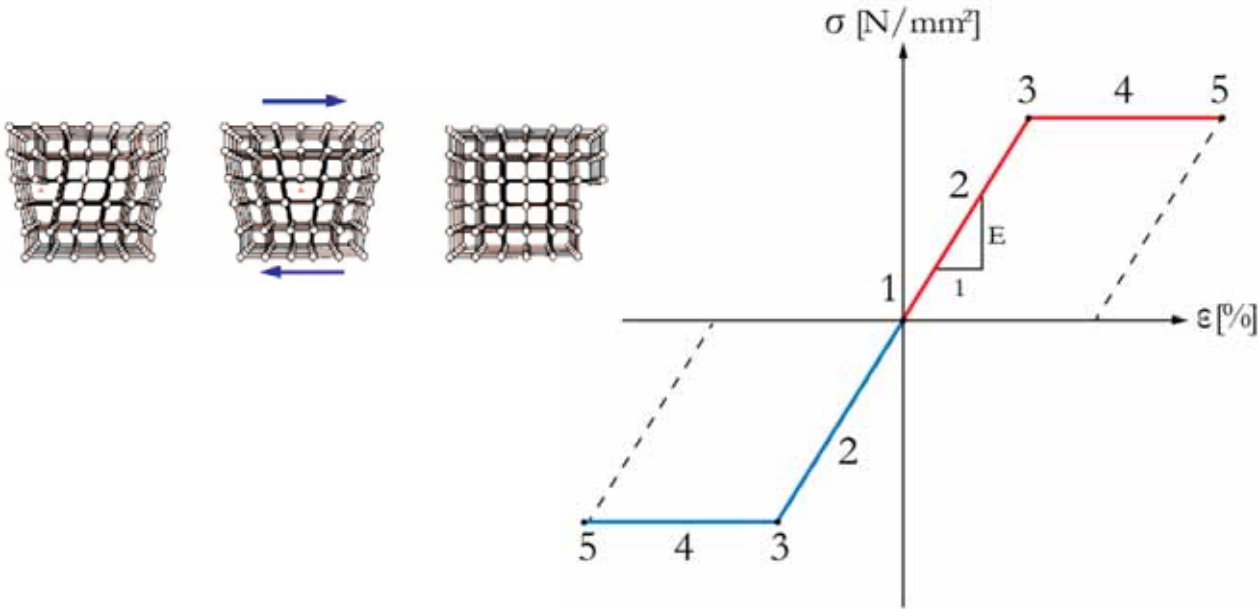


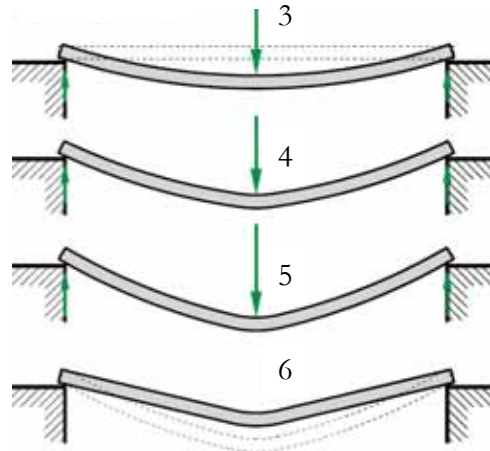
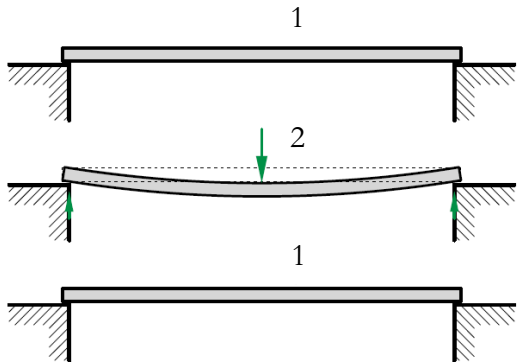
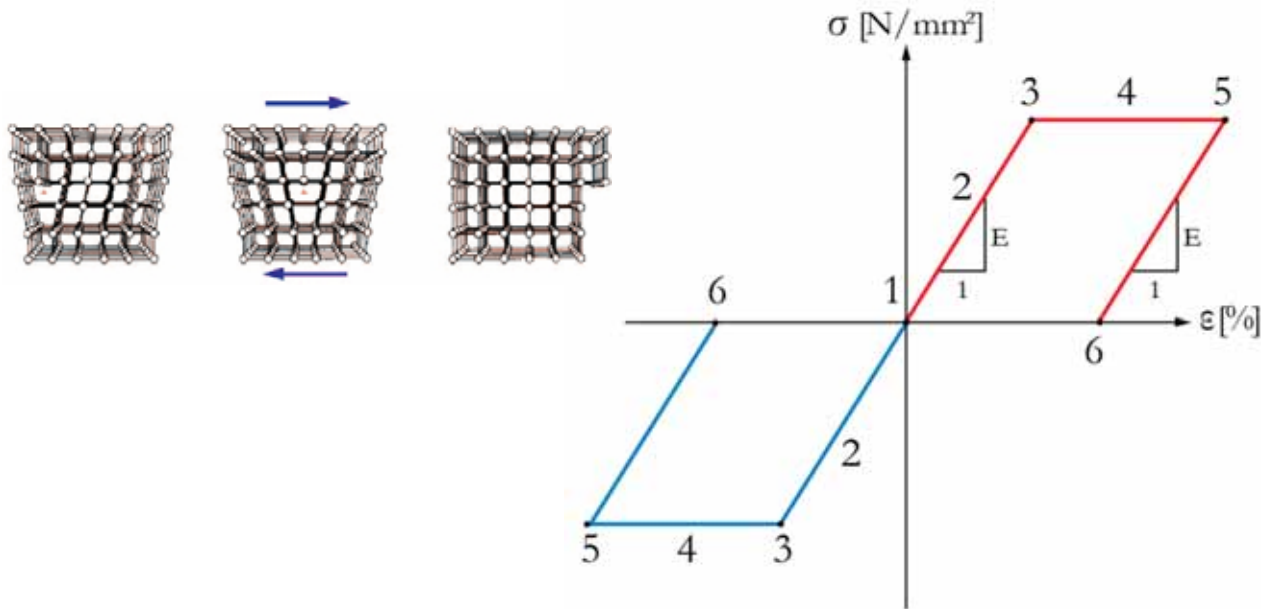




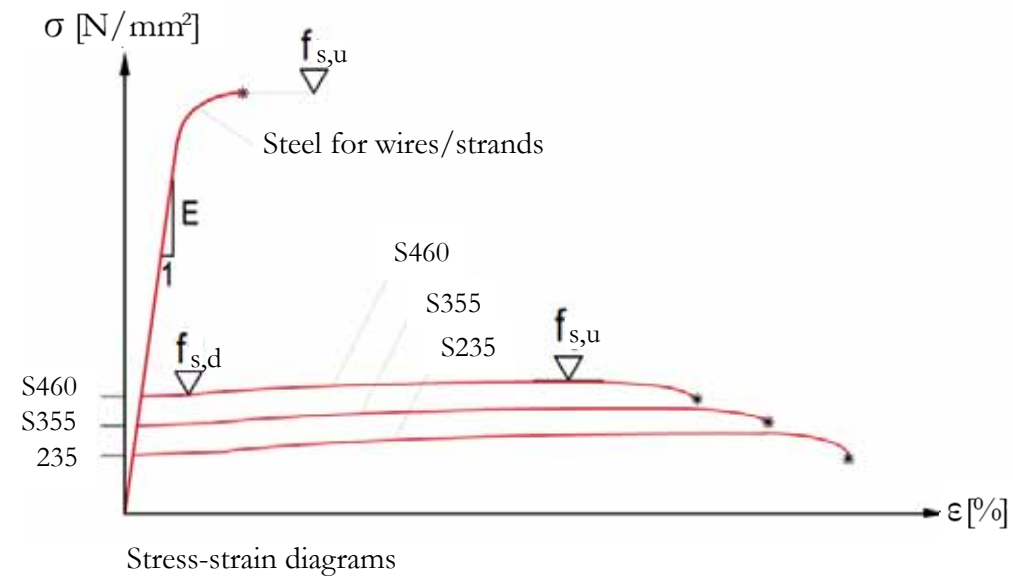


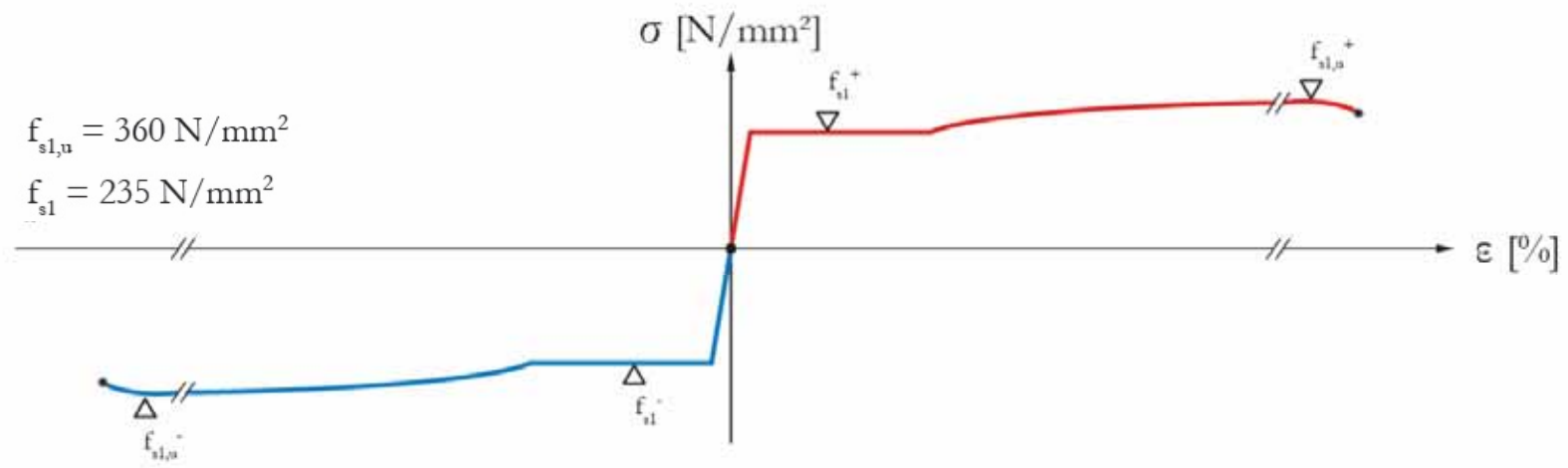




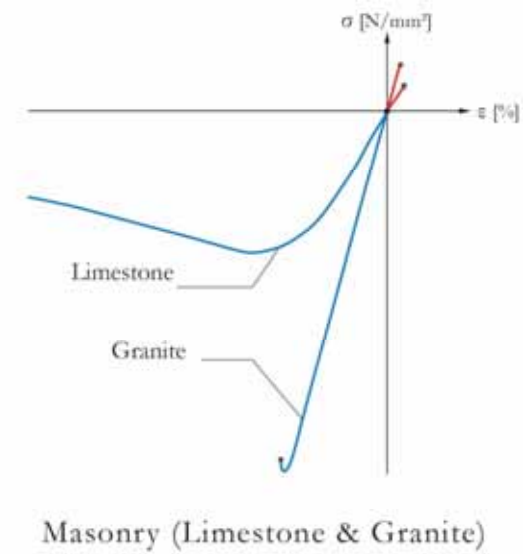
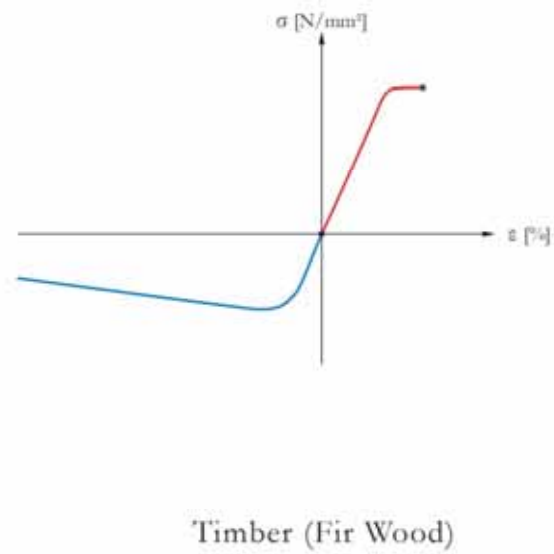
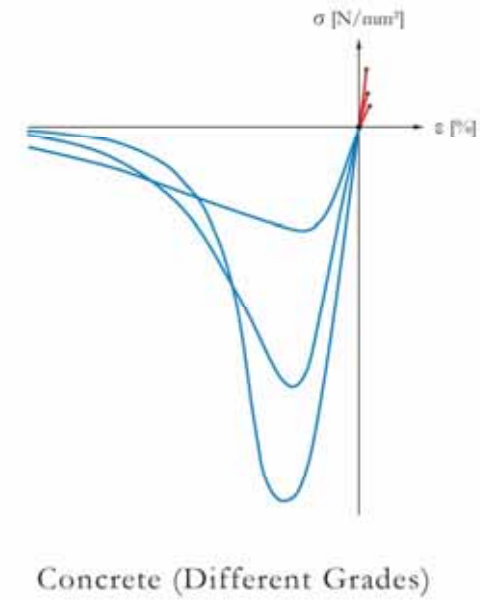
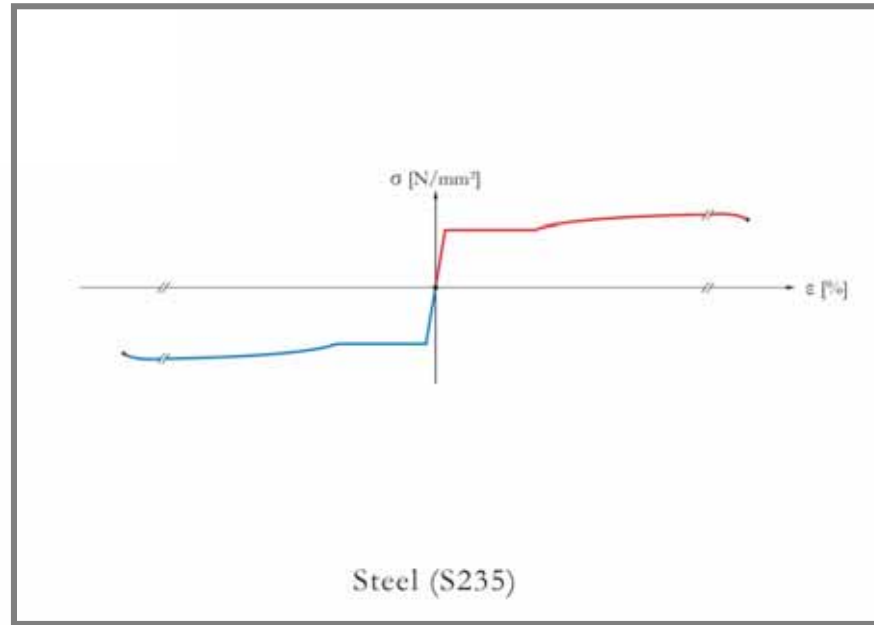


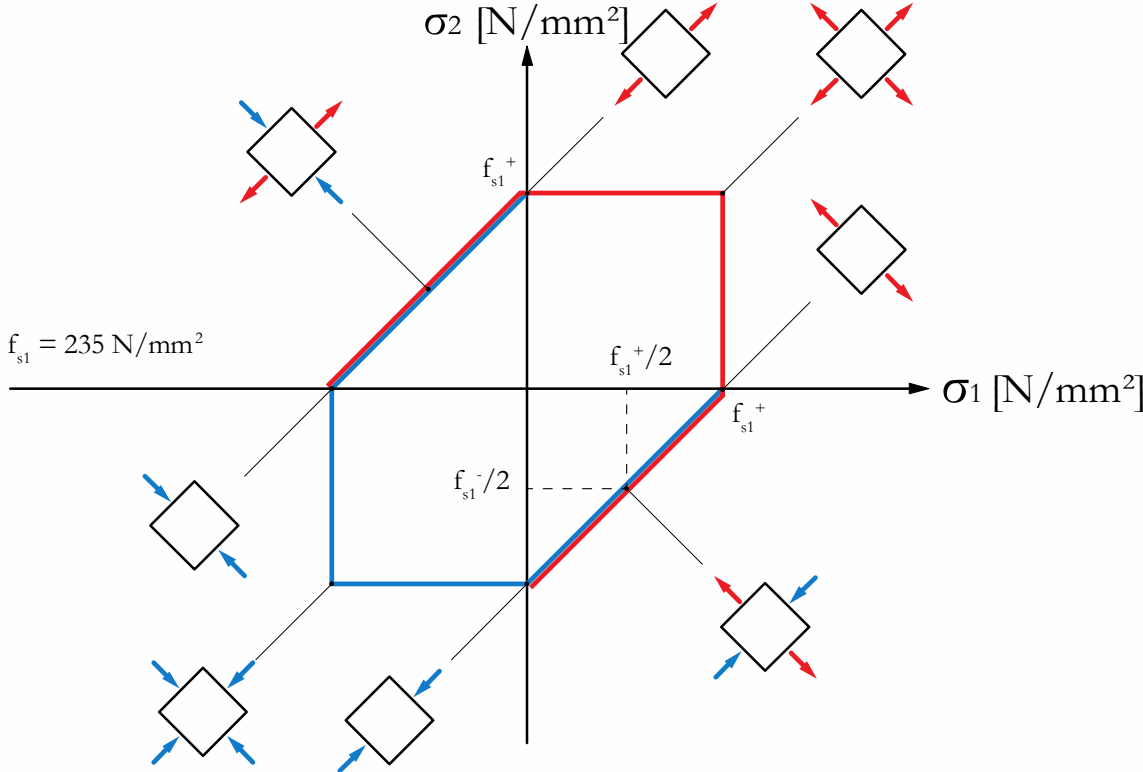
Steel type	Width w [mm]			
	$w \leq 40\text{mm}$		$40\text{mm} \leq w \leq 100\text{mm}$	
	$f_{s,d}$ [N/mm ²]	$f_{s,u}$ [N/mm ²]	$f_{s,d}$ [N/mm ²]	$f_{s,u}$ [N/mm ²]
S 235	235	360	215	340
S 275	275	430	255	410
S 355	355	510	335	490
S 460	460	550	430	530
Steel for wires/strands	1410 ÷ 1670		1570 ÷ 1860	

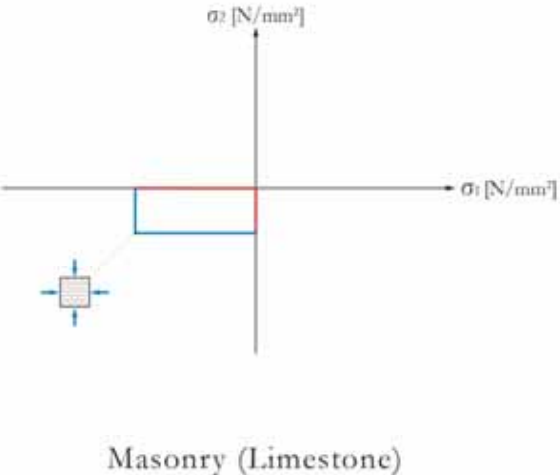
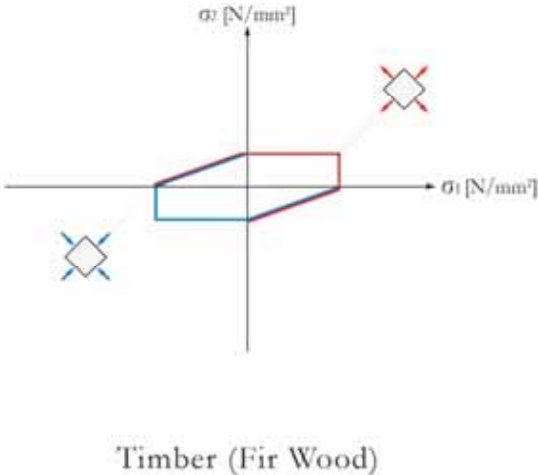
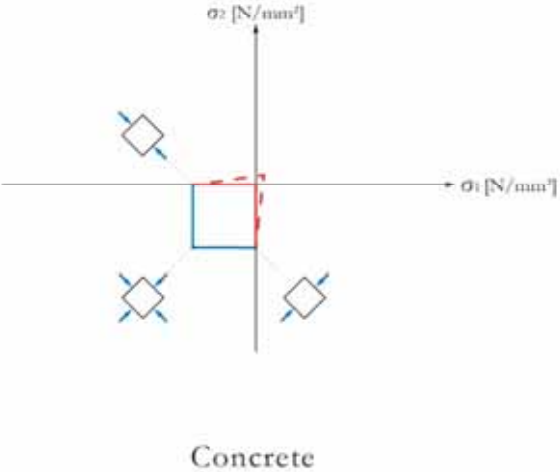
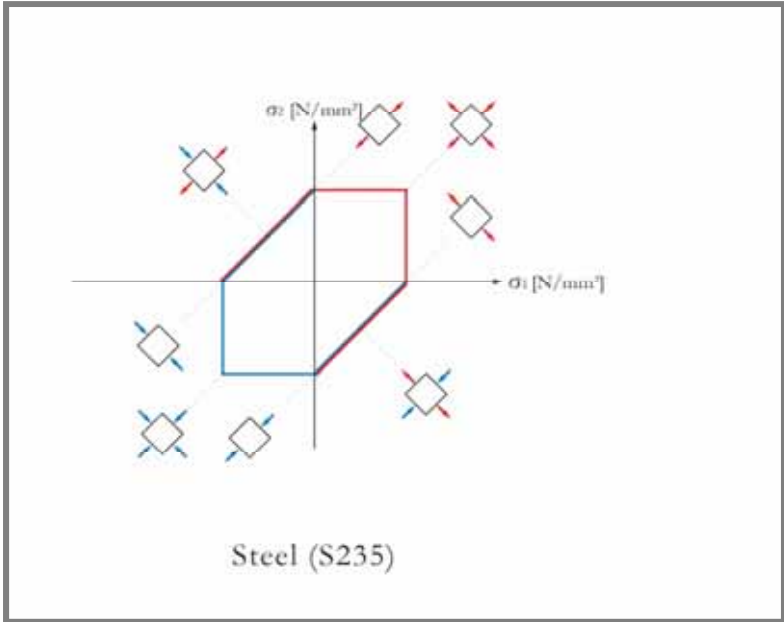


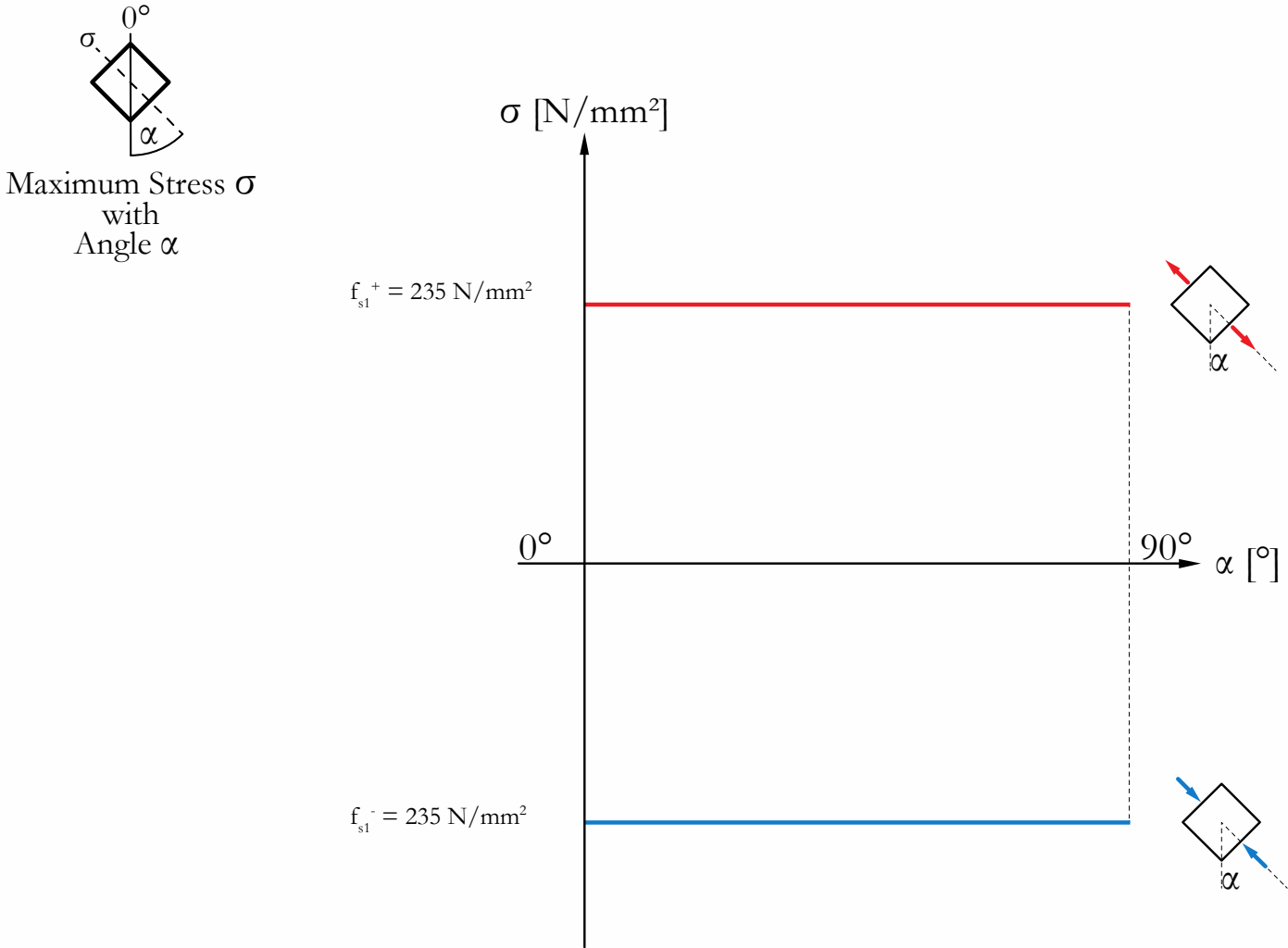


Stahl S235, Spannungs-Dehnungs-Diagramm
Steel S235, stress-strain diagram



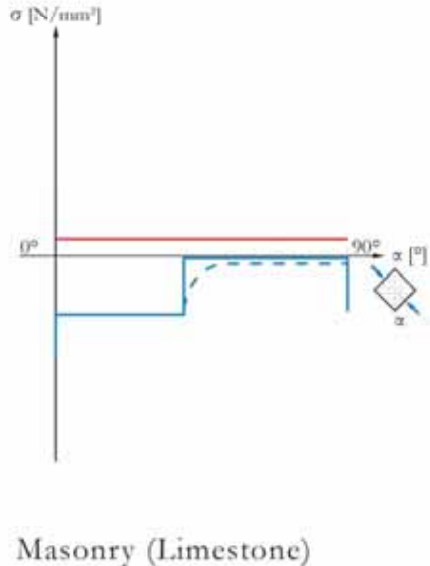
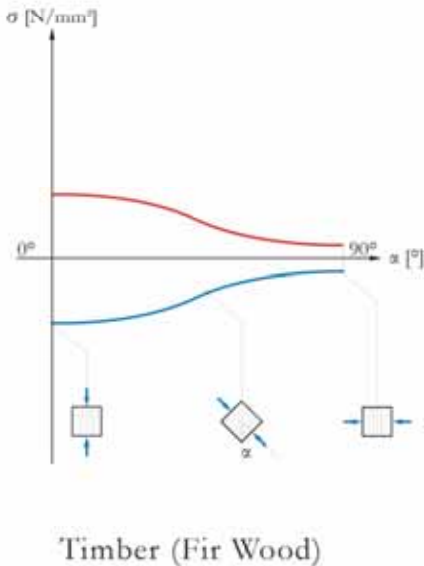
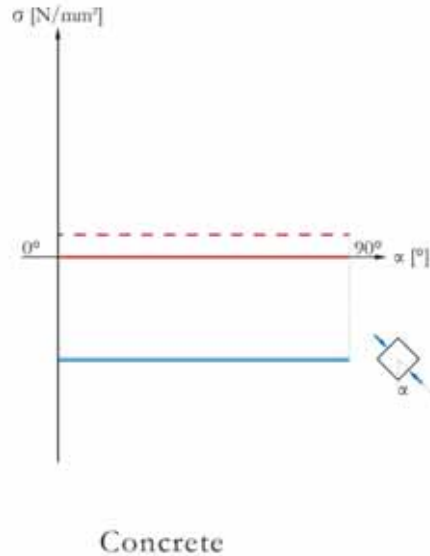
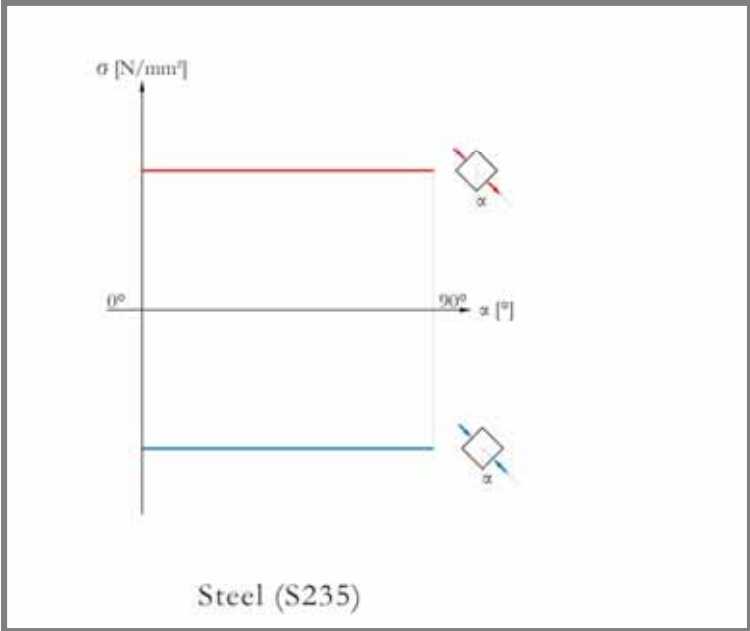






Stahl S235, Veränderung der Fließgrenze in Abhängigkeit des Beanspruchungswinkels

Steel S235, yield strength variation according to the stress angle



Veränderung der Fließgrenze in Abhängigkeit des Beanspruchungswinkels für die wichtigsten Baumaterialien

Yield strength variation according to the stress angle for main structural material

Stahl

Steel

Einführung
Introduction

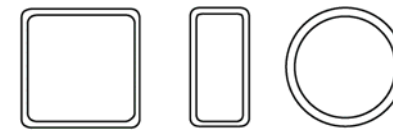
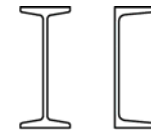
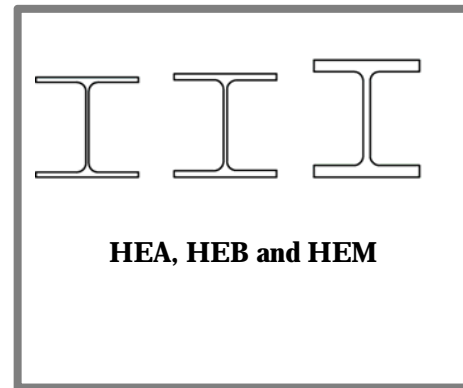
Mechanische Eigenschaften
Mechanical Properties

>> Bautechnologie
Building Technologies

Fallstudie: Haus R128
Case Study: House R128

Ausgewählte Projekte
Selected Projects

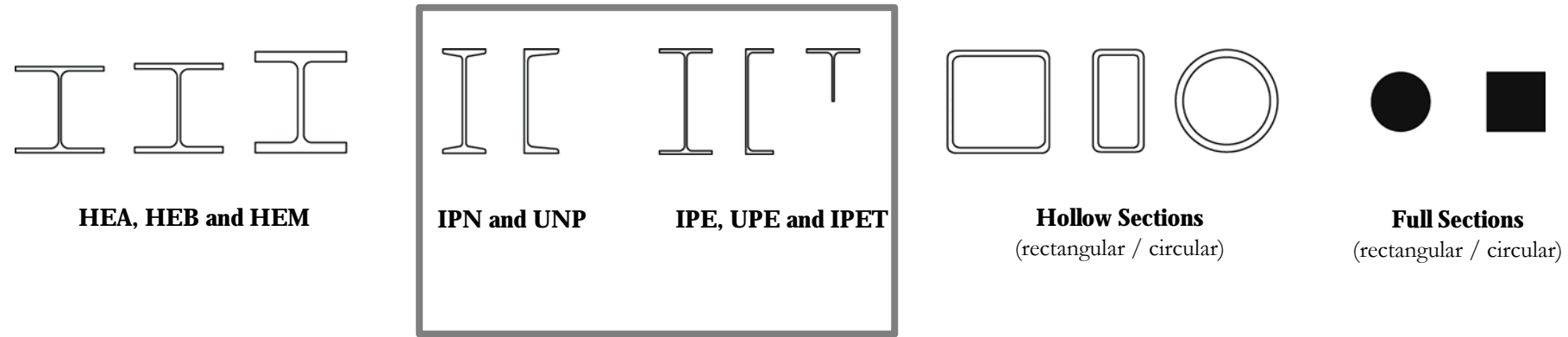
Live Demo
Stahlprofile
Steel profiles



HEA	HEA 100	96 mm x 100 mm	16,7 kg/m	to	HEA 1000	990 mm x 300 mm	272,0 kg/m
HEB	HEB 100	100 mm x 100 mm	20,4 kg/m		HEB 1000	1000 mm x 300 mm	314,0 kg/m
HEM	HEM 100	120 mm x 106 mm	41,8 kg/m		HEM 1000	1008 mm x 302 mm	349,0 kg/m



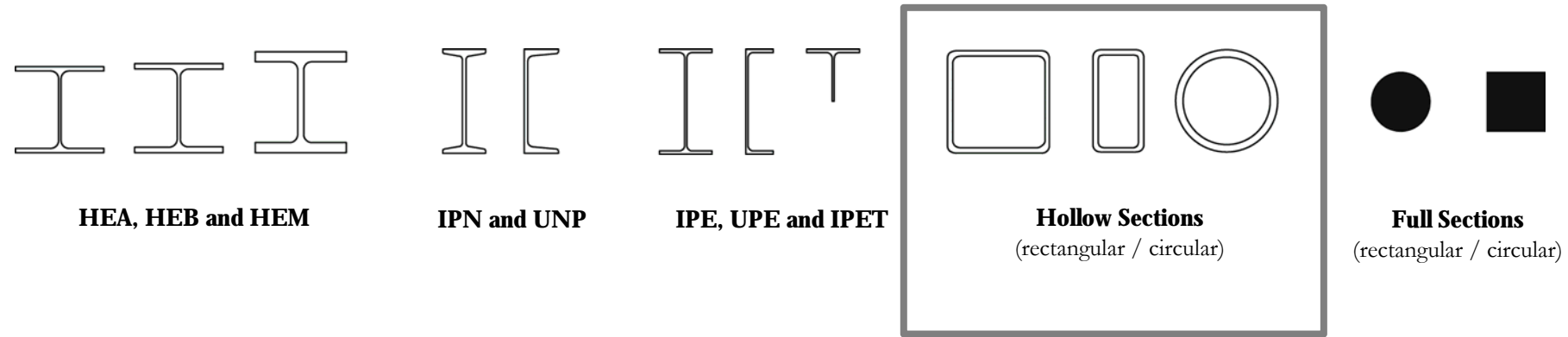
Farnsworth Haus, Illinois, 1951, Arch. Mies van der Rohe
Farnsworth House, Illinois, 1951, arch. Mies van der Rohe



INP	INP 80	80 mm x 42 mm	5,9 kg/m	to	INP 550	550 mm x 200 mm	166,0 kg/m
UNP	UNP 60	65 mm x 42 mm	7,1 kg/m		UNP 400	400 mm x 110 mm	71,8 kg/m
IPE	IPE 80	80 mm x 46 mm	6,0 kg/m	to	IPE 600	600 mm x 220 mm	122,0 kg/m
IPET	IPET 80	40 mm x 46 mm	3,0 kg/m		IPET 600	300 mm x 220 mm	61,2 kg/m
UPE	UPE 80	80 mm x 50 mm	7,9 kg/m		UPE 400	400 mm x 115 mm	72,2 kg/m



Seagram Building, New York, 1958, arch. Mies van der Rohe, eng. Severud Associates

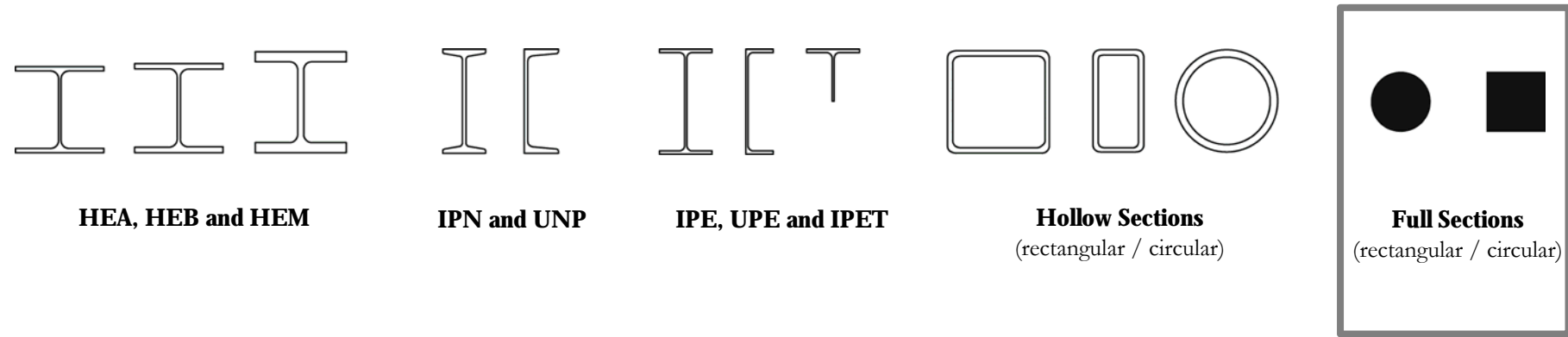


RRW/RRK _{square}	RRW 40 x 40	40 mm x 40 mm	3,4 kg/m	to	RRW 400 x 400	400 mm x 400 mm	191 kg/m
RRW/RRK _{hexagonal}	RRW 50 x 30	50 mm x 30 mm	3,6 kg/m		RRW 400 x 200	400 mm x 200 mm	141 kg/m
ROR _{round}	ROR 21,3	Ø 21,3 mm	0,9 kg/m		ROR 813	Ø 813 mm	159 kg/m



Sekundarschule in Losone, 1975, Arch. Livio Vacchini & Aurelio Galfetti

Secondary school Losone, 1975, arch. Livio Vacchini and Aurelio Galfetti



RND	RND 10	Ø 10 mm	0,6 kg/m	to	RND 500	Ø 500 mm	1540,0 kg/m
VKT	VKT 10	6 mm x 6 mm	0,3 kg/m		VKT 200	200 mm x 200 mm	314,8 kg/m



Centre Pompidou, Paris, 1977, arch. Renzo Piano, Rogers & Franchini, eng Peter Rice & Edmund Happold



GENIETET
RIVETED
(Maria Pia Bridge, Porto)



GESCHRAUBT
BOLTED
(Puls 5, Zürich)



GESCHWEISST
WELDED
(Stuttgart Airport)



Der in Brand geratene Crystal Palace, London, 30.11.1936

Crystal Palace on fire, London, 30.11.1936



Der in Brand geratene Crystal Palace, London, 30.11.1936

Crystal Palace on fire, London, 30.11.1936



Brandschutz-Verkleidung
Fireproof envelope



Aufschäumende Brandschutz-Beschichtung
Intumescent coating



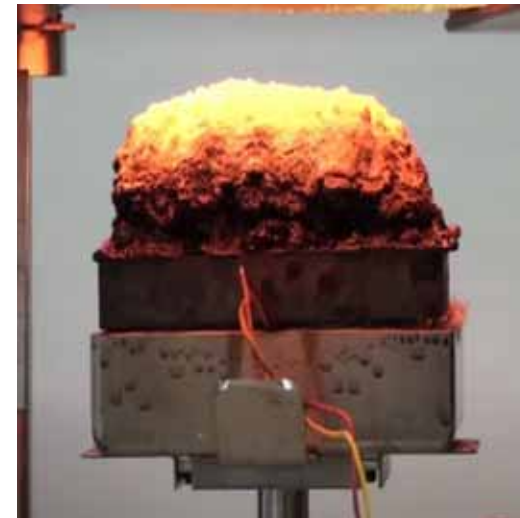
0 minutes



5 minutes



10 minutes



50 minutes

© Anna Frodesiak





BESCHICHTUNG (LACKFARBE)
PAIN T COATING



ZINK-BESCHICHTUNG
ZINC COATING



OBERFLÄCHENOXIDIERUNG
SURFACE OXIDATION
(corten steel / stainless steel)



Stahl

Steel

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>> Fallstudie: Haus R128
Case Study: House R128

Ausgewählte Projekte
Selected Projects

House R128

Stuttgart, 2000

Architect & Engineer: Werner Sobek Ingenieure



“In Werner Sobek’s view, construction at the beginning of the 21st century differs very little from that of past centuries in many respects: the integration of the most various developments to create a really new product is far too rare an event. Building construction evinces none of the innovative dynamics found, for instance, in the automobile industry where the latest developments in computer, materials and sensor technology are combined to produce unique synergetic effects.”

