Introduction to Structural Design

Me standing on top of an arch I built using the CASTonCAST system

Table of Contents

1. What is Structural Design?
2. Aim, content and structure of the course
3. Introduction to Graphic Statics

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1. **What is Structural Design?**
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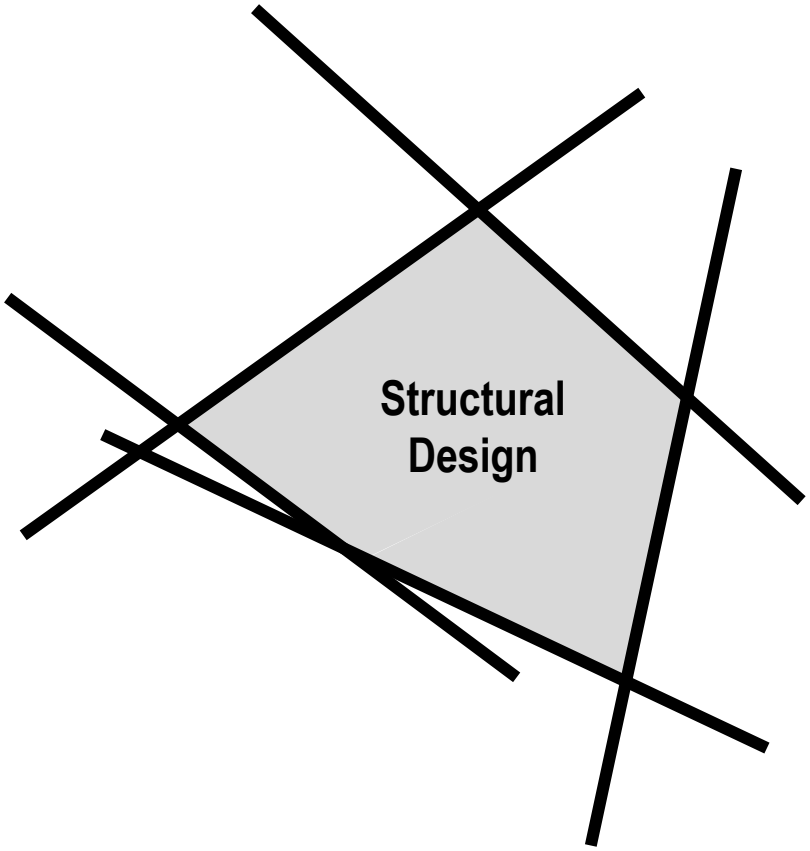
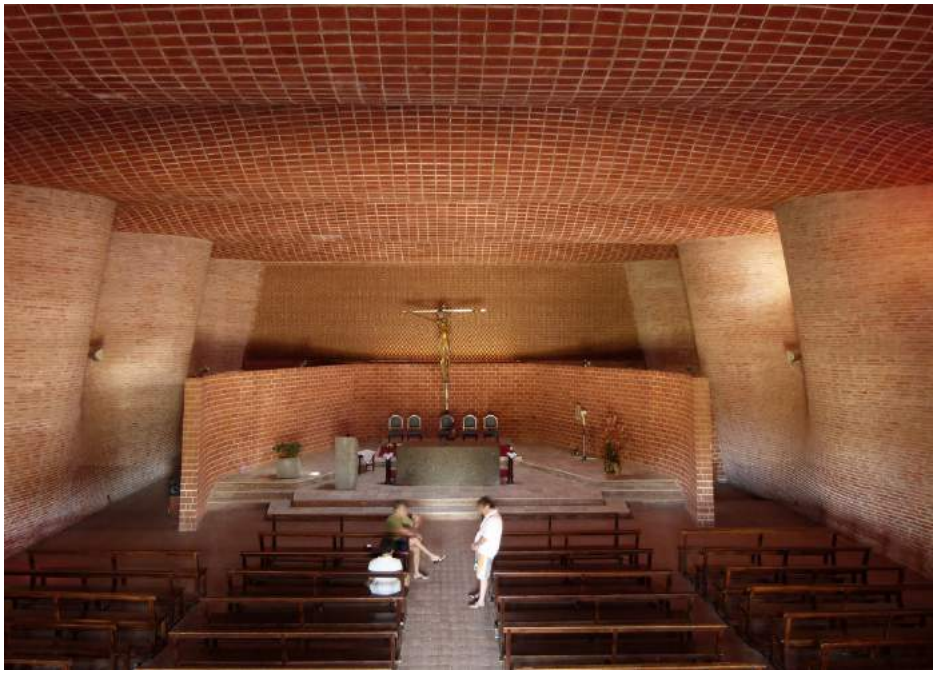
3. Introduction to Graphic Statics


Structural
Design

1. Without structure there is no architecture

A tent somewhere in the icy mountains

2. Structures without architecture are just structures



Eladio Dieste: Atlantida Church, 1960

3. What is the purpose of the structure?
What is the meaning of the structure?

Collapse of a building due to earquake

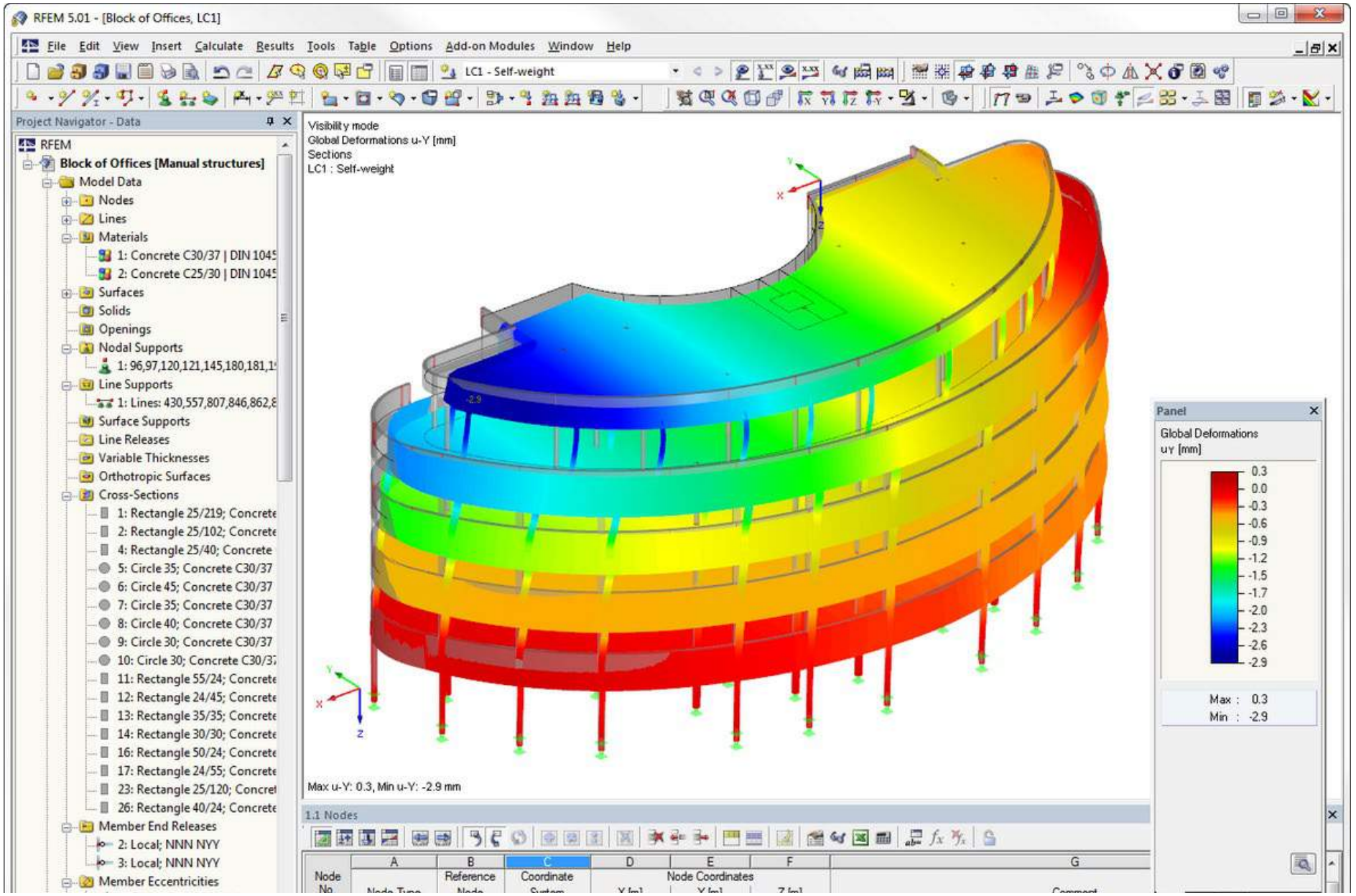
Daniel Libeskind: Royal Ontario Museum, Toronto, 2007.

4. Structural Design is not about doing mathematical calculations

«Structural design is concerned with much more than science and techniques: it is also very much concerned with art, common sense, sentiment, aptitud, and enjoyment of the task of creating opportune outlines to which scientific calculations will add finishing touches, substantiating that the structure is sound and strong in accordance with the requirements.

Mathematics is merely a convenient tool by which the designer determines the physical proportions and details of a planned structure in order to transform his ideas from the lines of a blueprint to the actuality of a finished structure»

Eduardo Torroja

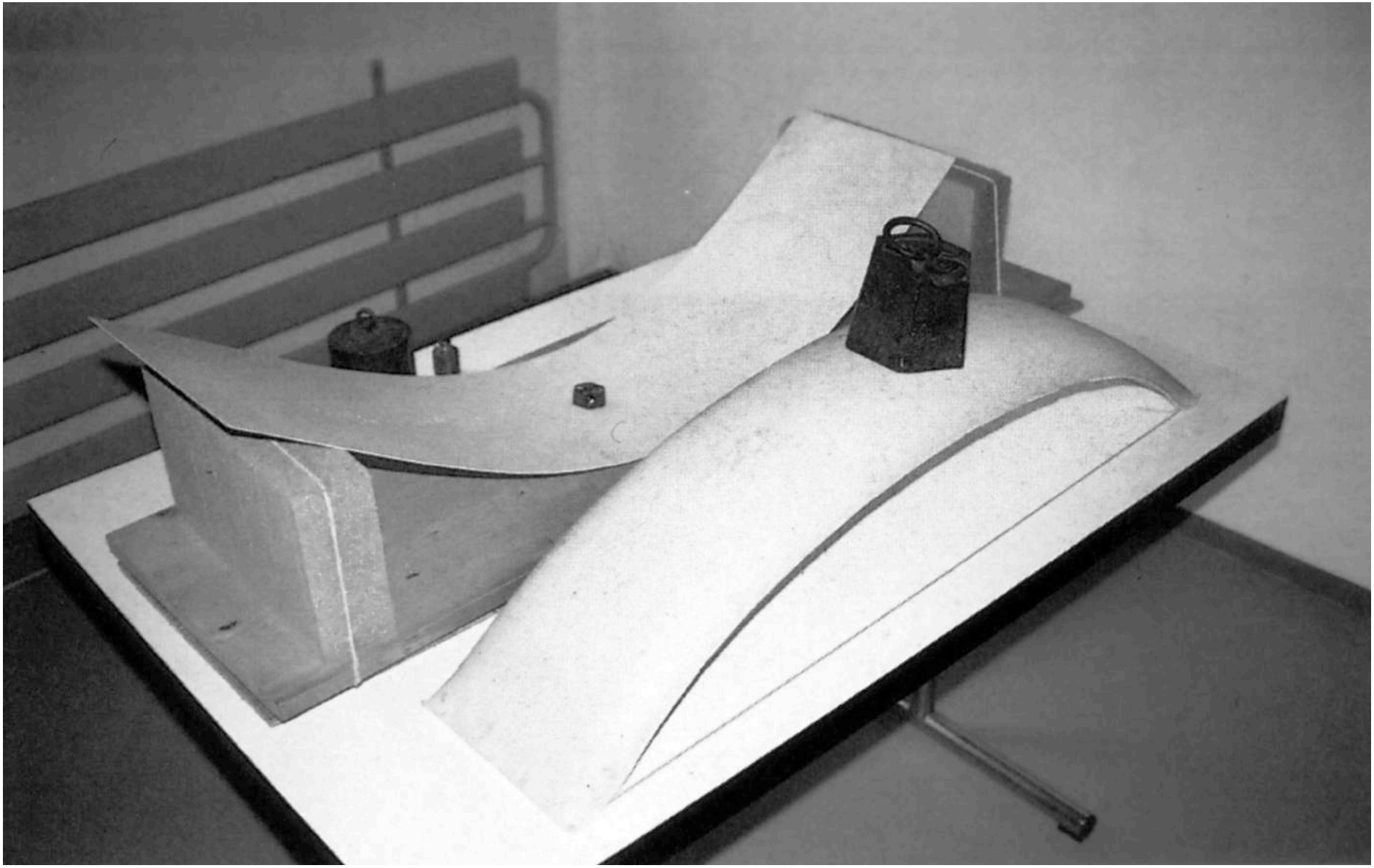


FEM structural analysis of a building.

5. Form matters

„The resistant virtues of the structures that we make depend on their form. It is through their form that they are stable and not because of an awkward accumulation of materials. There is nothing more noble and elegant from an intellectual point of view than this, resistance through form“.

Eladio Dieste



Model of Heinz Isler showing the structural resistance of doubly-curved surfaces

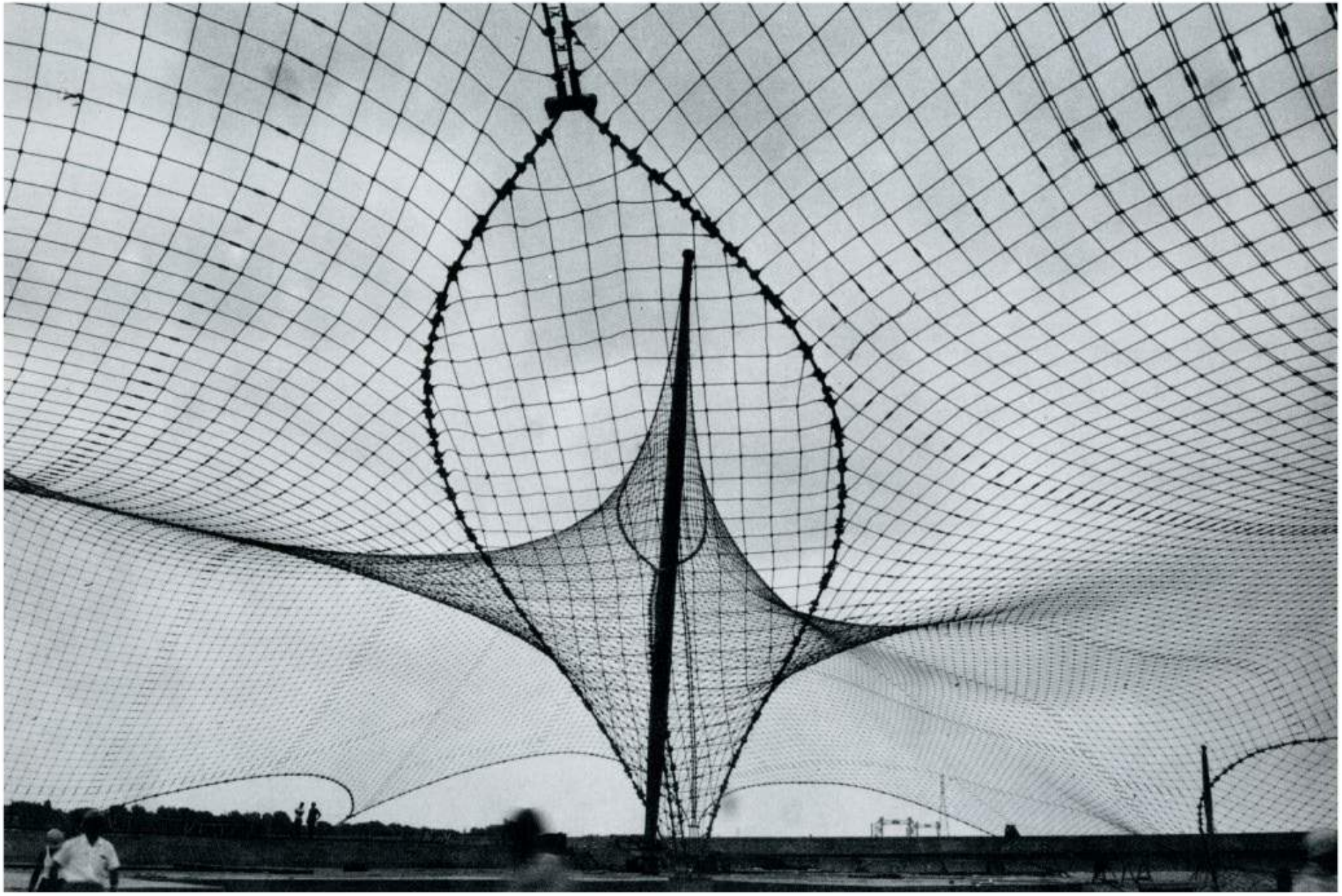
Heinz Isler: Sicli Company Building, Geneva, 1970

6. Nature knows something…but don't directly imitate nature

Spiderweb

„It's not very scientific to take nature as a model; nature can't be imitated because it's very complex. In principle it seems very simple but it is actually very complicated and should not be interpreted mistakenly. People say that I focus on bioology only to create new structure, but that's not true. I am just very curious to know what nature is".

Frei Otto

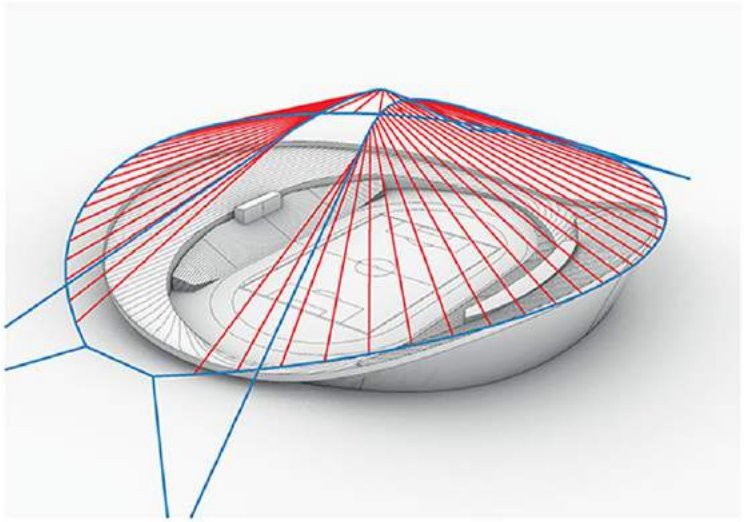


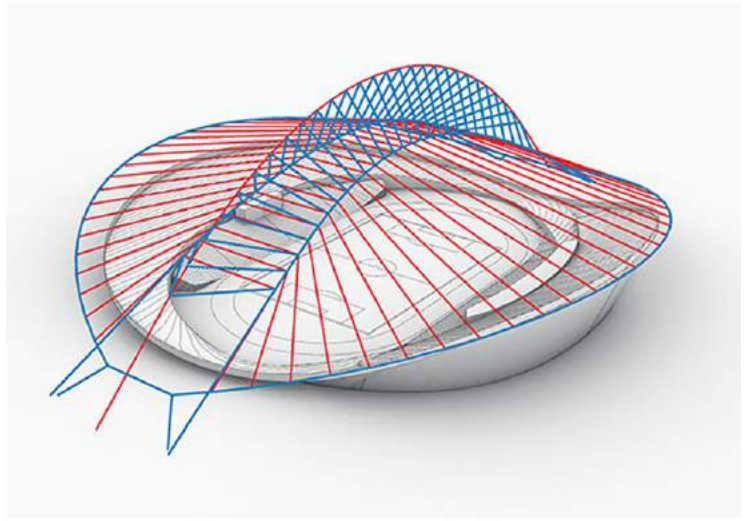
Frei Otto: Montreal Pavilion, Montreal, 1967.

