



**ARK-A3001 Design of Structures_Basics
Form & Force**

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Department of Civil Engineering

- Load cases**
 - dead load
 - live load
 - environmental load
- distributed load**
- point load**
- equilibrium**
- location plan**
- force plan**
- resultant force**
- lever principle**



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Equilibrium

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Basic Operation with Forces

two forces can be **added** into one resulting force

one force can be **separated** into two force



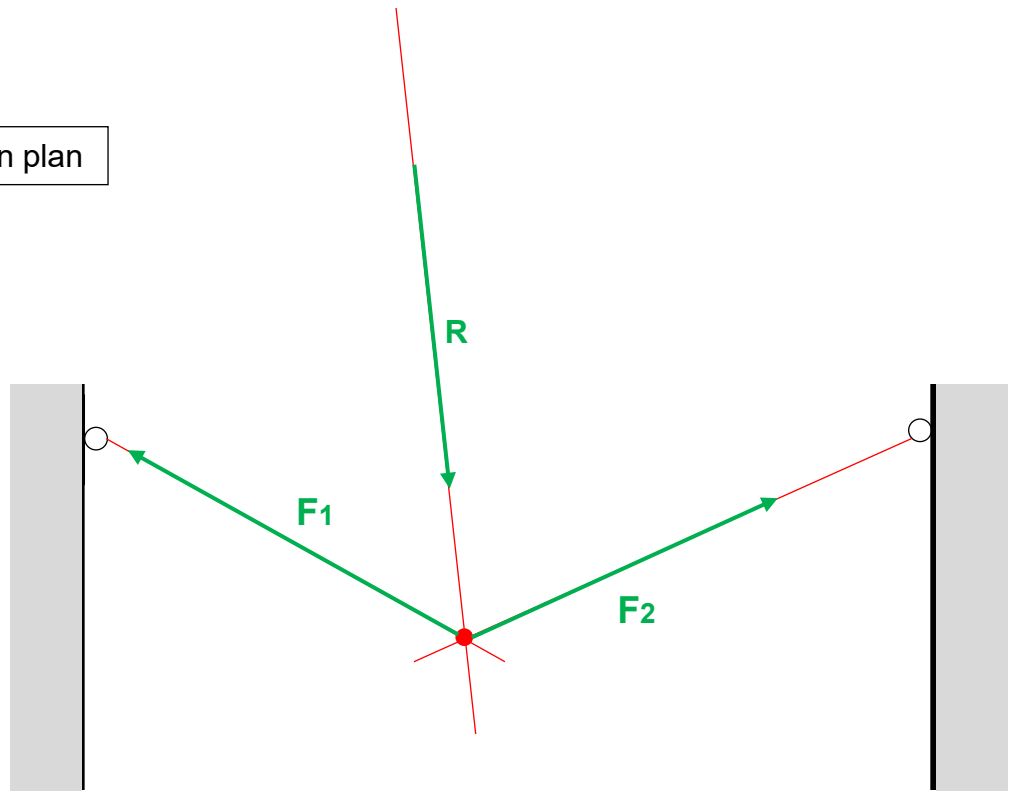
- Load cases**
- dead load
- live load
- environmental load

