

CIVE 546: Structural Design Optimization

Week 9 Graphical Statics and Form-Finding

Instructor:

Prof. Yi Shao

Fall 2024

Form Finding

How to determine the structural form/topology?

By intuition, which one is the right form and why?

(a)



(b)



(c)

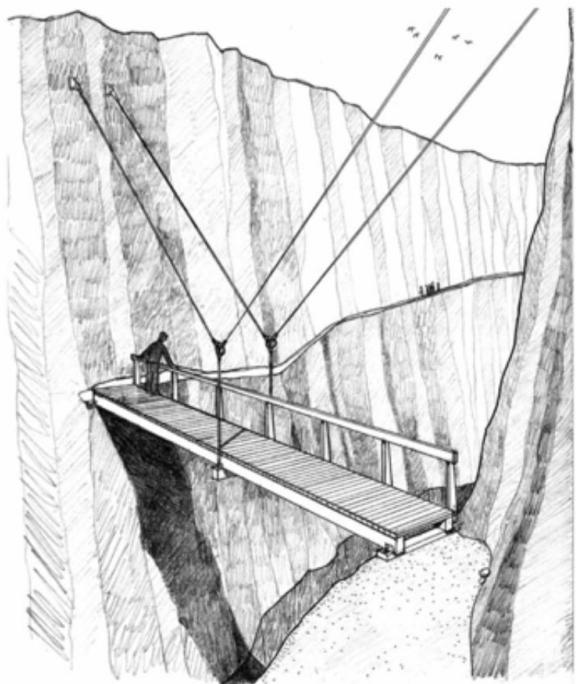


(d)

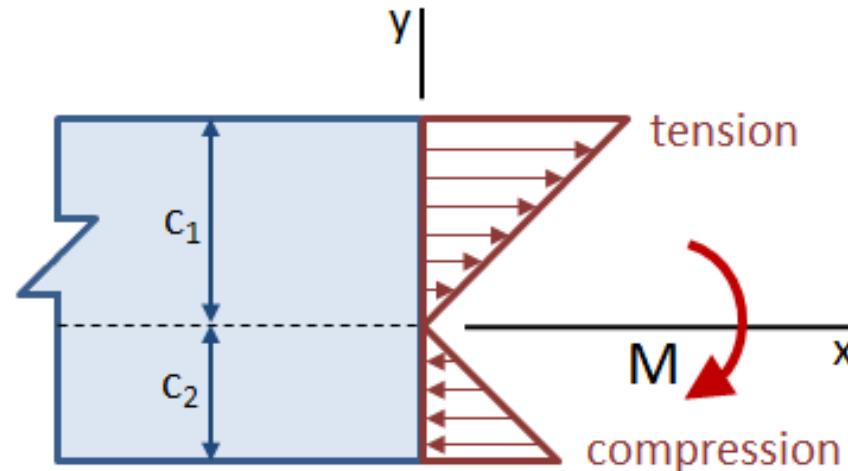


Form Finding

Funicular Structures: pure tension and compression members



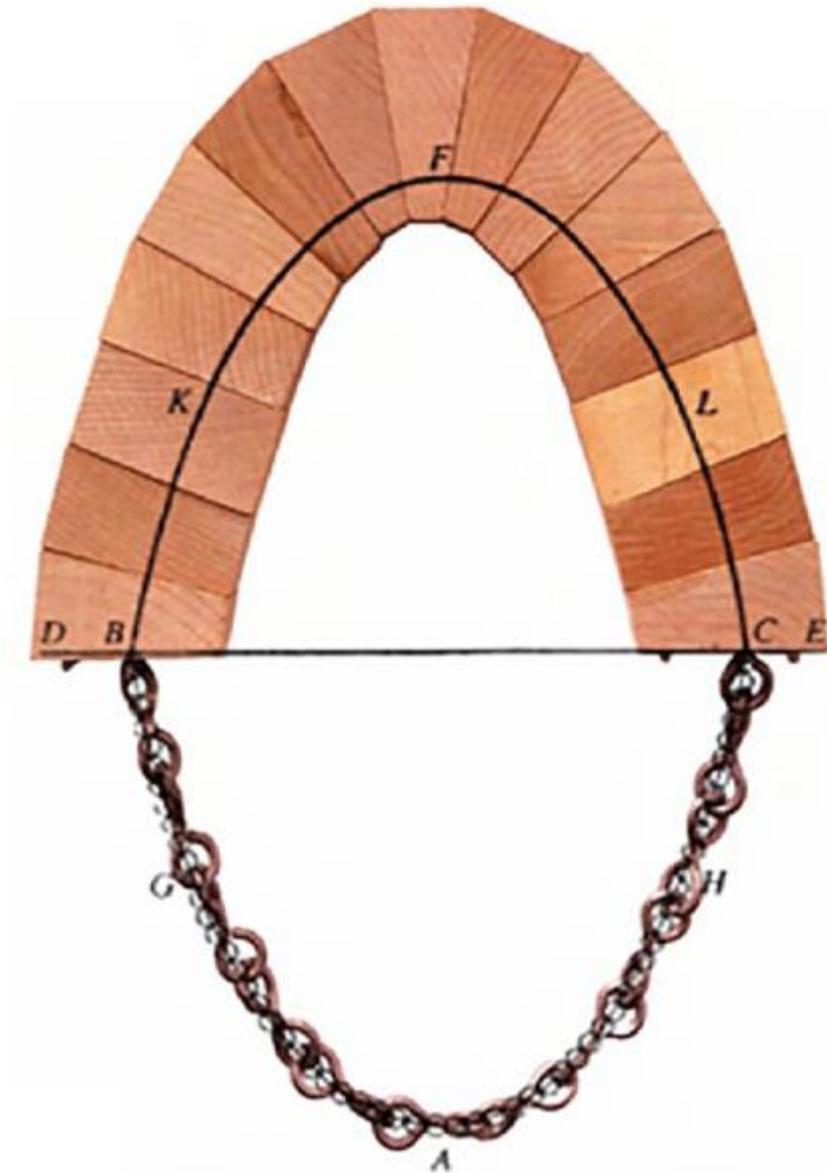
Bending is not an efficient mechanism
We would like funicular structures!



Form Finding

Physical models

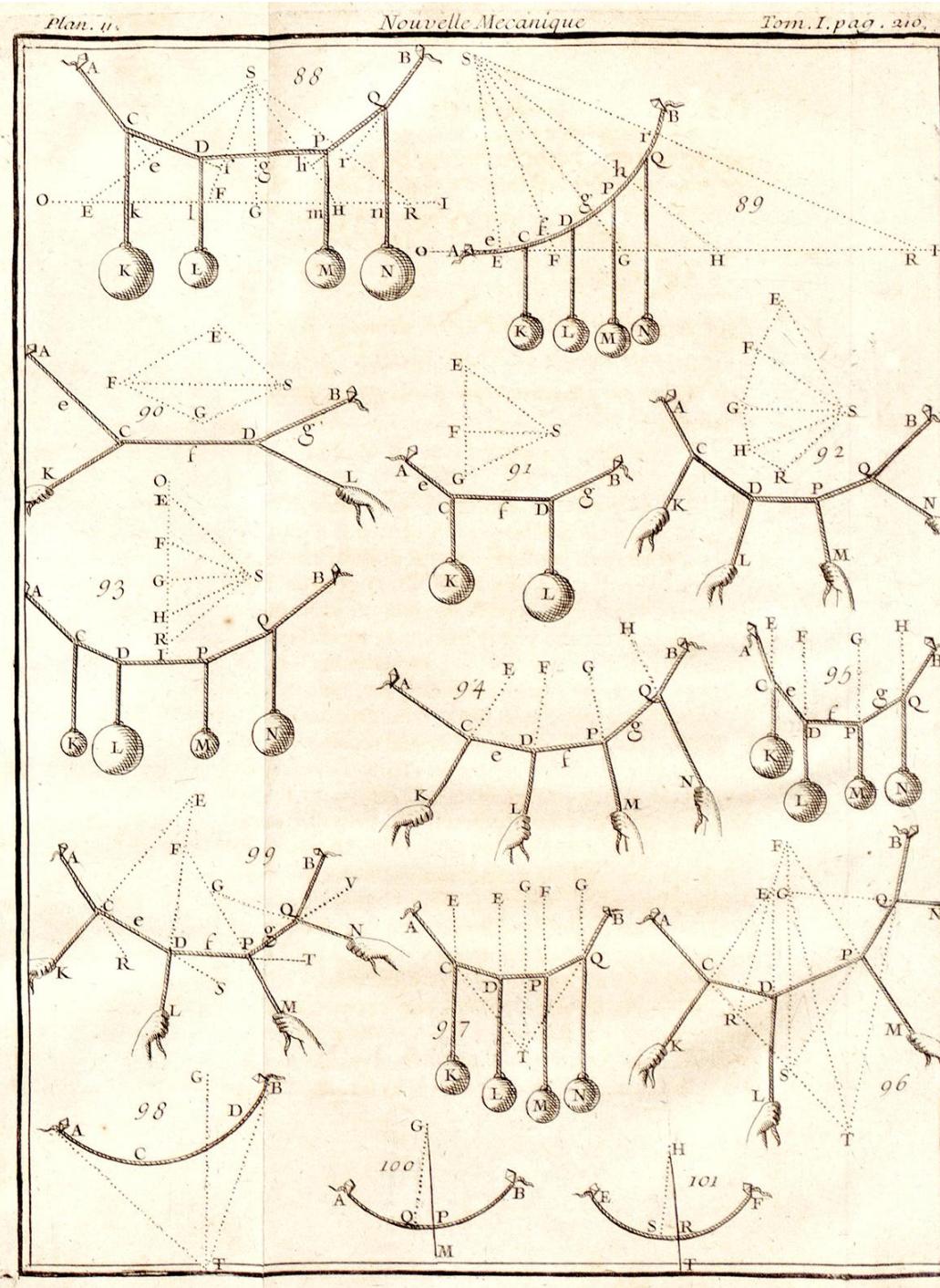
A flexible chain makes a rigid arch



Form Finding

Physical models

Varignon, 1725

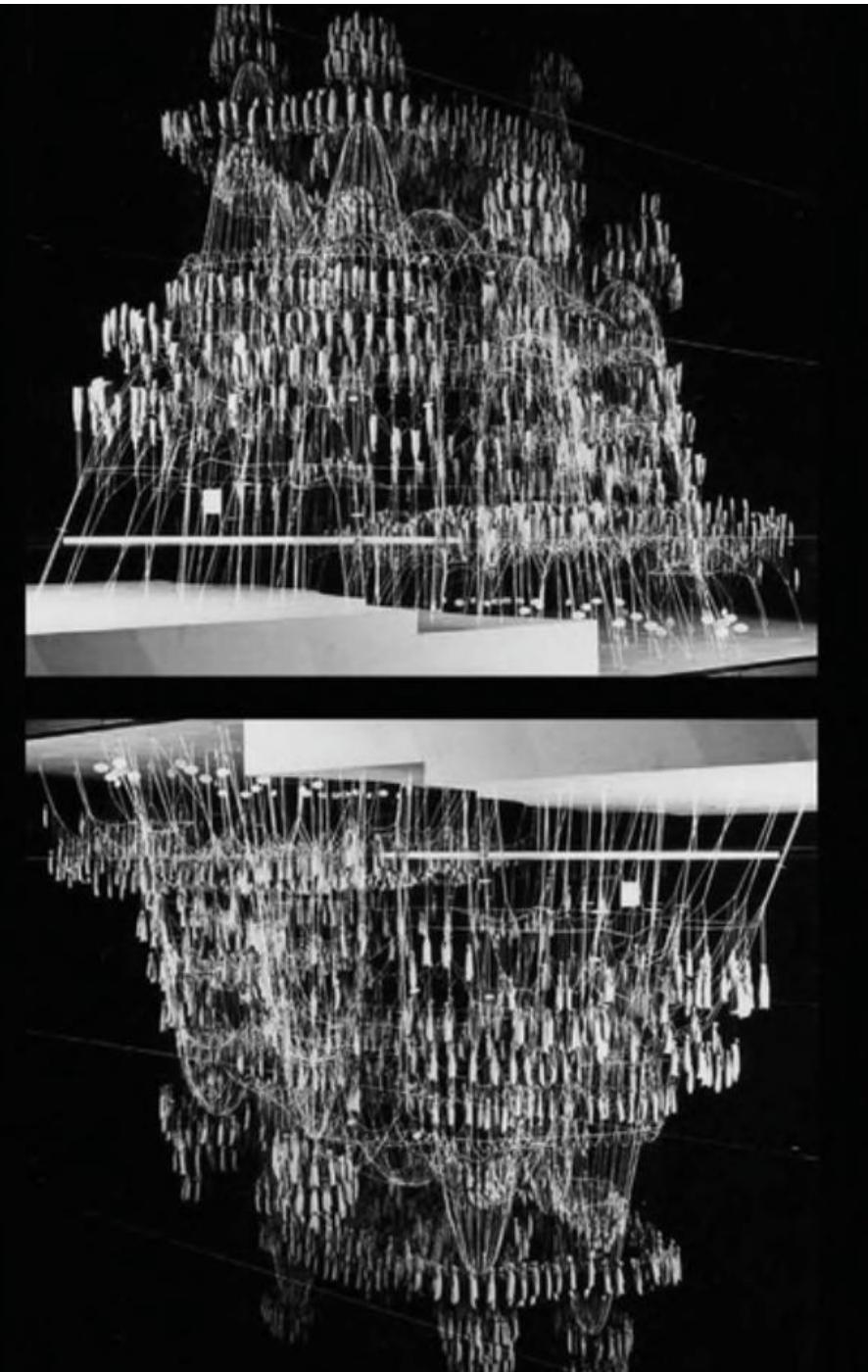


Form Finding

Physical models

1889 – Gaudí's Hanging Chain Models

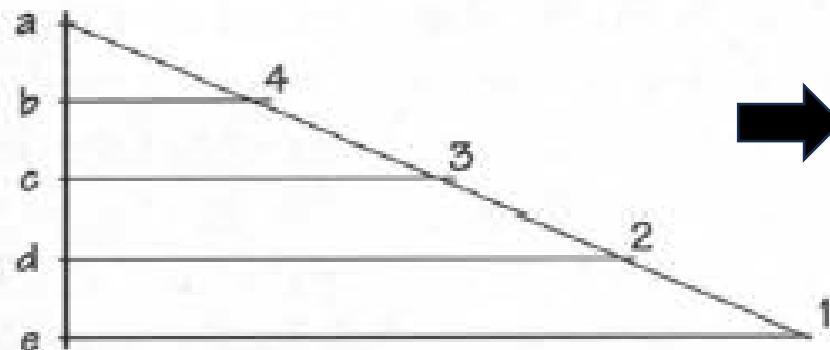




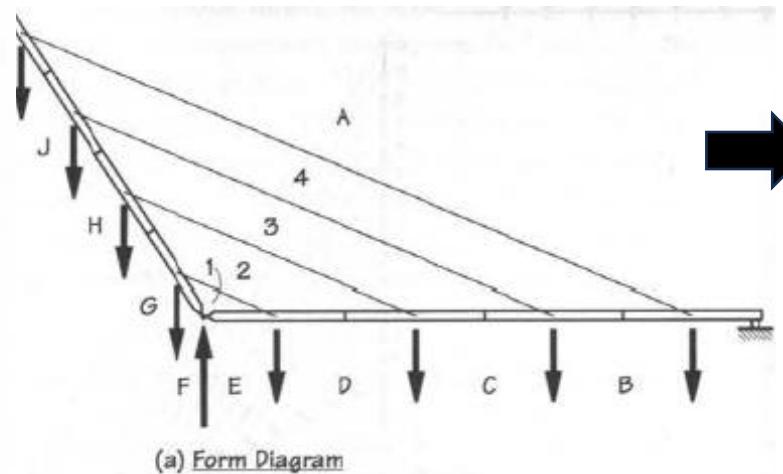
[Crypt, Colònia Güell, Barcelona](#)