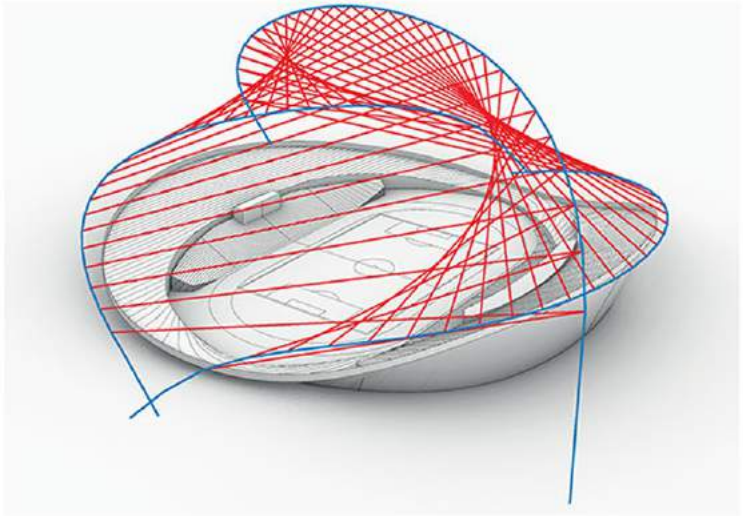
7. Creativity is essential

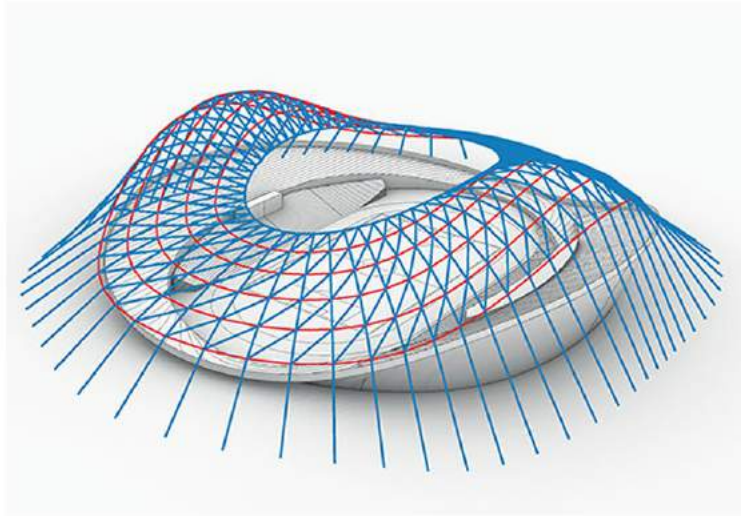
„During the conceptual phase in particular, it is imperative for the engineer to pay special attention to the internal forces, to make the load-bearing form congruent with these forces and, most importantly, to exhaust the possibilities offered by three-dimensional structural analysis“.

Joseph Schwartz









Patrick Ole Ohlbrock and Pierluigi D'Acunto: Combinatorial Equilibrium Modelling

8. Each material likes a certain form

«To express is to drive.
And when you want to give something presence,
you have to consult nature.
And there is where design comes in.

And if you think of brick, for instance,
and you say to brick:
'What do you want, brick?'
And brick says to you:
'I like an arch.'
And if you say to brick:
'Look, I want one, too, but arches are expensive and I can use a concrete lintel.'
And then you say:
'What do you think of that, brick?'
Brick says:
'... I like an Arch' »

Louis I. Kahn

Louis Kahn: Fort Wayne Performing Arts Theater, Indiana, 1958-73.

9. The term efficiency can be very confusing

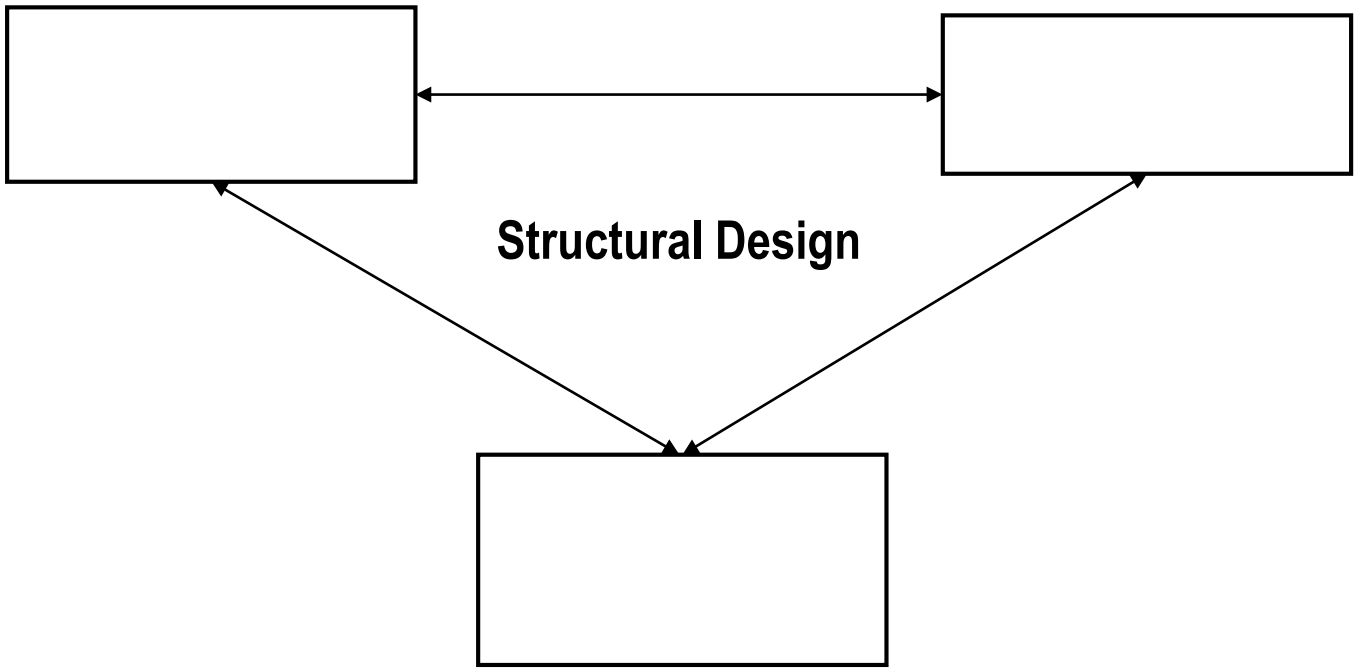
Felix Candela, Los Manantiales restaurant, 1958

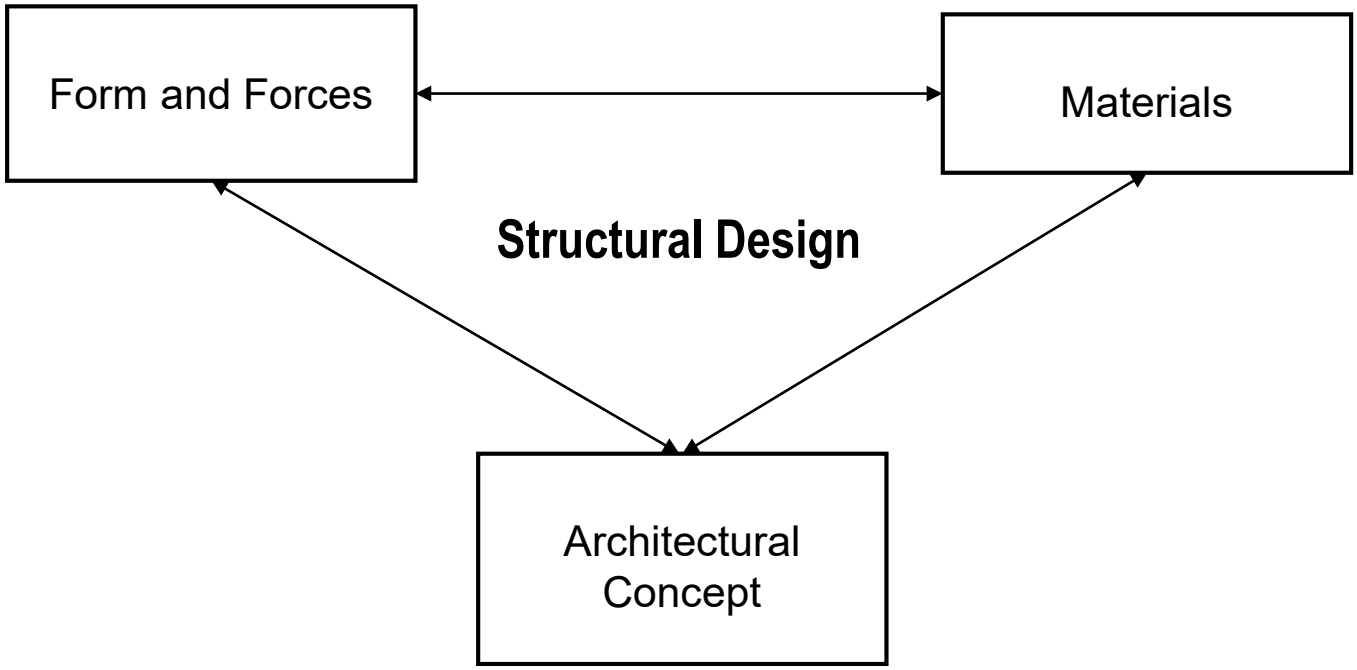
Felix Candela, Los Manantiales restaurant, 1958

10. A building whose architecture and structure are not close together reflects a bad relationship between the architect and the engineer.

Frank Gehry, Los Angeles Concert Hall, 2003

Frank Gehry, Los Angeles Concert Hall, 2003


Structural Design


Form and Forces
Materials
Structural Design
Architectural
Concept

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BACHELOR

MASTER

Structural Design I

Form and Force

Structural Design II

Structural Design III

Material

Structural Design IV

Design Project

Computational Structural Design I

Computational Graphic Statics

Computational Structural Design II

Form-finding and Fabrication

Architecture and Structure

Design

Force Material Form

History and Theory

Introduction to Structural Design

Introduction

1. Cables and Arches

Exercise 1: Cables and Arches

2. Arch-cables and Trusses

Exercise 2: Arch-cable and Trusses

3. Beams and Frames

Exercise 3: Beams and Frames

4. Plates and Bracing

Exercise 4: Plates and Bracing

5. Materials

Exercise 5: Materials

6. Structural Design

Exercise 6: Structural Design

At the conclusion of this course, students will be able to:

1. Visualize the internal forces within two-dimensional structural elements.
2. Understand the relationship between the form of a structure and the internal forces within it.
3. Identify the most important structural typologies.
4. Use graphic statics for the form-finding and analysis of structures.
5. Carry out basic dimensioning of structural elements.
6. Conduct basic assessment of the structural behaviour of a building.
7. Understand the structural and architectural possibilities of the most important building materials.

Schedule

Week	Date	Type	Title
1	**17.09.2020**	**Lecture 0**	**Introduction**
2	**24.09.2020**	**Lecture 1**	**Cables and Arches**
3	01.10.2020	Exercise 1	Cables and Arches
4	**08.10.2020**	**Lecture 2**	**Arch-cables and Trusses**
5	15.10.2020	Exercise 2	Arch-cables and Trusses
-	22.10.2020	-	Seminar Week
7	**29.10.2020**	**Lecture 3**	**Beams and Frames**
8	05.11.2020	Exercise 3	Beams and Frames
9	**12.11.2020**	**Lecture 4**	**Plates and Bracing**
10	19.11.2020	Exercise 4	Plates and Bracing
11	**26.11.2020**	**Lecture 5**	**Materials**
12	03.12.2020	Exercise 5	Materials
13	**10.12.2020**	**Lecture 6**	**Structural Design**
14	17.12.2020	Exercise 6	Structural Design

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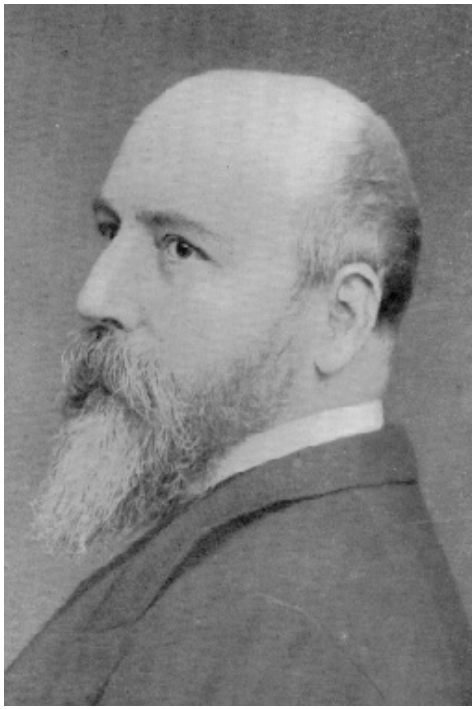
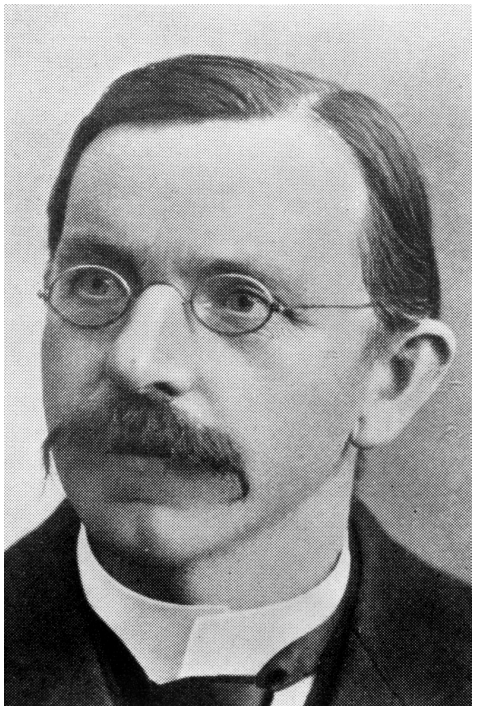
Carl Culmann
1821 - 1881

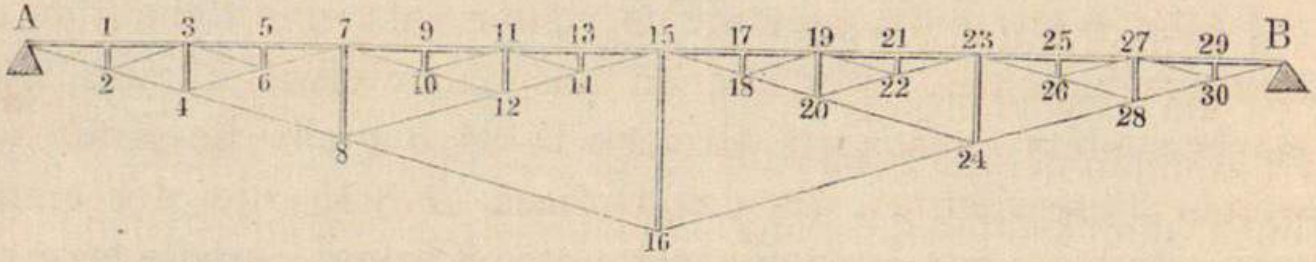


Luigi Cremona
1830 - 1903



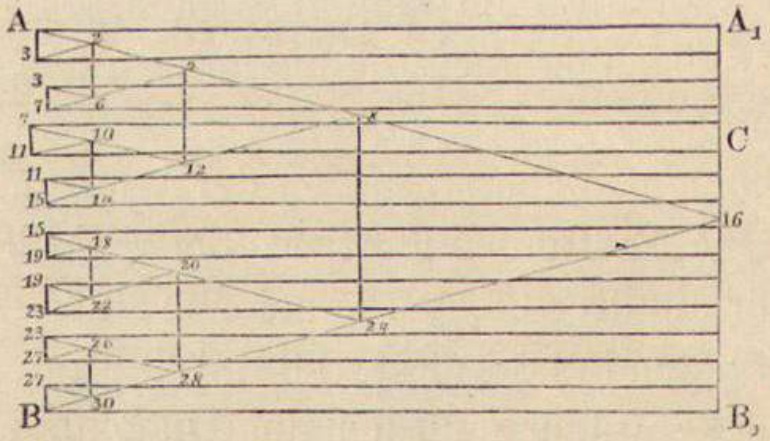
Karl-Wilhelm Ritter
1847-1905

Fig. 168.

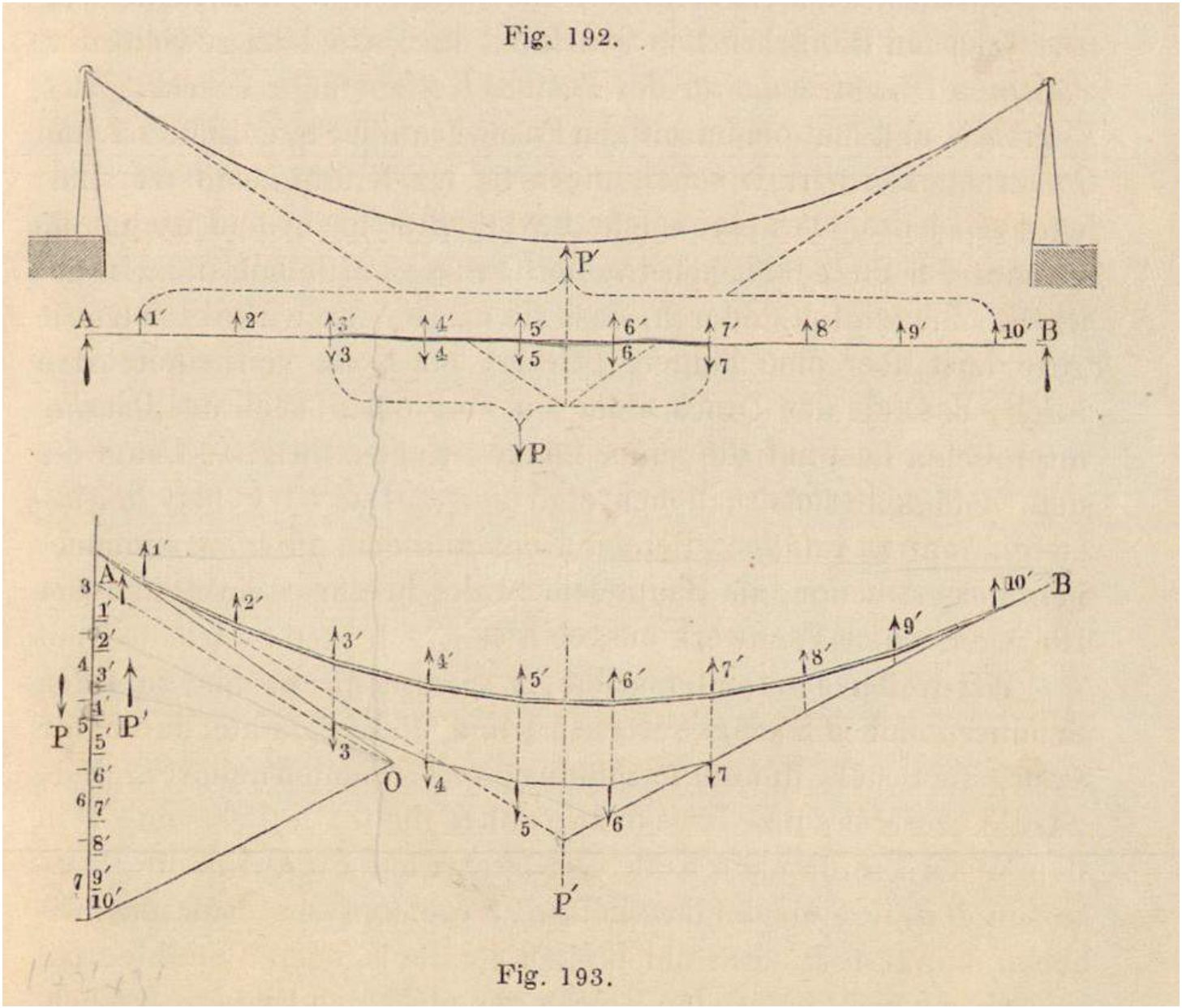


tungen 2 4 und 4 6 mittelst des Kräftedreiecks 2 4 6 (Fig. 169) und giebt uns die Spannung 4 6 in der entsprechenden Schlauderstrecke. Diese mit der vom Pfosten 5 6 (Fig. 168) herrührende Spannung

Fig. 169.

