

# Tragwerksentwurf II

## *Structural Design II*

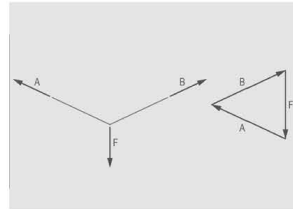
Philippe Block



Tragwerksentwurf  
*Structural Design*



1. Gleichgewicht  
*1. Equilibrium*



2. Graphische Statik  
*2. Graphic statics*



3. Seile  
*3. Cables*



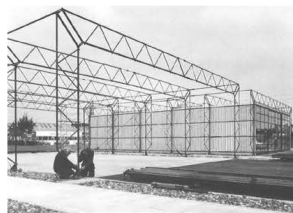
4. Bogen  
*4. Arches*



5. Bogen-Seil  
*5. Arch-cables*

## Tragwerksentwurf I *Structural Design I*

## Tragwerksentwurf II *Structural Design II*



6. Fachwerke  
*6. Trusses*



7. Balken  
*7. Beams*



8. Rahmen  
*8. Frames*



9. Platten  
*9. Plates*



10. Stützen  
*10. Columns*

# Balken

## *Beams*



Vom Fachwerk zum Balken

*From trusses to beams*

Tragverhalten eines einfachen Balkens

*Structural behaviour of a simple beam*

Stahlbetonträger

*Reinforced concrete beams*

Stahlträger

*Steel beams*

Balken unter konzentrierten und verteilten Lasten

*Beams under concentrated and distributed loads*

Konsole unter konzentrierten und verteilten Lasten

*Cantilever under concentrated and distributed loads*

Analyse von Balken

*Analysis of beams*

Variation der Randbedingungen

*Variation of boundary conditions*

Gerberträger

*Gerber's beam (hinged girder system)*

Durchlaufträger

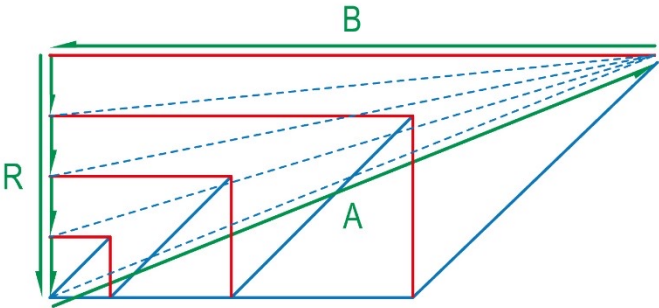
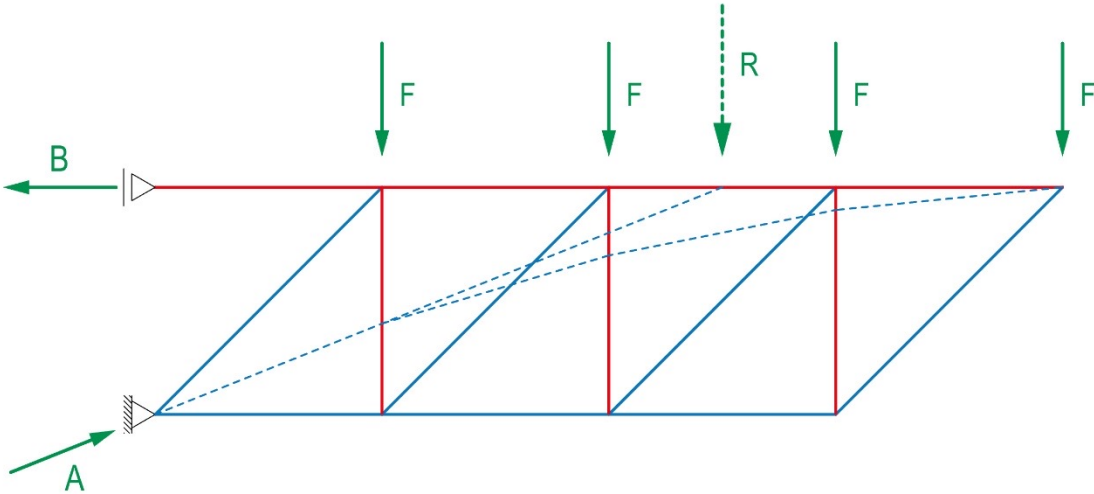
*Continuous beam*

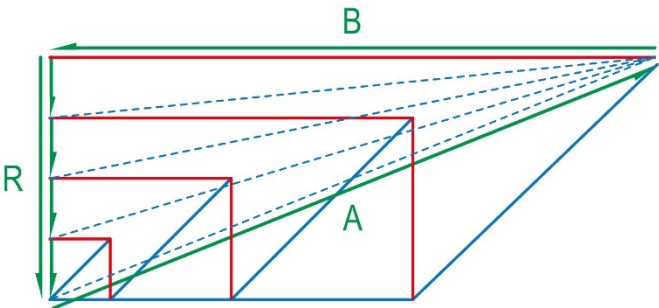
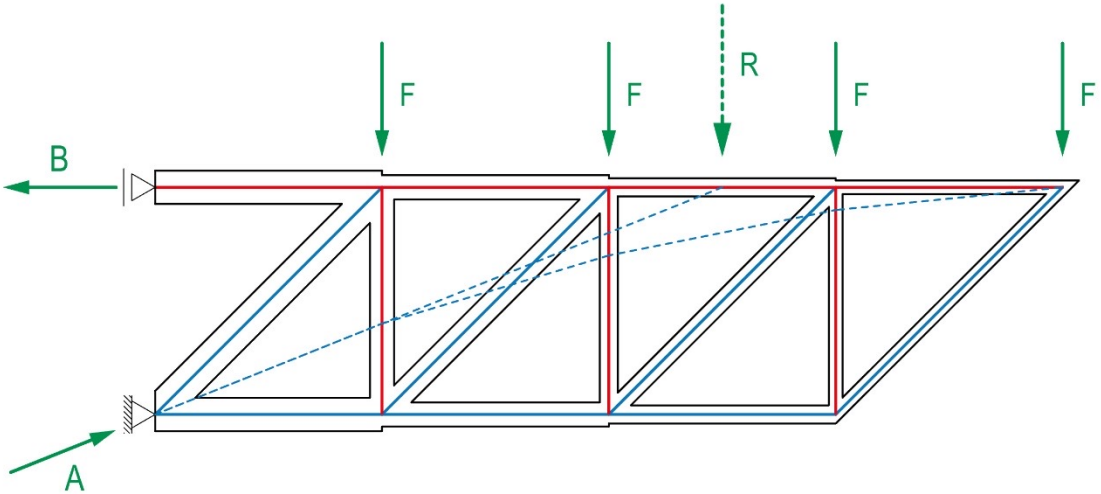
Schlankheit von Balken

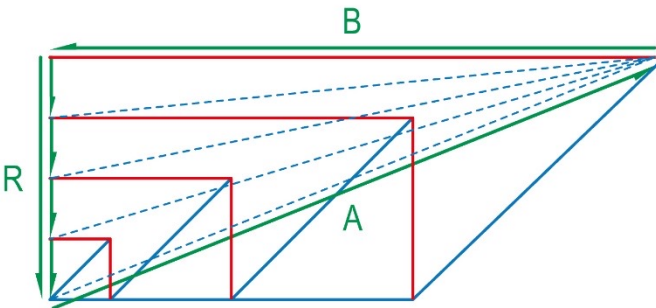
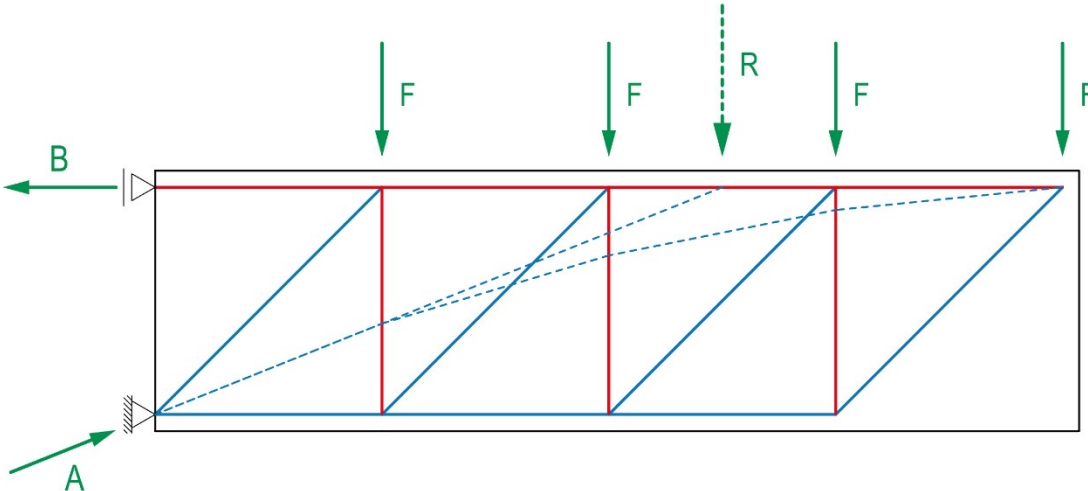
*Slenderness of beams*

Scheiben

*Deep beams*







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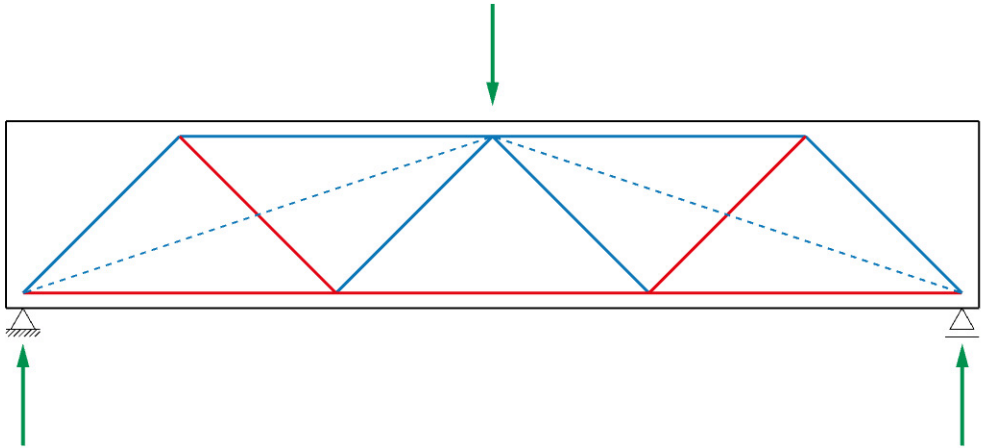
Scheiben

*Deep beams*

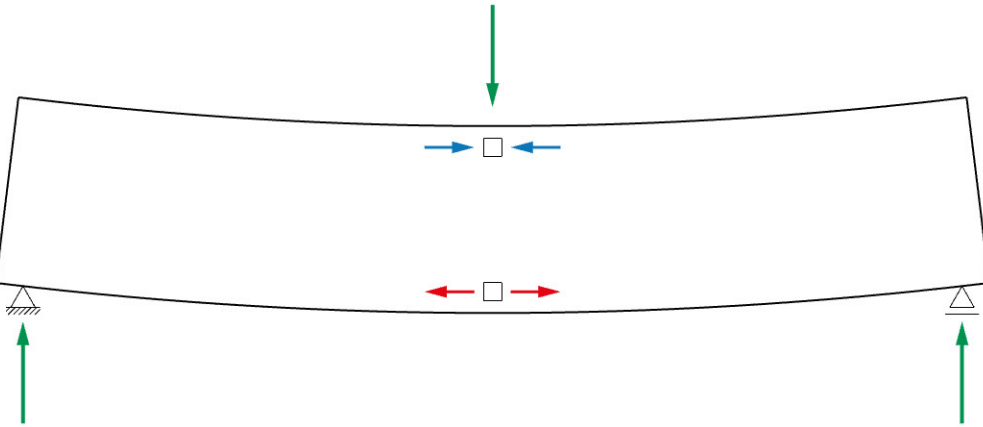
Bogen, Seil		Bogen-Seiltragwerk	
Als äusseres Tragwerk	Als inneres Tragwerk	Als äusseres Tragwerk	Als inneres Tragwerk
			<p>Beton vorgespannt</p> <p>Stahl/ Holz</p> <p>Beton, gerissen</p>
Bogen, Seil, Membran, Schale	Membranwirkung	Bogen-Seiltragwerk, Fachwerk, Raumfachwerk	Balken, Balkenroste, Platten

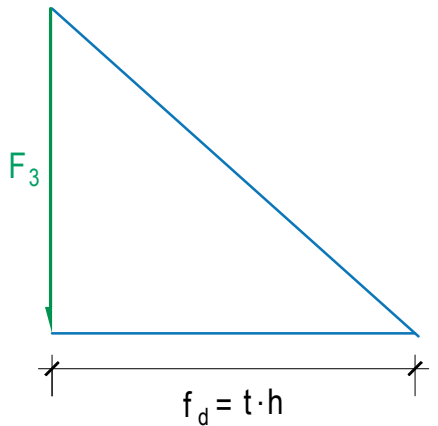
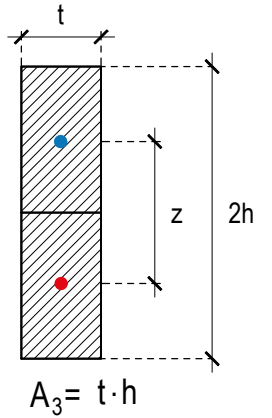
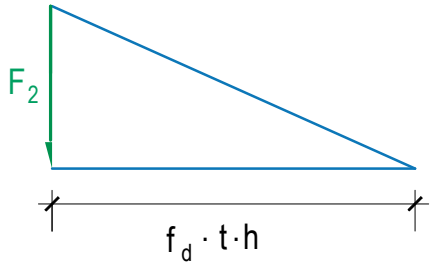
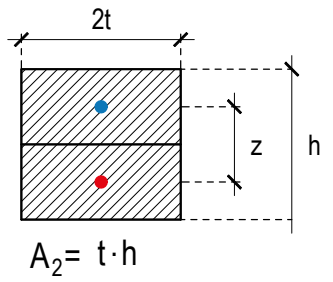
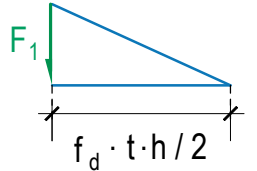
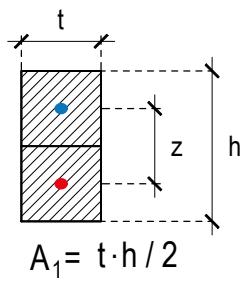
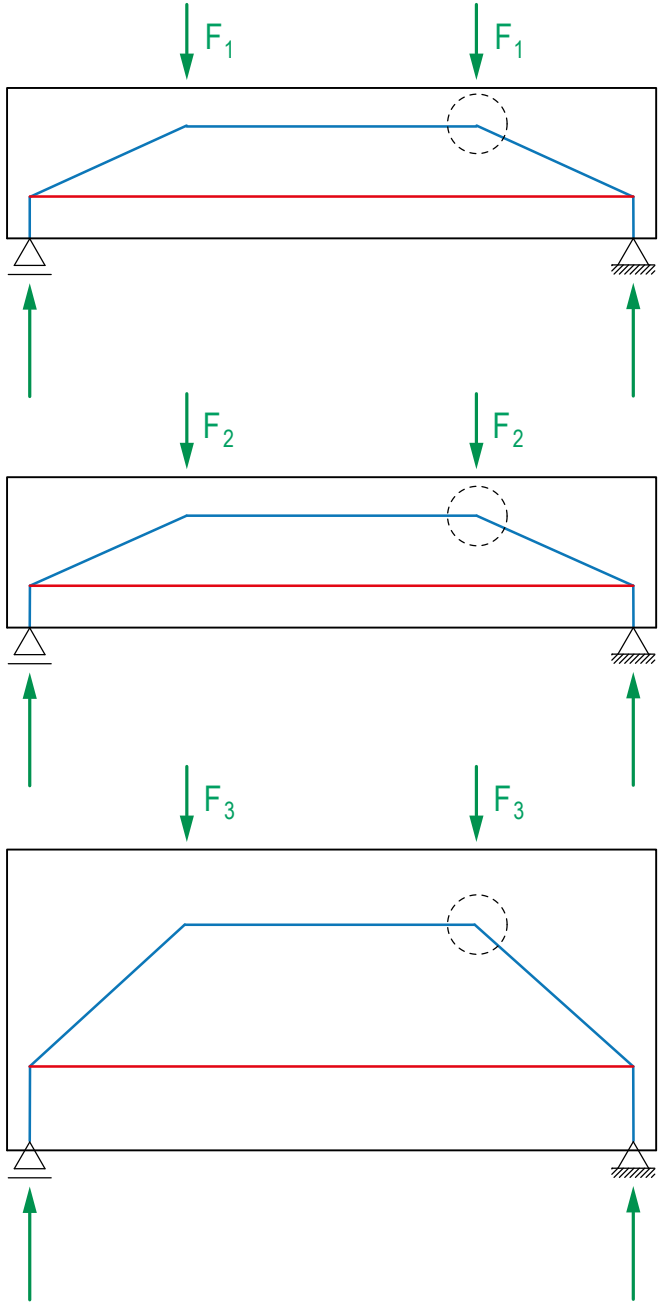


Forceflow  
*Kräftefluss*



Deflection  
*Ablenkung*





# Balken

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Tragverhalten eines einfachen Balkens

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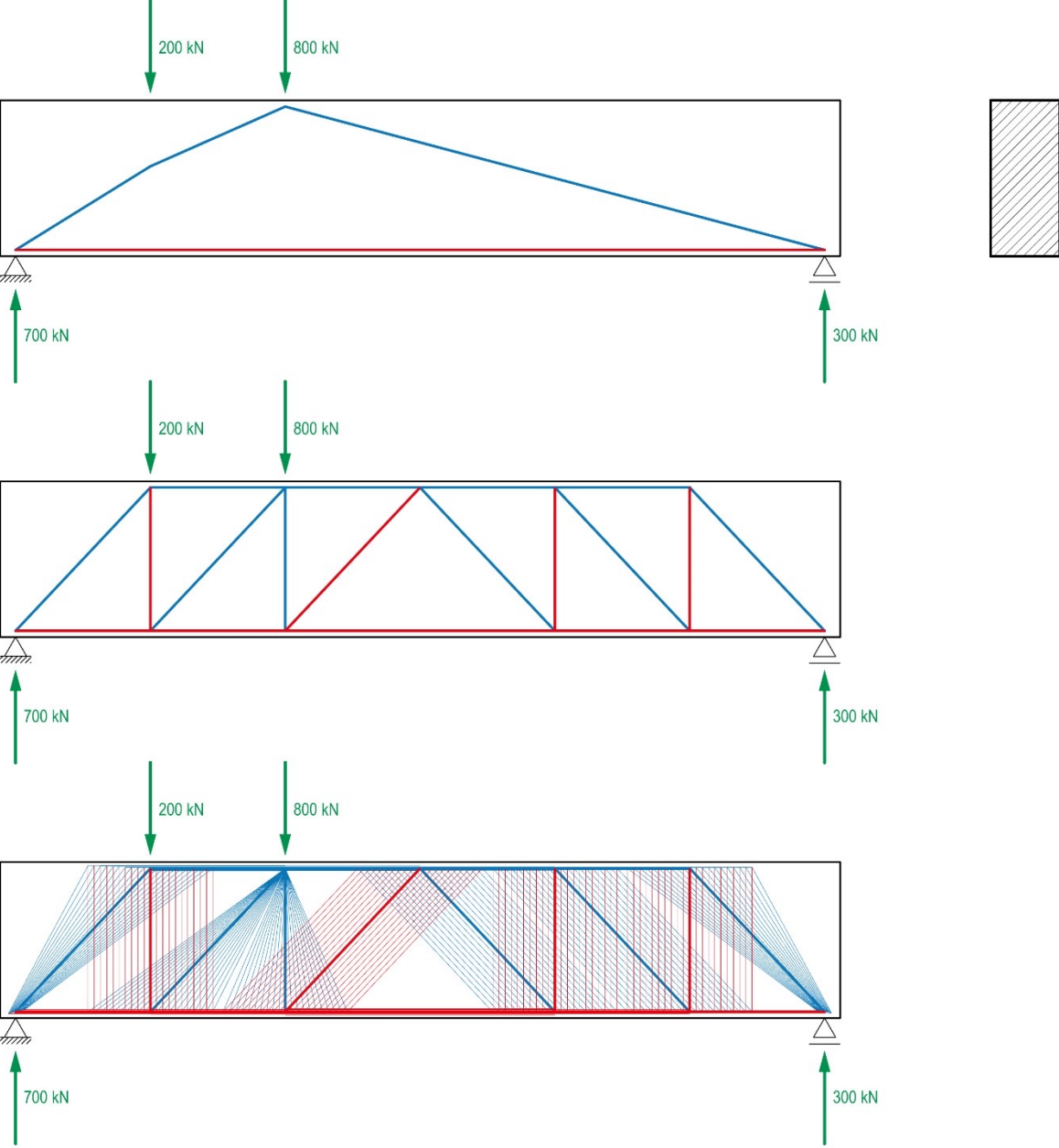
*Continuous beam*

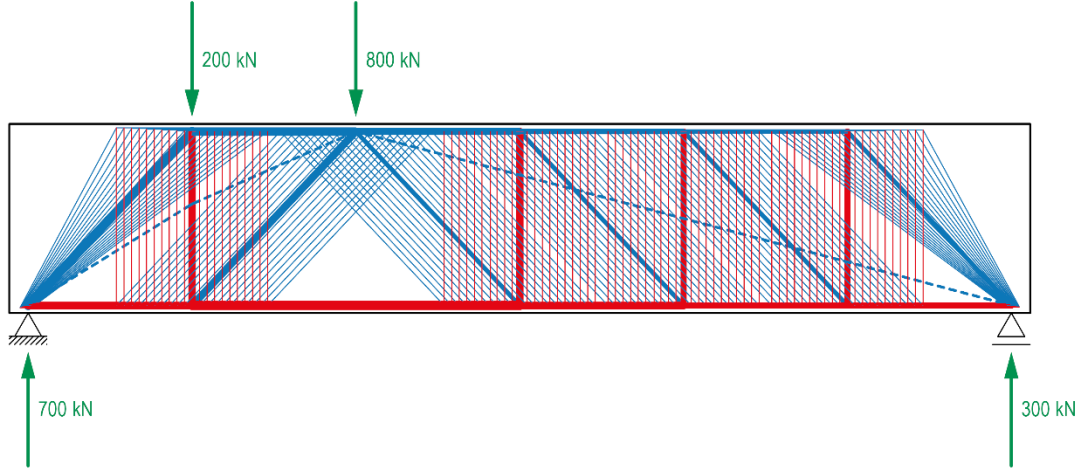
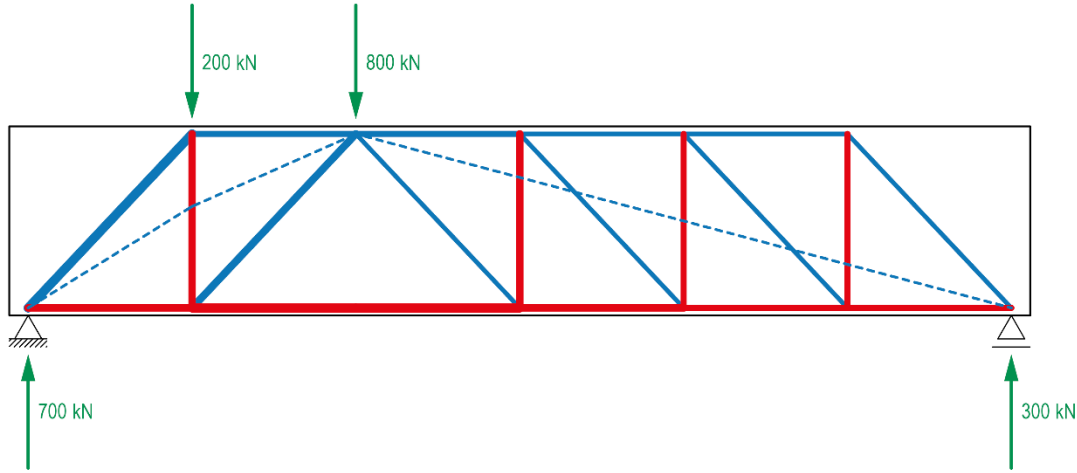
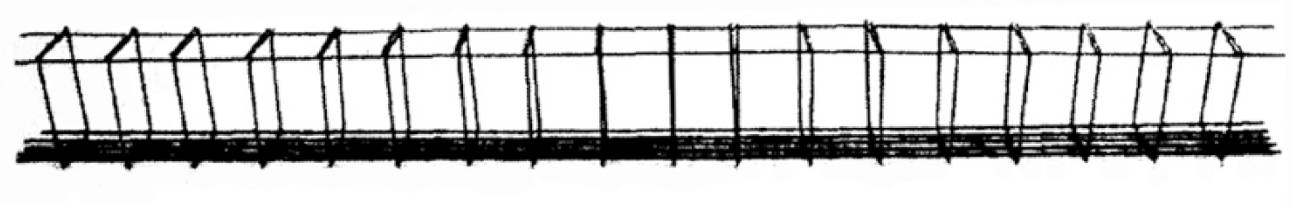
Schlankheit von Balken