Form Finding

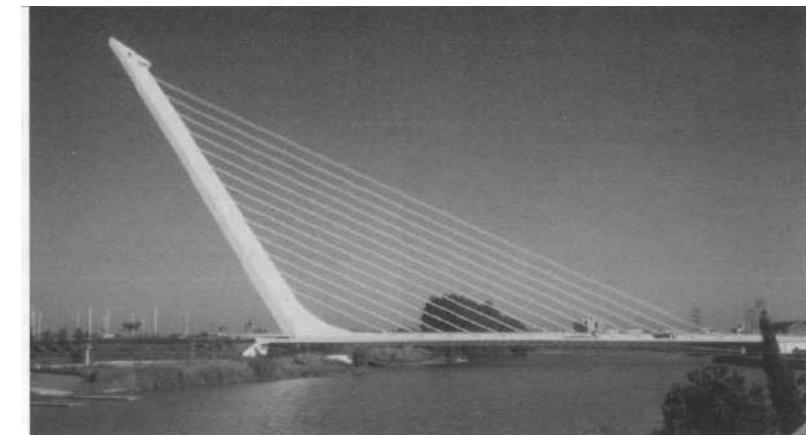
Graphical Statics: a powerful and versatile tool for form finding



(b) Partial Force Polygon



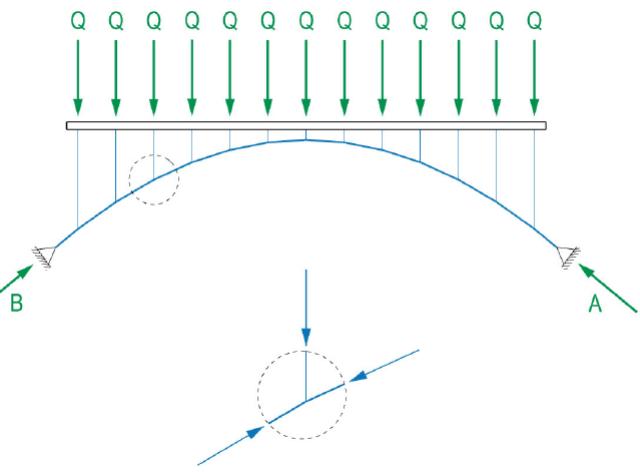
(a) Form Diagram



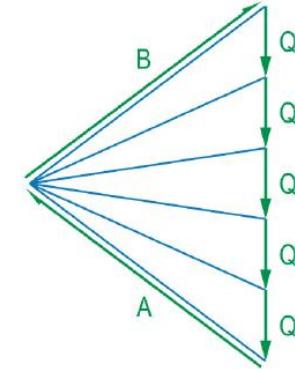
Santiago Calatrava: Alamillo Bridge, Sevilla, 1992

Form Finding

Graphical Statics: applications



Force diagram



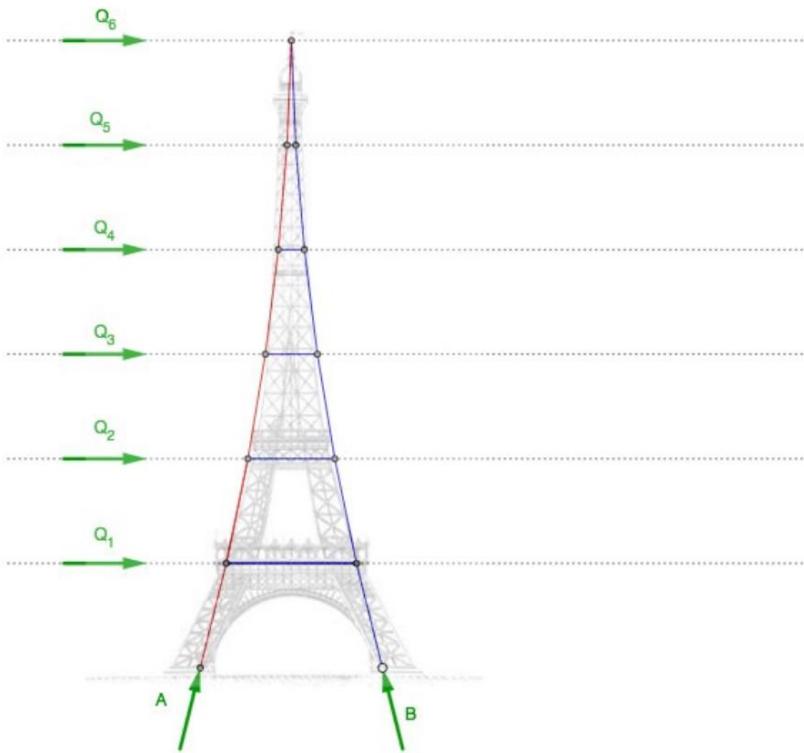
Robert Maillart: Valschielbachbridge, Donath, 1925

Form Finding

Graphical Statics: applications

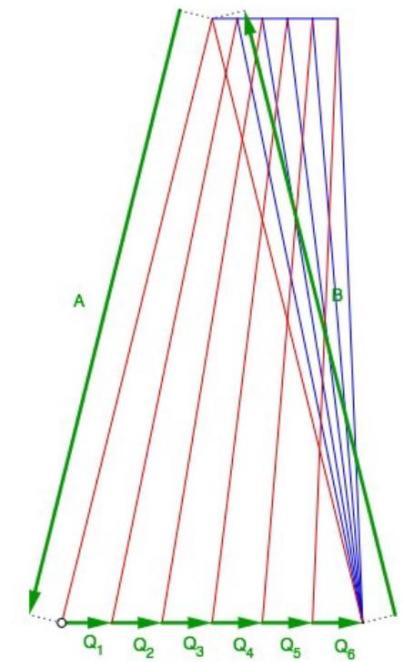


Form Diagram



eiffel tower

Force Diagram



Form Finding

Graphical Statics: applications



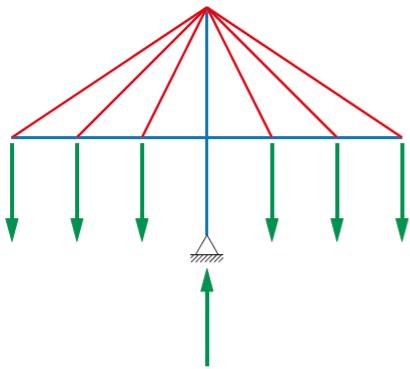
Foster+Partners, Michel Virlogeux: Millau Viaduct, nahe Montpellier, France, 2004



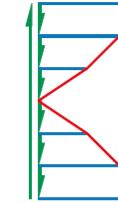
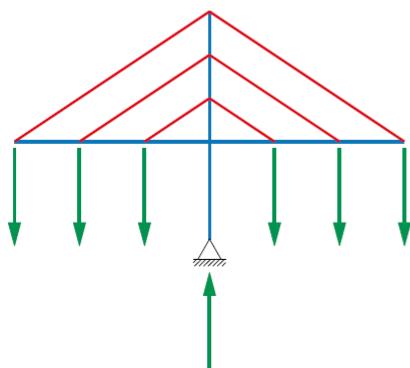
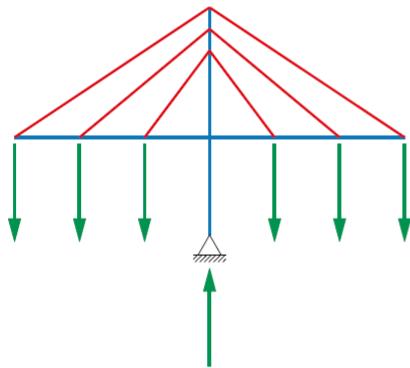
Christian Menn: Sunnibergbrücke, zwischen Klosters und Serneus, 2005

Form Finding

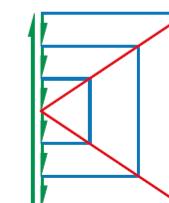
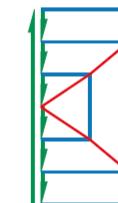
Graphical Statics: applications