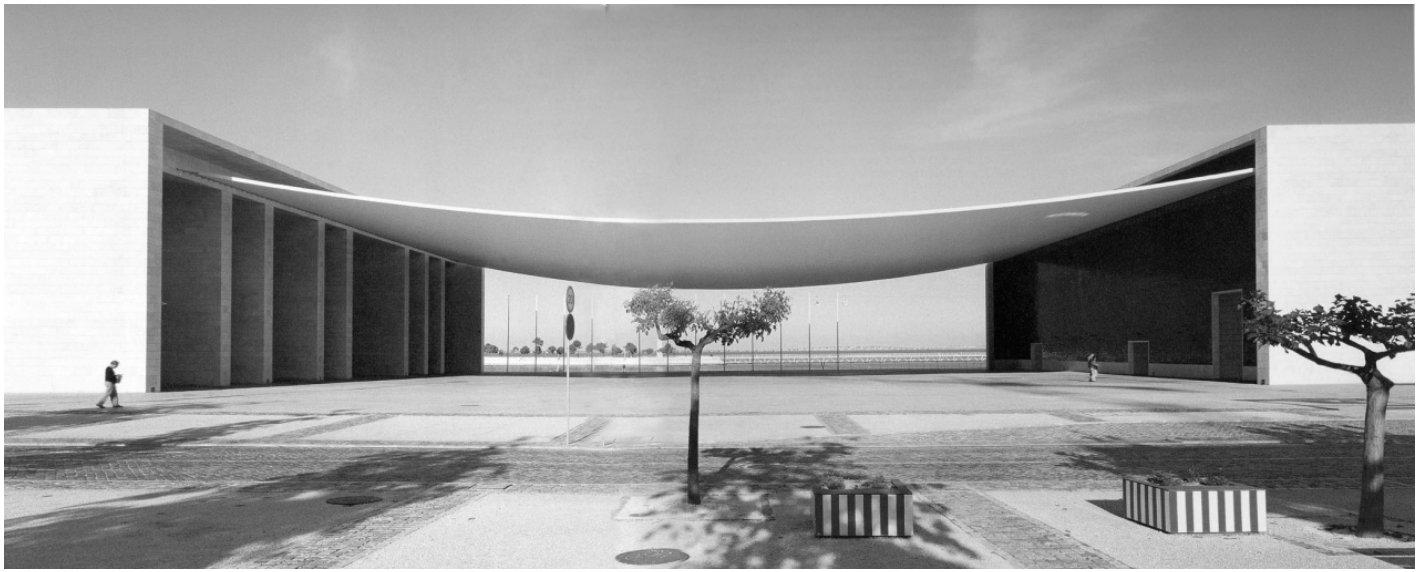


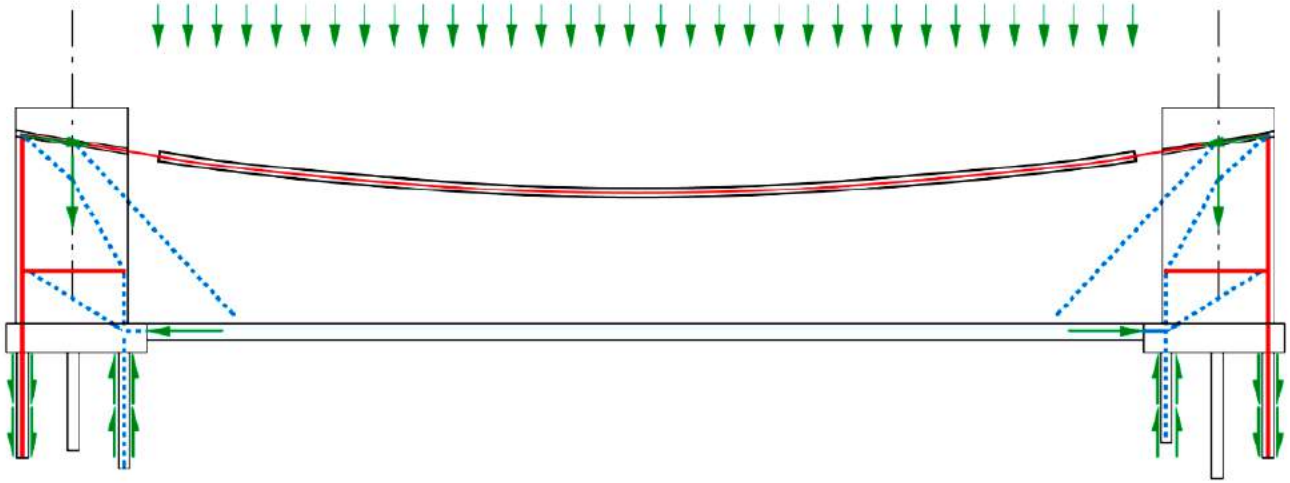
Carl Culmann, Die graphische Statik, S. 465



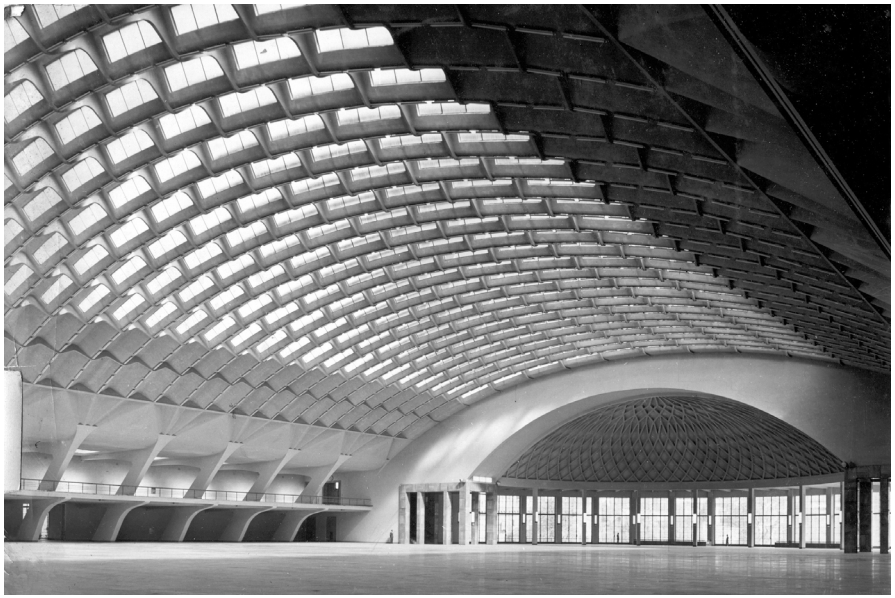
Carl Culmann, Die graphische Statik, S. 556

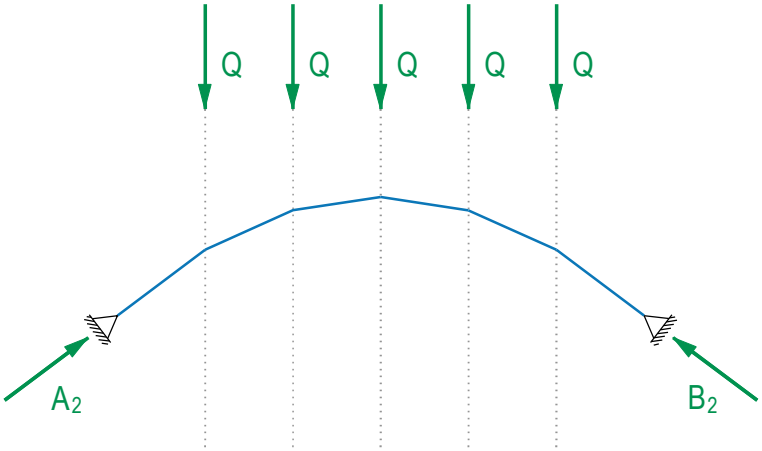
- Visualization of the internal forces in a structure
- Understand the relationship between the form and internal forces
- It can be used to analyze and design structures

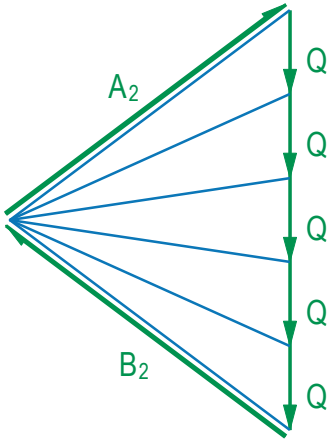


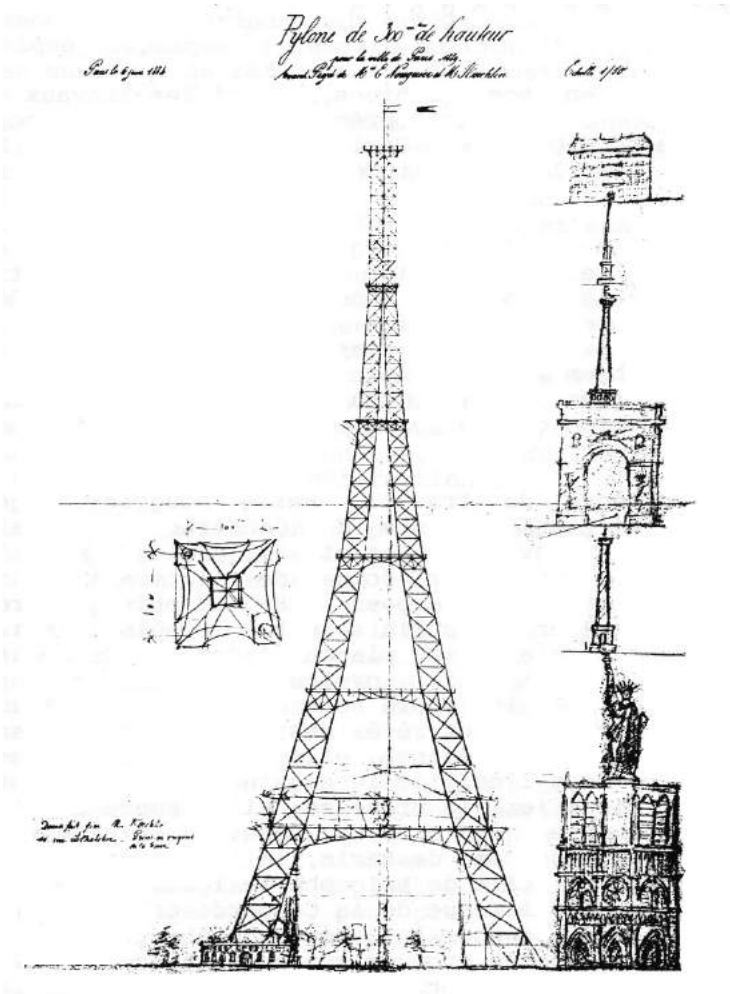


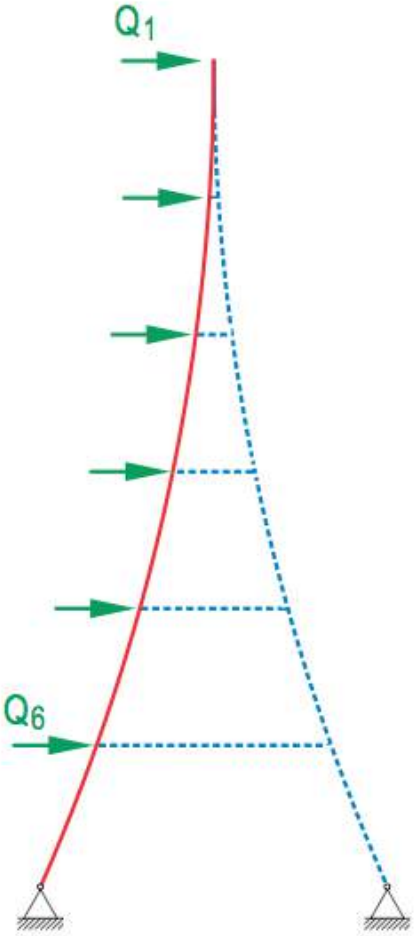
Alvaro Siza, Cecil Balmond : Expo Pavillion of Portugal, Lissabon, 1998

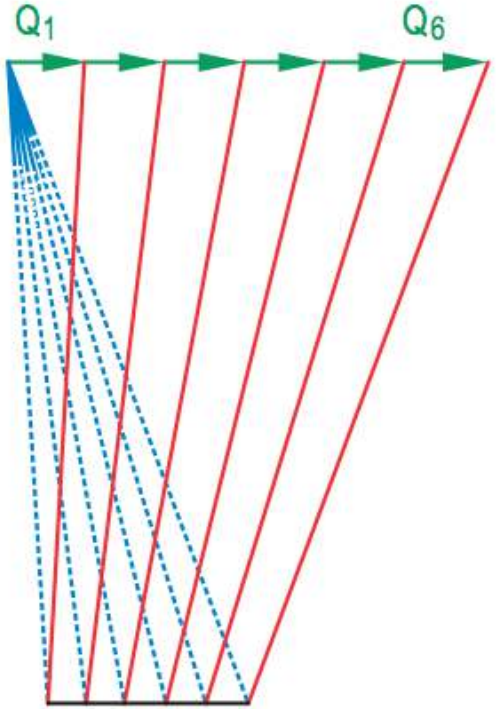



Q
Q
Q
Q
Q
A2
B2

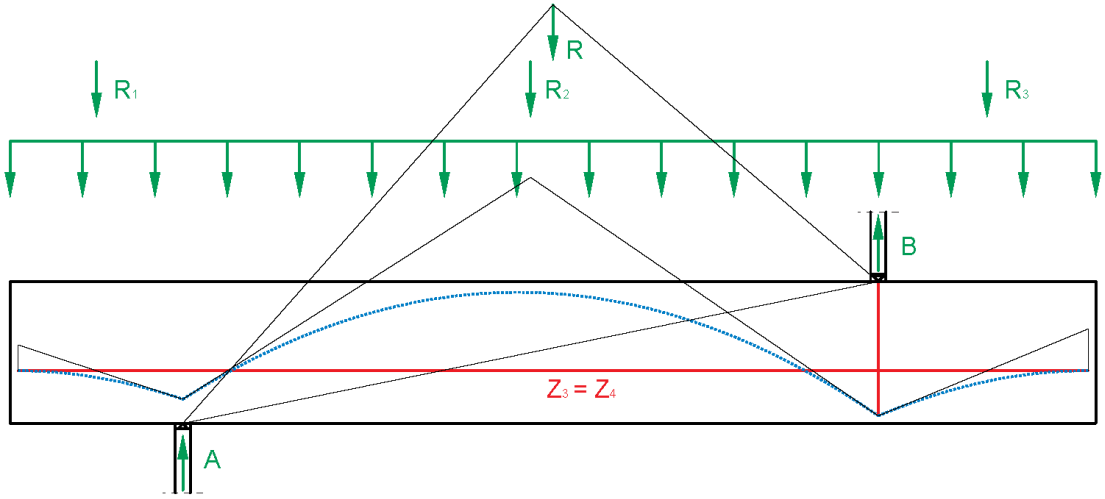

A2
Q
Q
Q
Q
Q
B2

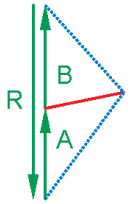


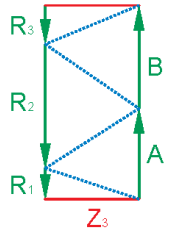




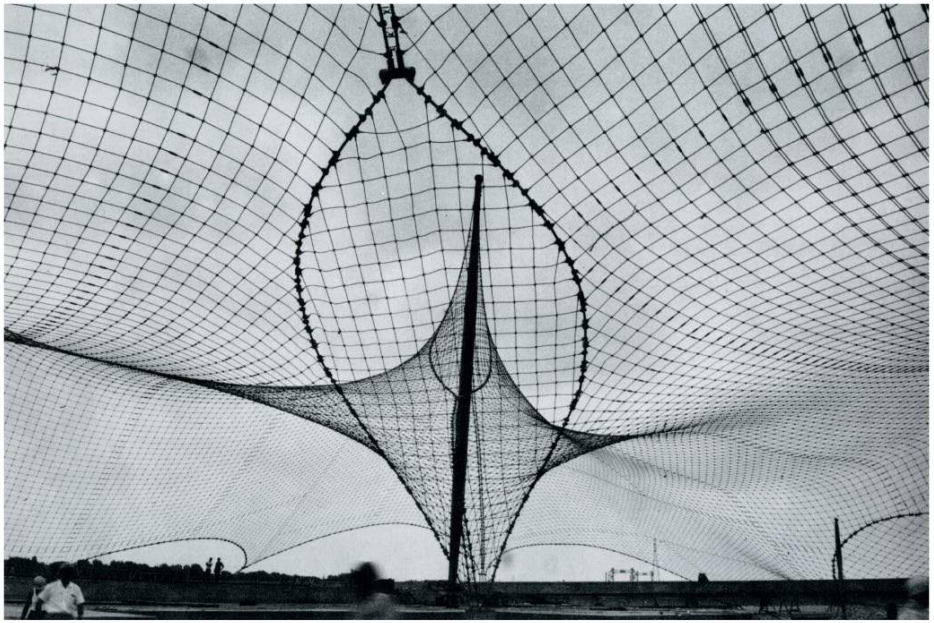
Structural Design Concept of the Eiffel Tower

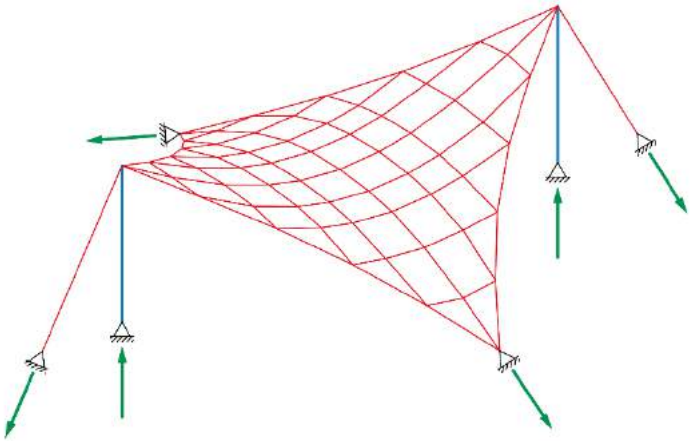




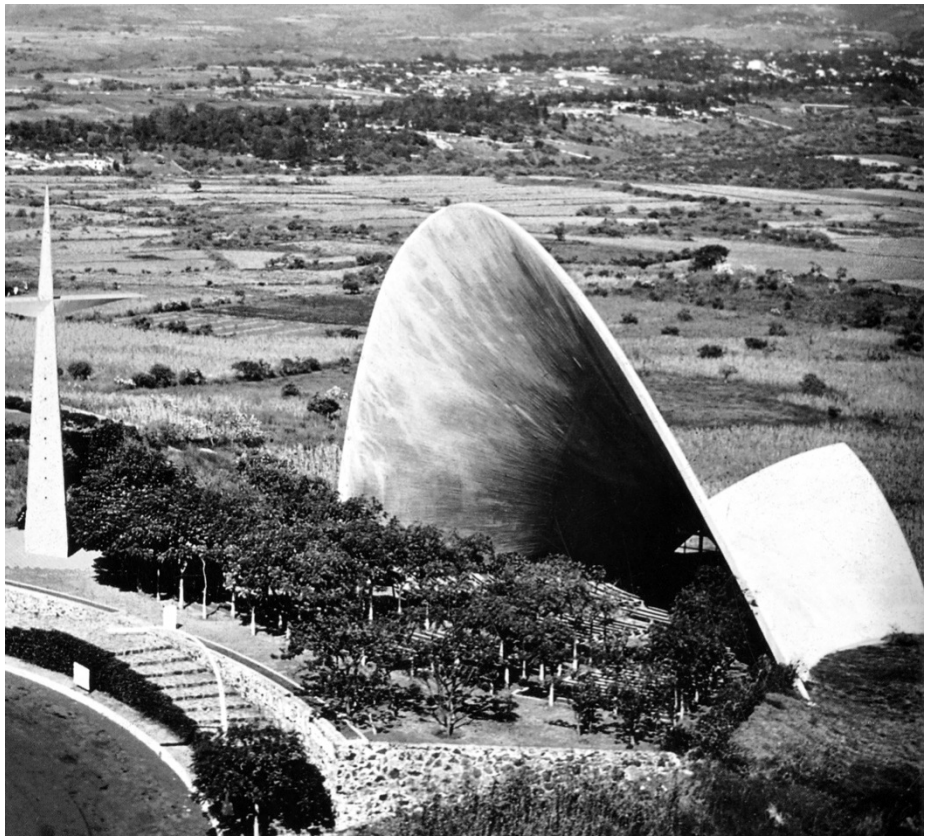


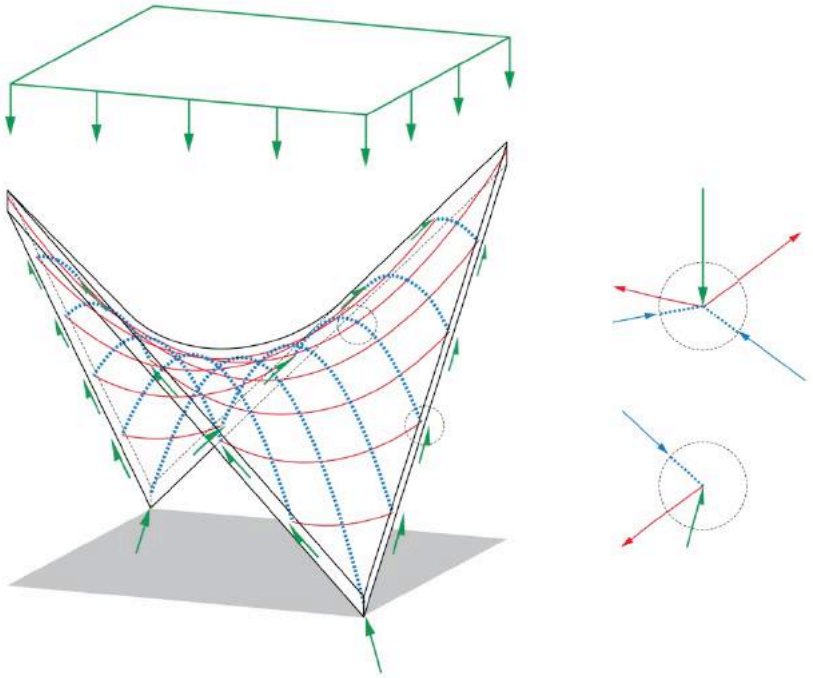
Maison á Floirac, Bordeaux, 1998, Arch.: Rem Koolhaas, Eng.: Cecil Balmond