Werner Blaser

“I didn’t want to create something that future generations would have to cope with, so I made sure everything is easily recyclable.”

Werner Sobek

Zero Energy Building

Null Energie aus externen Quellen

ZERO energy from external sources

Solar cells
Self-sufficient

Zero Emission Building

Null Kohlendioxidemissionen

ZERO carbon dioxide emissions

Triple-glazing with high quality glass
No combustion-based processes
permitted in the building

Zero Waste Building

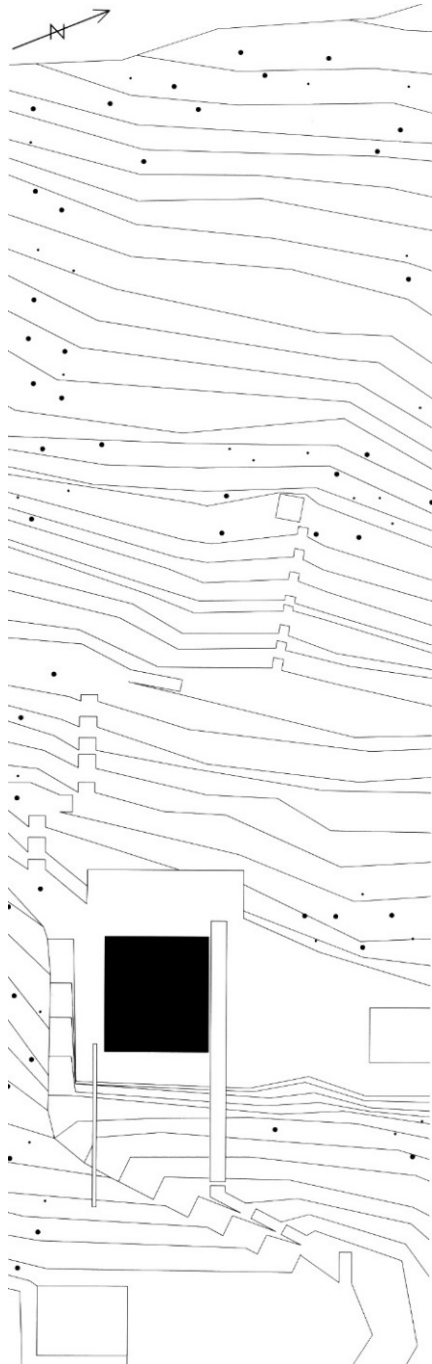
Null Abfall

ZERO waste

All building elements can be fully
recycled (no disposal)
Modularity
Joints

© Gracie Meek & Joseph McGranahan, Cornell University









© Roland Halbe

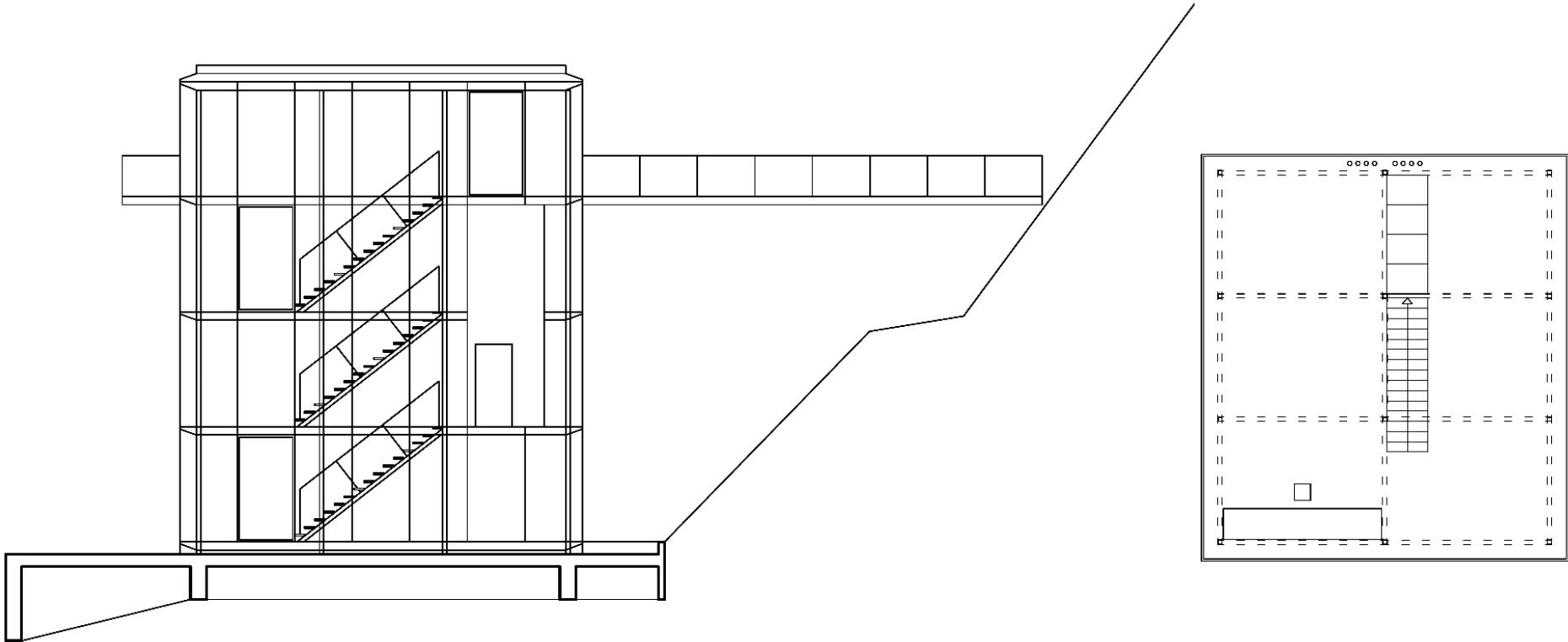
“I was governed by the ideal of living in three-dimensional transparency so that I could always feel close to nature. The technology just helped me achieve that ideal.”

Werner Sobek



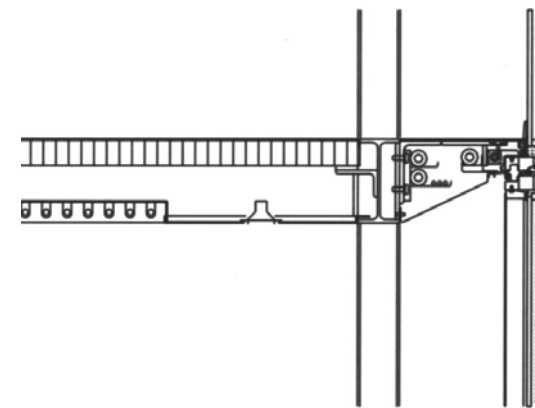
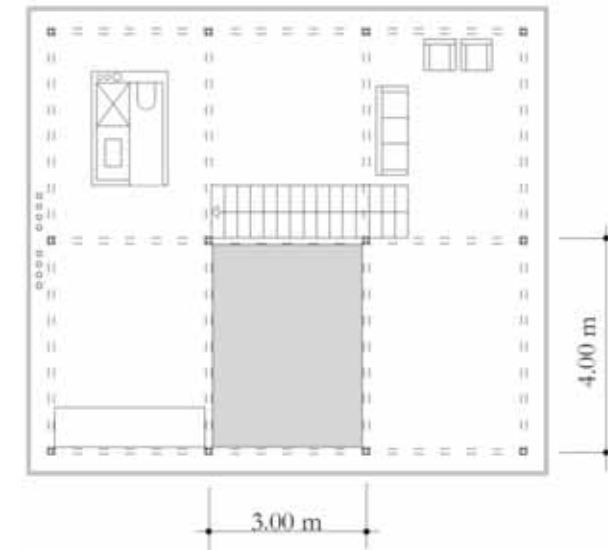
© Roland Halbe



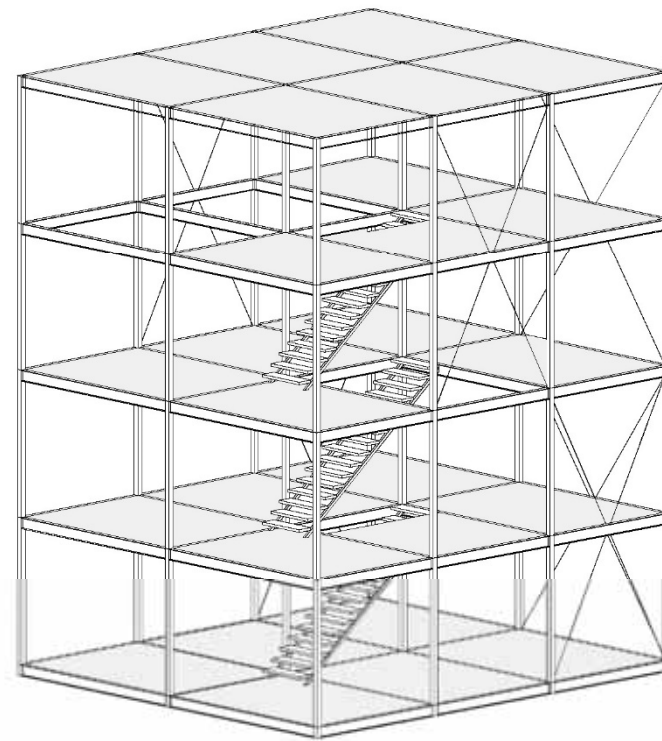


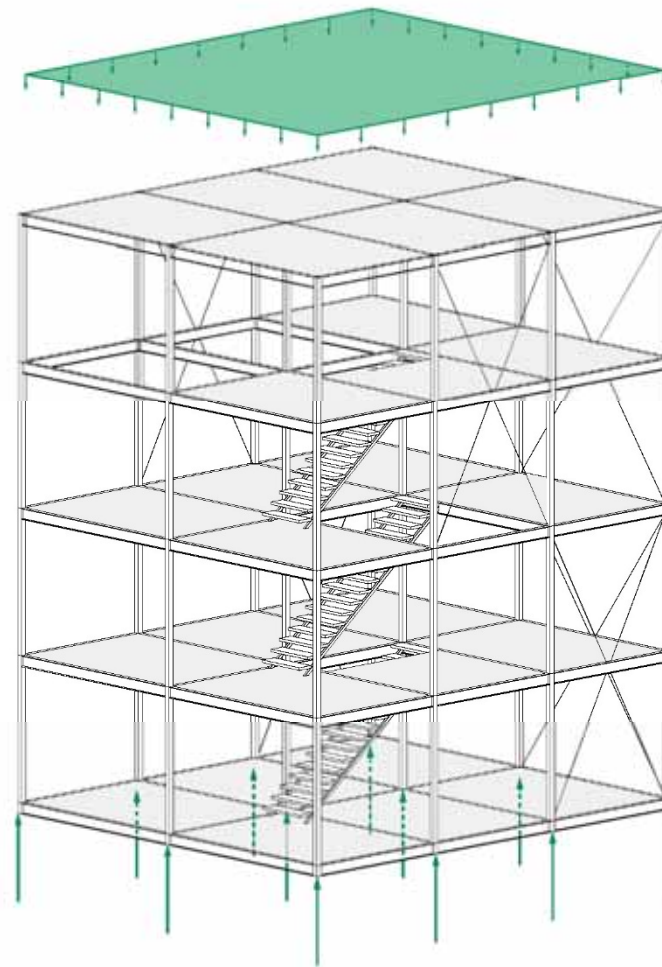
Schnitt und Grundriss

Section and floor plan

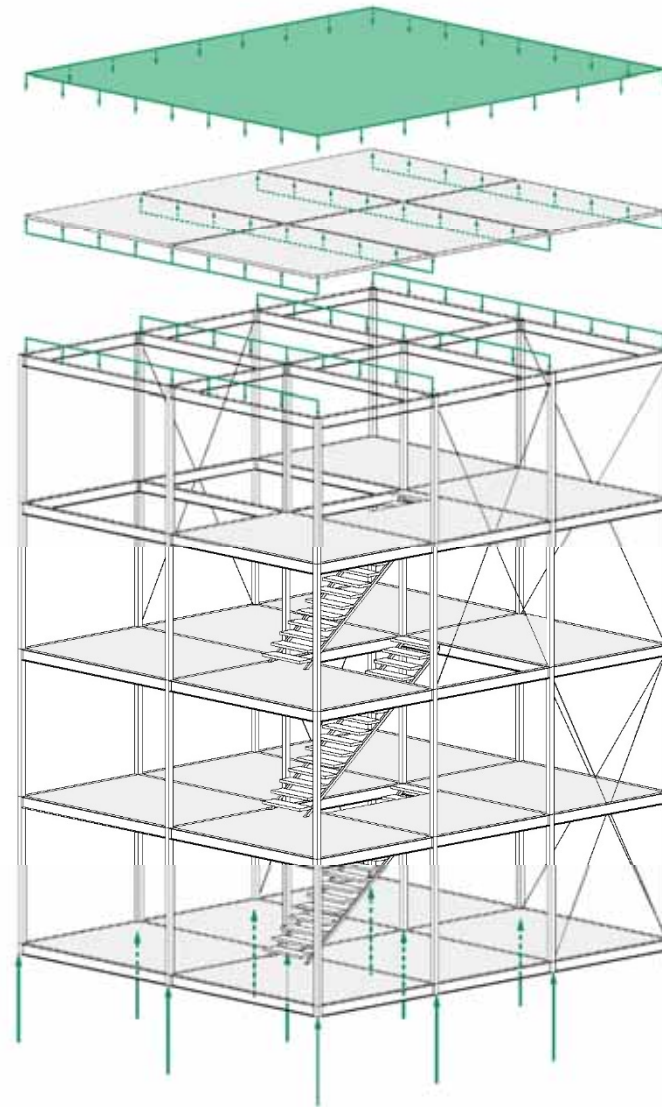


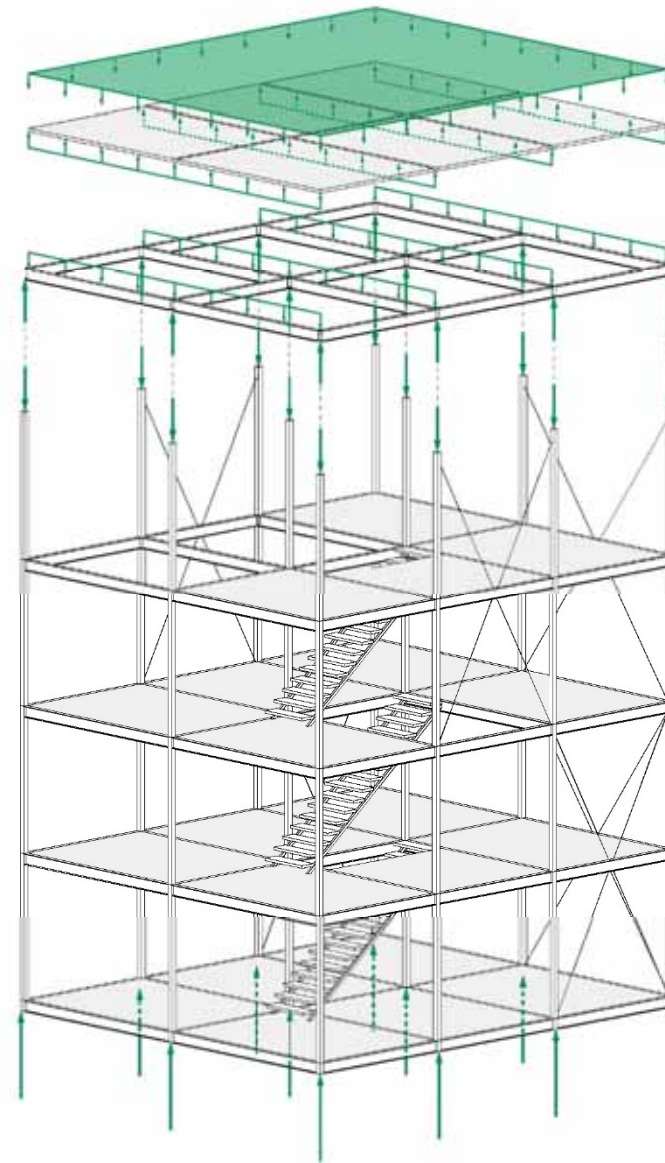
Strukturmodul (3.0 x 4.0m)
Structurale module (3.0 x 4.0m)



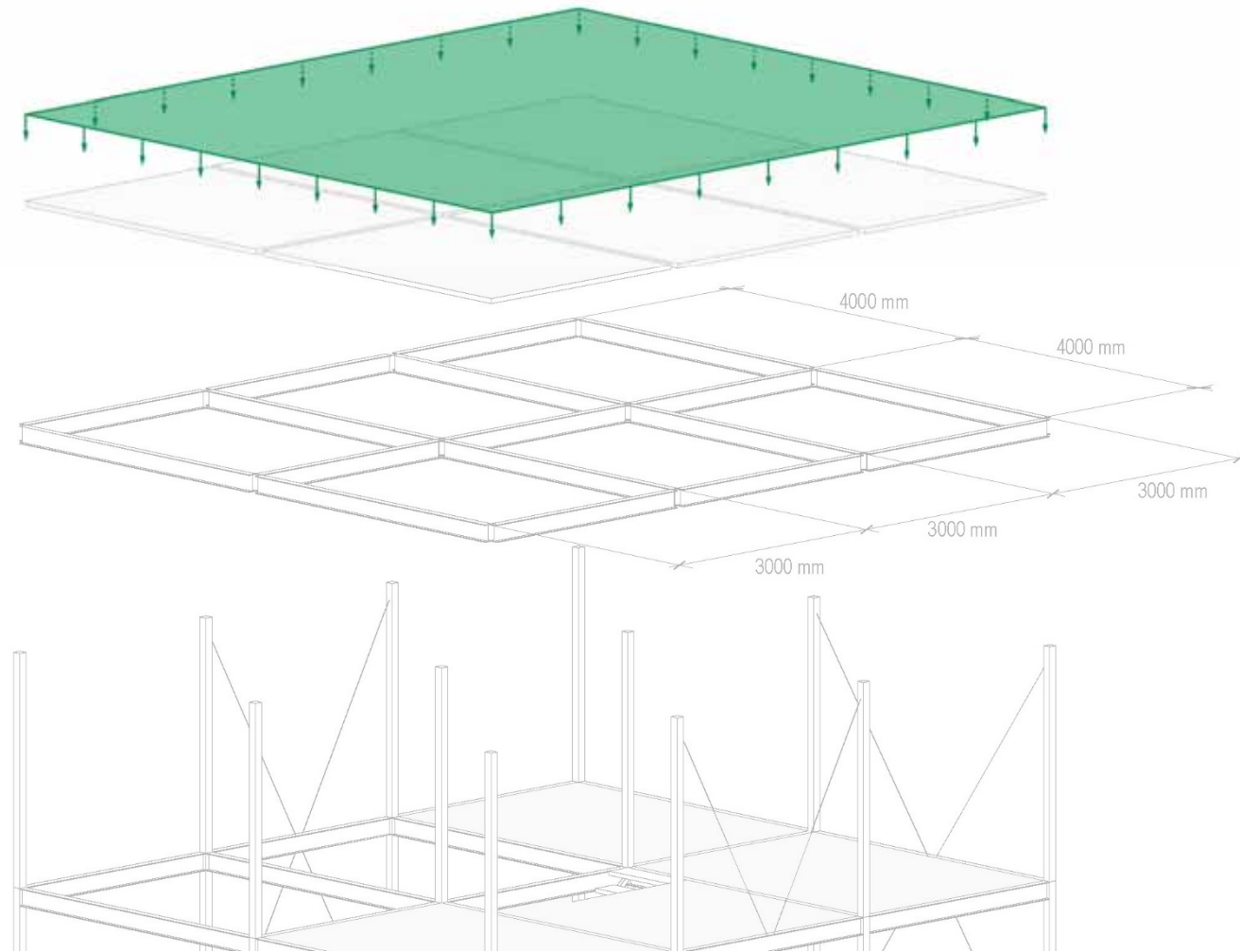


Vertikale Lasten
Vertical loads



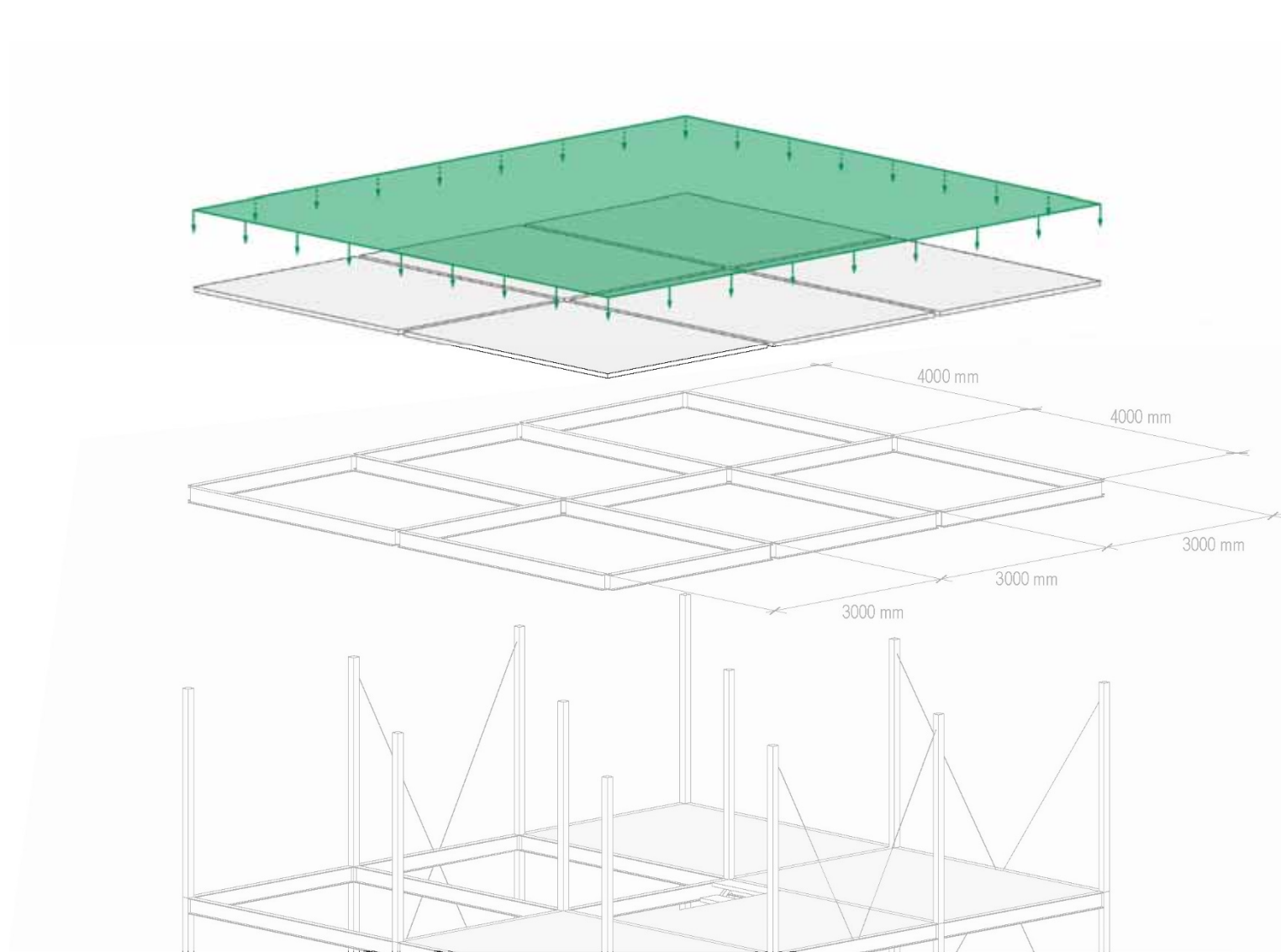


Vertikale Lasten
Vertical loads



Dead loads (self-weight)
 $g = 1.8 \text{ kN/m}^2$

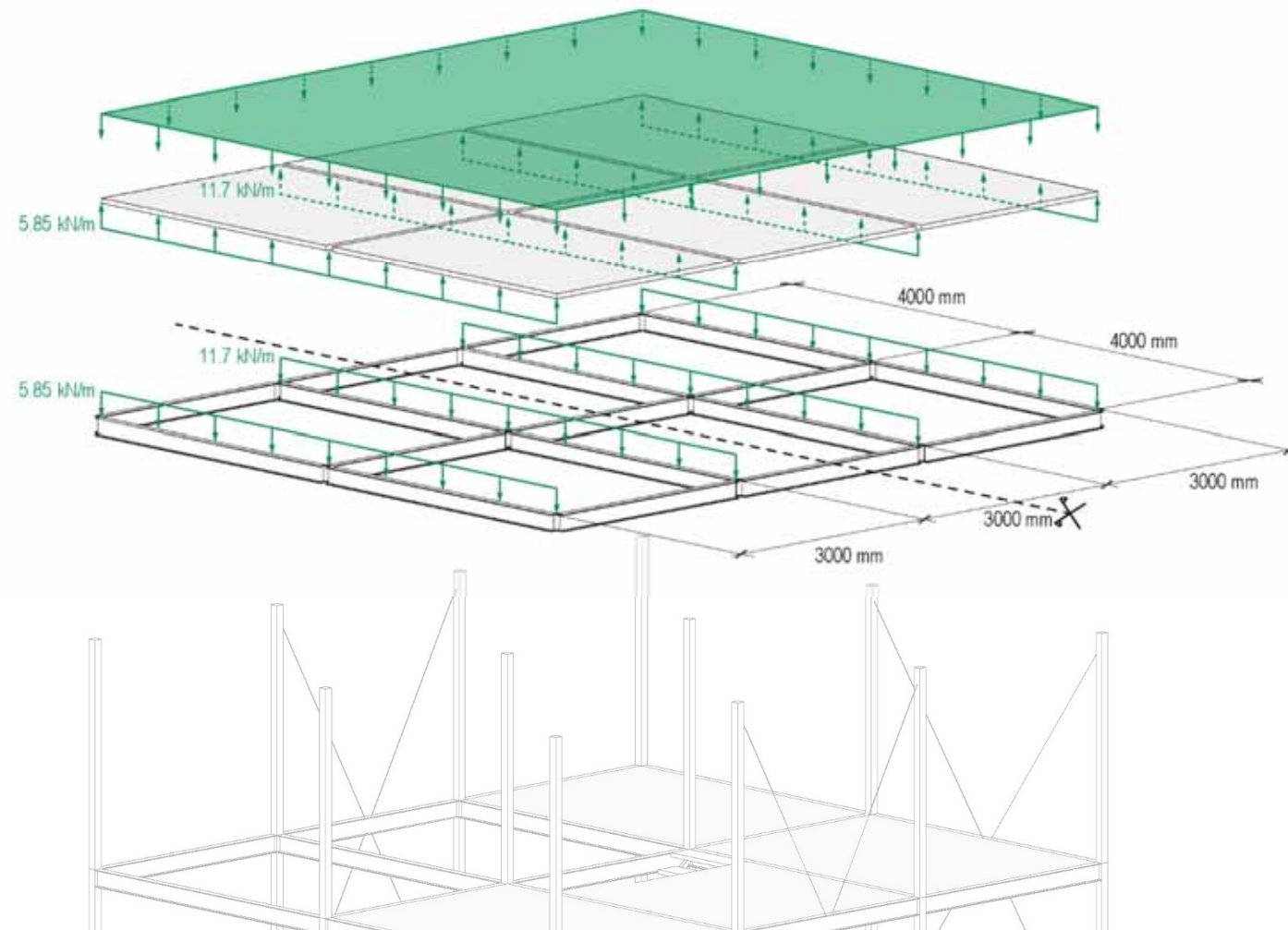
Live loads (snow)
 $q_{\text{snow}} = 1.0 \text{ kN/m}^2$



Dead loads (self-weight)
 $g = 1.8 \text{ kN/m}^2$

Live loads (snow)
 $q_{\text{snow}} = 1.0 \text{ kN/m}^2$

$$q_{\text{d,slab}} = 1.35 \cdot g + 1.5 \cdot q_{\text{snow}} \\ = 3.9 \text{ kN/m}^2$$

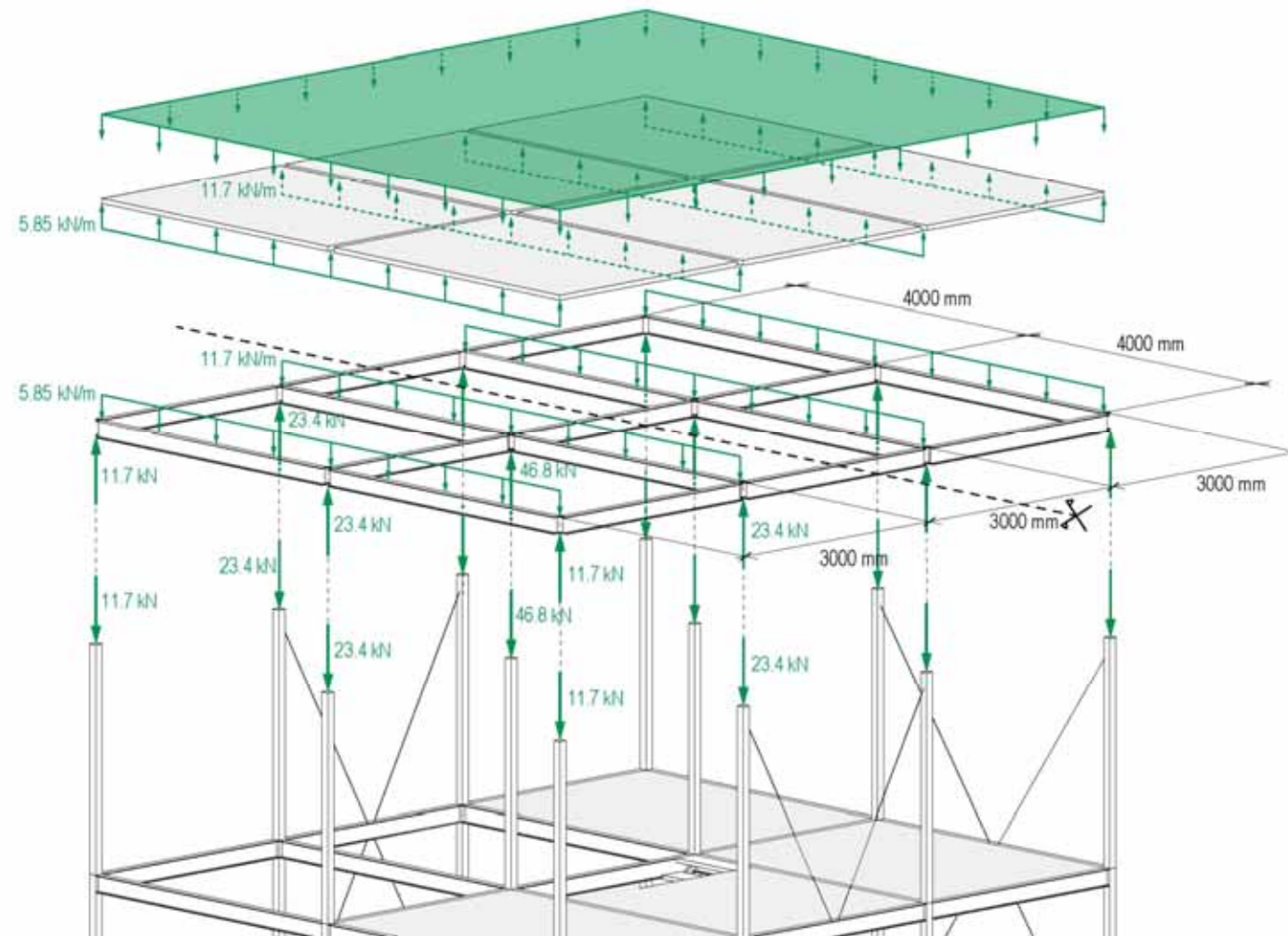


Dead loads (self-weight)
 $g = 1.8 \text{ kN/m}^2$

Live loads (snow)
 $q_{\text{snow}} = 1.0 \text{ kN/m}^2$

$$q_{\text{d,slab}} = 1.35 \cdot g + 1.5 \cdot q_{\text{snow}} \\ = 3.9 \text{ kN/m}^2$$

$$q_{\text{d,beam}} = 3.9 \cdot 3.0 = 11.7 \text{ kN/m}$$



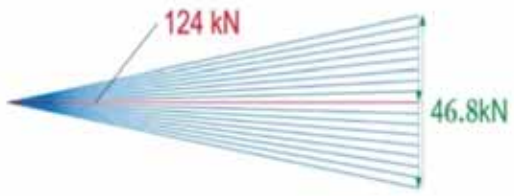
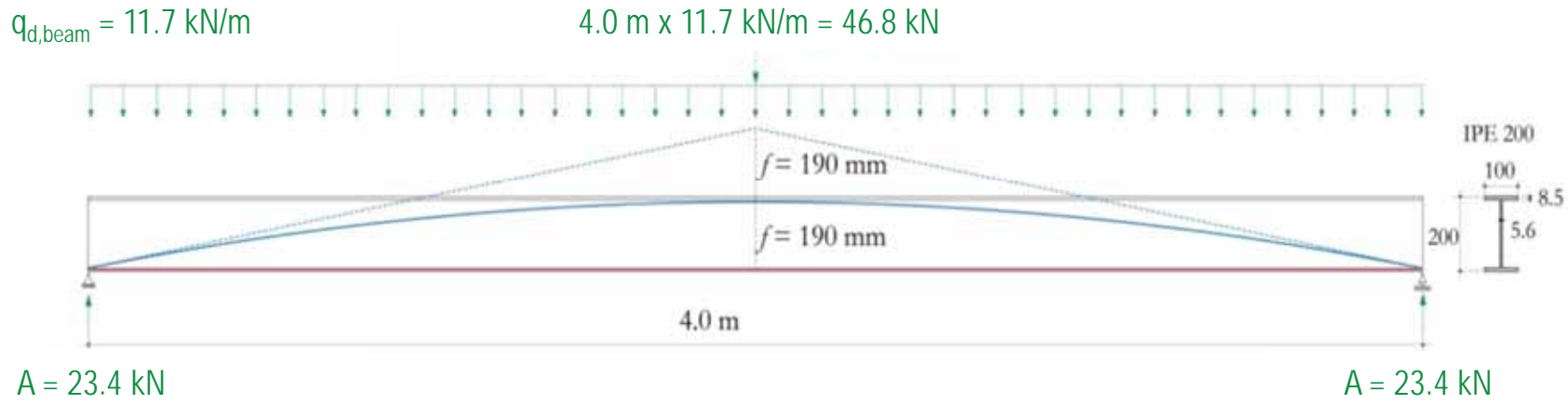
Dead loads (self-weight)
 $g = 1.8 \text{ kN/m}^2$

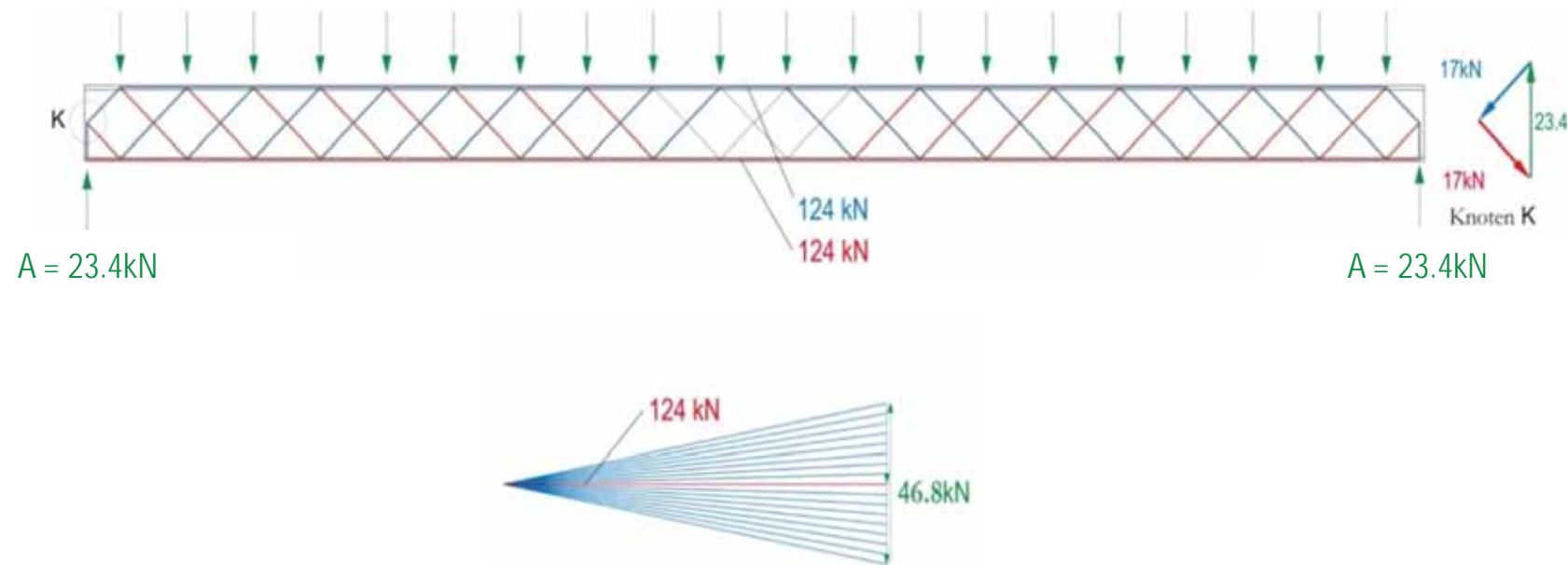
Live loads (snow)
 $q_{\text{snow}} = 1.0 \text{ kN/m}^2$