resultant force

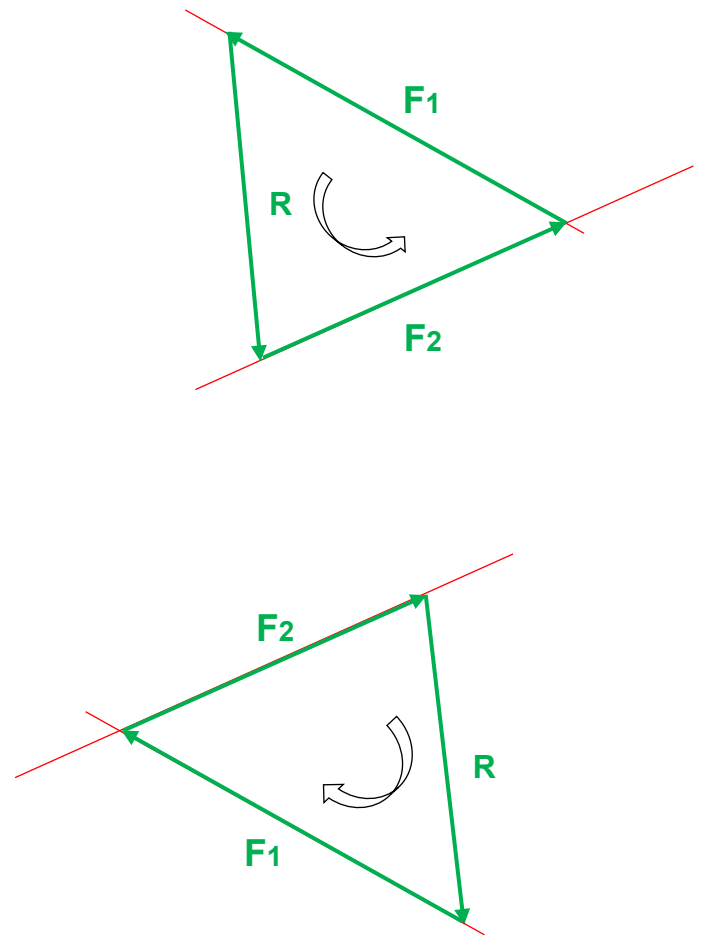
distribute forces to specific points

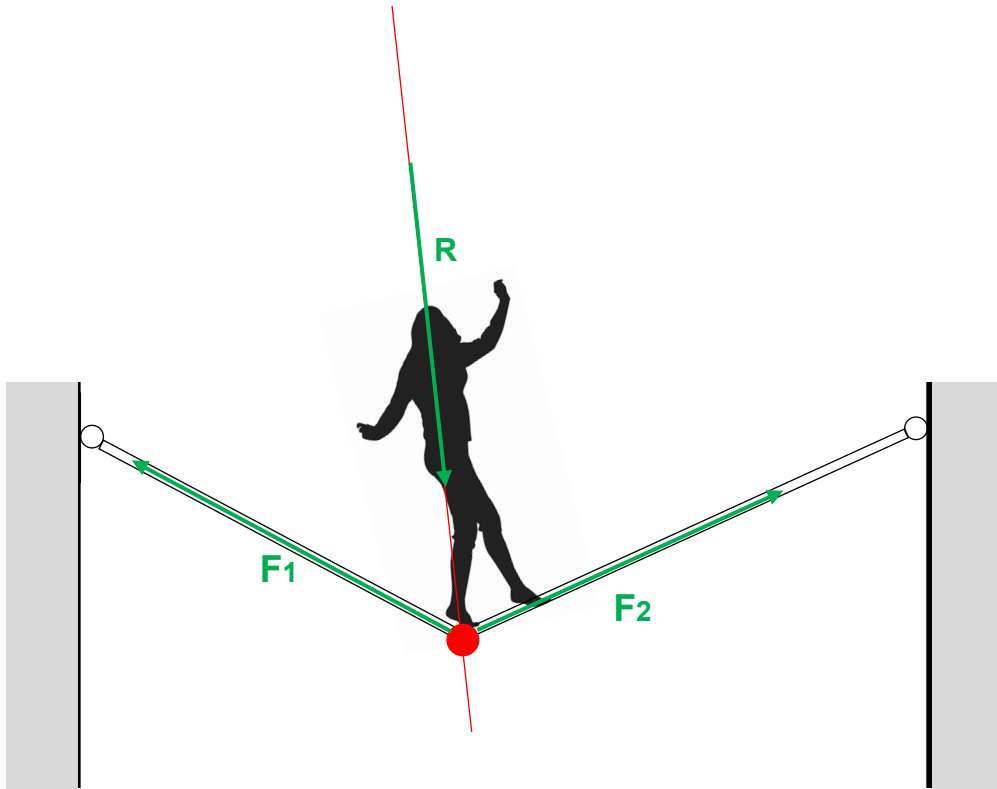
basic idea: building structure as a possibility to guide forces in space according to design interest