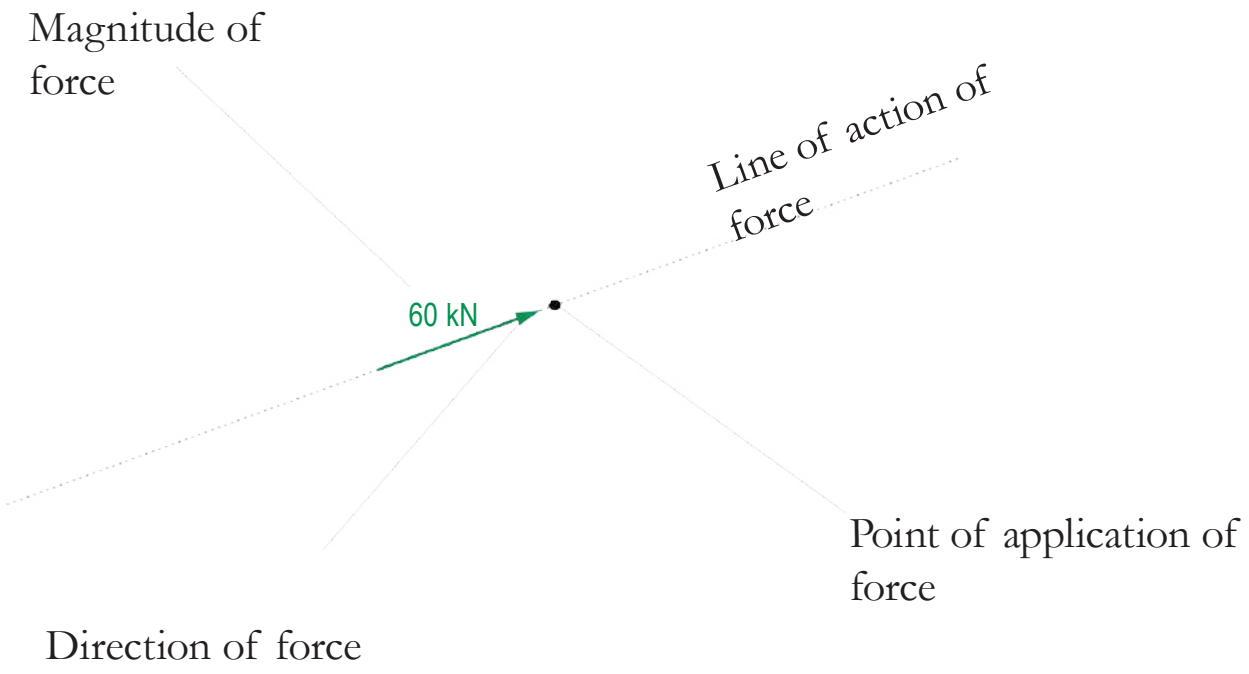


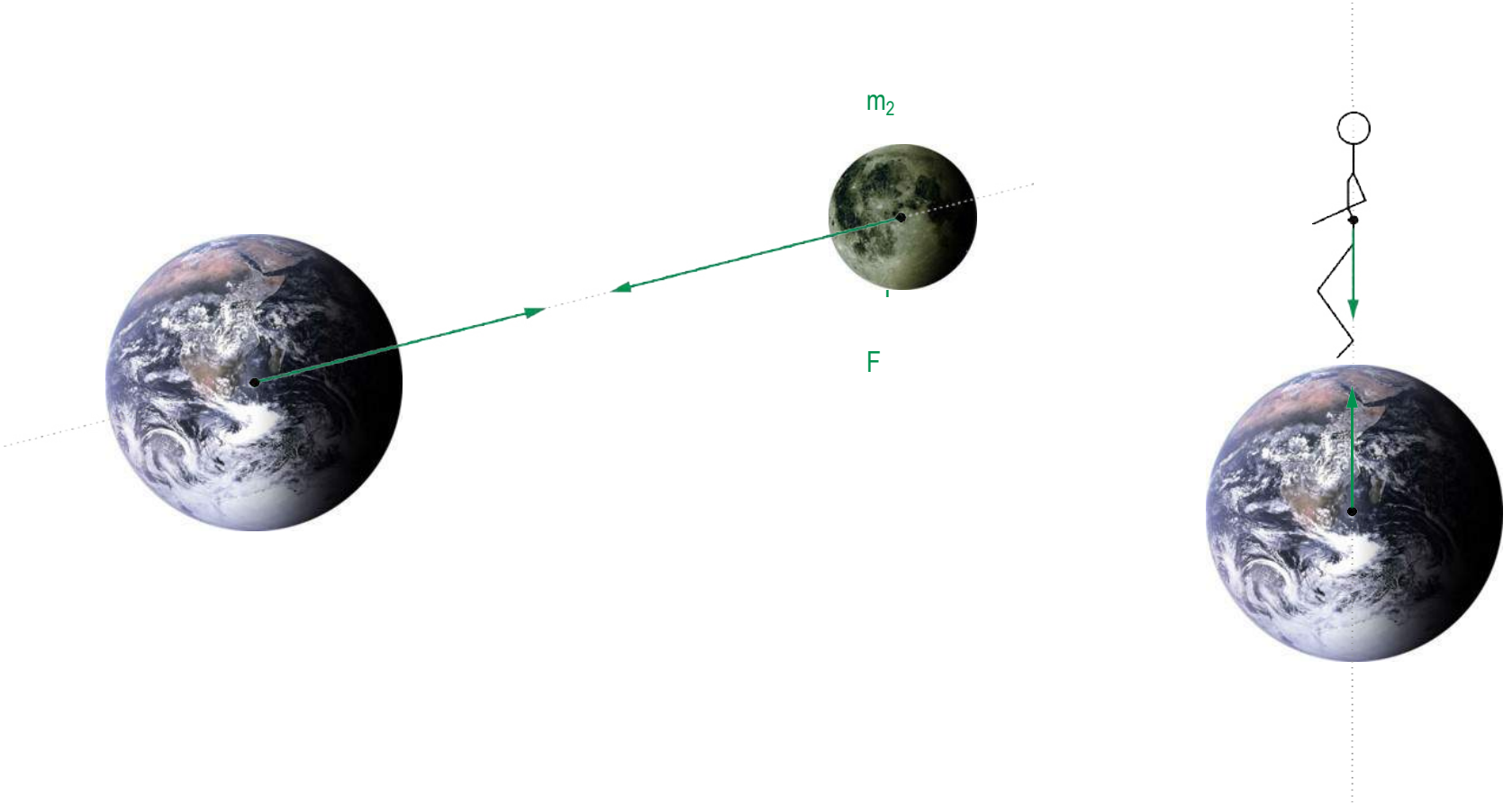
Frei Otto: Montreal Pavilion, Montreal, 1967.





Capilla abierta, Lomas de Cuernavaca, Felix Candela, 1959


Magnitude of force
Line of action of force
60 kN
Point of application of force
Direction of force