Form diagram



Force diagram

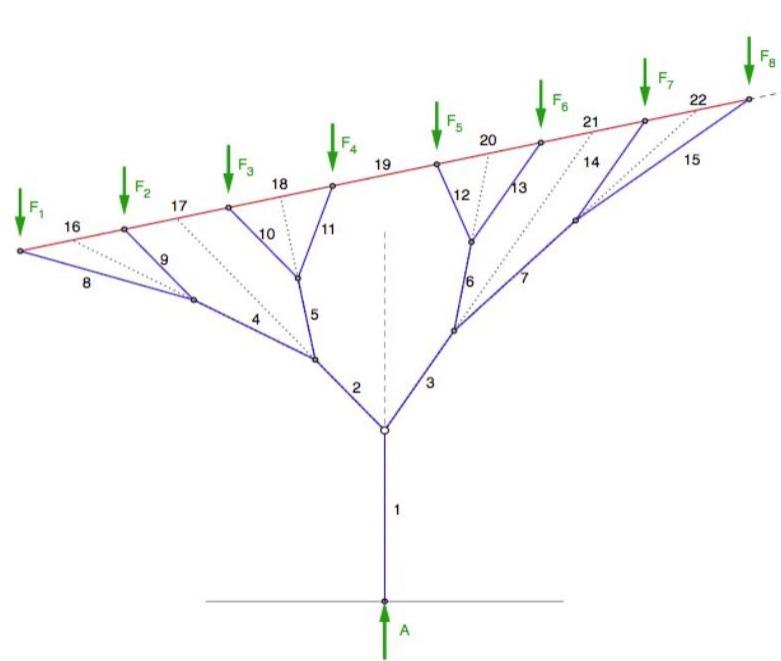


Form Finding

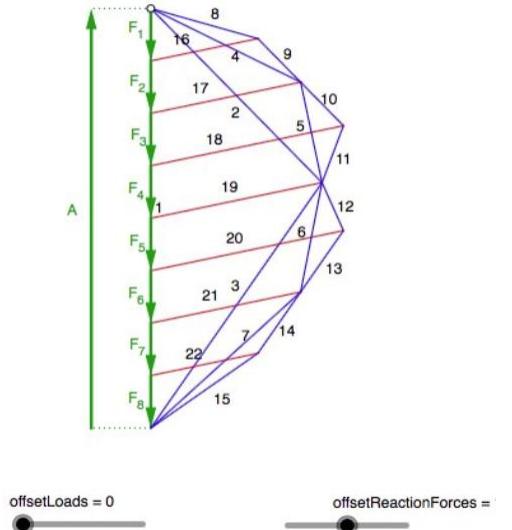
Graphical Statics: applications



Form Diagram



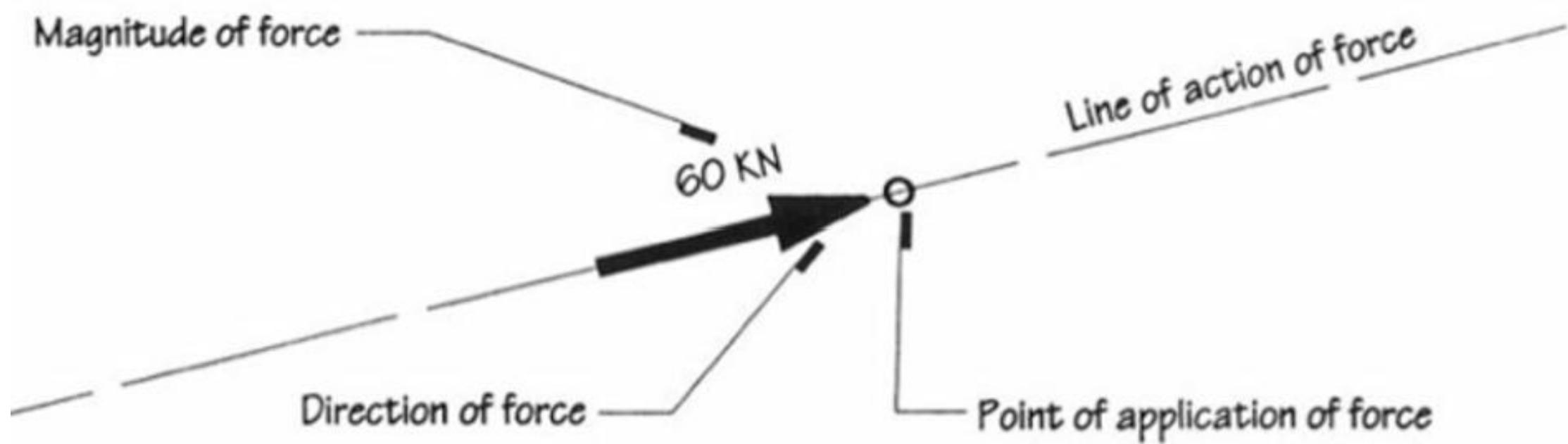
Force Diagram



Gerkan, Mark & Partner,
Schlaich Bergermann:
Stuttgart Airport Terminal 3,
2004

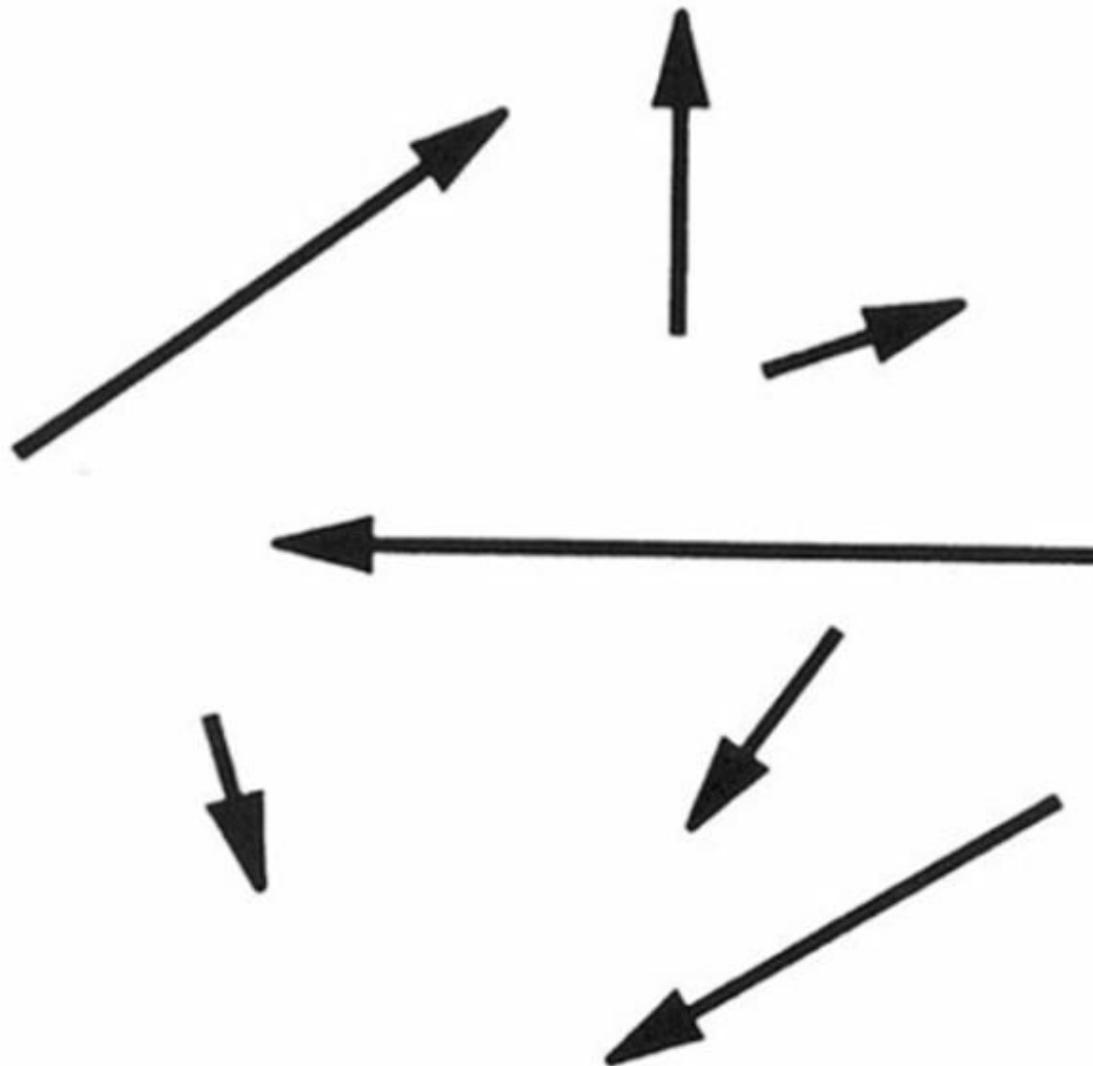
Graphical Statics

Basic Concepts: forces



Graphical Statics

Basic Concepts: length scale

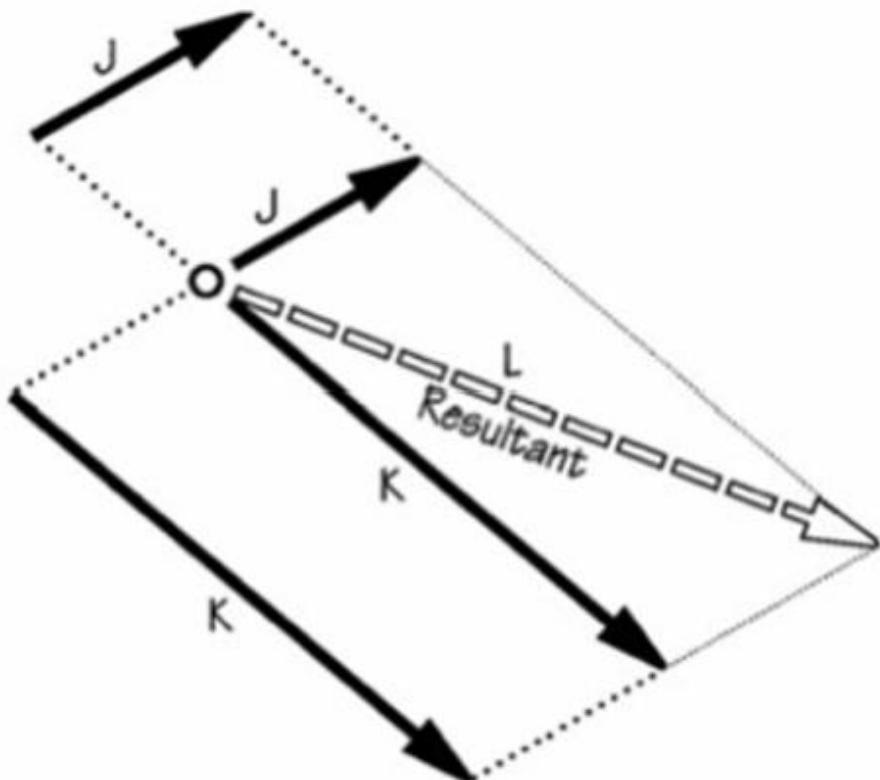


Scale 1 in. = 100 lb

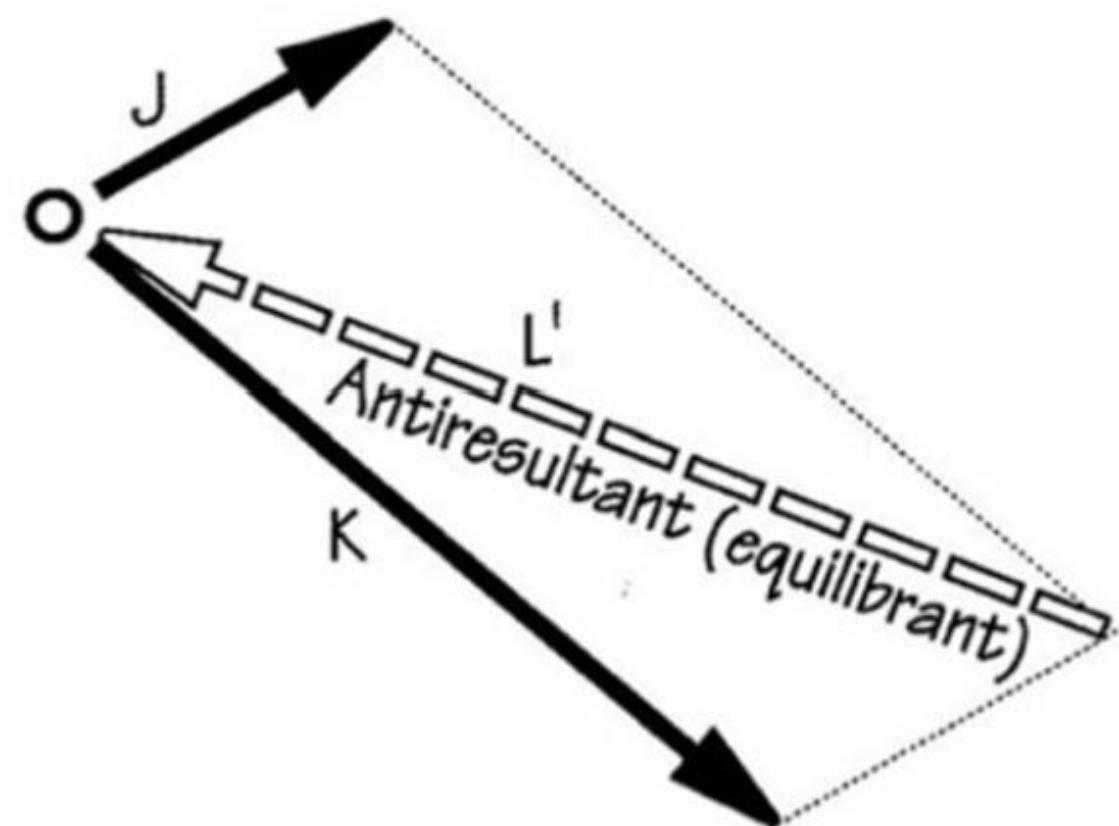
Graphical Statics

Basic Concepts: equivalent and equilibrium

Equivalent force



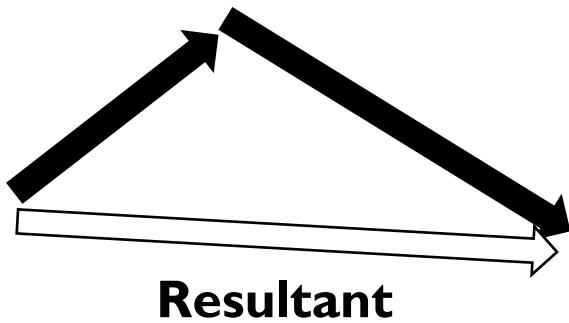
Forces in equilibrium



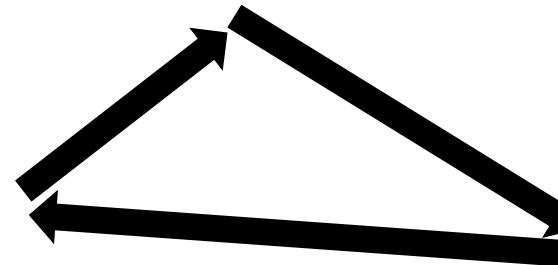
Graphical Statics

Basic Concepts: force polygons

Equivalent force

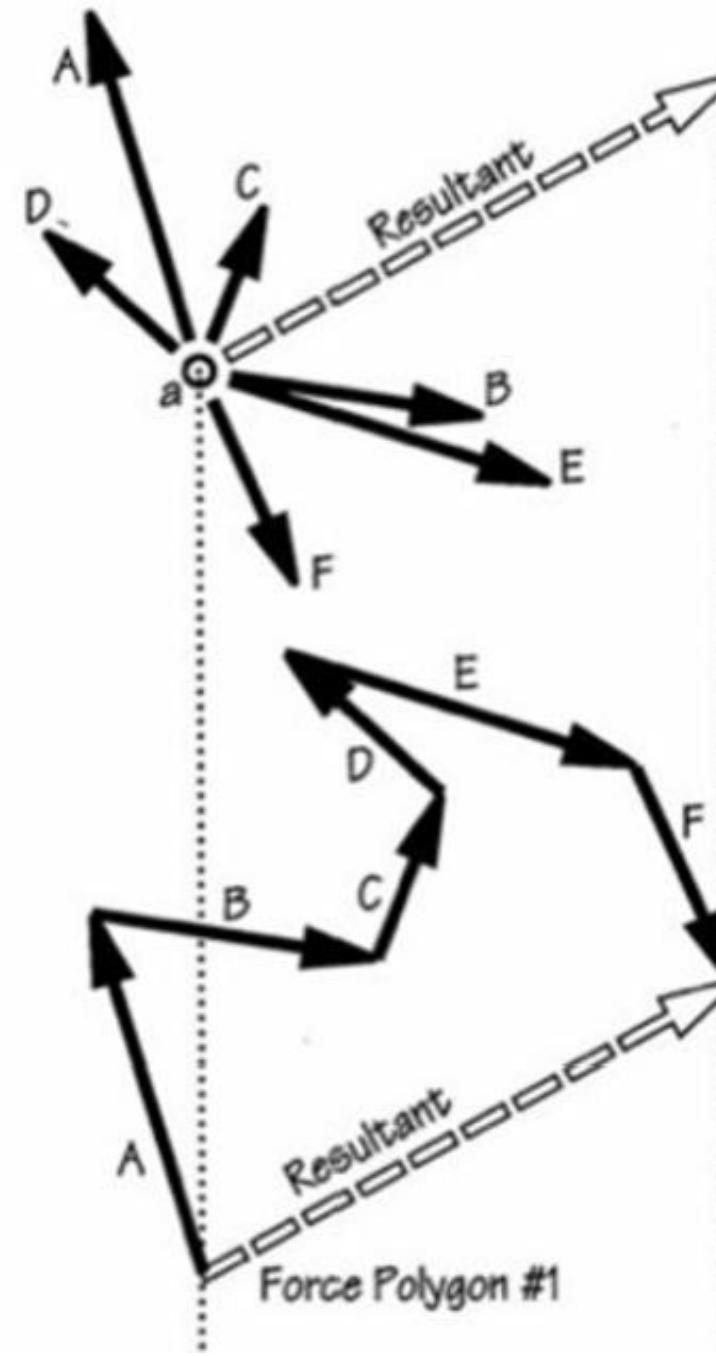


Forces in equilibrium



Graphical Statics

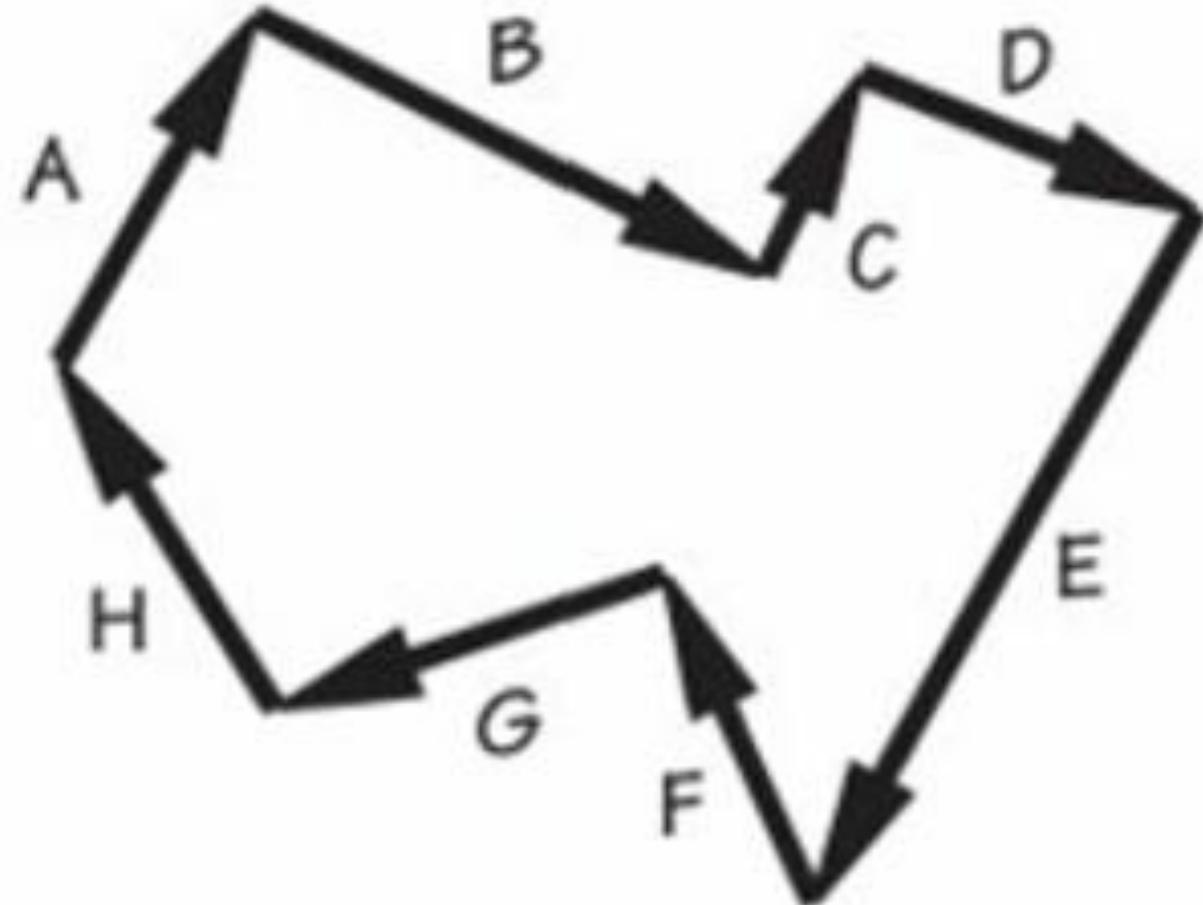
Basic Concepts: force polygon



Graphical Statics

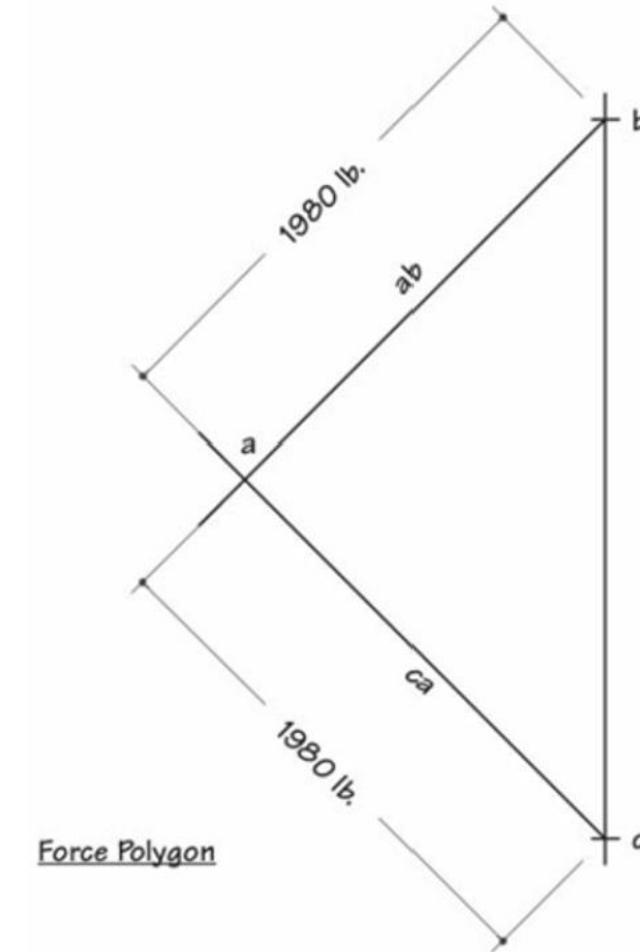
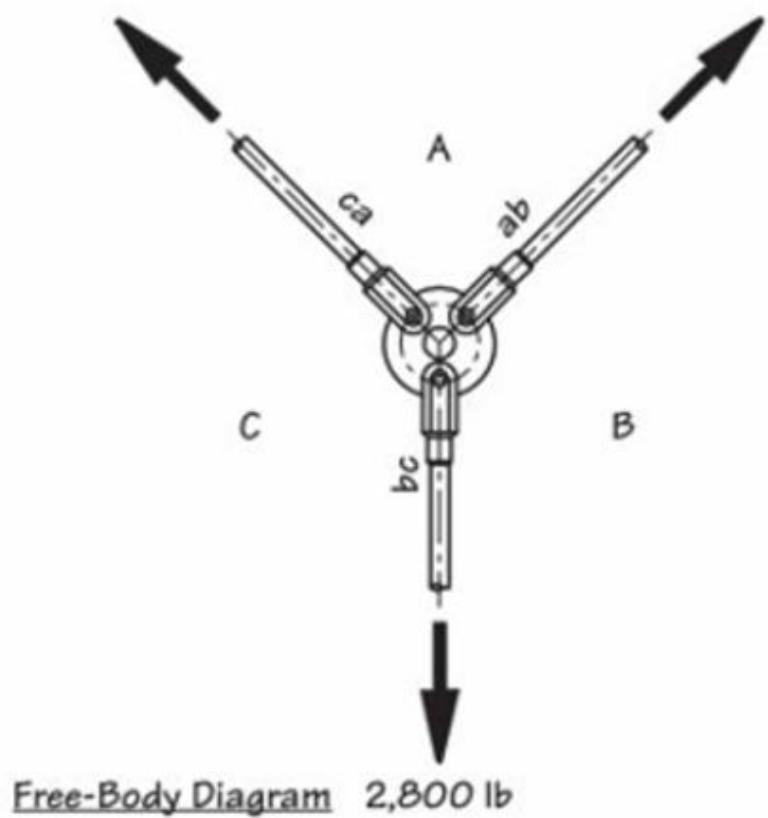
Basic Concepts: force polygon