*Slenderness of beams*

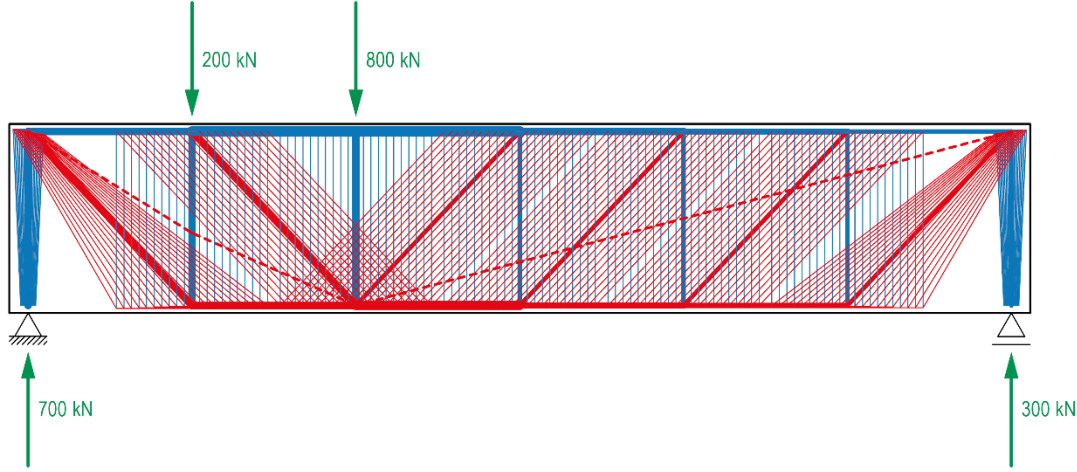
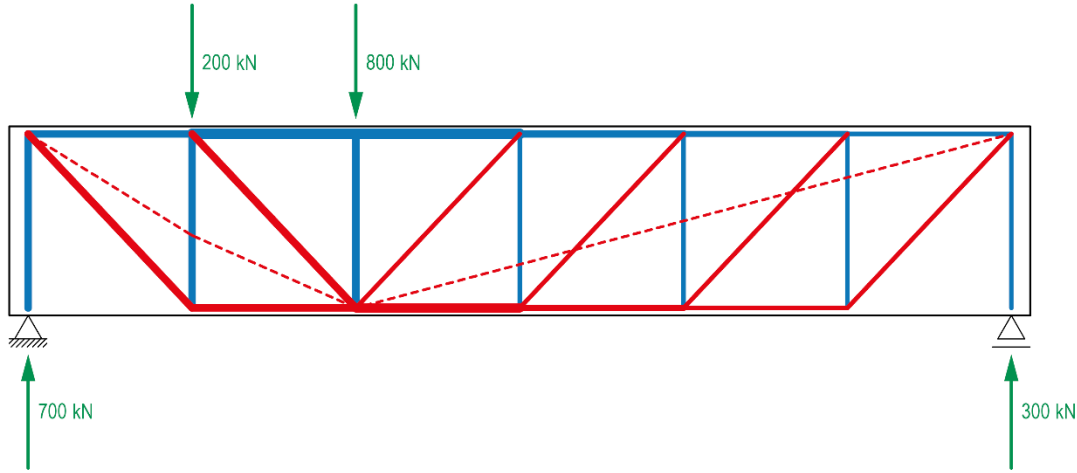
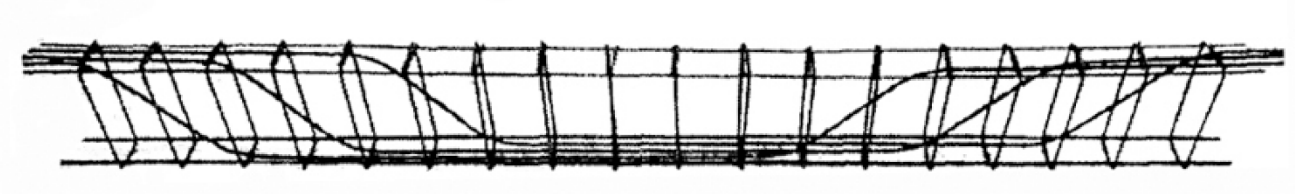
Scheiben

*Deep beams*





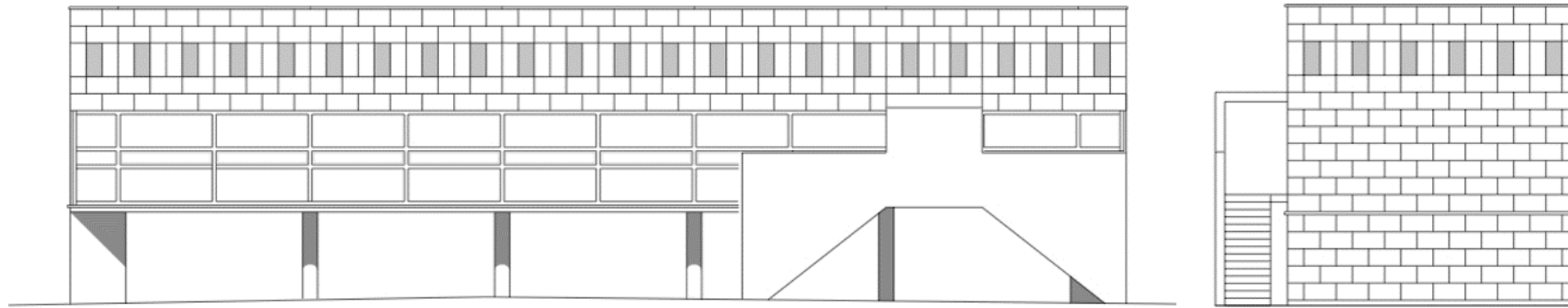


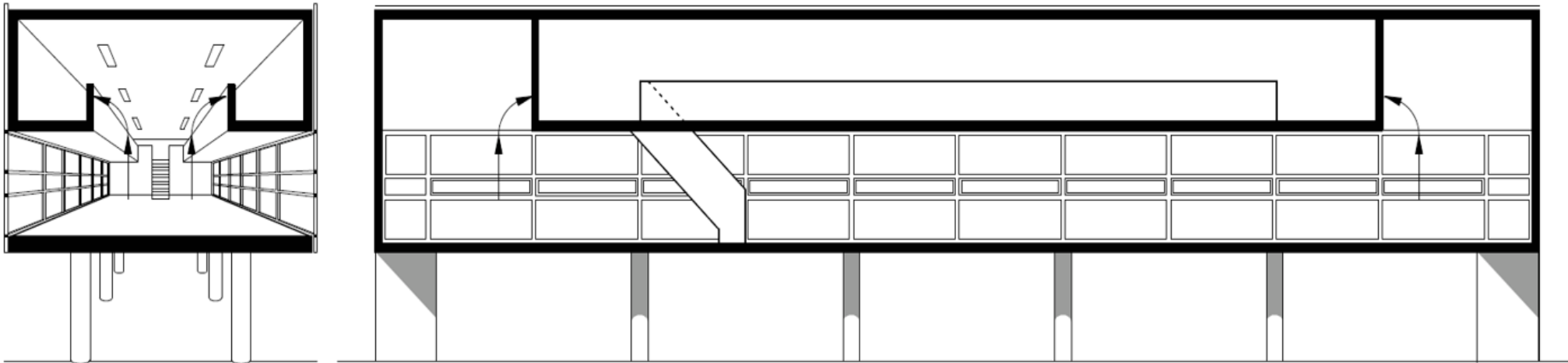




Studio di Architettura Livio Vacchini, Locarno, 1985







Studio di Architettura Livio Vacchini, Locarno, 1985

# Balken

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*From trusses to beams*

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*Reinforced concrete beams*

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*Gerber's beam (hinged girder system)*

Durchlaufträger

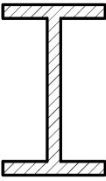
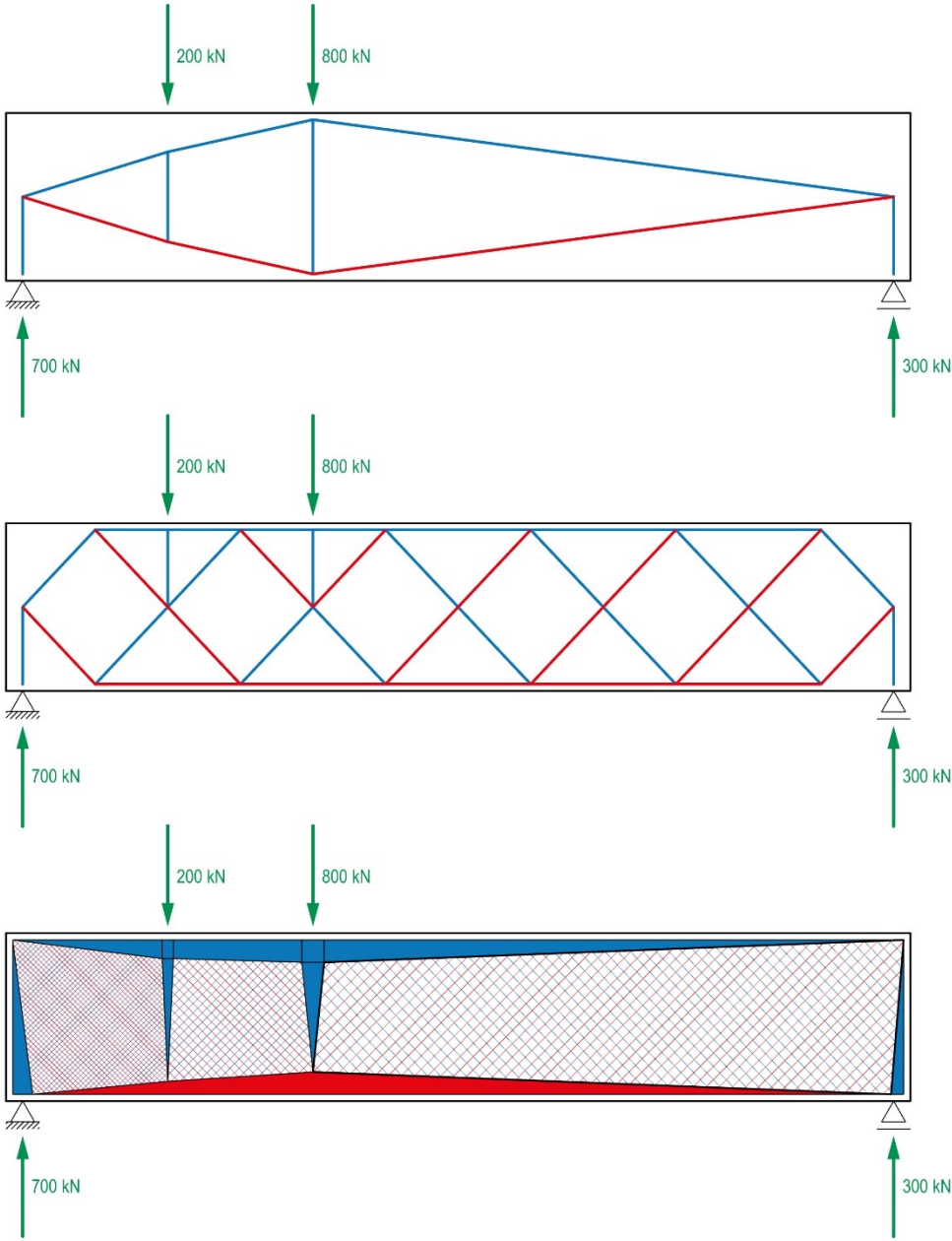
*Continuous beam*

Schlankheit von Balken

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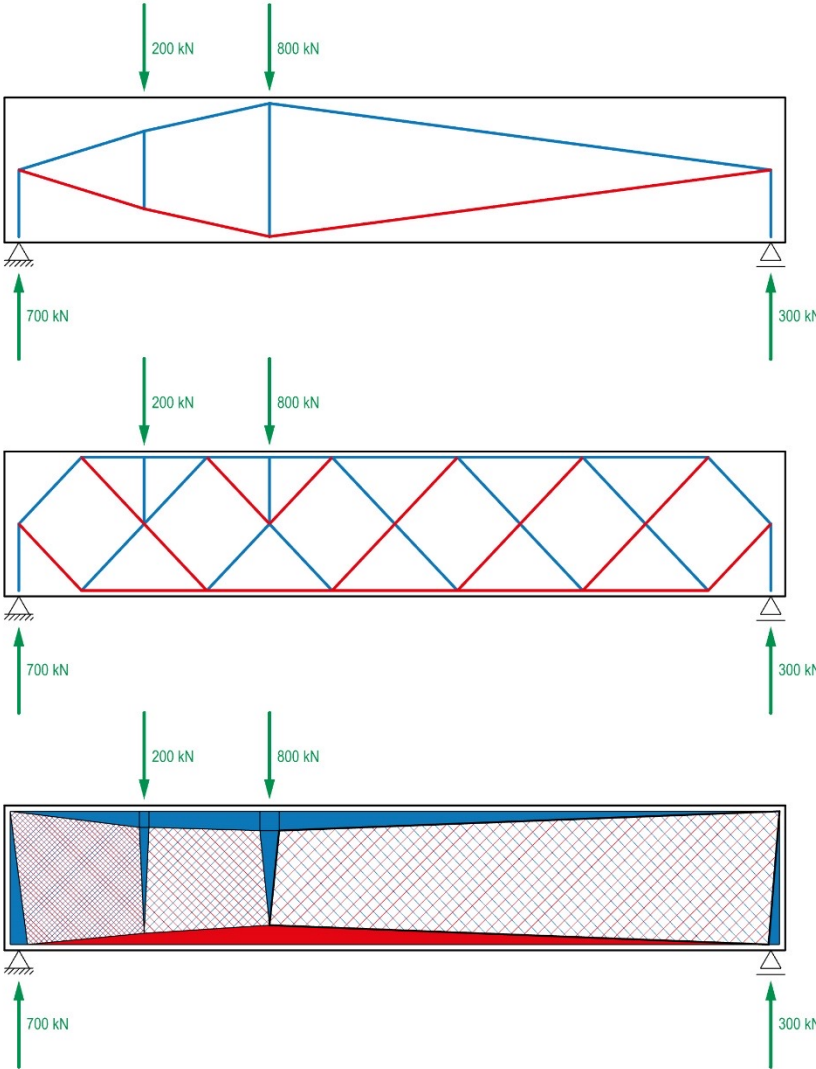
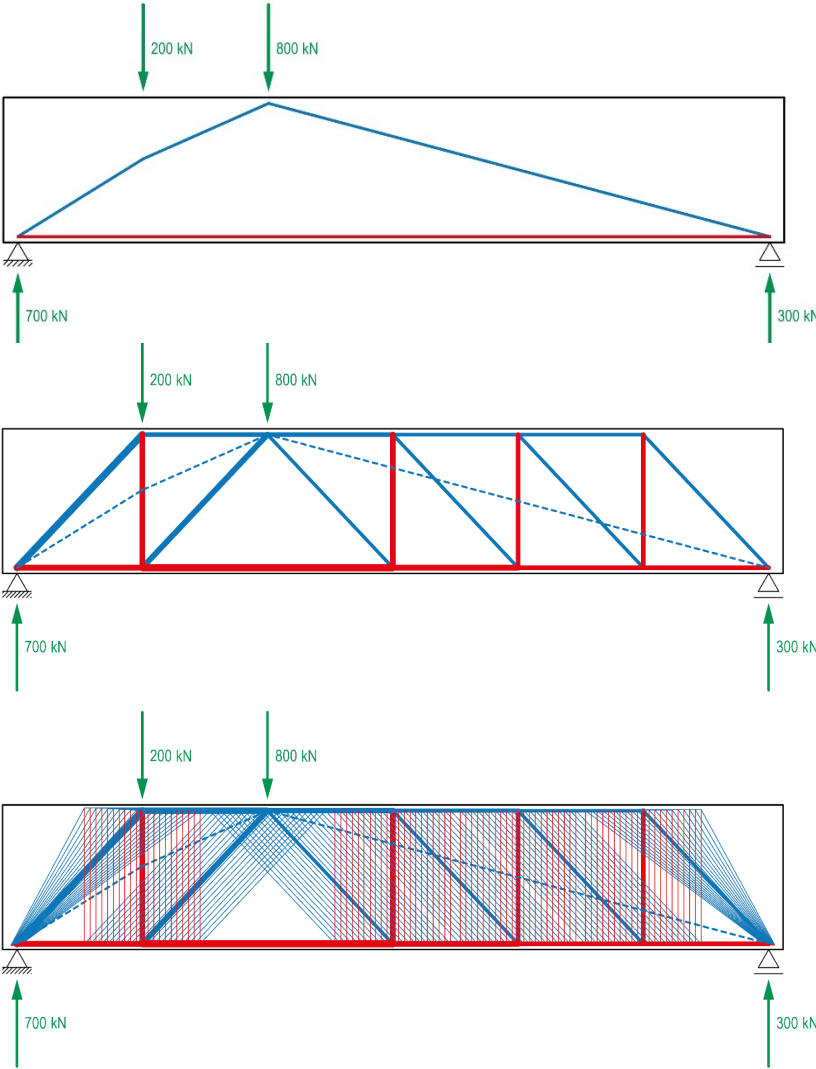
Scheiben

*Deep beams*



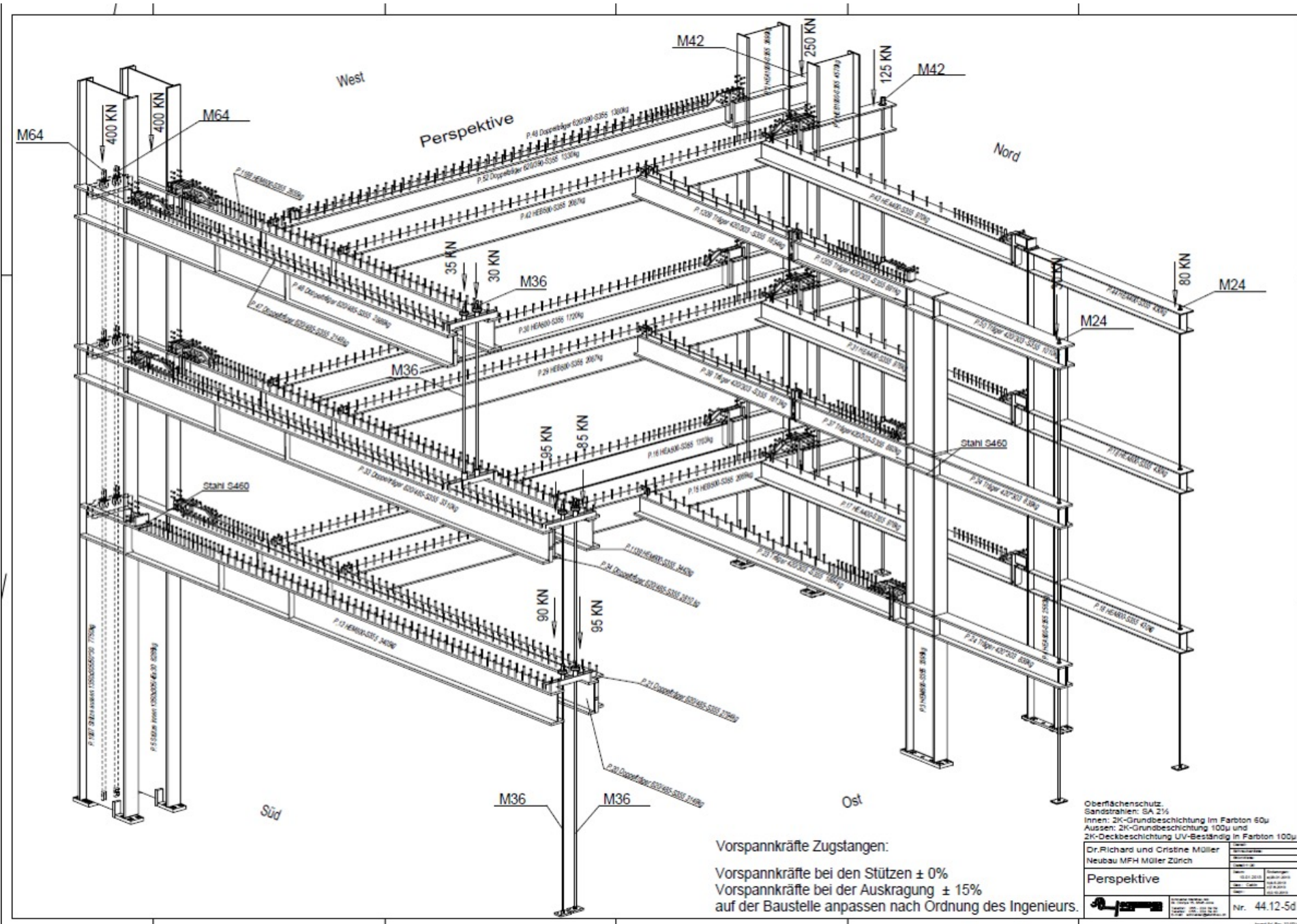
Stahlbeton  
Reinforced concrete

Stahl  
Steel





Haus Krönleinstrasse, Christian Kerez & Joseph Schwartz, Zürich, 2013



Haus Krönleinstrasse, Christian Kerez & Joseph Schwartz, Zürich, 2013



Haus Krönleinstrasse, Christian Kerez & Joseph Schwartz, Zürich, 2013





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*Continuous beam*

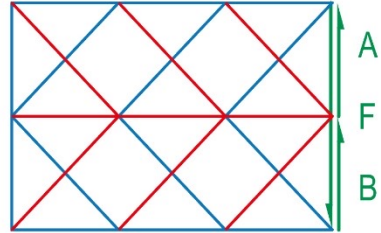
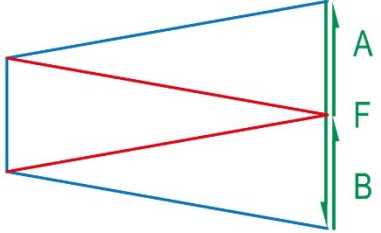
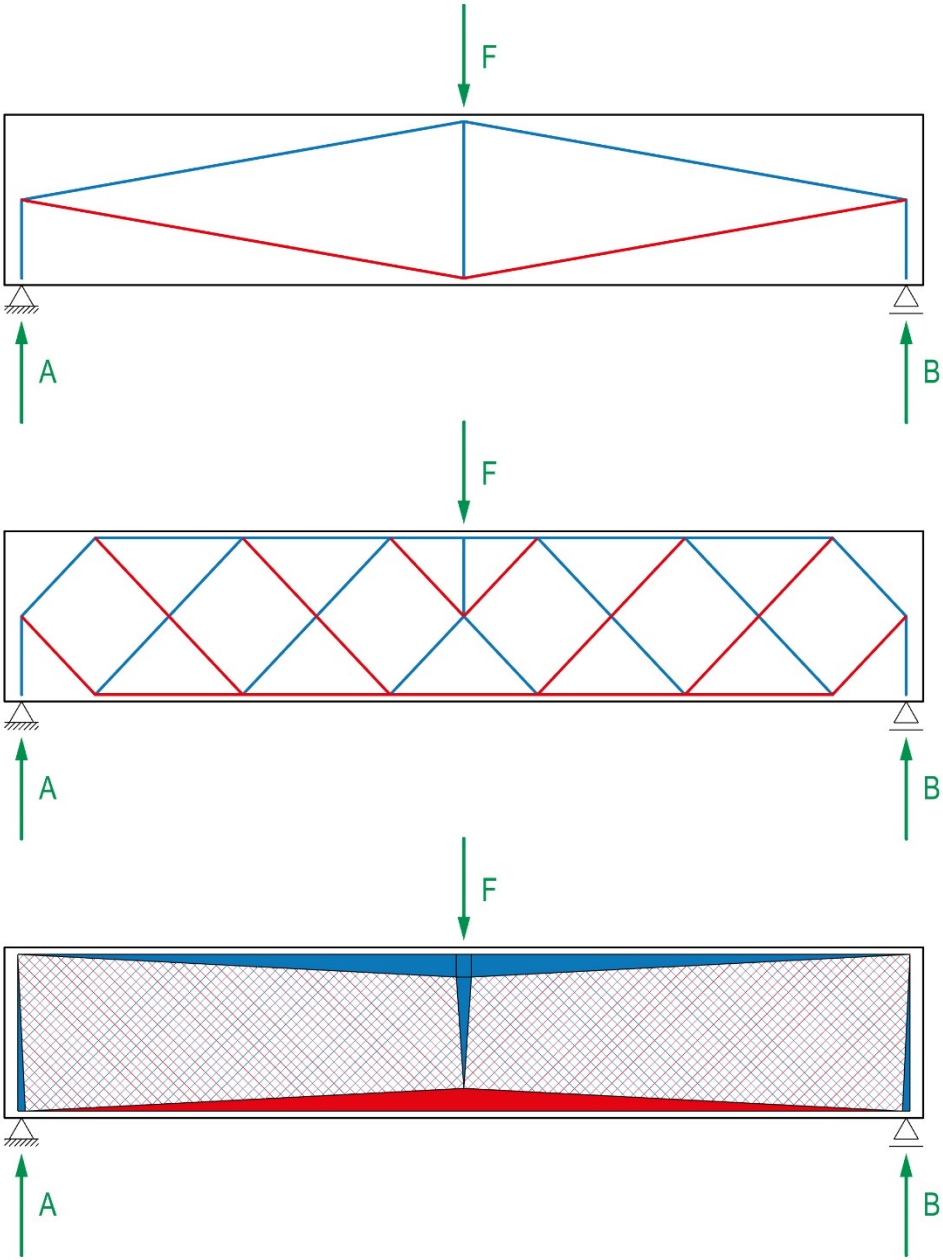
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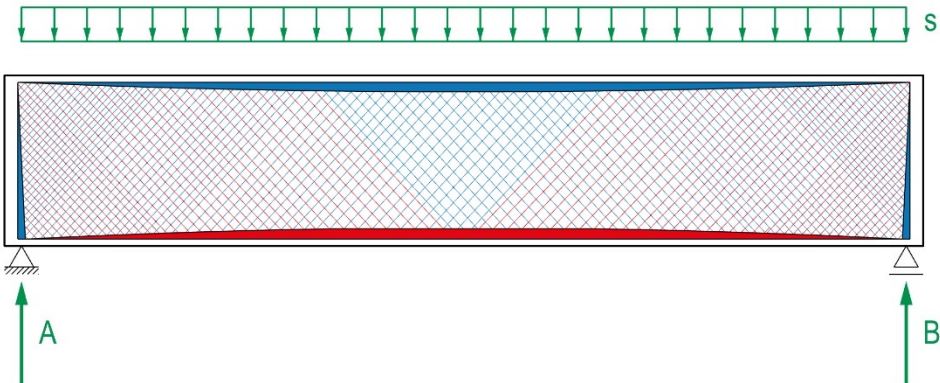
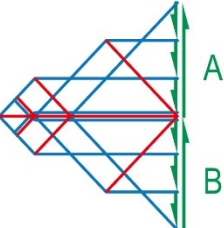
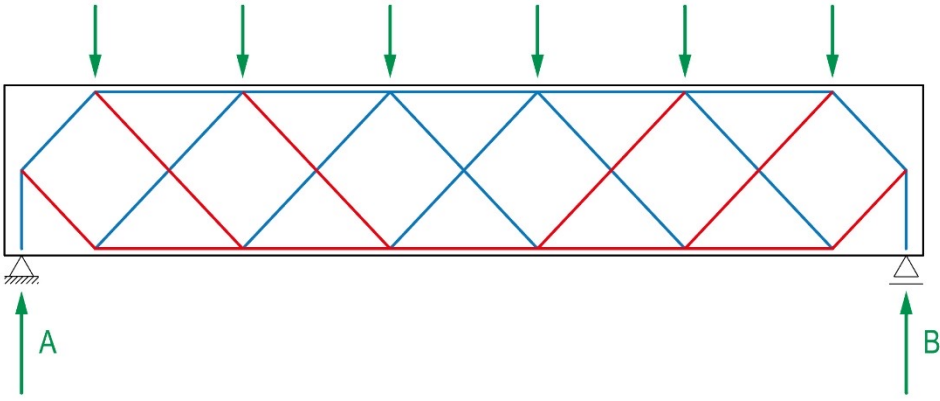
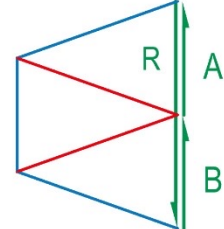
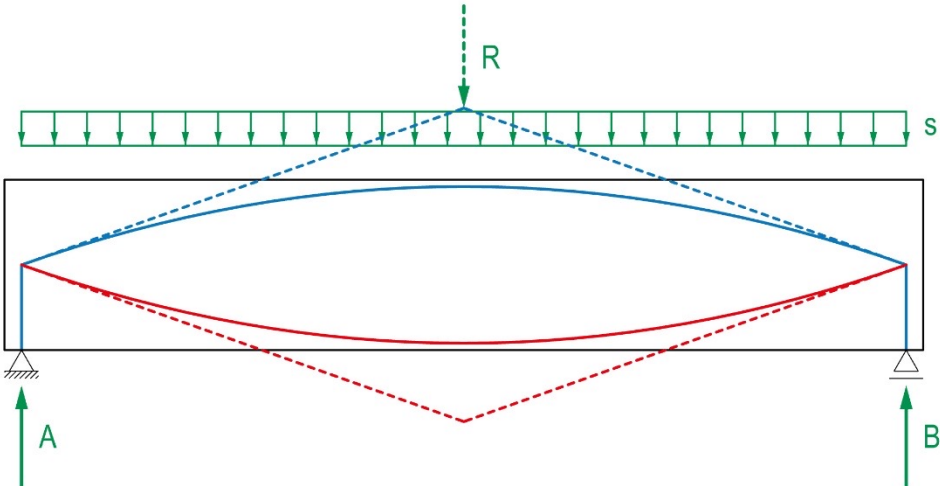
Scheiben