Gravity

Types of loads

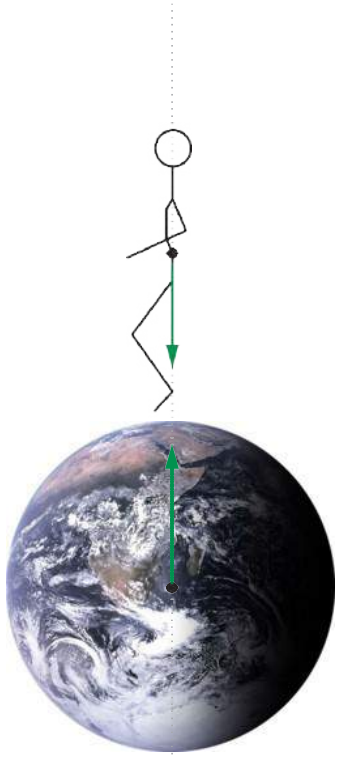
Types of loads

Types of loads

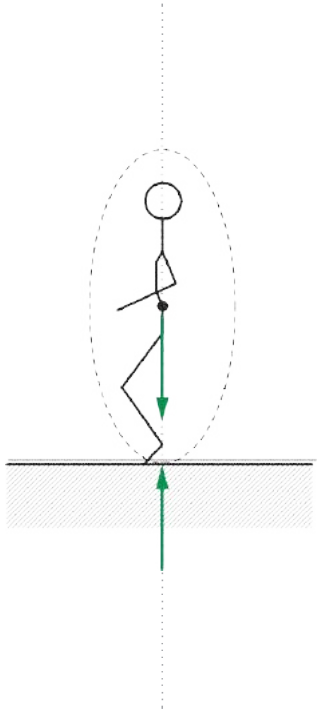
Types of loads

Types of loads

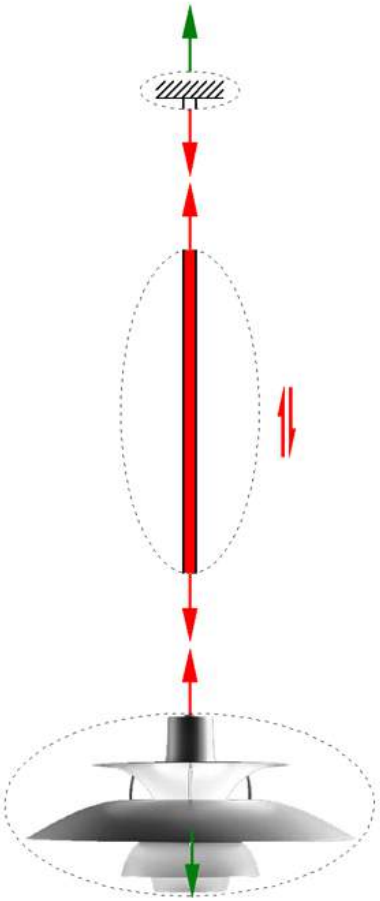
Subsystem

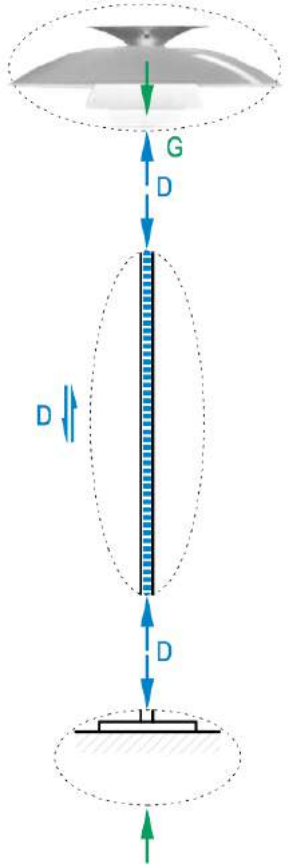


Form diagram in Subsystem

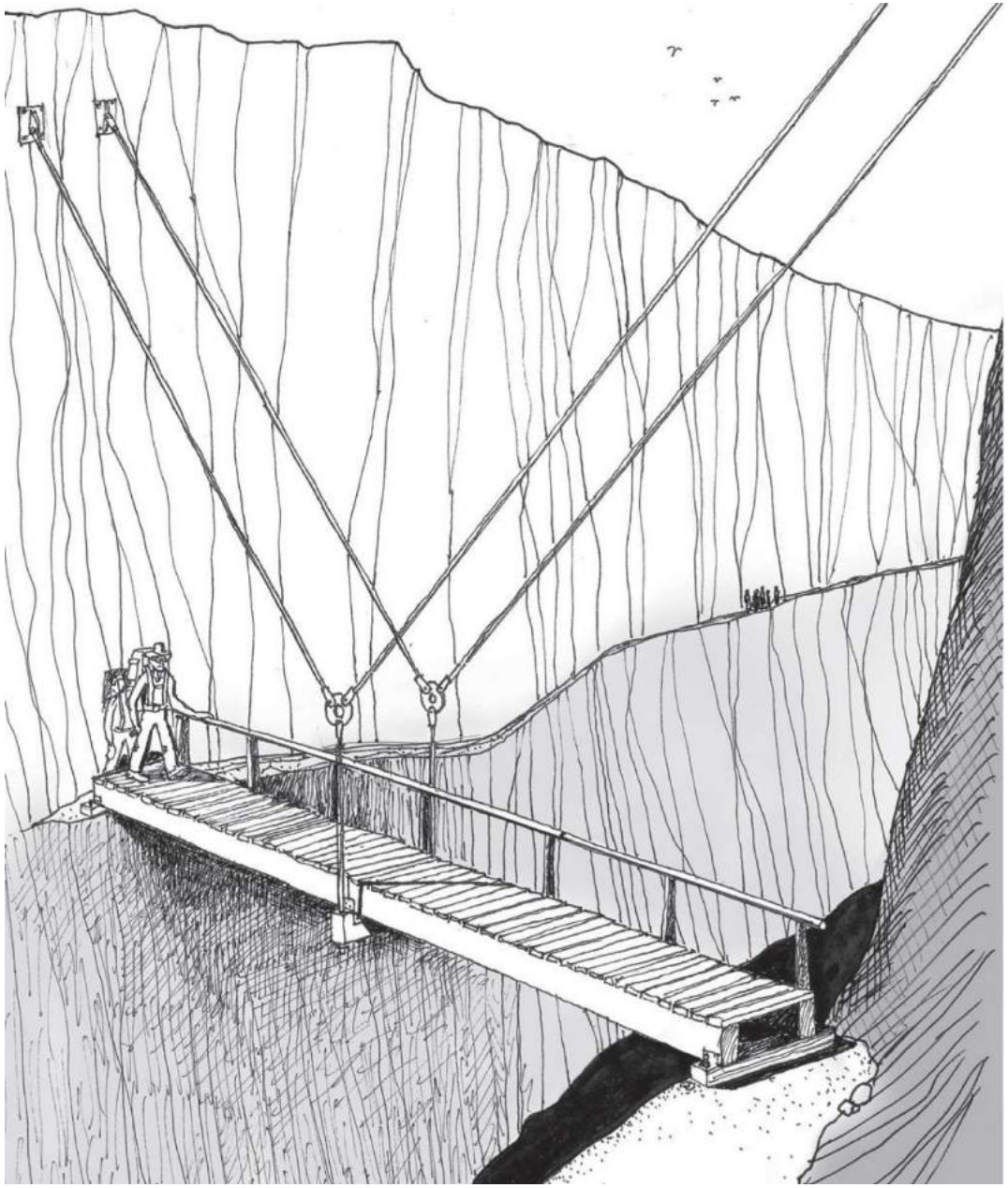


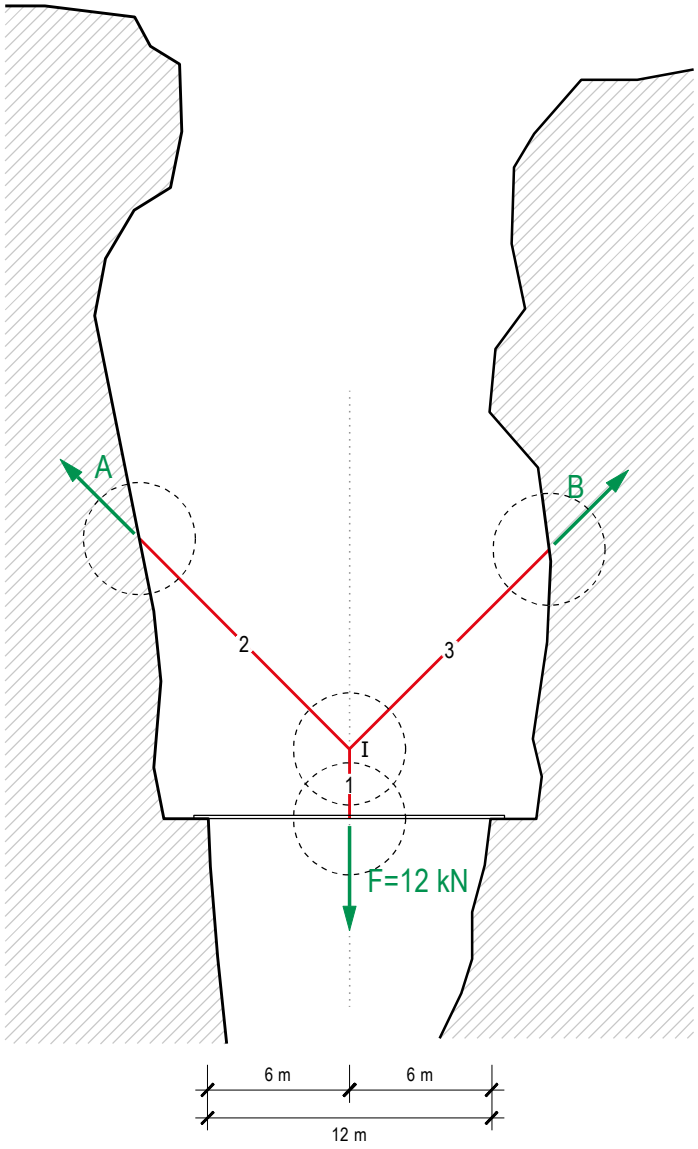
Force diagram



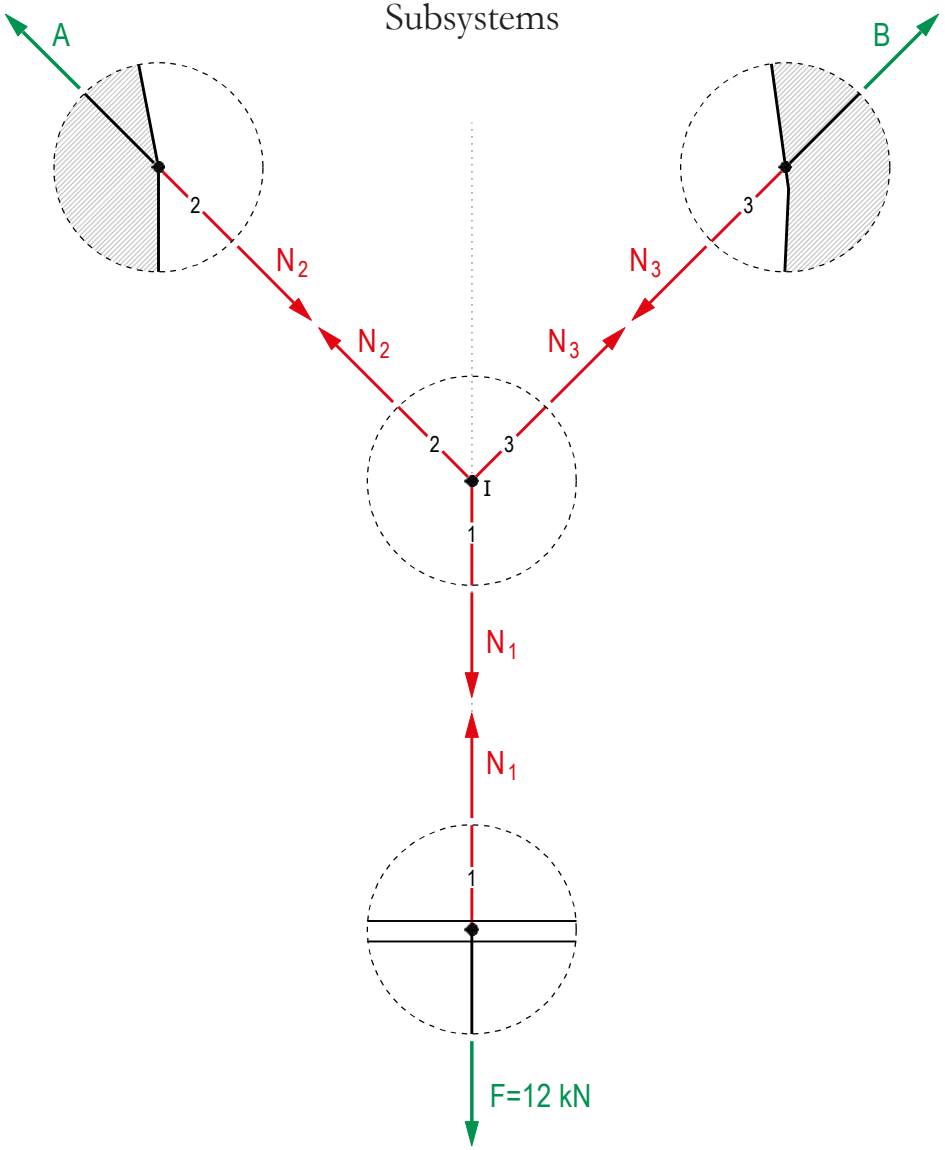


Internal forces

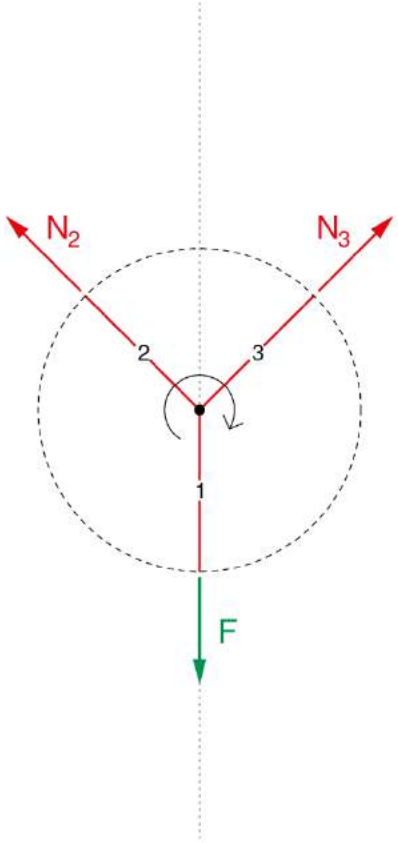




Subsystems



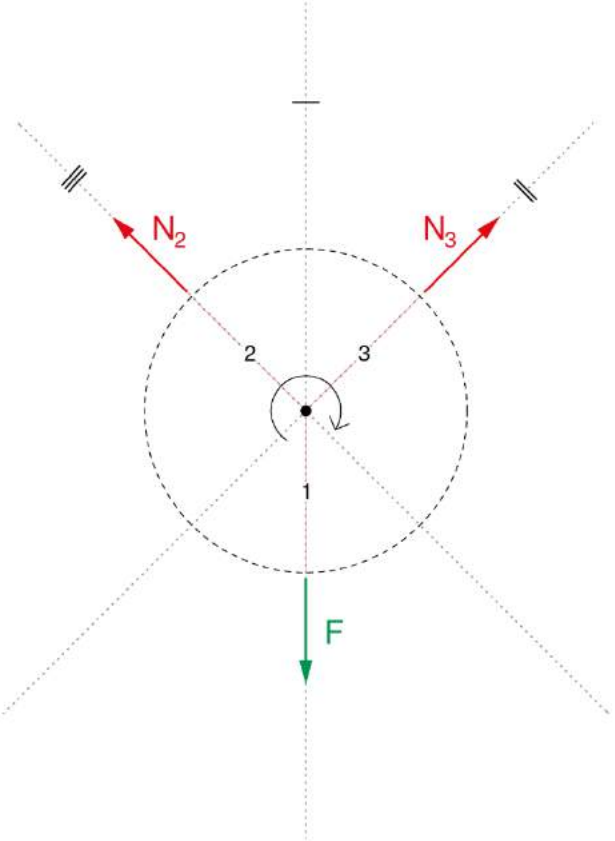
Subsystem



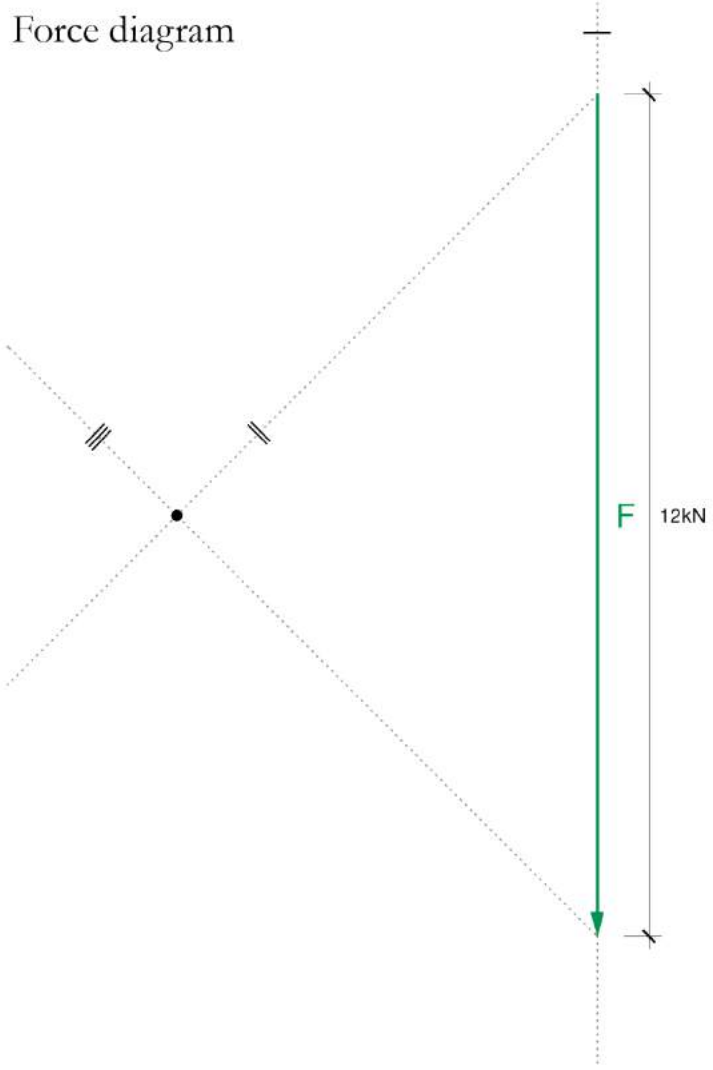
Force diagram

Scale 1 cm = 1 kN

Subsystem

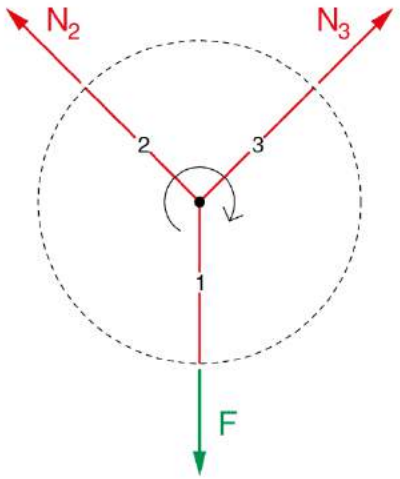


Force diagram

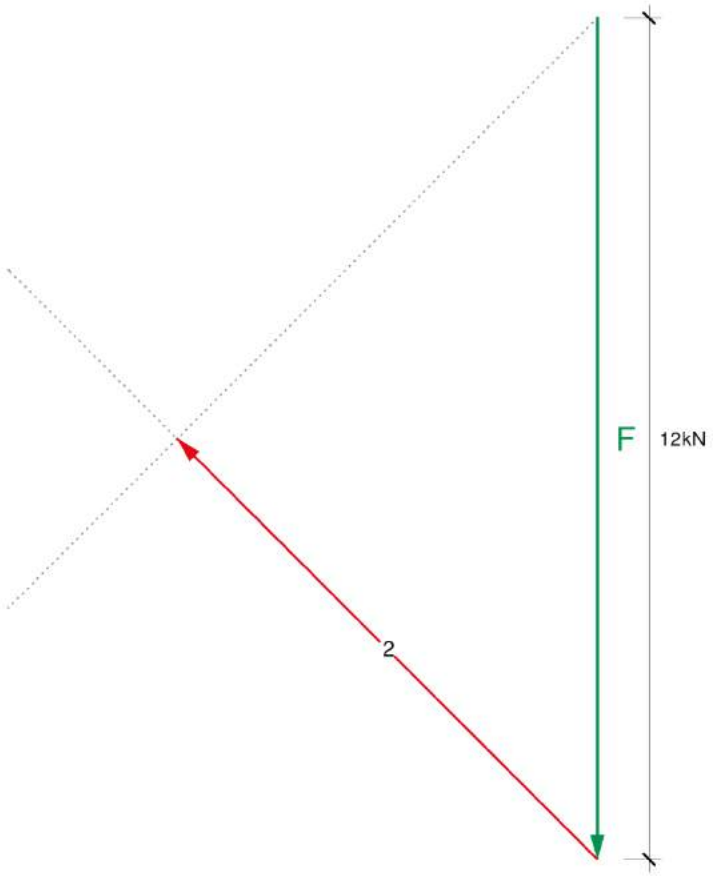


Scale 1 cm = 1 kN

Subsystem

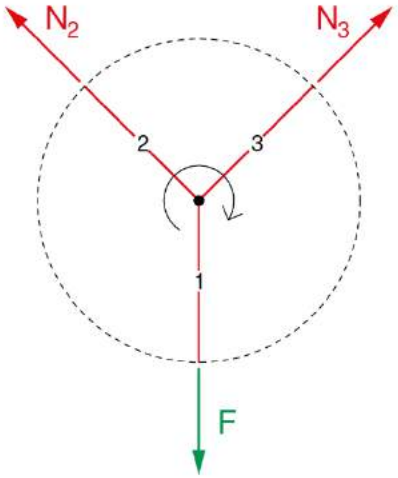


Force diagram



Scale 1 cm = 1 kN

Subsystem



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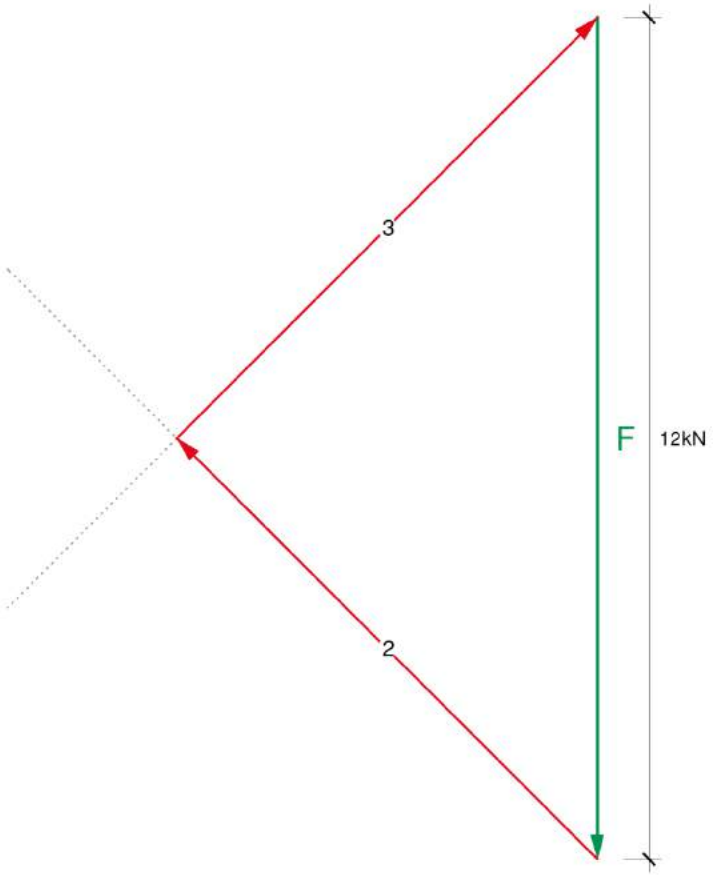
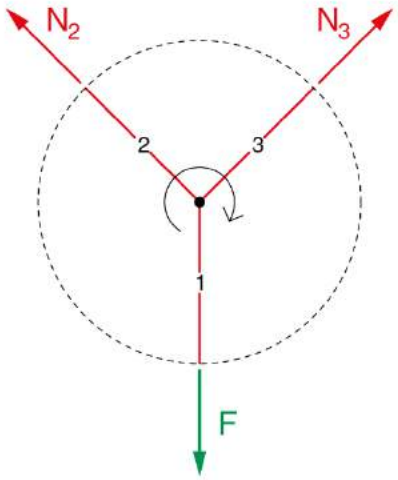


Scale 1 cm = 1 kN

Subsystem



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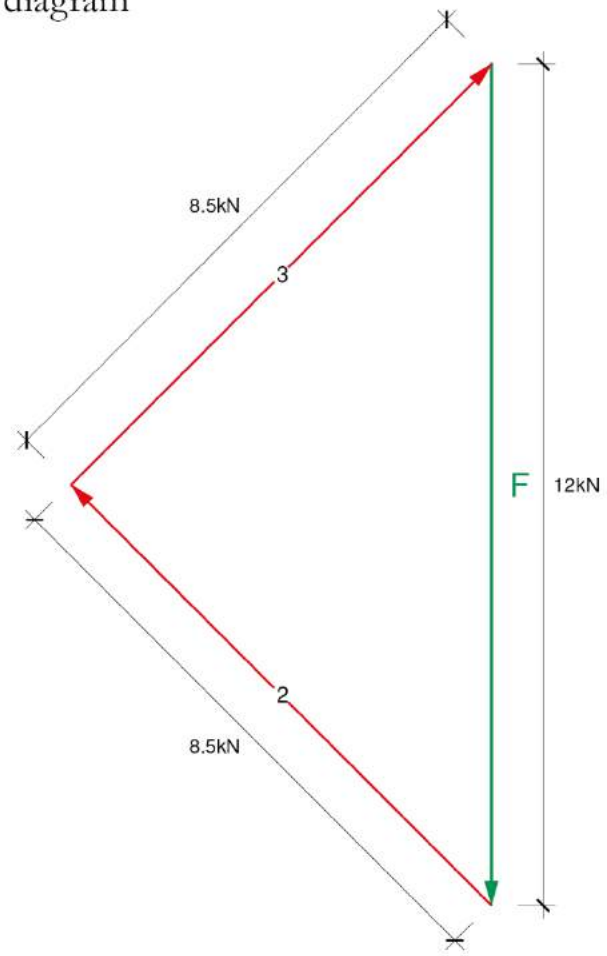
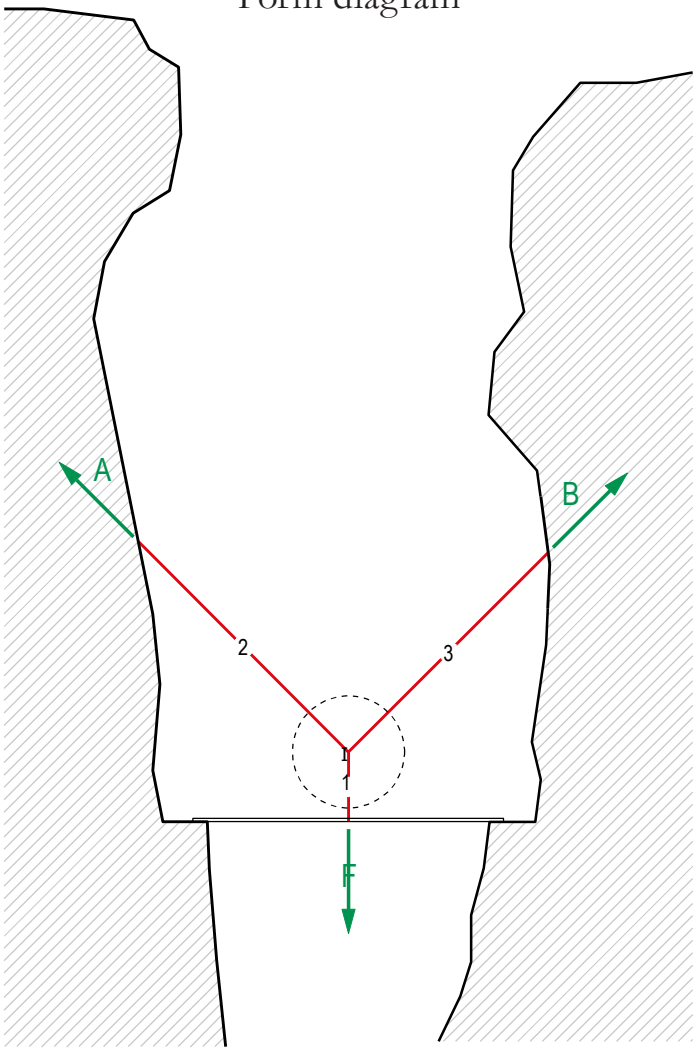
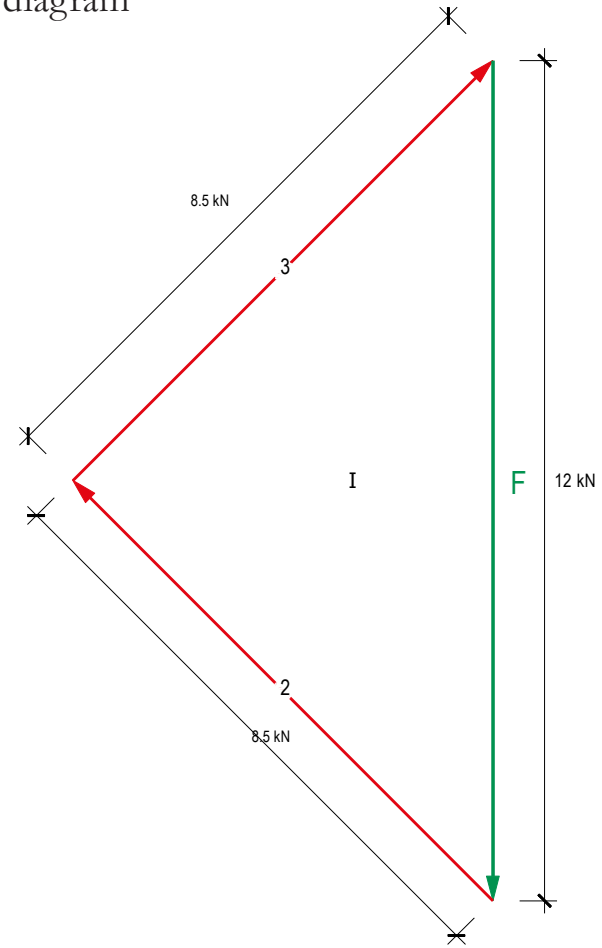