Closed forced polygon → equilibrium



Graphical Statics

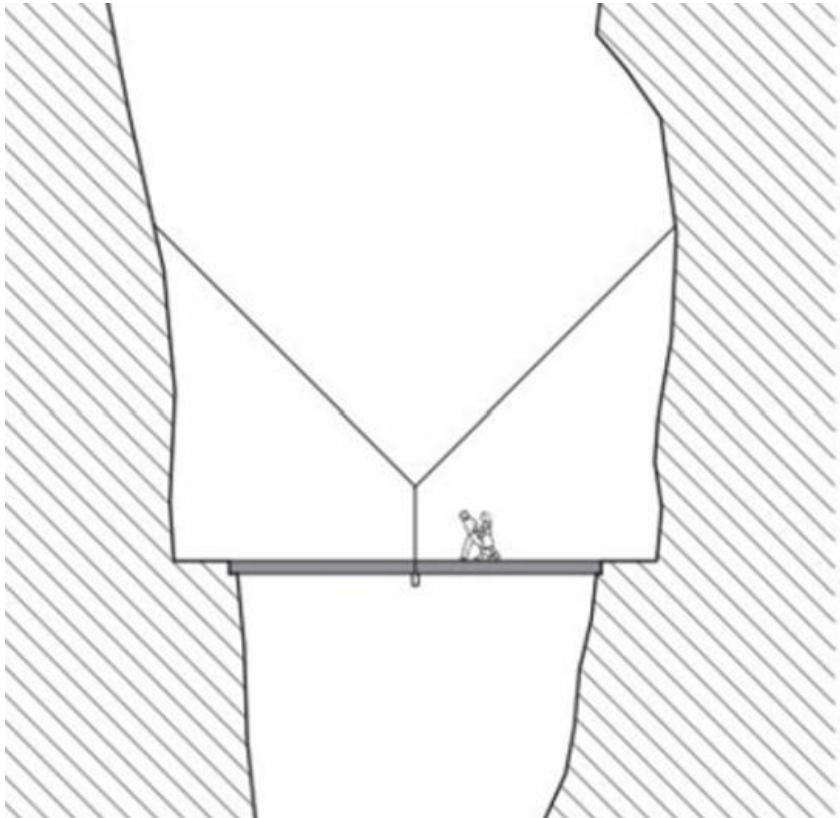
Bow's notation



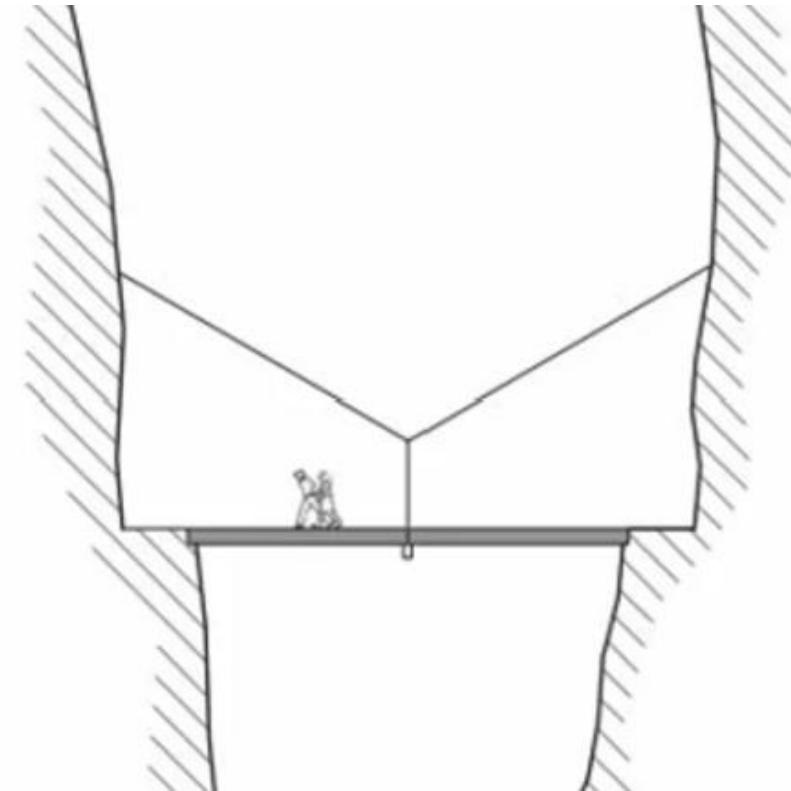
Graphical Statics

A case study: a suspension bridge design

Case 1



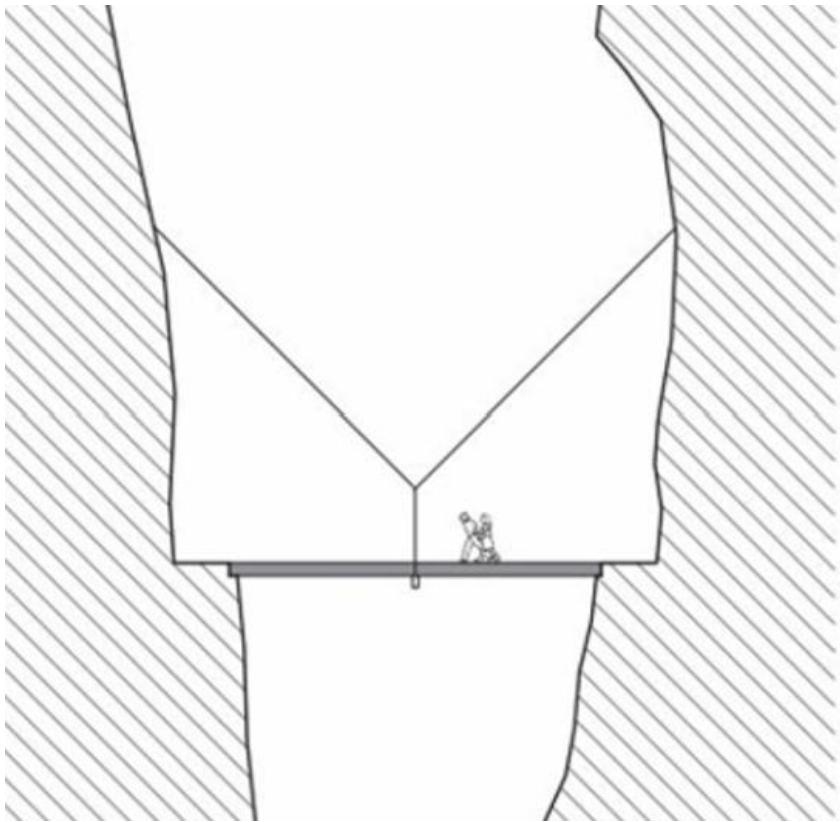
Case 2



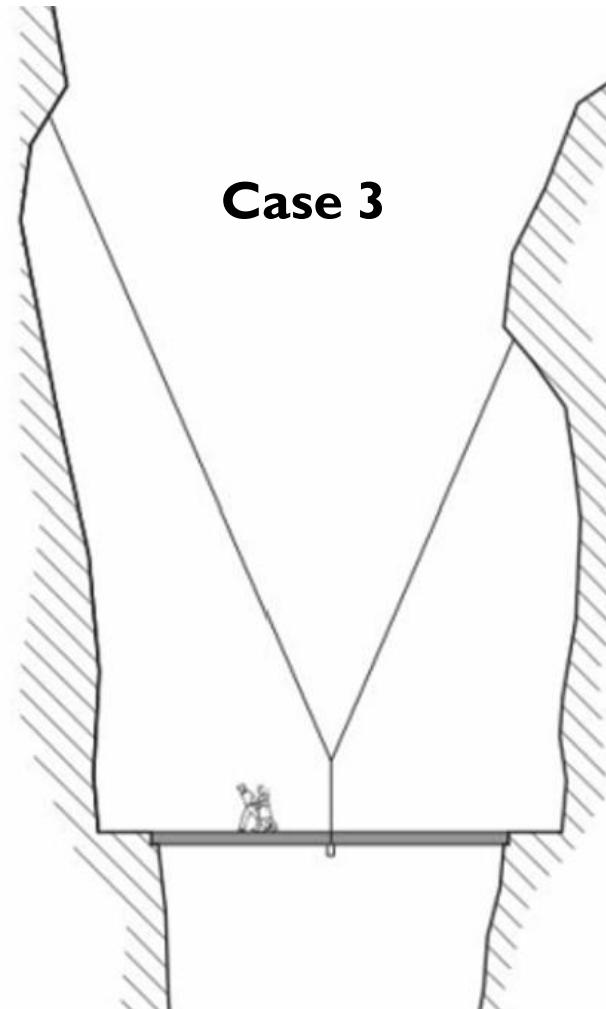
Graphical Statics

A case study: a suspension bridge design

Case 1



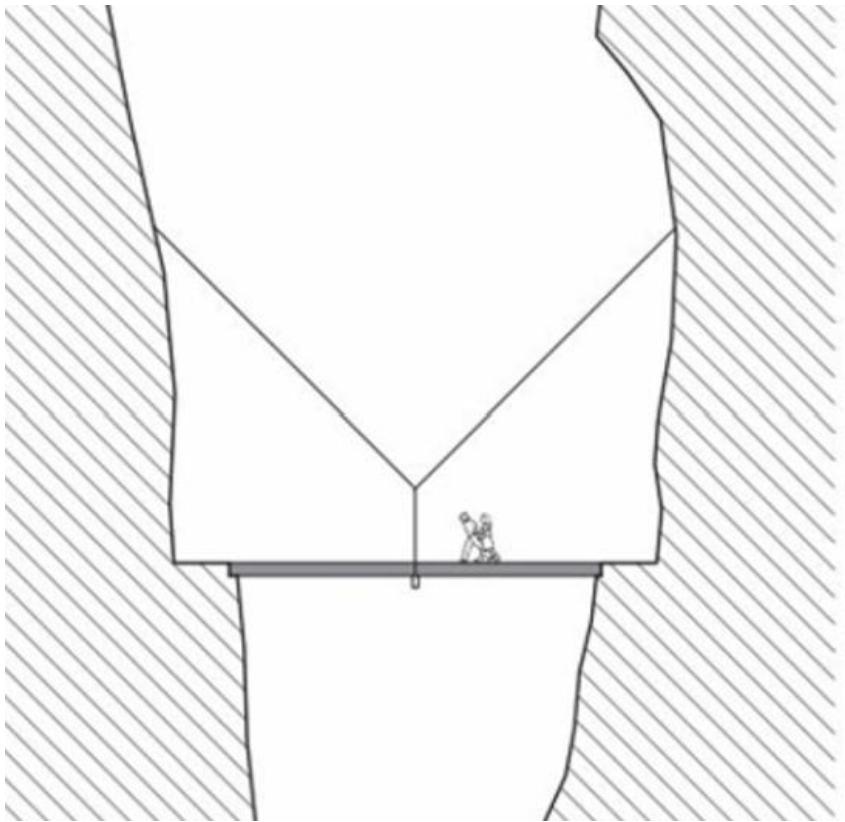
Case 3



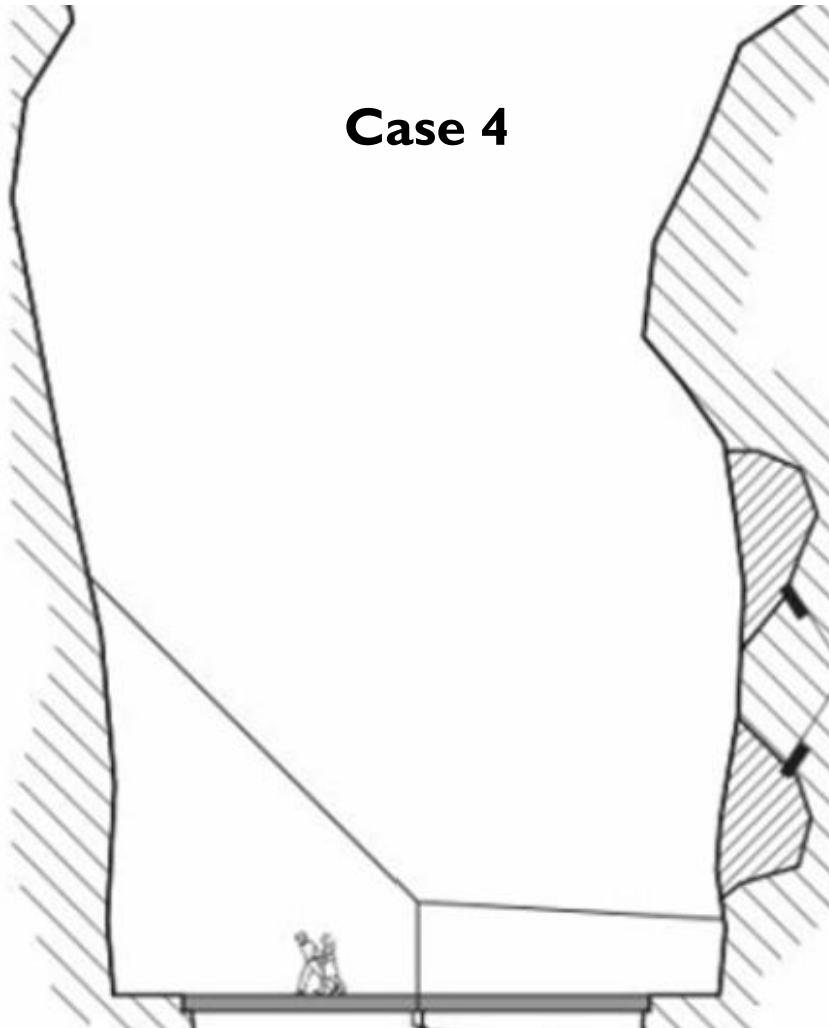