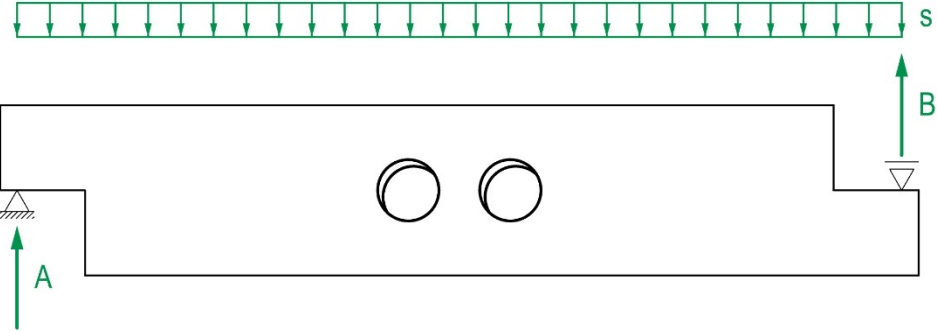
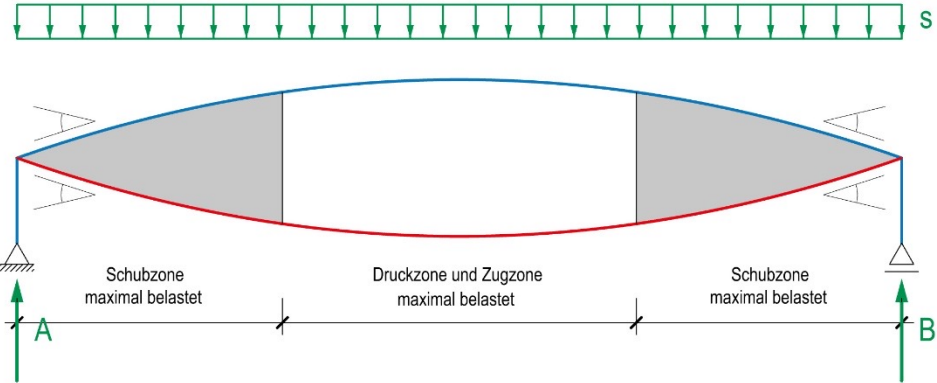
*Deep beams*

*Beams under concentrated and distributed loads*



*Beams under concentrated and distributed loads*





Bogen, Seil		Bogen-Seiltragwerk	
Als äusseres Tragwerk	Als inneres Tragwerk	Als äusseres Tragwerk	Als inneres Tragwerk
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Durchlaufträger

*Continuous beam*

Schlankheit von Balken

*Slenderness of beams*

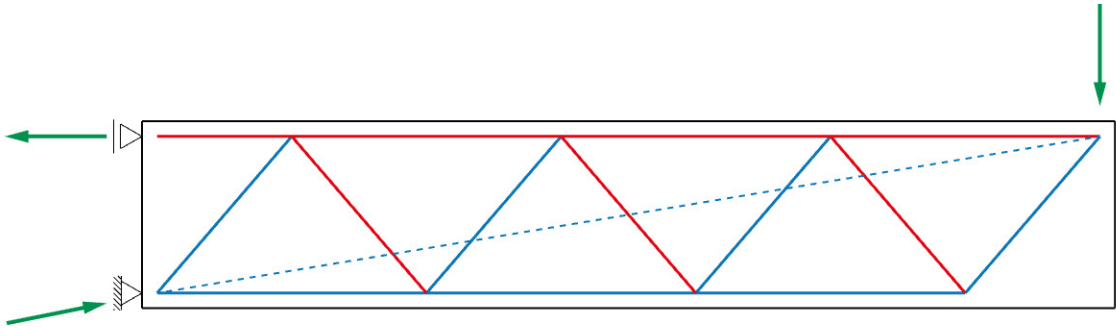
Scheiben

*Deep beams*

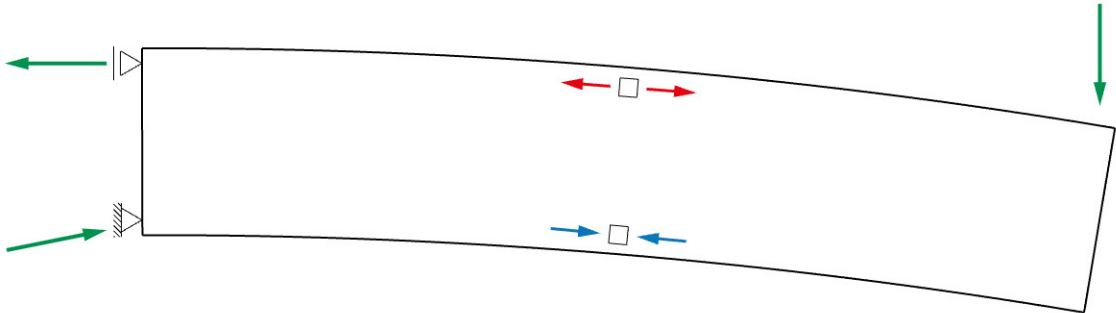


*Cantilever under concentrated and distributed loads*

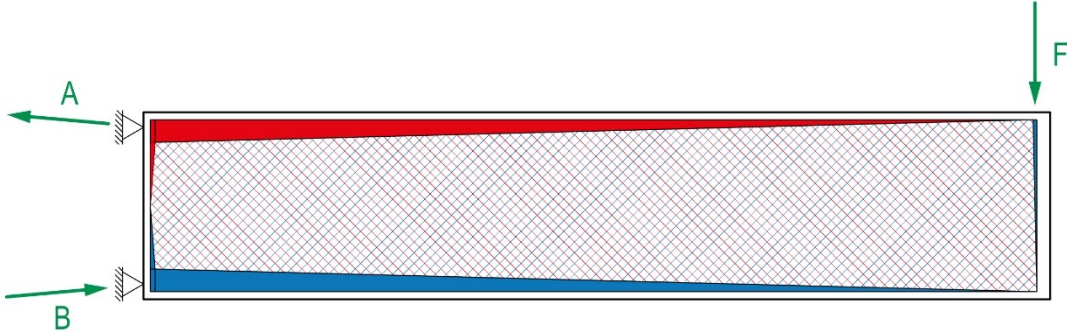
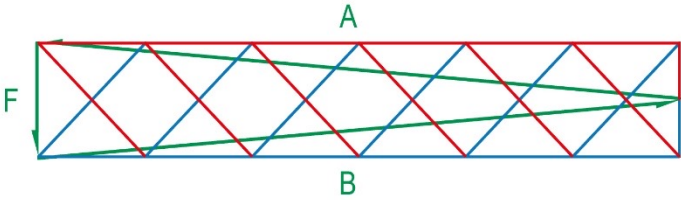
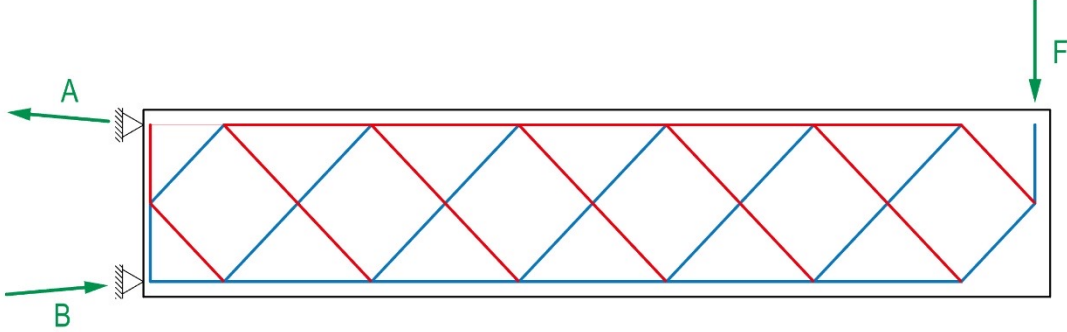
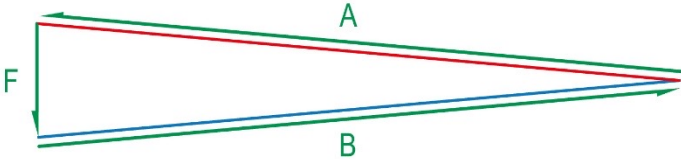
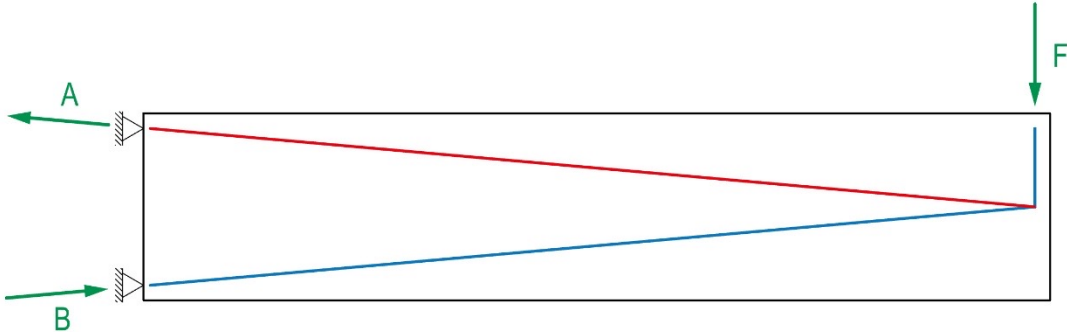
Forceflow  
*Kräftefluss*



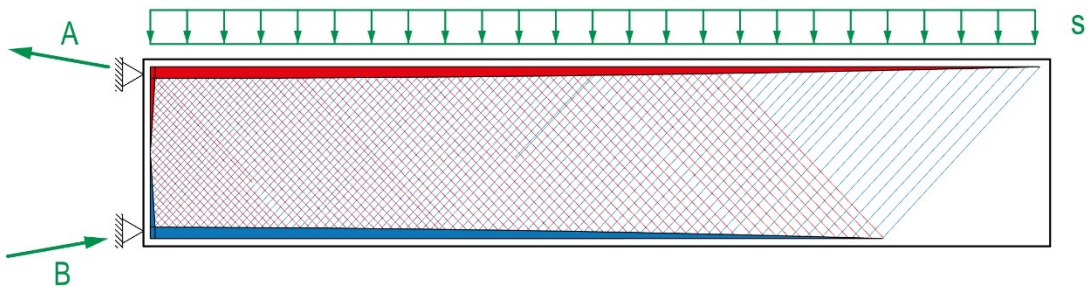
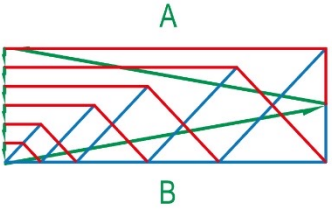
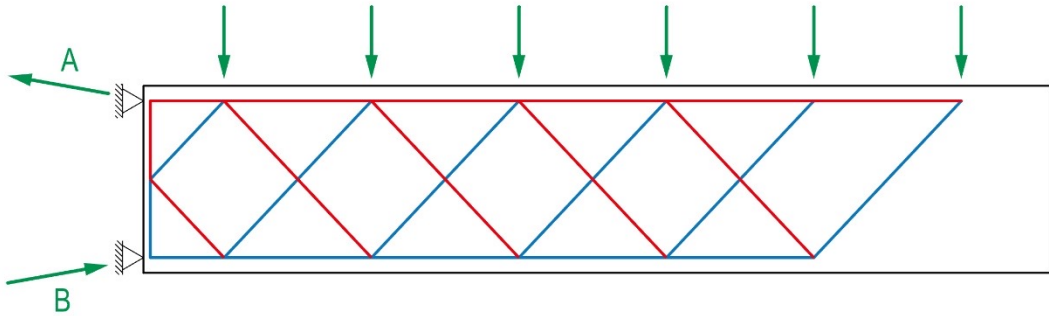
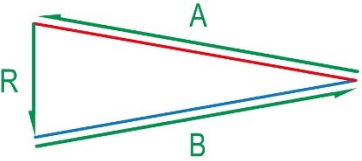
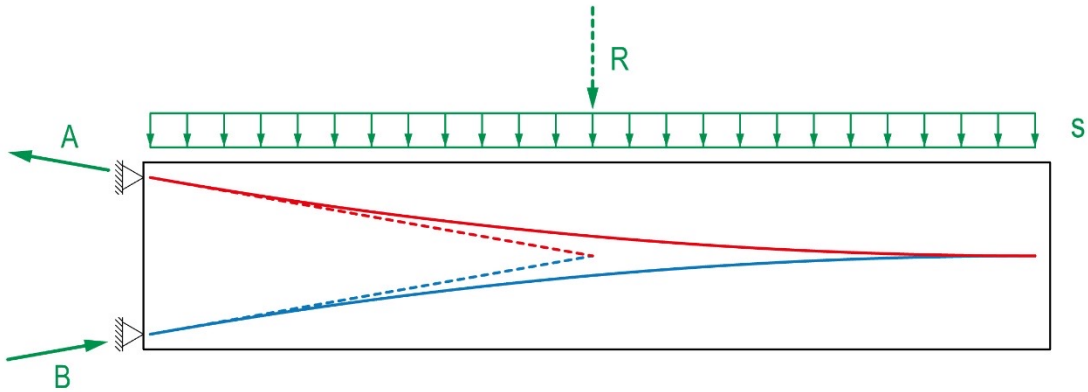
Deflection  
*Ablenkung*



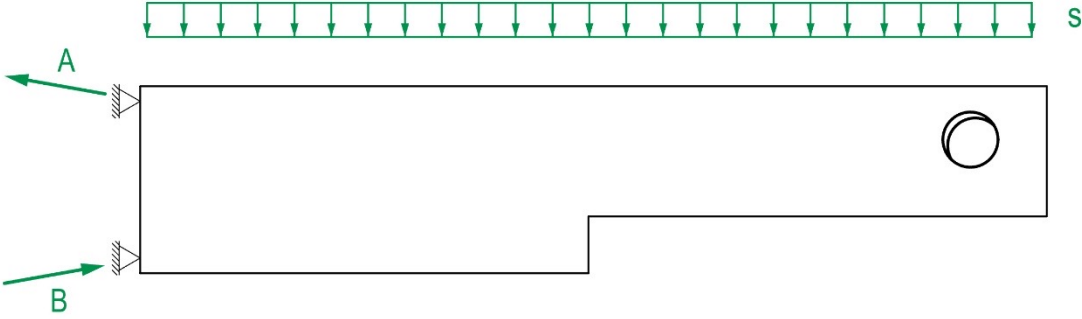
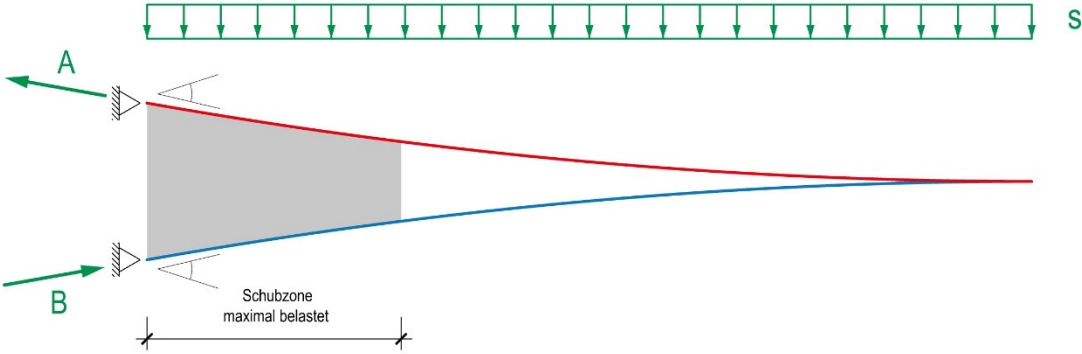
*Cantilever under concentrated and distributed loads*

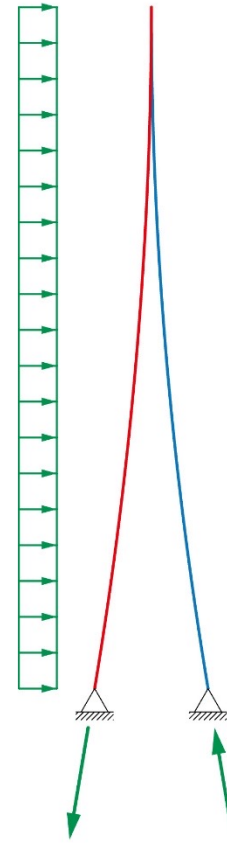
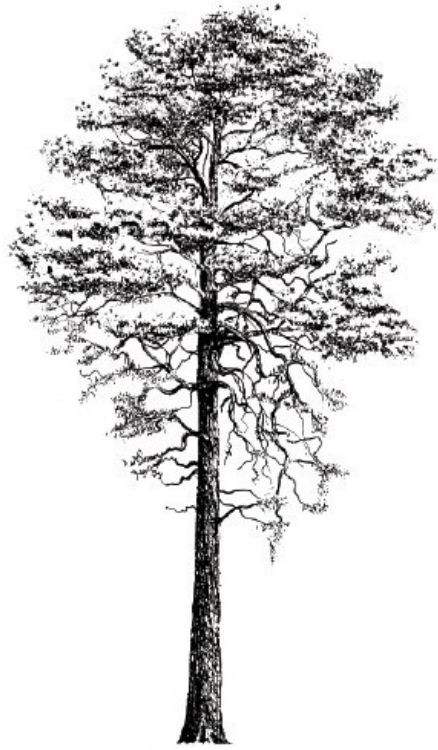


*Cantilever under concentrated and distributed loads*



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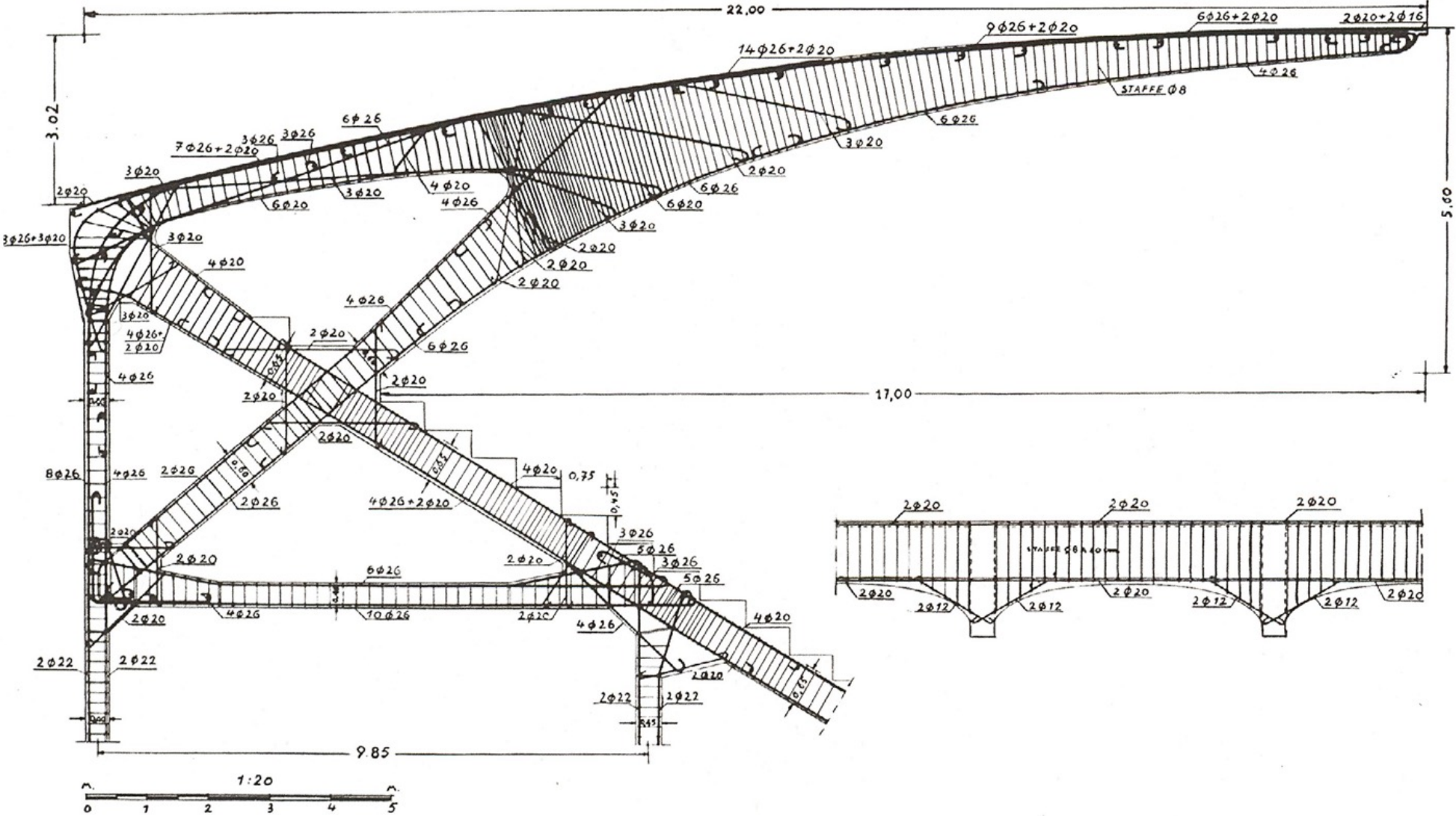




John Andrews & WMZ Architects, Nicolet, Dressel Associates & Bruno Thürlimann: CN Tower, Toronto, 1976



Pier Luigi Nervi, Stadio G. Berta, Florenz, 1931



Pier Luigi Nervi, Stadio G. Berta, Florenz, 1931



Stutz + Bolt + Partner, Joseph Schwartz; Überdachung Bahnhofplatz Winterthur, 2013





Stutz + Bolt + Partner, Joseph Schwartz; Überdachung Bahnhofplatz Winterthur, 2013



Stutz + Bolt + Partner, Joseph Schwartz; Überdachung Bahnhofplatz Winterthur, 2013

# Balken

## *Beams*

Vom Fachwerk zum Balken

*From trusses to beams*

Tragverhalten eines einfachen Balkens

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*Analysis of beams*

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*Gerber's beam (hinged girder system)*

Durchlaufträger

*Continuous beam*

Schlankheit von Balken

*Slenderness of beams*

Scheiben

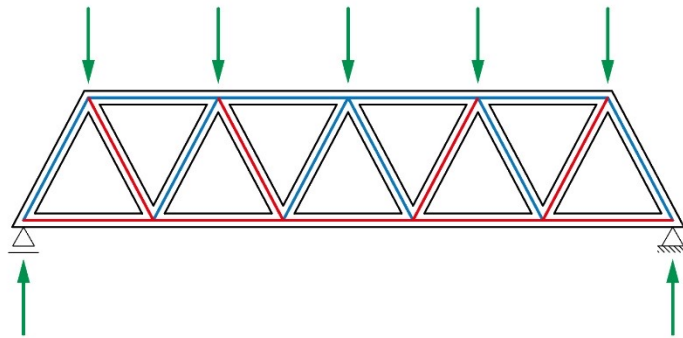
*Deep beams*

## Fachwerk

- Globales Gleichgewicht (statisch bestimmt)
- Innere Kräfte (statisch bestimmt)

*Truss*

- *Global equilibrium (statically determinate)*
- *Internal forces (statically determinate)*