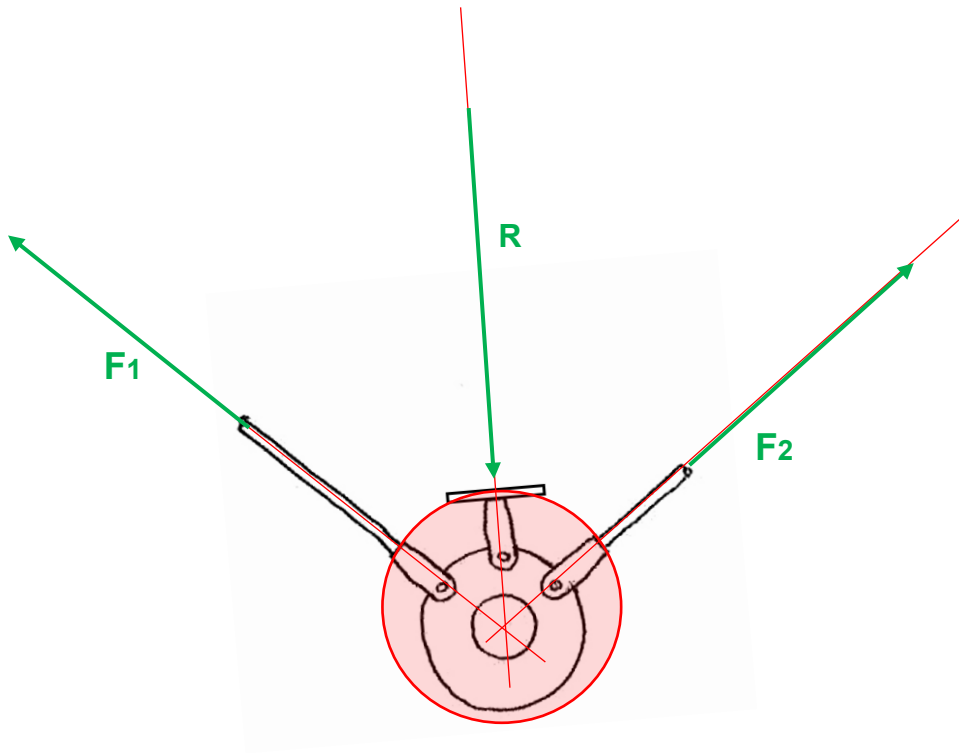
location plan

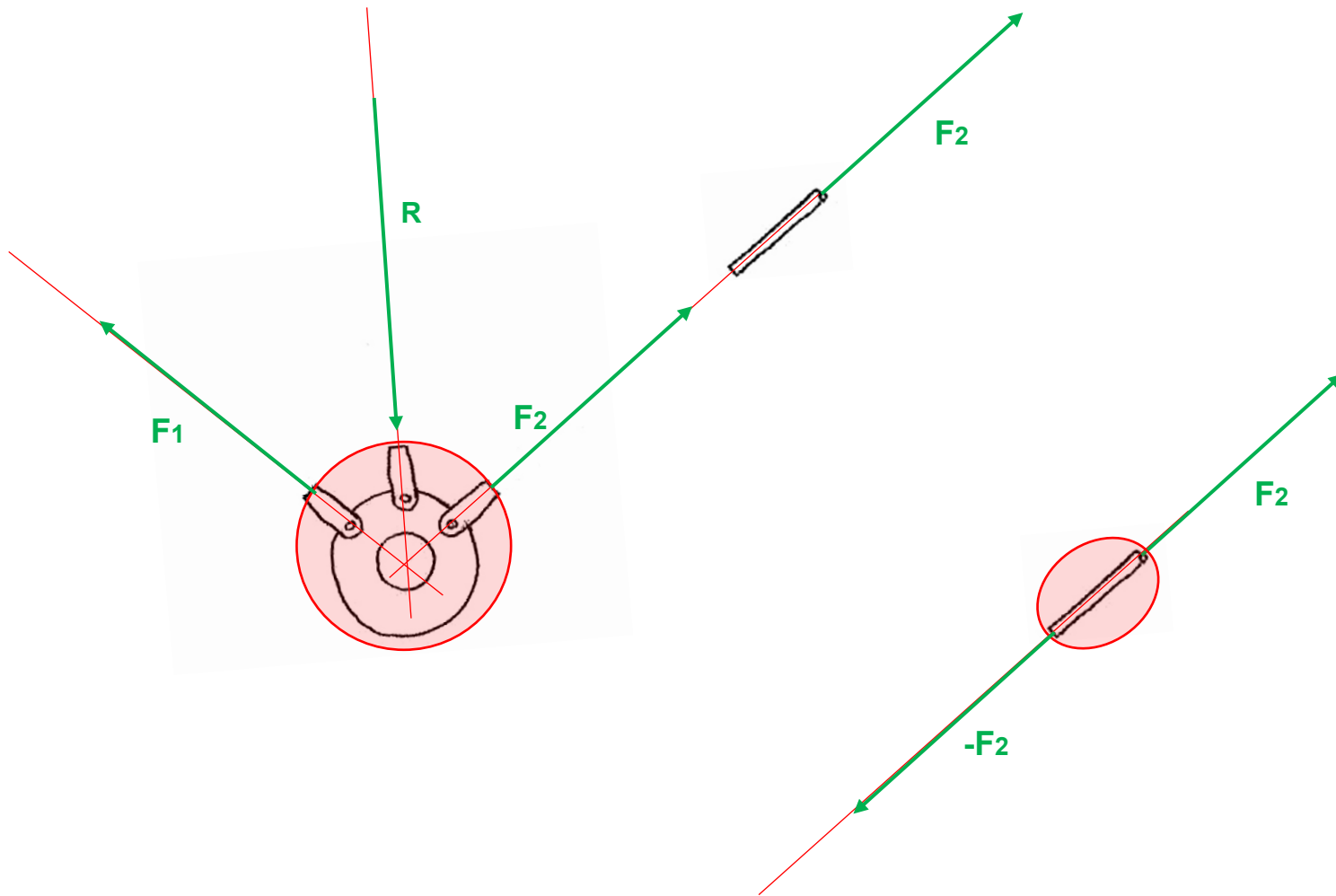


force plan

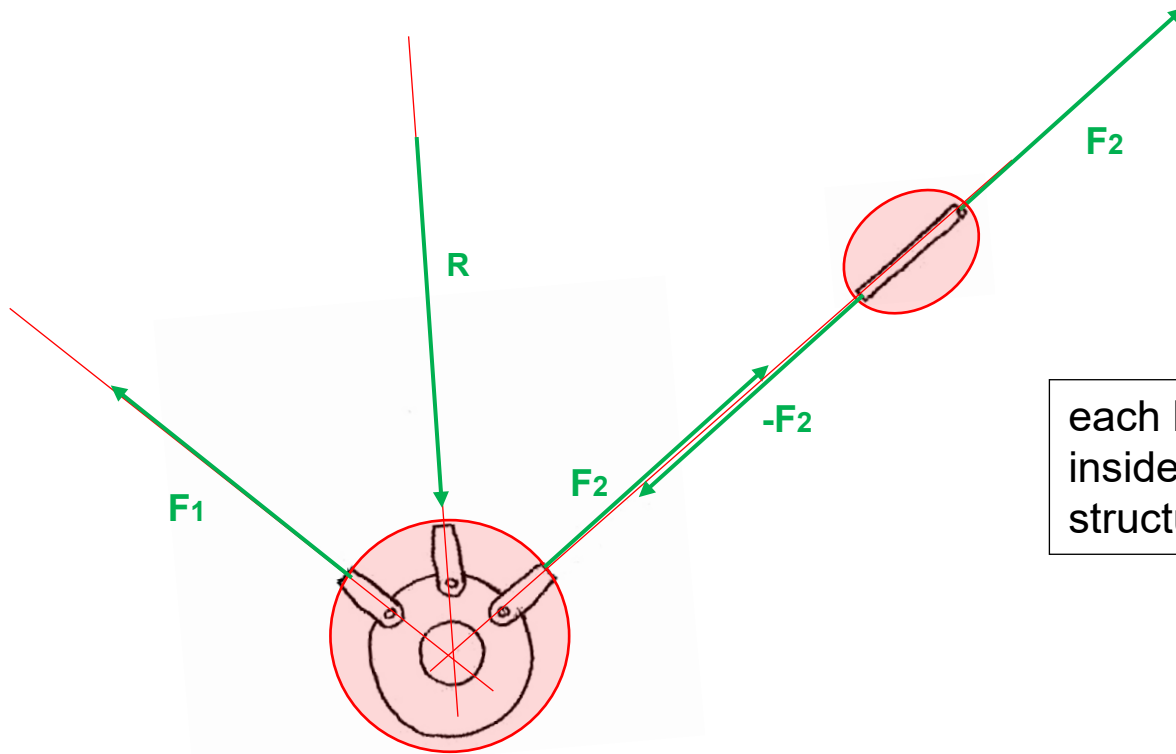