Graphical Statics

A case study: a suspension bridge design

Case 1



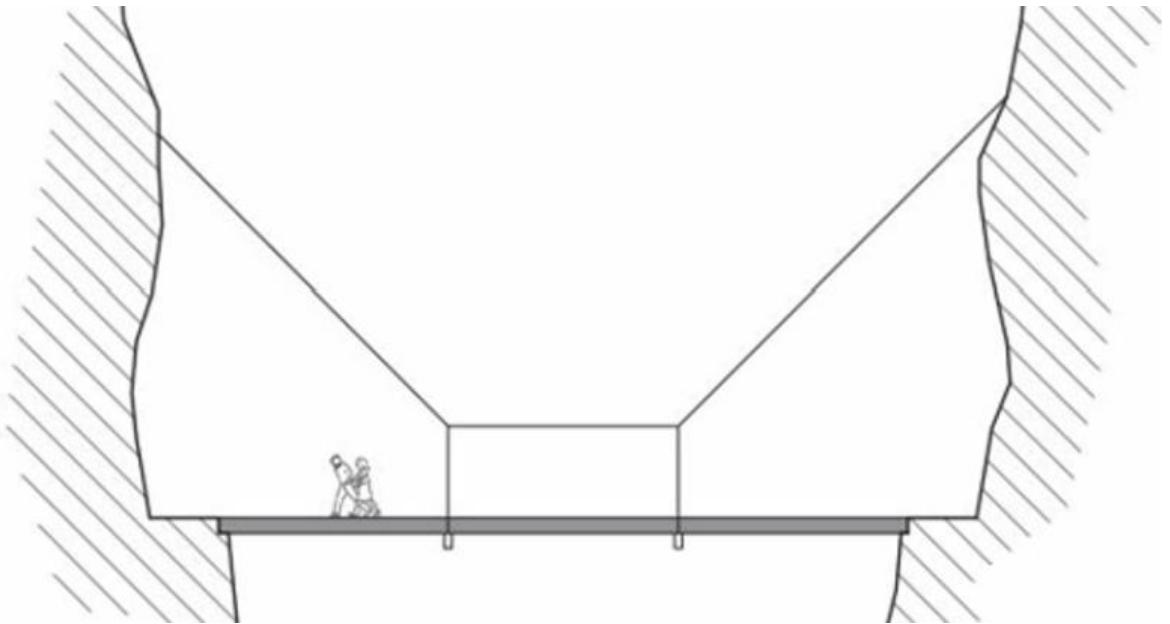
Case 4



Graphical Statics

A case study: a suspension bridge design

Case 5

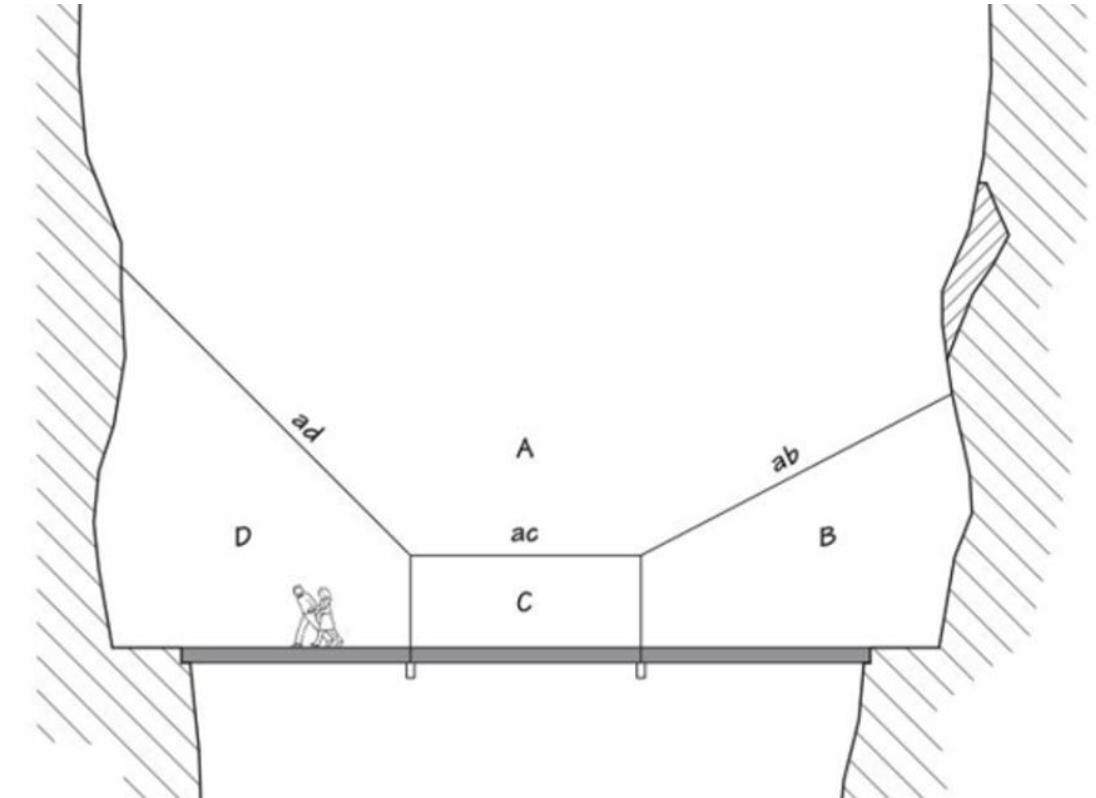
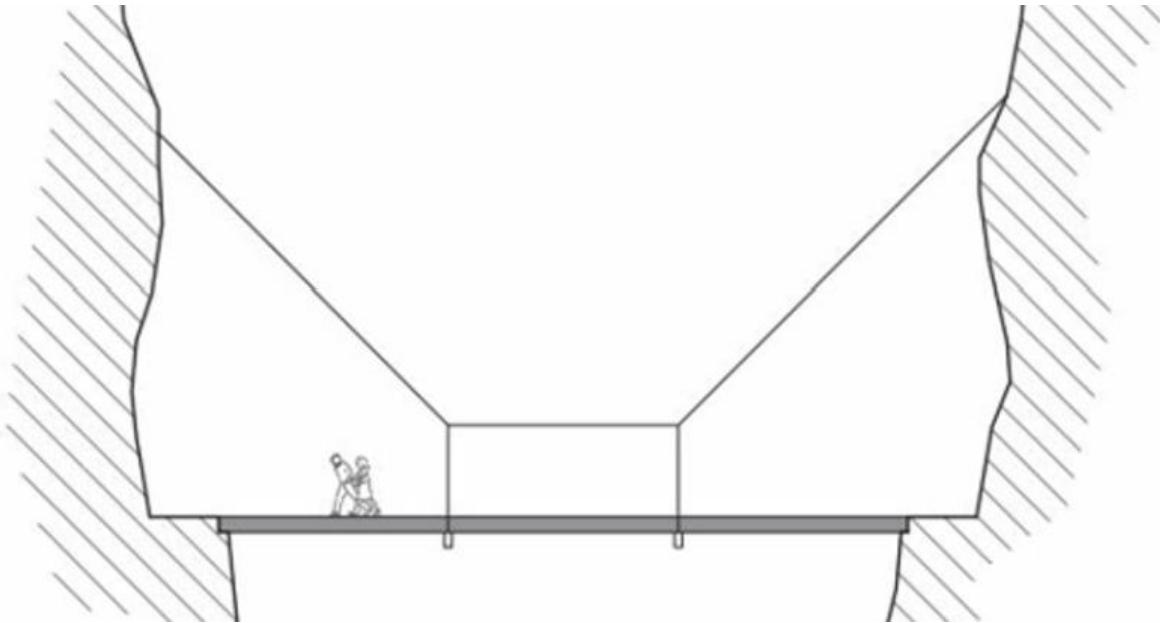


Graphical Statics

A case study: a suspension bridge design

Can we only change one cable?

Case 6

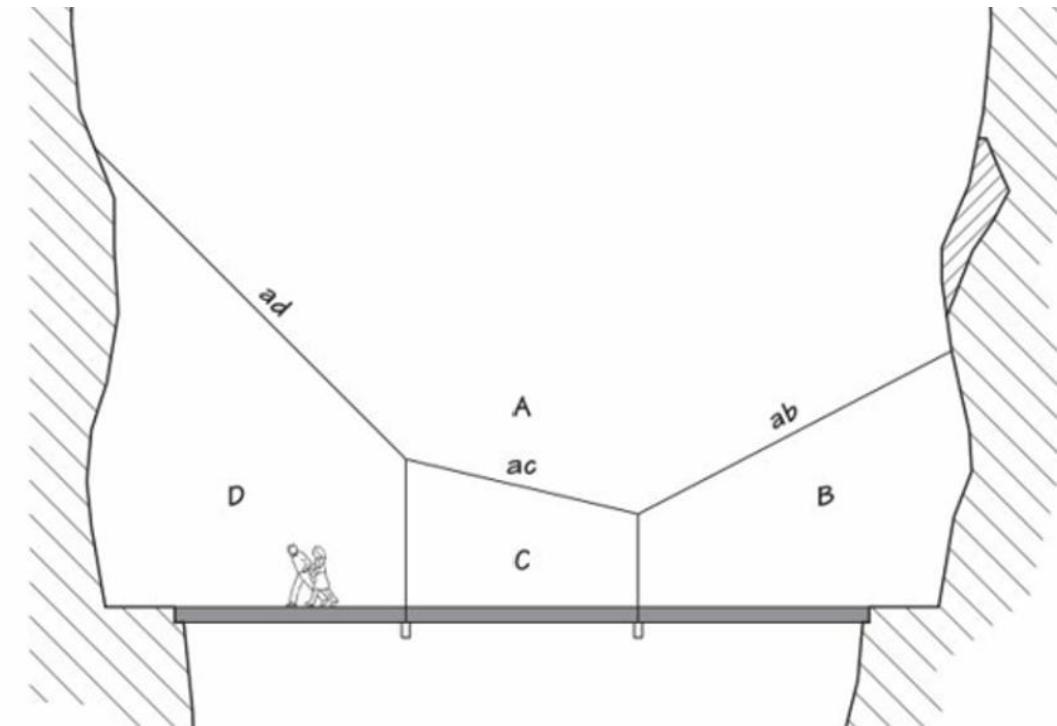
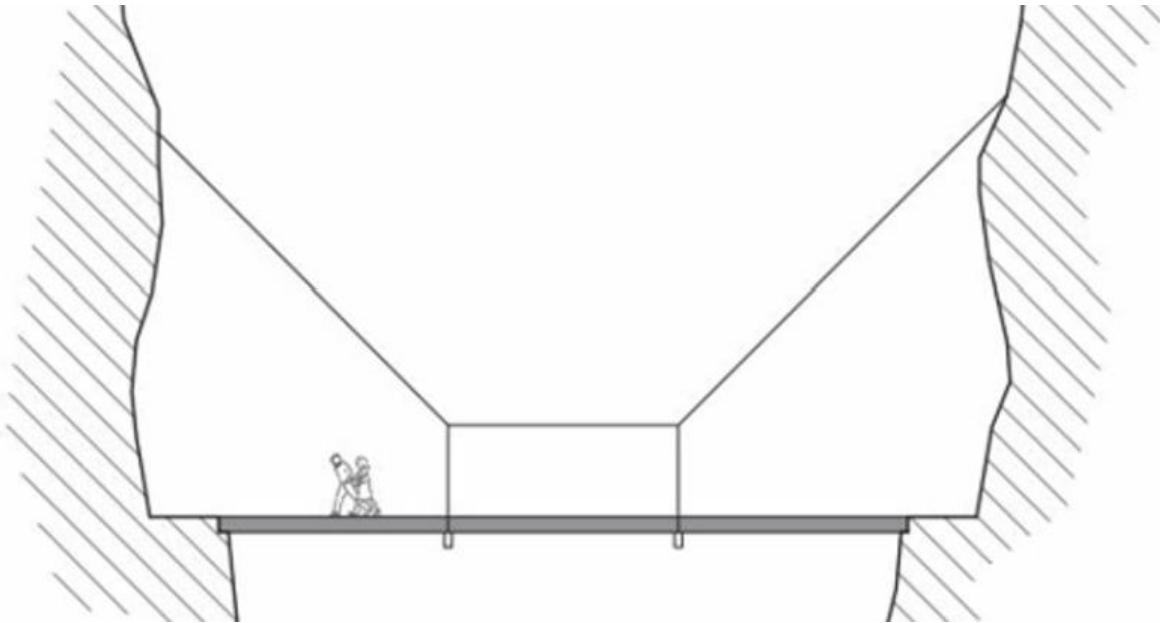