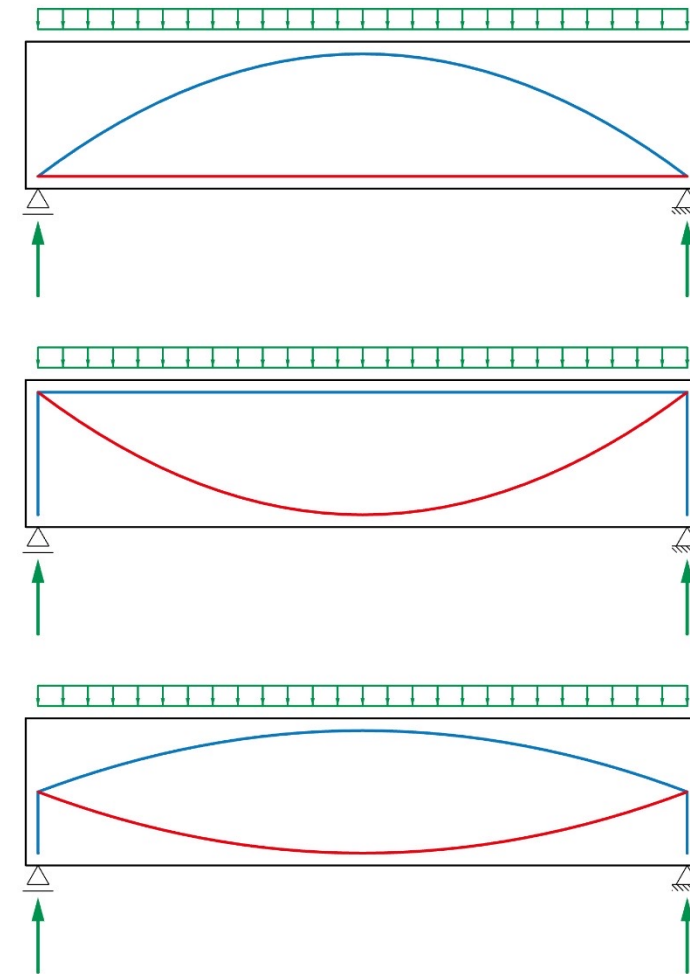


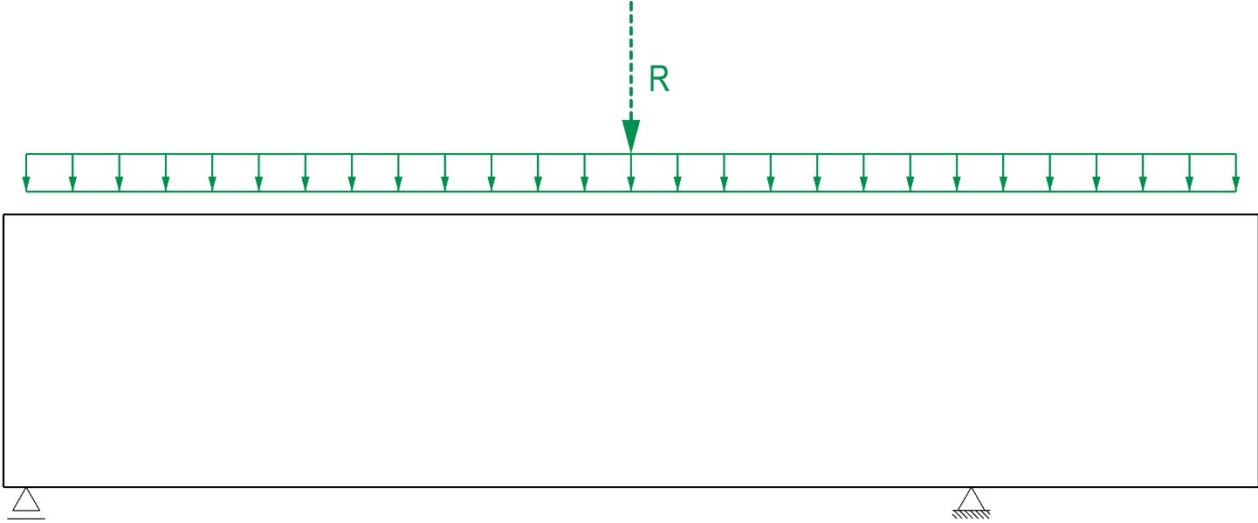
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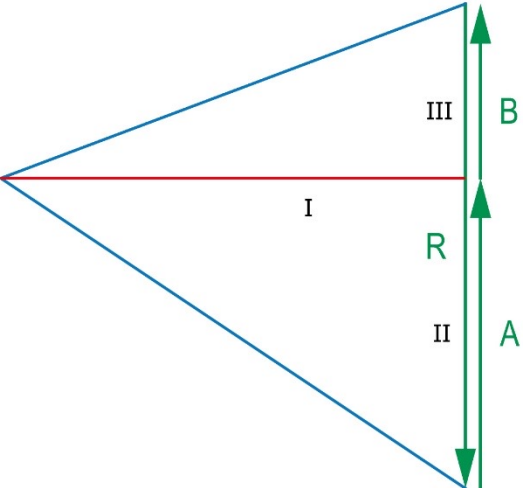
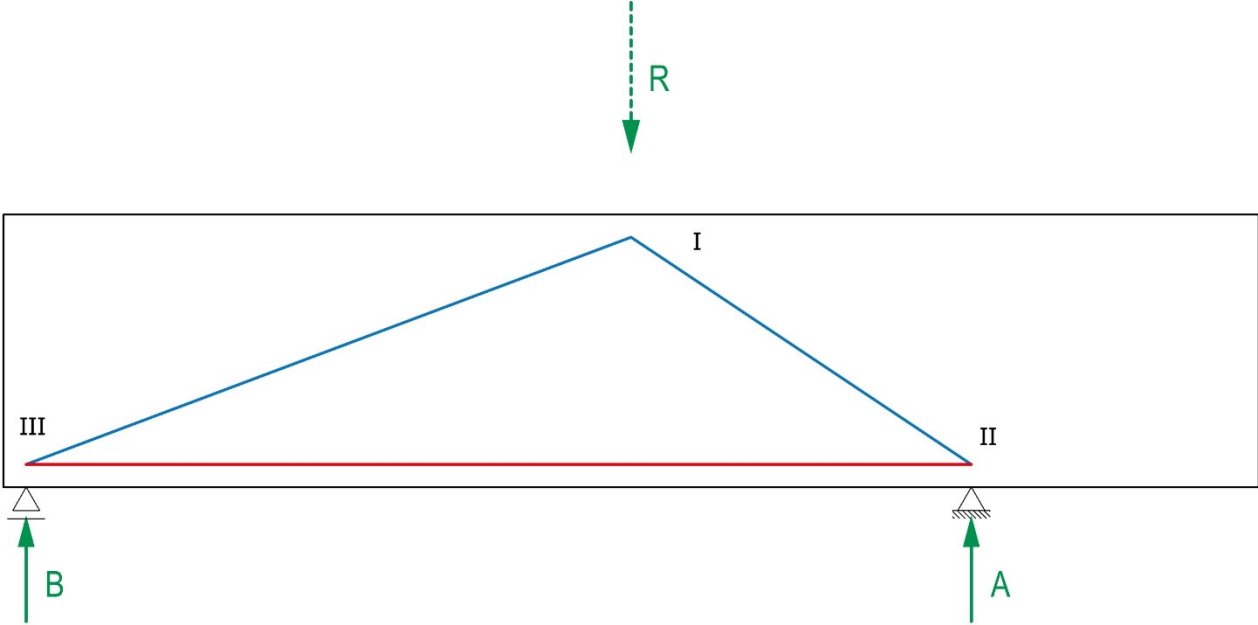
- Globales Gleichgewicht (statisch bestimmt)
- Innere Kräfte (statisch unbestimmt)

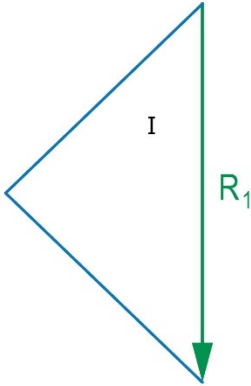
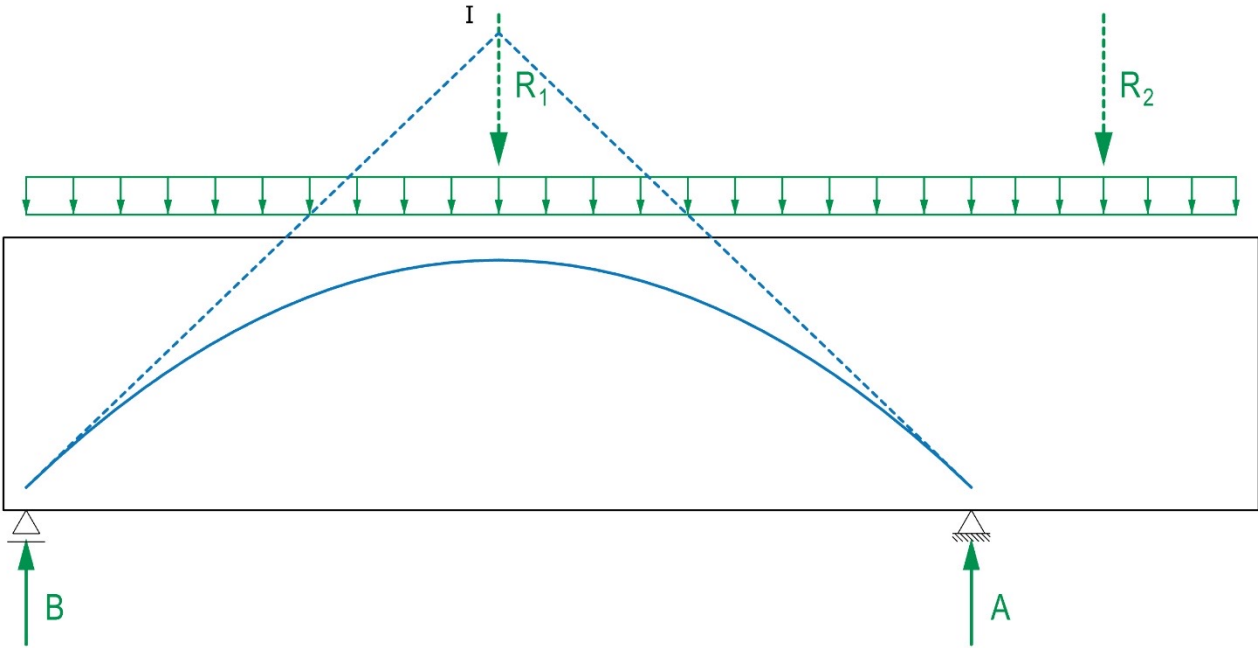
*Beam*

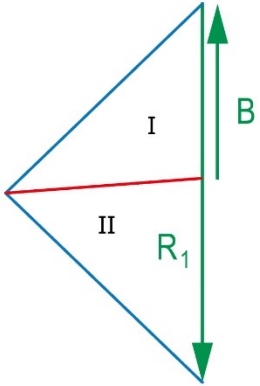
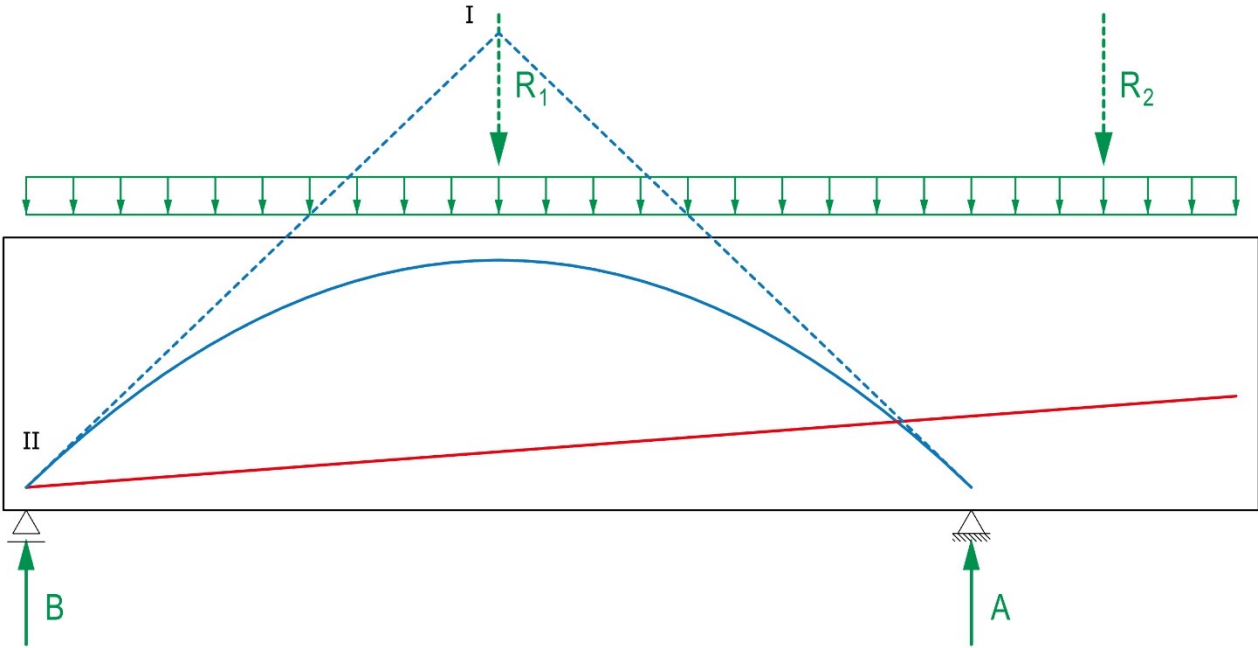
- *Global equilibrium (statically determinate)*
- *Internal forces (statically indeterminate)*



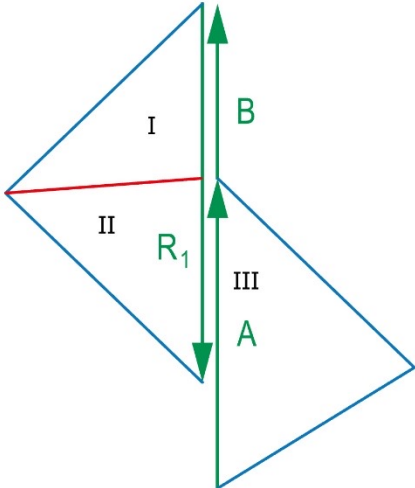
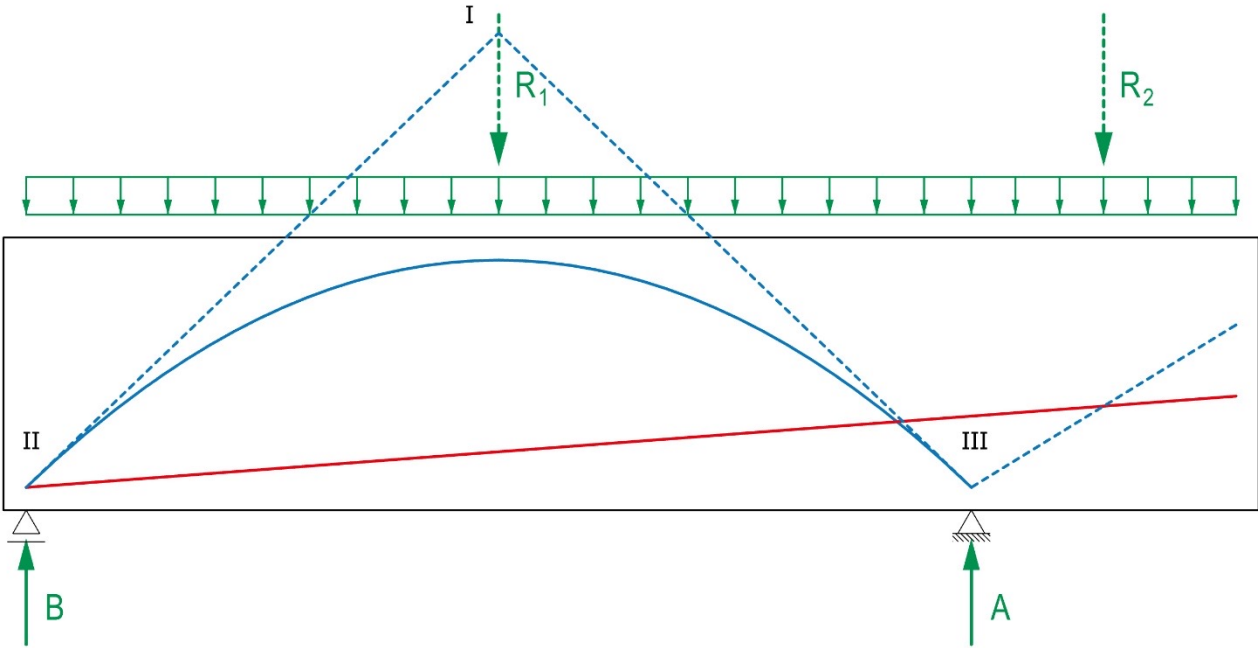


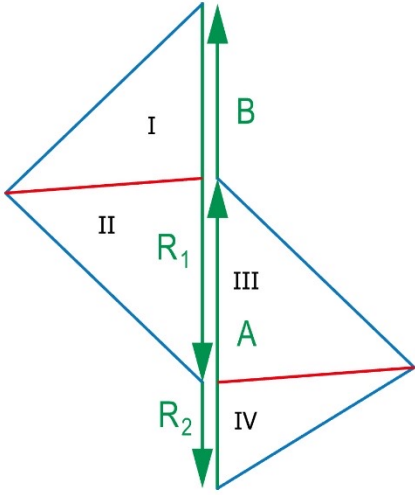
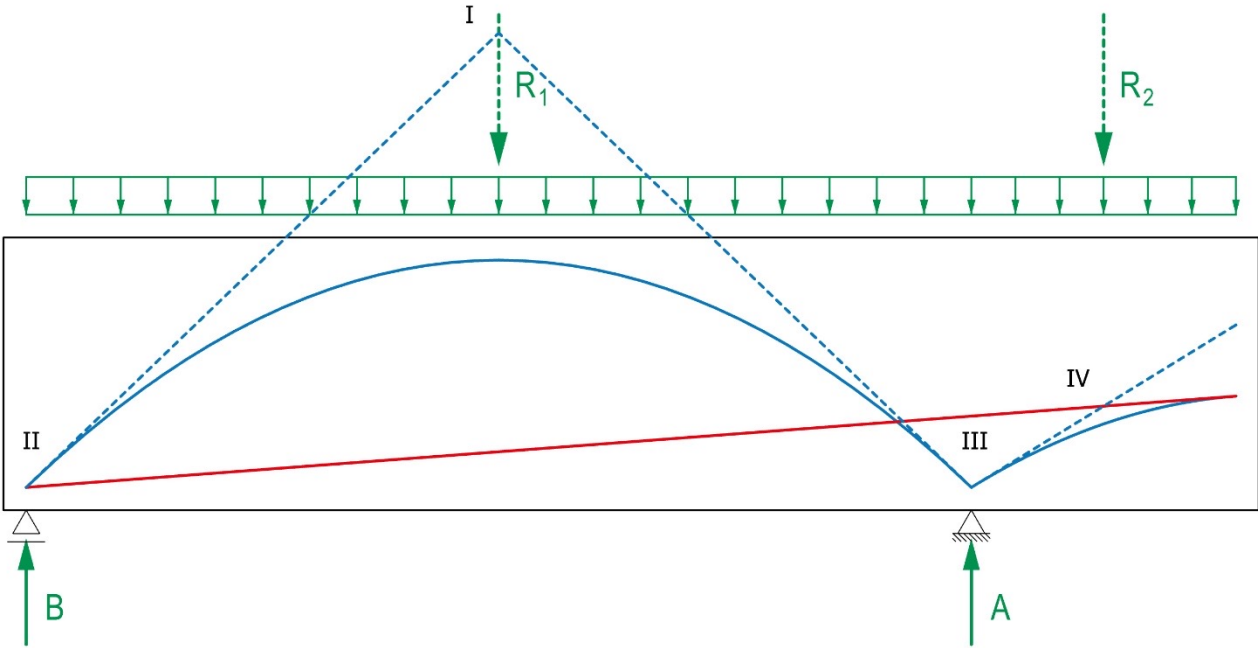


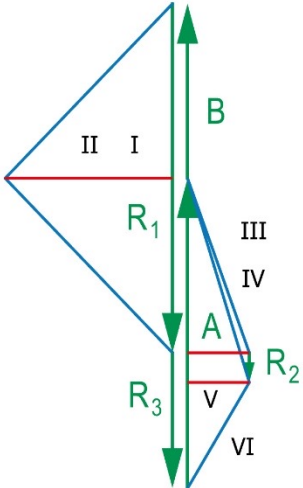
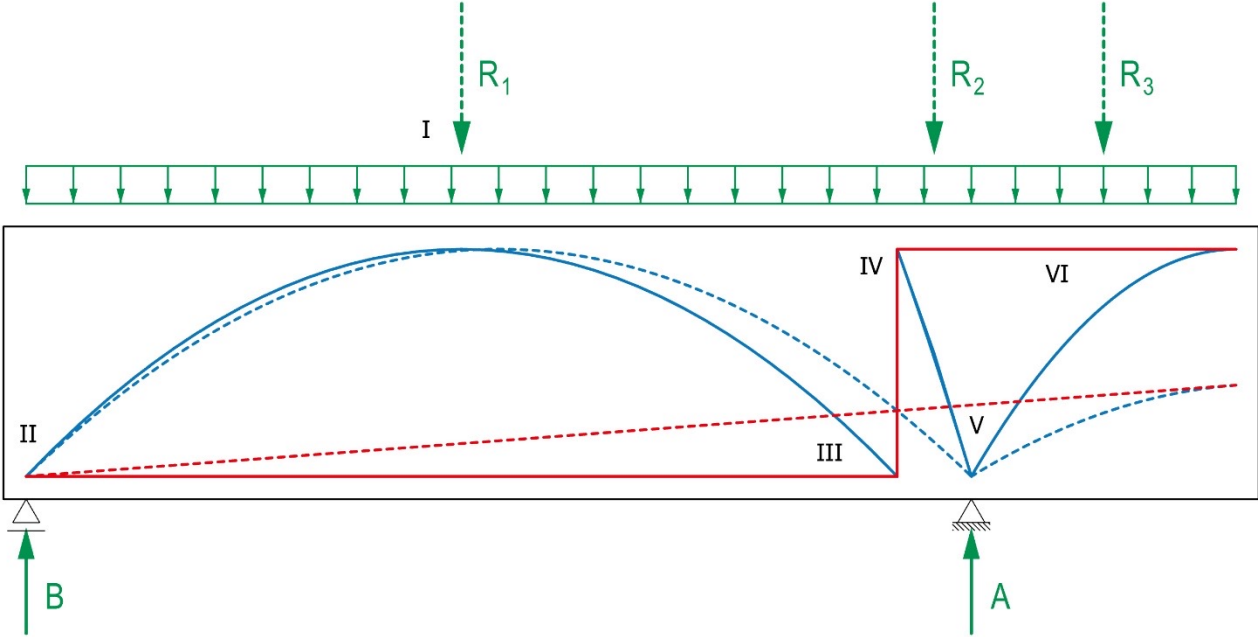