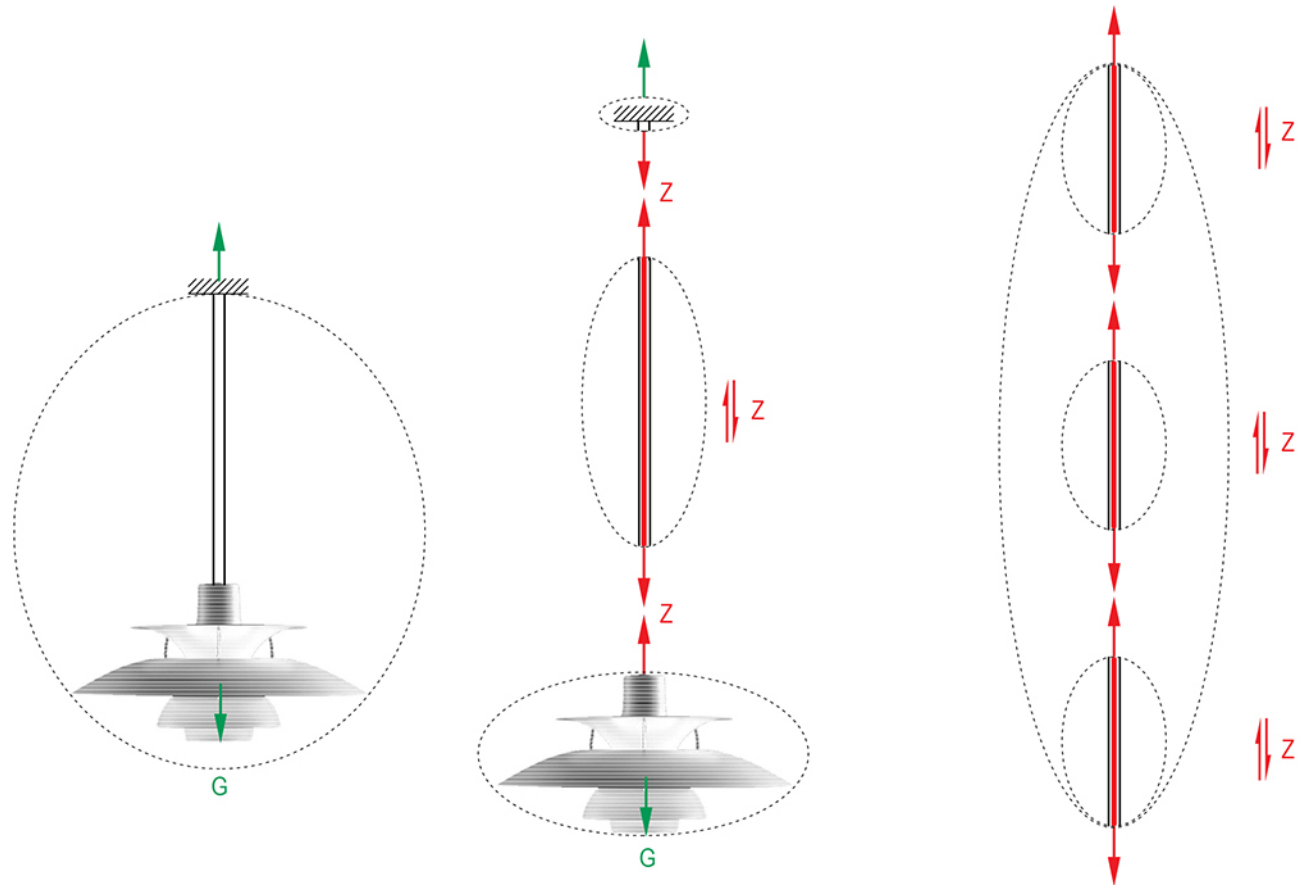
the forces add up to zero
 the line of action of the forces intersect in one point