Scale 1 cm = 1 kN

Form diagram

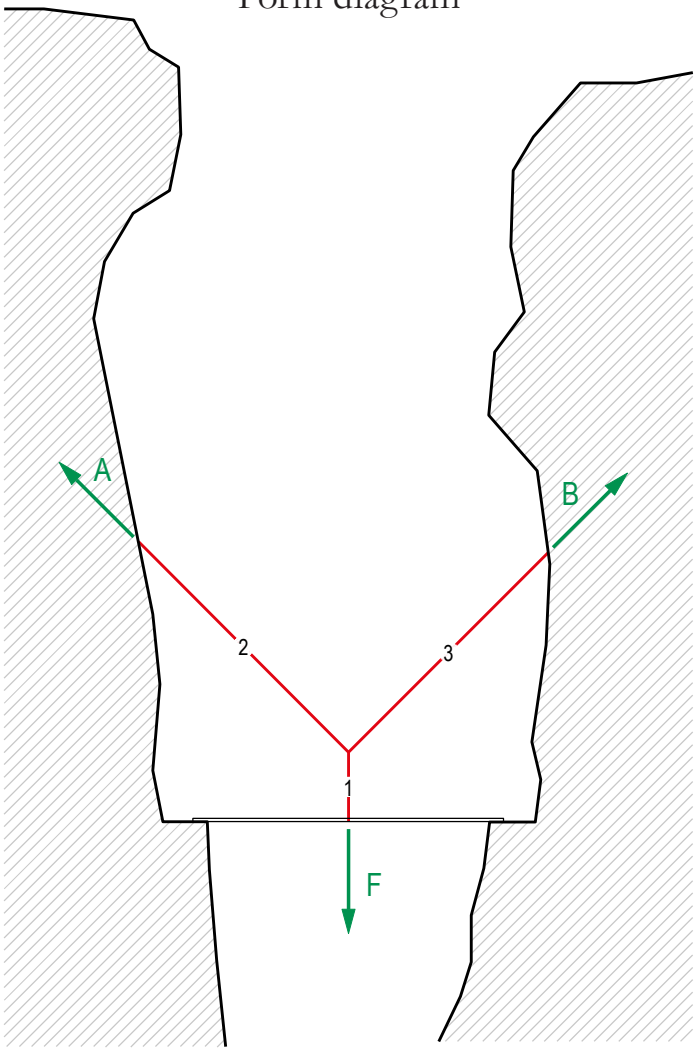


Force diagram



Scale 1 cm = 1 kN

Form diagram



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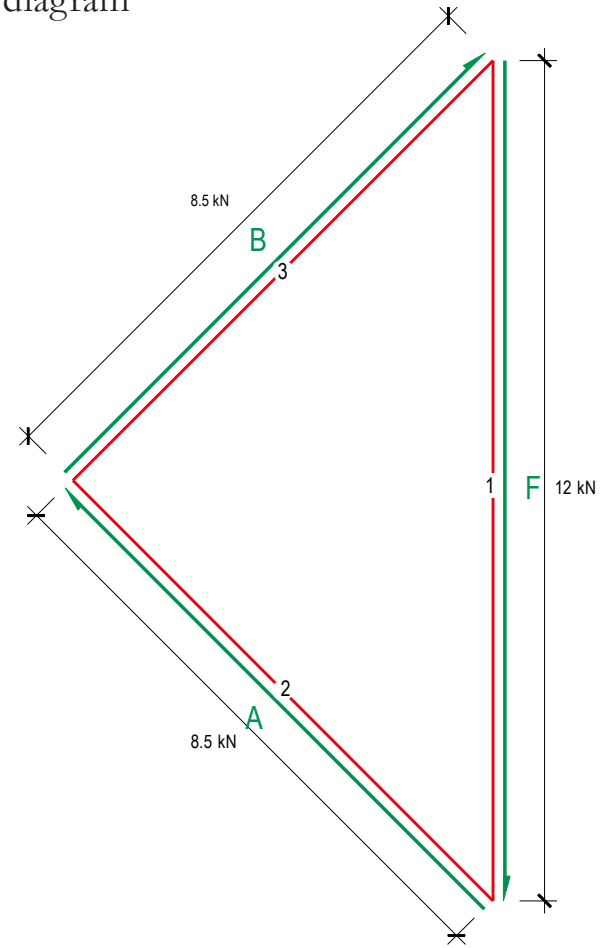

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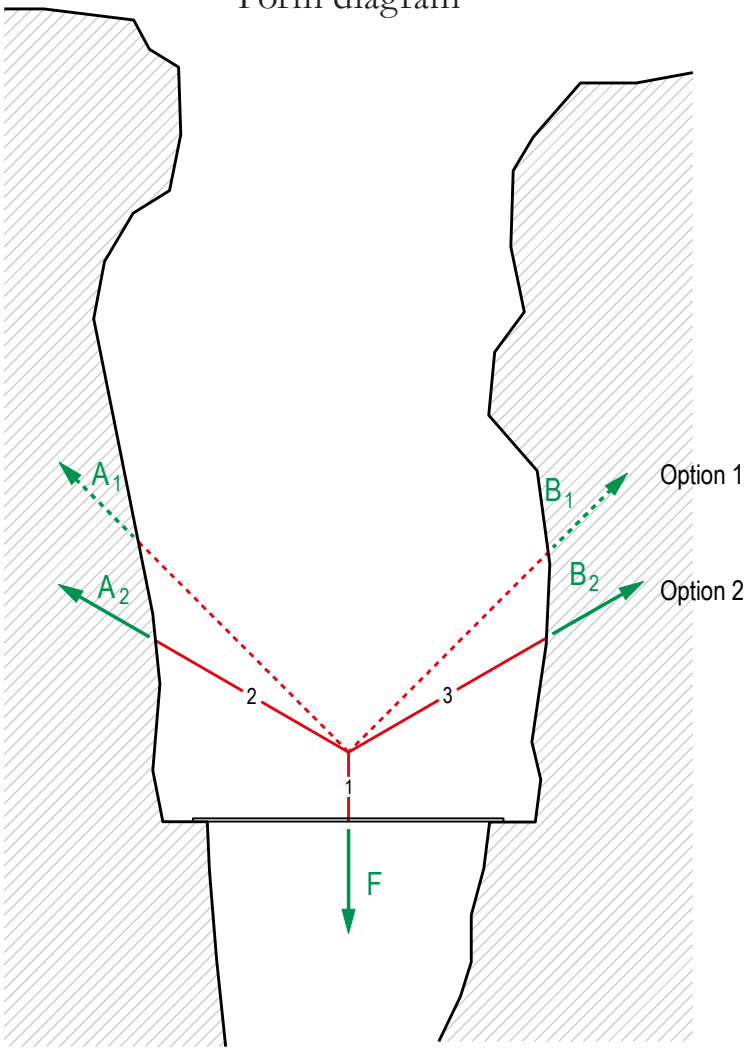

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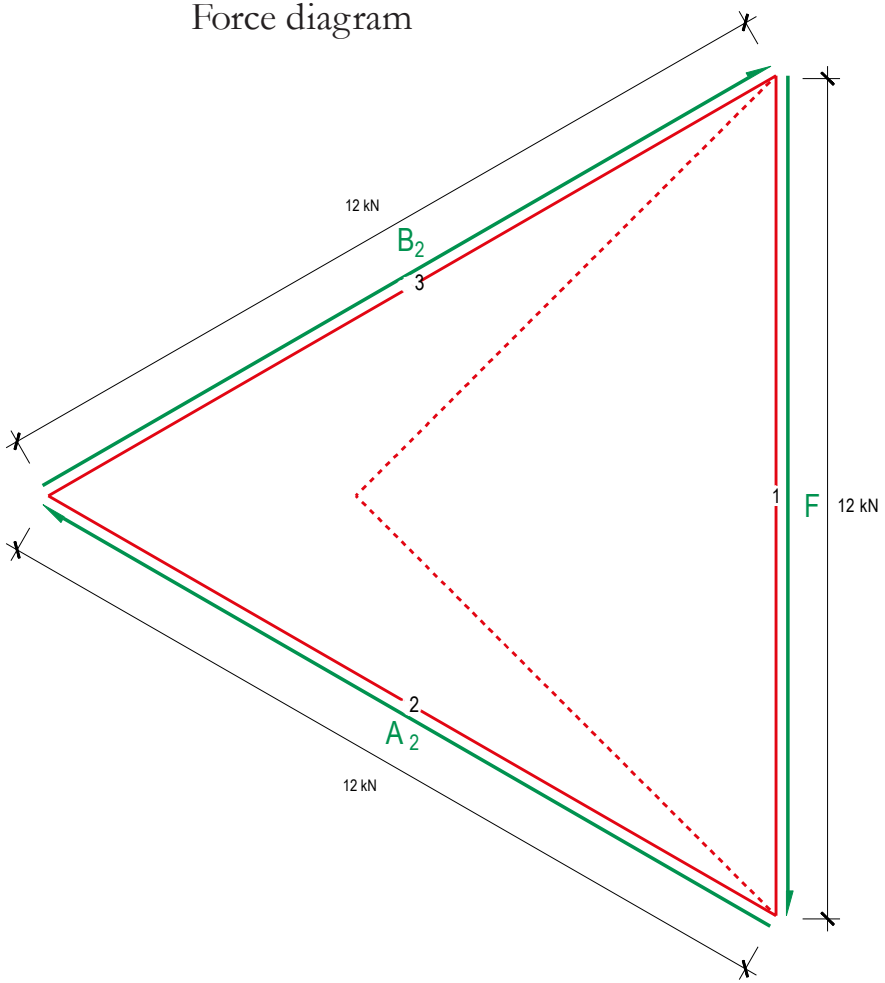
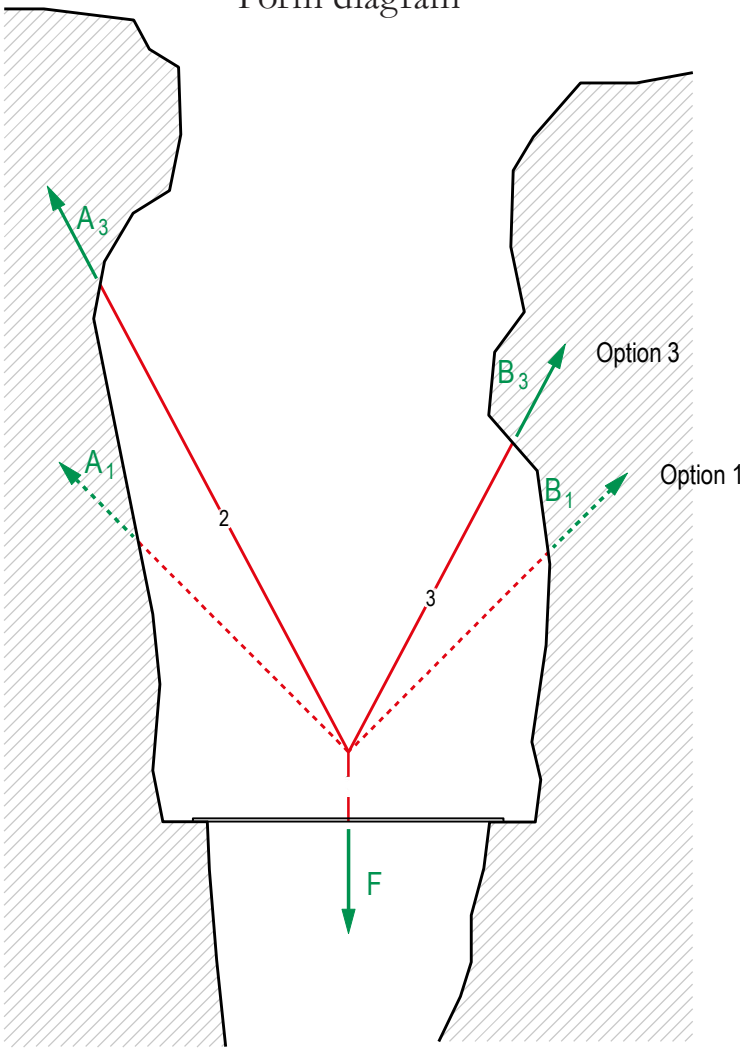


Scale 1 cm = 1 kN

Form diagram



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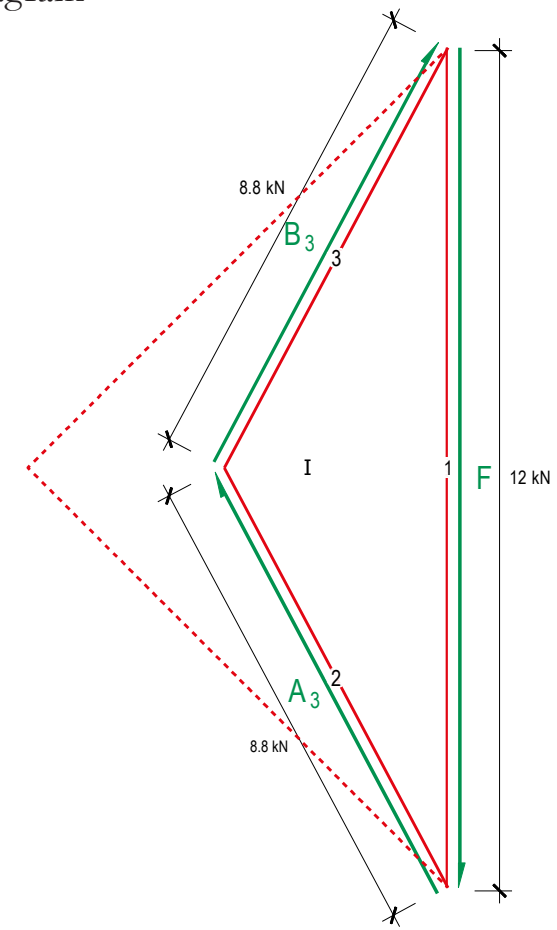
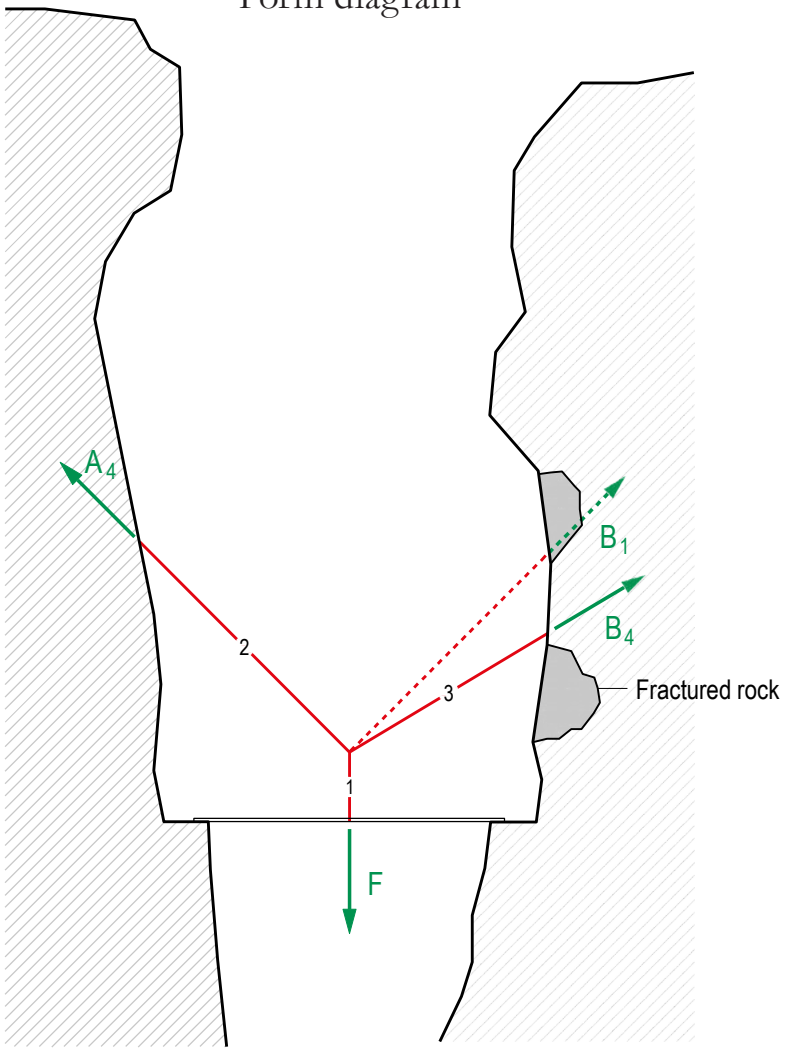
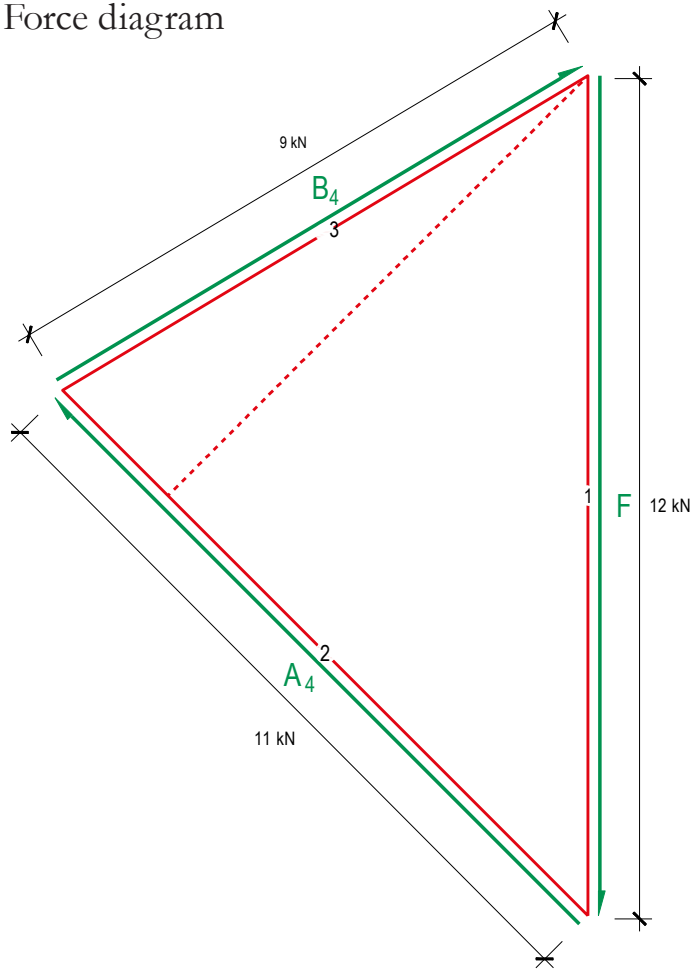