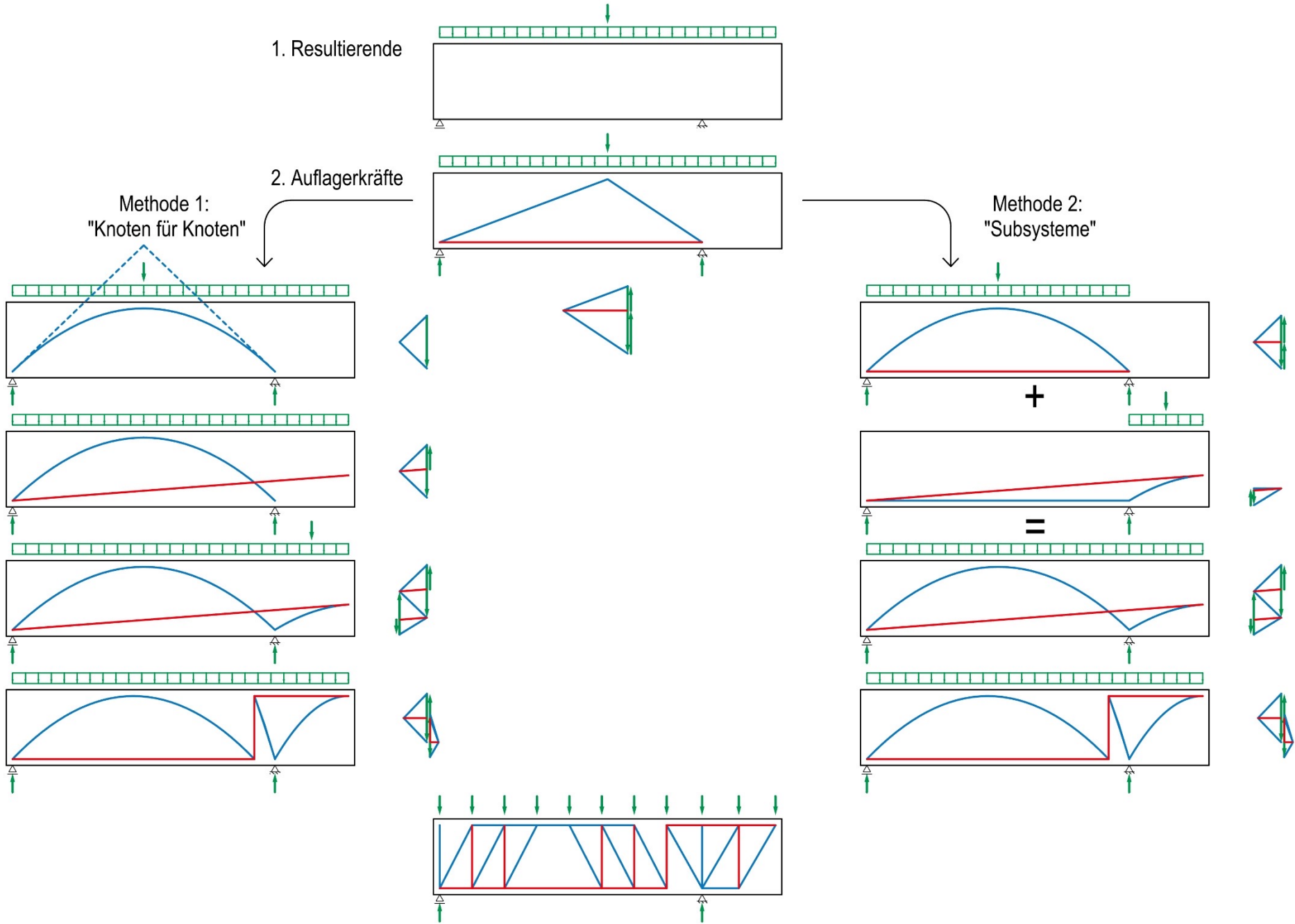












# Balken

## *Beams*

Vom Fachwerk zum Balken

*From trusses to beams*

Tragverhalten eines einfachen Balkens

*Structural behaviour of a simple beam*

Stahlbetonträger

*Reinforced concrete beams*

Stahlträger

*Steel beams*

Balken unter konzentrierten und verteilten Lasten

*Beams under concentrated and distributed loads*

Konsole unter konzentrierten und verteilten Lasten

*Cantilever under concentrated and distributed loads*

Analyse von Balken

*Analysis of beams*

>>

Variation der Randbedingungen

*Variation of boundary conditions*

Gerberträger

*Gerber's beam (hinged girder system)*

Durchlaufträger

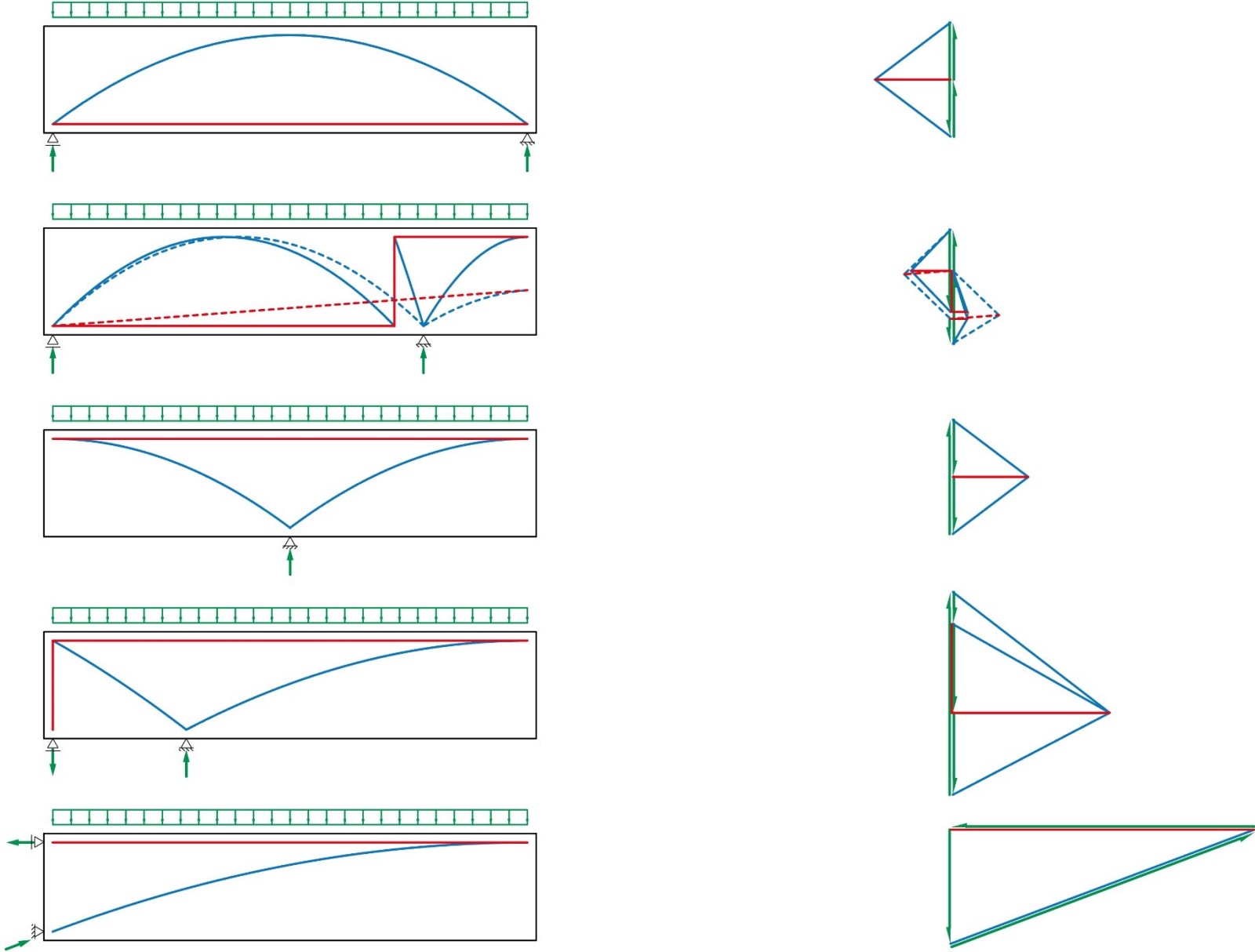
*Continuous beam*

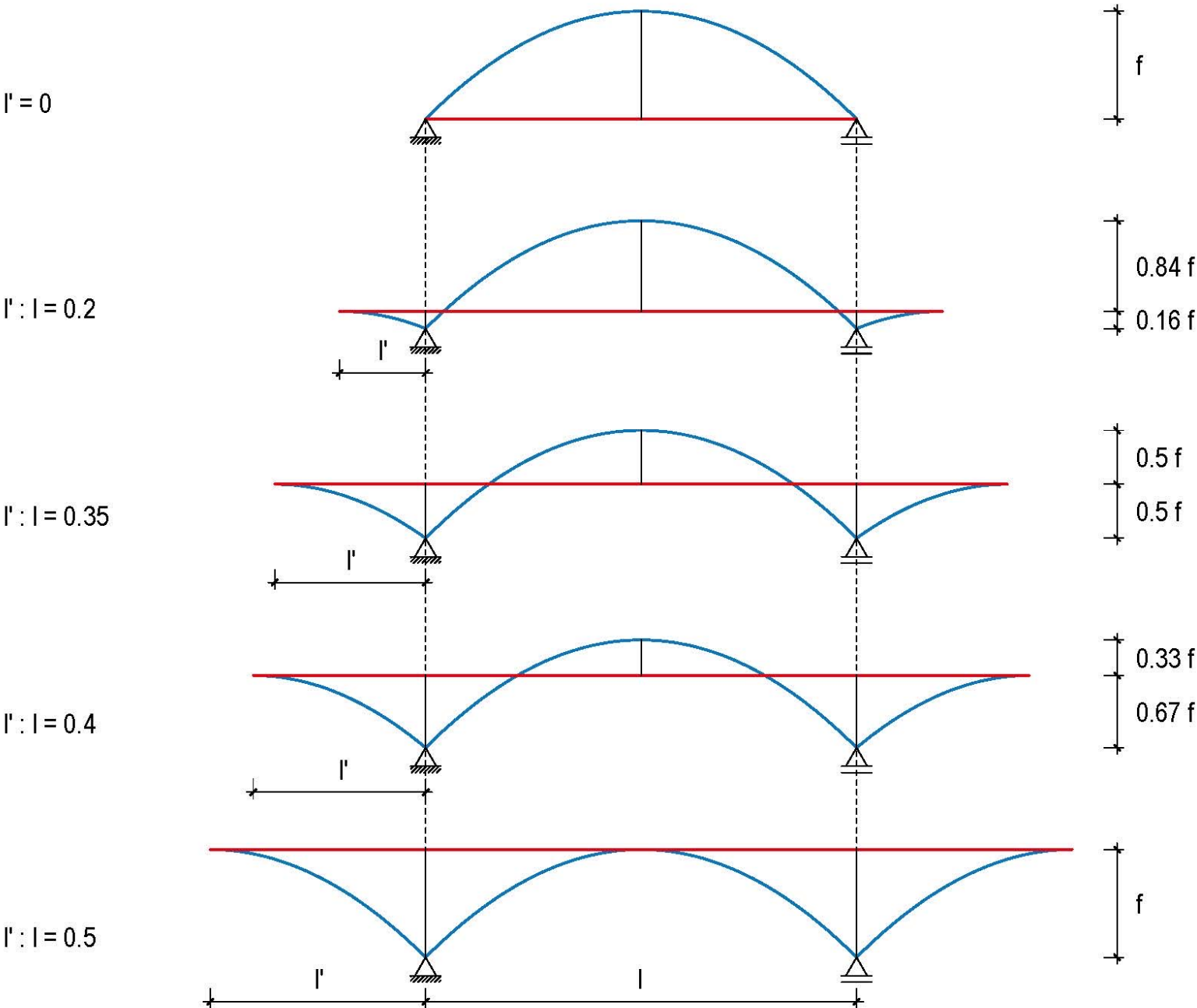
Schlankheit von Balken

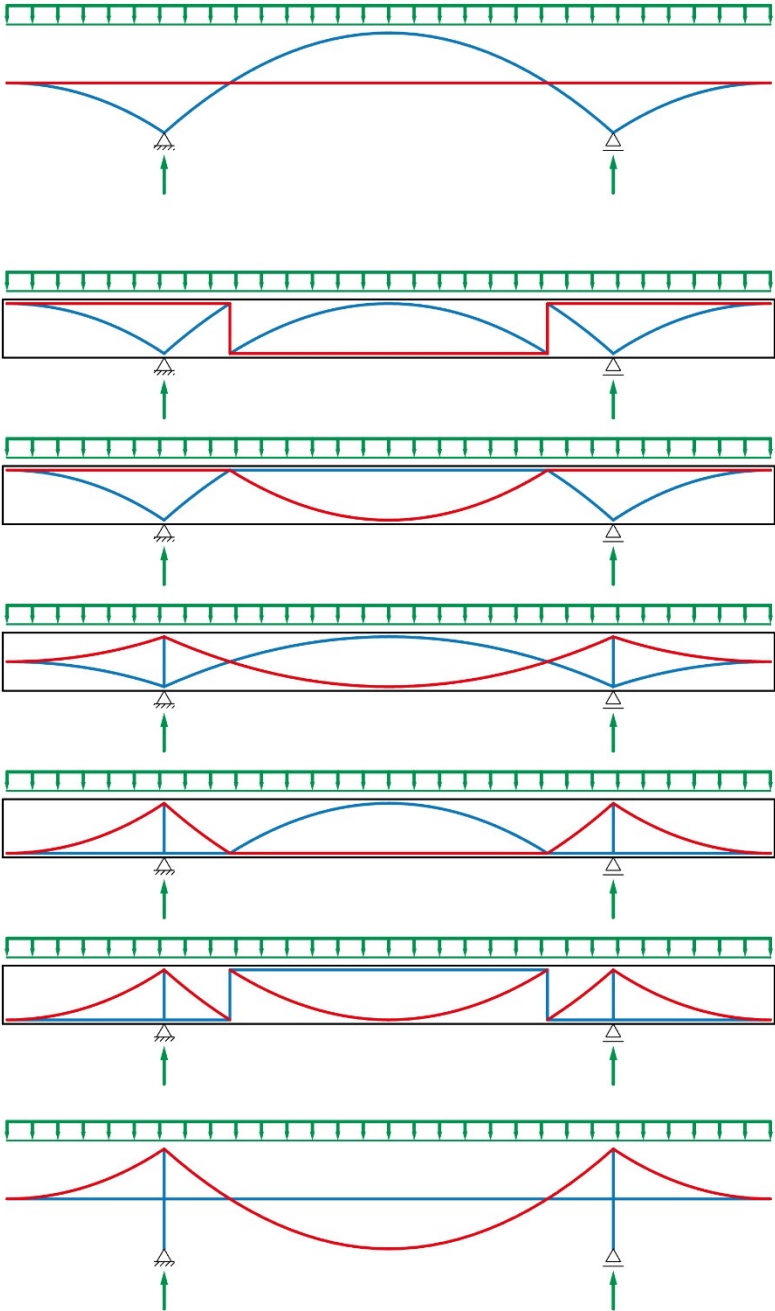
*Slenderness of beams*

Scheiben

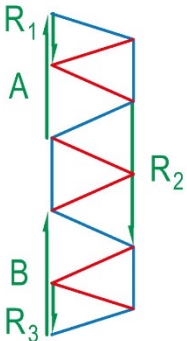
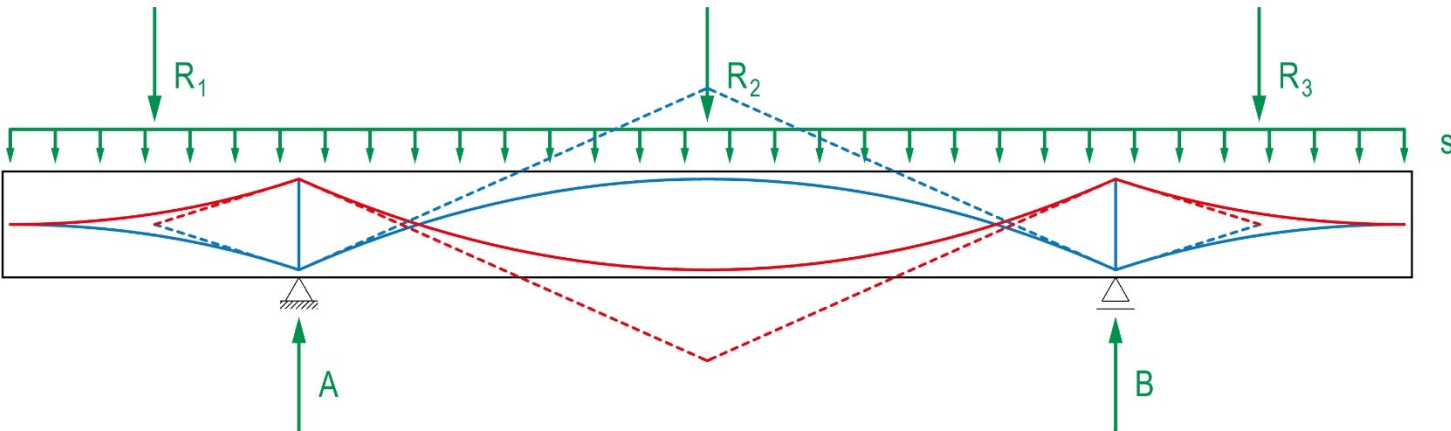
*Deep beams*



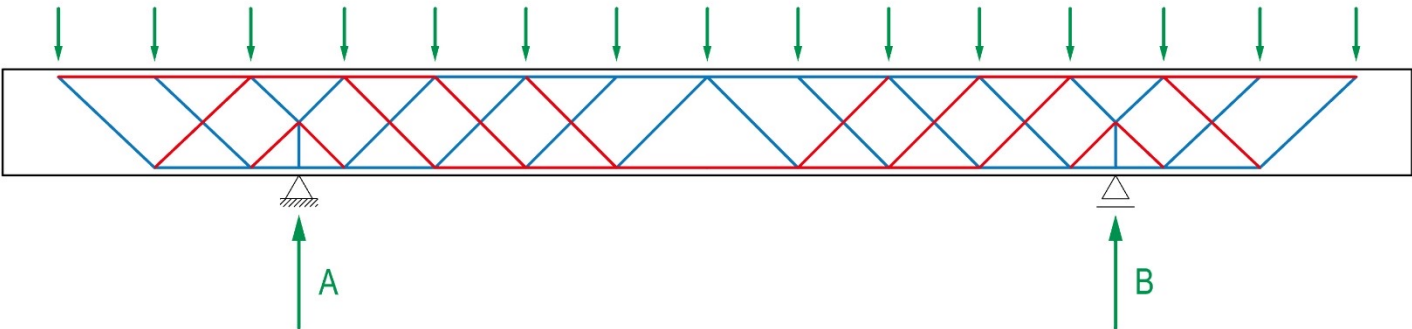




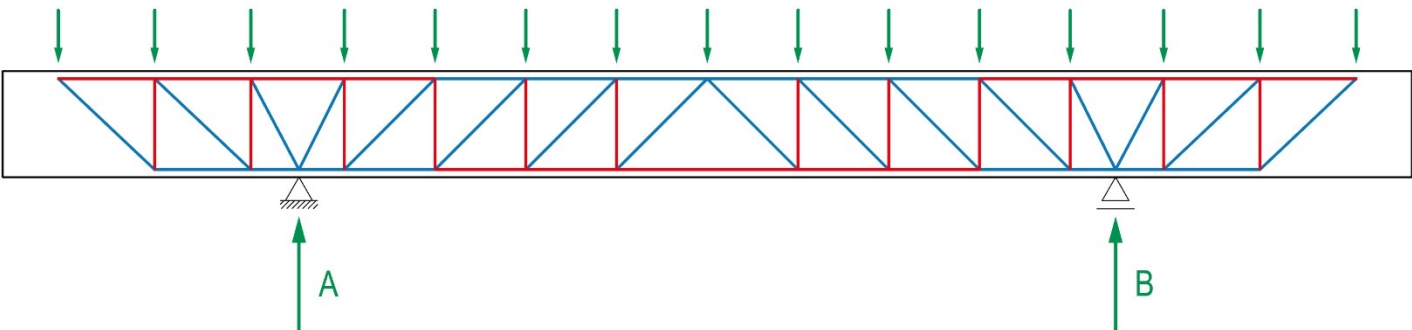


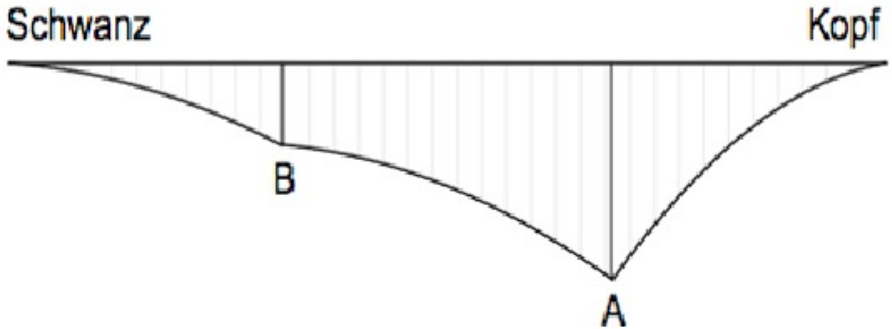
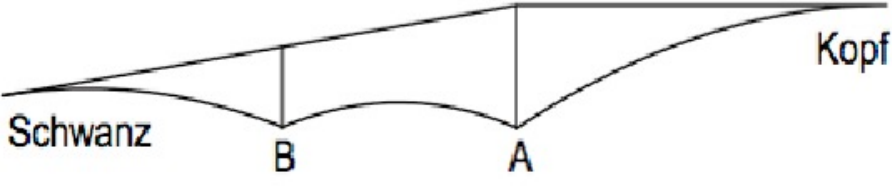
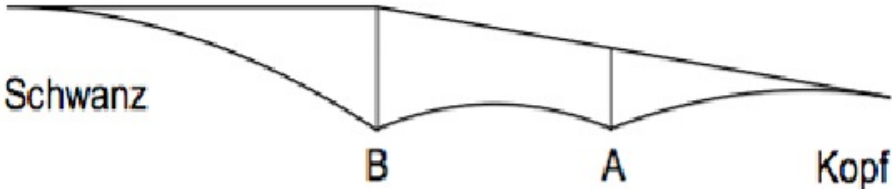
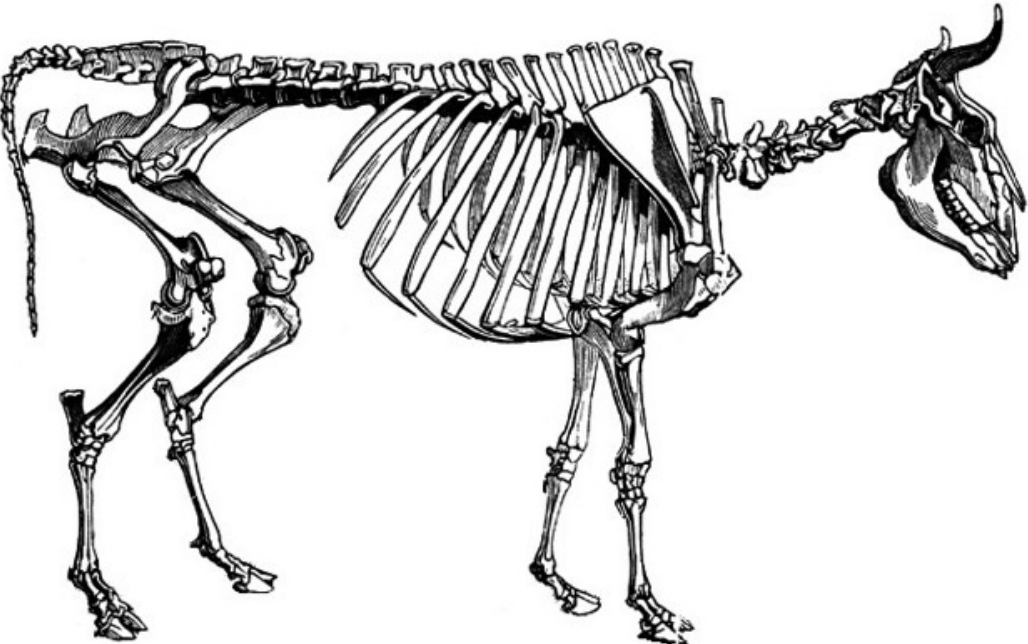
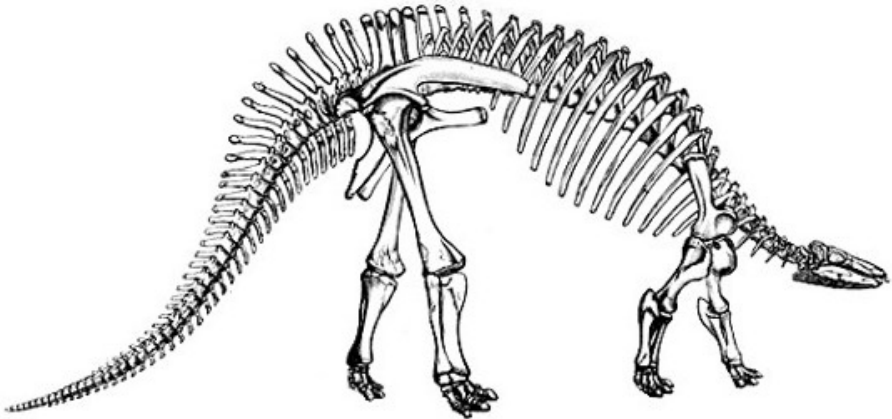


Stahl  
*Steel*

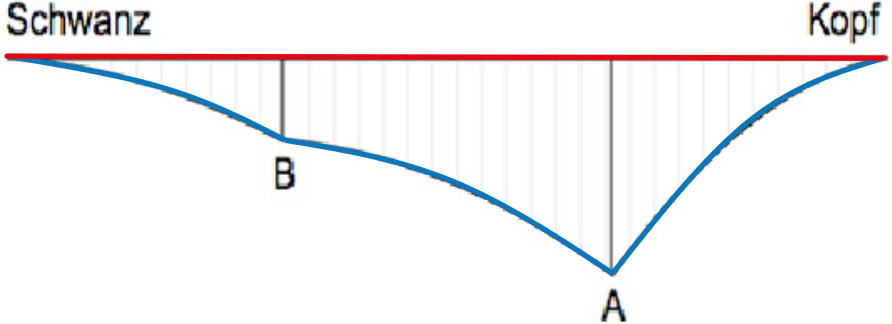
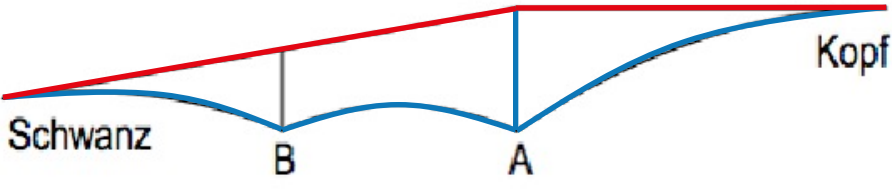
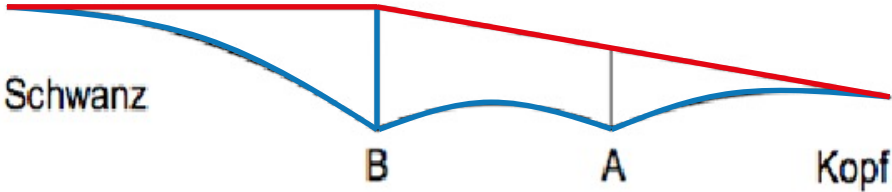
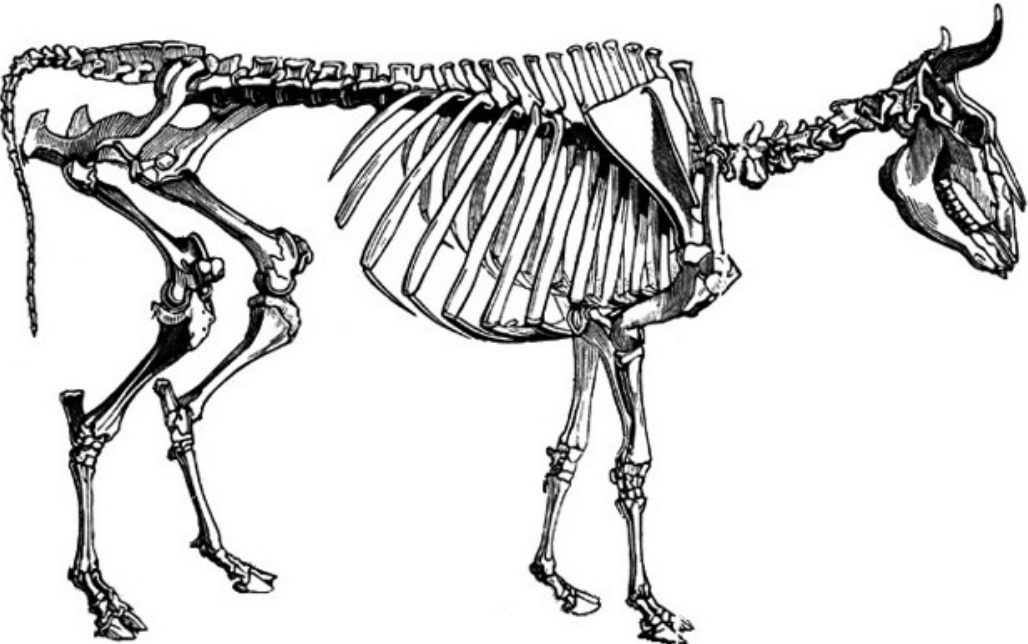
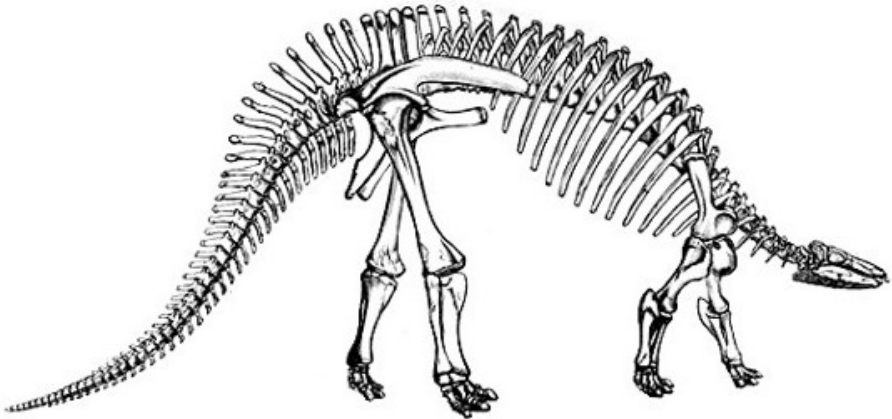