each load is producing forces inside the material of the structure, so-called **inner forces**

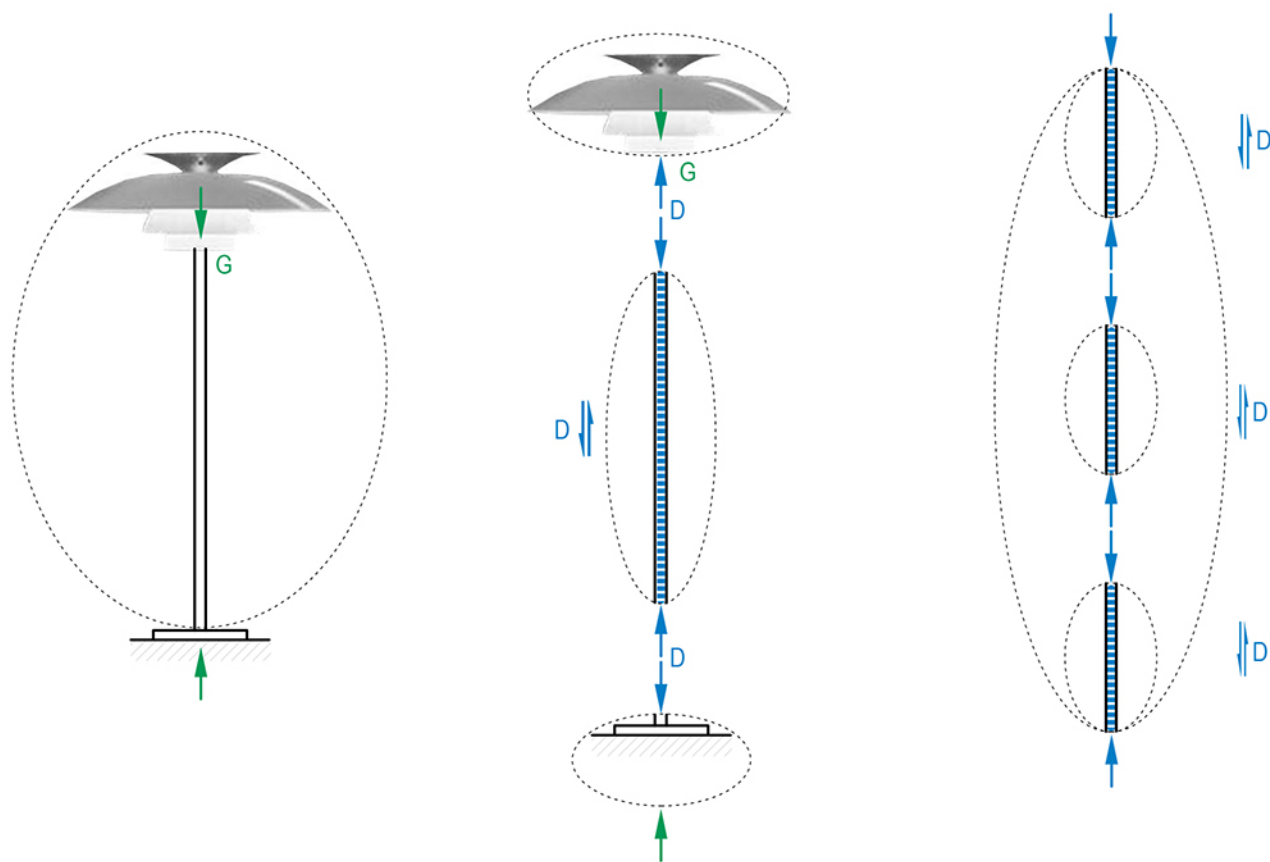
For a building structure to be in equilibrium means that every part of the structure is in equilibrium

Inner Force



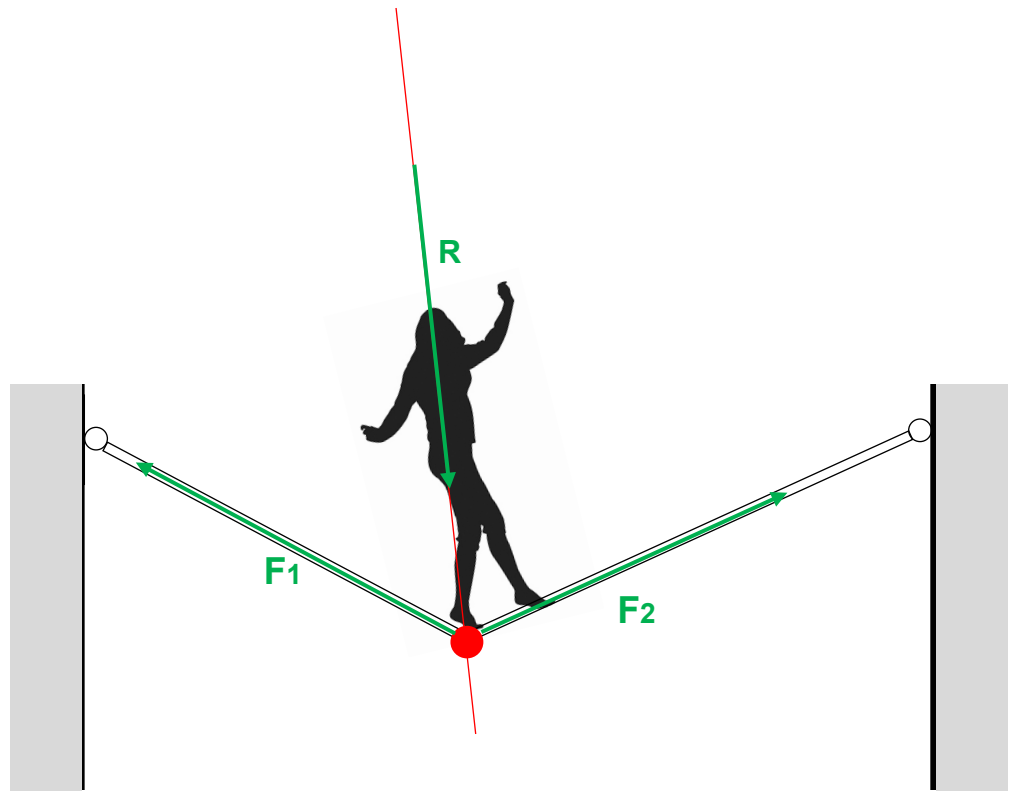
tension
force pulling away from subsystem