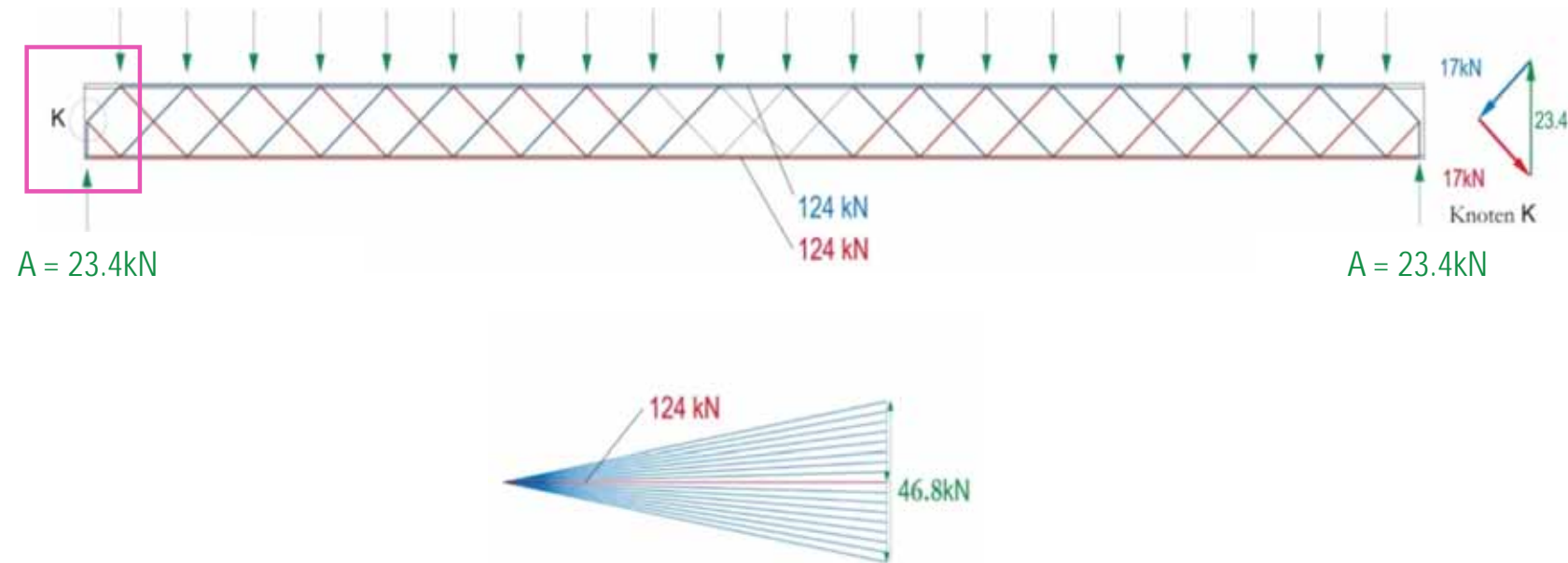
$$q_{d,\text{slab}} = 1.35 \cdot g + 1.5 \cdot q_{\text{snow}} = 3.9 \text{ kN/m}^2$$

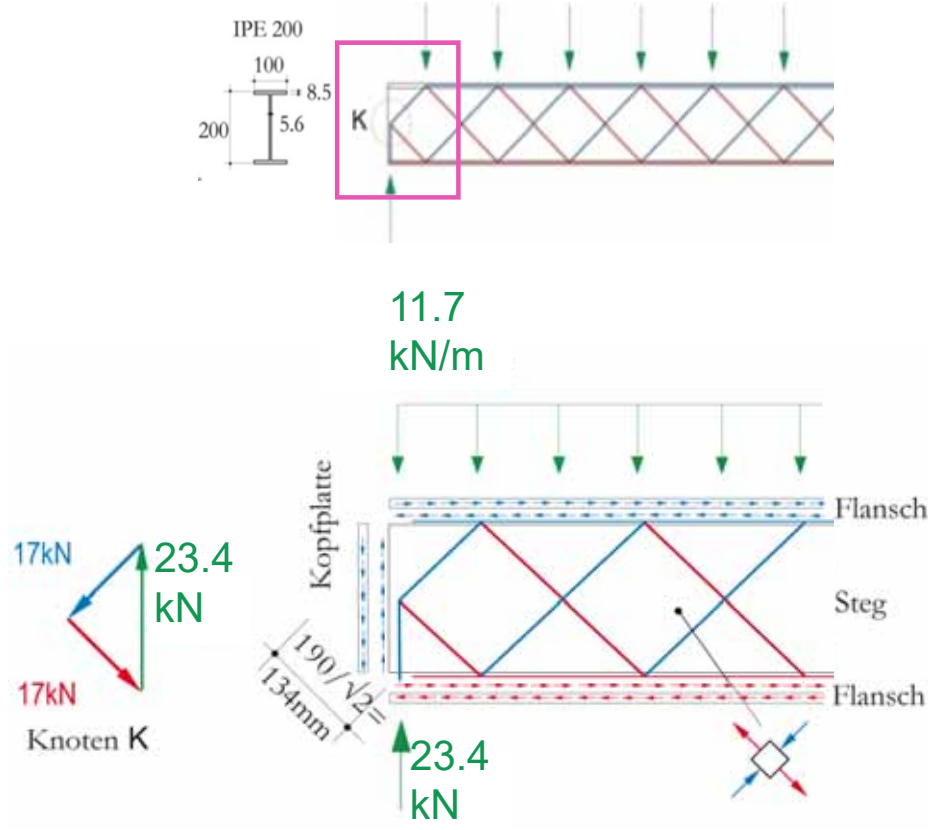
$$q_{d,\text{beam}} = 3.9 \cdot 3.0 = 11.7 \text{ kN/m}$$

$$q_{d,\text{col}} = (11.7 \cdot 4.0) / 2 = 23.4 \text{ kN}$$



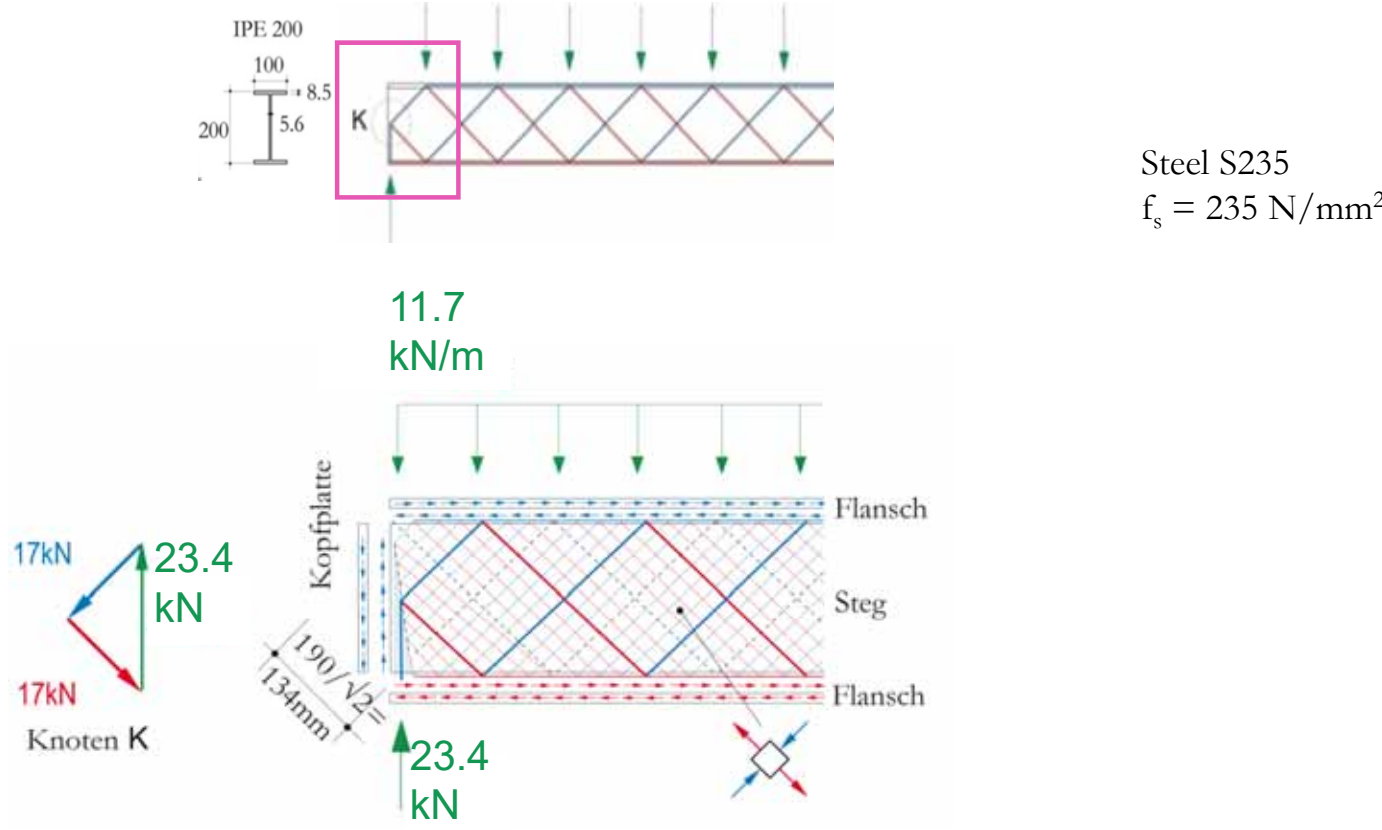


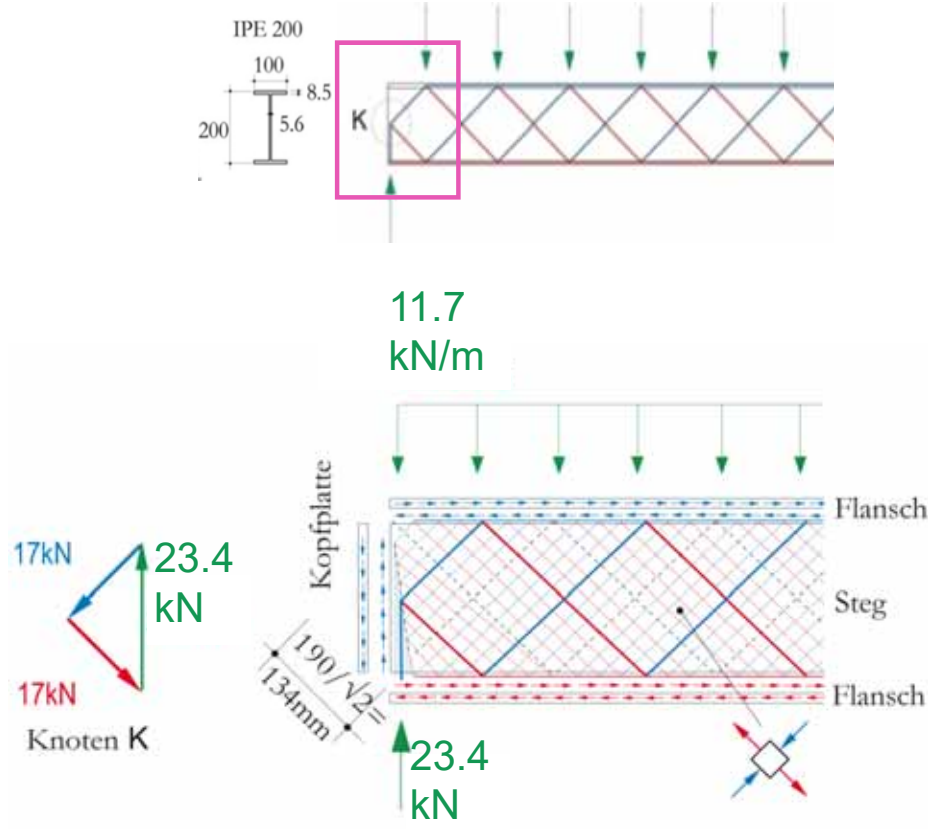




Innere Kräfte im Stahlträger

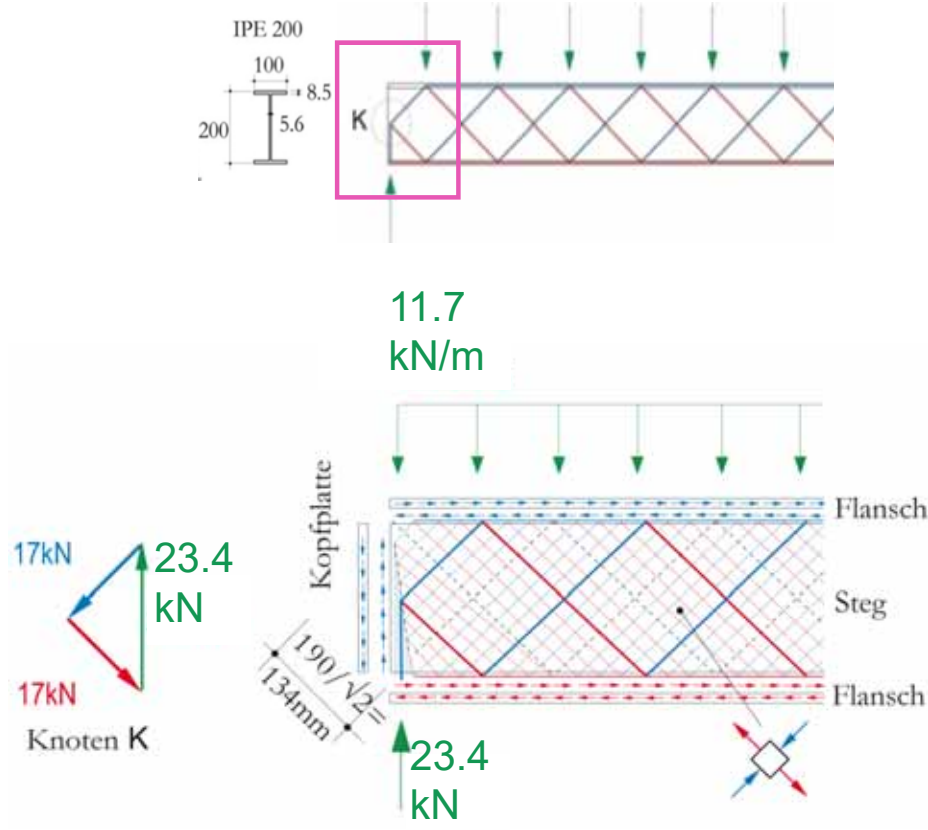
Internal forces in the steel beam





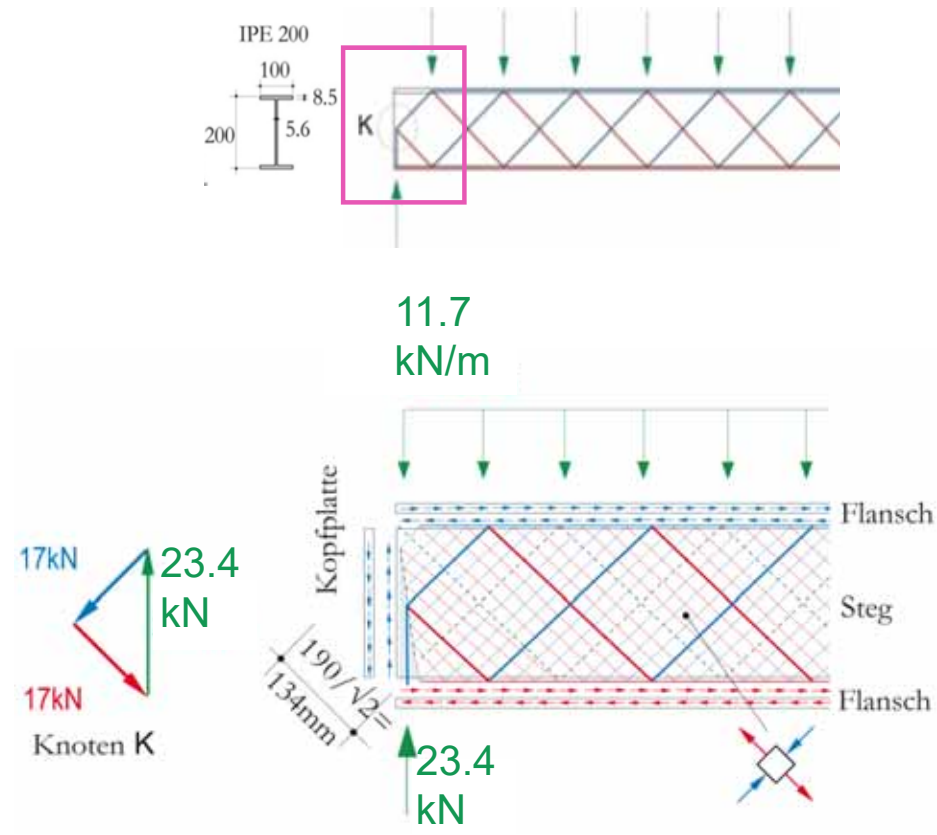
Steel S235
 $f_s = 235 \text{ N/mm}^2$
 $f_{s,d} = 235 / 1.05 = 224 \text{ N/mm}^2$

Innere Kräfte im Stahlträger
Internal forces in the steel beam



Steel S235
 $f_s = 235 \text{ N/mm}^2$
 $f_{s,d} = 235 / 1.05 = 224 \text{ N/mm}^2$

$N = 17 \text{ kN} = 17000 \text{ N}$



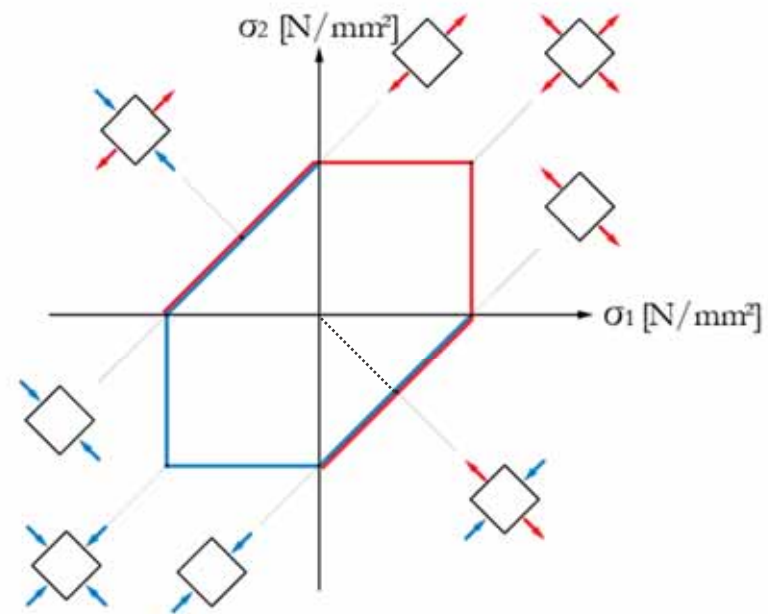
Steel S235

$$f_s = 235 \text{ N/mm}^2$$

$$f_{s,d} = 235 / 1.05 = 224 \text{ N/mm}^2$$

$$N = 17 \text{ kN} = 17000 \text{ N}$$

$$A = 134 \text{ mm} \cdot 5.6 \text{ mm} = 750 \text{ mm}^2$$



Steel

Steel S235

$$f_s = 235 \text{ N/mm}^2$$

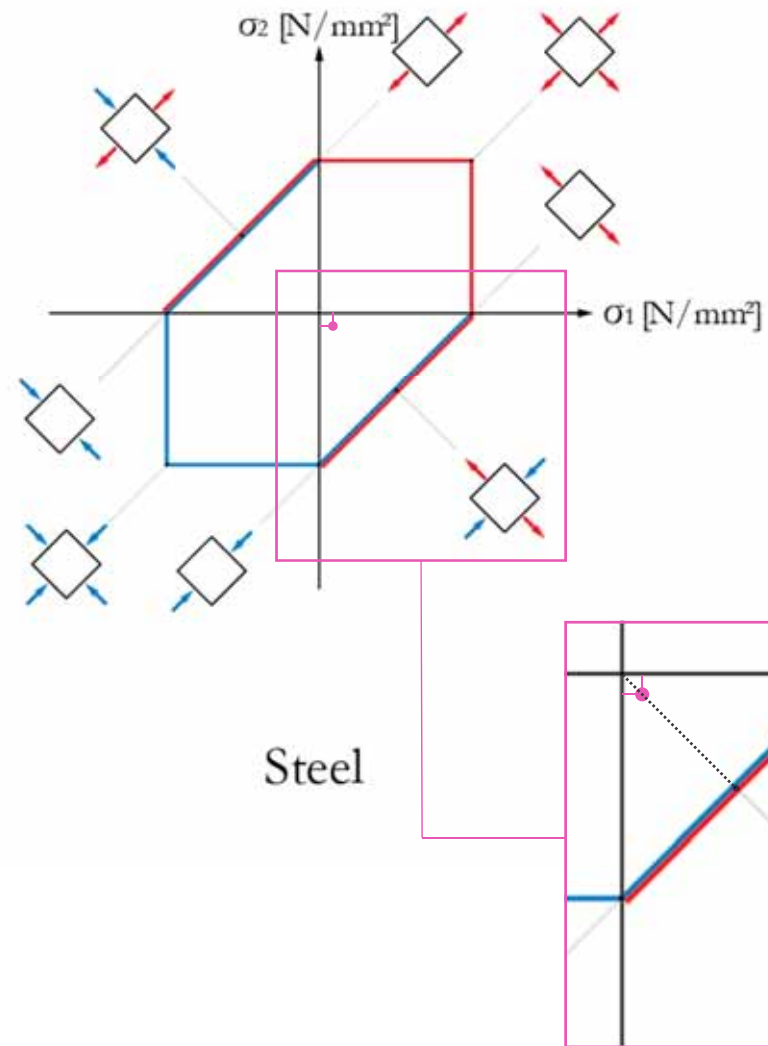
$$f_{s,d} = 235 / 1.05 = 224 \text{ N/mm}^2$$

$$N = 17 \text{ kN} = 17000 \text{ N}$$

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Stress check

$$|\sigma_1| = |\sigma_2| = N/A = 17000/750 = 23 \text{ N/mm}^2$$



Steel S235

$$f_s = 235 \text{ N/mm}^2$$

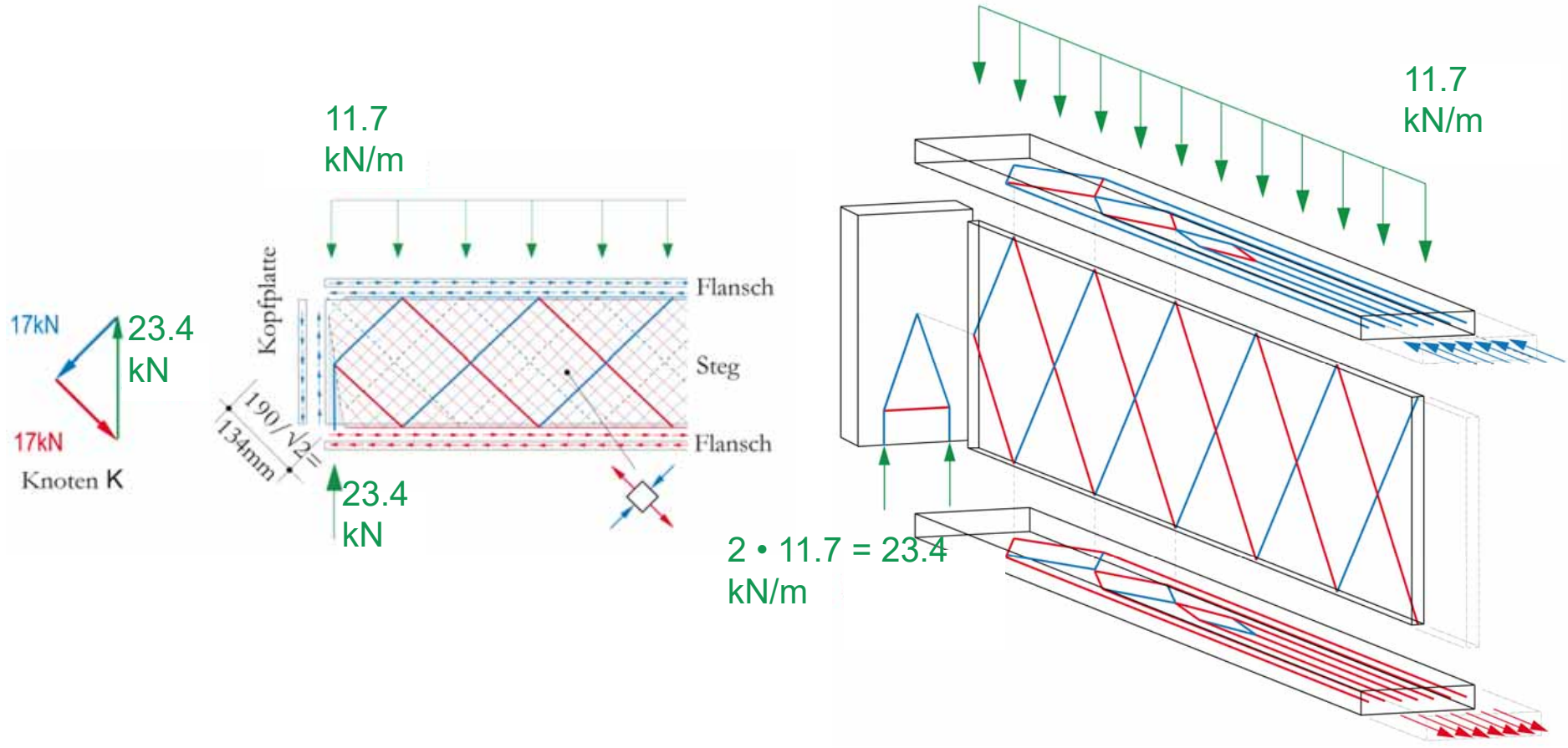
$$f_{s,d} = 235 / 1.05 = 224 \text{ N/mm}^2$$

$$N = 17 \text{ kN} = 17000 \text{ N}$$

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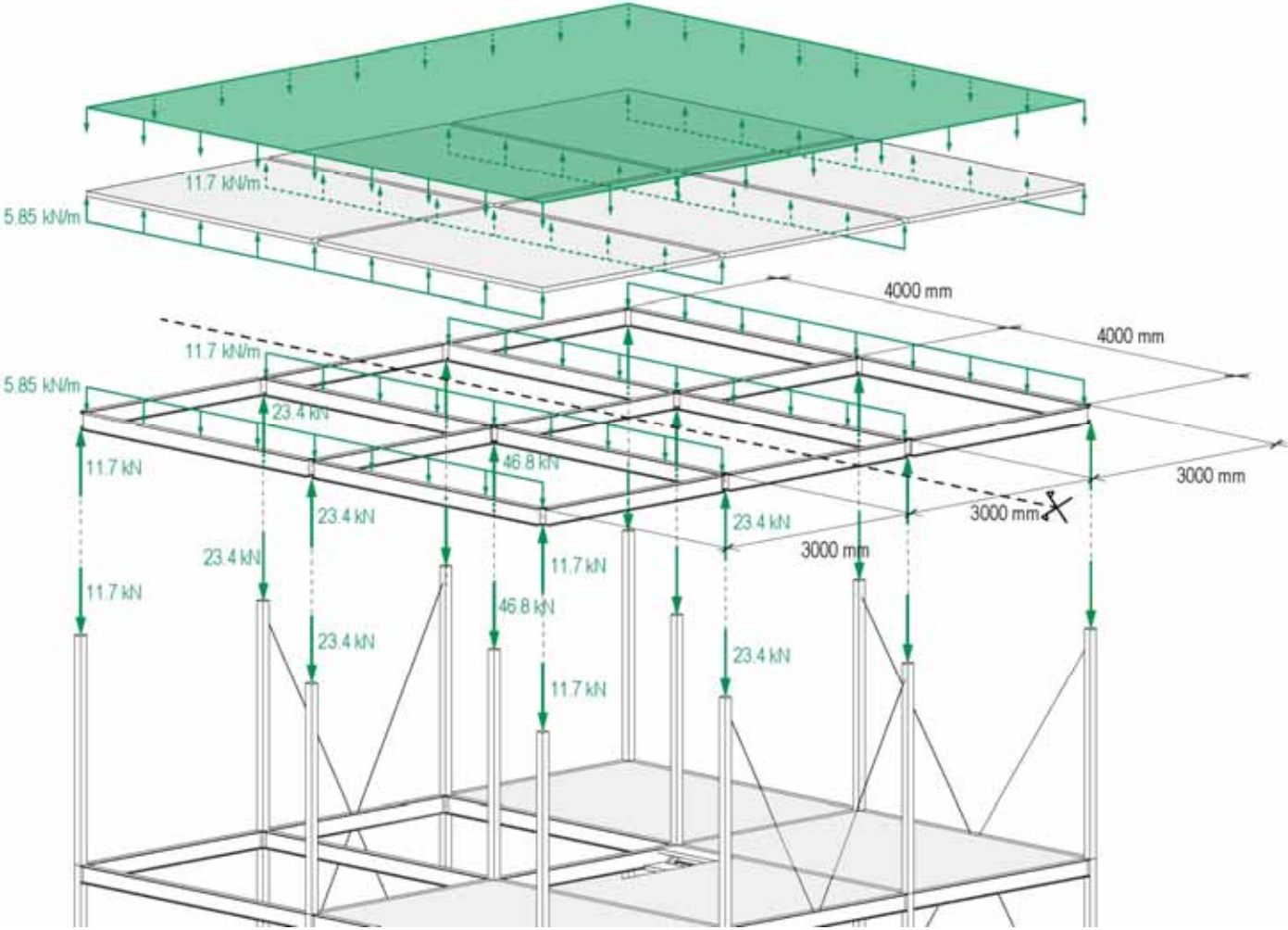
Stress check

$$|\sigma_1| = |\sigma_2| = N/A = 17000/750 = 23 \text{ N/mm}^2$$



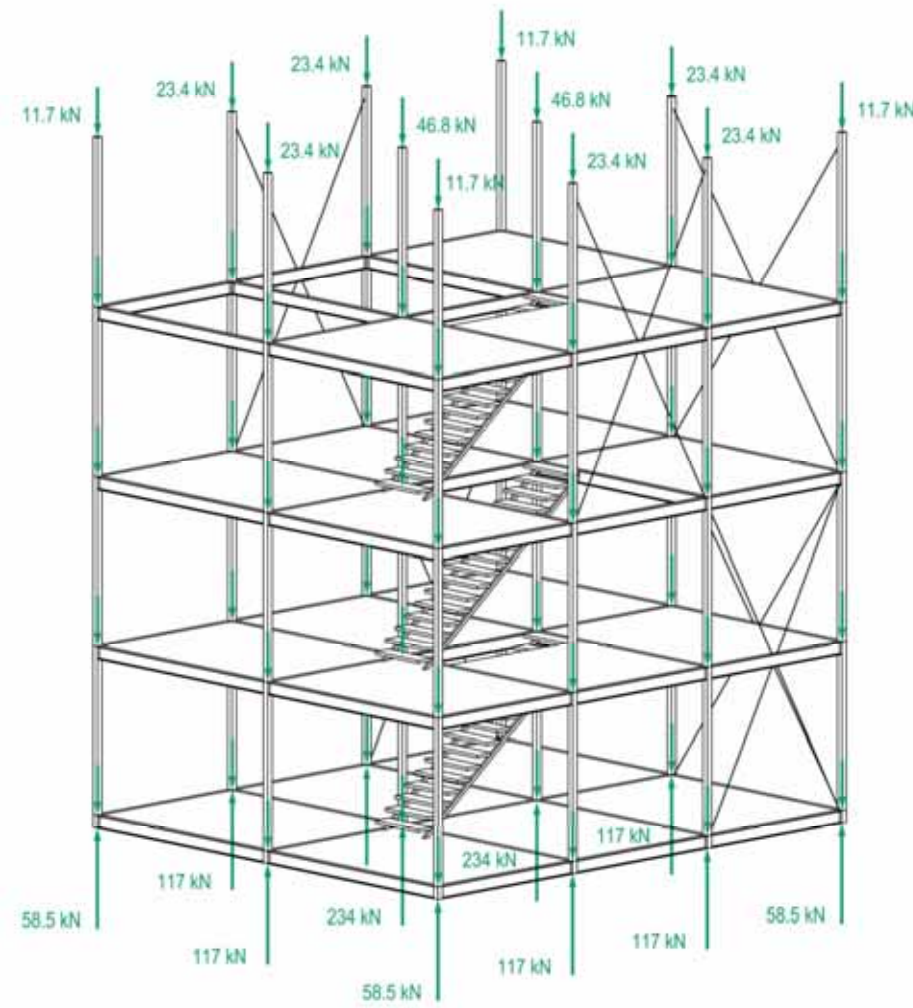
Innere Kräfte im Stahlträger

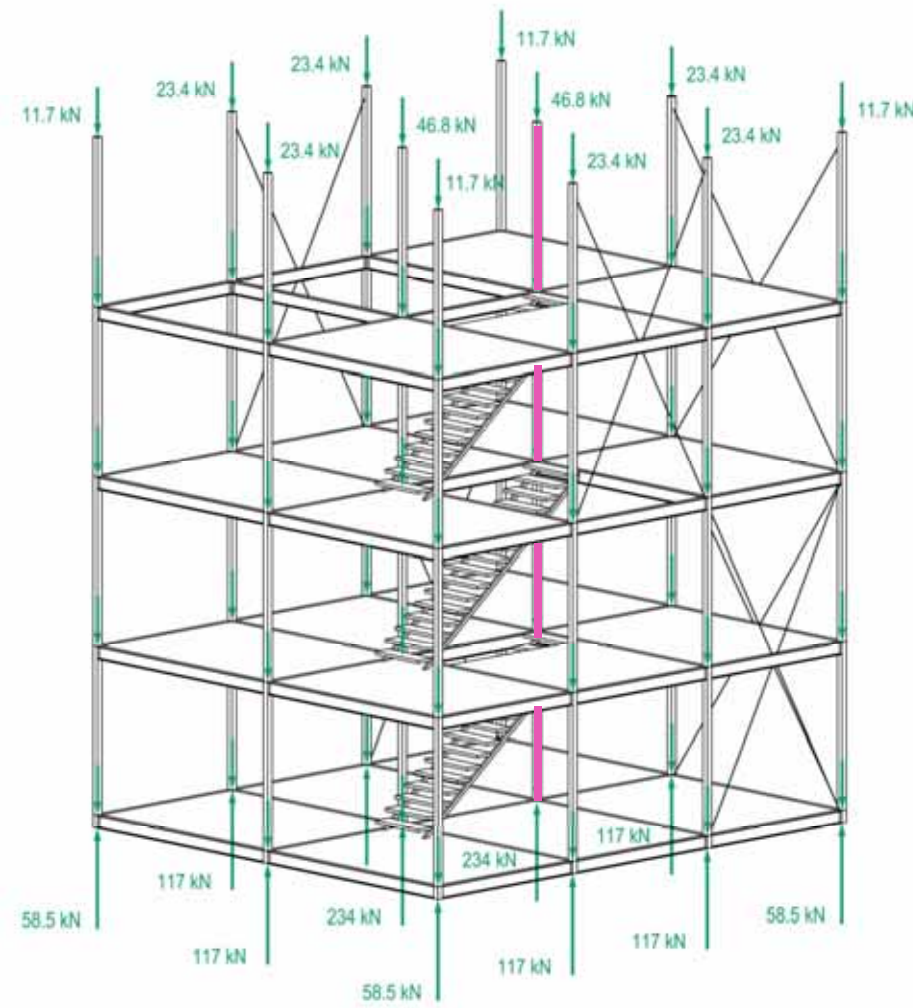
Internal forces in the steel beam



Vertikale Lasten

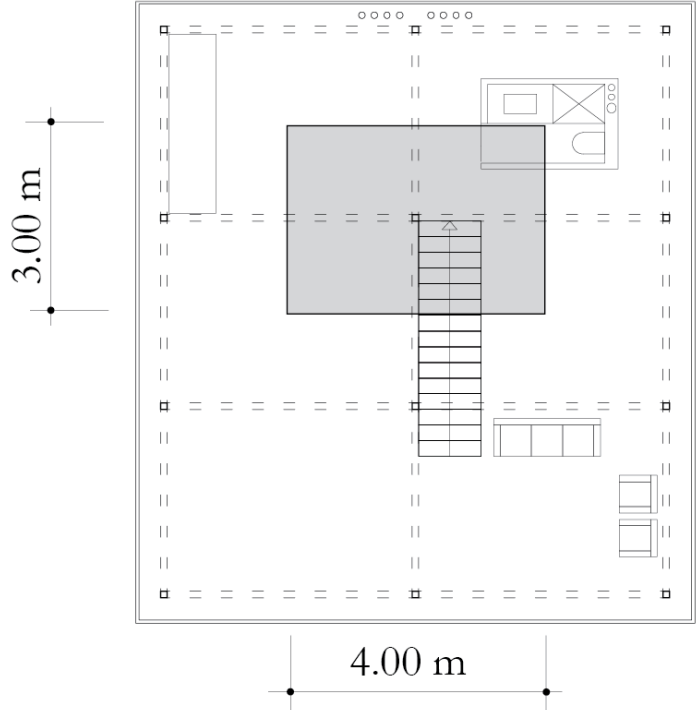
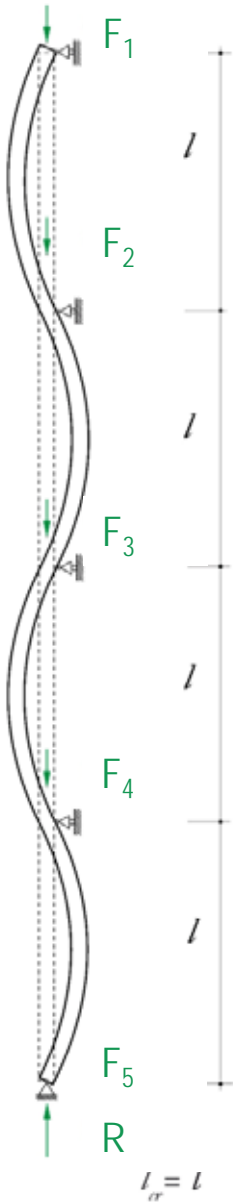
Vertical loads