Stahlbeton  
*Reinforced concrete*



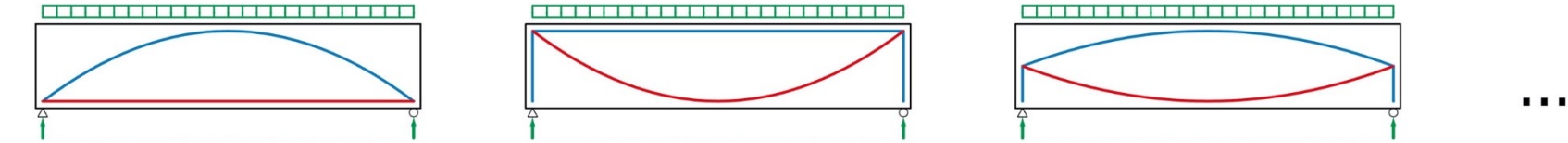


D'Arcy W. Thomson, „On growth and form“, 1917

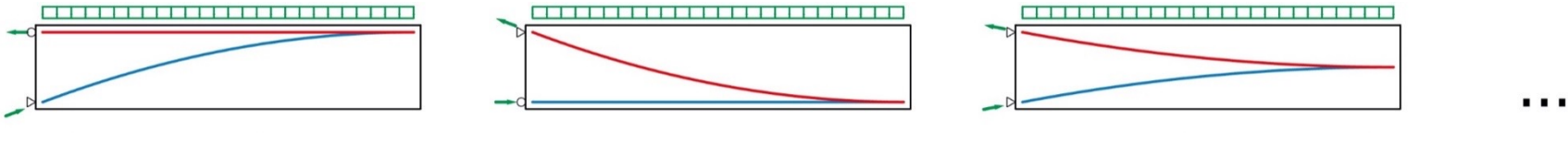


D'Arcy W. Thomson, „On growth and form“, 1917

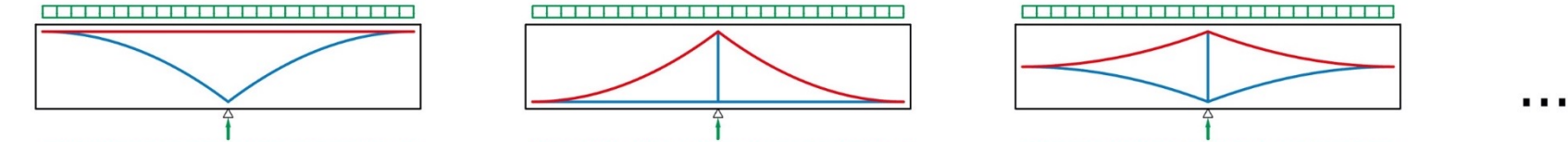
Überspannung



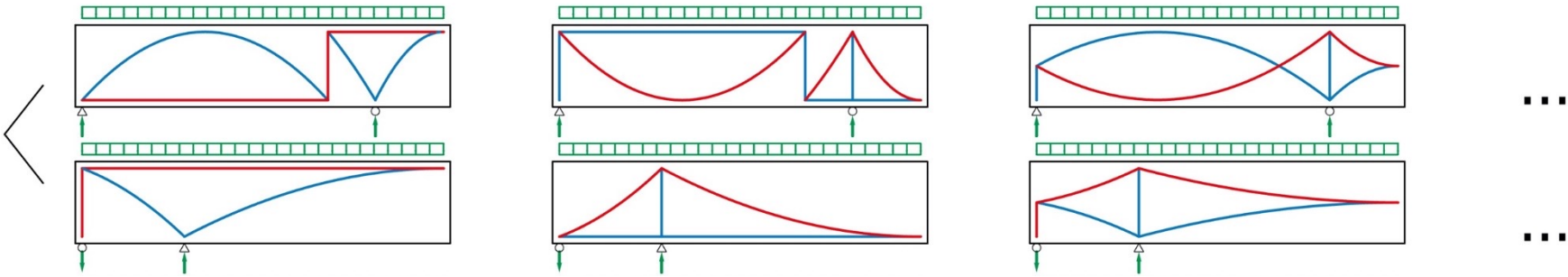
Auskragung



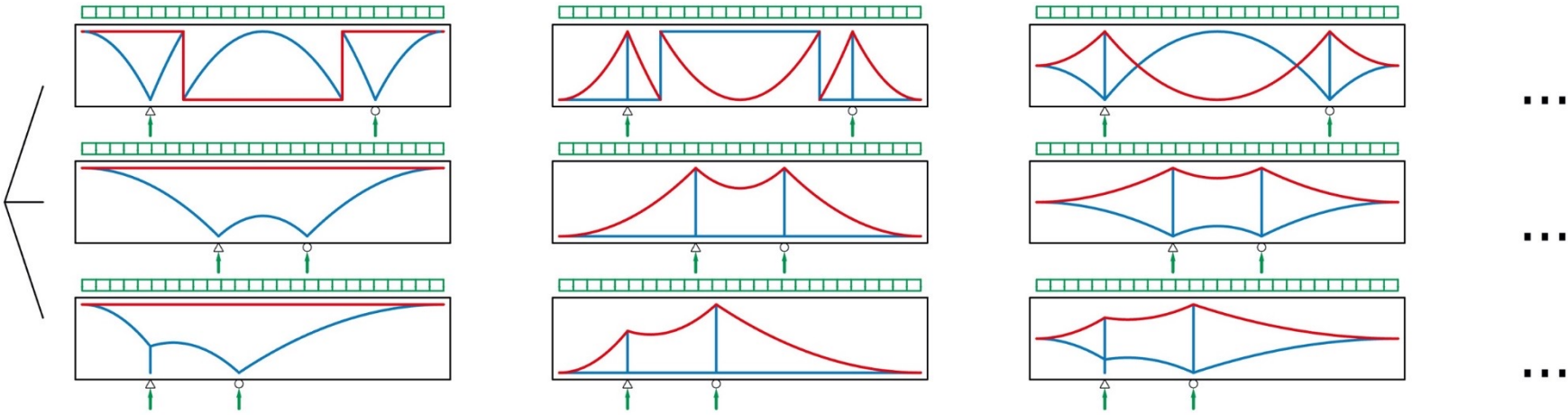
Zwei Auskragungen



Überspannung und Auskragung



Überspannung und zwei Auskragungen



# Balken

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*Analysis of beams*

Variation der Randbedingungen

*Variation of boundary conditions*

>>

Gerberträger

*Gerber's beam (hinged girder system)*

Durchlaufträger

*Continuous beam*

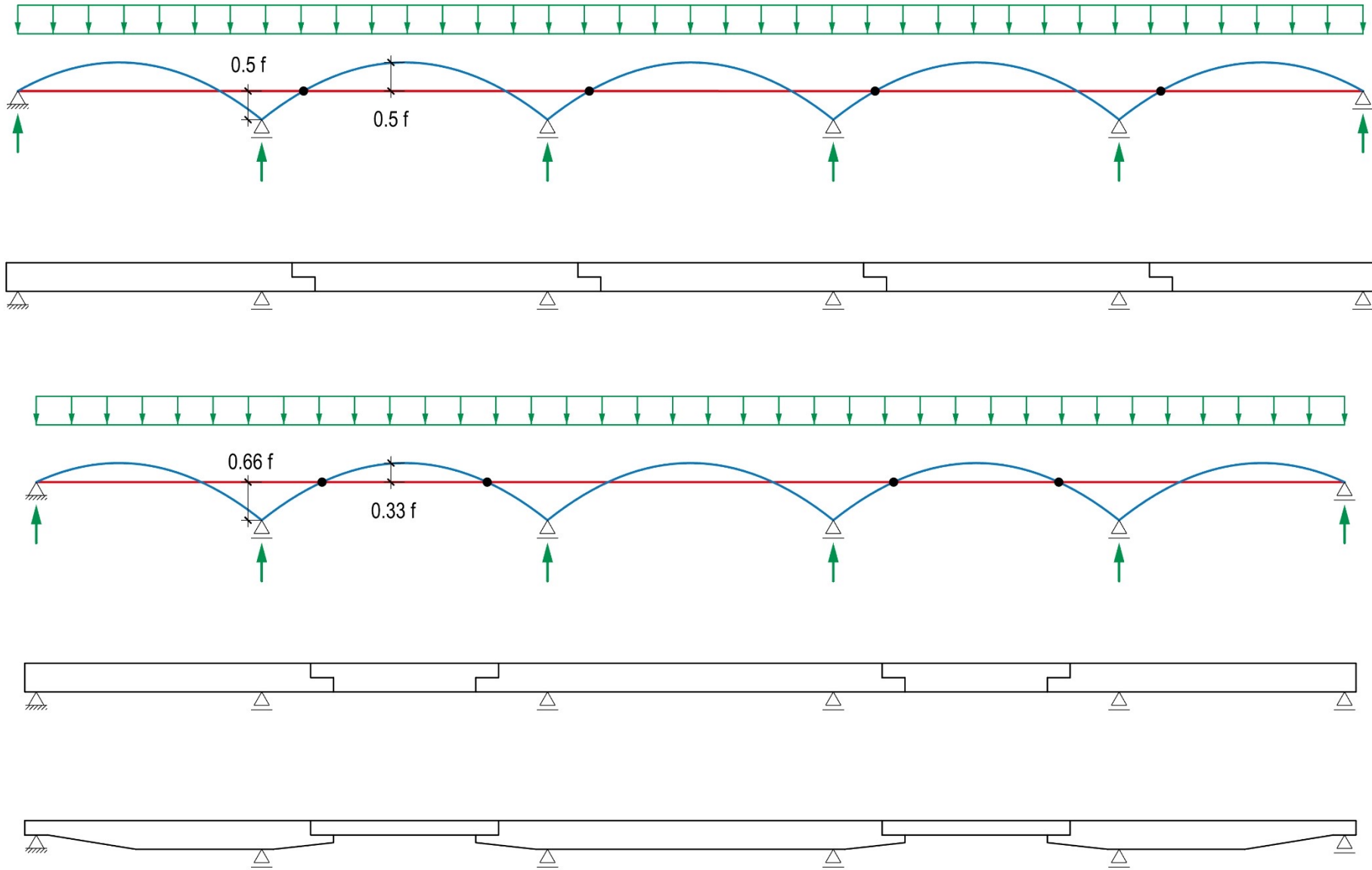
Schlankheit von Balken

*Slenderness of beams*

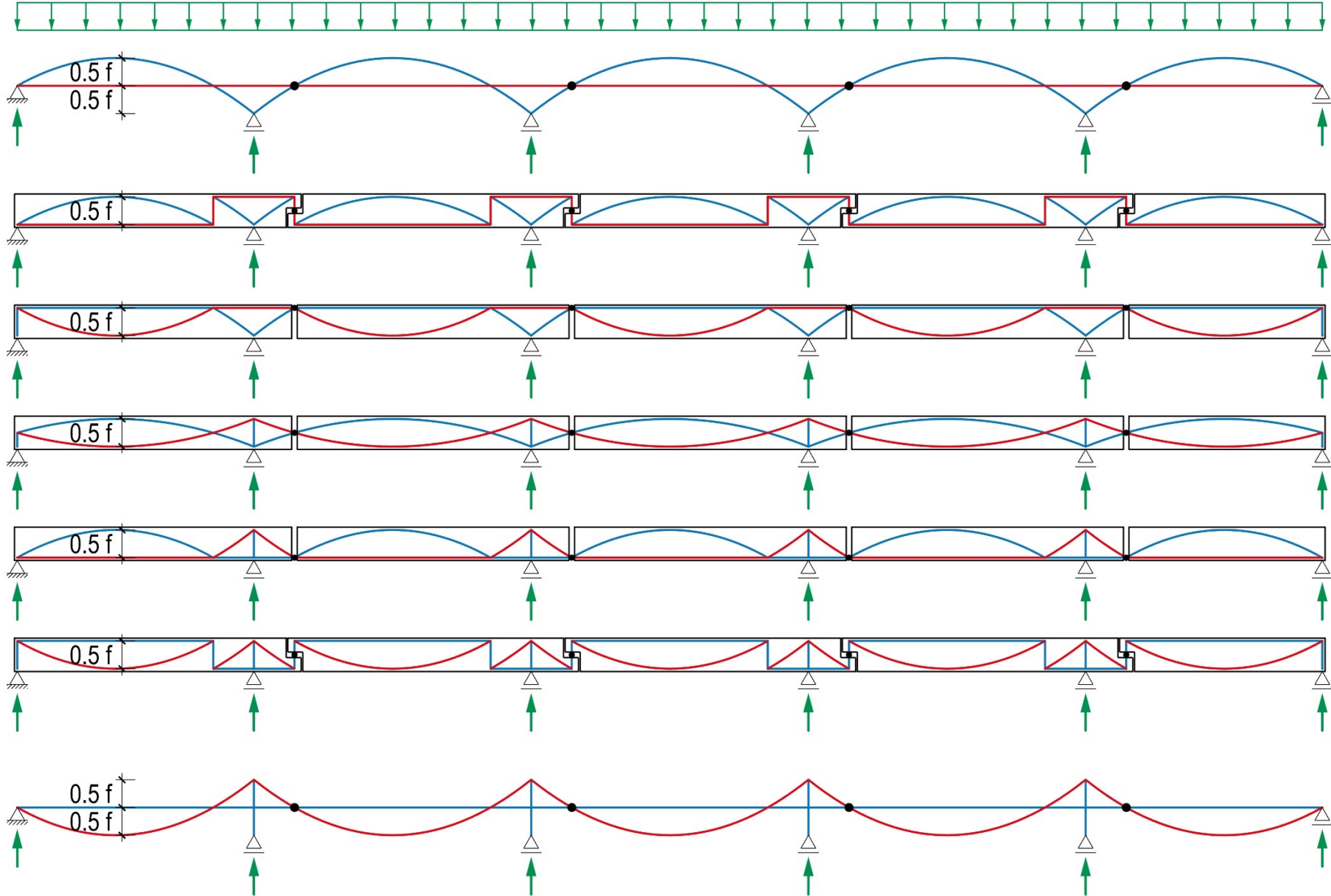
Scheiben

*Deep beams*

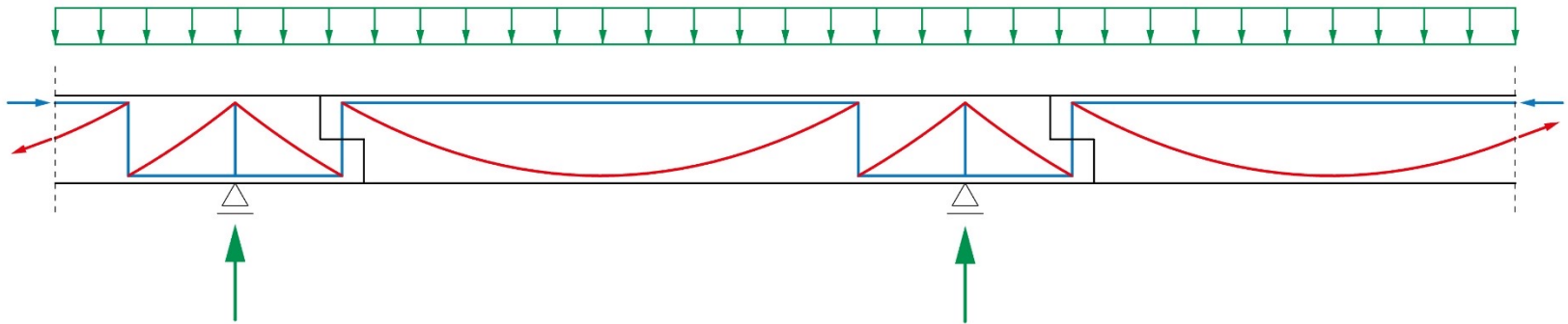
*Gerber's beam (hinged girder system)*



*Gerber's beam (hinged girder system)*

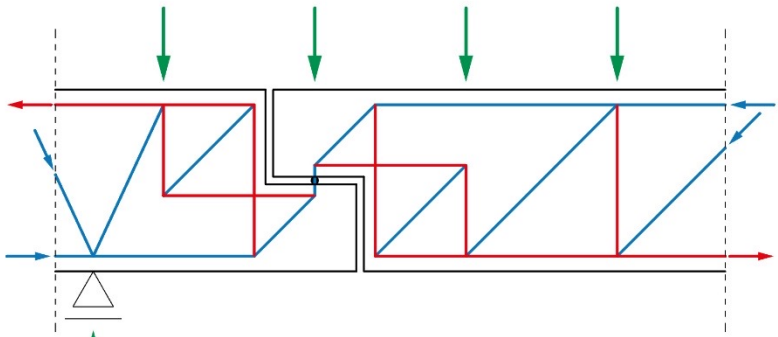


*Gerber's beam (hinged girder system)*



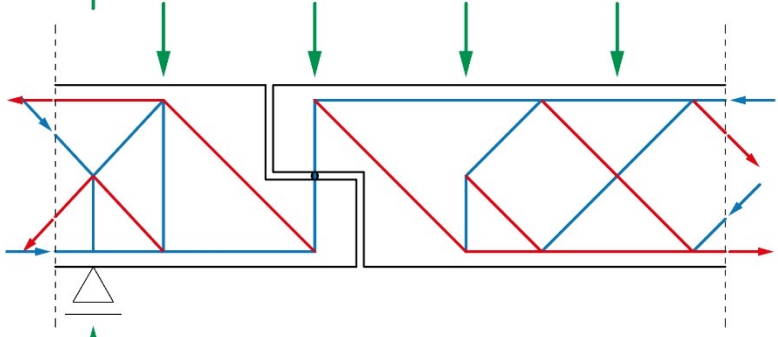
Stahlbeton

*Reinforced concrete*



Stahl

*Steel*





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>>

Durchlaufträger

*Continuous beam*

Schlankheit von Balken

*Slenderness of beams*

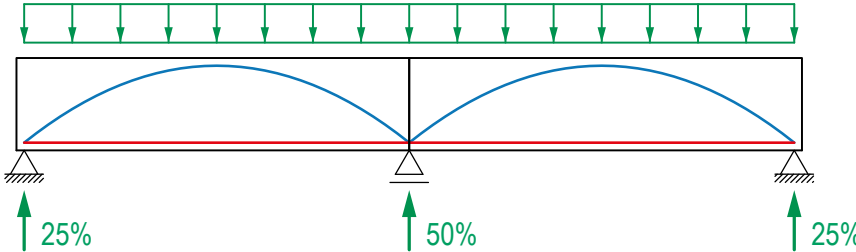
Scheiben

*Deep beams*

*Continuous beam*

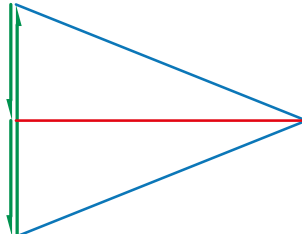
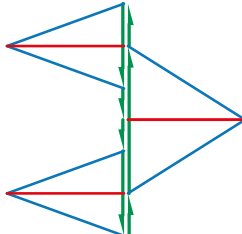
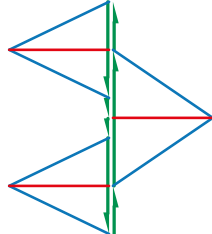
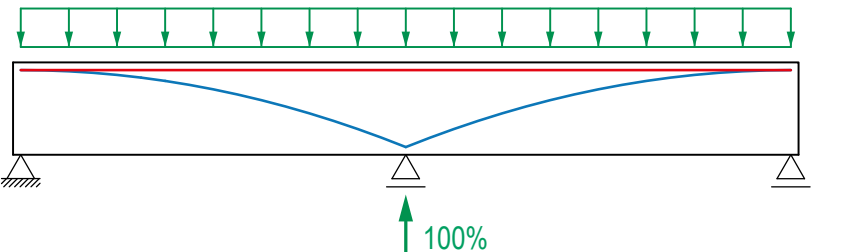
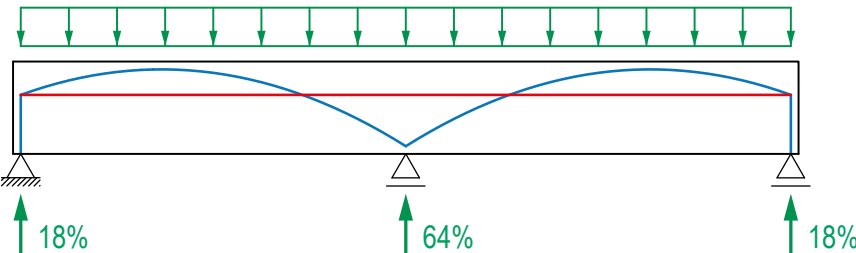
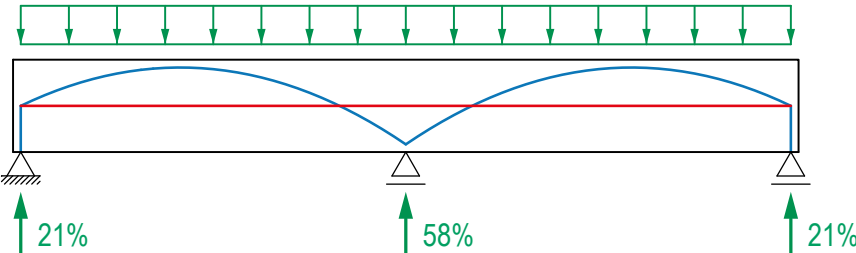
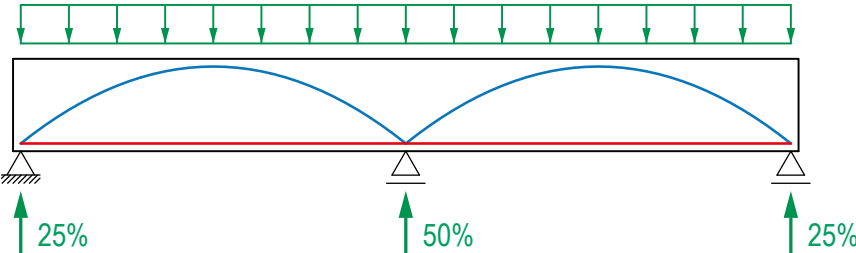
Einfach gelagerter Balken

*Simply supported beam*

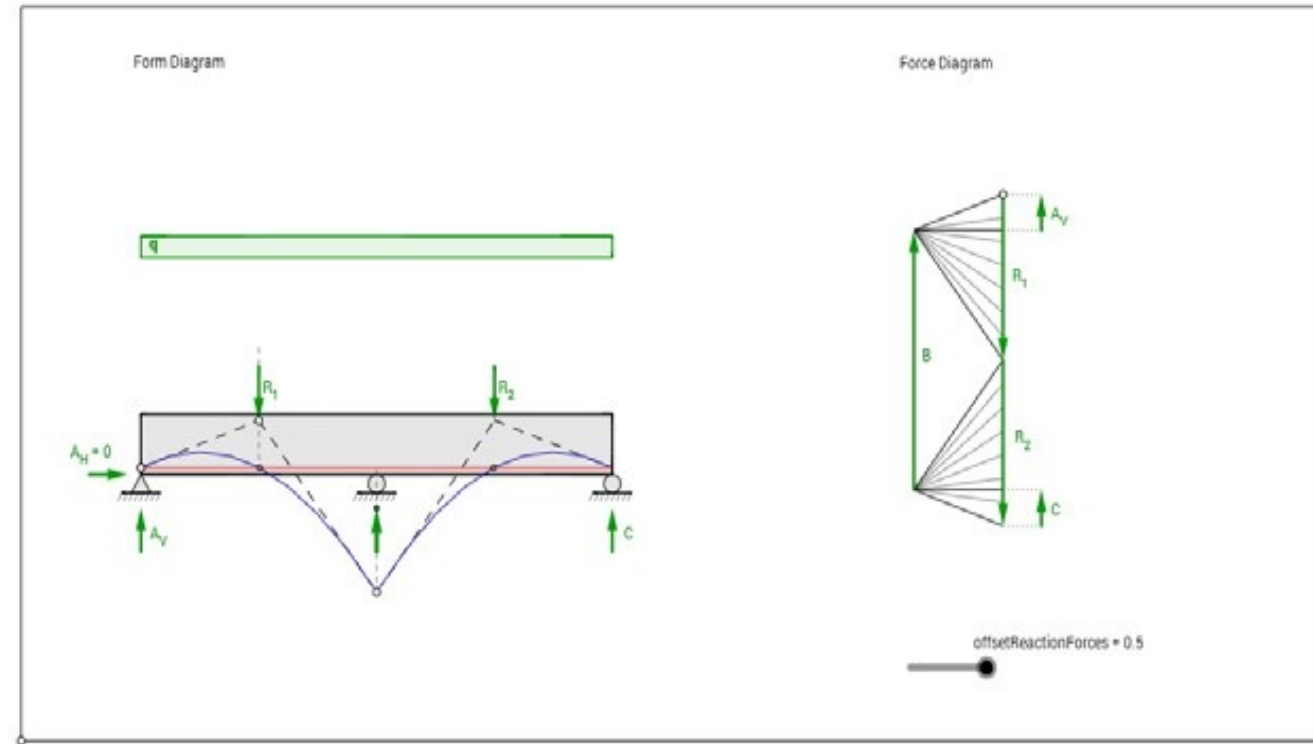


Durchlaufträger

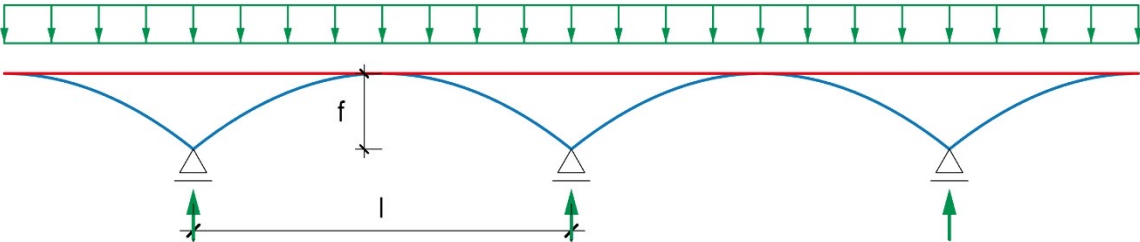
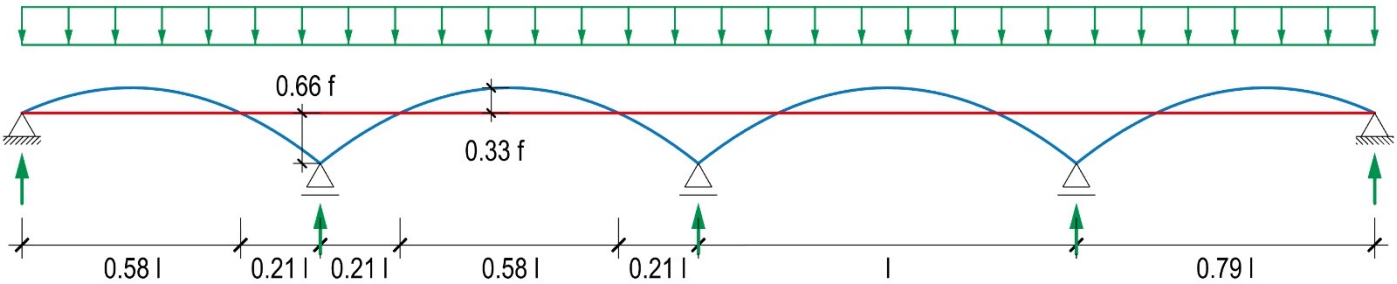
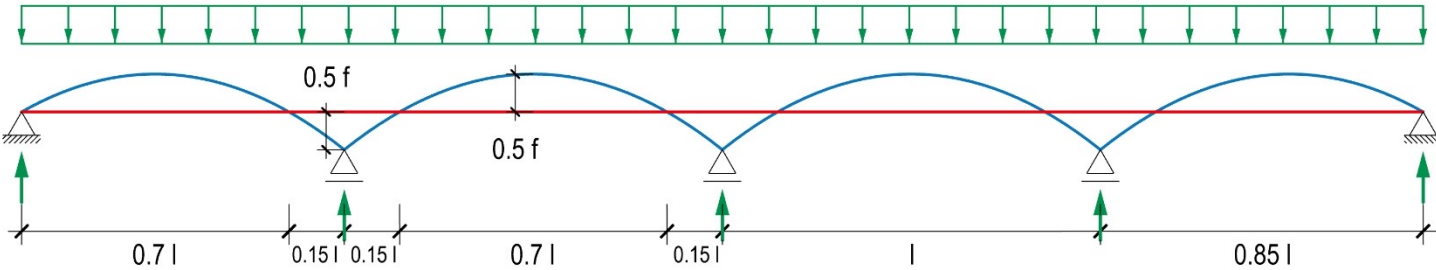
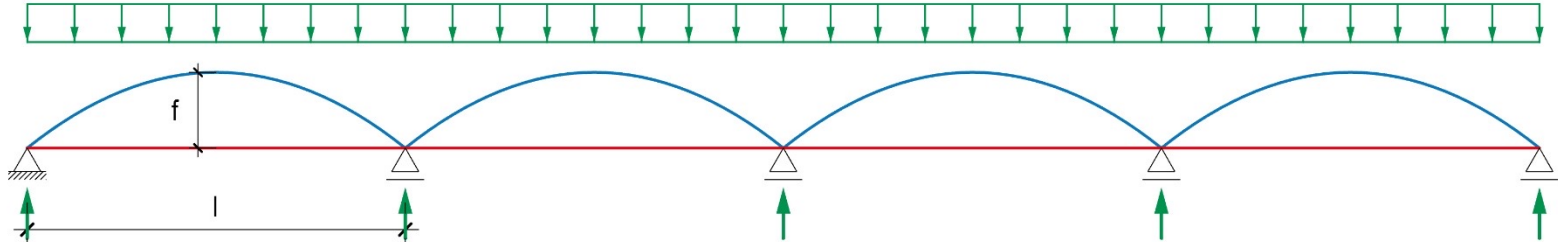
*Continuous beam*