Inner Force

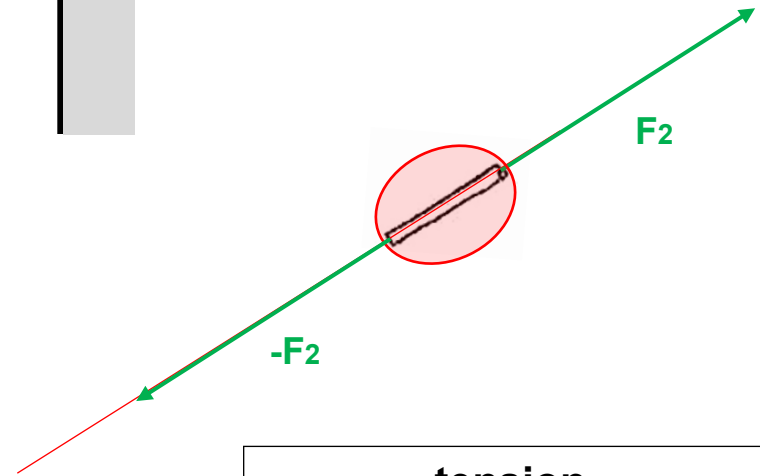


compression
force pushing towards the subsystem

Inner Force



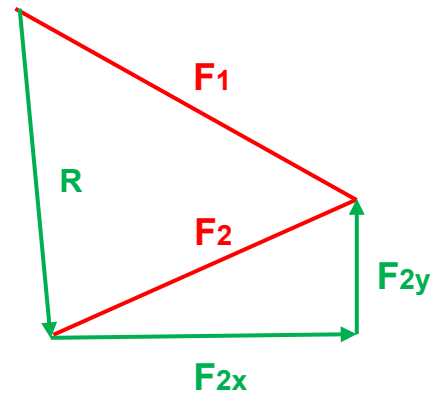
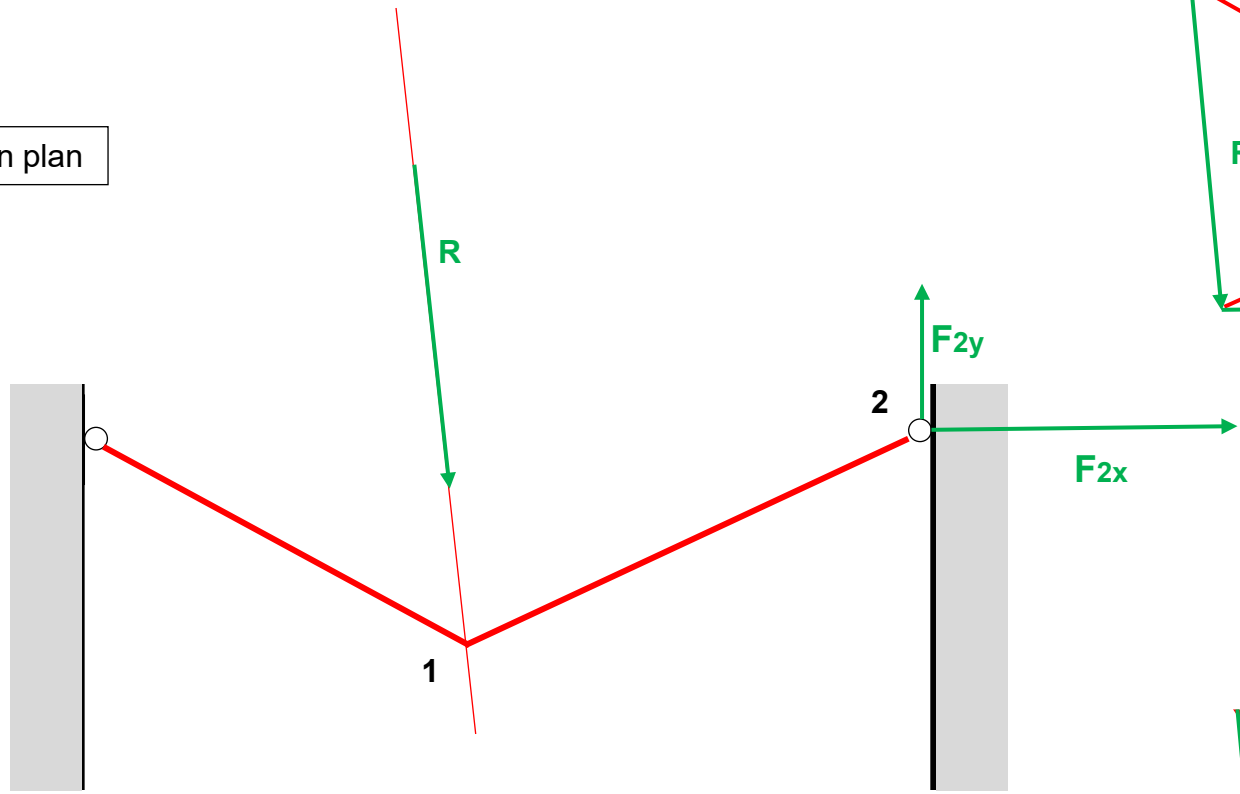
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tension
force pulling away from subsystem