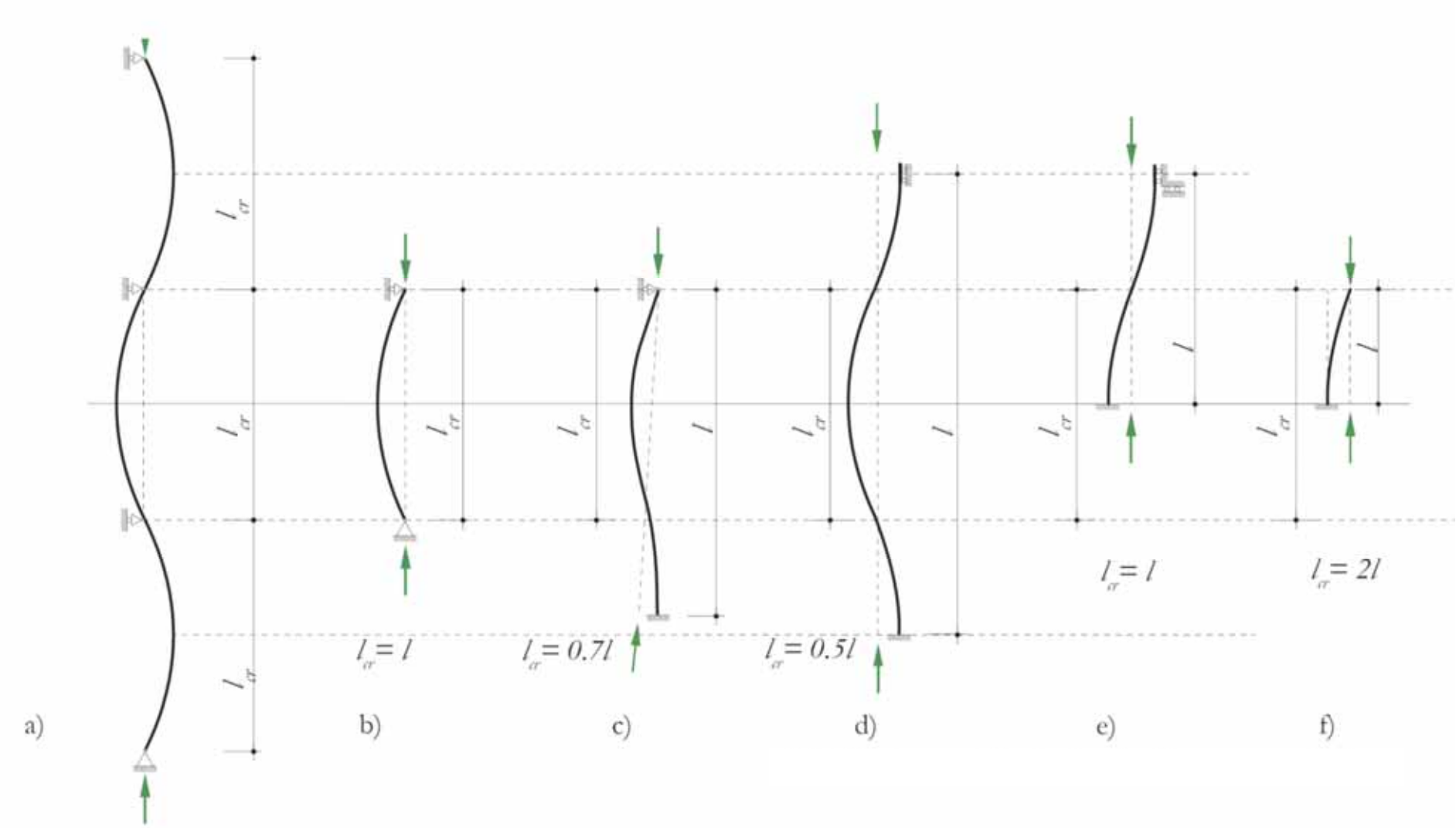




Vertical loads on the central column

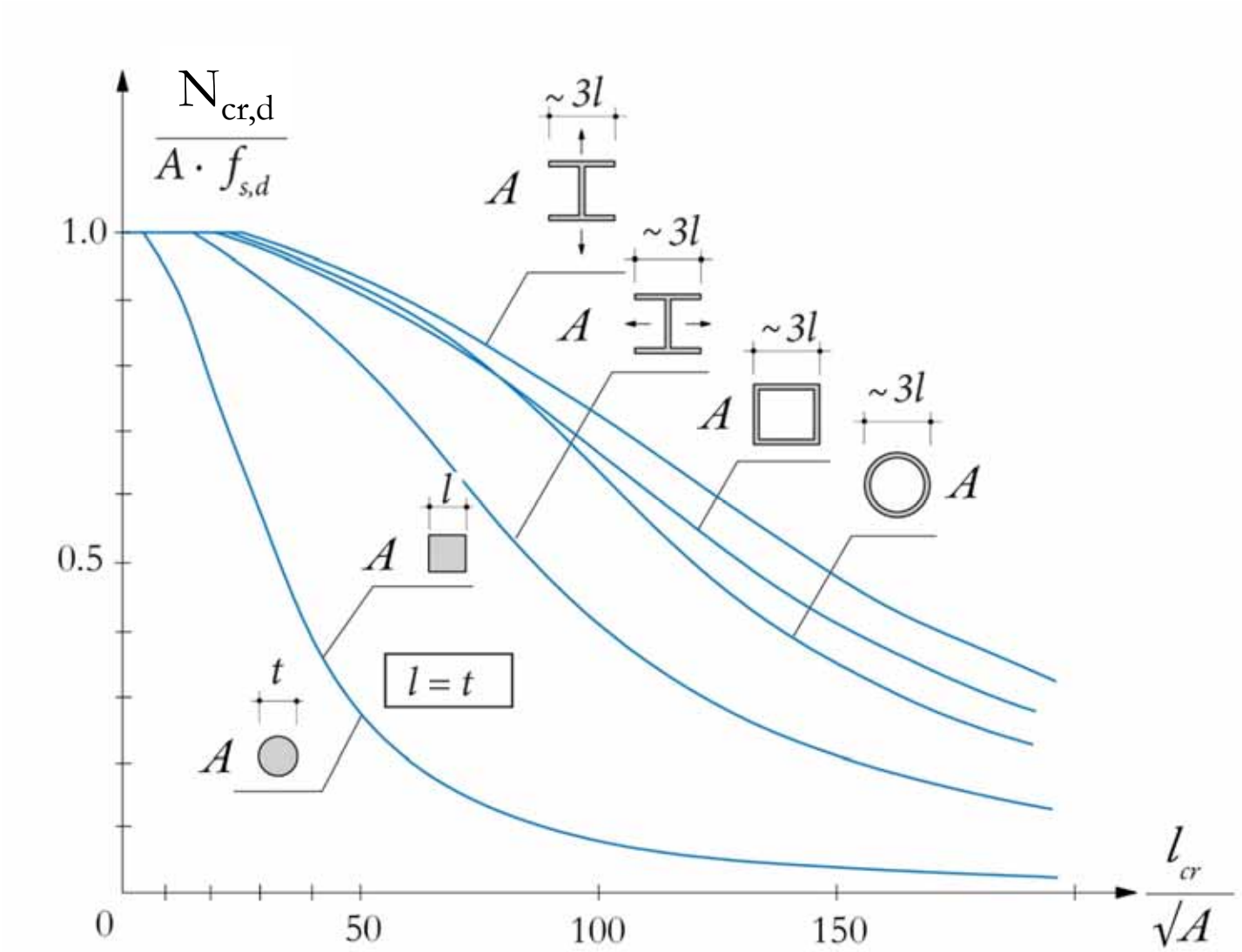


Ground plan with tributary area



Kritische Längen von Elementen unter axialem Druck

Critical lengths of elements under axial compression



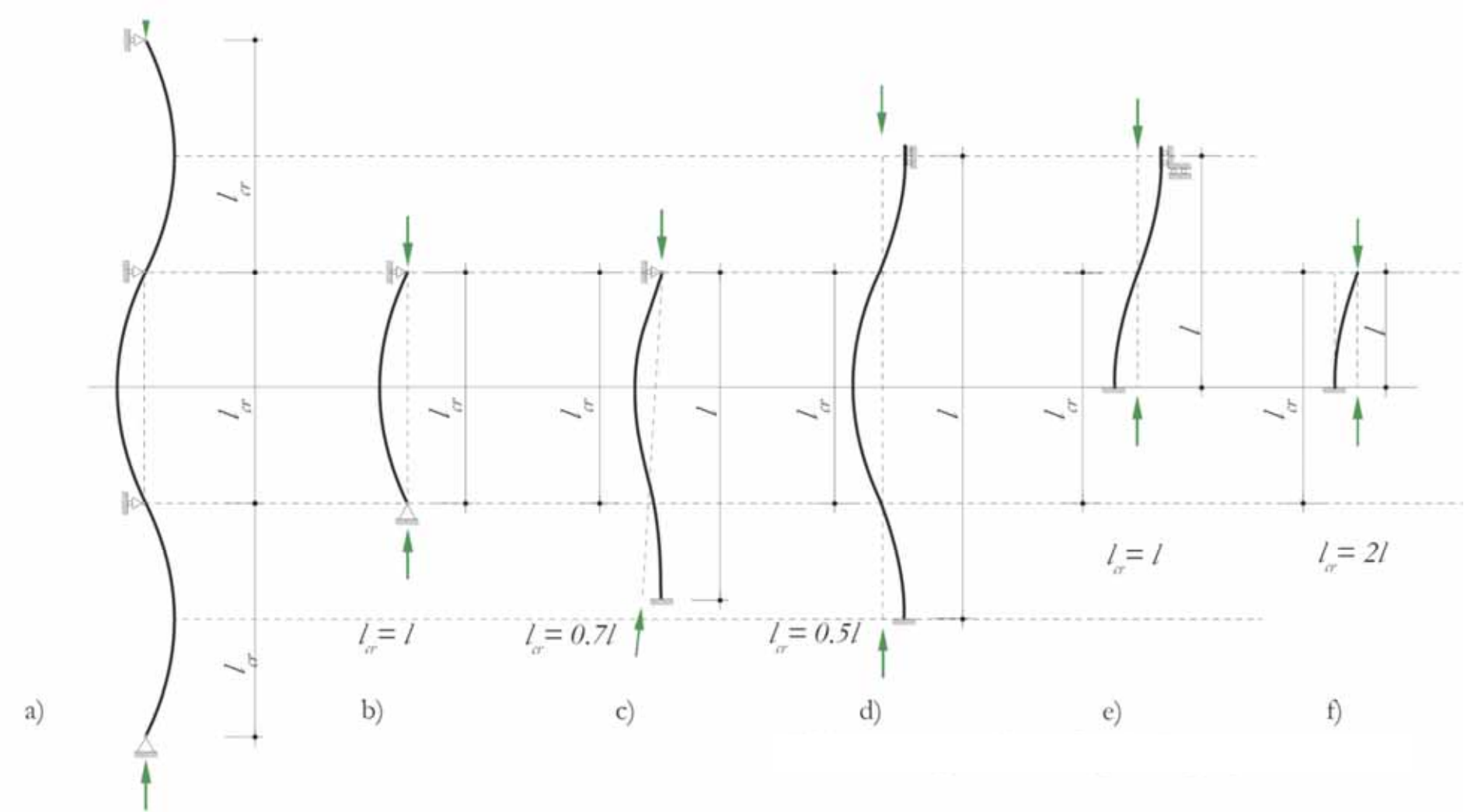
Knickkurven von Stahlprofilen

Buckling curves of steel profiles

Live Demo

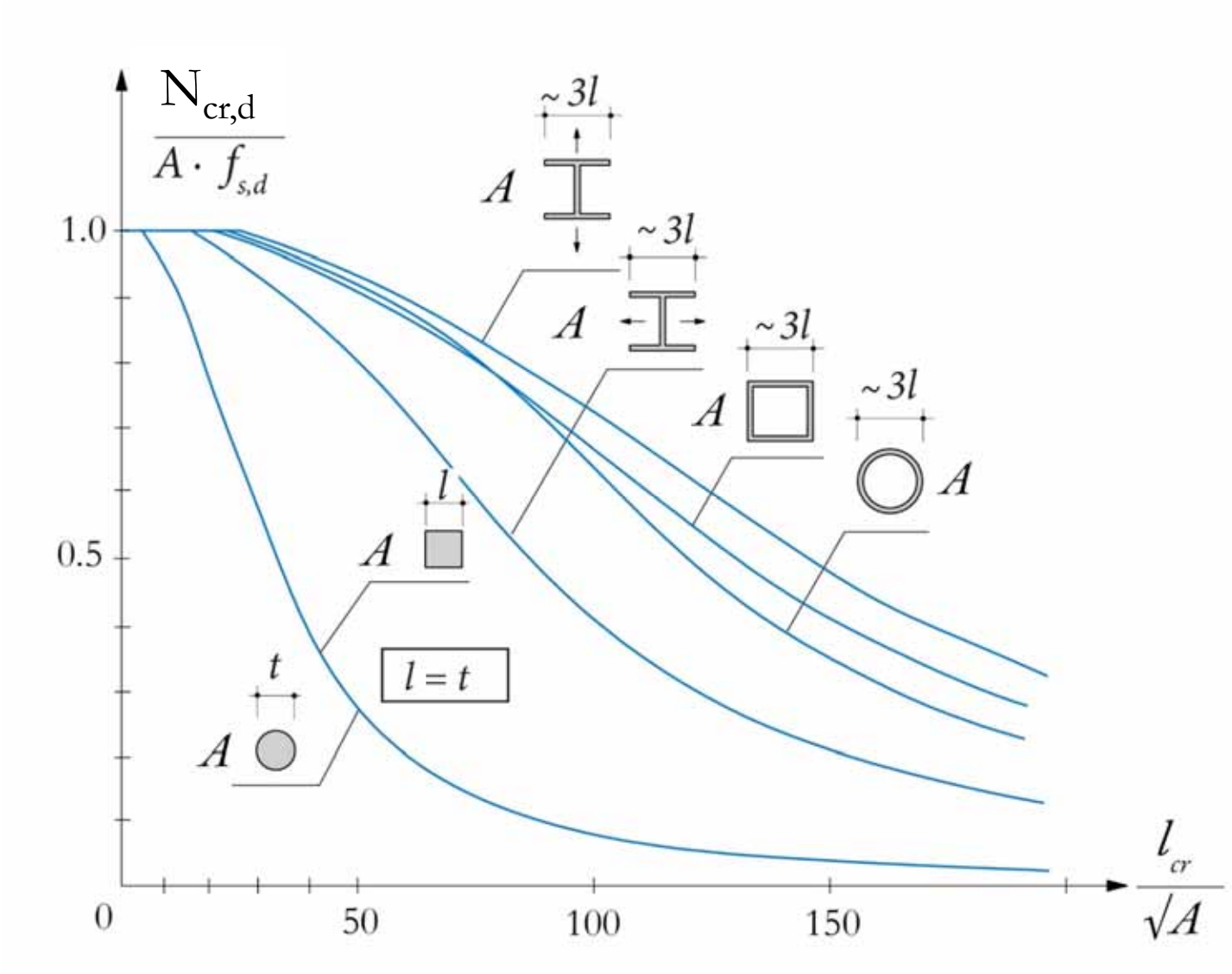
Knicken

Buckling



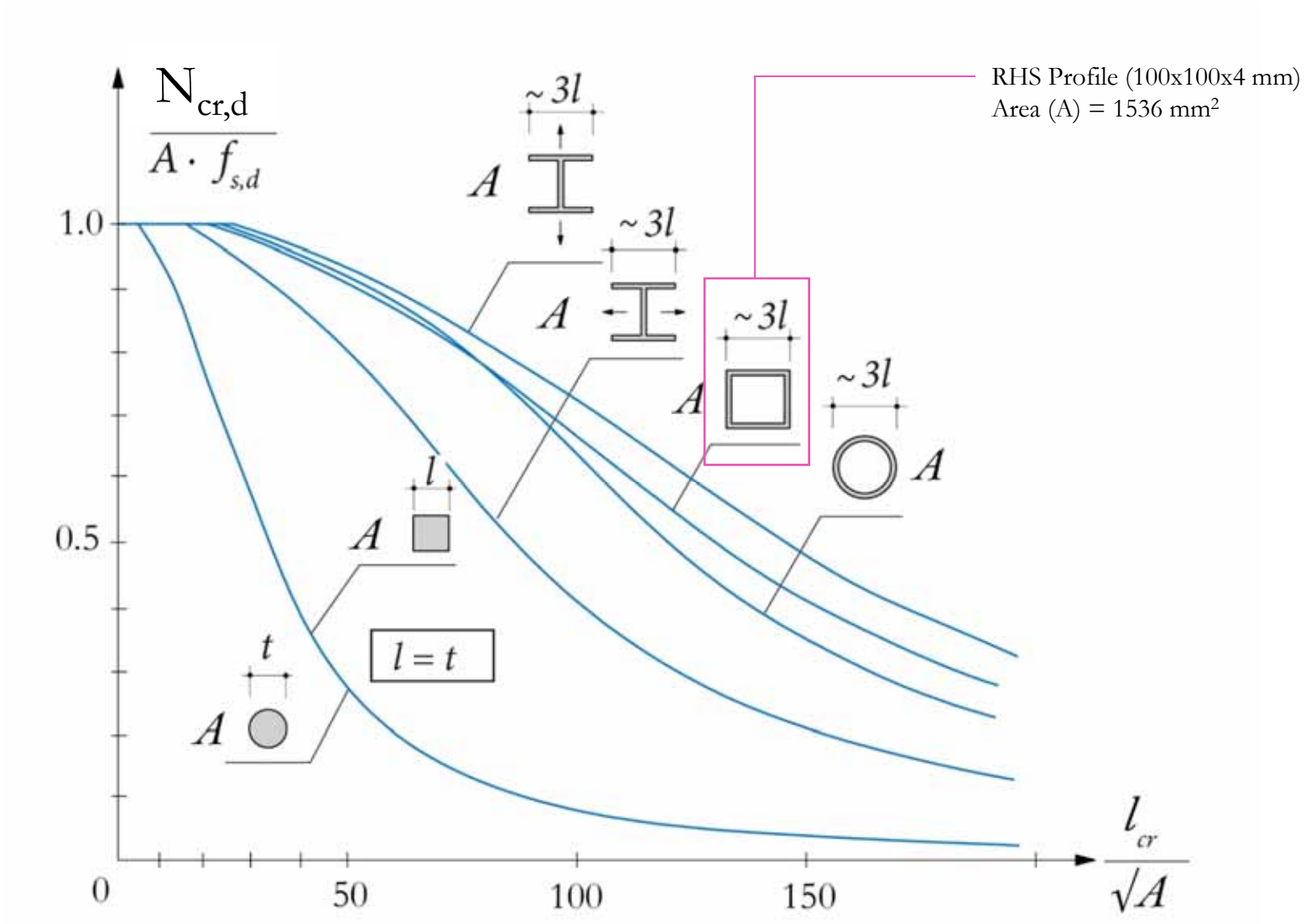
Kritische Längen von Elementen unter axialem Druck