eQ: continuous beam

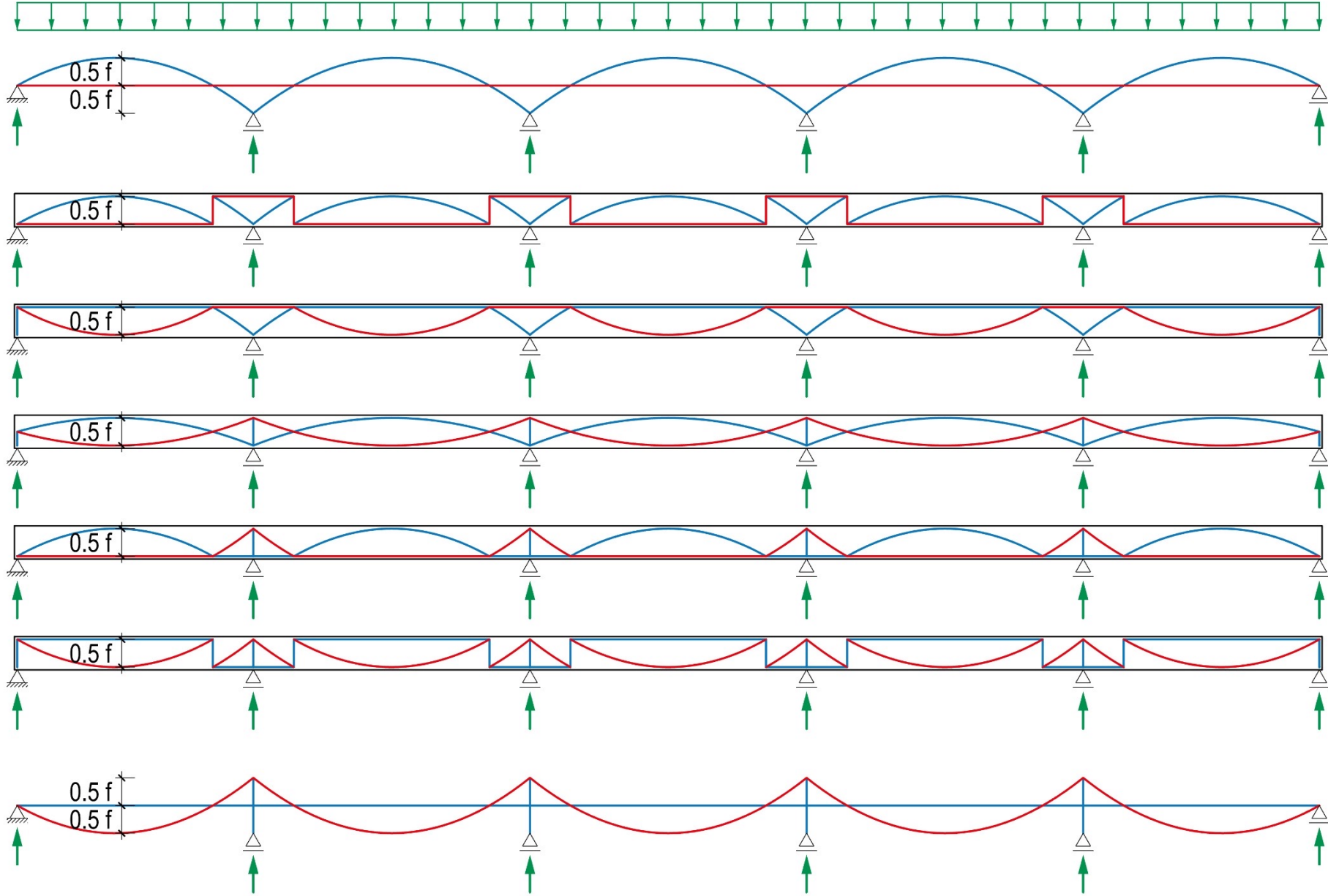


<http://www.block.arch.ethz.ch/eq/drawing/view/40>





Arnold Bürkli: Quaibrücke, Zürich, 1884





Hochmoselbrücke Rheinland-Pfalz, 2019

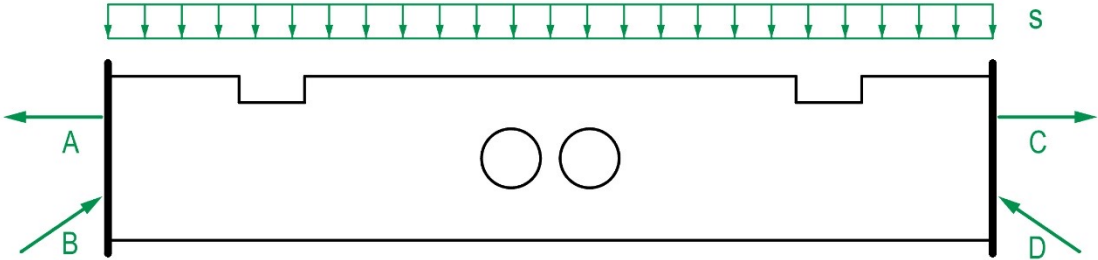
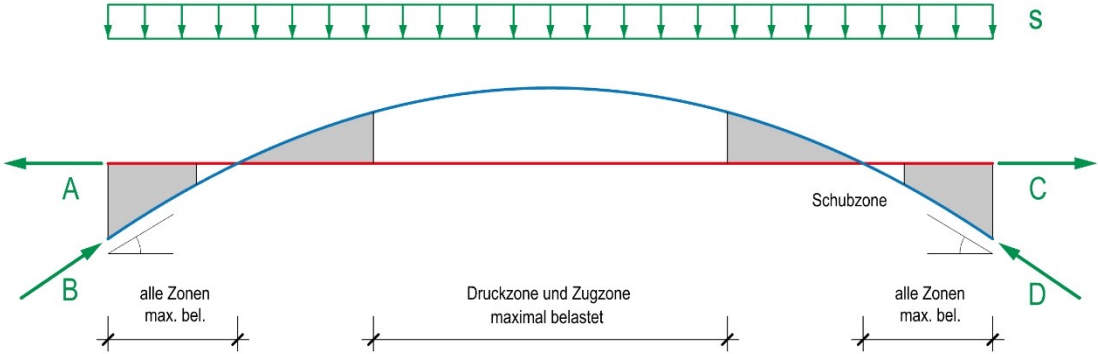


Felsenaubrücke Bern, C. Menn, 1975





Carré d'Art Museum, Nîmes, Arch.: N. Foster, , Ing.: Ove Arup & OTH Méditerranée, 1993



# Balken

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*Gerber's beam (hinged girder system)*

Durchlaufträger

*Continuous beam*

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Schlankheit von Balken

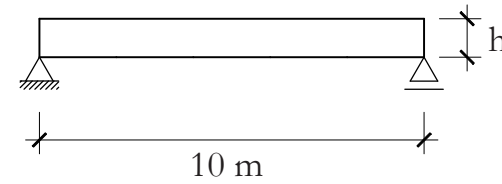
*Slenderness of beams*

Scheiben

*Deep beams*

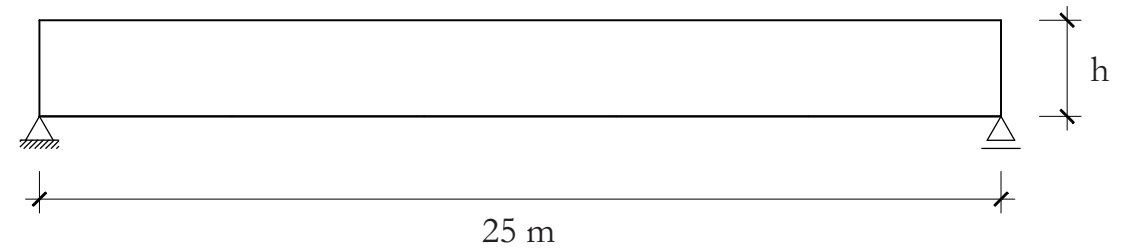
Material	Tragwerk	wirtschaftliche Schlankheit $l/h$ für einfache Balken *
Stahl	Vierendeelträger	7 – 10
	Fachwerkträger	10 - 15
	Raumfachwerk	12 - 18
	Balken	15 - 20
Stahlbeton	Balken	12 – 18
	Platten	20 – 25
Spannbeton	Balken	18 – 25
	Platten	28 – 35
Holz	Balken	15 - 20

\* Bei Konsolen entspricht  $l$  der zweifachen Spannweite der Konsole, bei Balken mit Konsolen bzw. Durchlaufträgern entspricht  $l$  dem Abstand der beiden zwischen den Auflagern liegenden Gelenken.



$$h = 10 \text{ m} / 15 = 0.66 \text{ m}$$

$$h = 10 \text{ m} / 20 = 0.5 \text{ m}$$



$$h = 25 \text{ m} / 15 = 1.66 \text{ m}$$

$$h = 25 \text{ m} / 20 = 1.25 \text{ m}$$



Haus Krönleinstrasse, Christian Kerez & Joseph Schwartz, Zürich, 2013

# Balken

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Durchlaufträger

*Continuous beam*

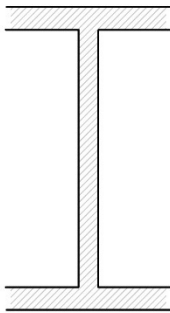
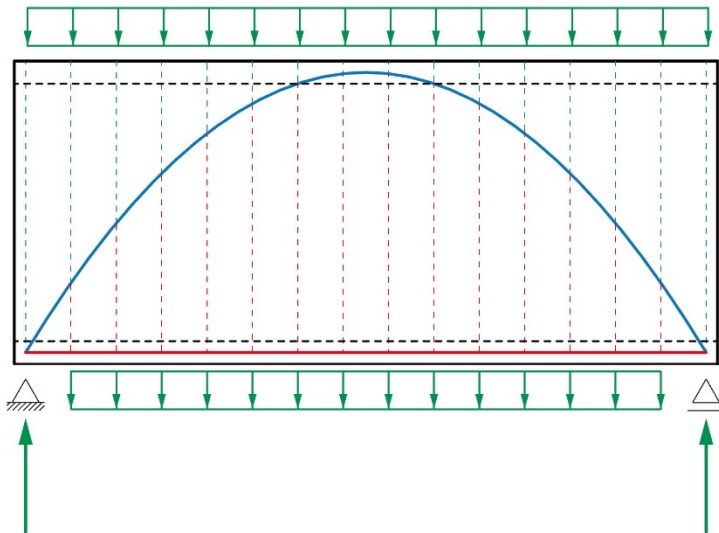
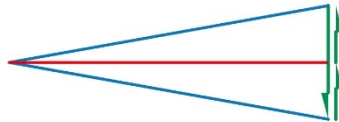
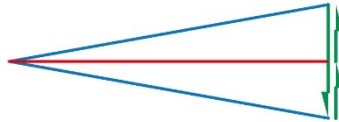
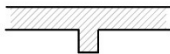
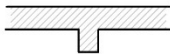
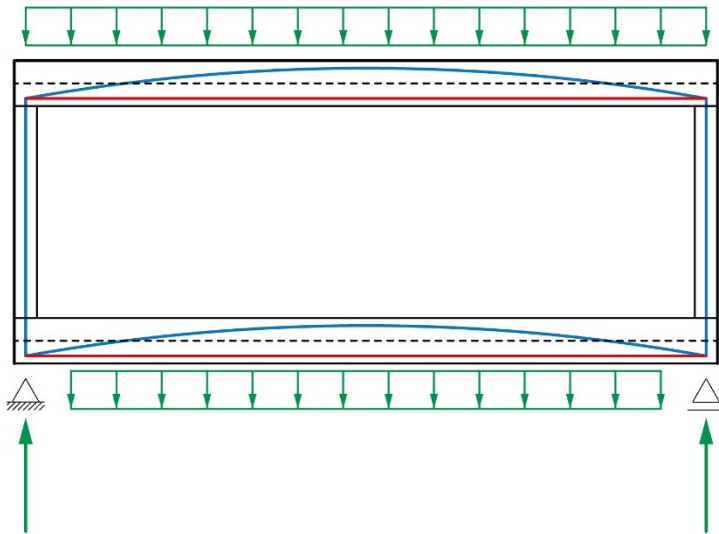
Schlankheit von Balken

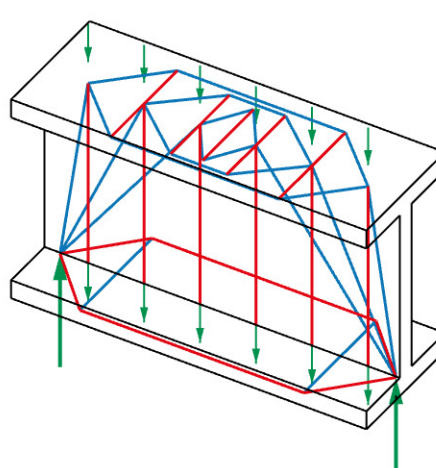
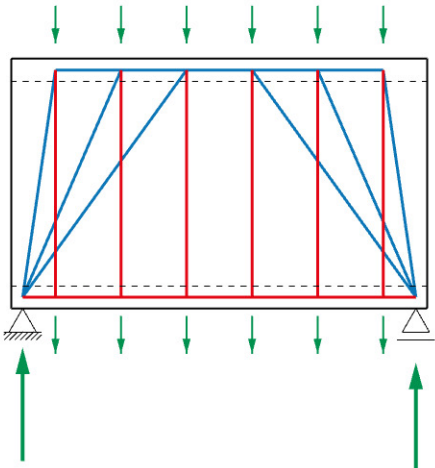
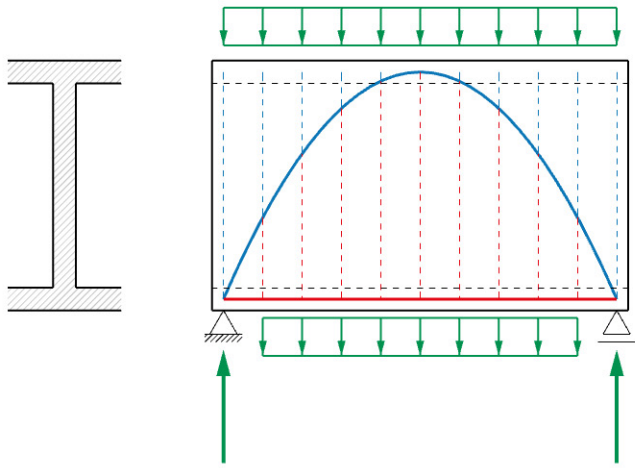
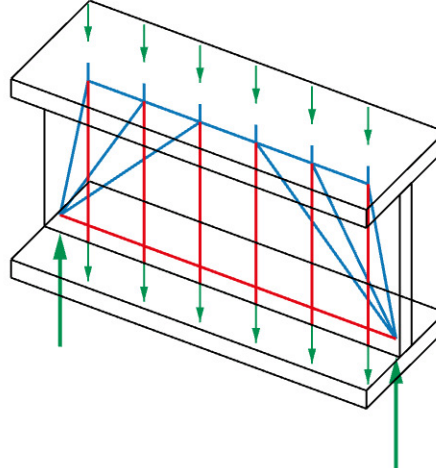
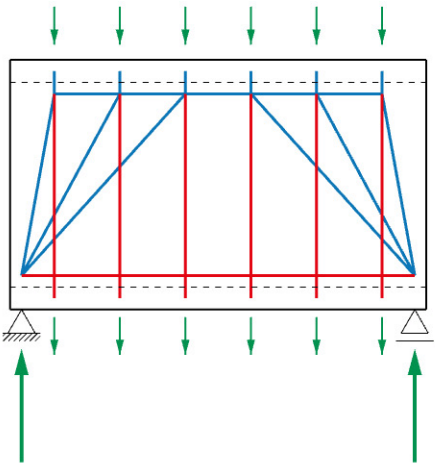
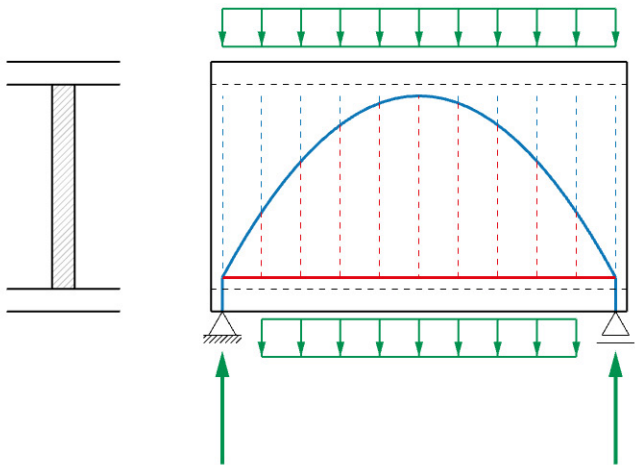
*Slenderness of beams*

>>

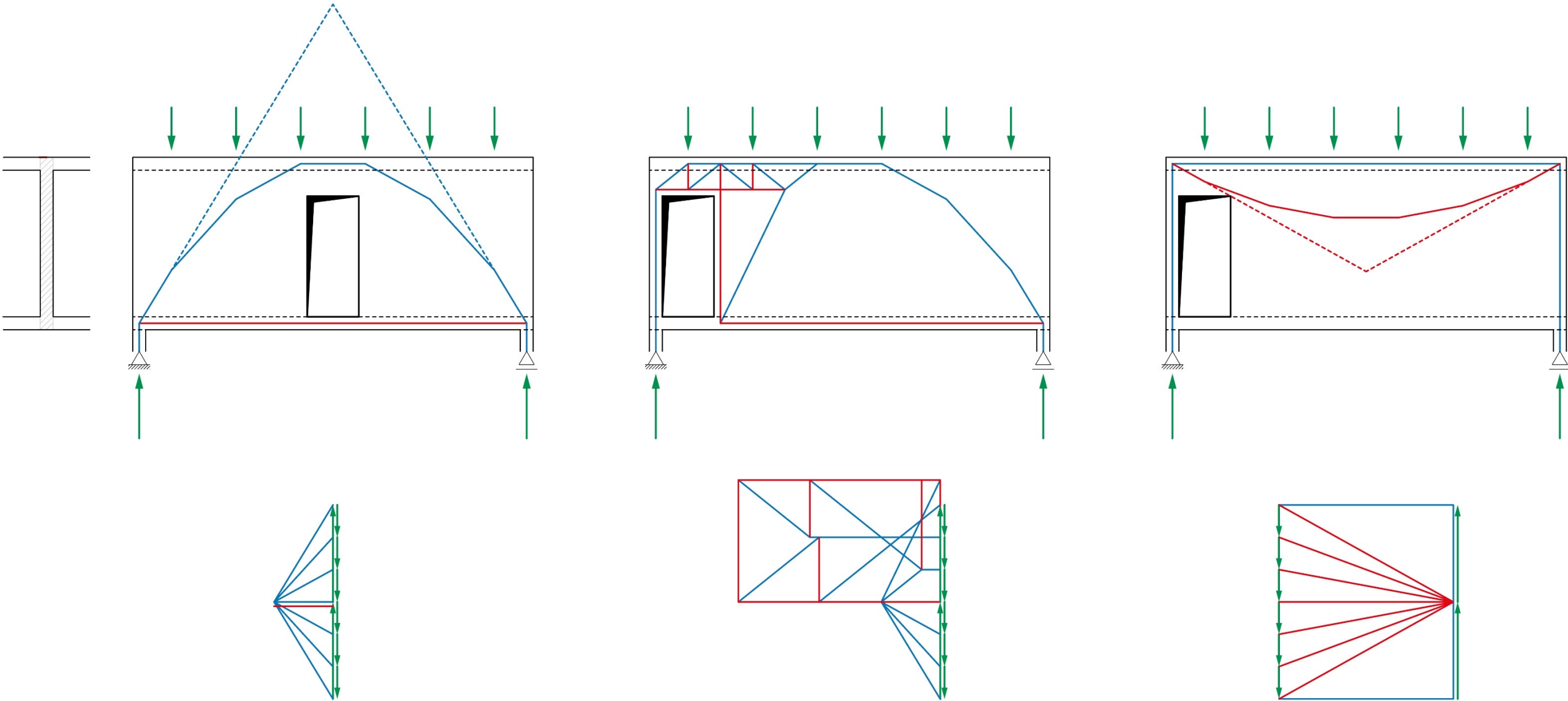
Scheiben

*Deep beams*



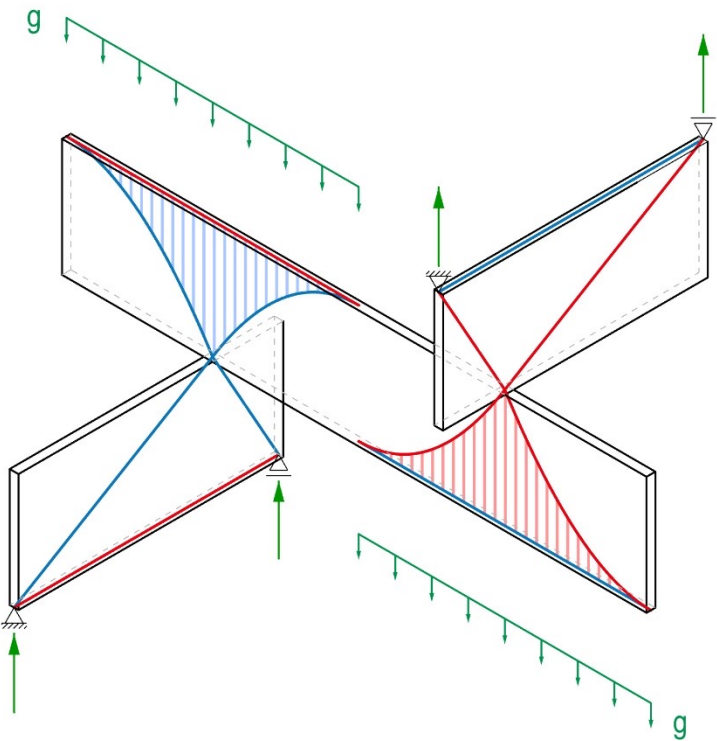
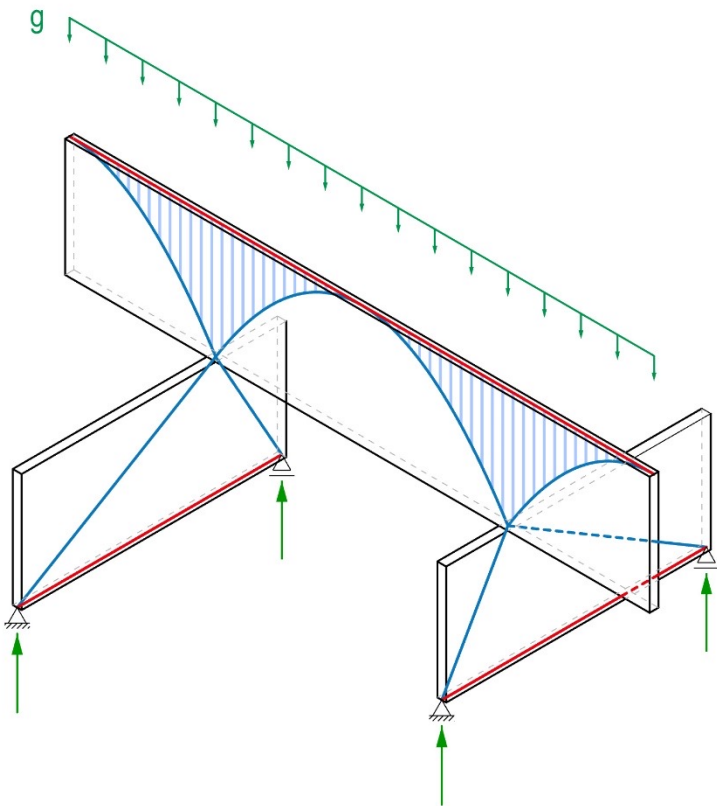


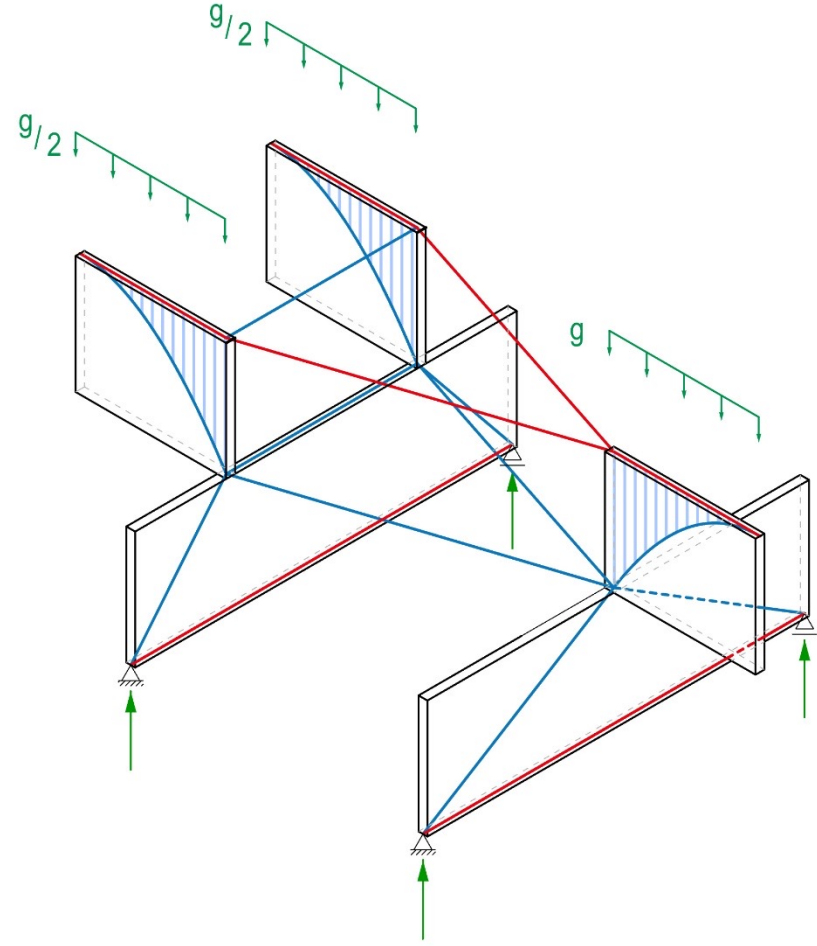
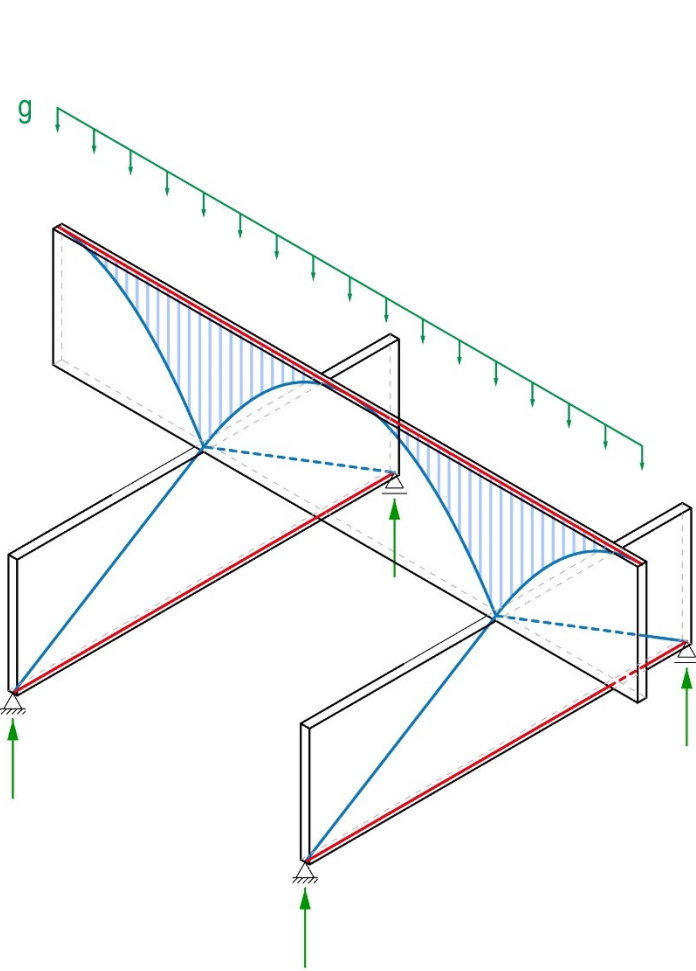