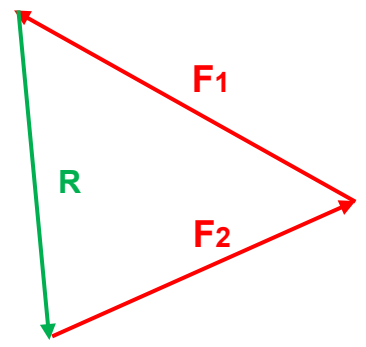
Inner Force

location plan

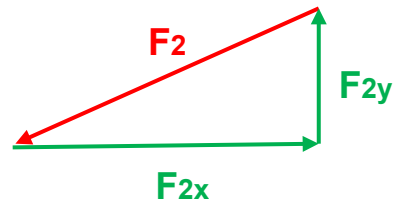


force plan

at 1



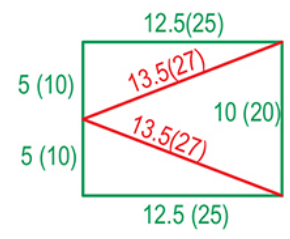
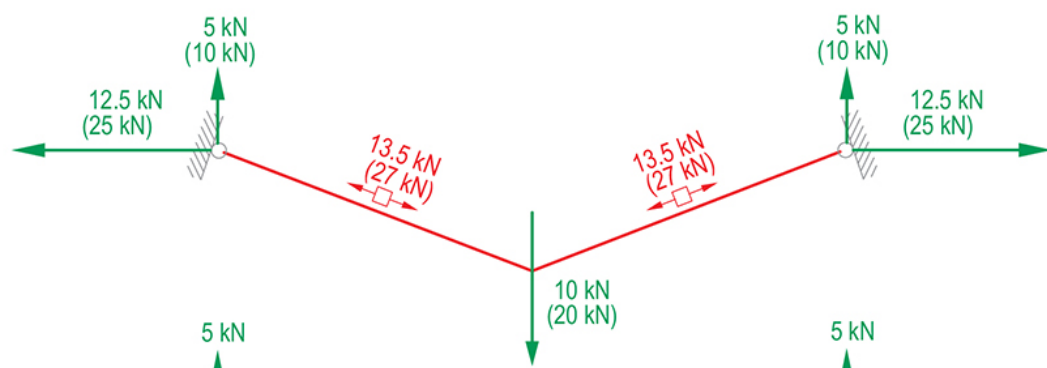
at 2



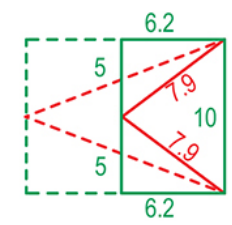
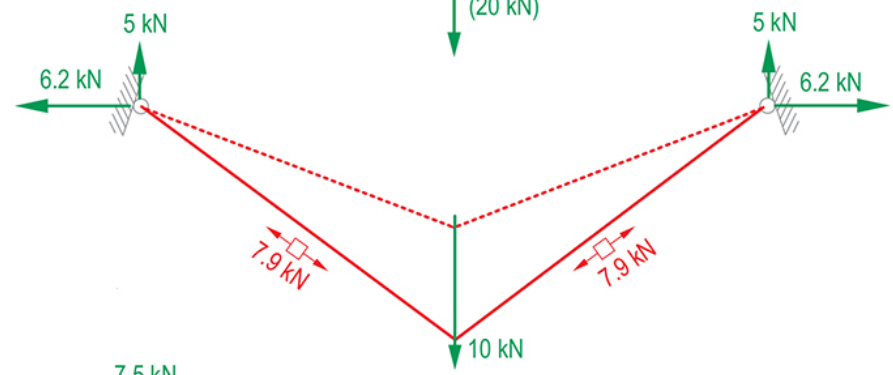
Equilibrium

cable

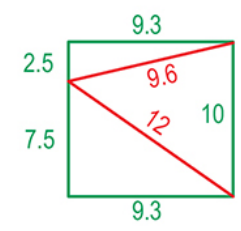
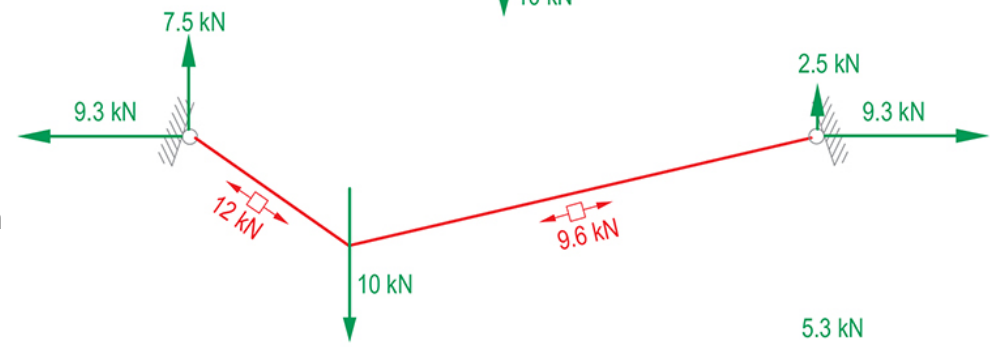
single / double load



single / double deviation



uneven load condition



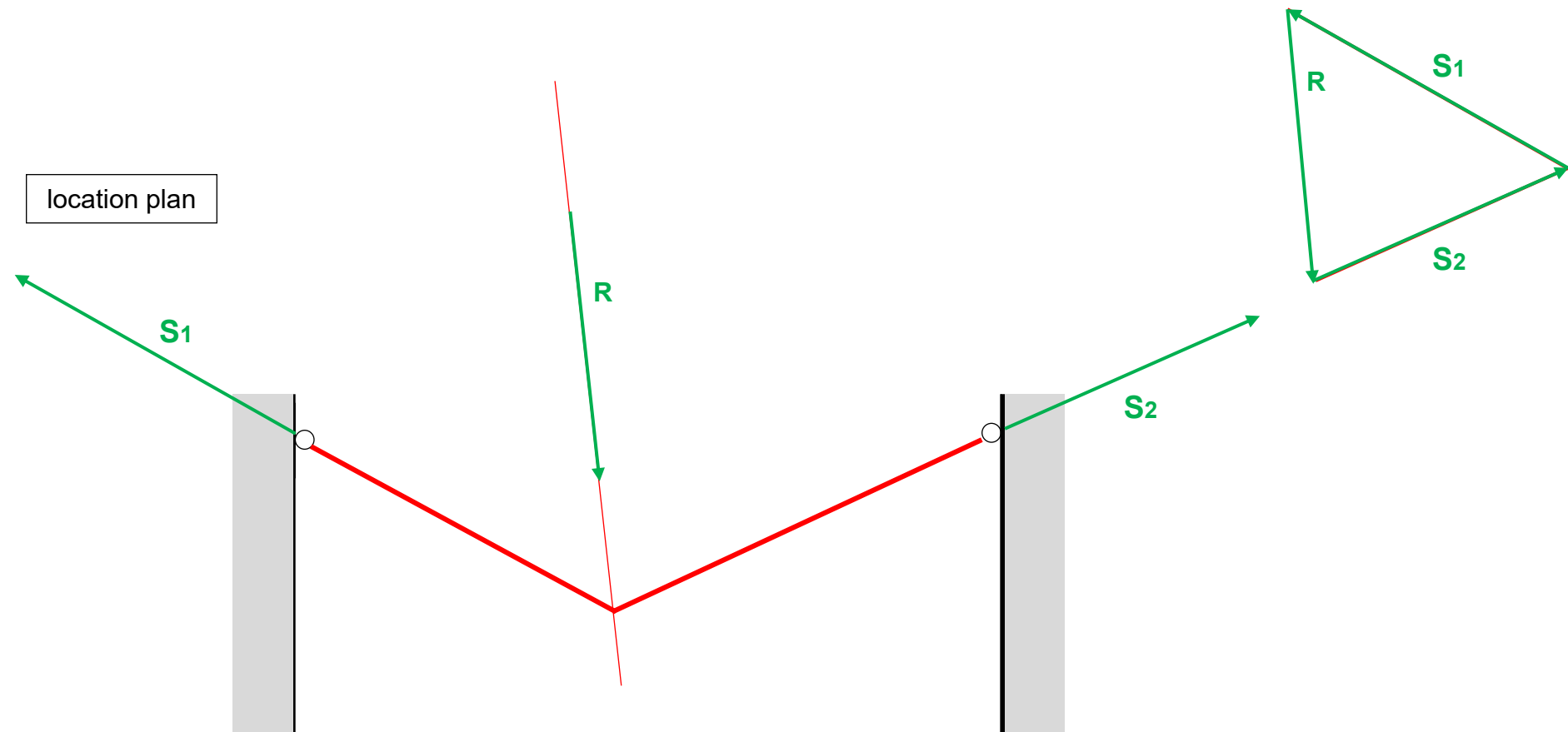
The form of a building structure is closely tight to the magnitude and direction of forces in the structure.