Critical lengths of elements under axial compression



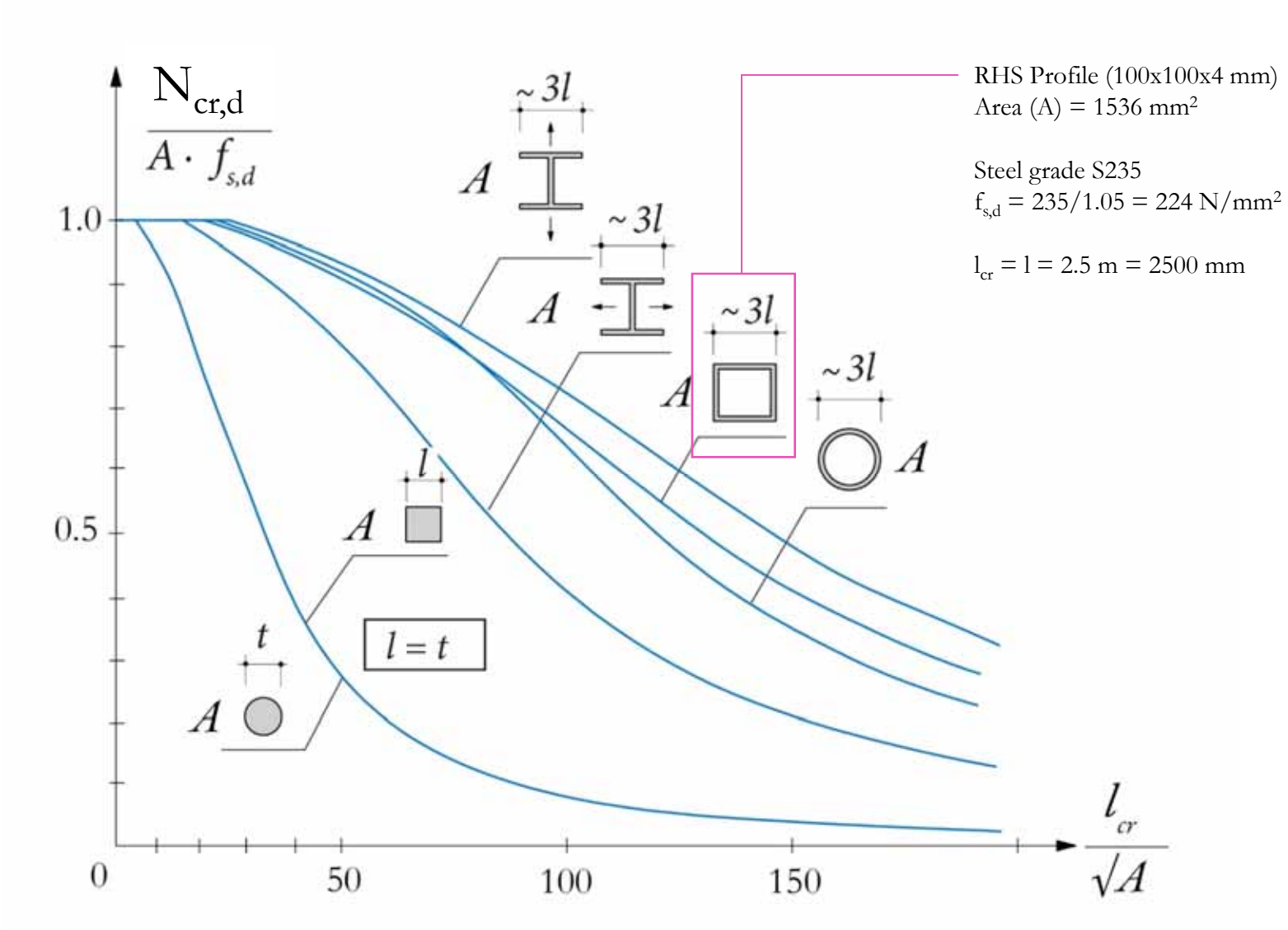
Knickkurven von Stahlprofilen

Buckling curves of steel profiles



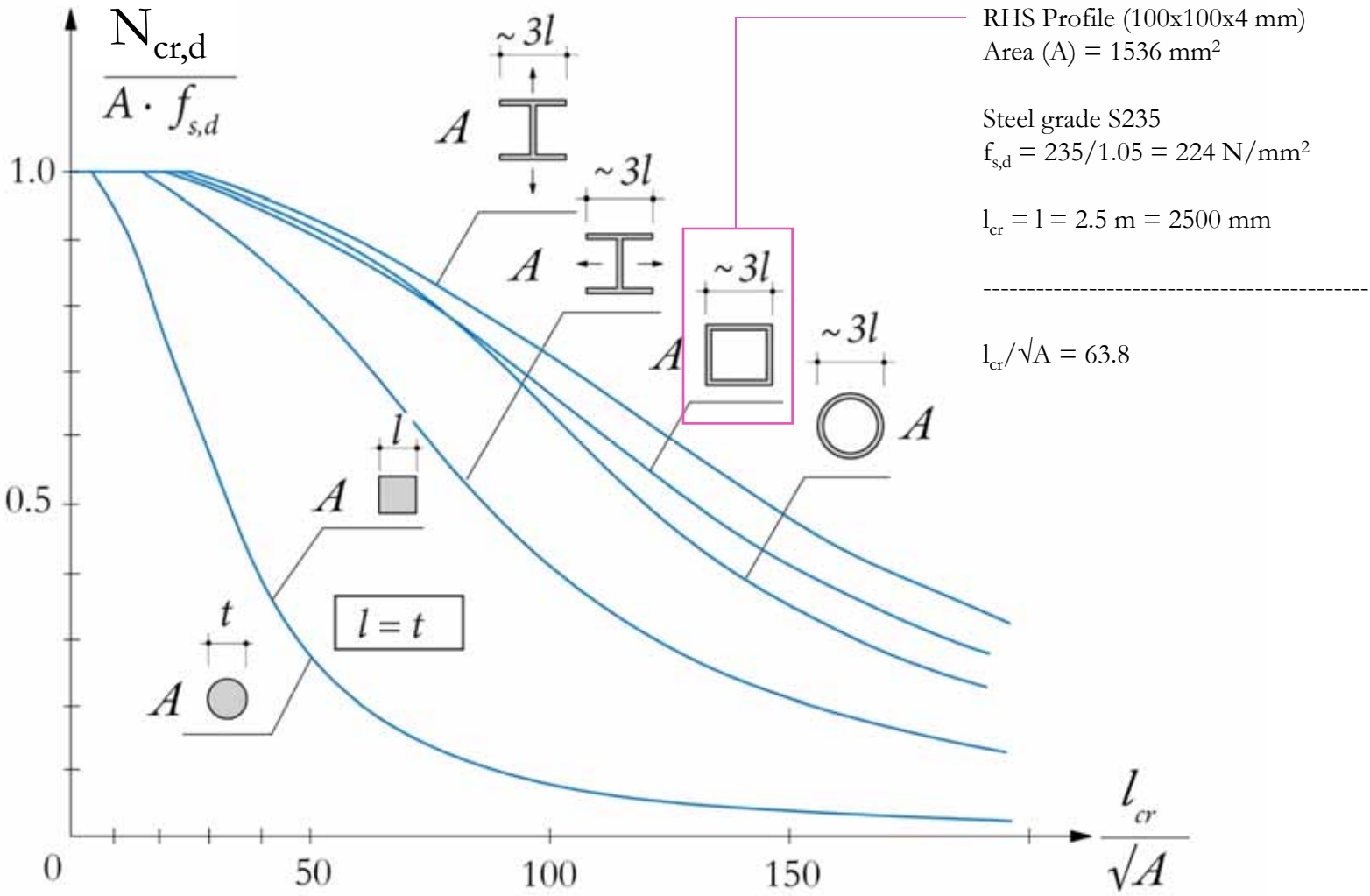
Knickkurven von Stahlprofilen

Buckling curves of steel profiles



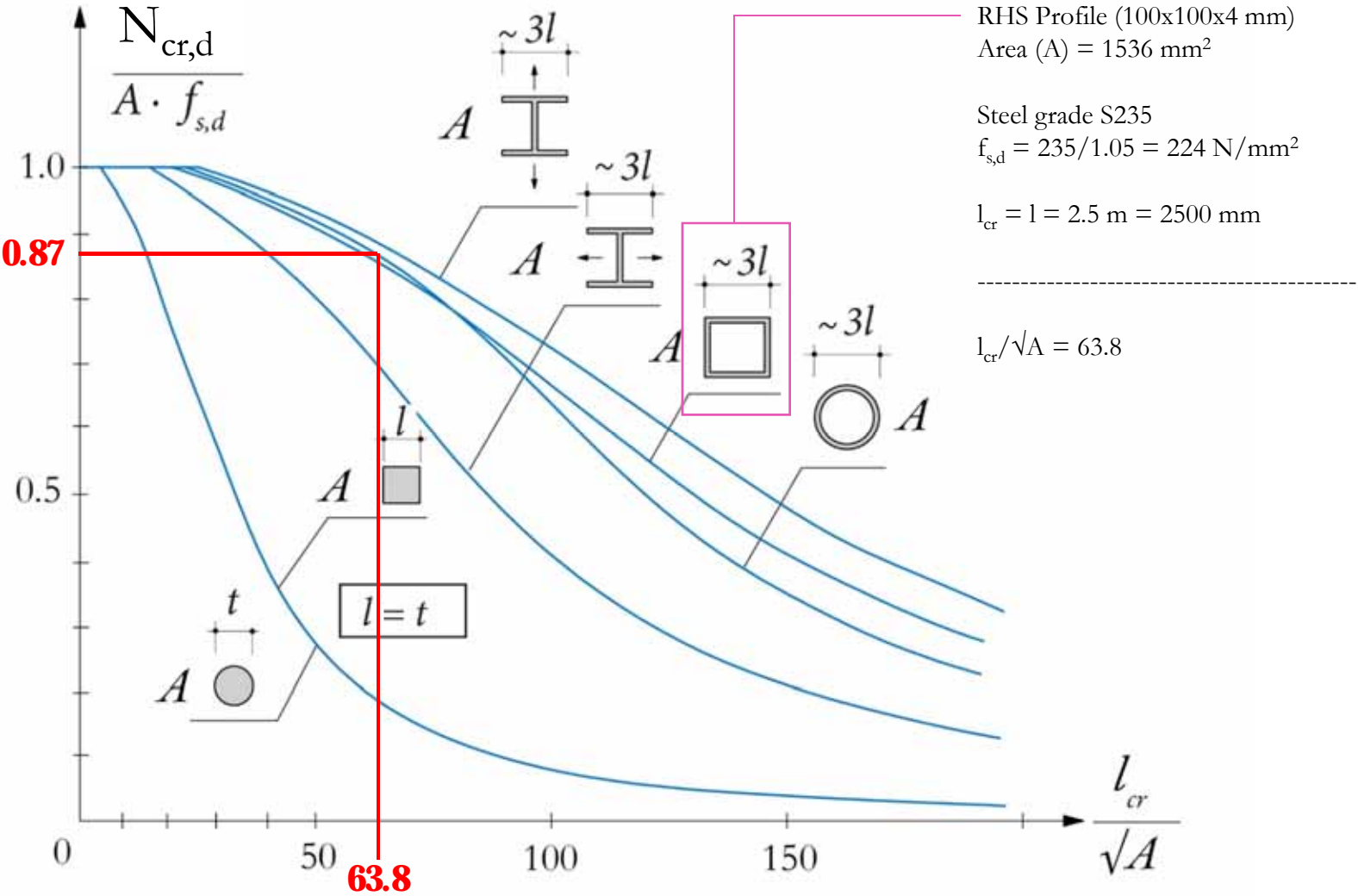
Knickkurven von Stahlprofilen

Buckling curves of steel profiles



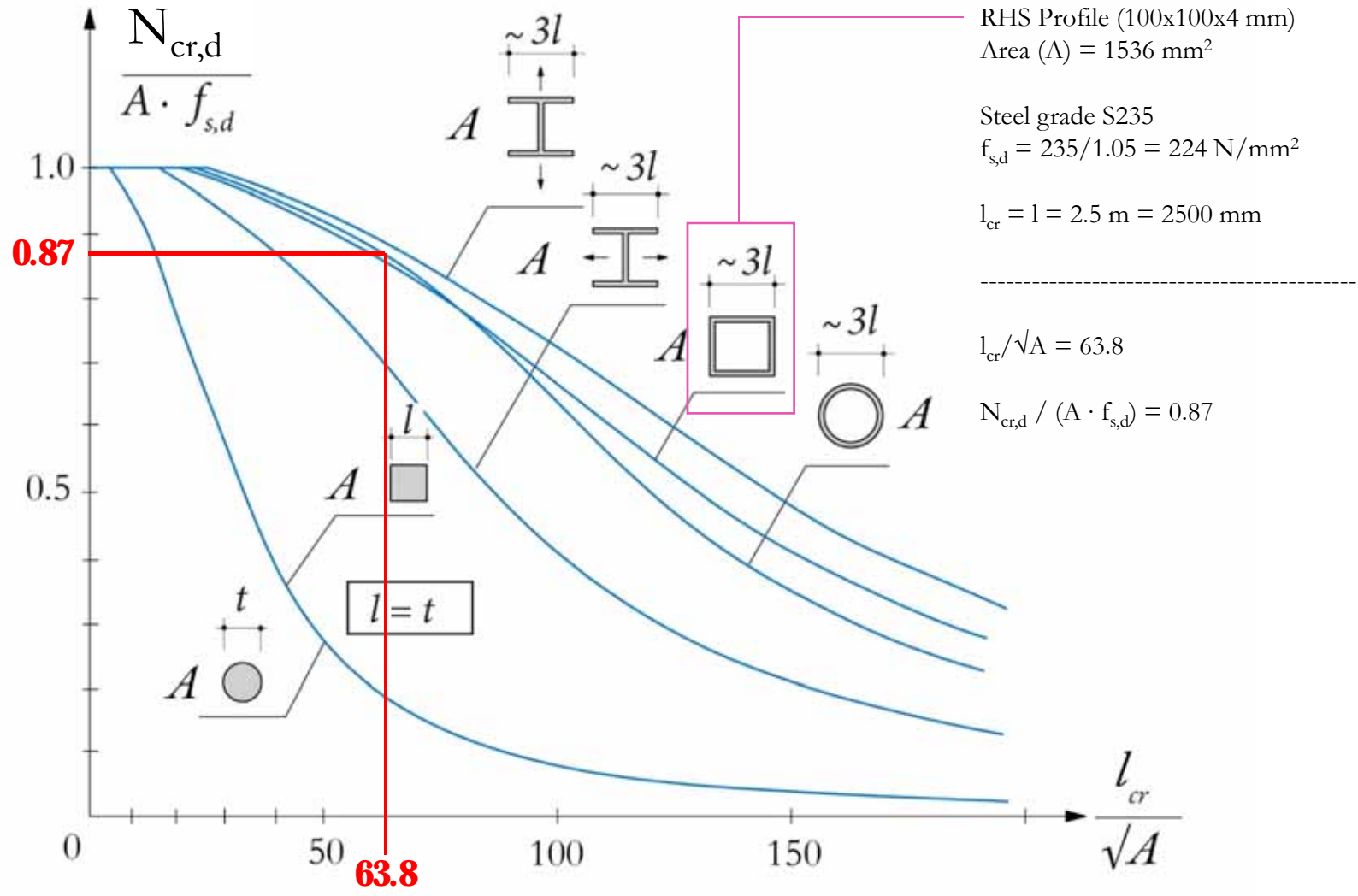
Knickkurven von Stahlprofilen

Buckling curves of steel profiles



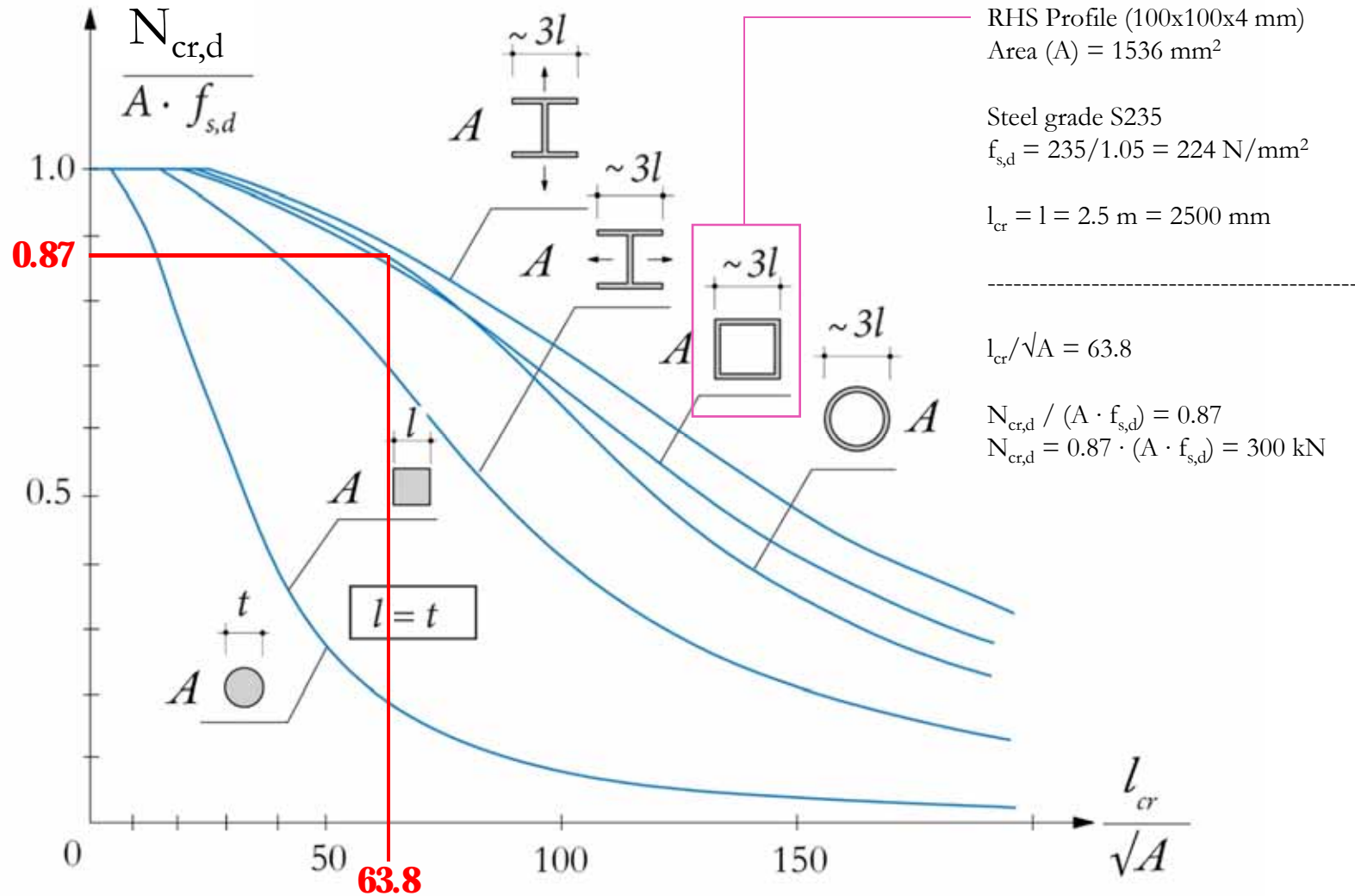
Knickkurven von Stahlprofilen

Buckling curves of steel profiles



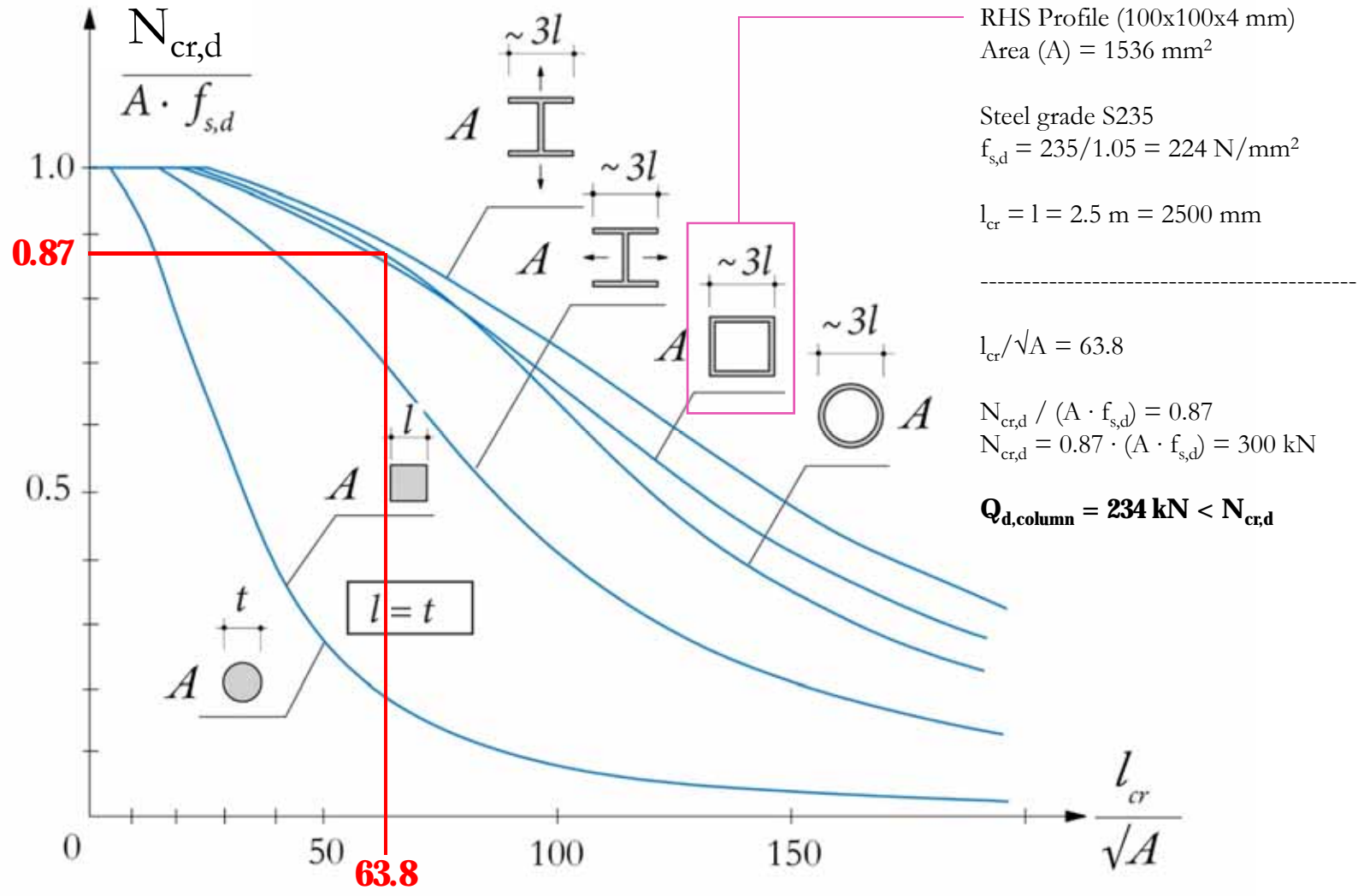
Knickkurven von Stahlprofilen

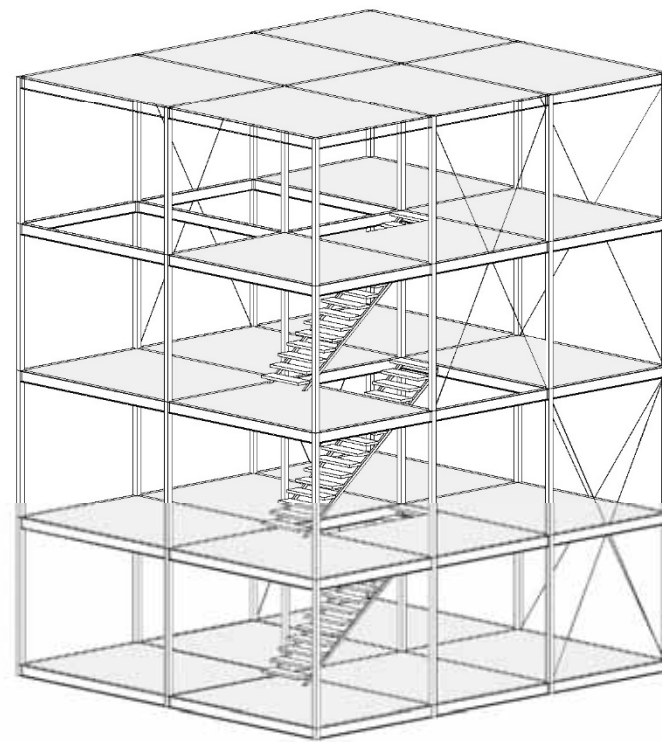
Buckling curves of steel profiles

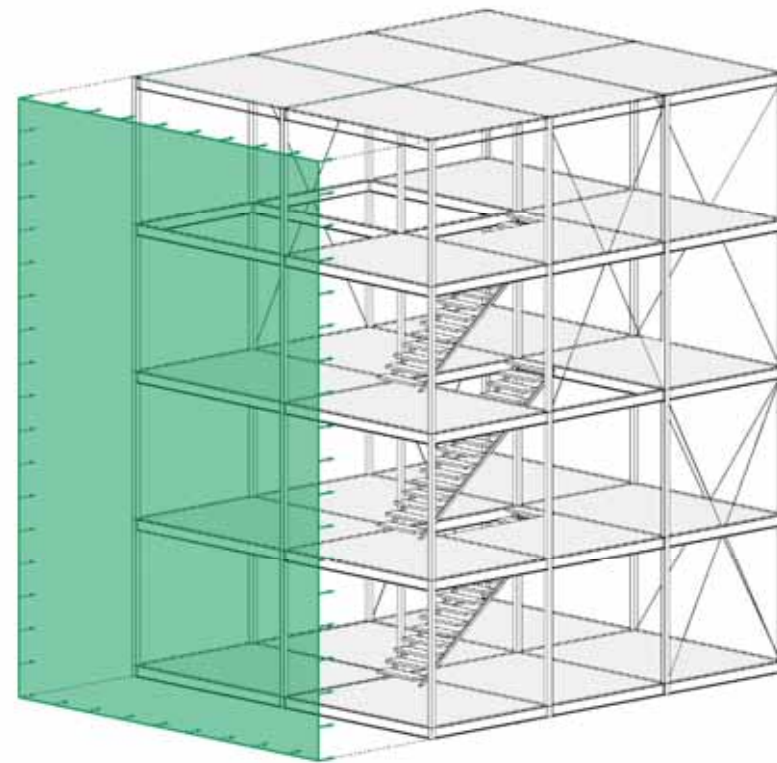


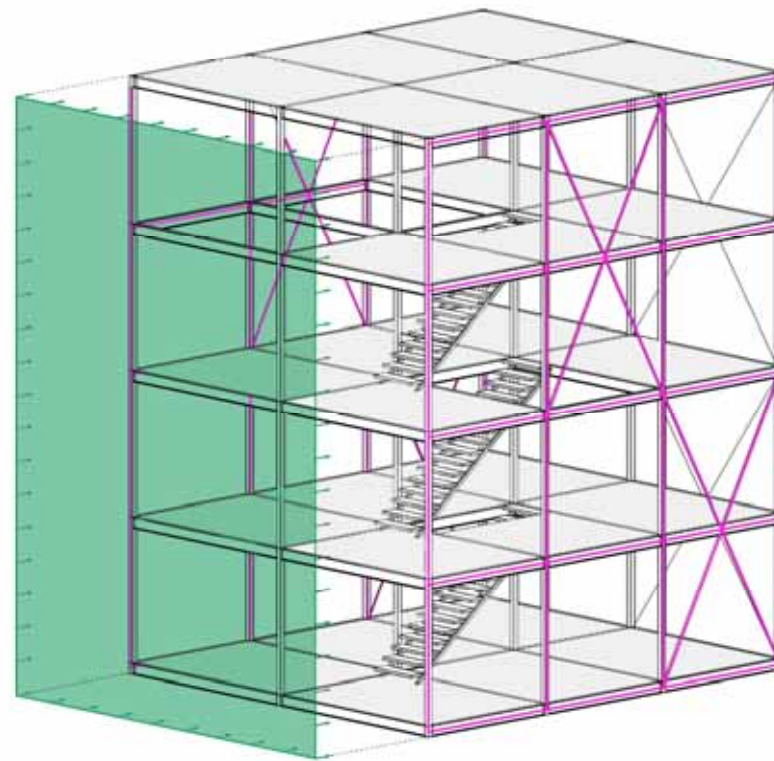
Knickkurven von Stahlprofilen

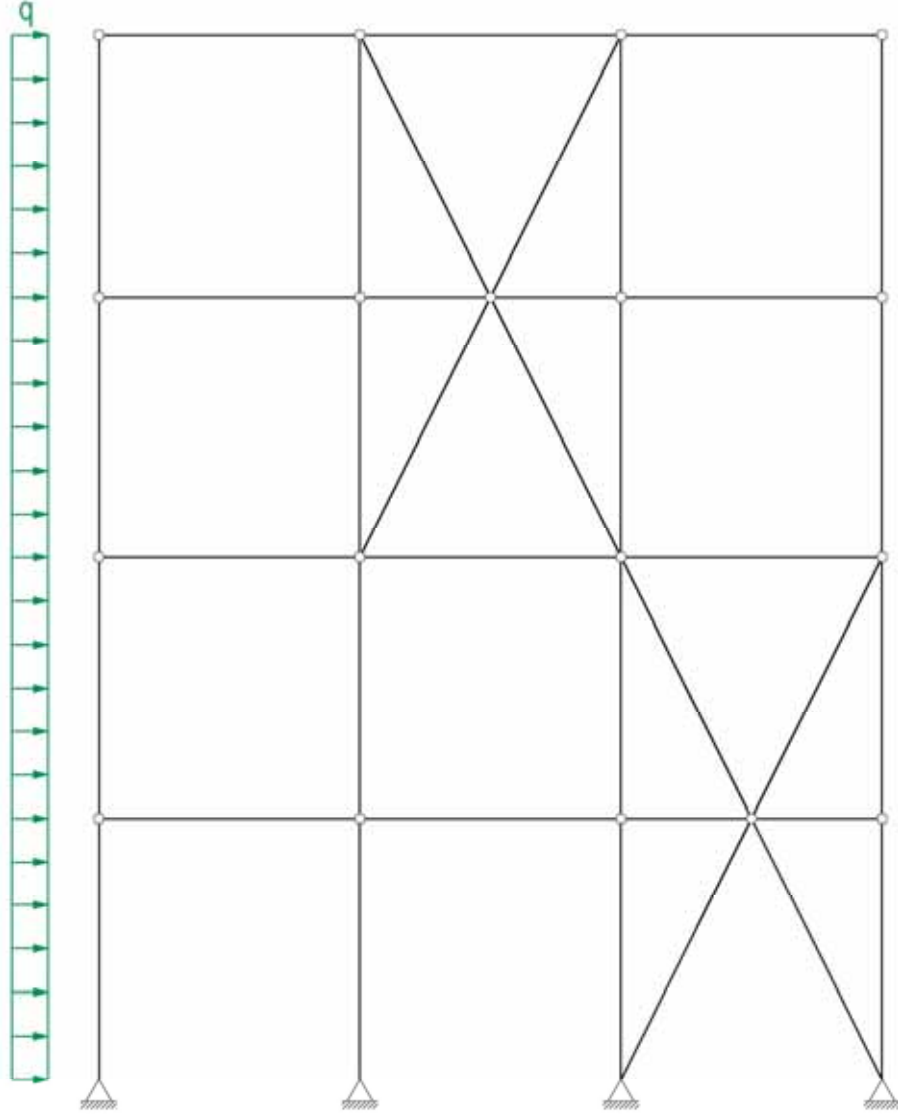
Buckling curves of steel profiles





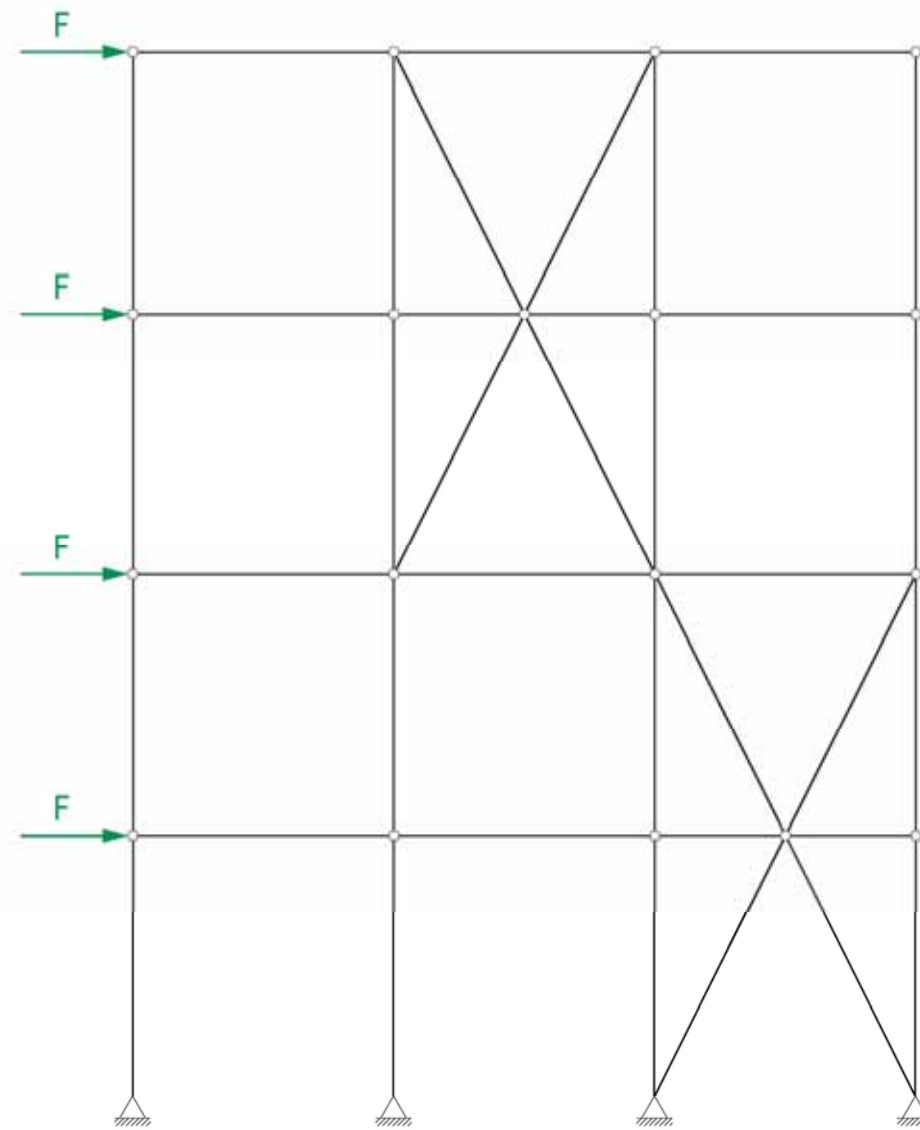


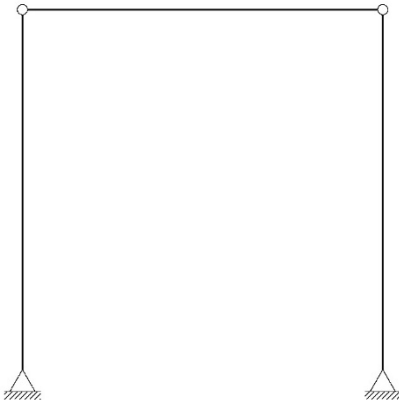


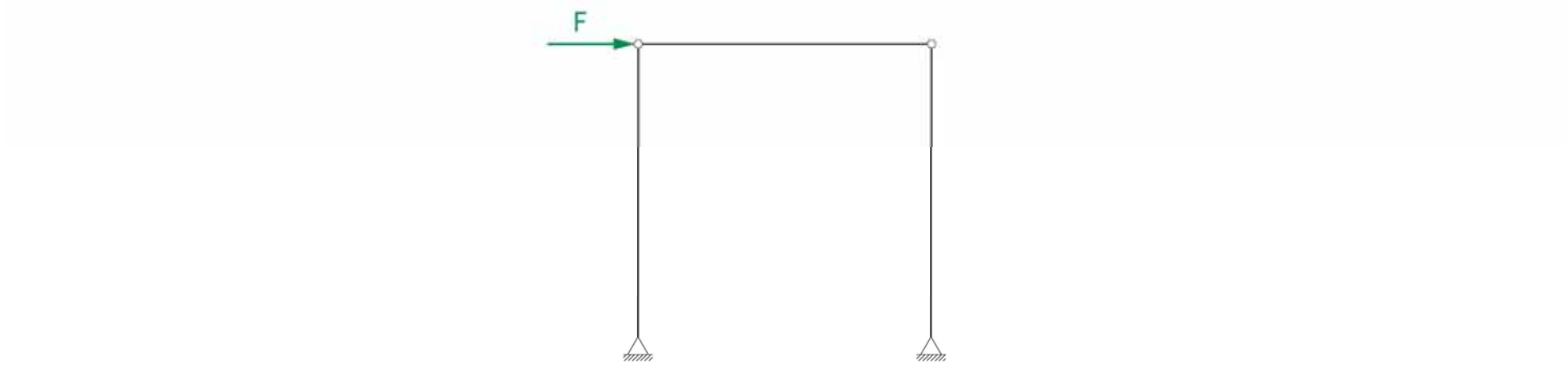


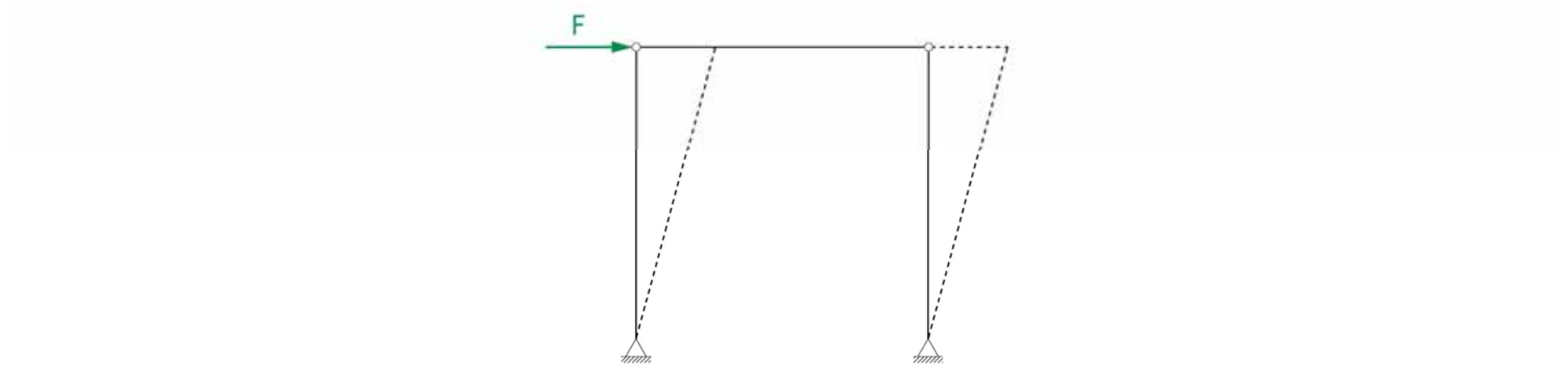
Horizontale Einwirkungen

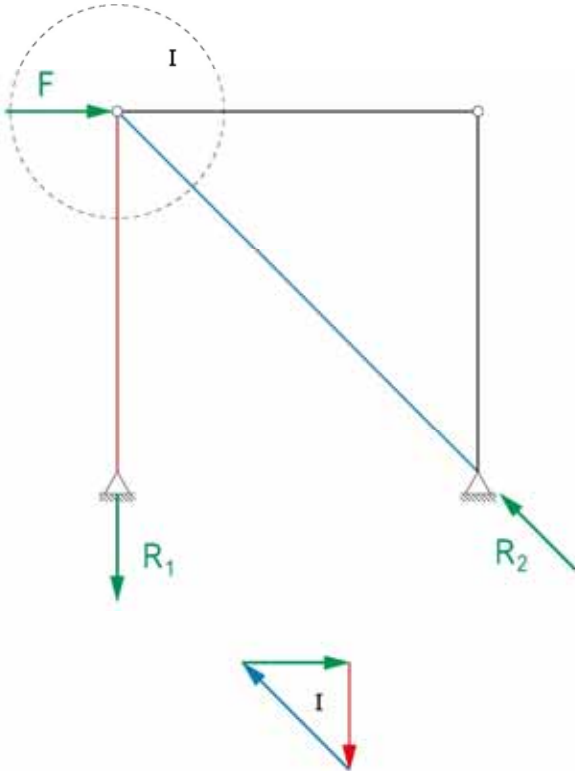
Horizontal loads

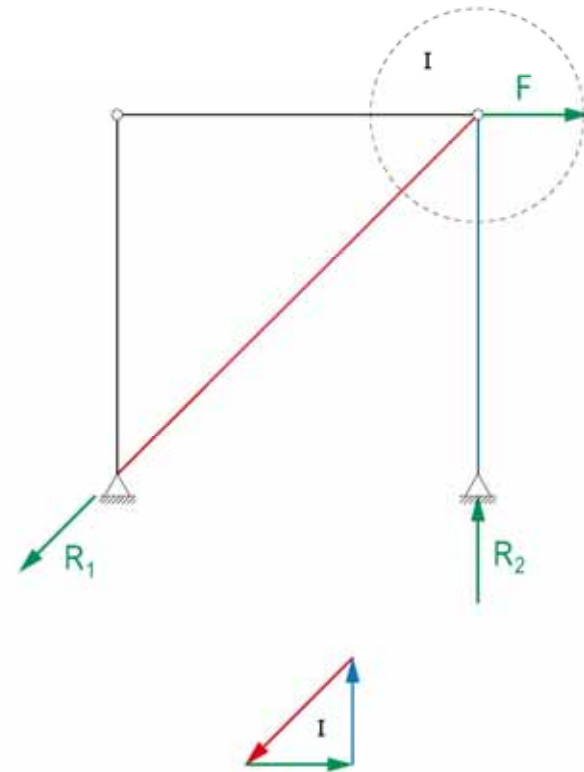


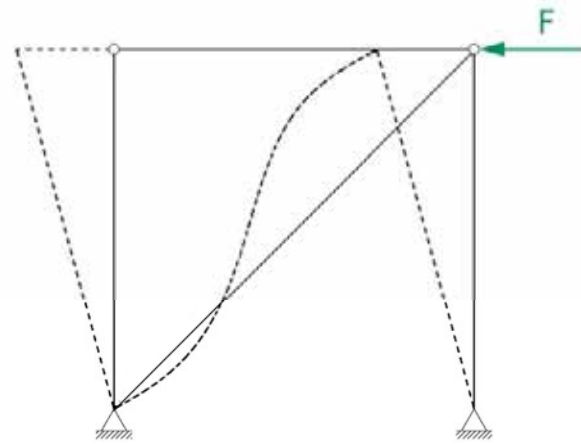


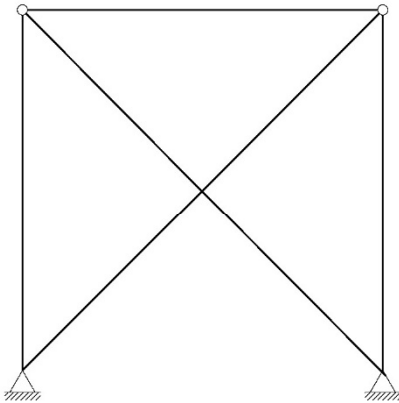


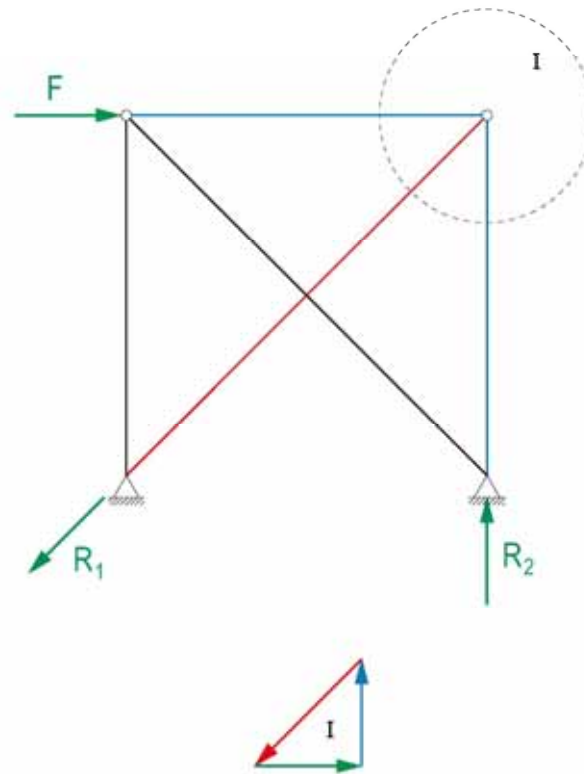


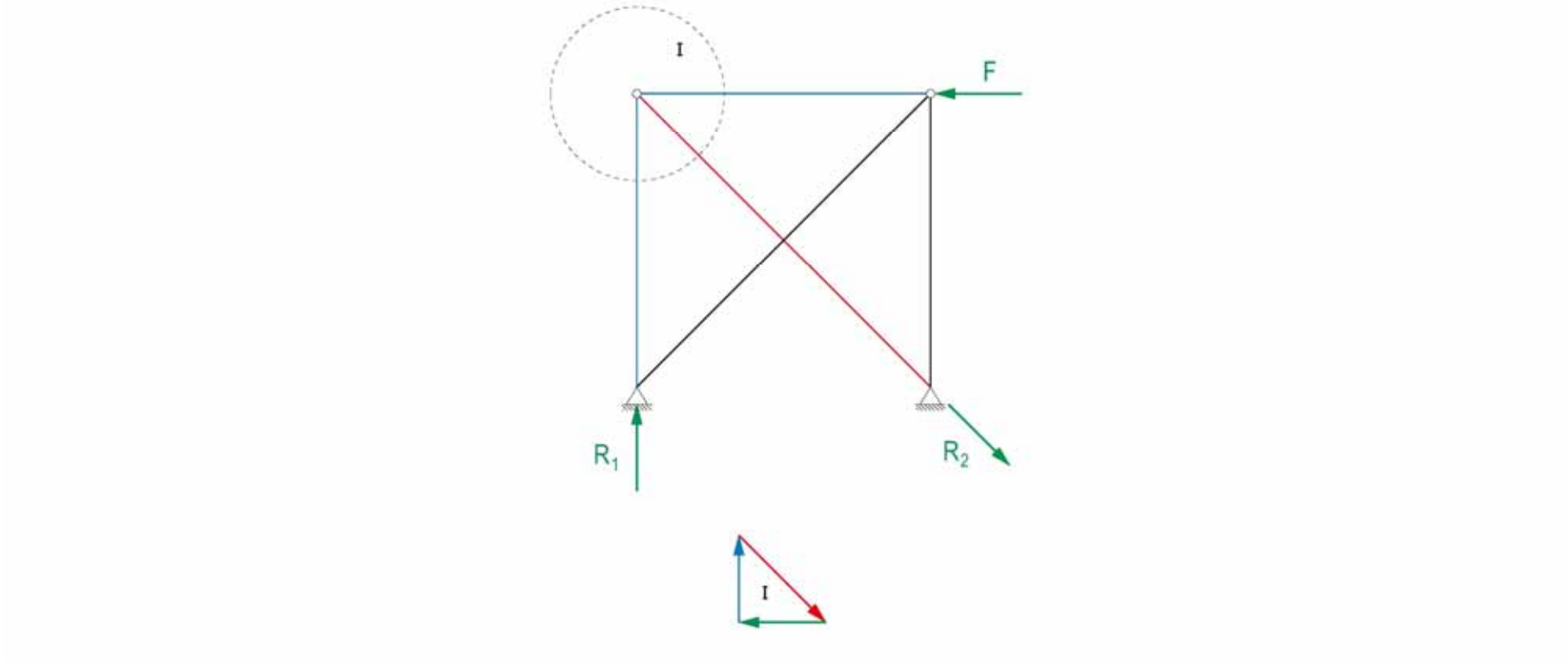








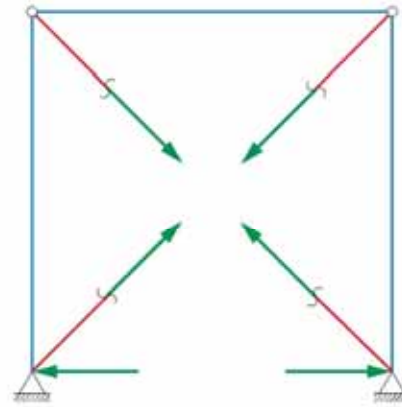