Graphical Statics

A case study: a suspension bridge design

Not all forms work in funicular structure

Case 6

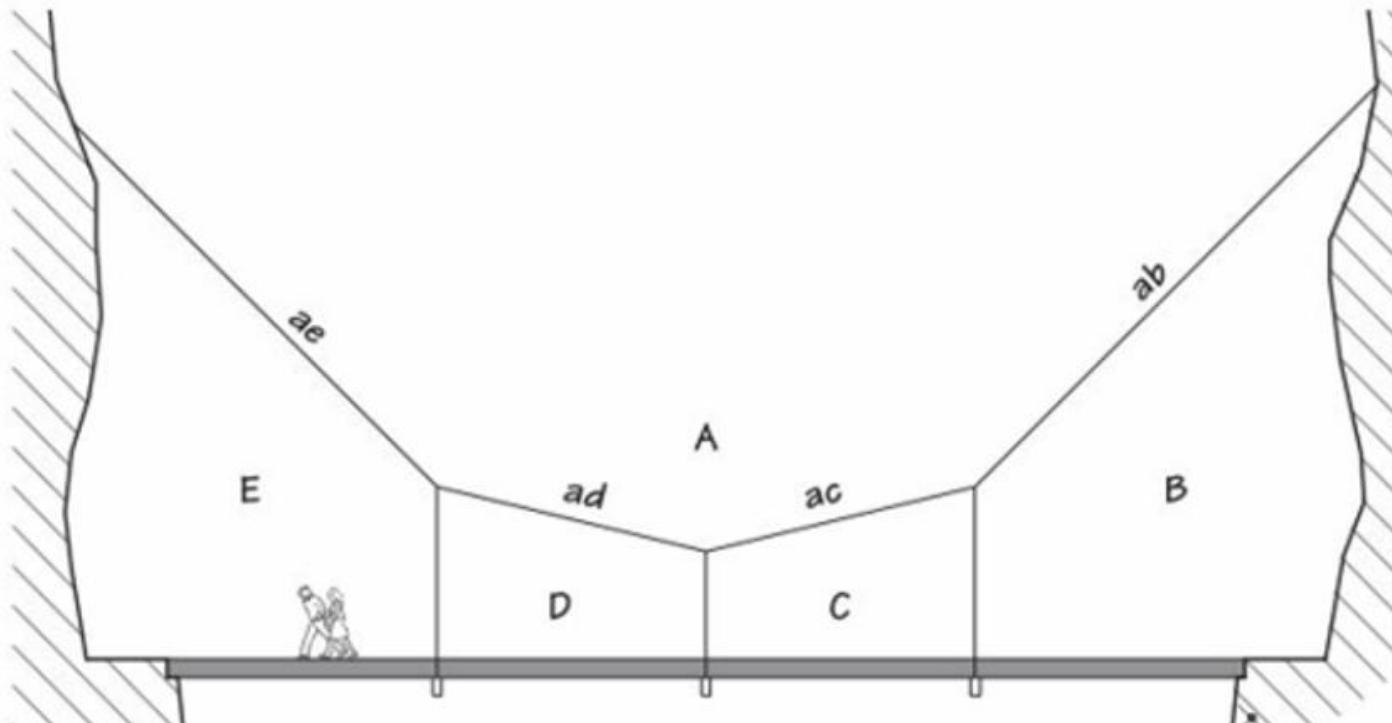


Graphical Statics

A case study: a suspension bridge design

Case 7

Symmetric
Max anchoring load
Cable > 8ft above bridge deck



Graphical Statics

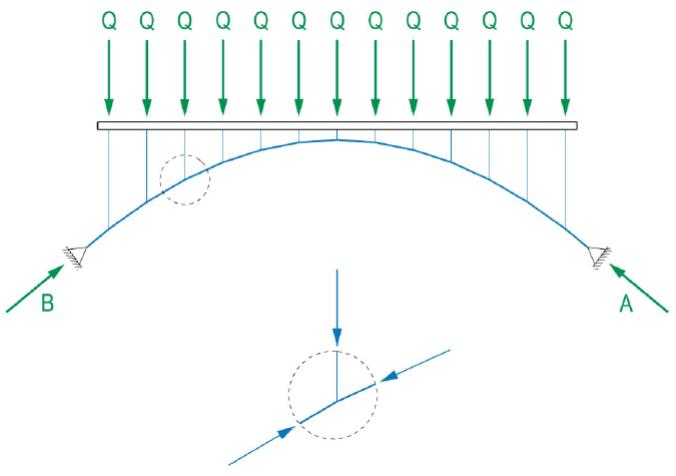
Real-word application



Designed by Schlaich Bergermann et al. (1988)
Bad Windsheim, Germany.

Graphical Statics

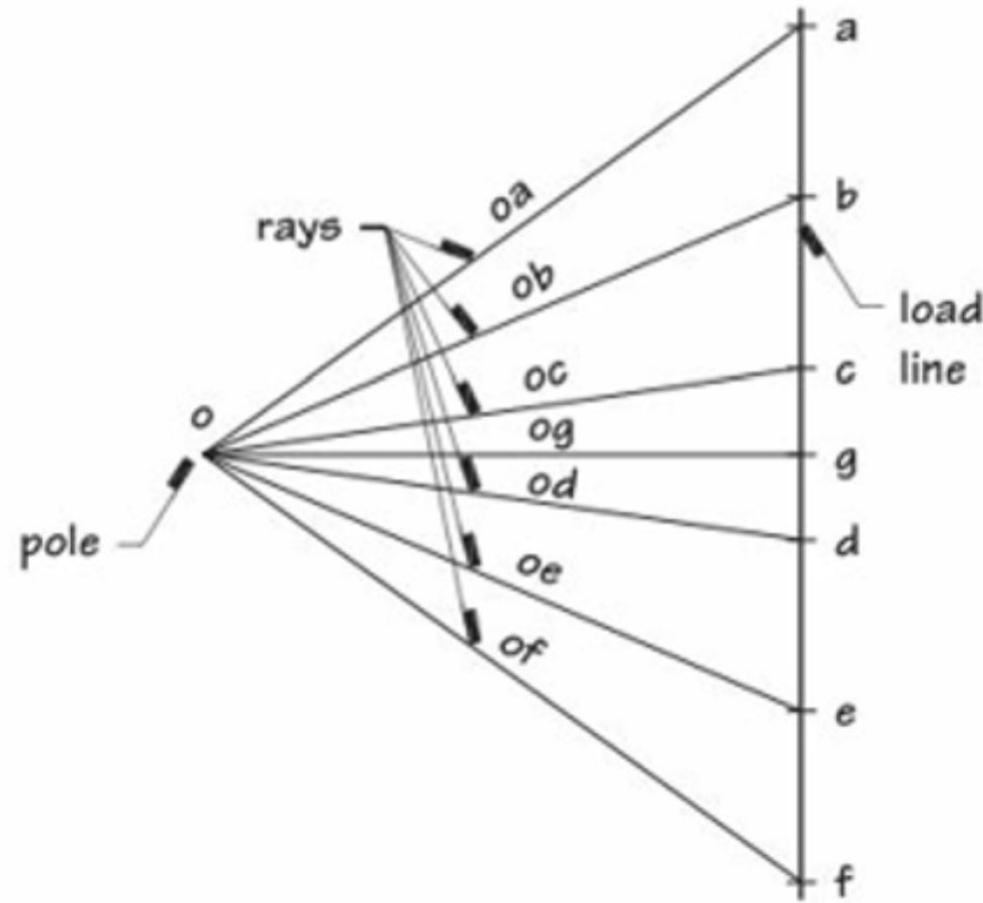
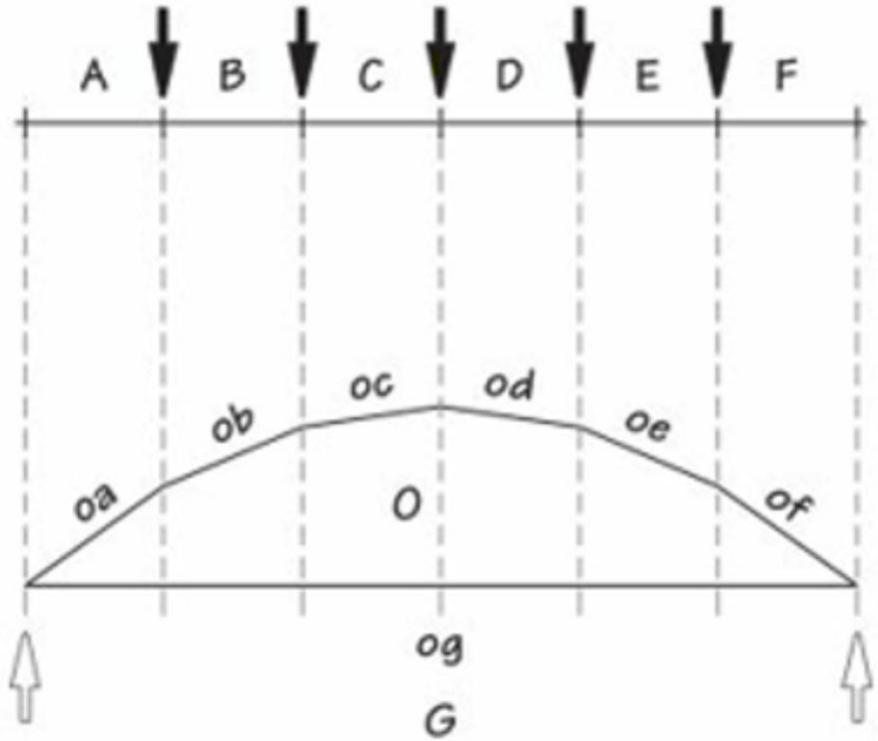
Arch Design