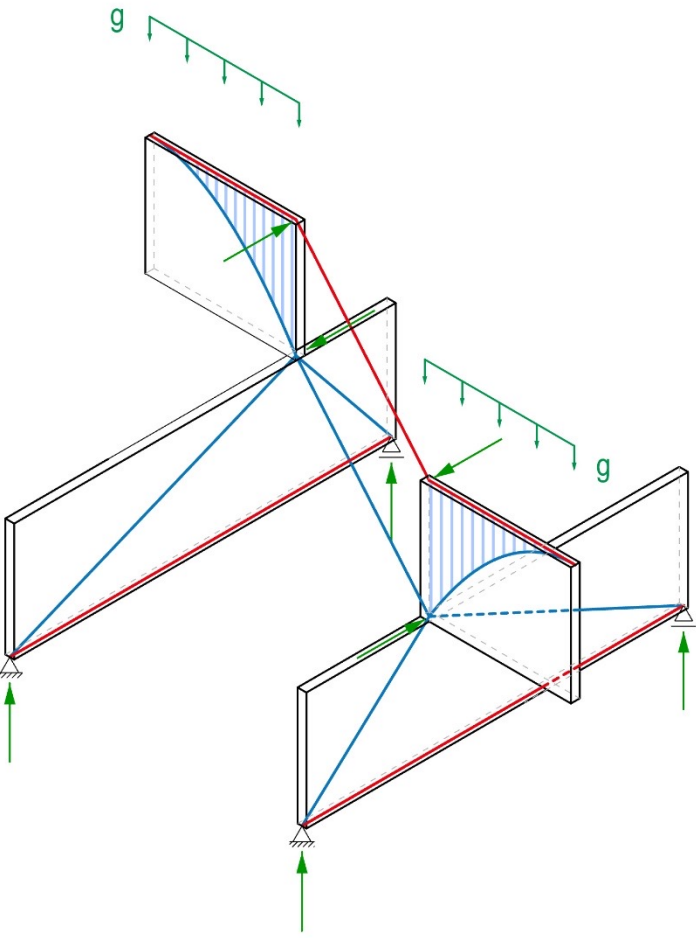
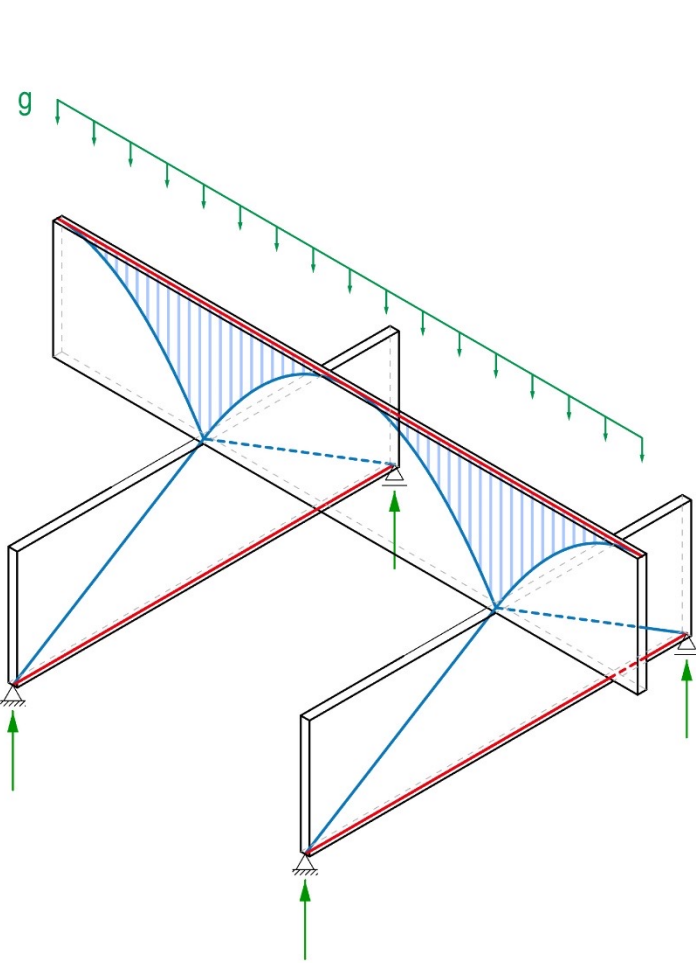




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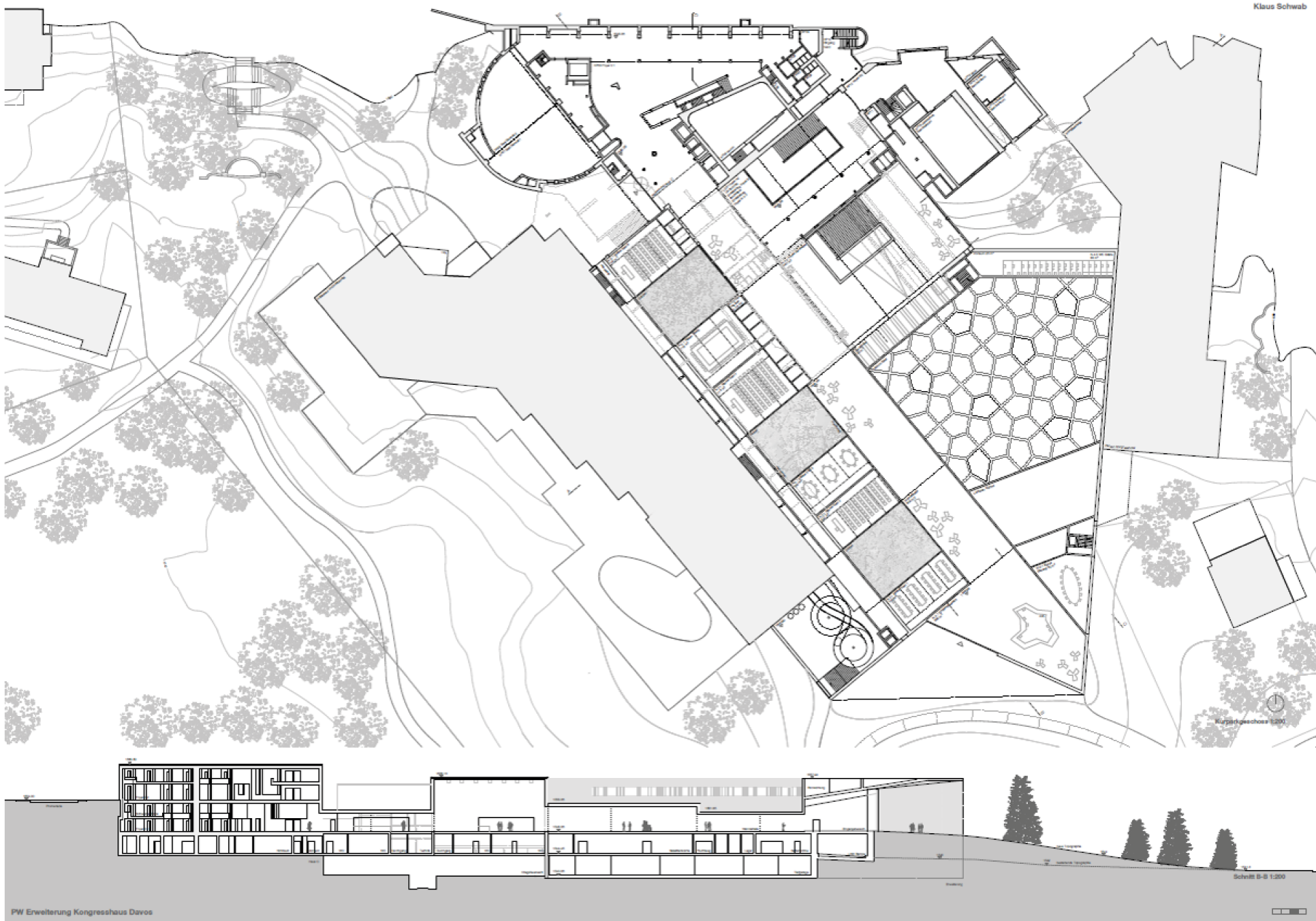




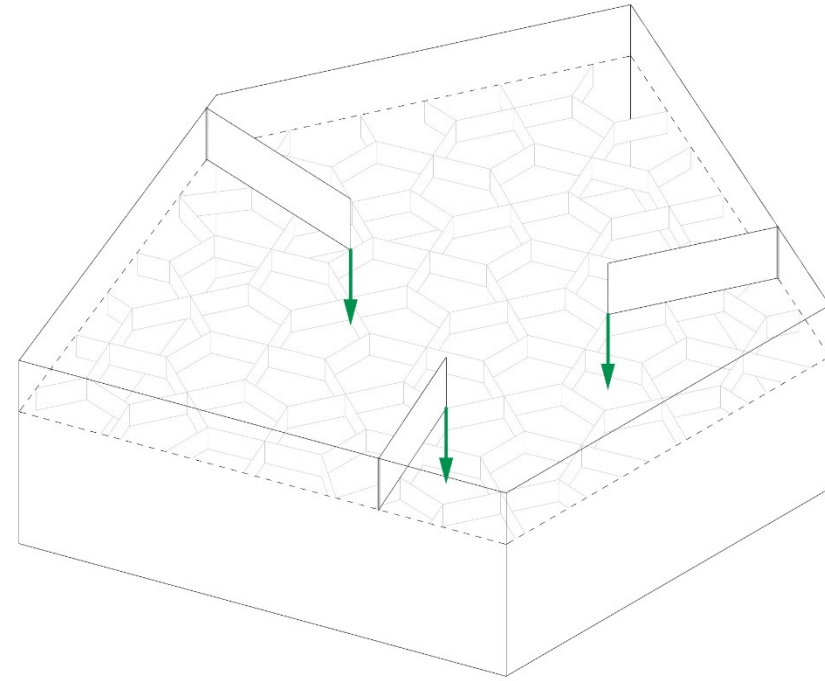
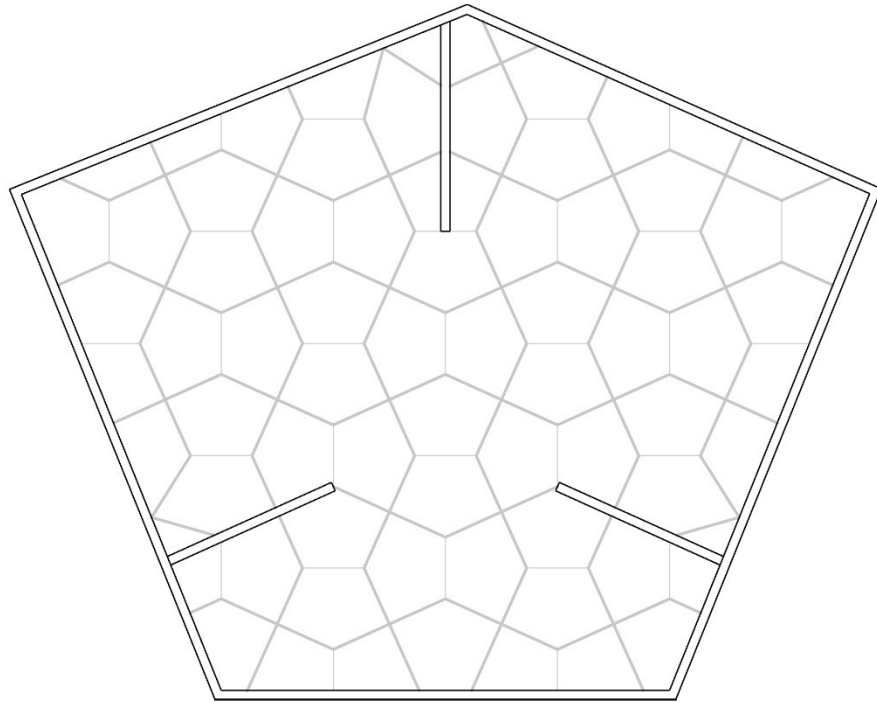




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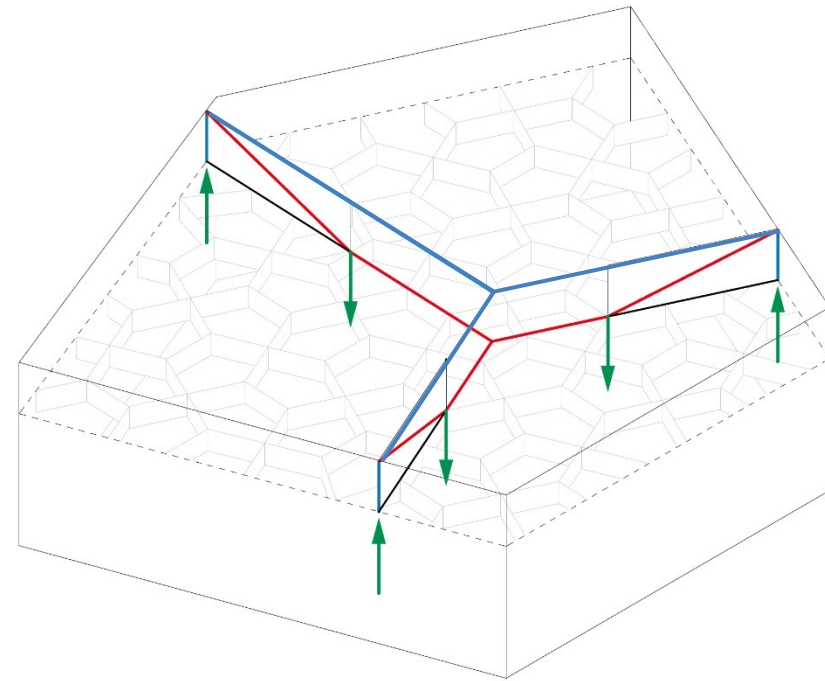
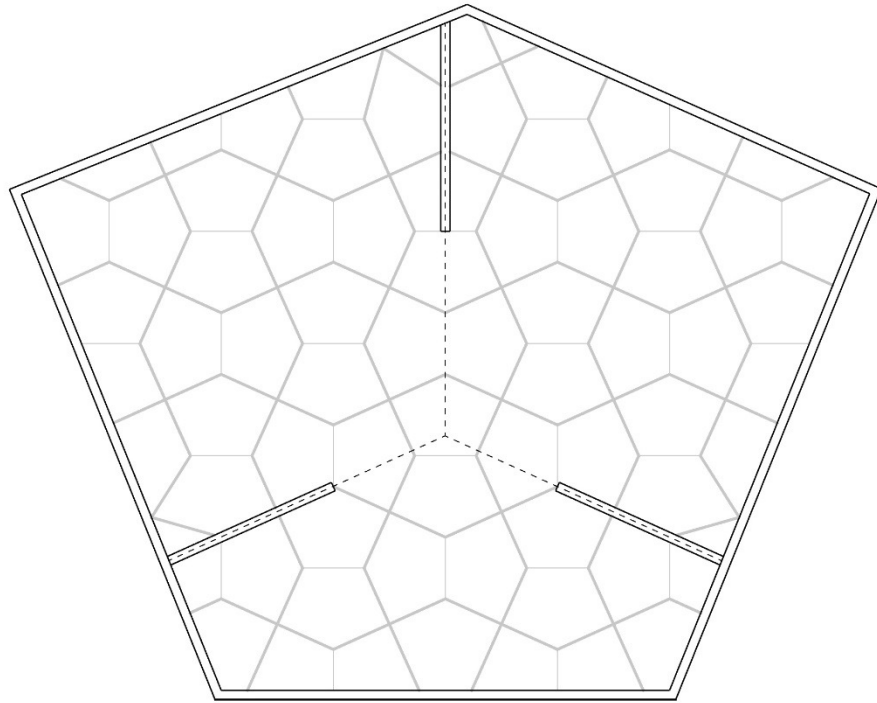


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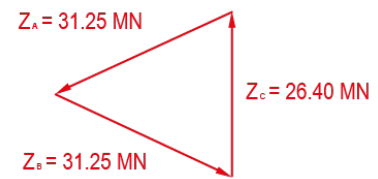
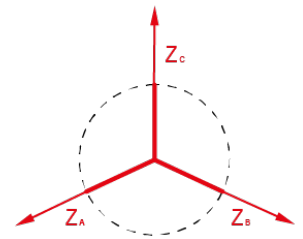
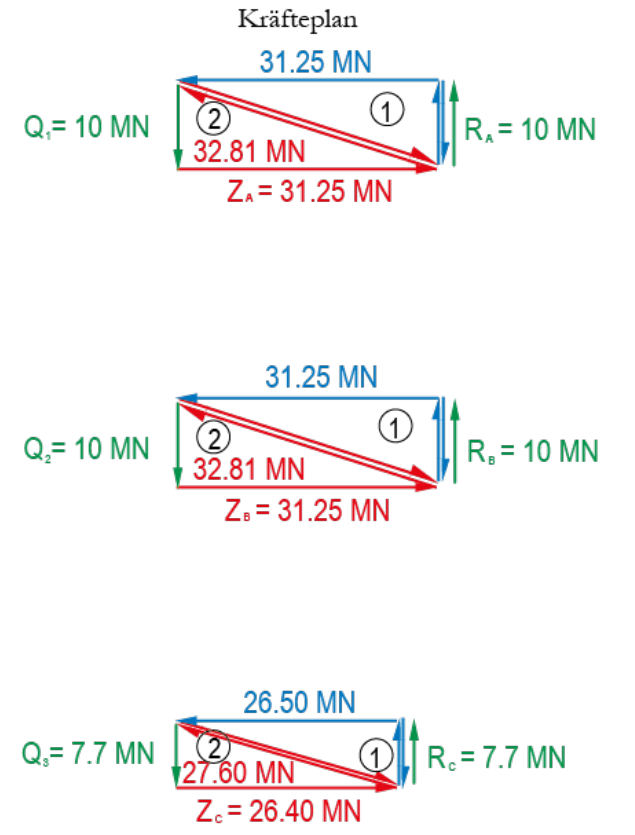
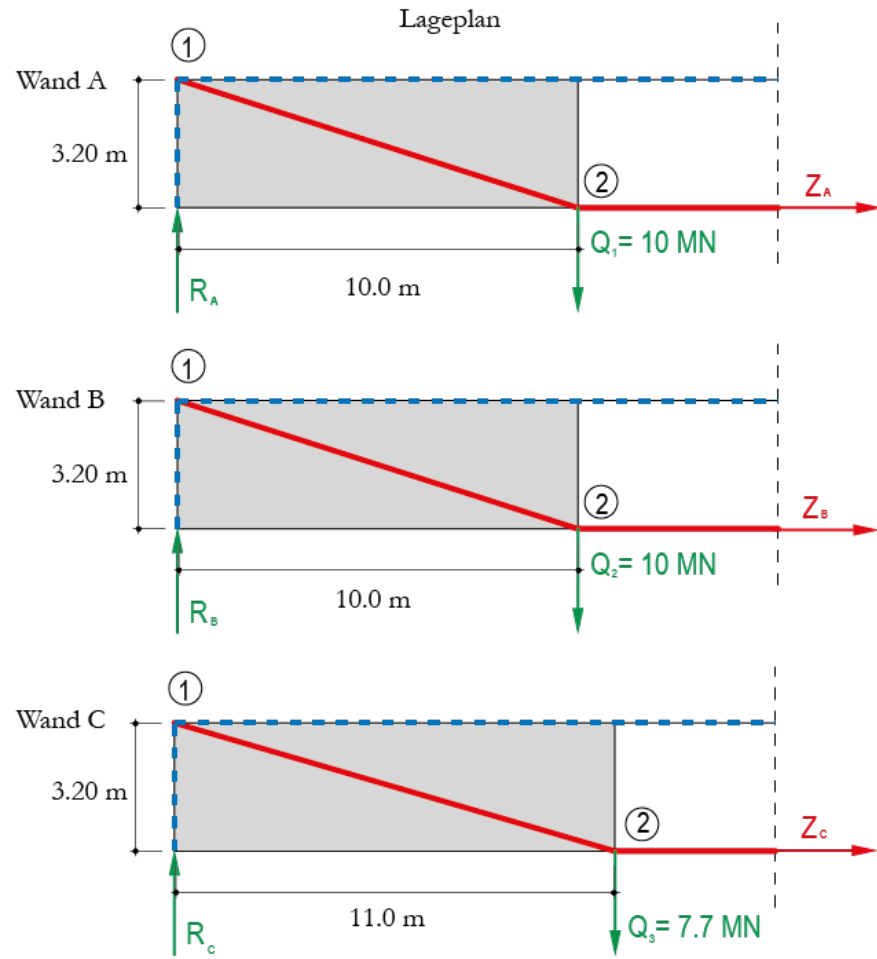
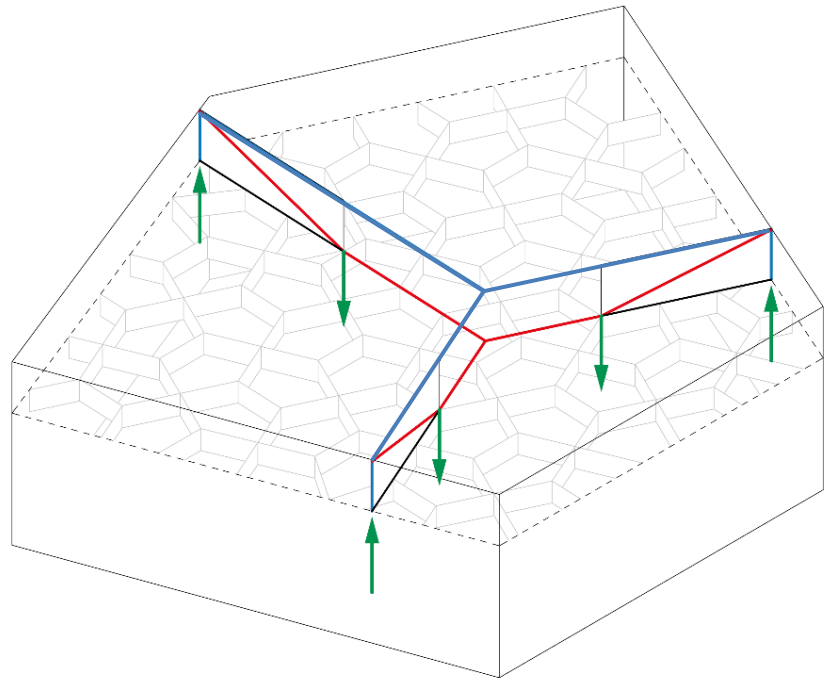


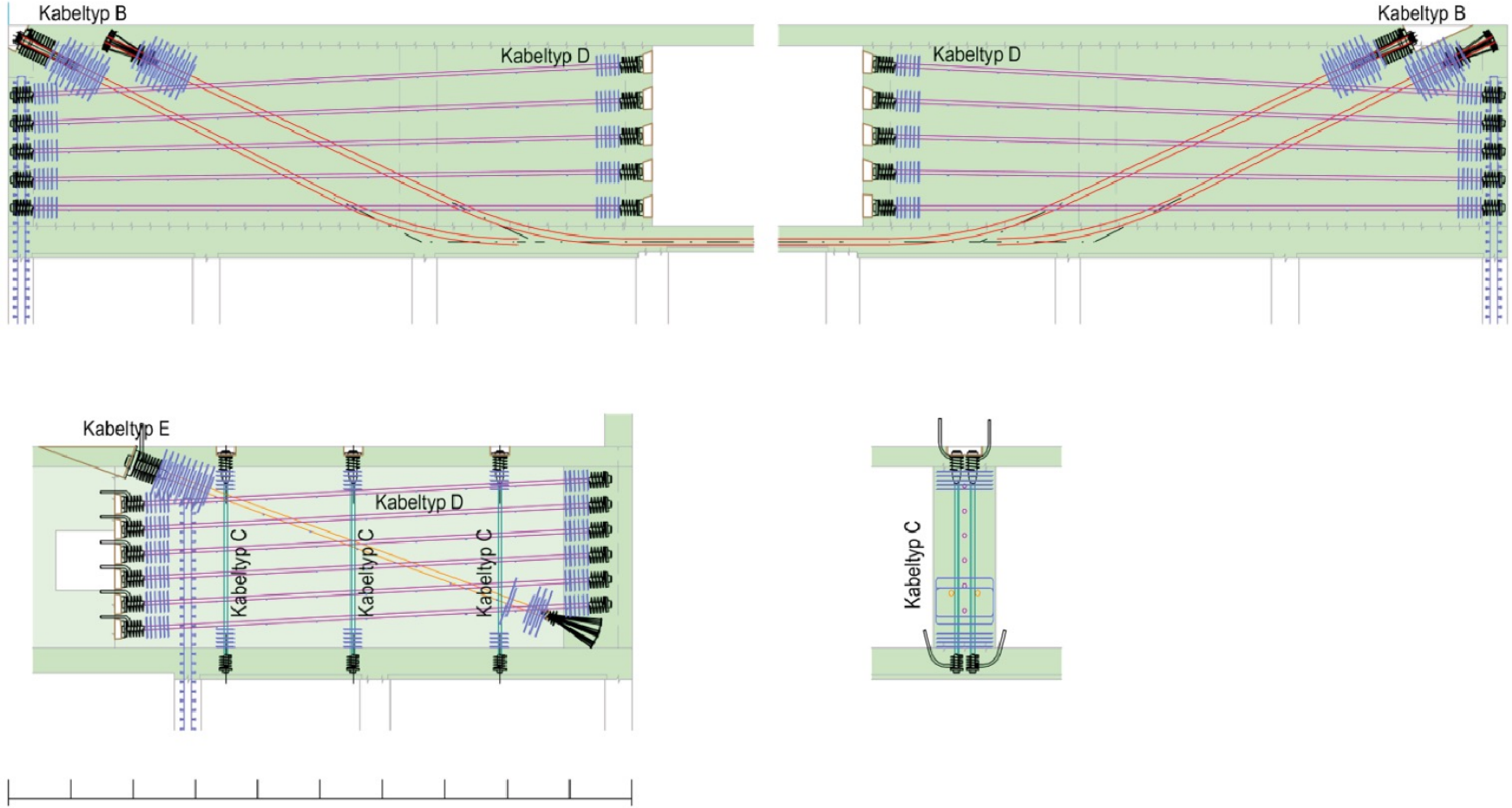
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