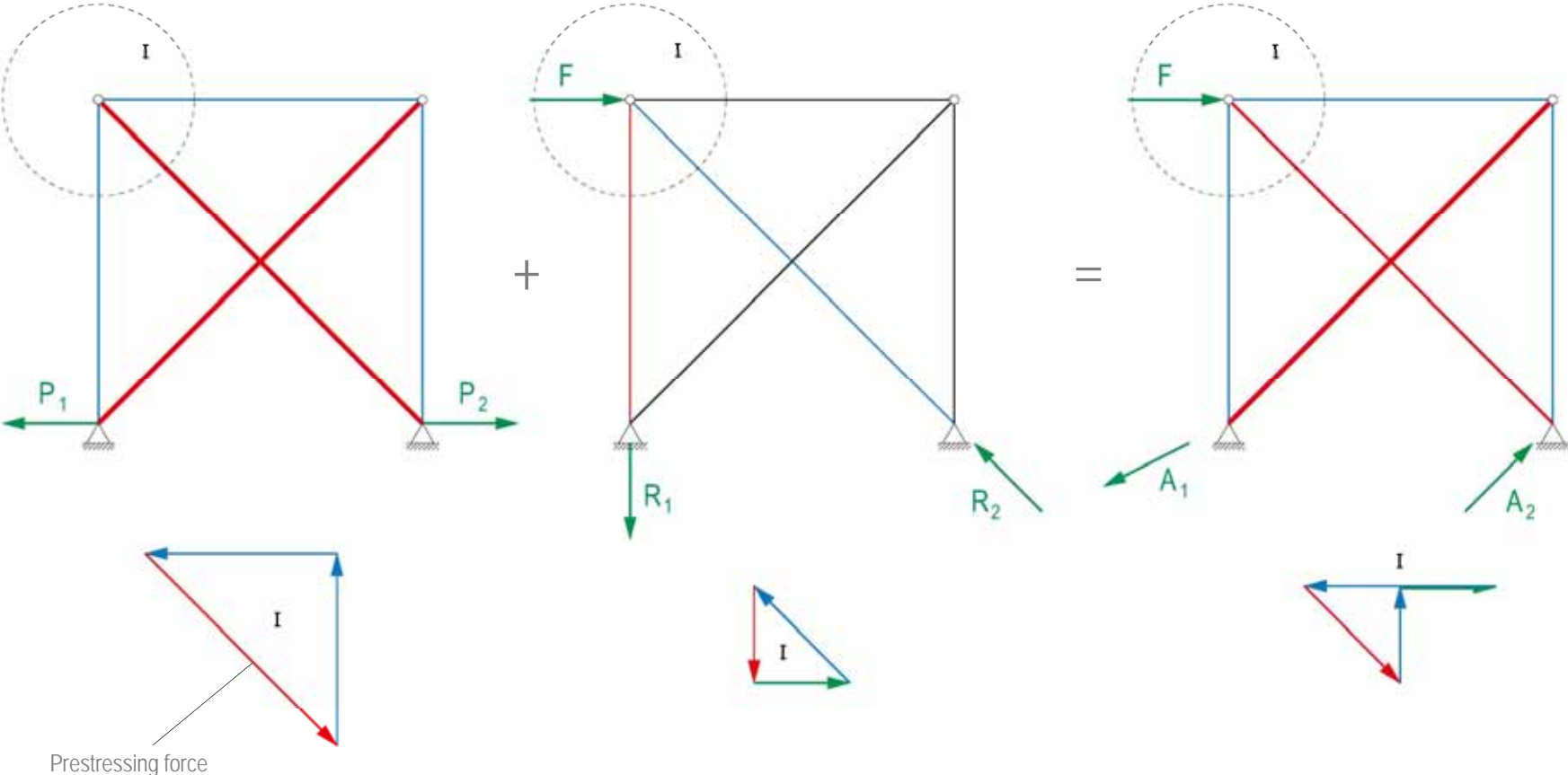


Live Demo

Horizontale Stabilität

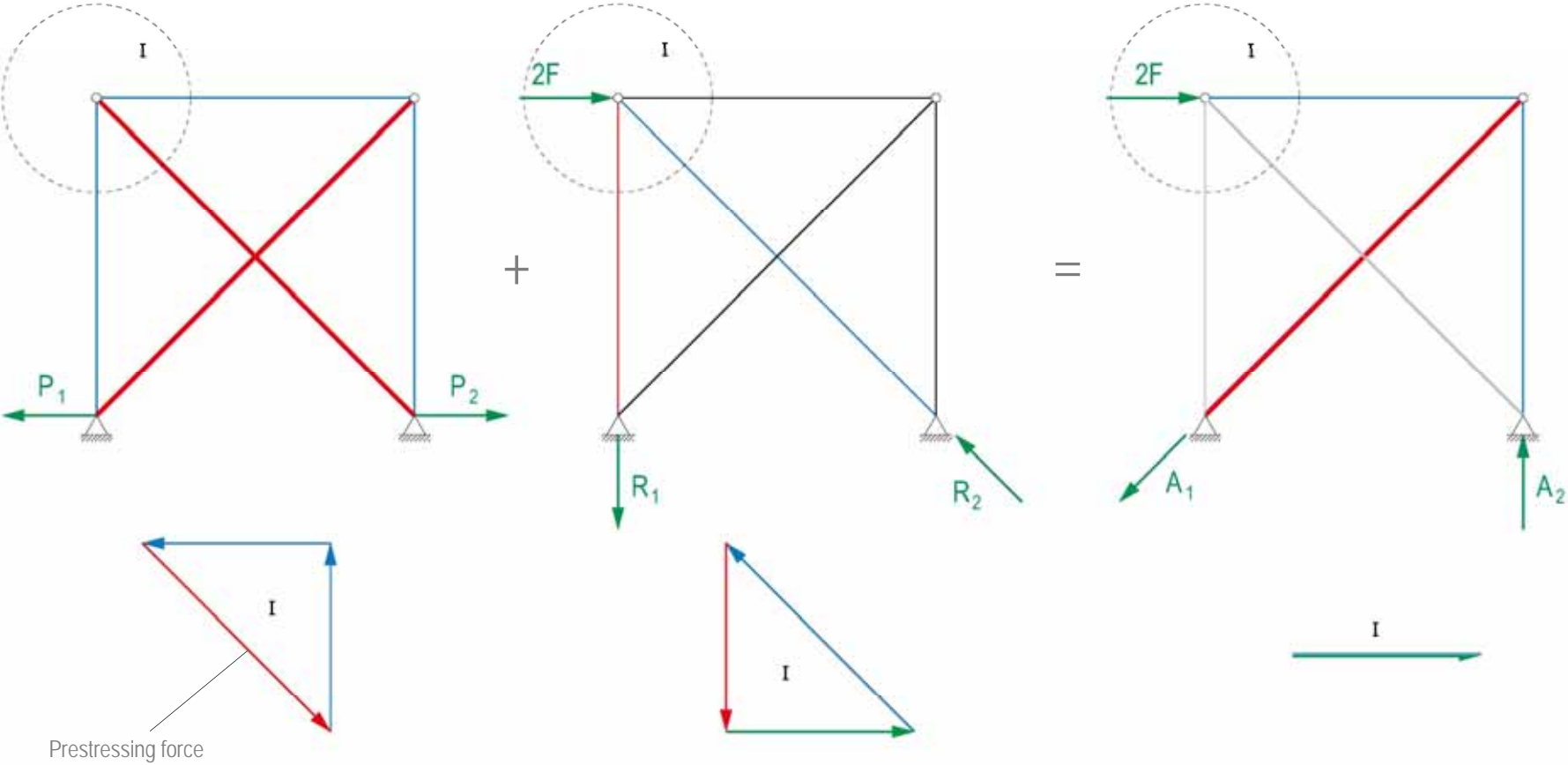
Horizontal Stability





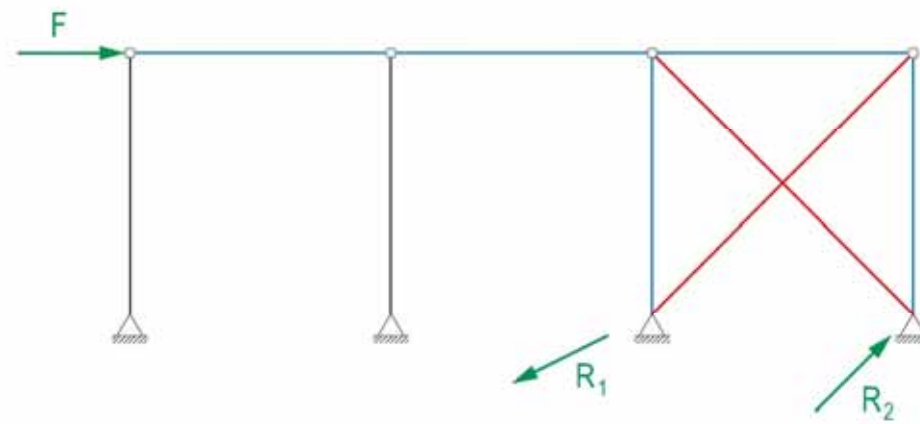
Horizontale Lasten

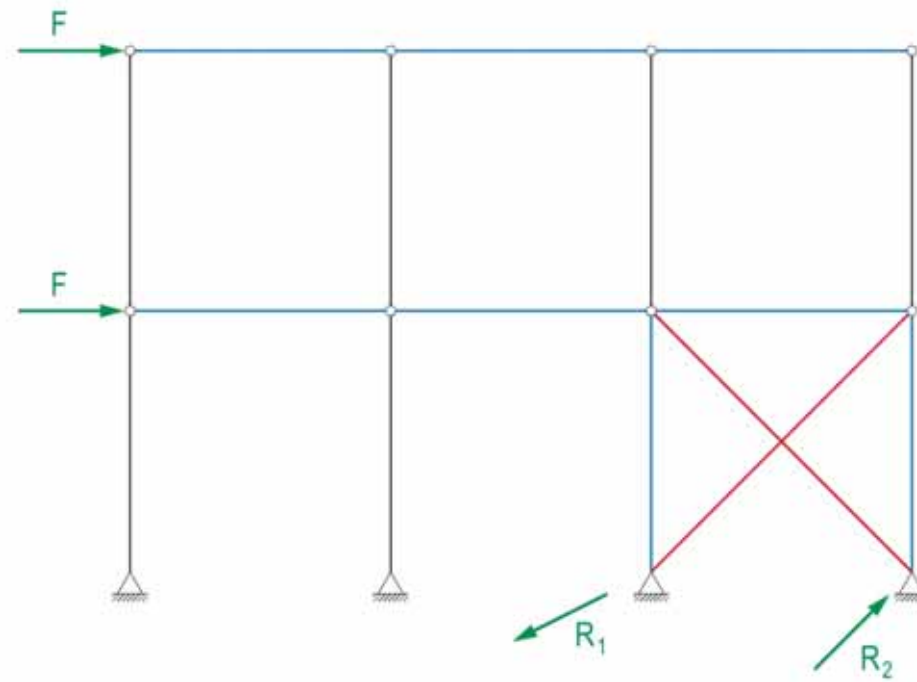
Horizontal loads

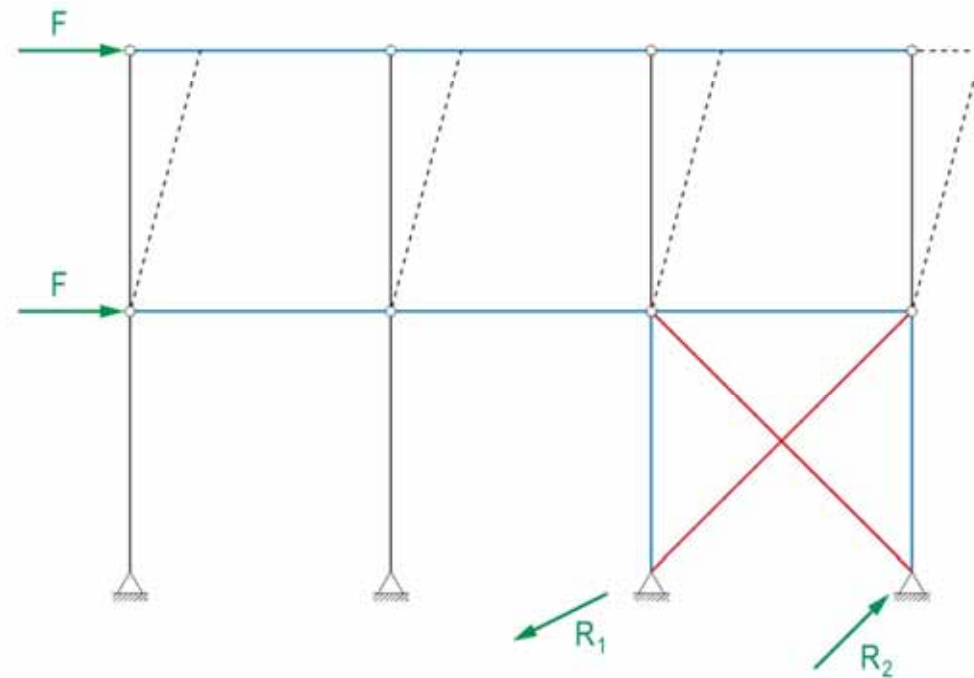


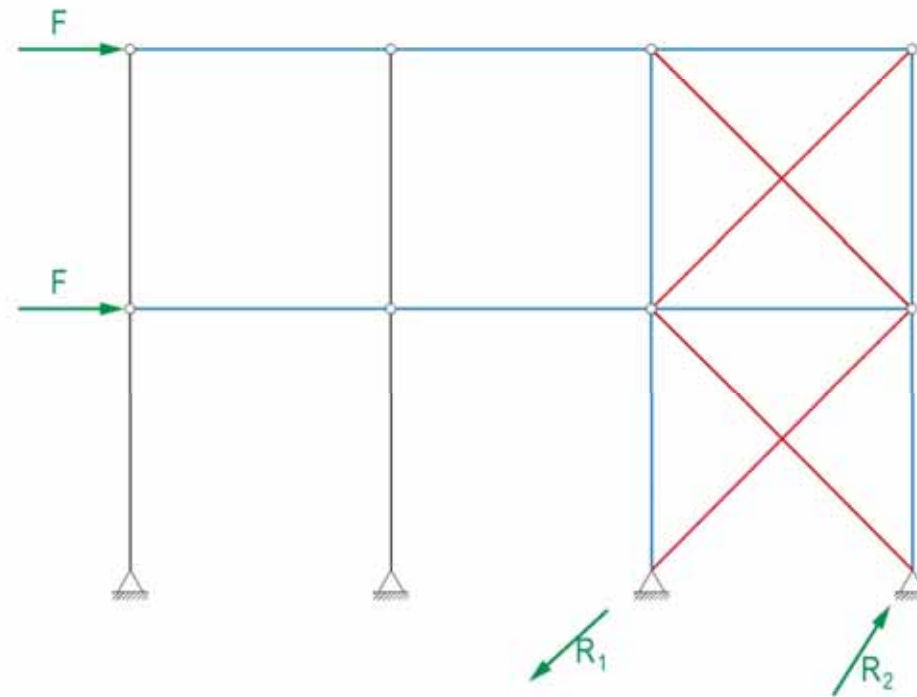
Horizontale Einwirkungen

Horizontal loads

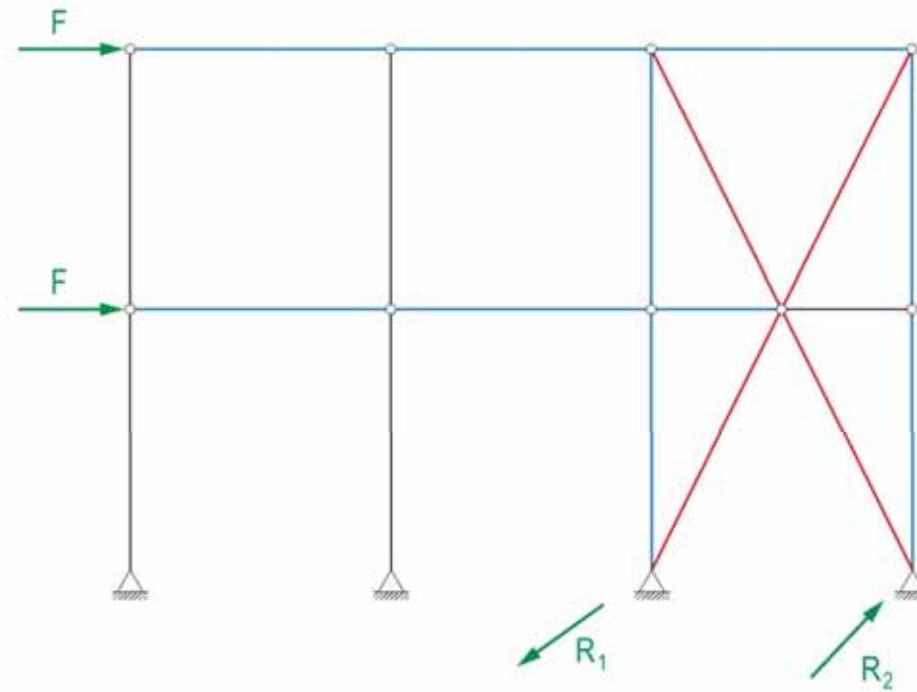


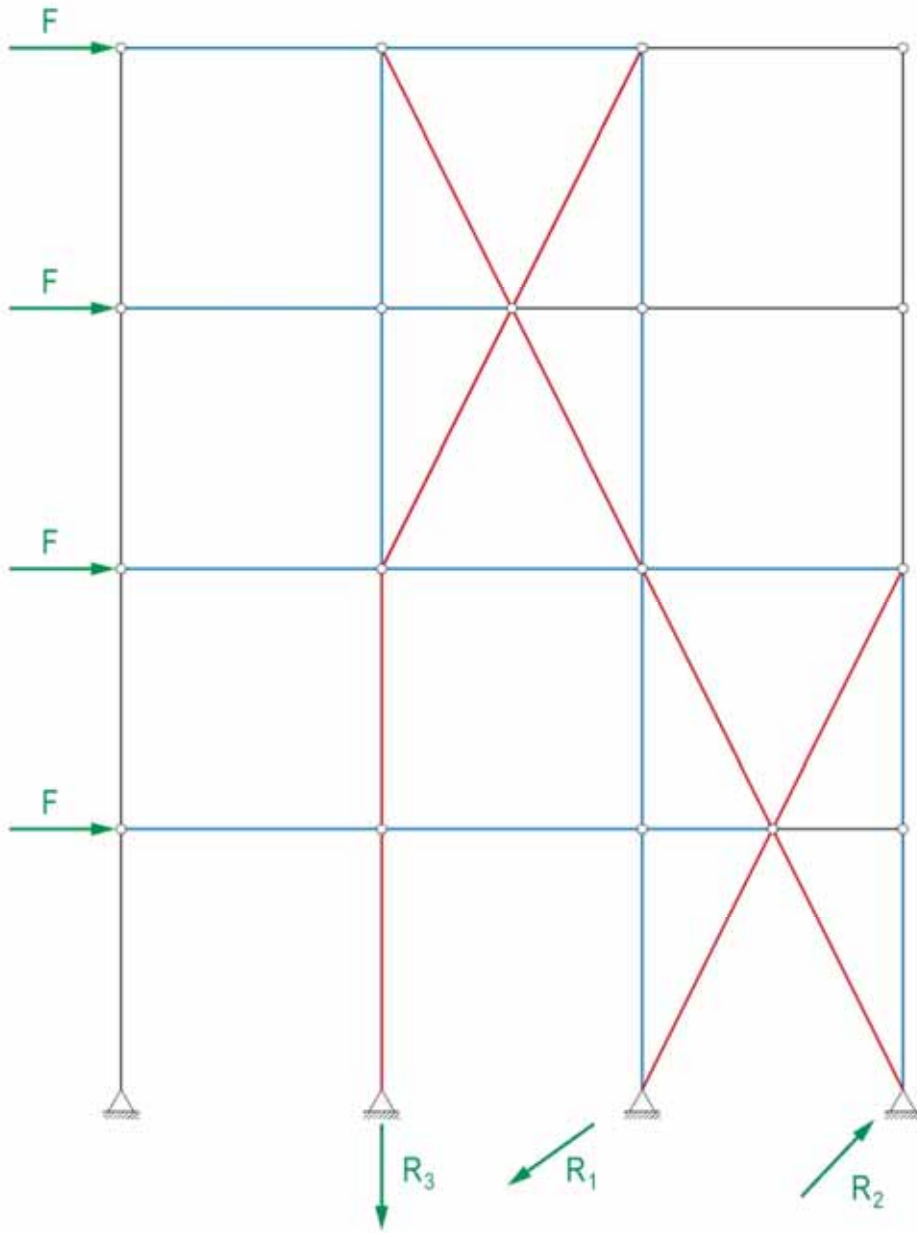






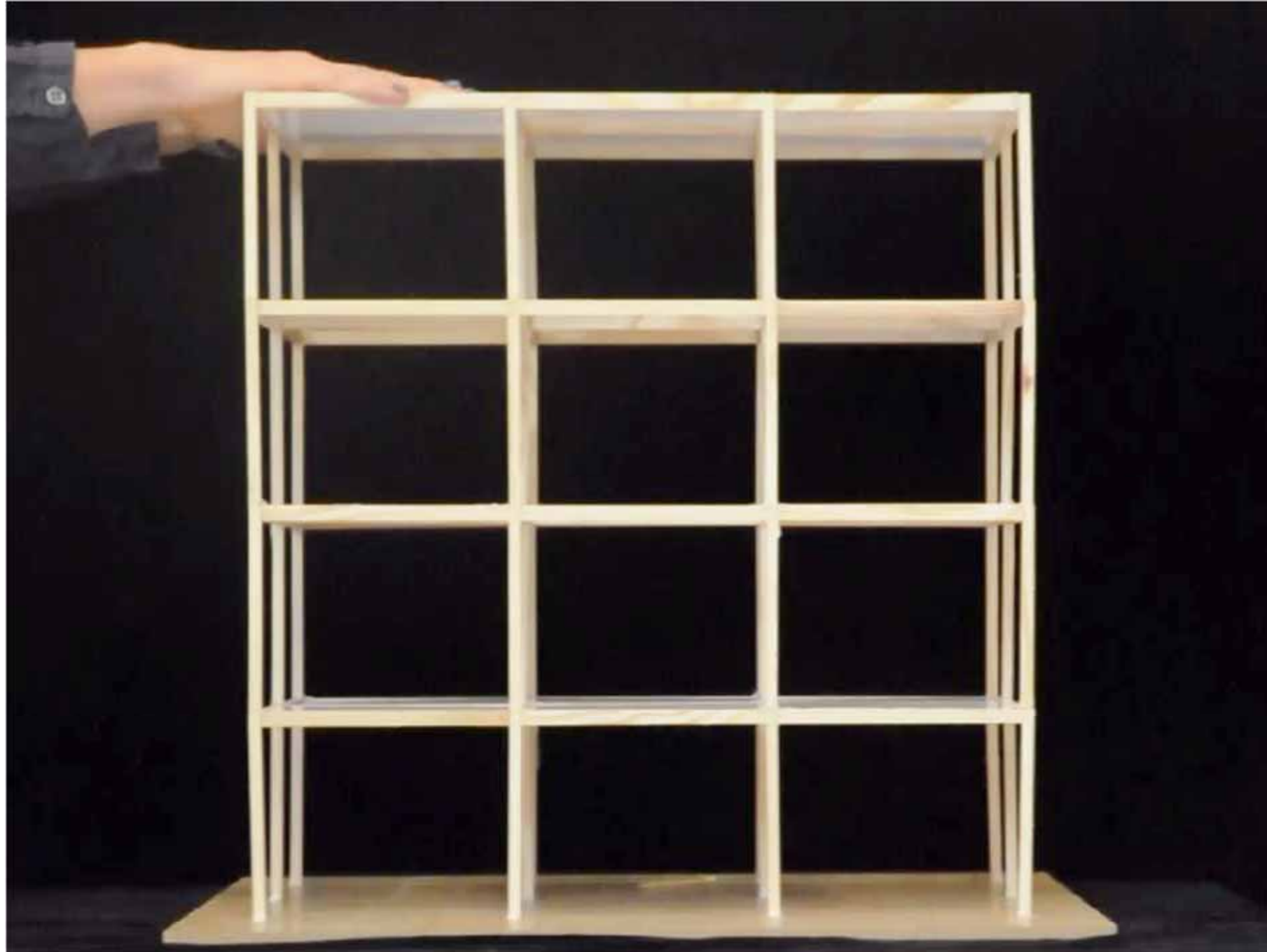
Horizontale Einwirkungen
Horizontal loads



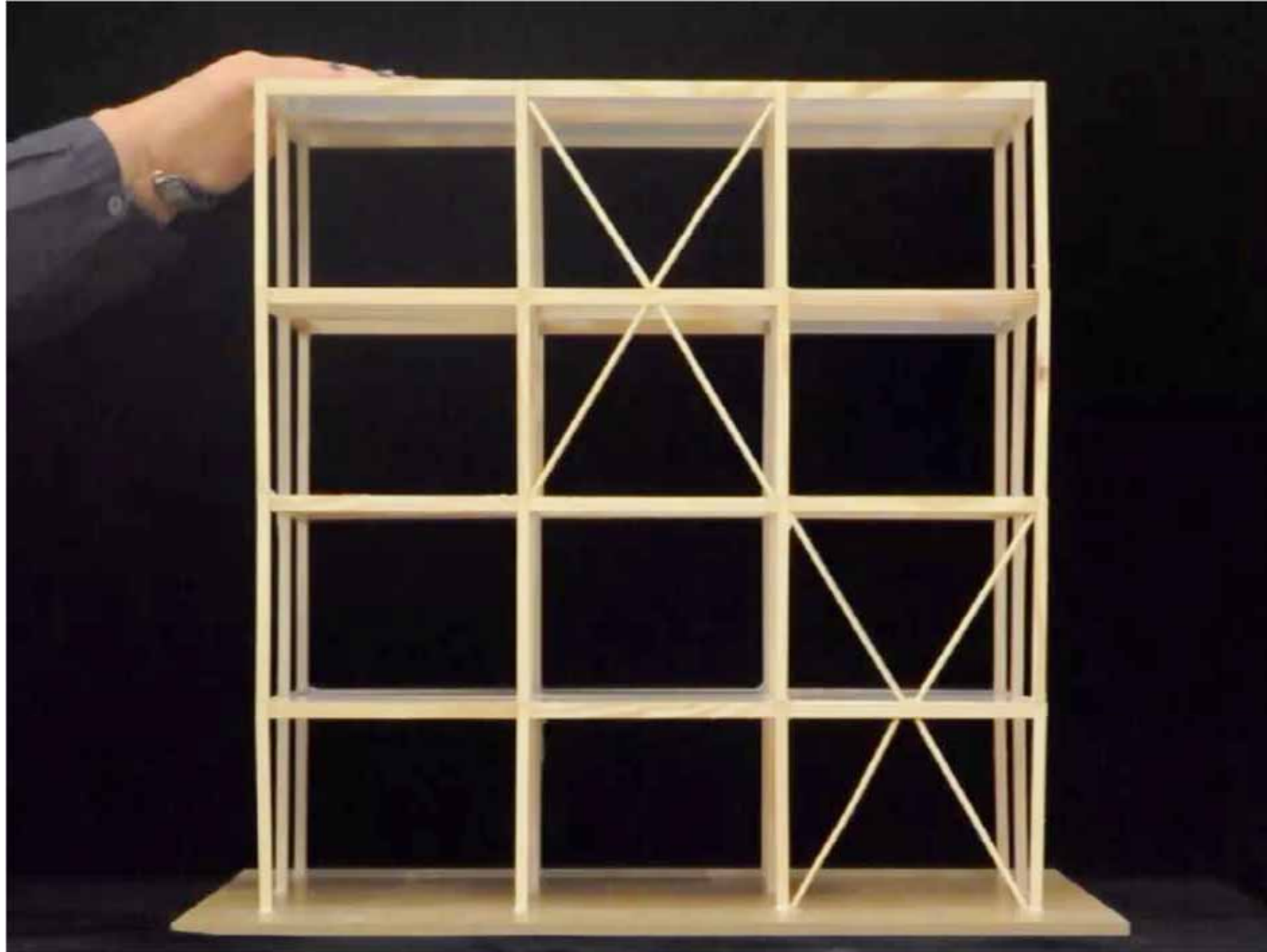


Horizontale Einwirkungen

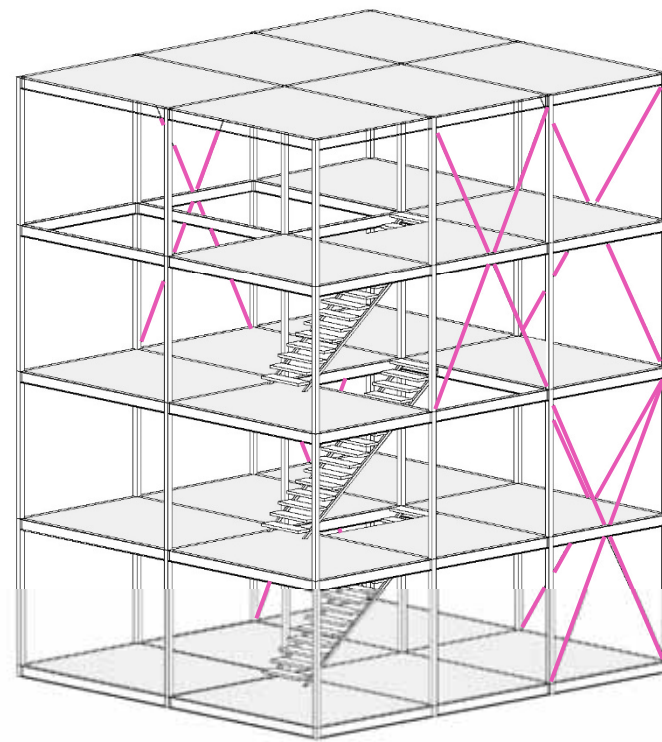
Horizontal loads



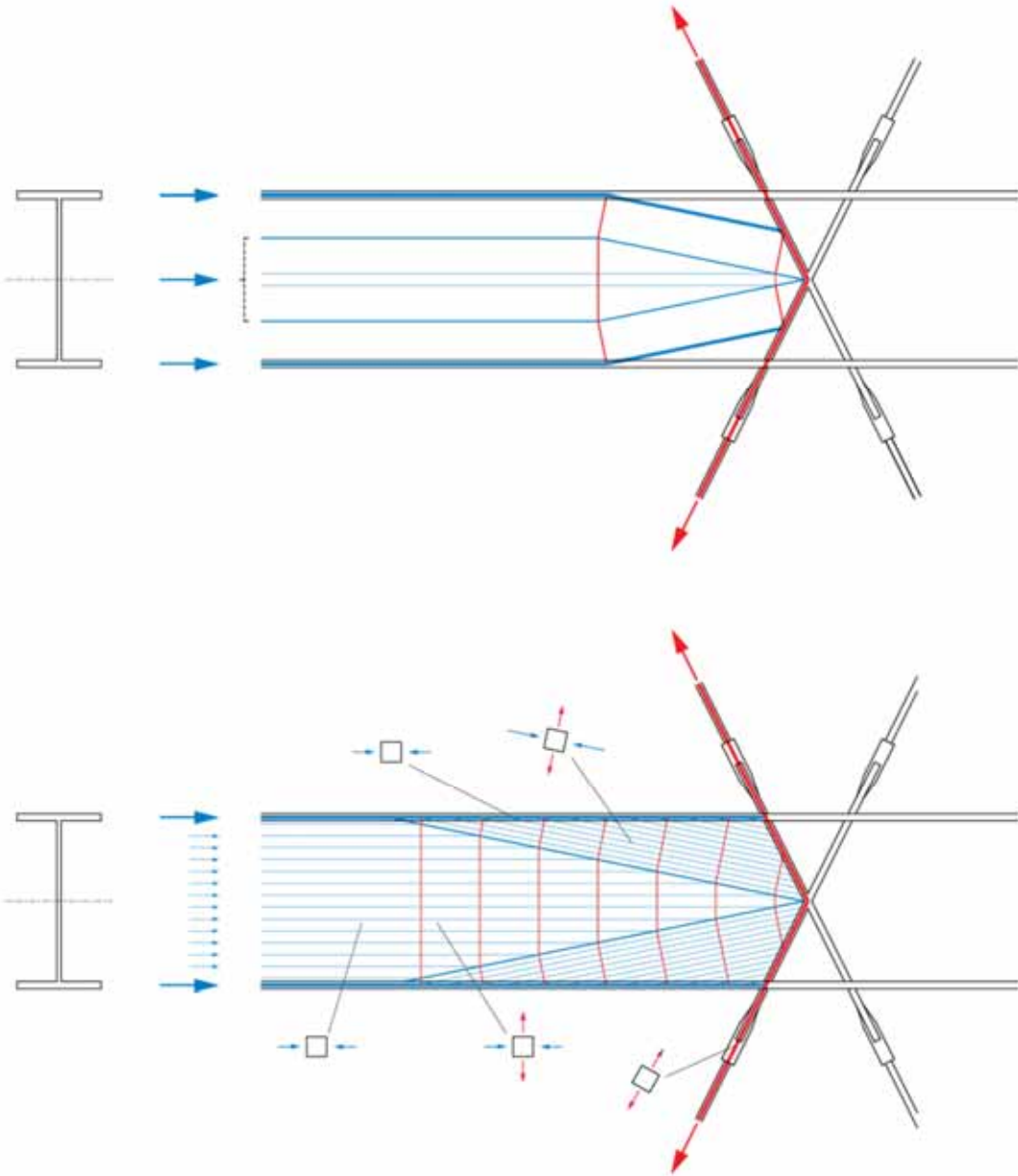
Horizontale Einwirkungen
Horizontal loads



Horizontale Einwirkungen
Horizontal loads

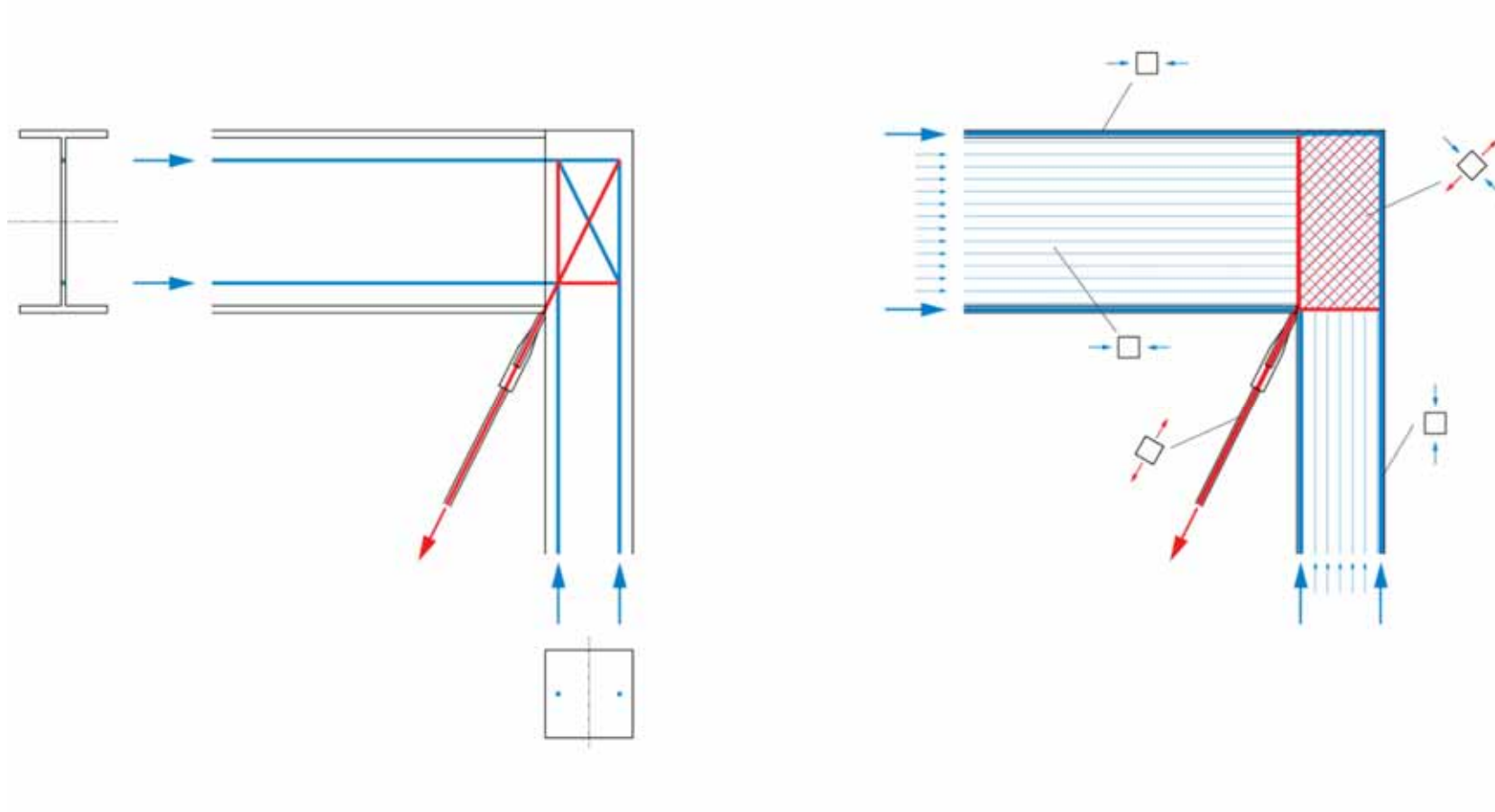


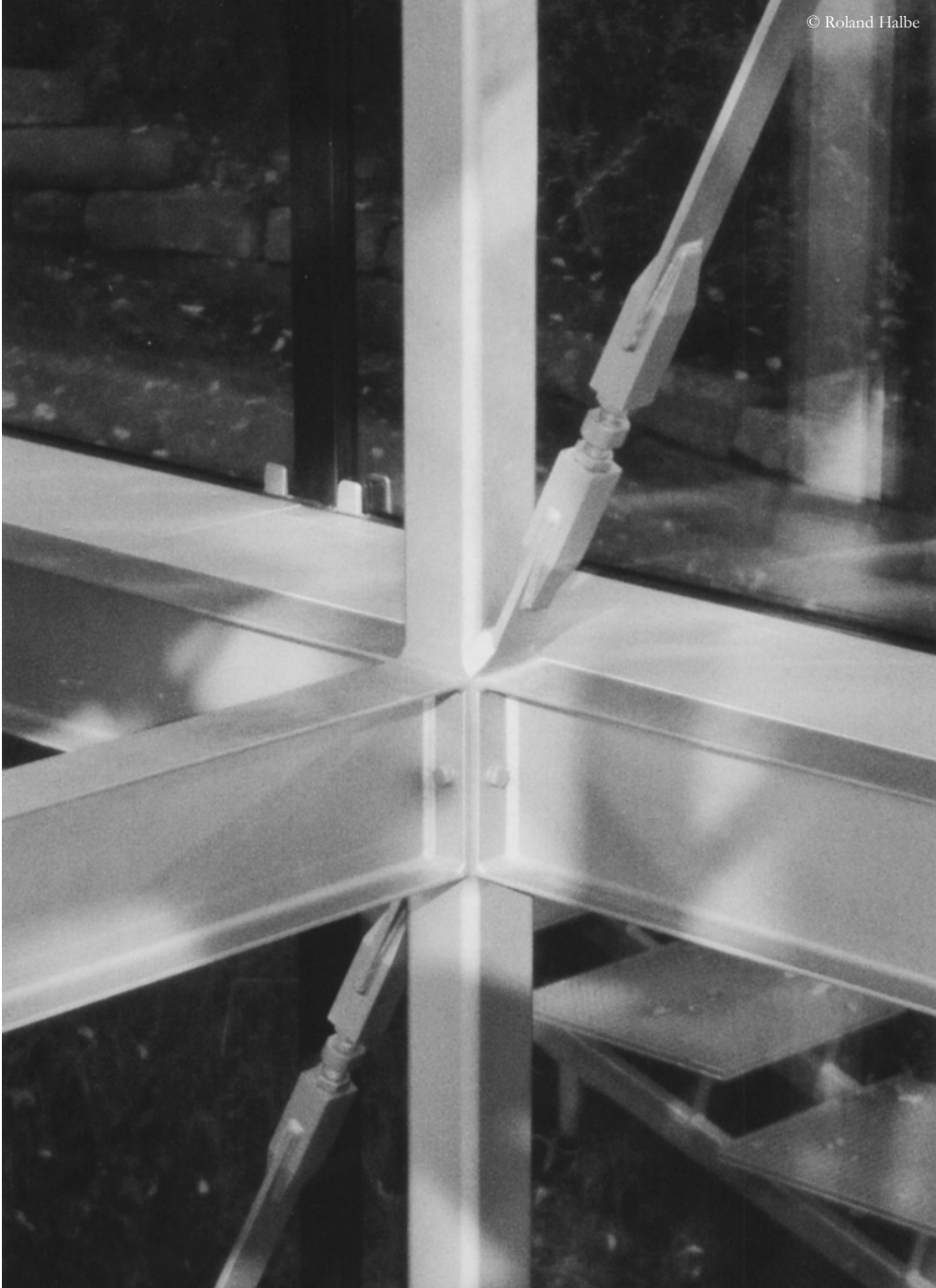




Innere Kräfte in Profilen und Schweißnähten

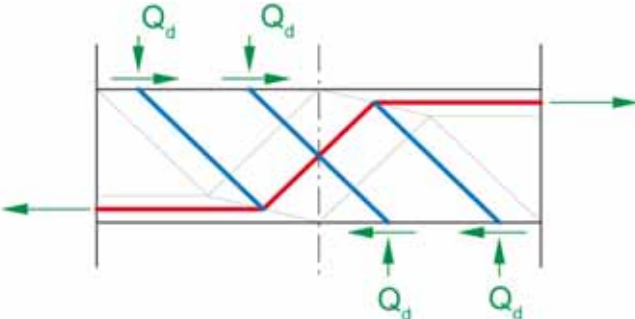
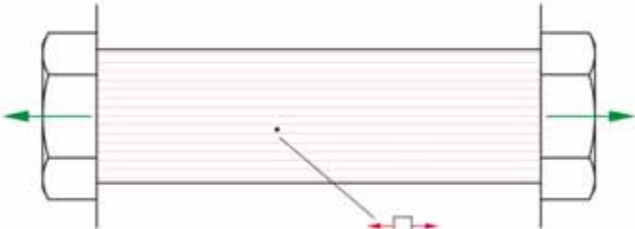
Internal forces in profiles and welded joints



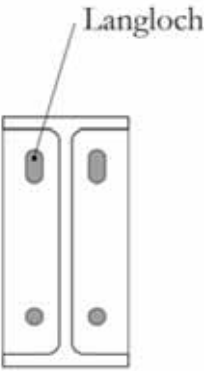
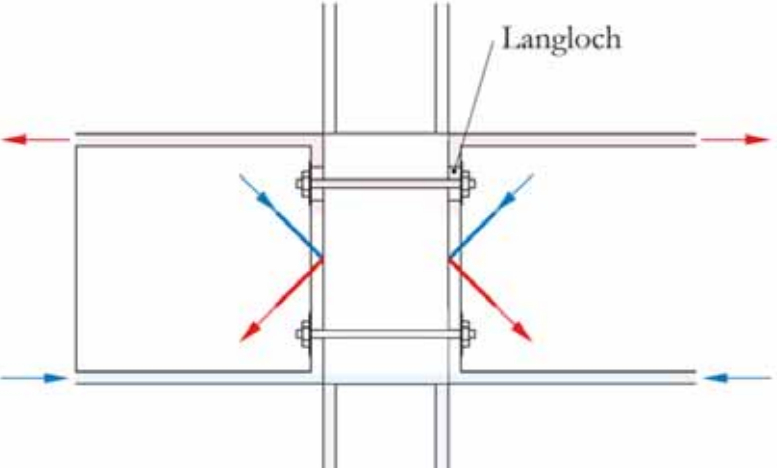
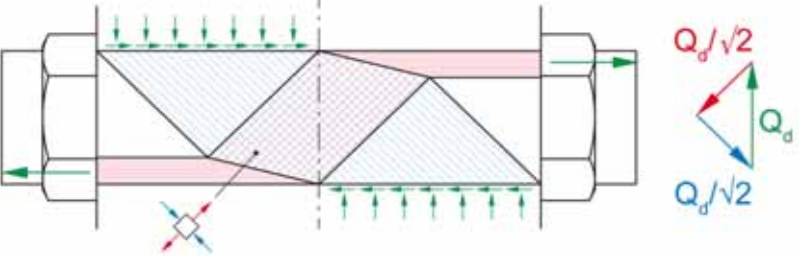




a) obere Schrauben

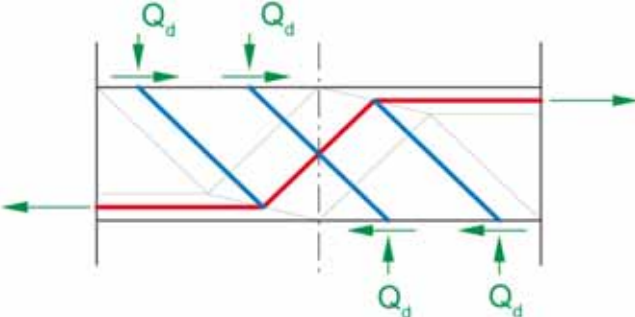
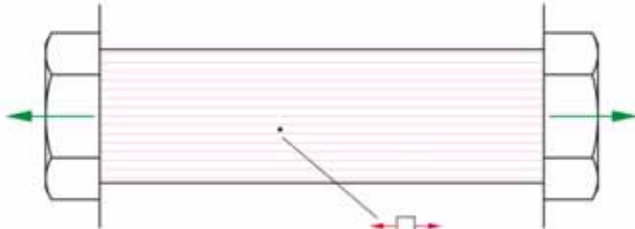


b) untere Schrauben

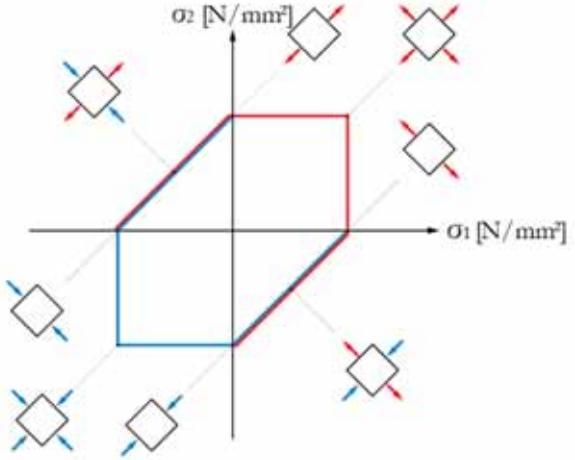
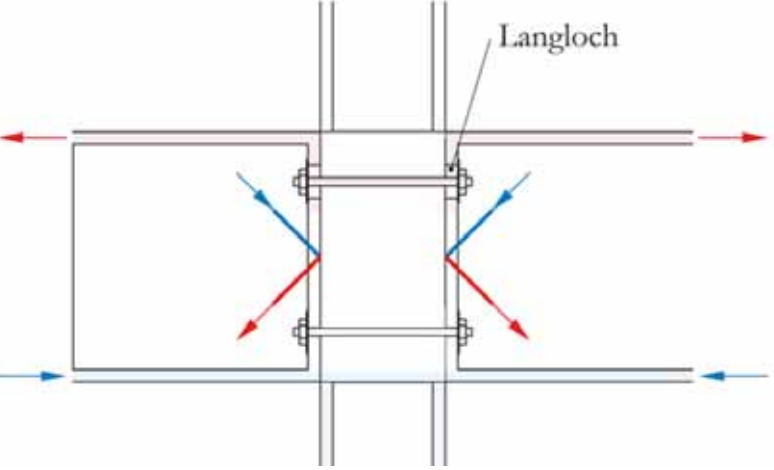
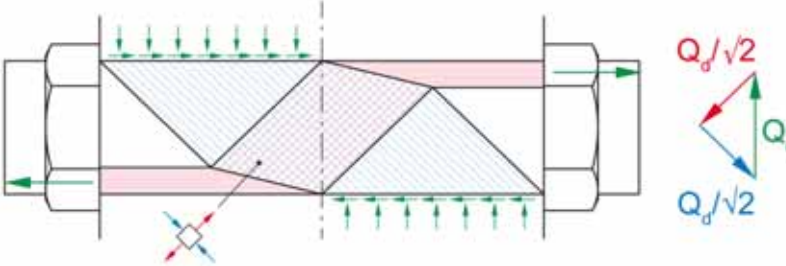