Robert Maillart: Valschielbachbridge, Donath, 1925

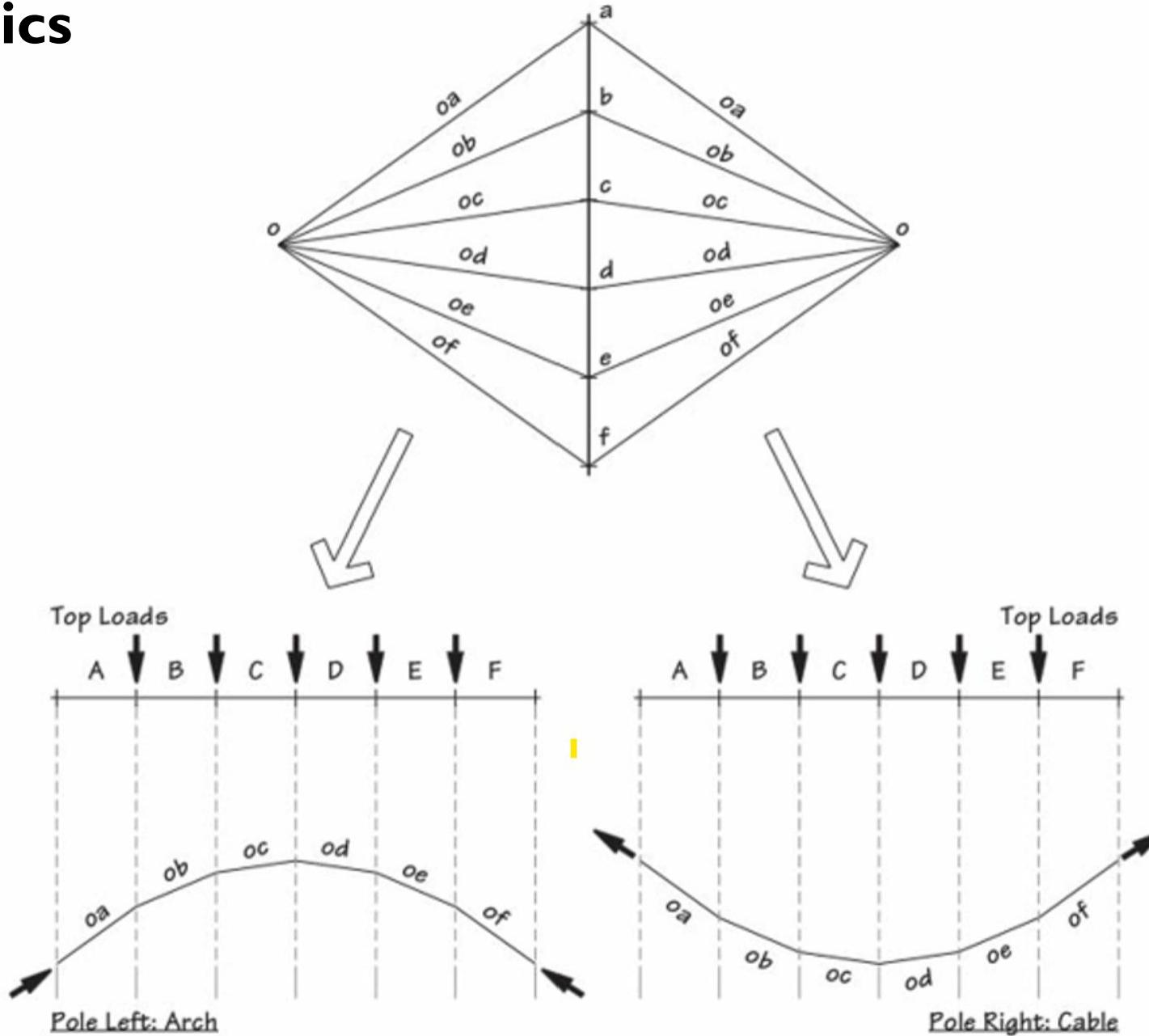
Graphical Statics

Arch



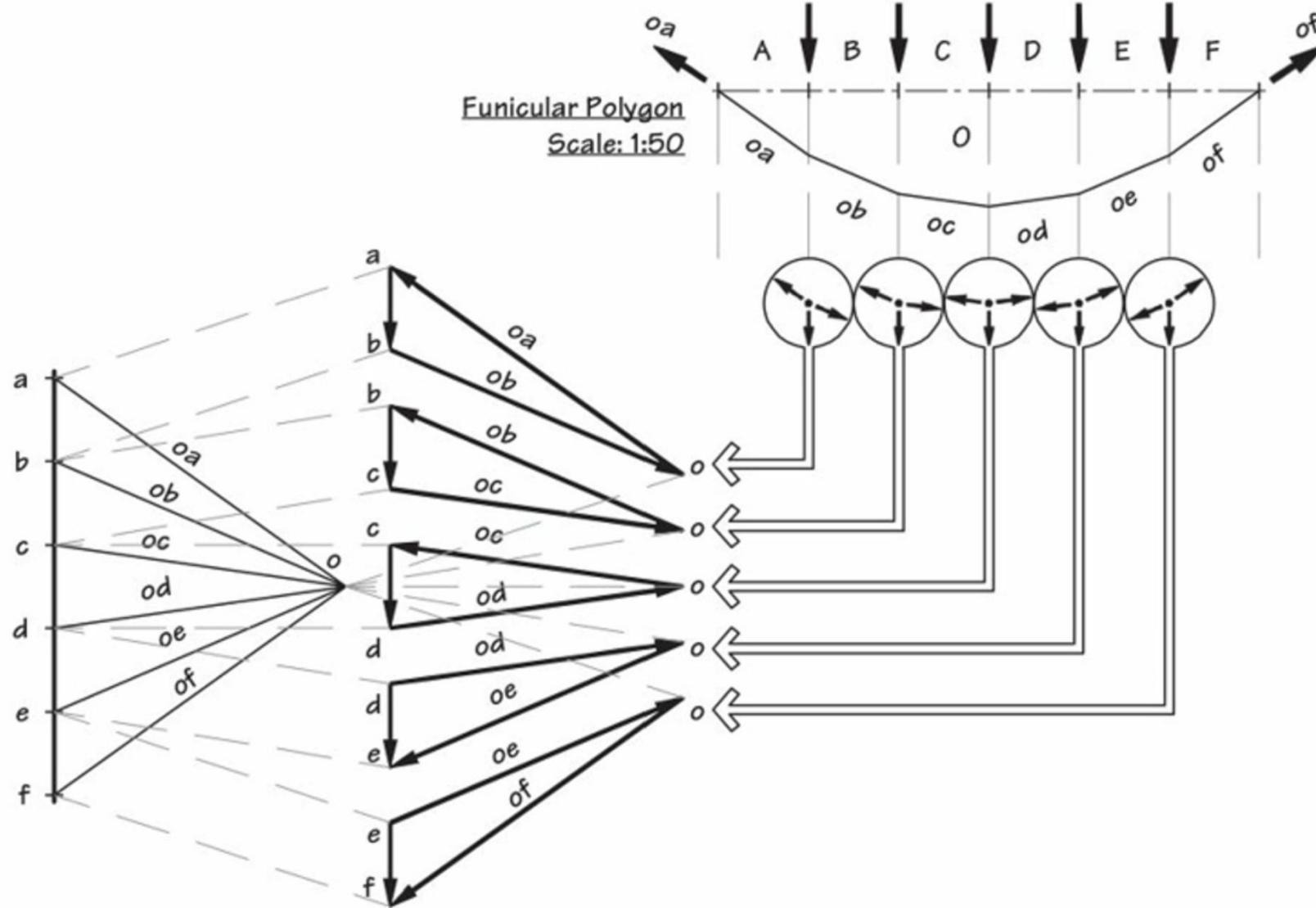
Graphical Statics

Arch → Cable



Graphical Statics

Arch Design



Graphical Statics

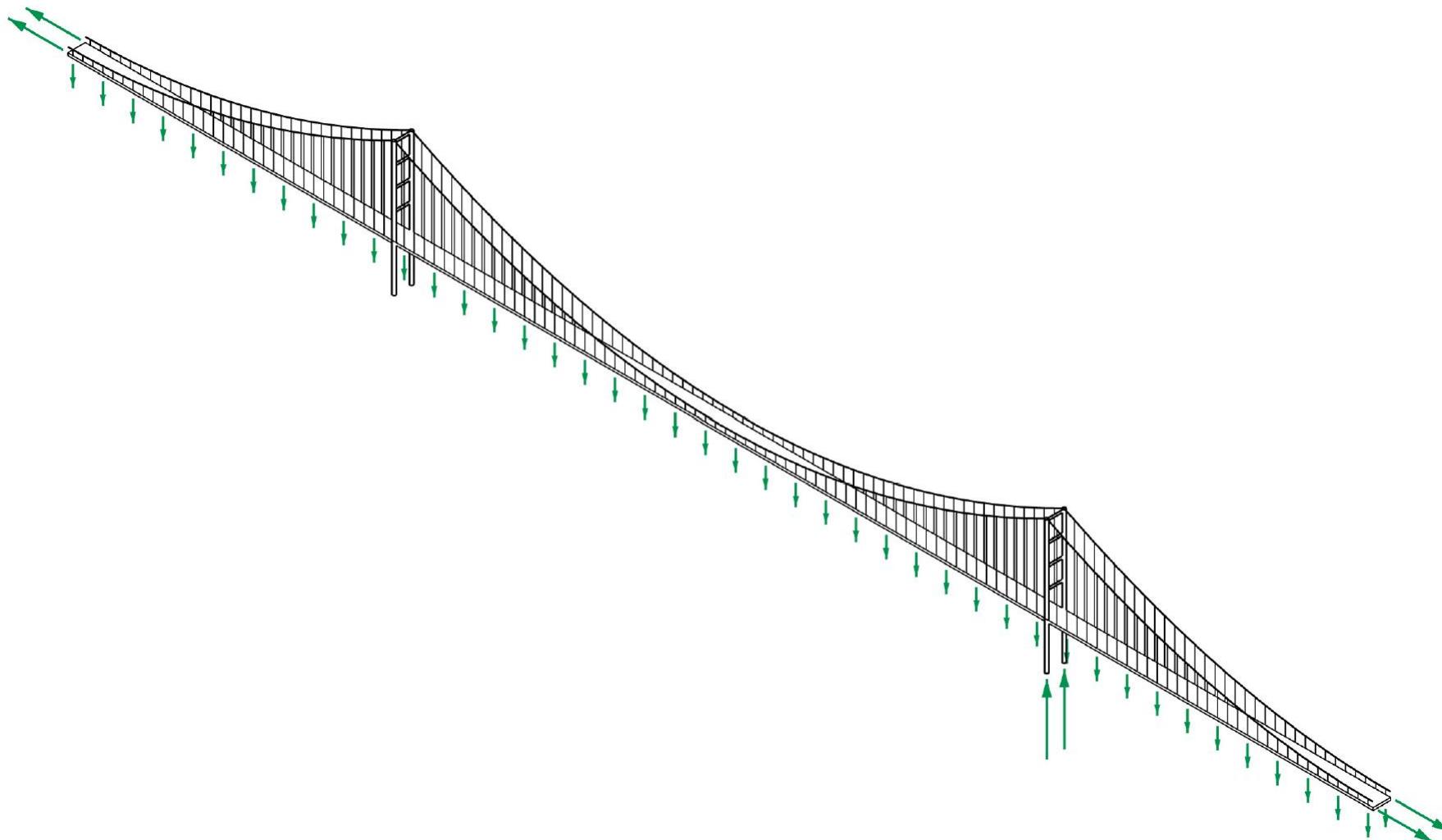
Cable Design



Joseph Strauss: Golden Gate Bridge, San Francisco, 1937

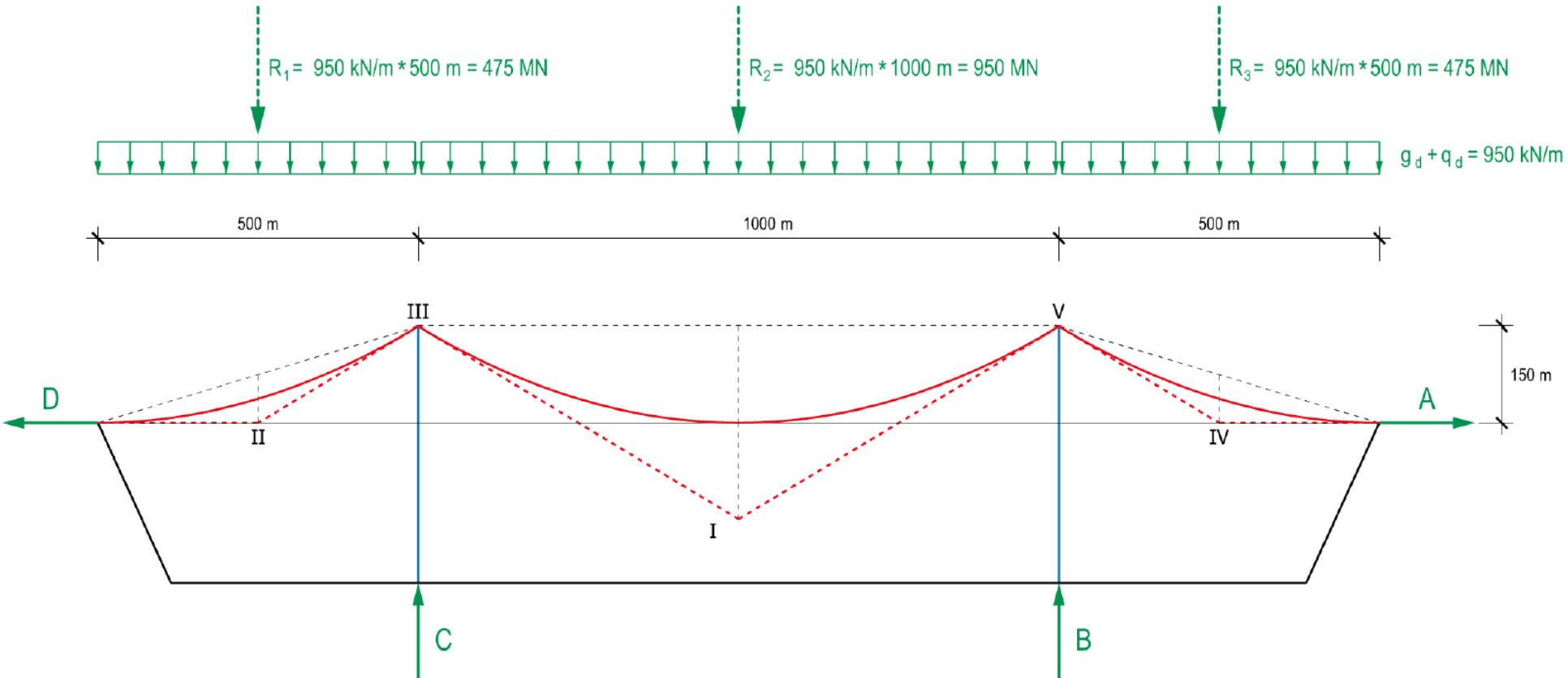
Graphical Statics

Cable Design



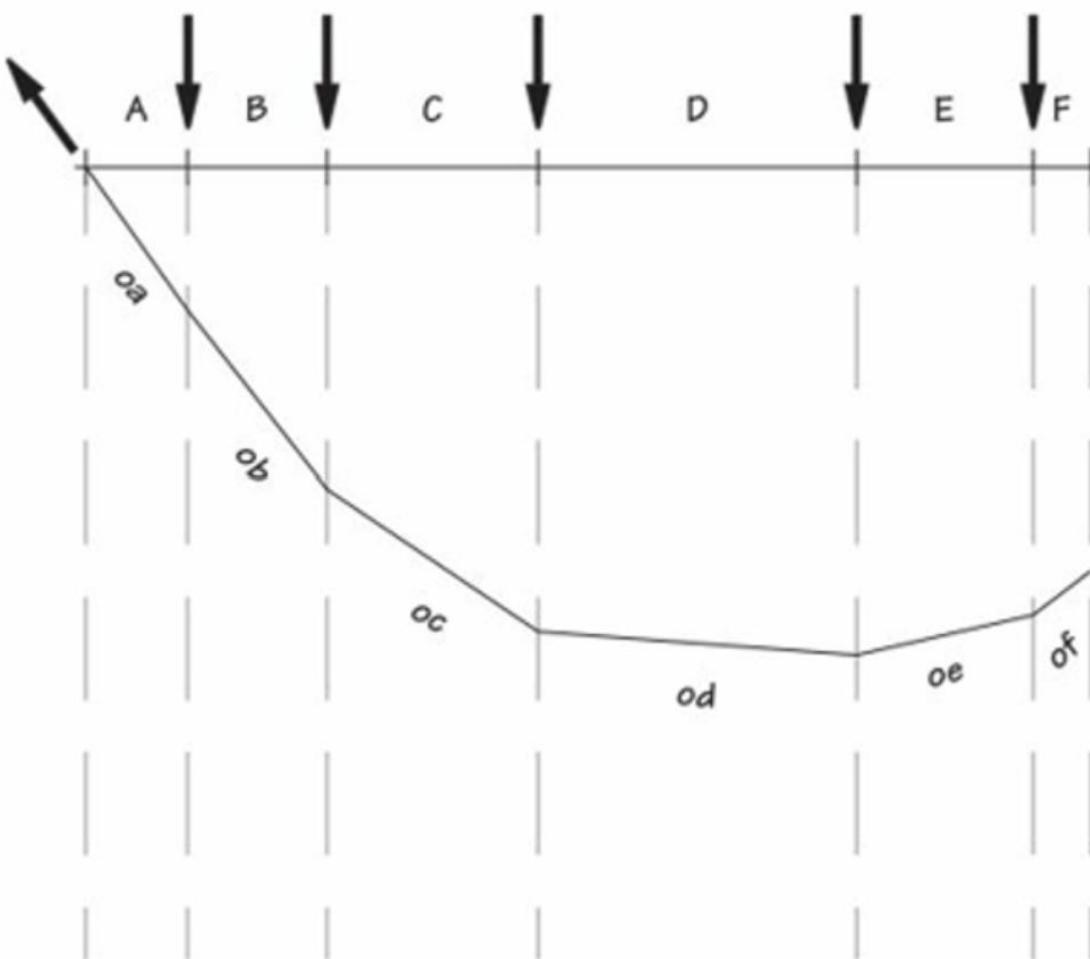
Graphical Statics

Cable Design

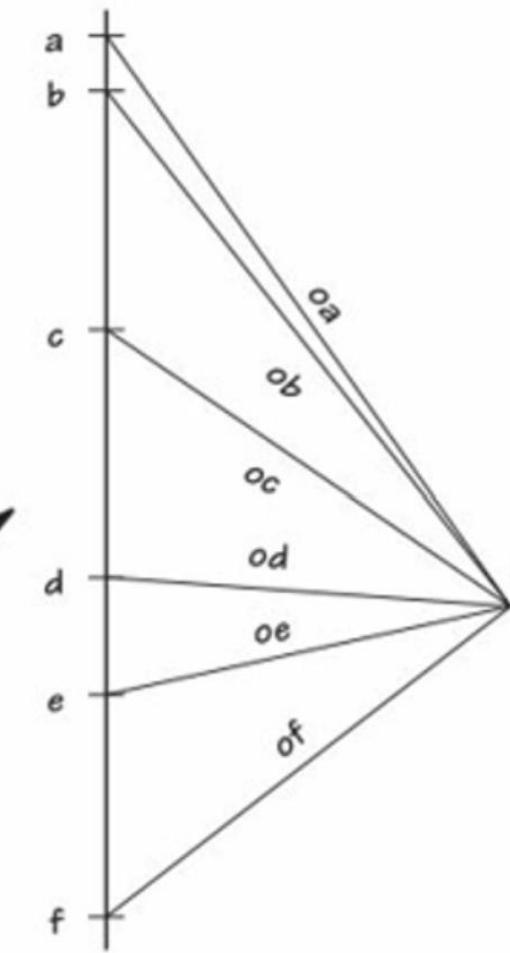


Graphical Statics

Cable Design



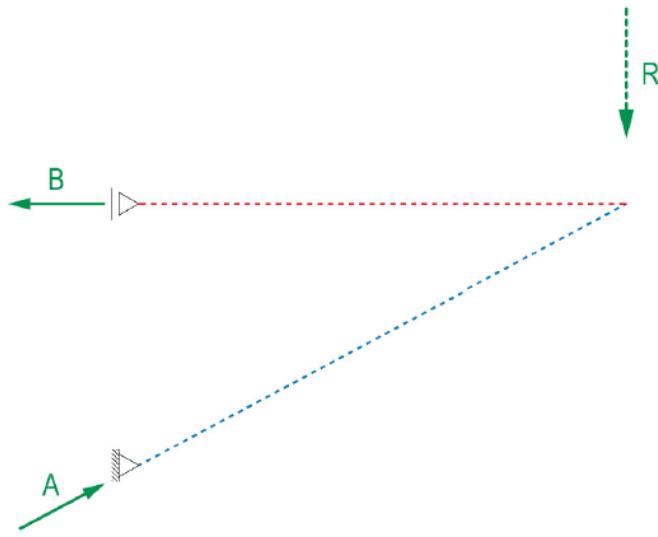
Funicular Polygon



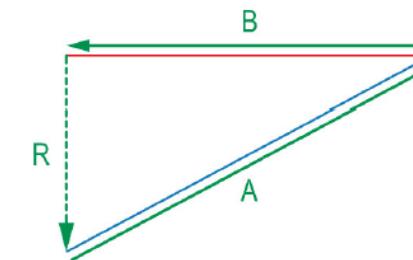
Force Polygon

Graphical Statics

Cantilever