Scale 1 cm = 1 kN

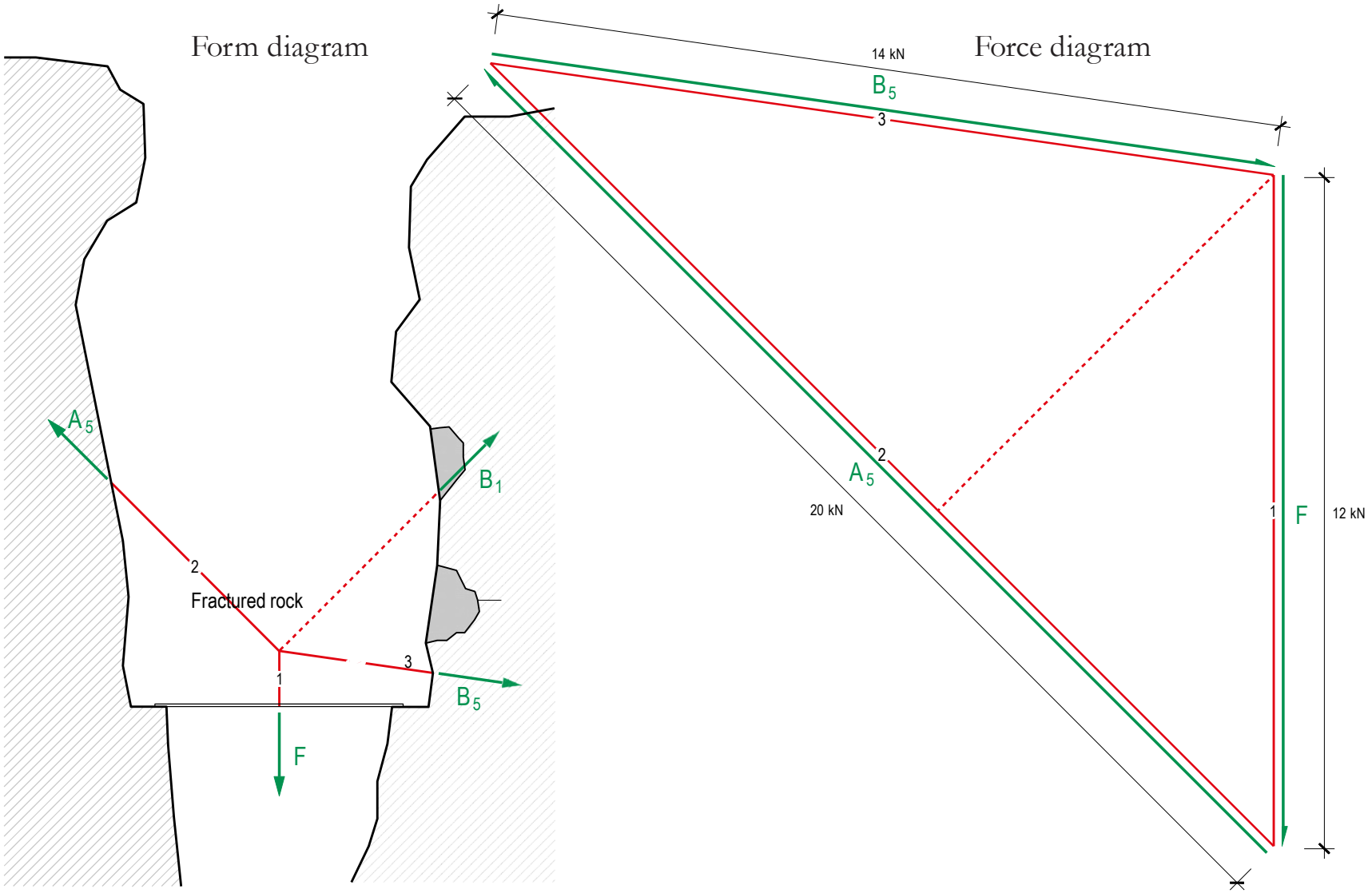
Form diagram



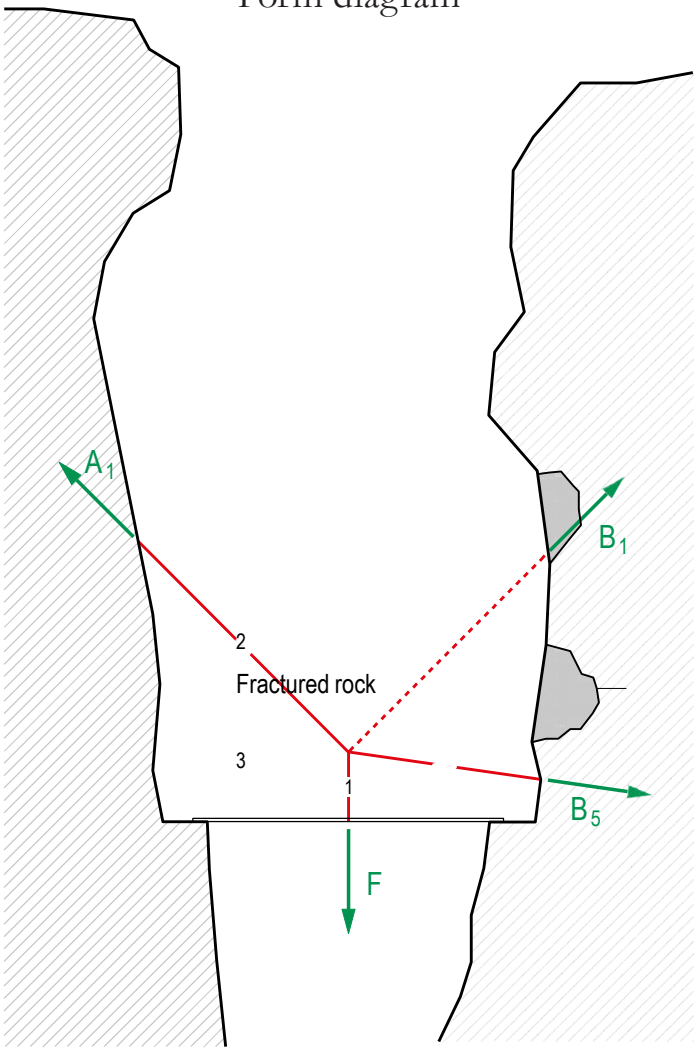
Force diagram



Scale 1 cm = 1 kN

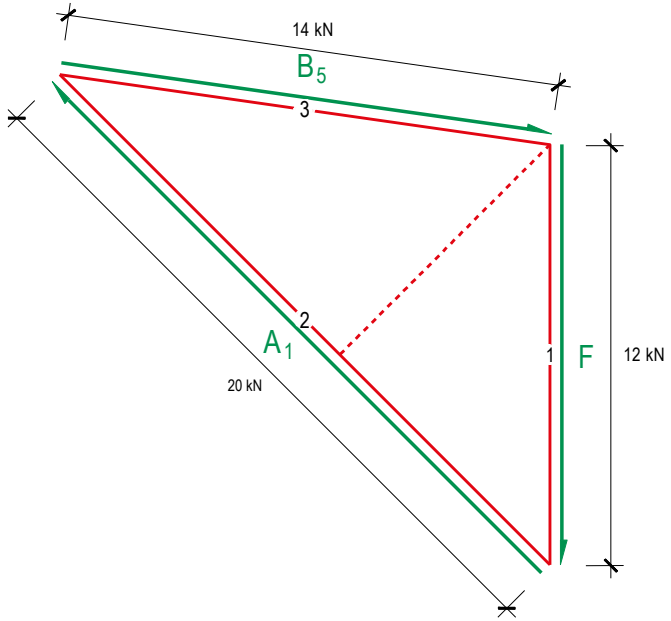

Form diagram
Force diagram
A5
B1
2
Fractured rock
3
1
B5
F
14 kN
B5
3
2
A5
20 kN
1
F
12 kN
Scale 1 : 100
Scale 1 cm = 1 kN