a) obere Schrauben



b) untere Schrauben



Stahl

Steel

Einführung
Introduction

Mechanische Eigenschaften
Mechanical Properties

Bautechnologie
Building Technologies

Fallstudie: Haus R128
Case Study: House R128

>> Ausgewählte Projekte
Selected Projects

2D ELEMENTS IN PLANE

2D ELEMENTS IN SPACE

3D STRUCTURES

2D ELEMENTS IN PLANE



Picture Window House
Shigeru Ban

2D ELEMENTS IN SPACE



Leutschenbach School
Christian Kerez & Joseph Schwartz

3D STRUCTURES



Birdwatching Tower
Johansen Skovsted Arkitekter

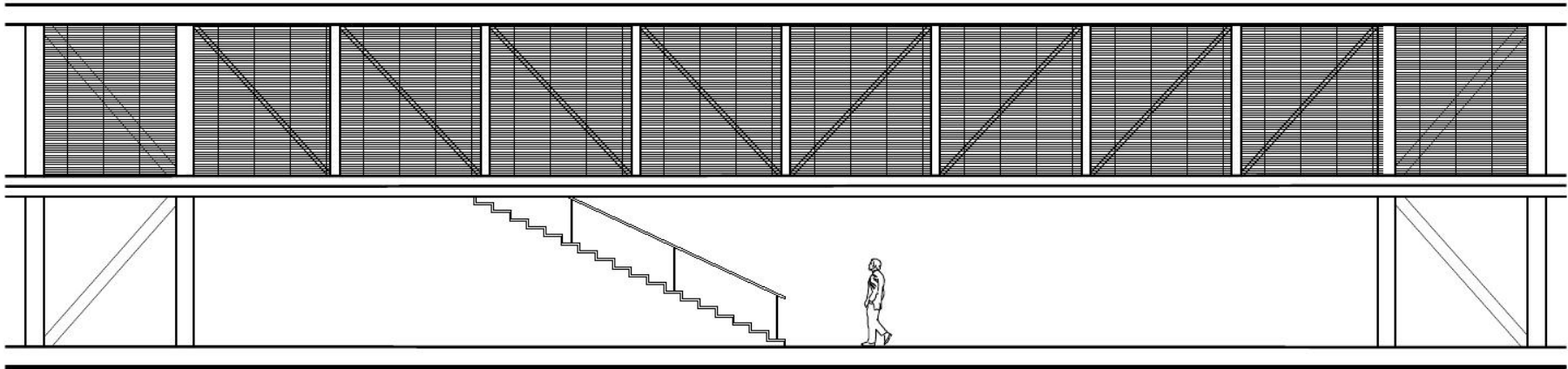
Picture Window House

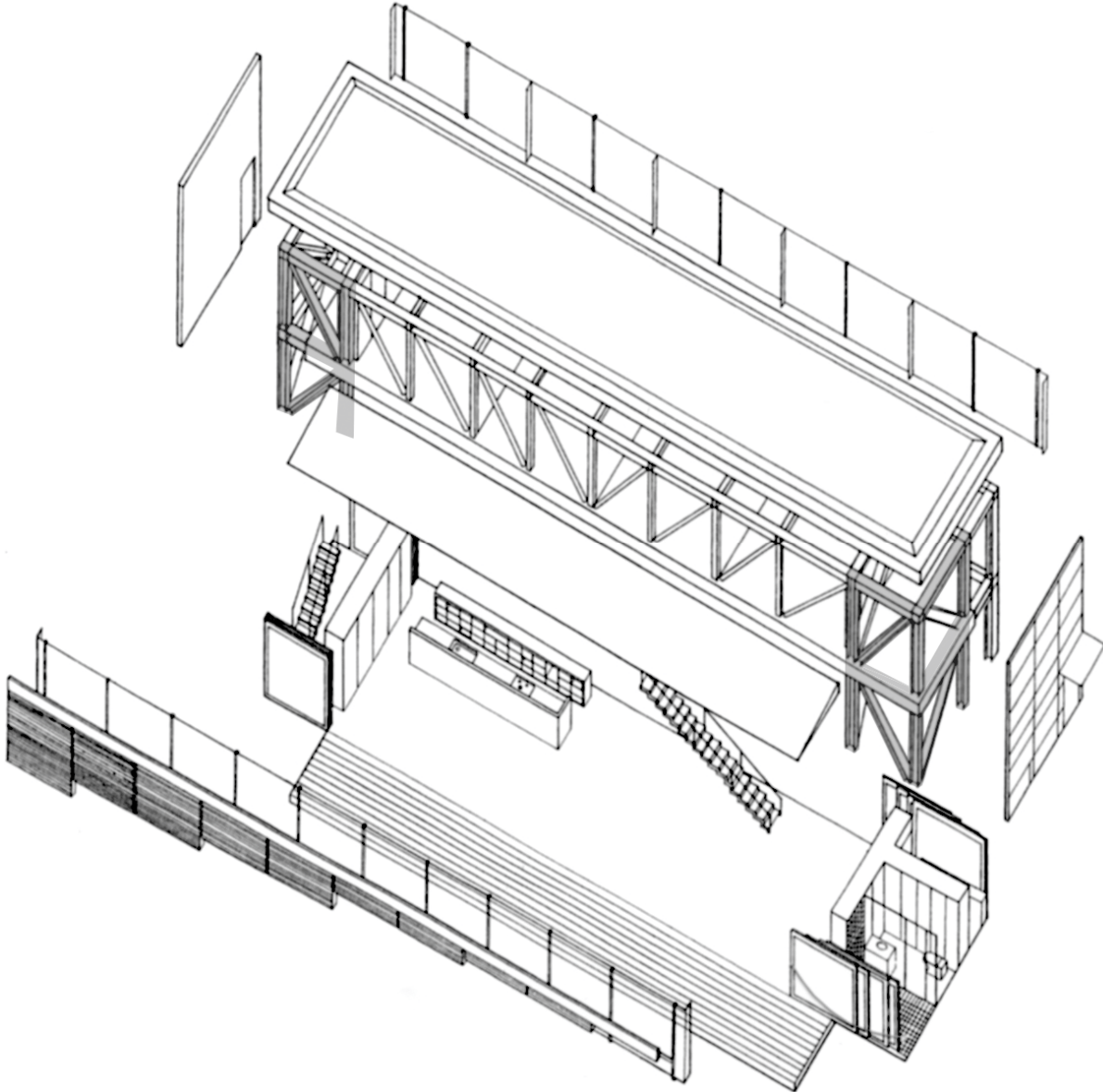
Shizuoka, 2002

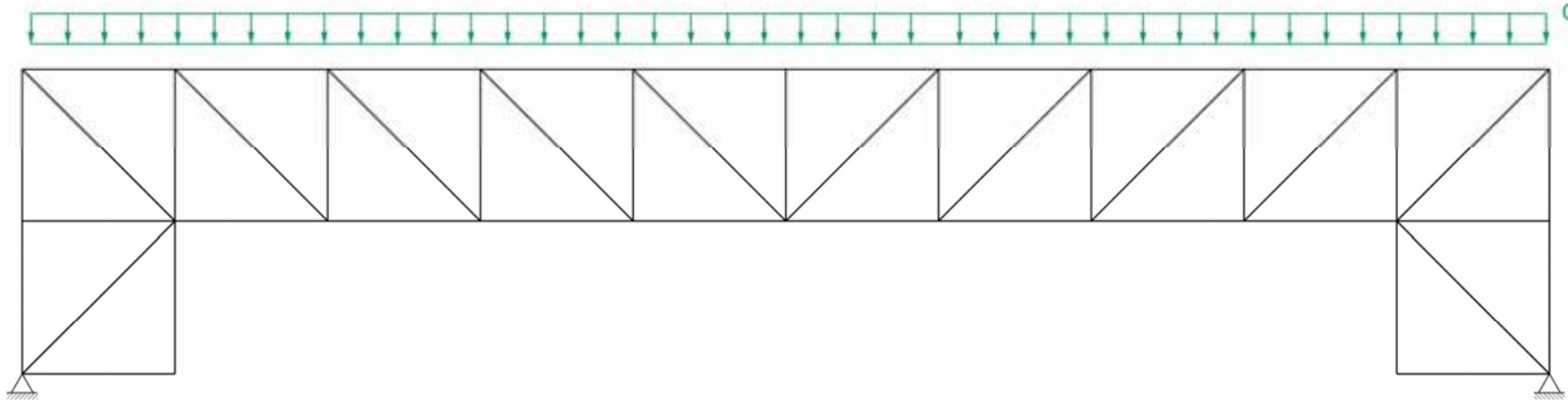
Architect: Shigeru Ban

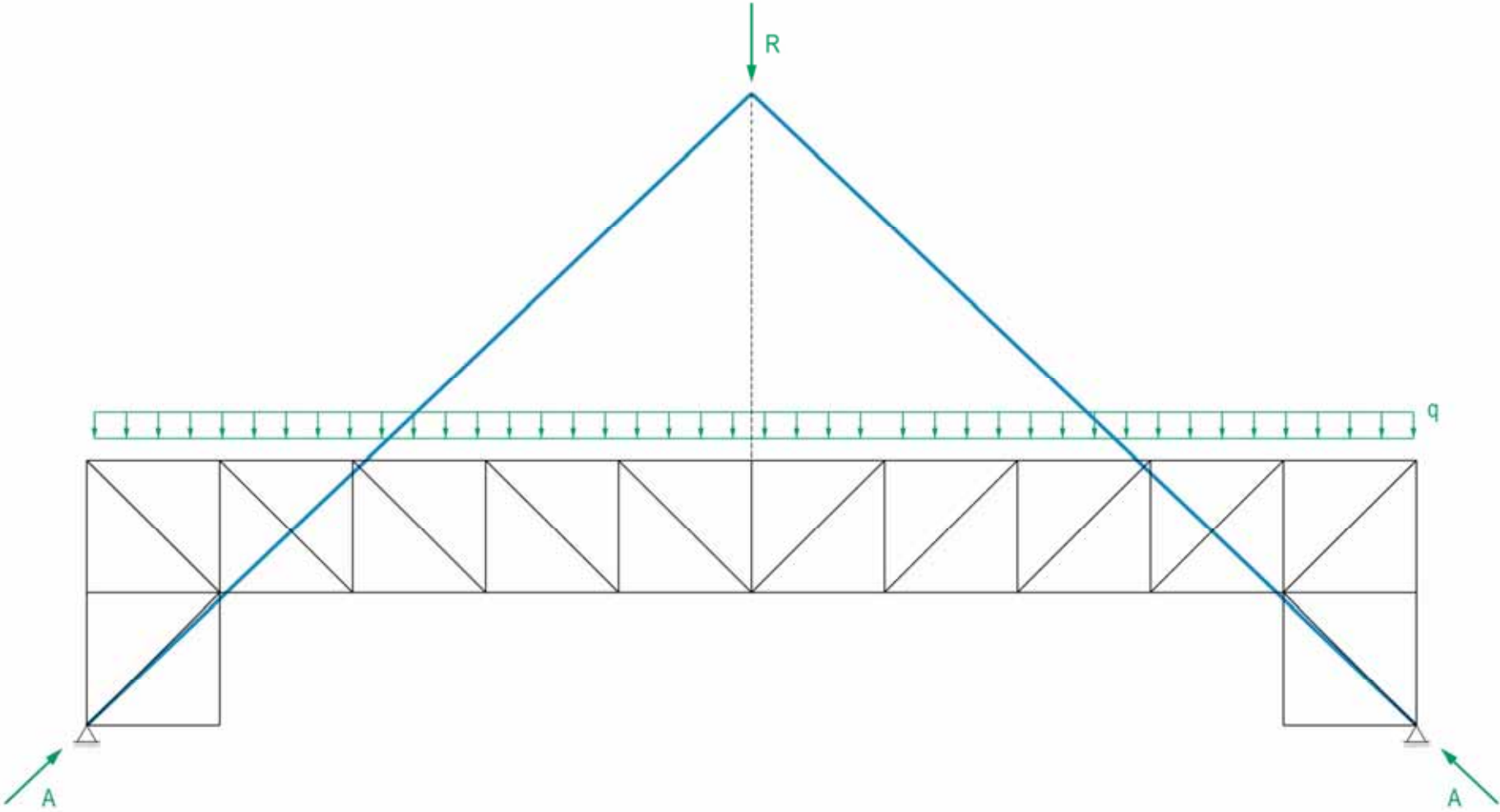
Engineer: Hoshino Engineer

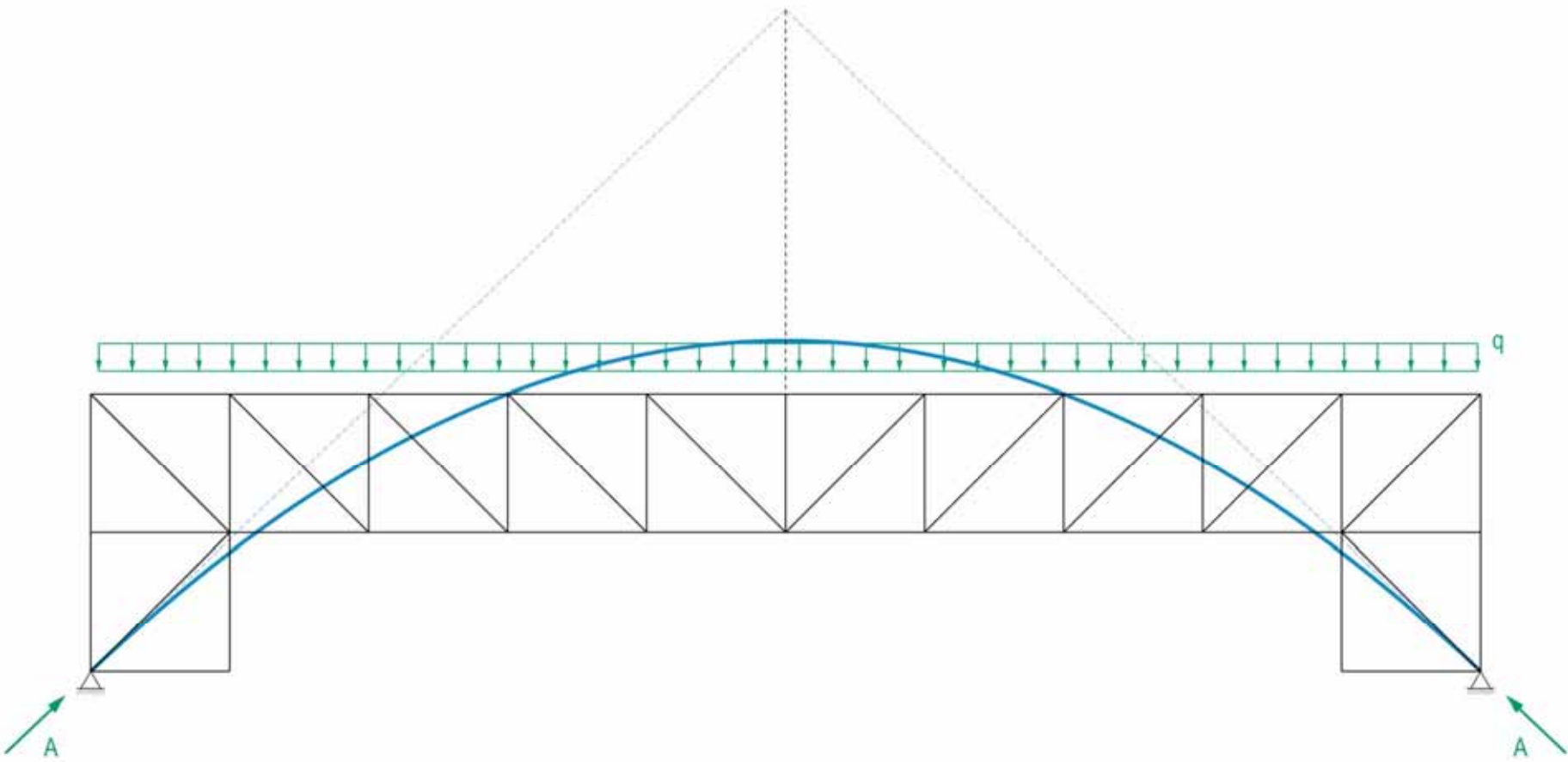


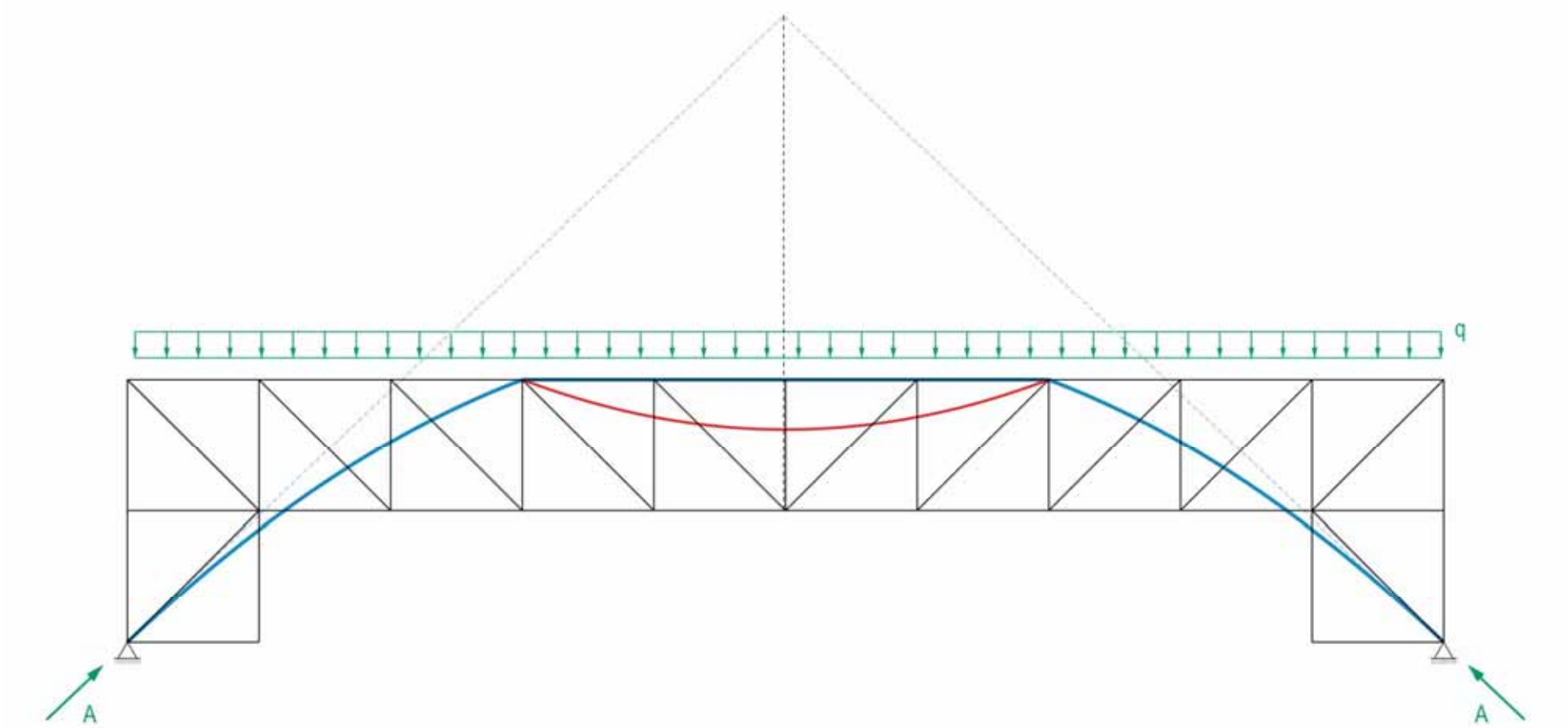


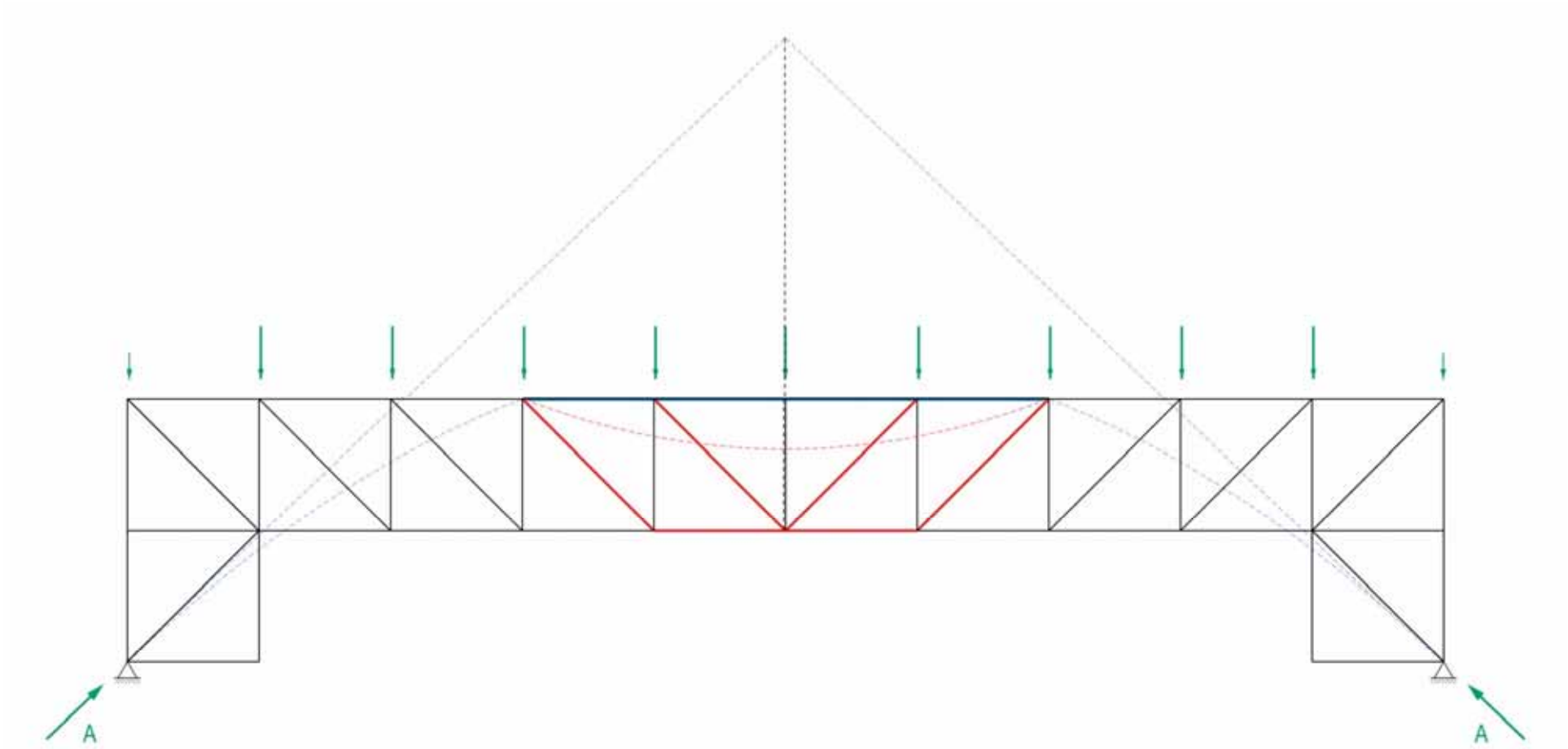


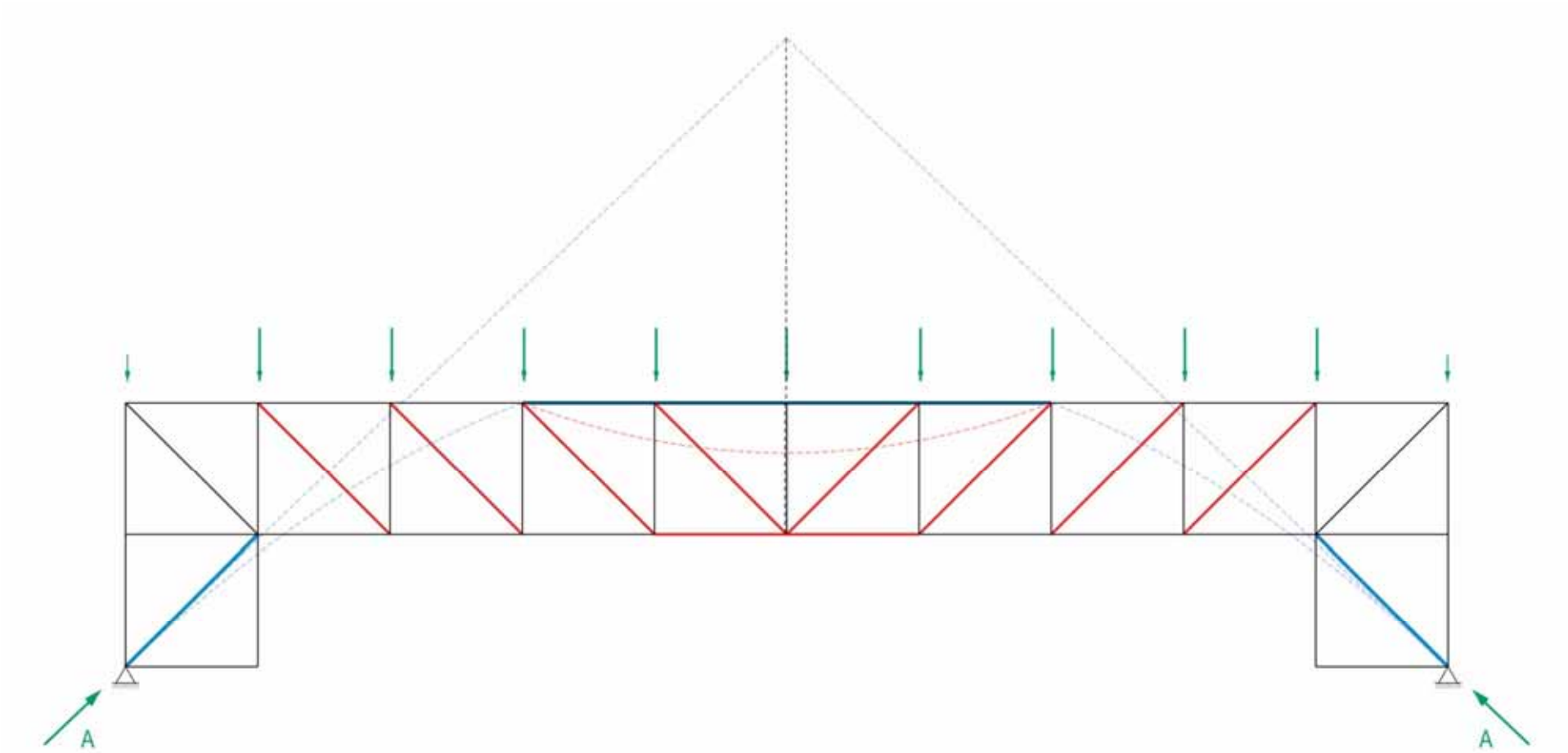


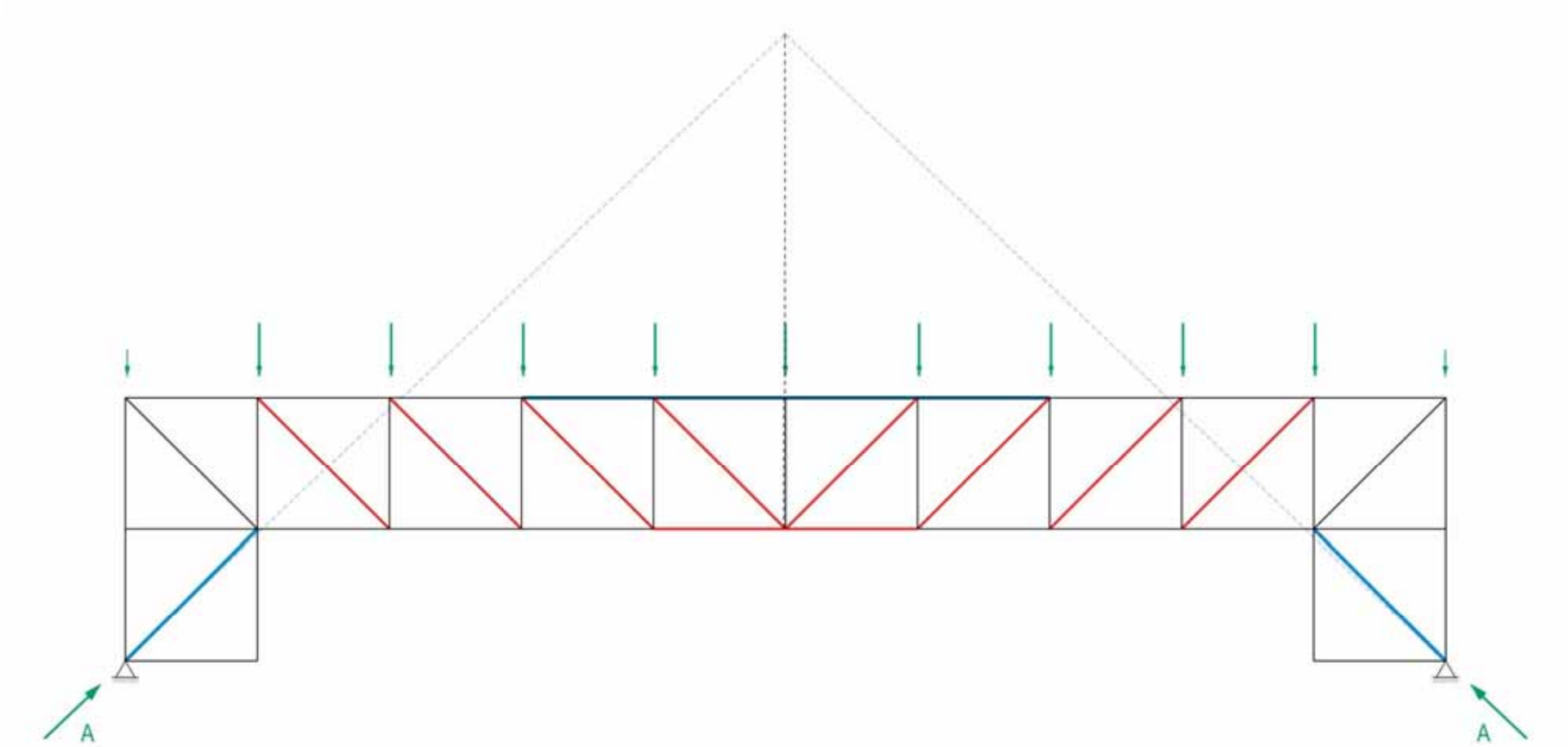


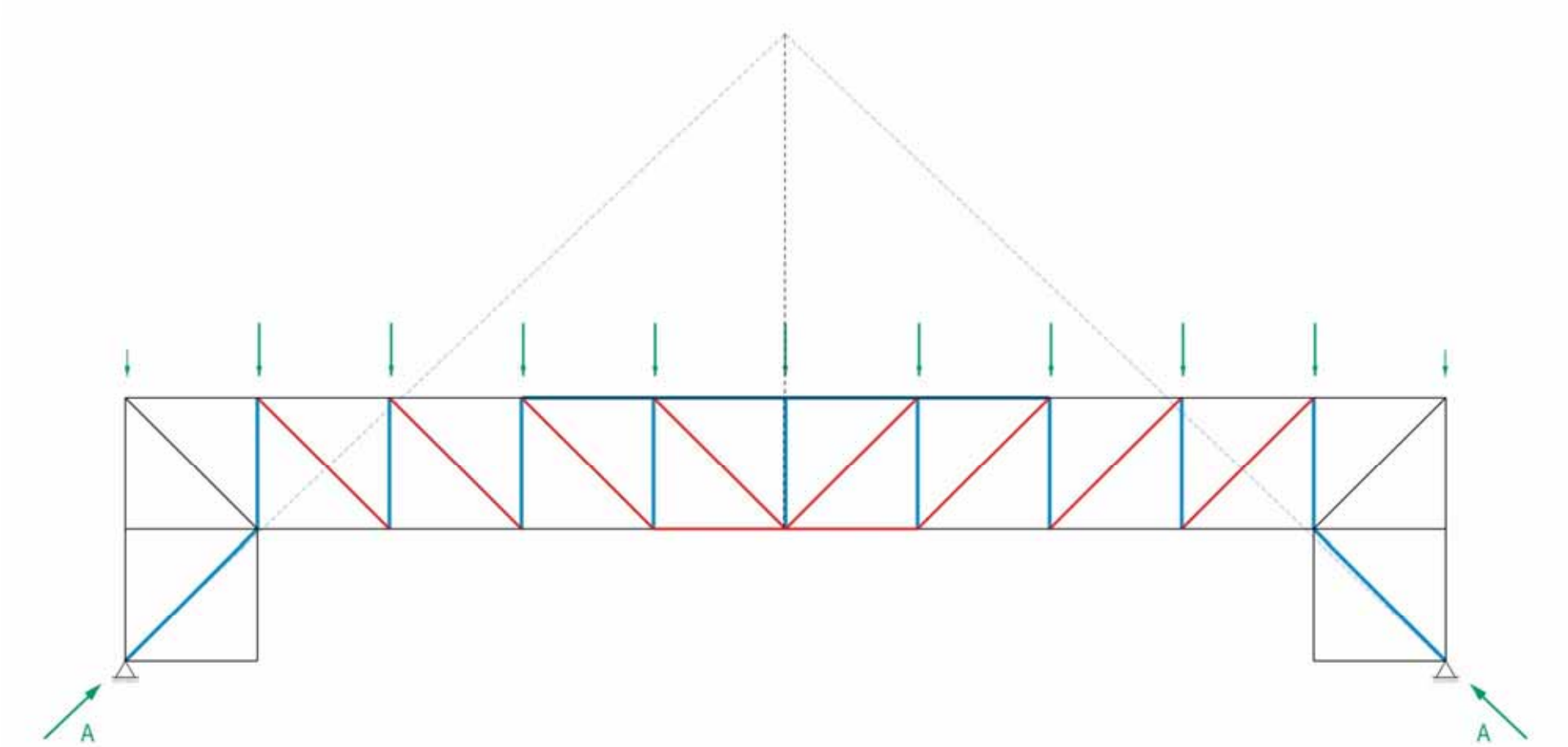


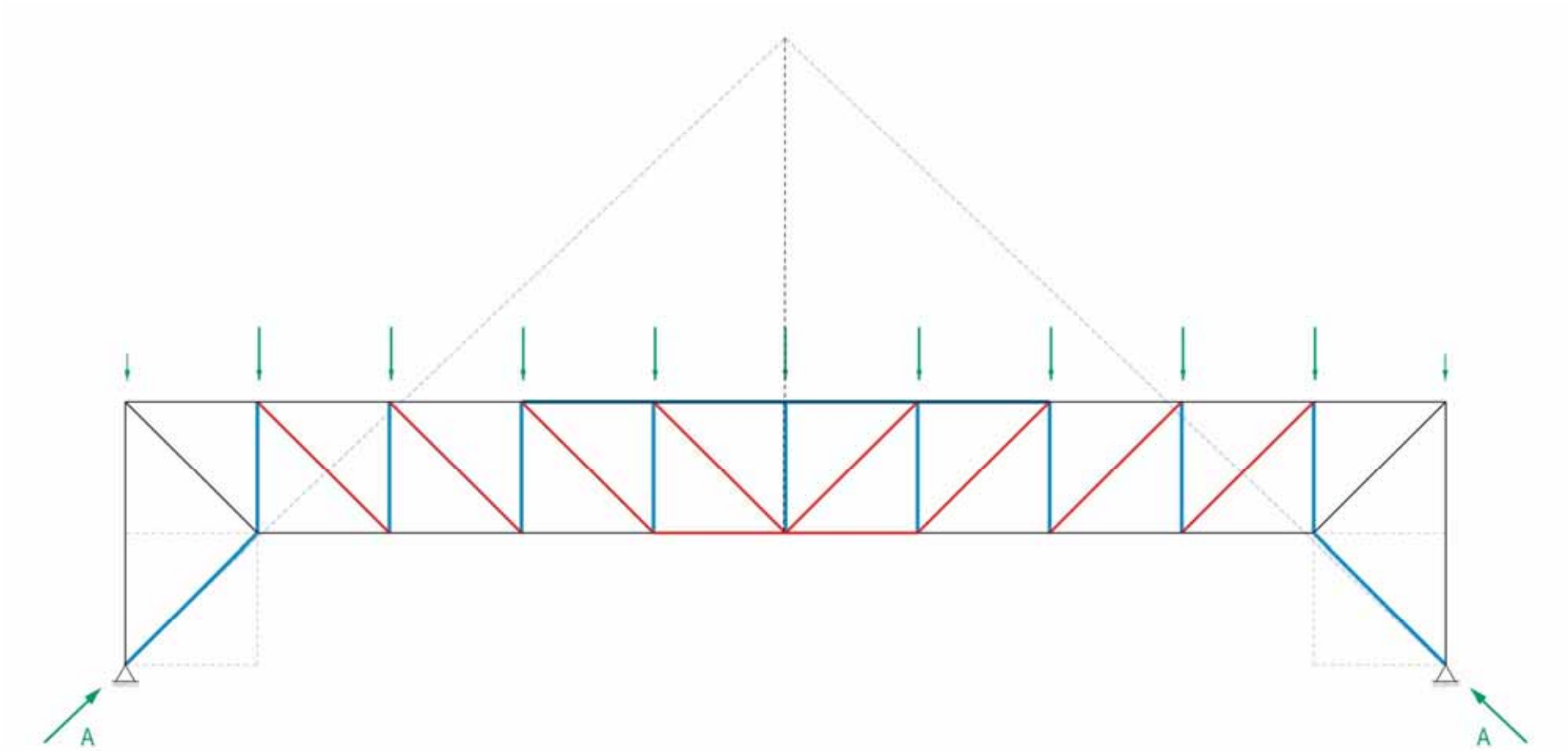


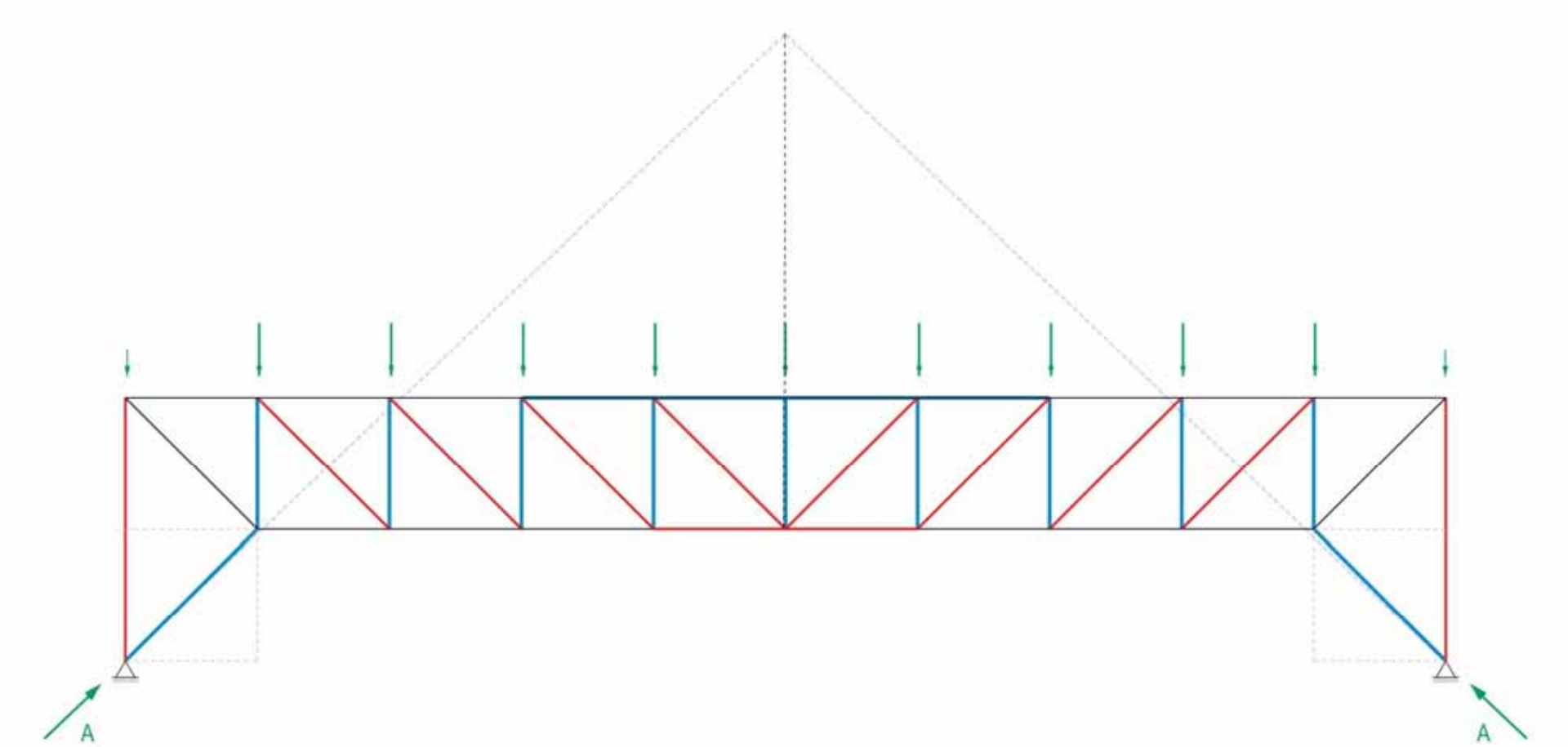


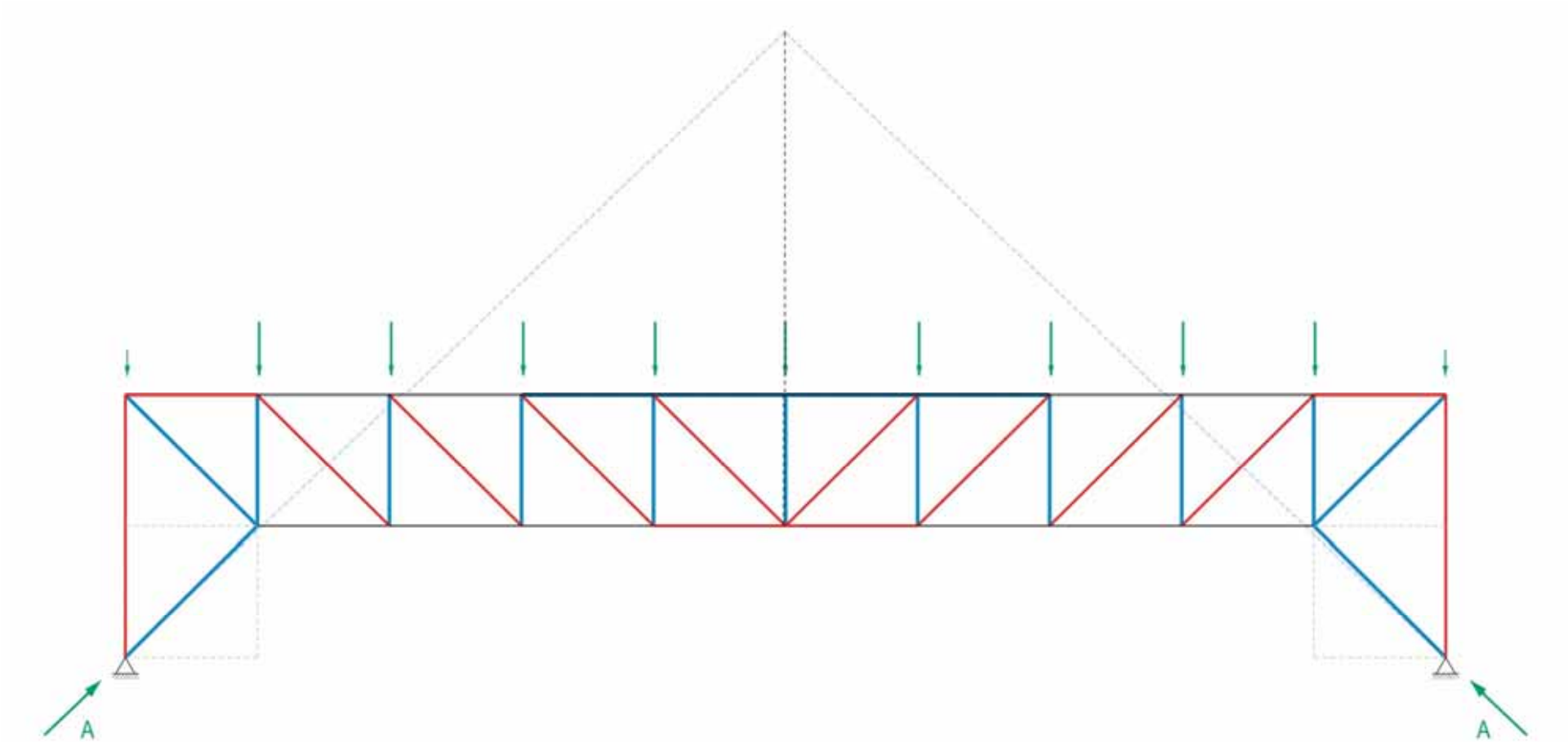


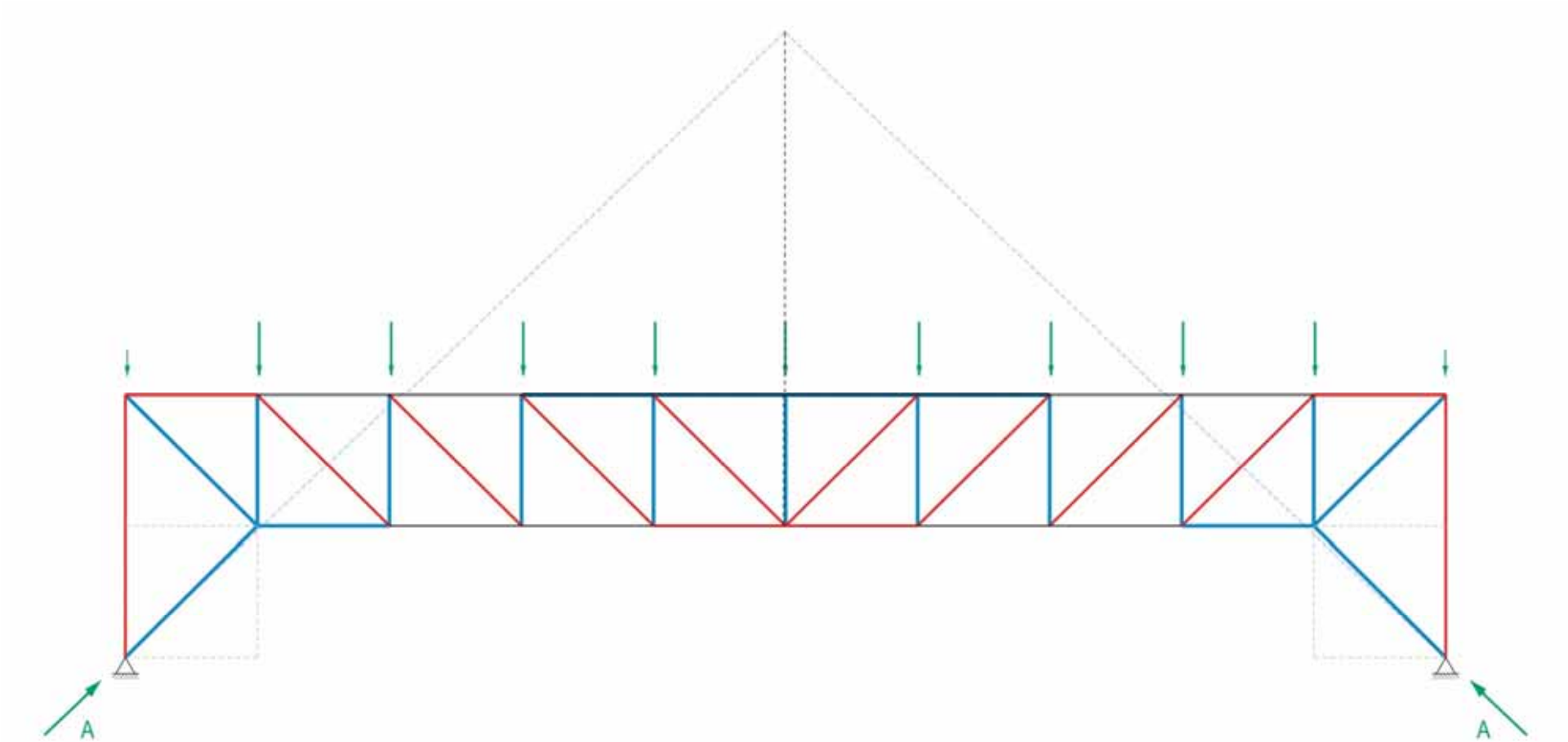


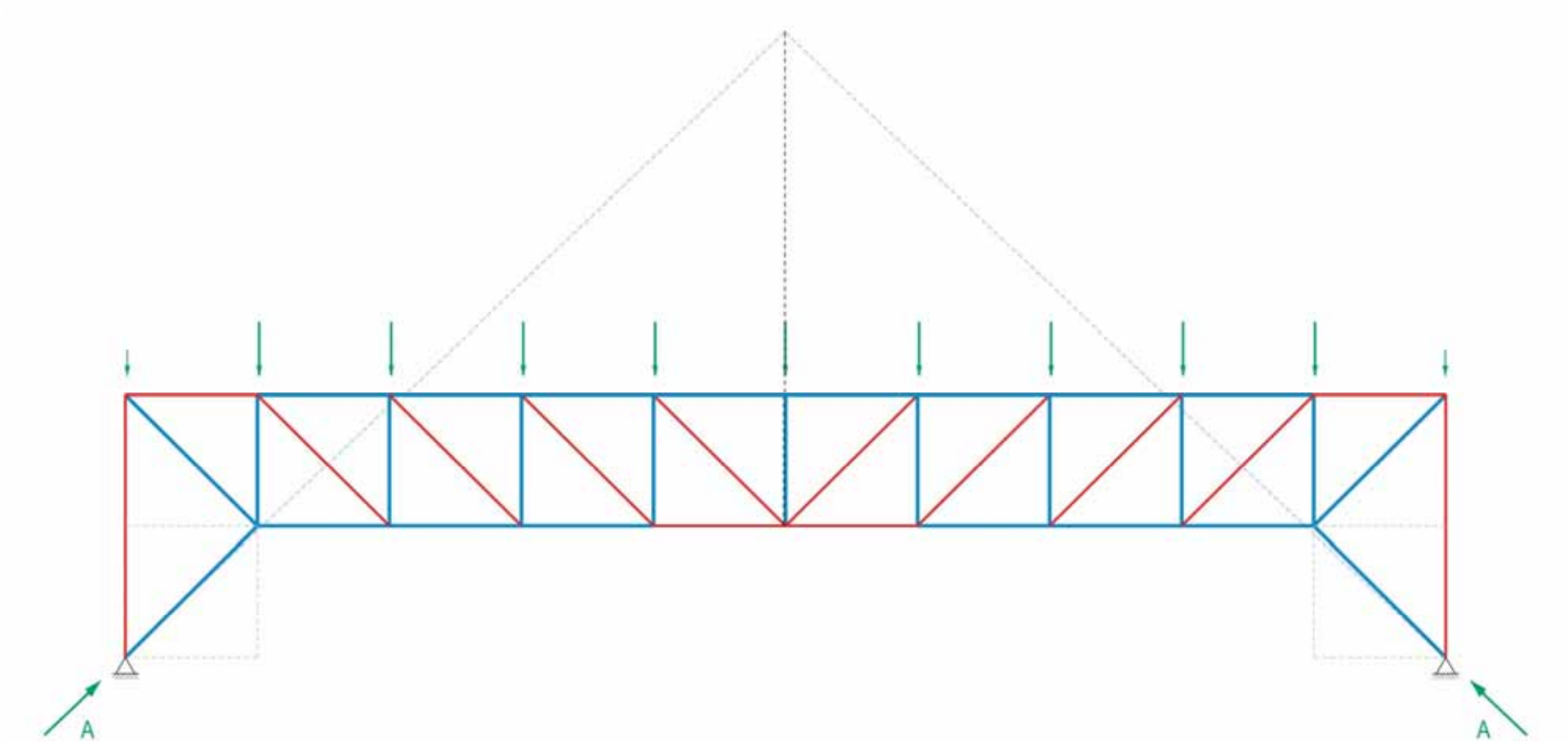


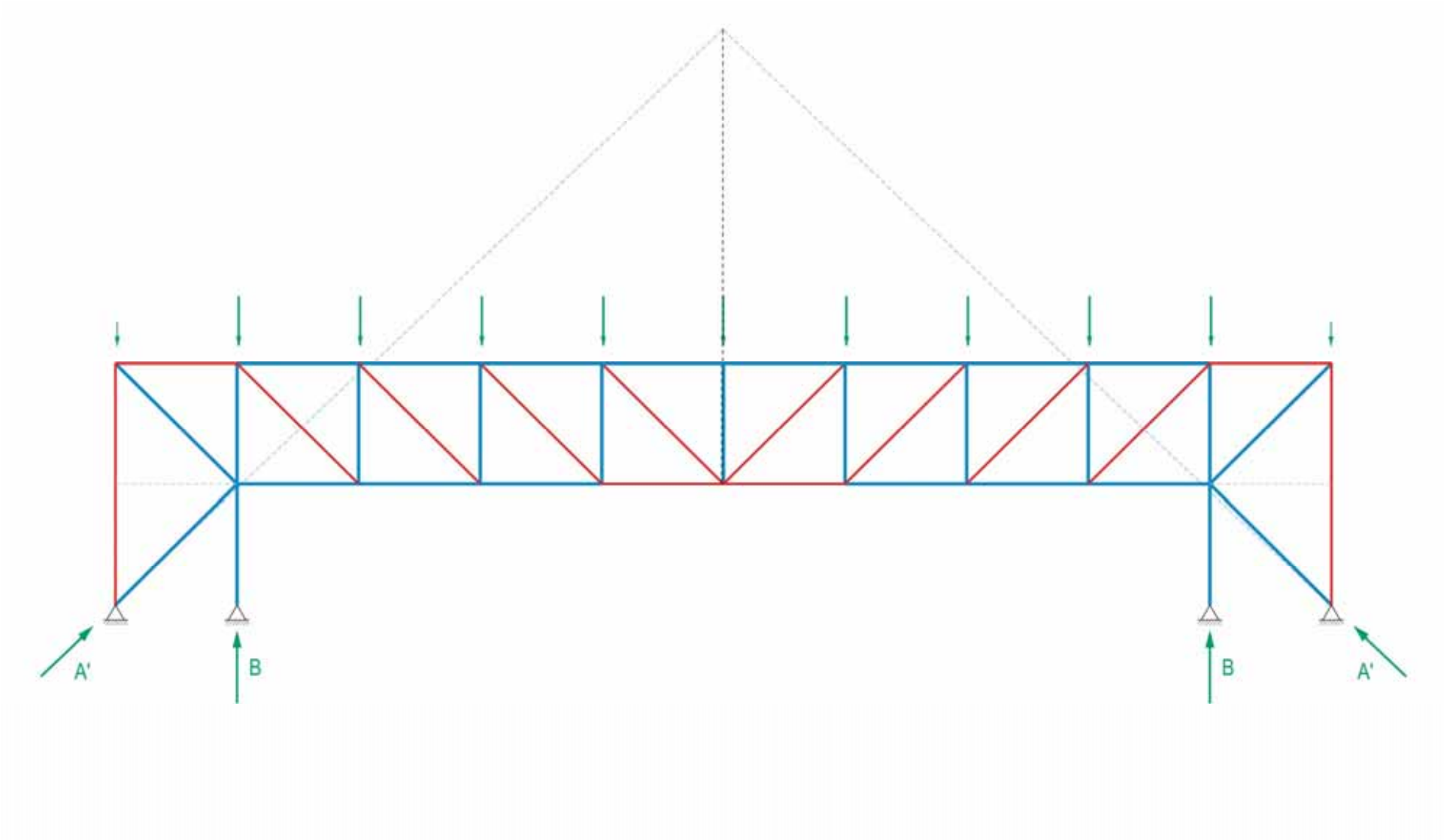












School Leutschenbach

Zürich, 2009

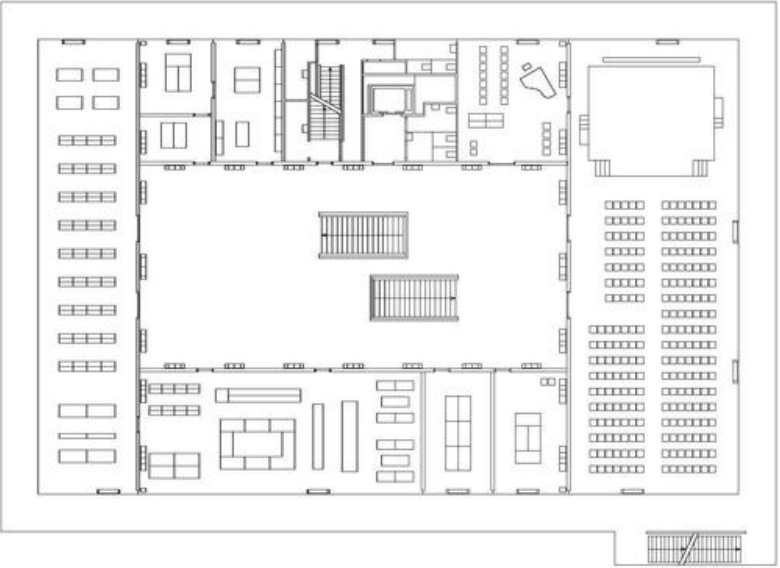