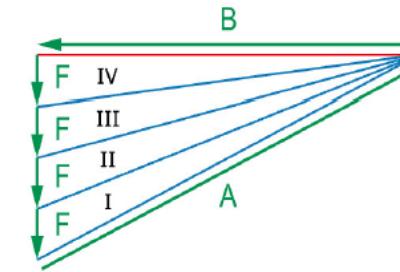
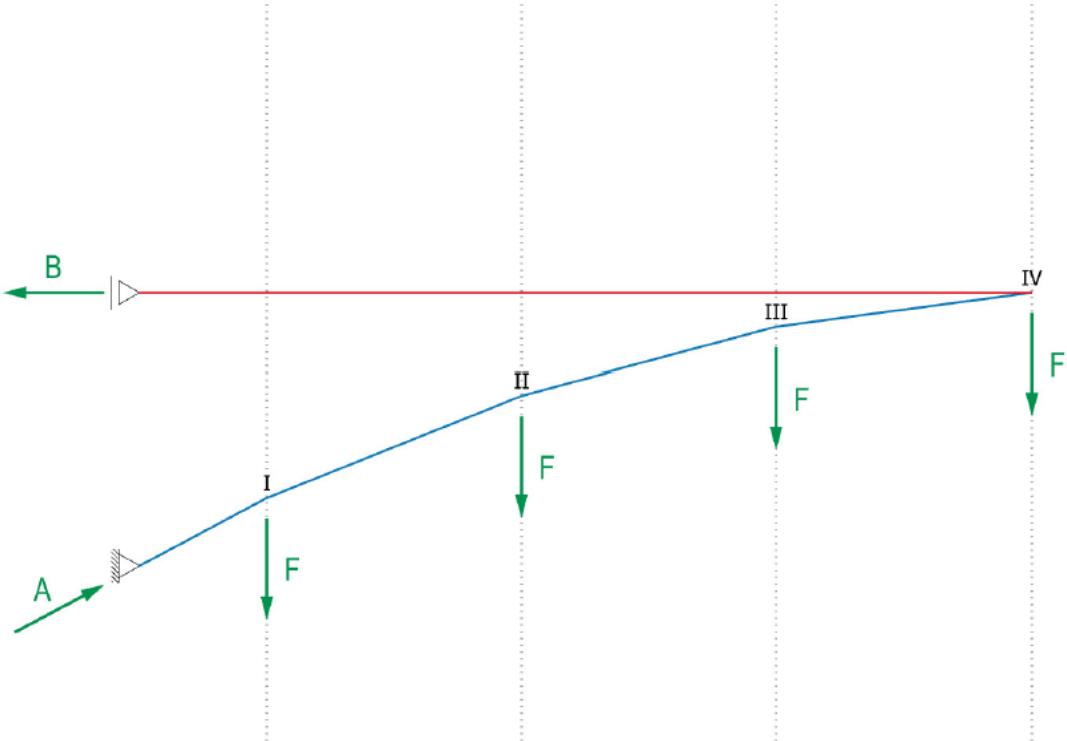
Form diagram



Force diagram

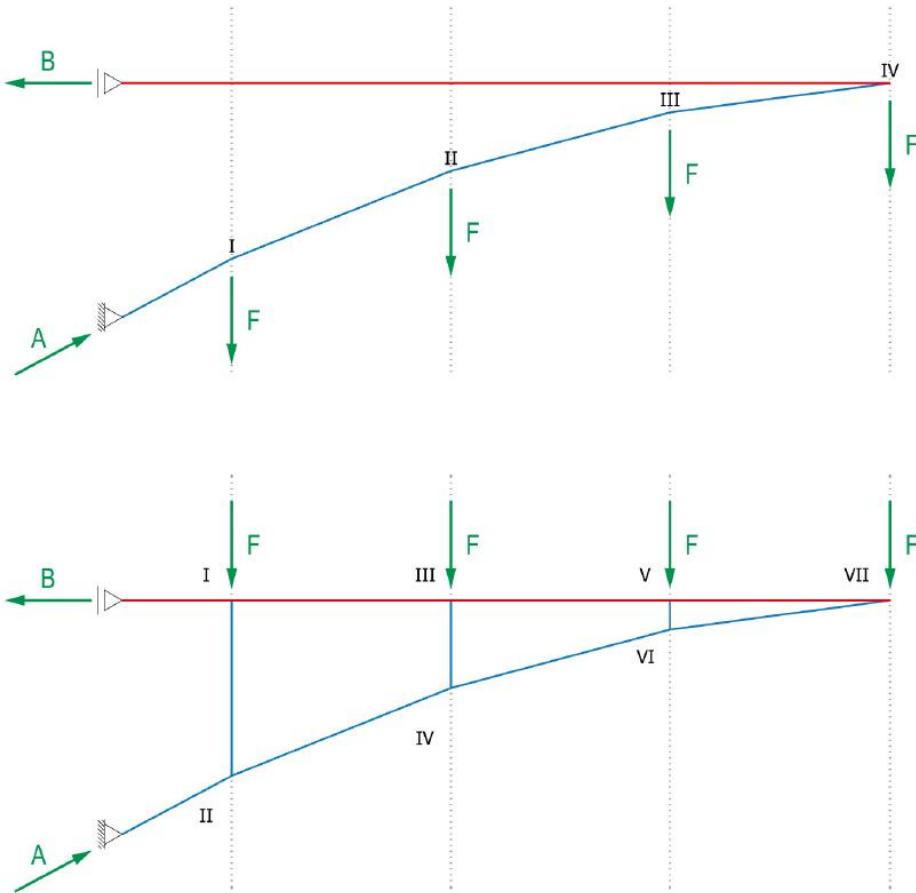
Graphical Statics

Cantilever

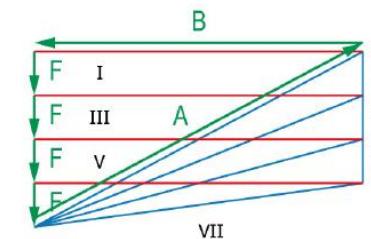
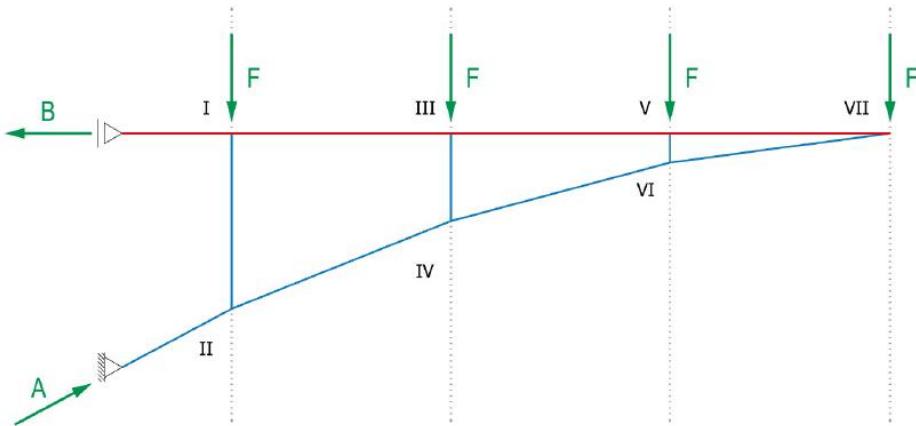
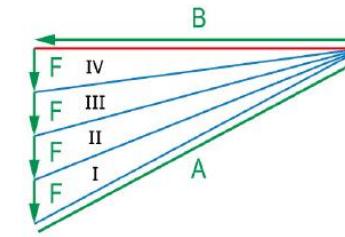


Graphical Statics

Cantilever



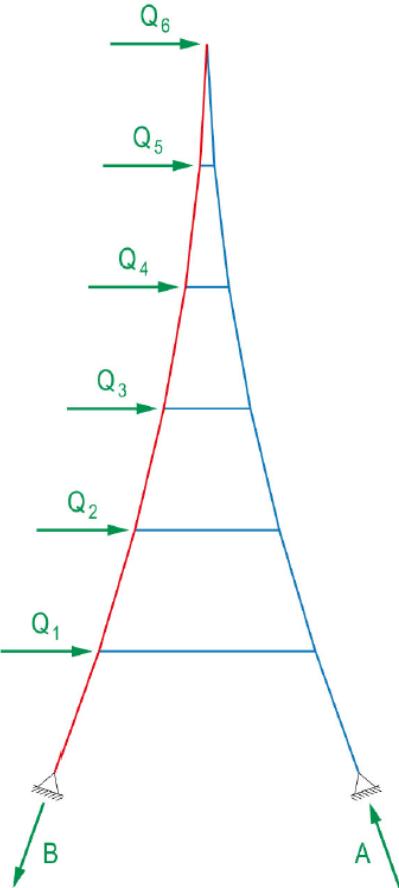
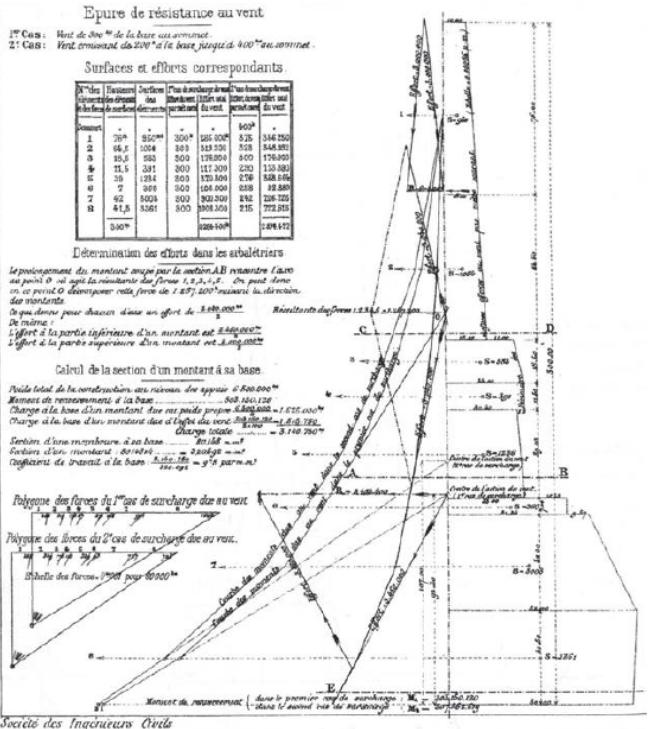
Form diagram



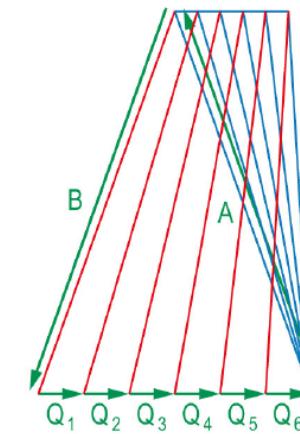
Force diagram

Graphical Statics

Eiffel Tower!



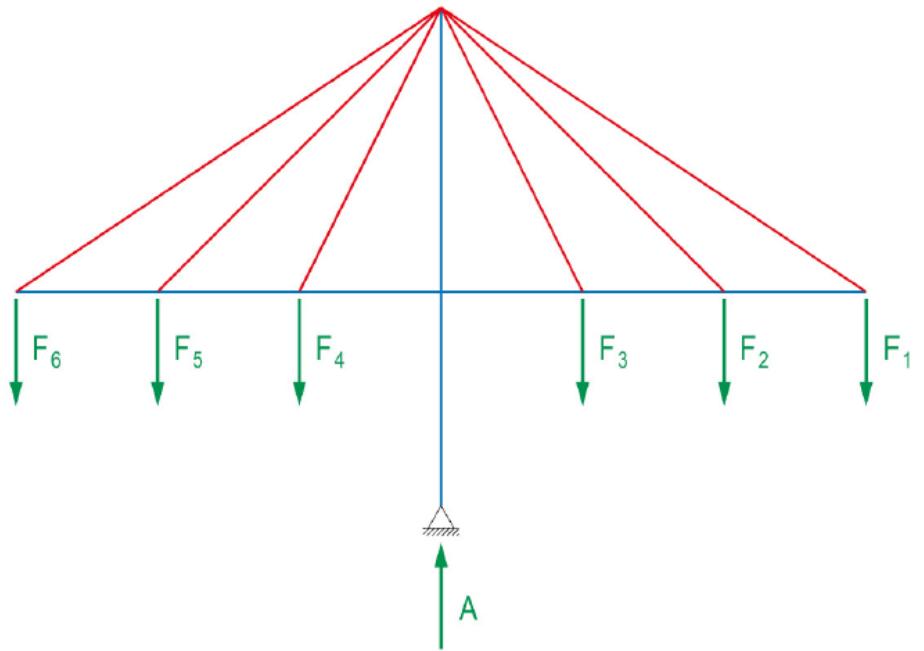
Form diagram



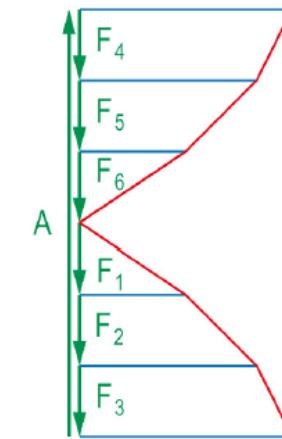
Force diagram

Graphical Statics

Cable-Stayed bridge



Form diagram



Force diagram

Graphical Statics

A harp-shape cable-stayed bridge