Form diagram



Scale 1 : 100

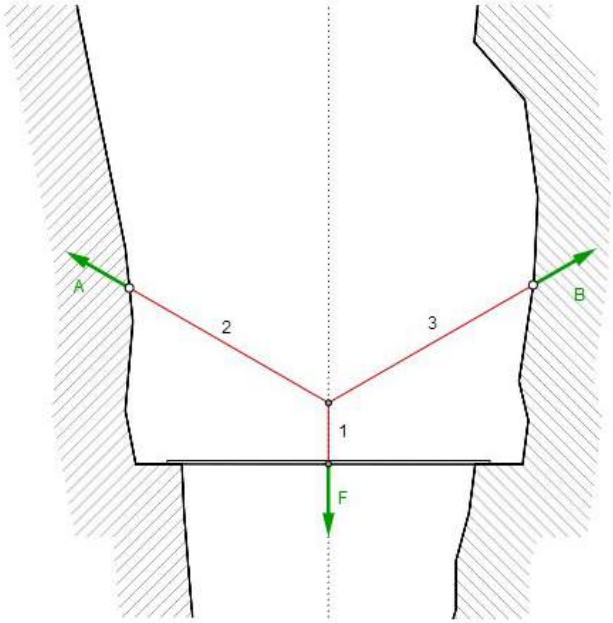
Force diagram



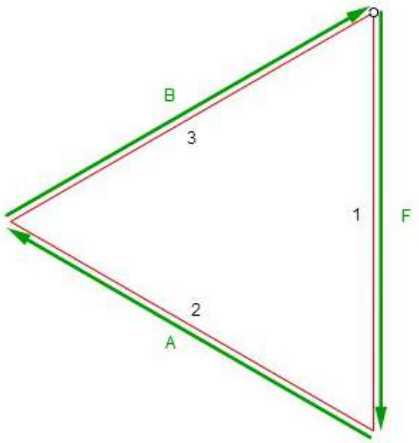
Scale 1 cm = 2 kN

eQ: Pedestrian Bridge 1

Form Diagram
1 unit :: 1m

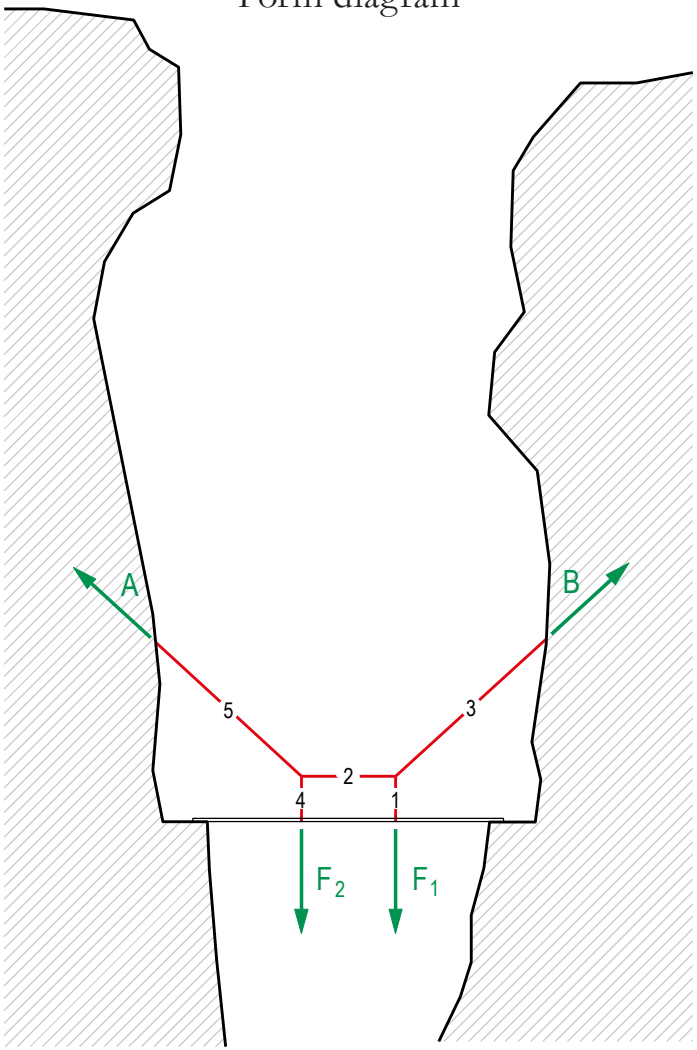


Force Diagram
1 unit :: 0.7 kN

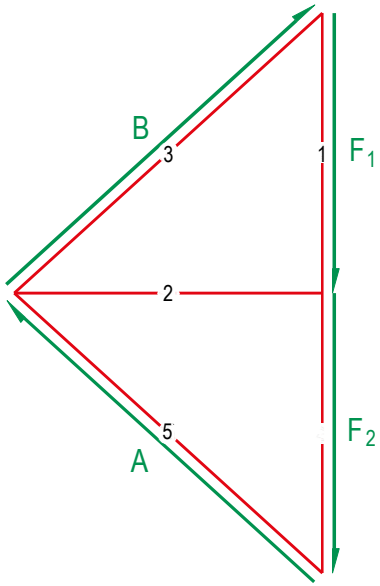


http://www.block.arch.ethz.ch/eq/drawing/view/2

Form diagram

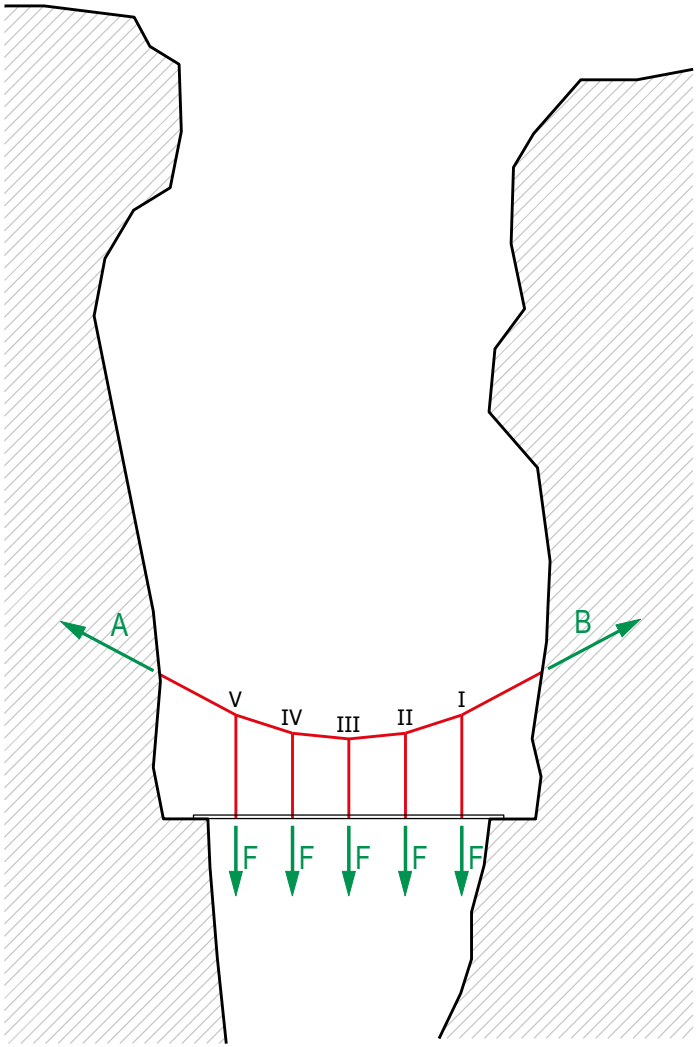


Force diagram



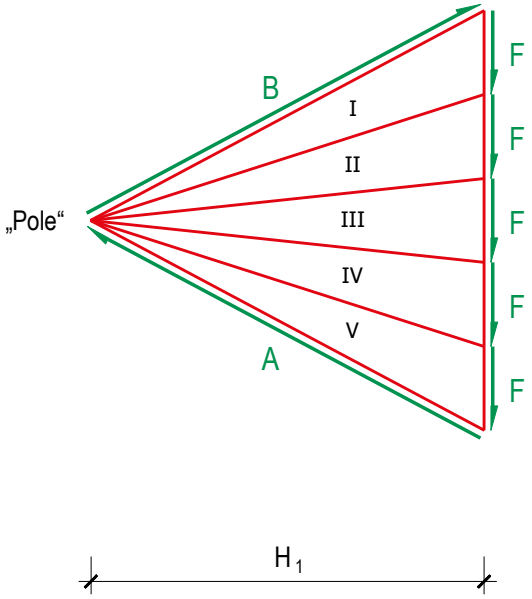
Form diagram

Scale 1 : 100

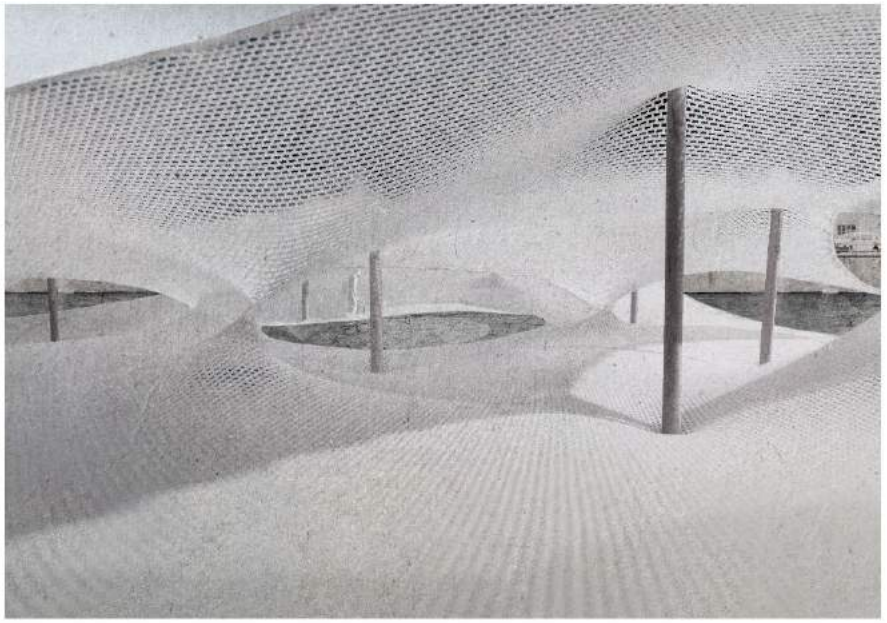


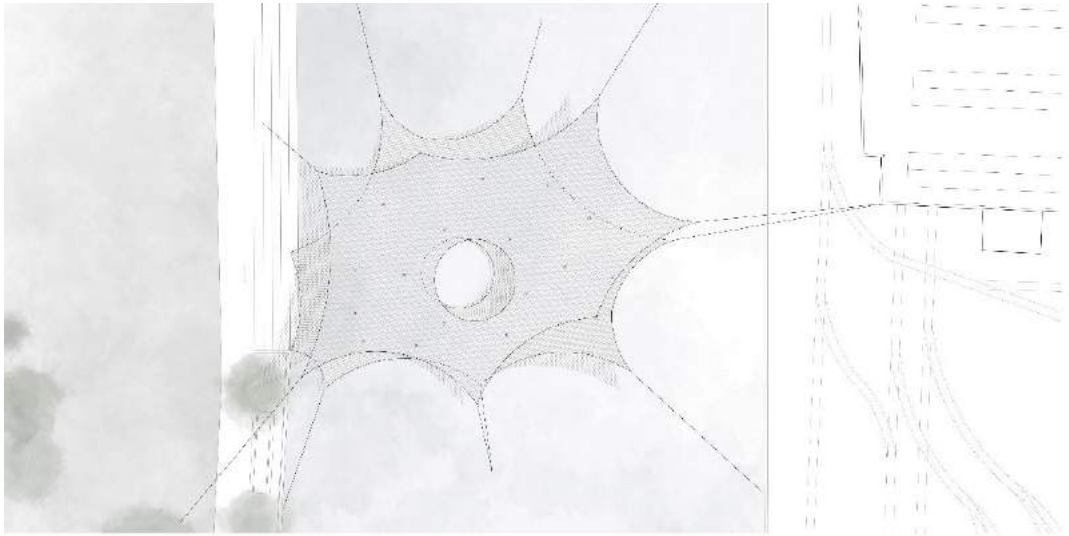
Force diagram

Scale 1 cm = 1 kN

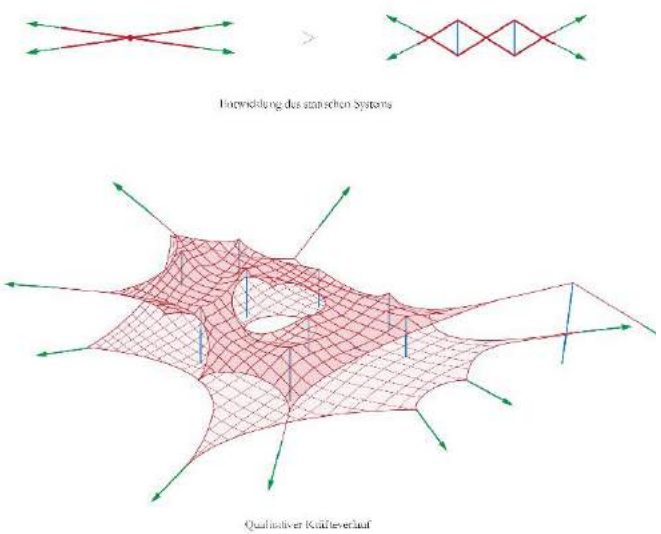


Irving Morrow: Golden Gate Bridge, San Francisco, 1933





Grundriss 1 : 300



Entwicklung des statischen Systems

Qualitativer Kräfteverlauf

Matheo Michels, Christian Ort, Agnieszka Latak and Rebecca Witz

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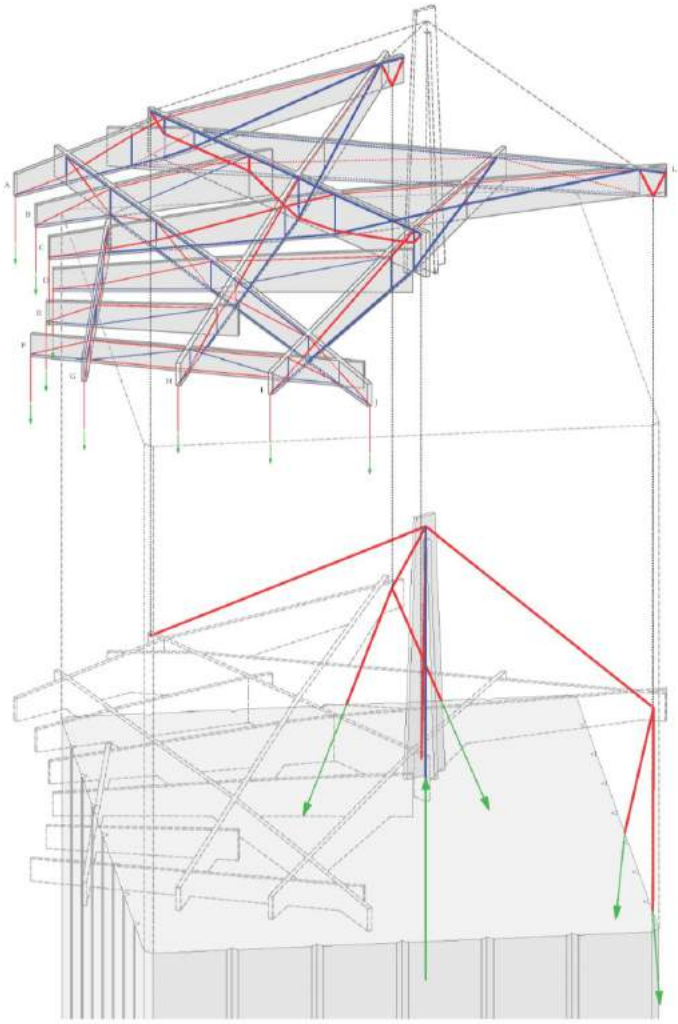
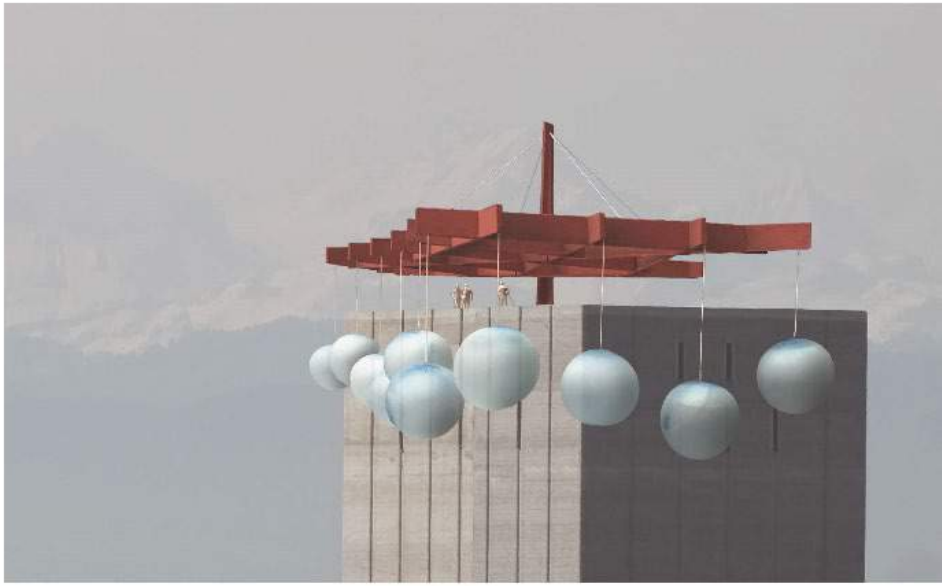
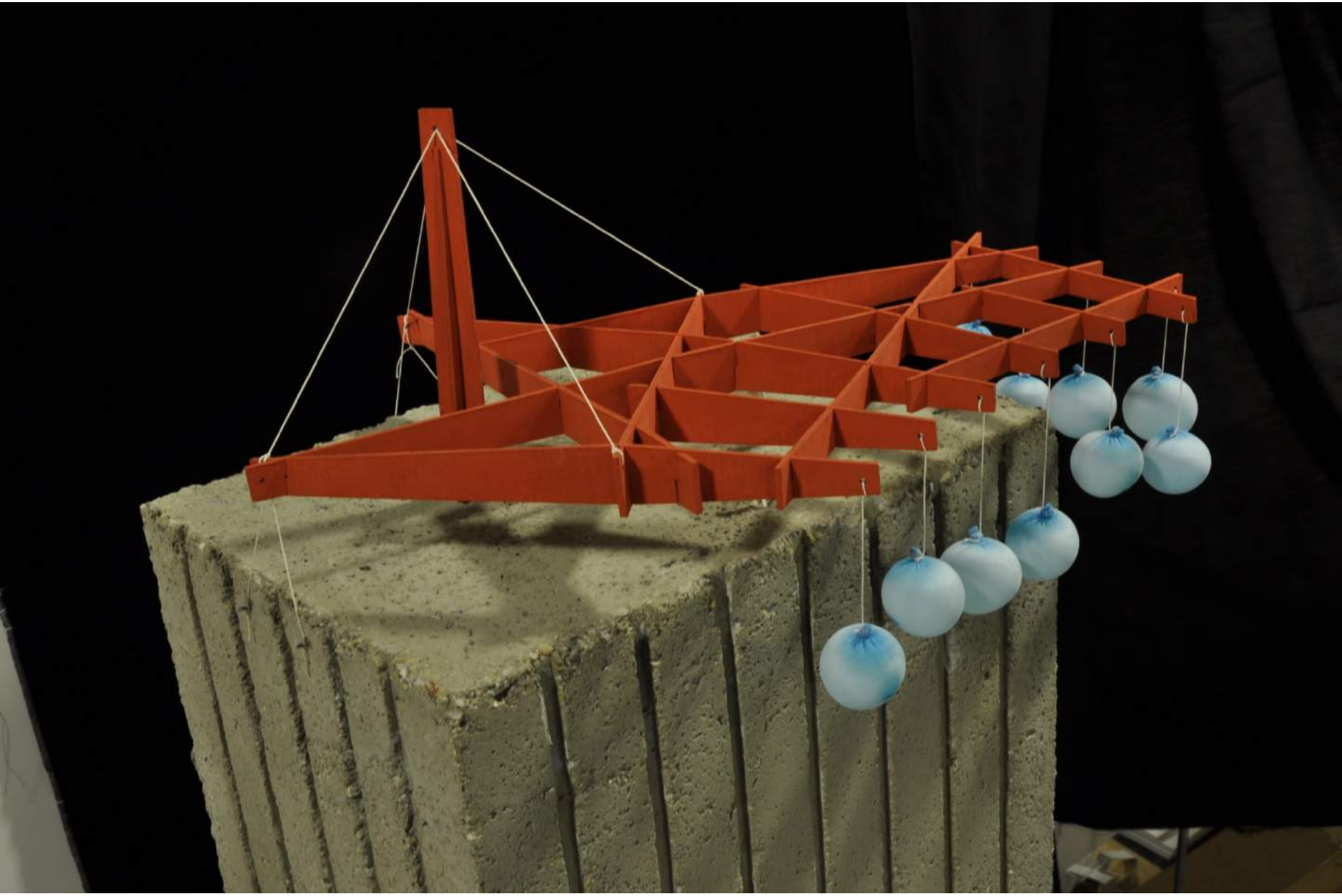
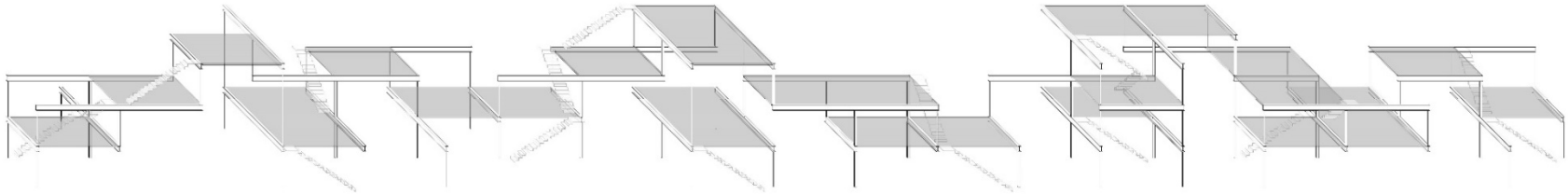




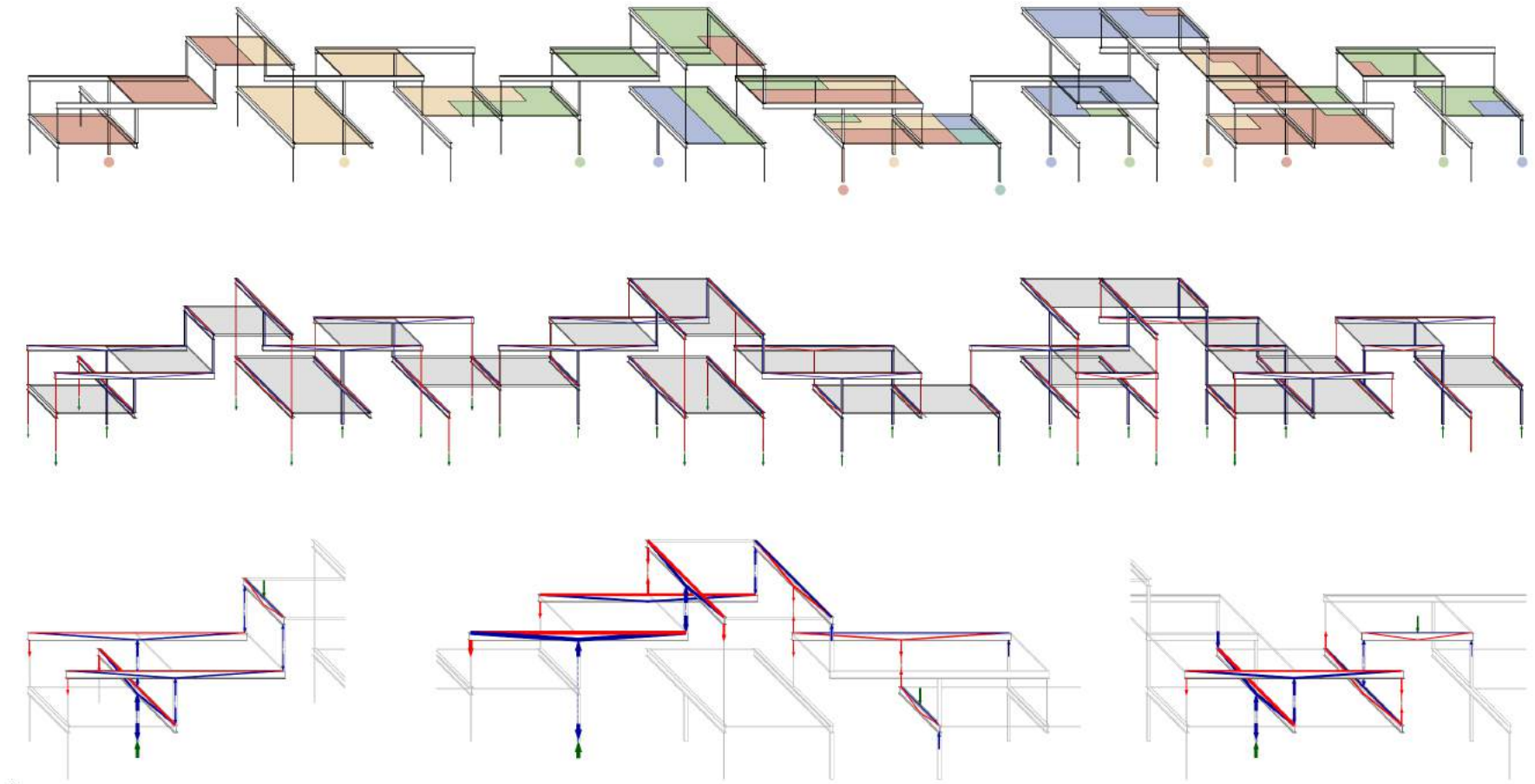
Roman Dürst, Marc Over, Maria Theis and Silvio Koch



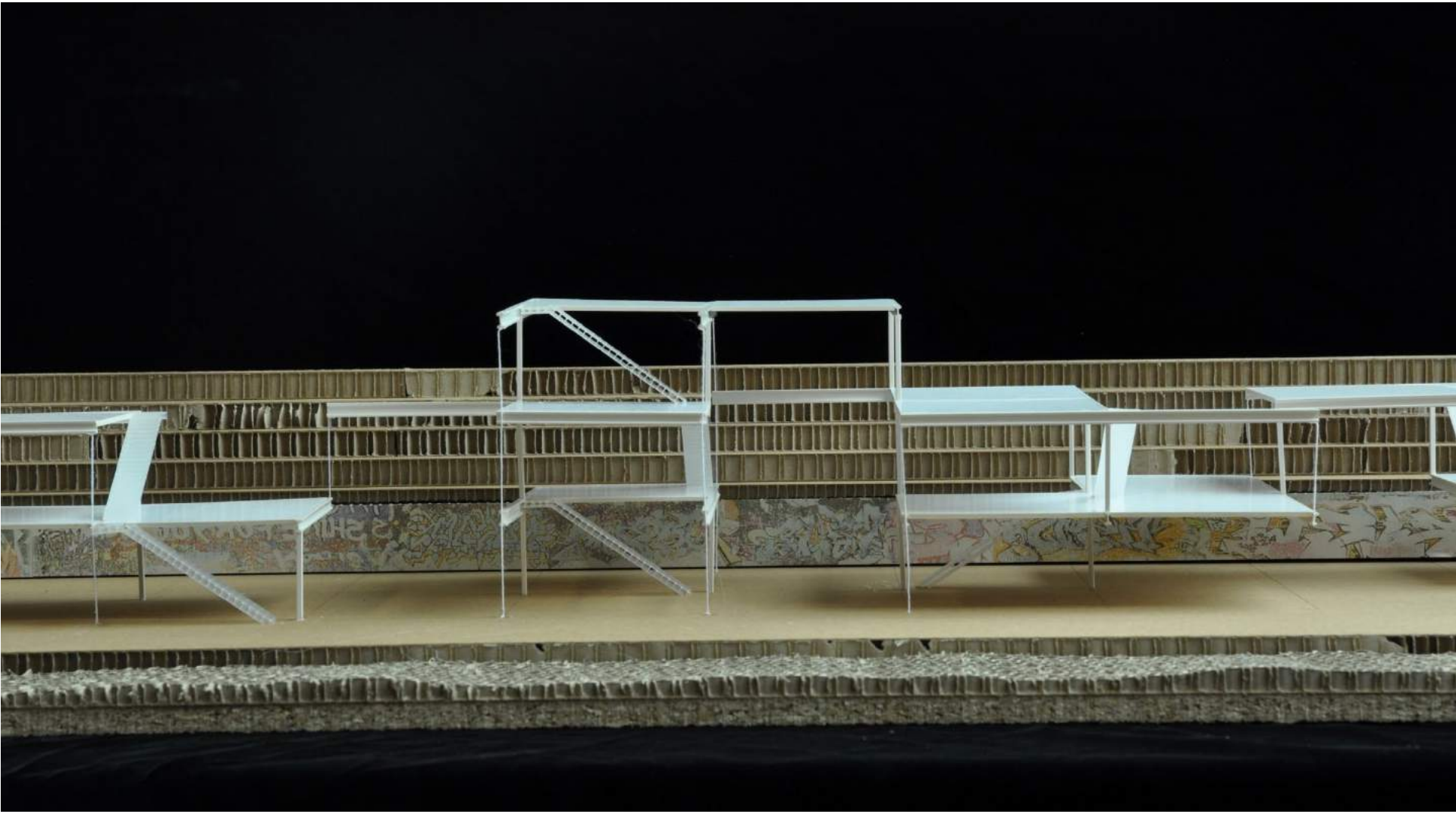
Roman Dürst, Marc Over, Maria Theis and Silvio Koch



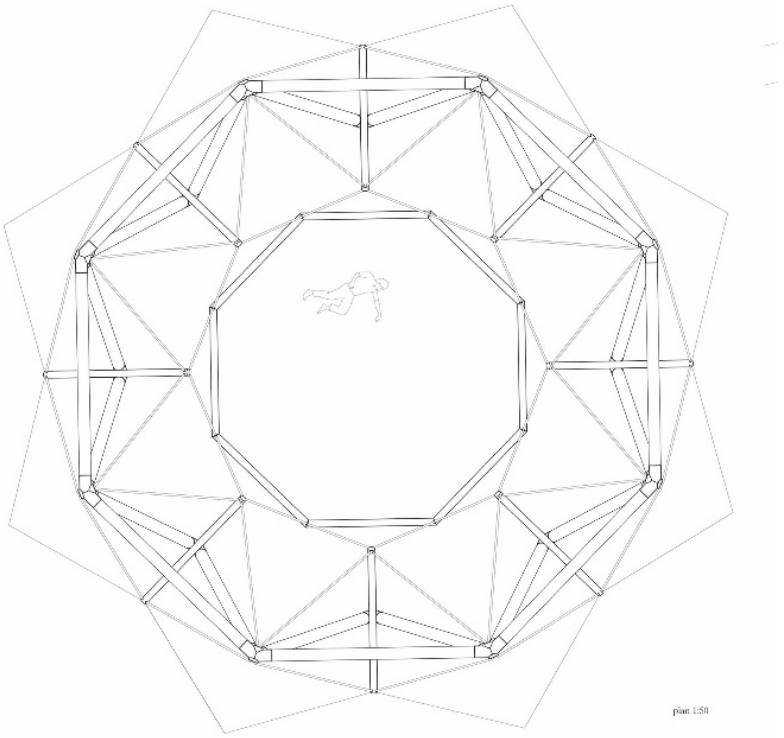
Artai Sanchez, Kerstin Spiekermann, Nadja Widmer and Nicolas Wild

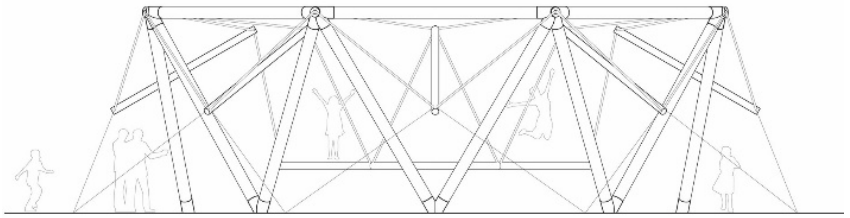


Artai Sanchez, Kerstin Spiekermann, Nadja Widmer and Nicolas Wild

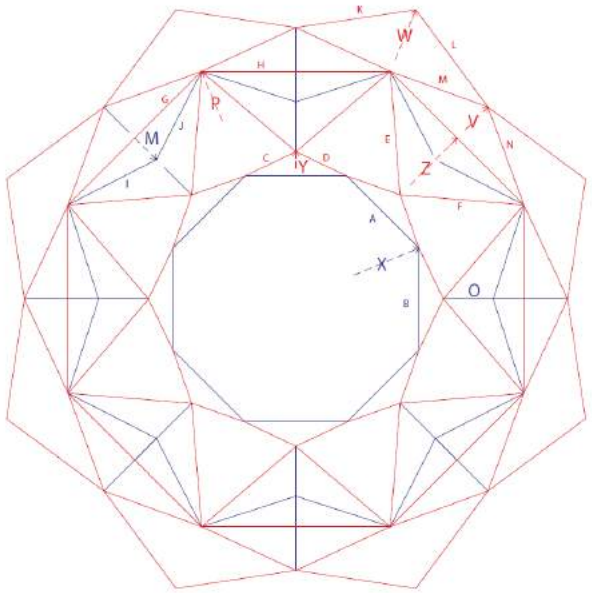


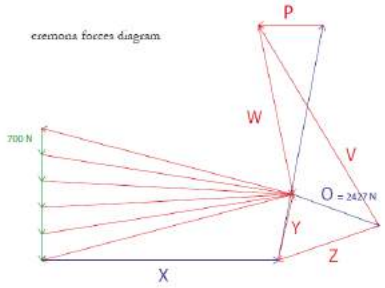
Artai Sanchez, Kerstin Spiekermann, Nadja Widmer and Nicolas Wild



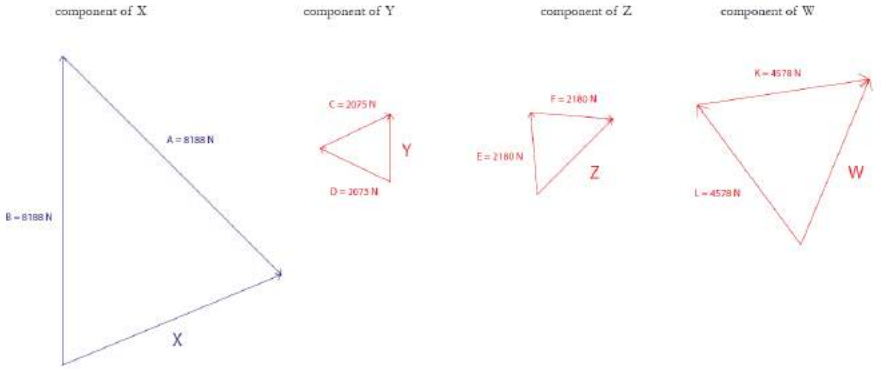


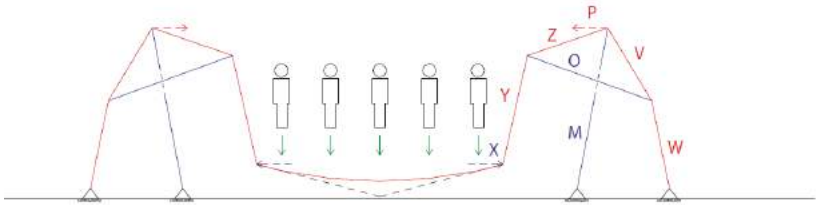
Valentin Locher, Julien Tacca, Böwing Nick and Vetterli Noemie

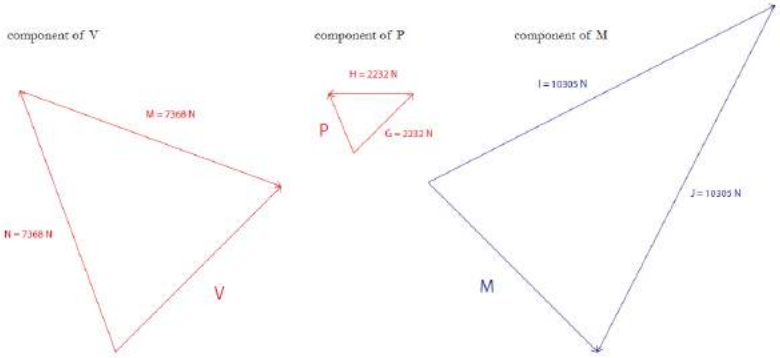




The Cremona diagrams allows to understand the disposition, strength and paths of forces inside the structure in a simple and graphical way.
Its reading has to be done in the elevation illustration and most of the time vectors need to be reinterpretated with the plan.
By combining the two readings and understandings from these, we can find the real forces in the structure.







Valentin Locher, Julien Tacca, Böwing Nick and Vetterli Noemie