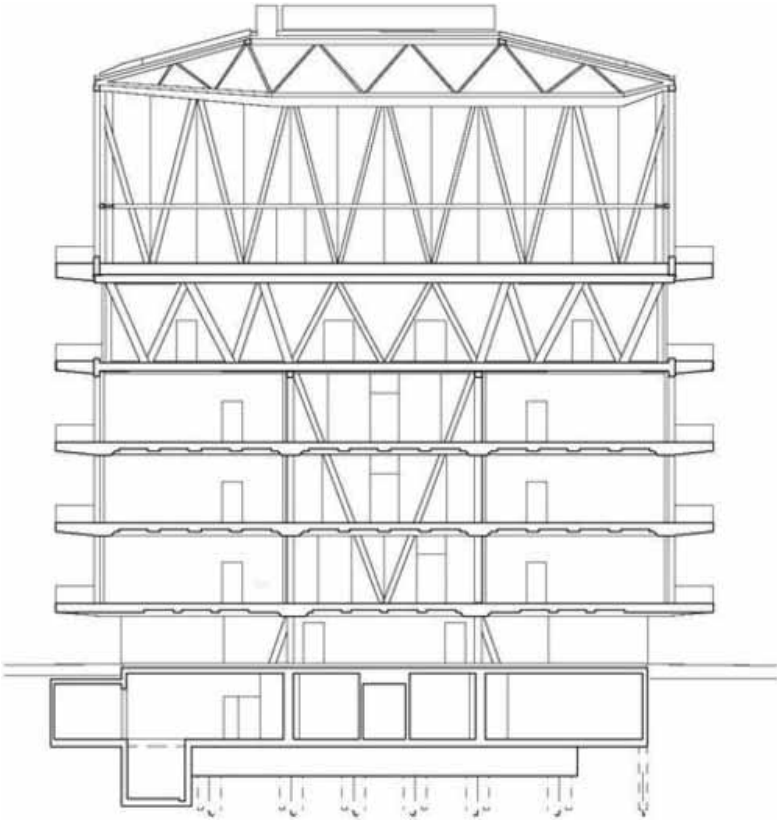
Architect: Christian Kerez

Engineer: Joseph Schwartz

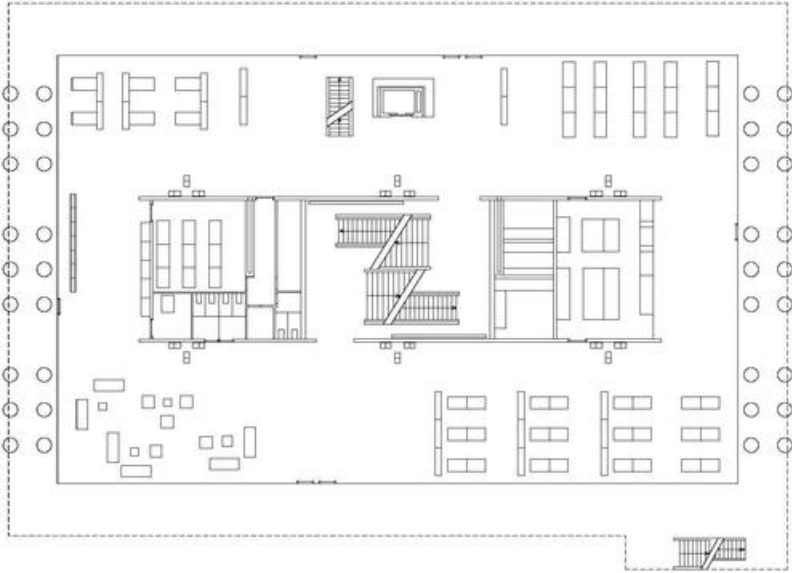








4th floor





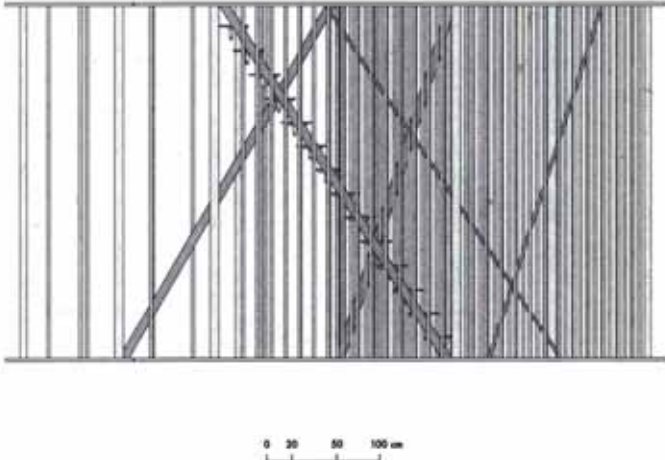
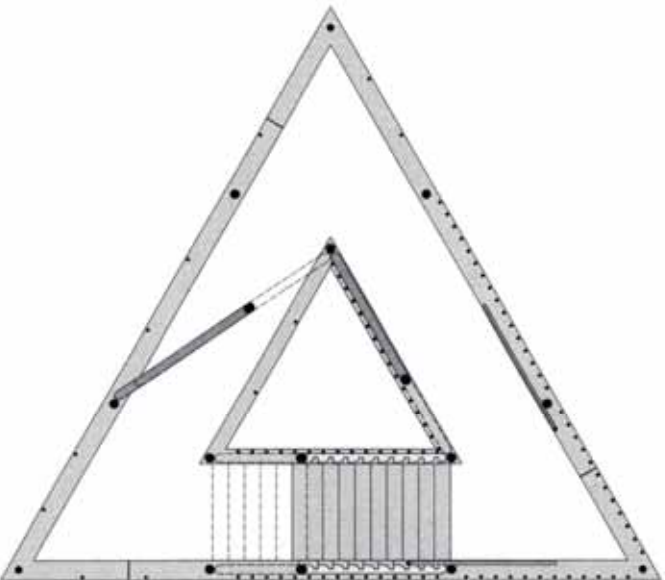
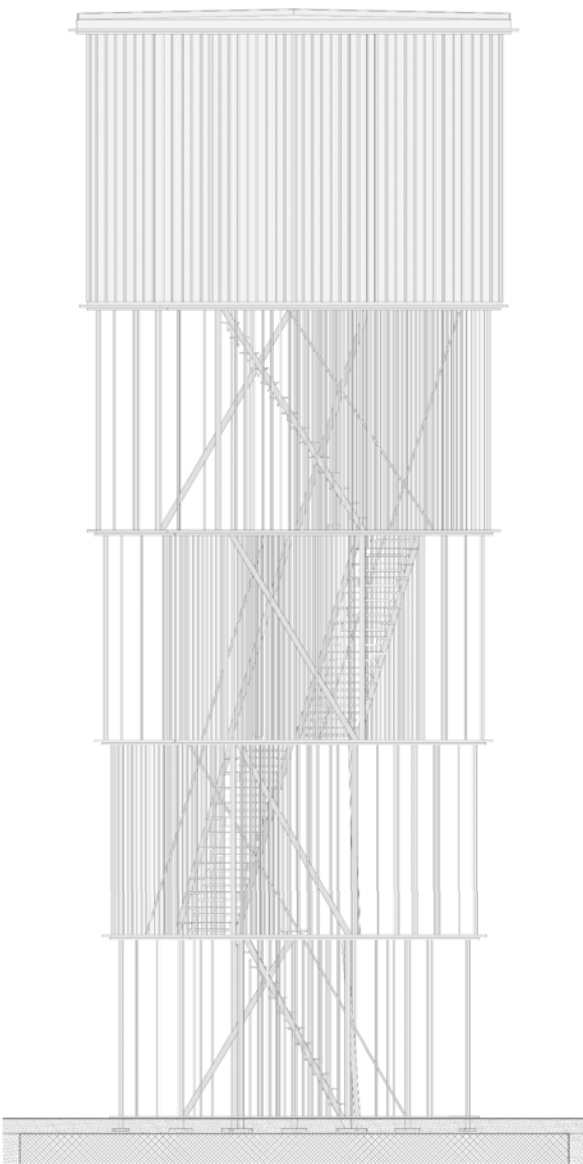
Birdwatching Tower

Tipperne, 2017

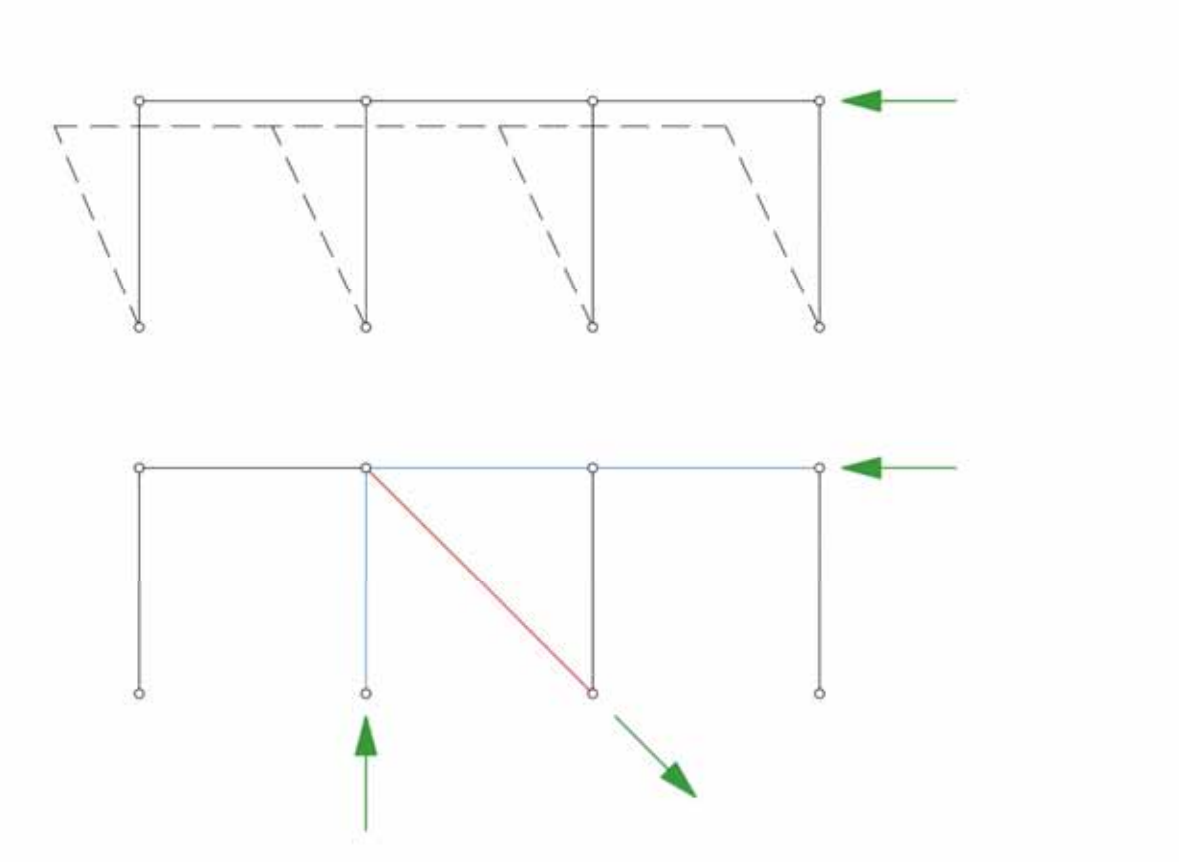
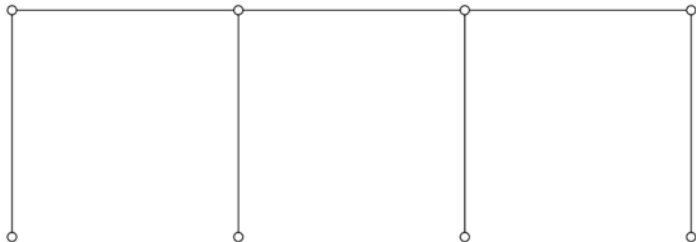
Architect: Skovsted Arkitekter

Engineer: Ingeniørgruppen Vestjylland APS



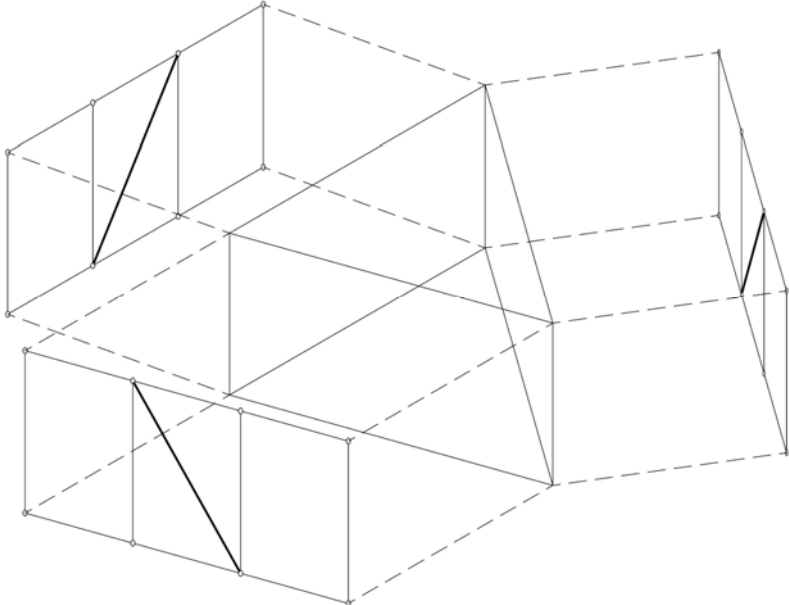
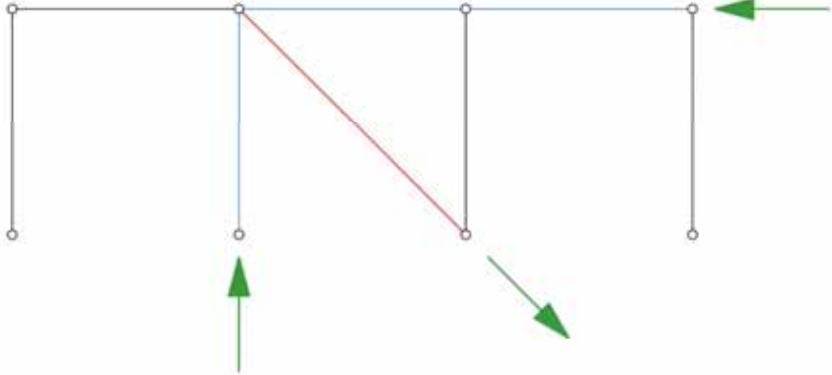
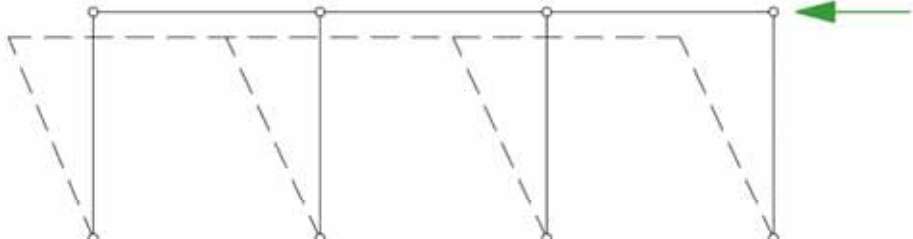
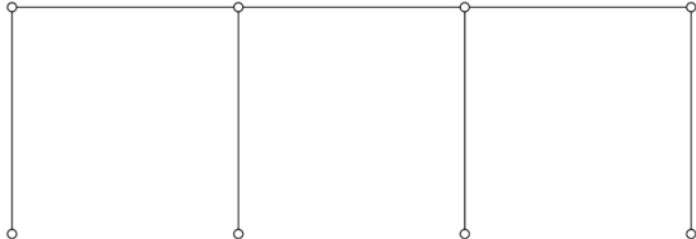


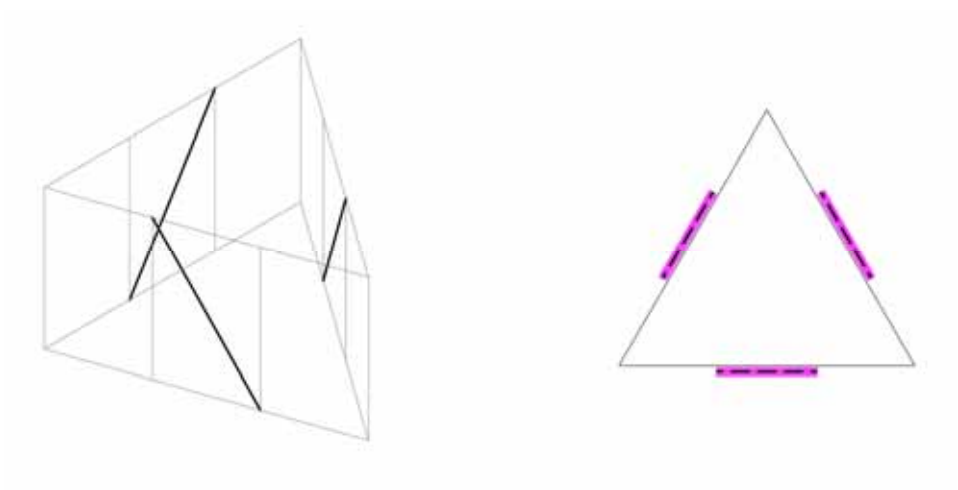
Selected Projects

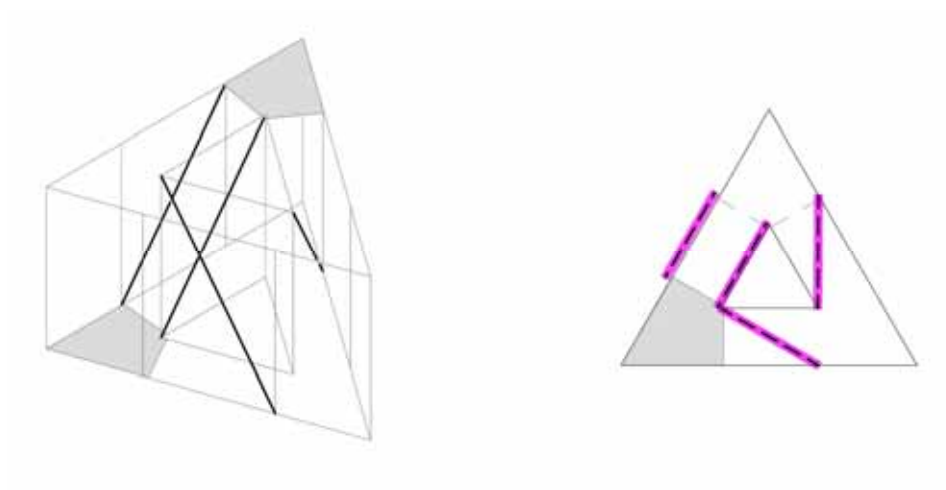


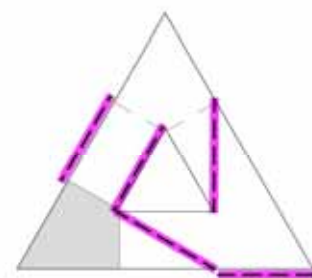
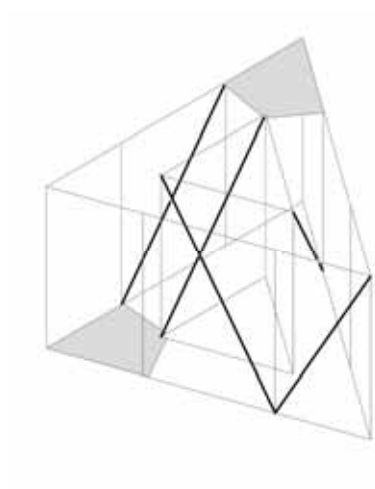
Horizontale Einwirkungen

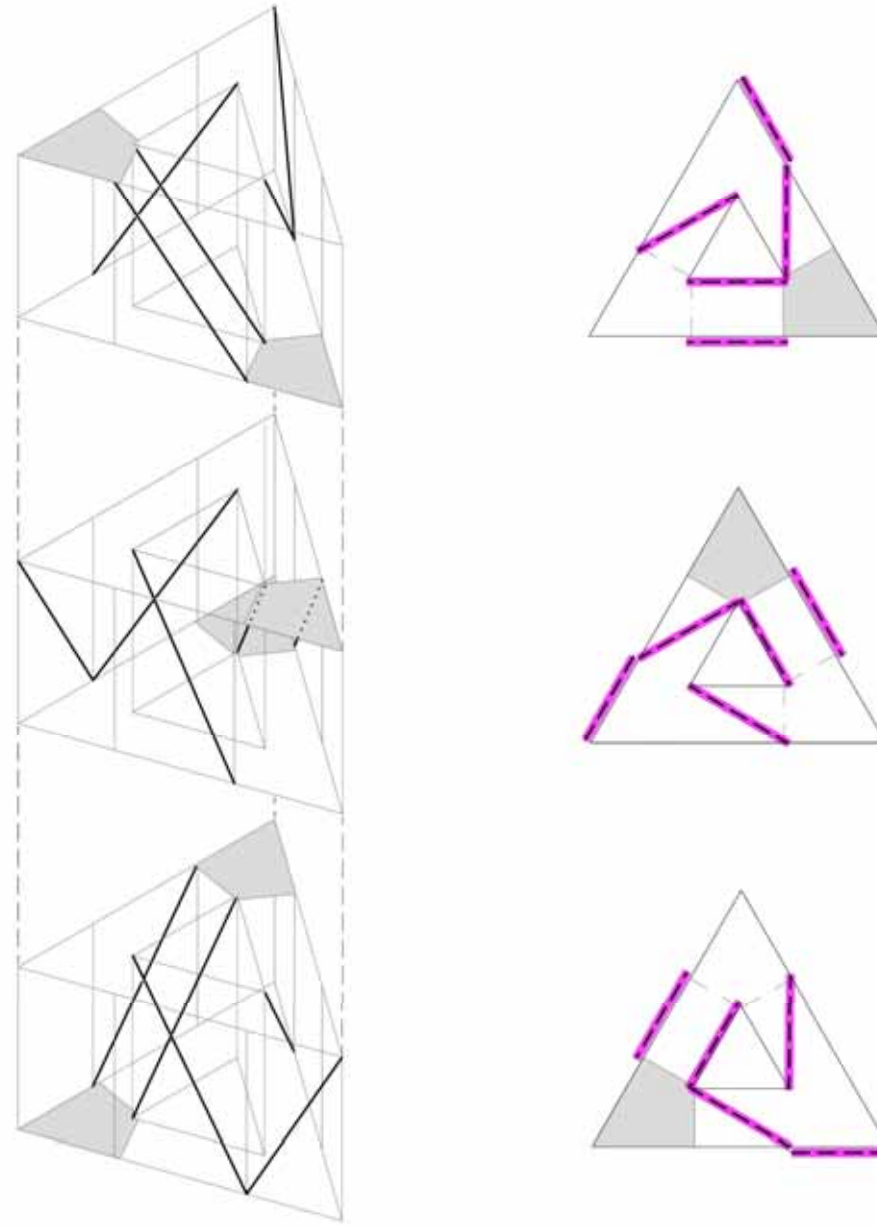
Horizontal forces



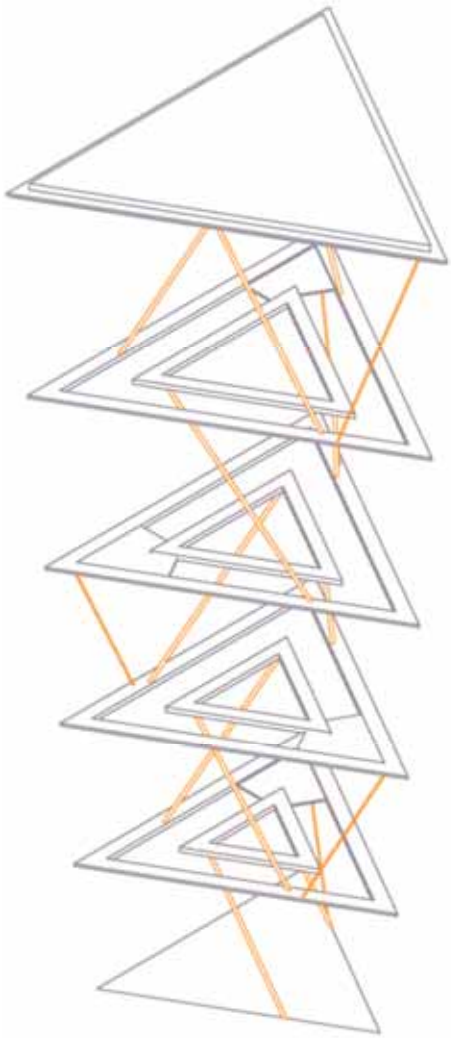




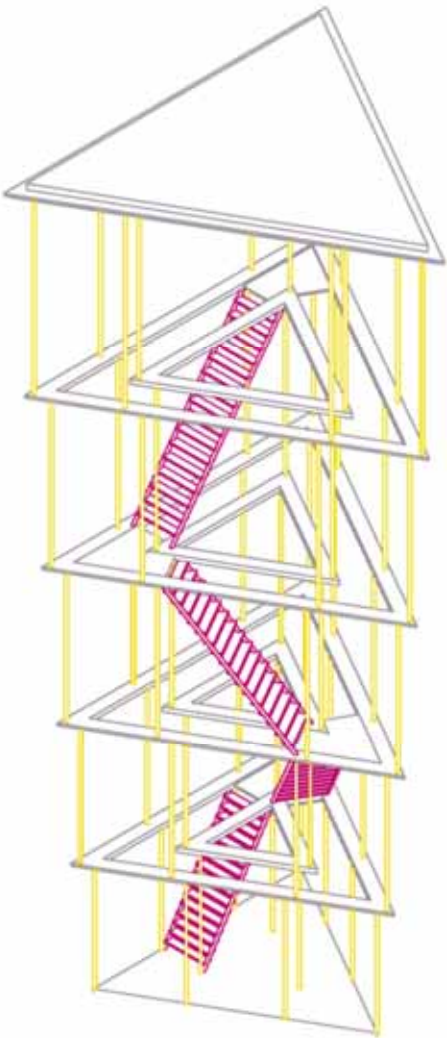




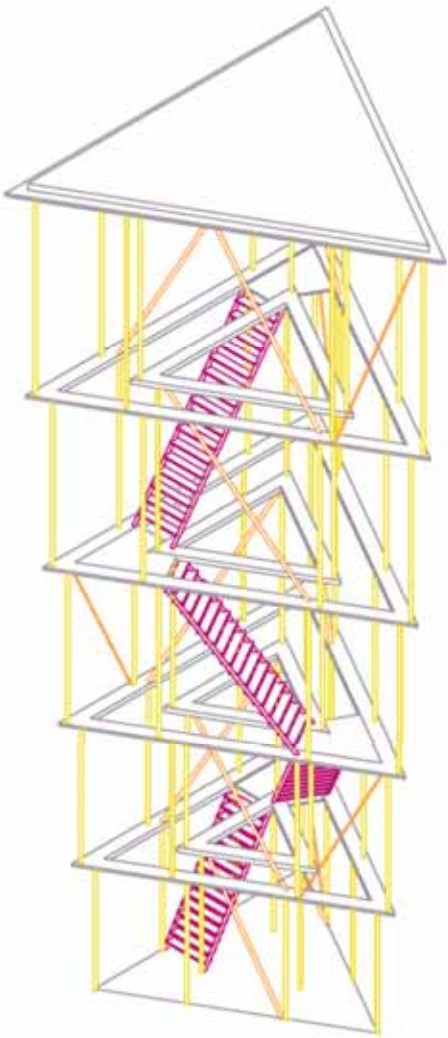
Stapelung und Drehung des Basismoduls
Stacking and rotation of the basic module



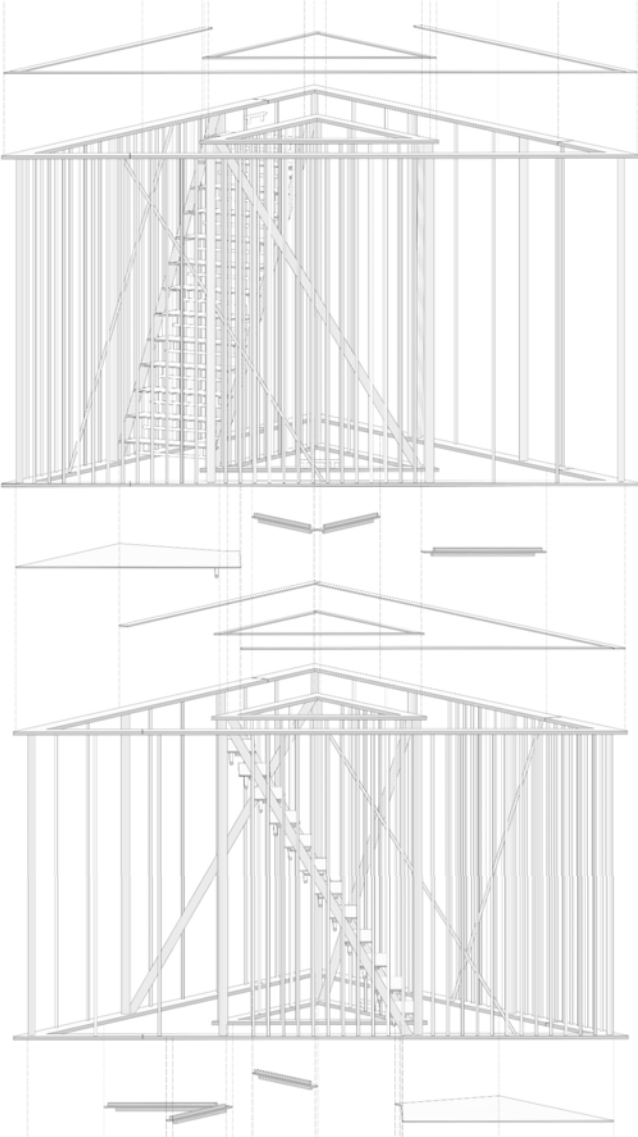
Diagonal supports



Stairs and vertical supports



Complete system



Axonometrie von einem Stahl Modul

Axonometry of a steel module





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