Equilibrium

cable

force plan

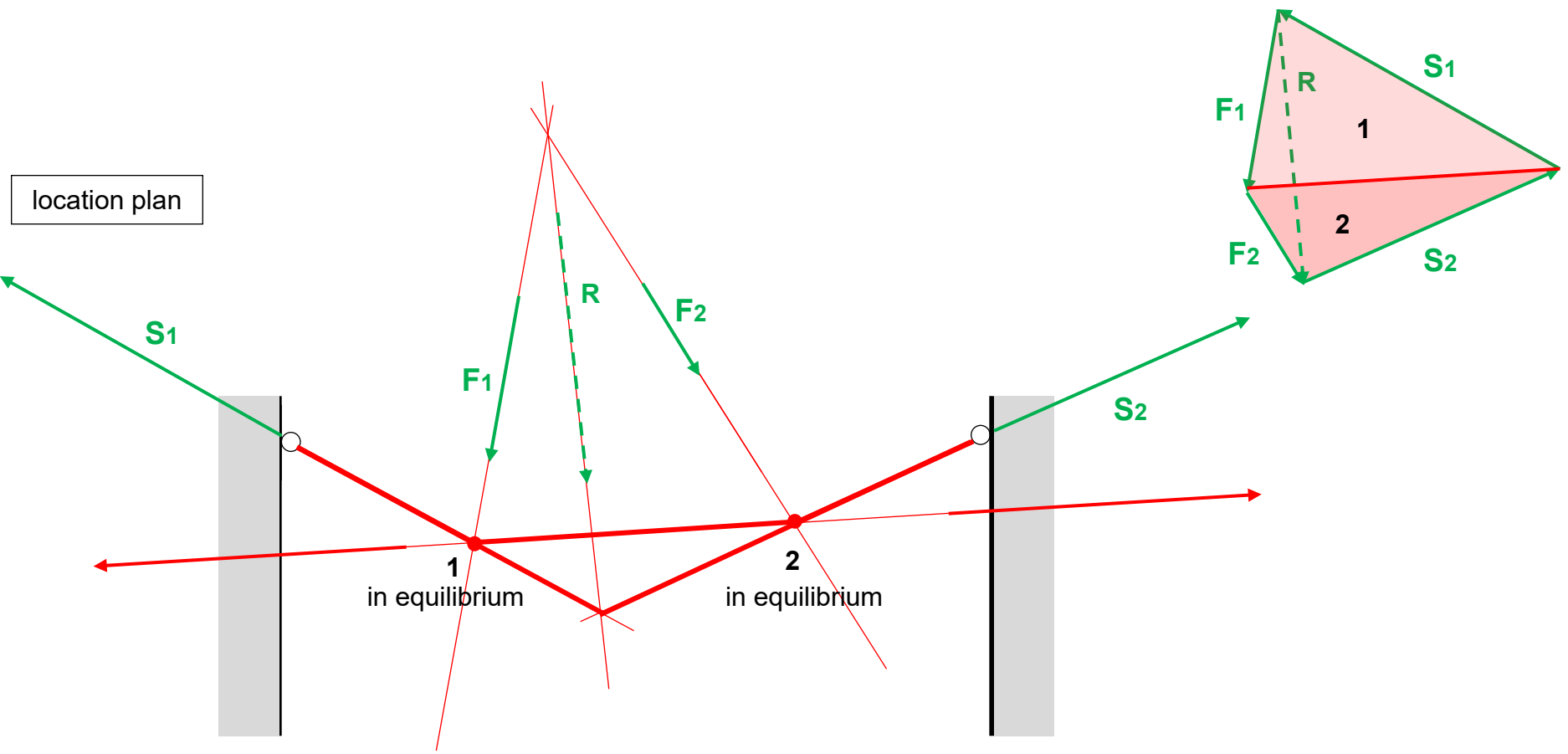
location plan



Equilibrium cable

force plan

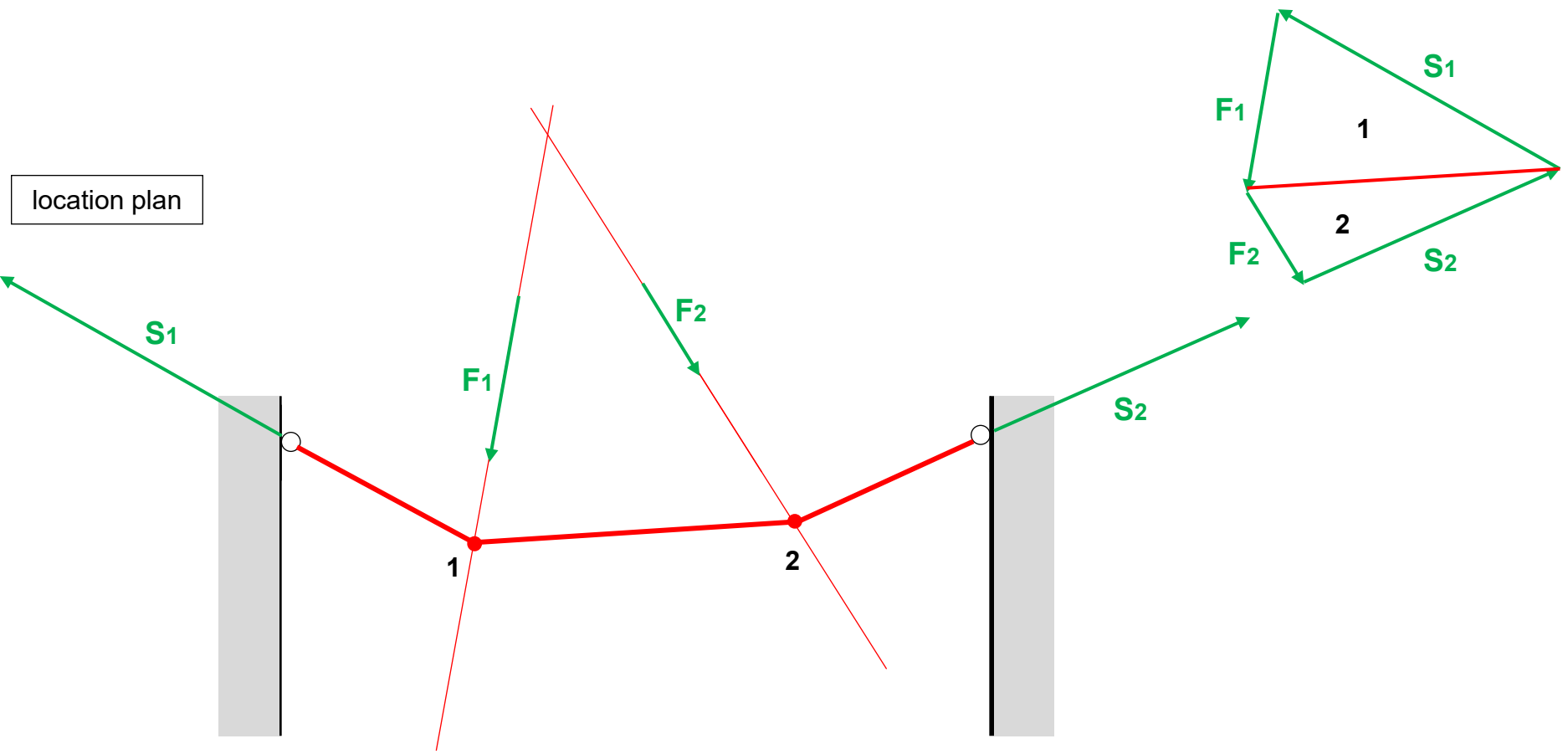
location plan



Equilibrium cable

force plan

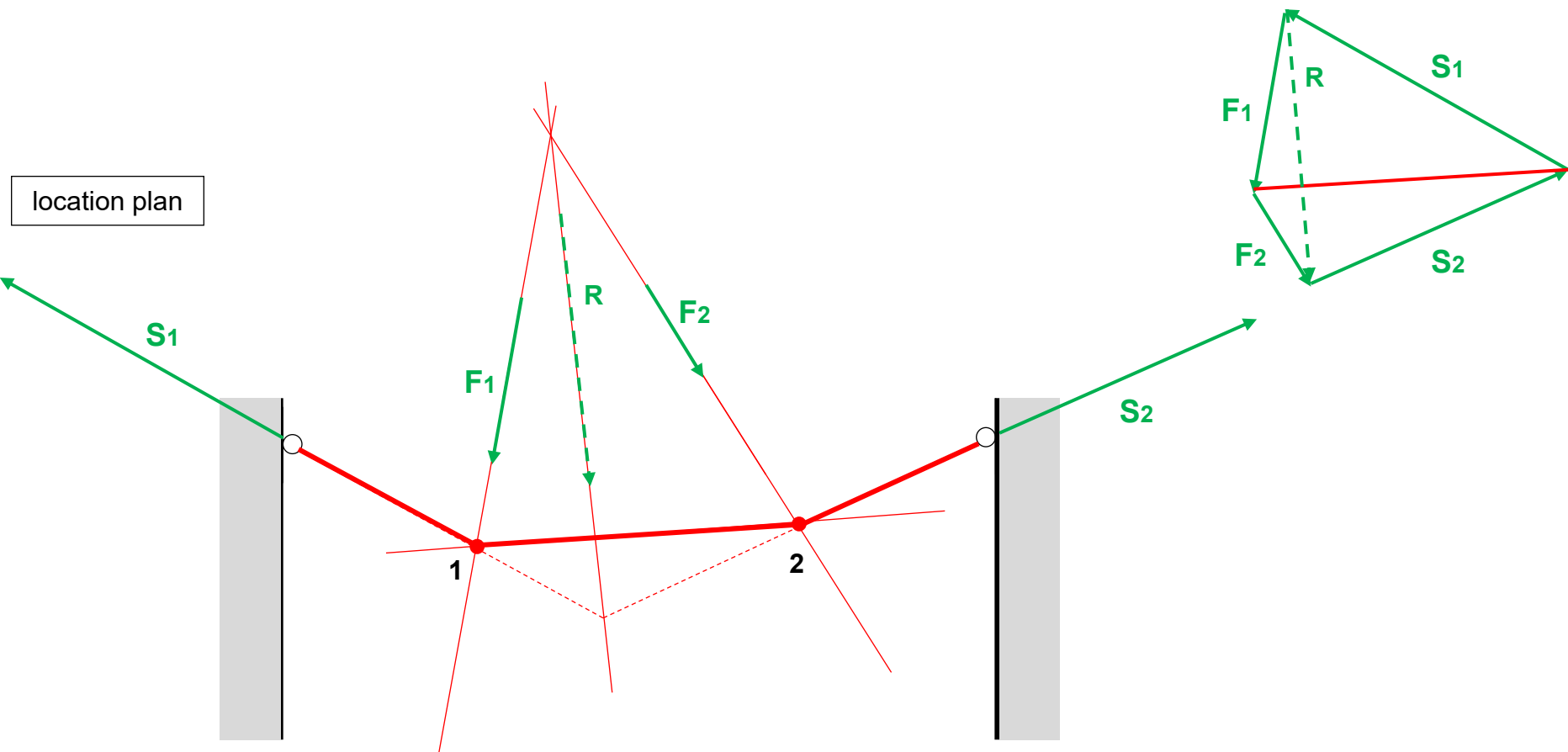
location plan



Equilibrium

cable

force plan



Step 1: construct R in force plan and location plan

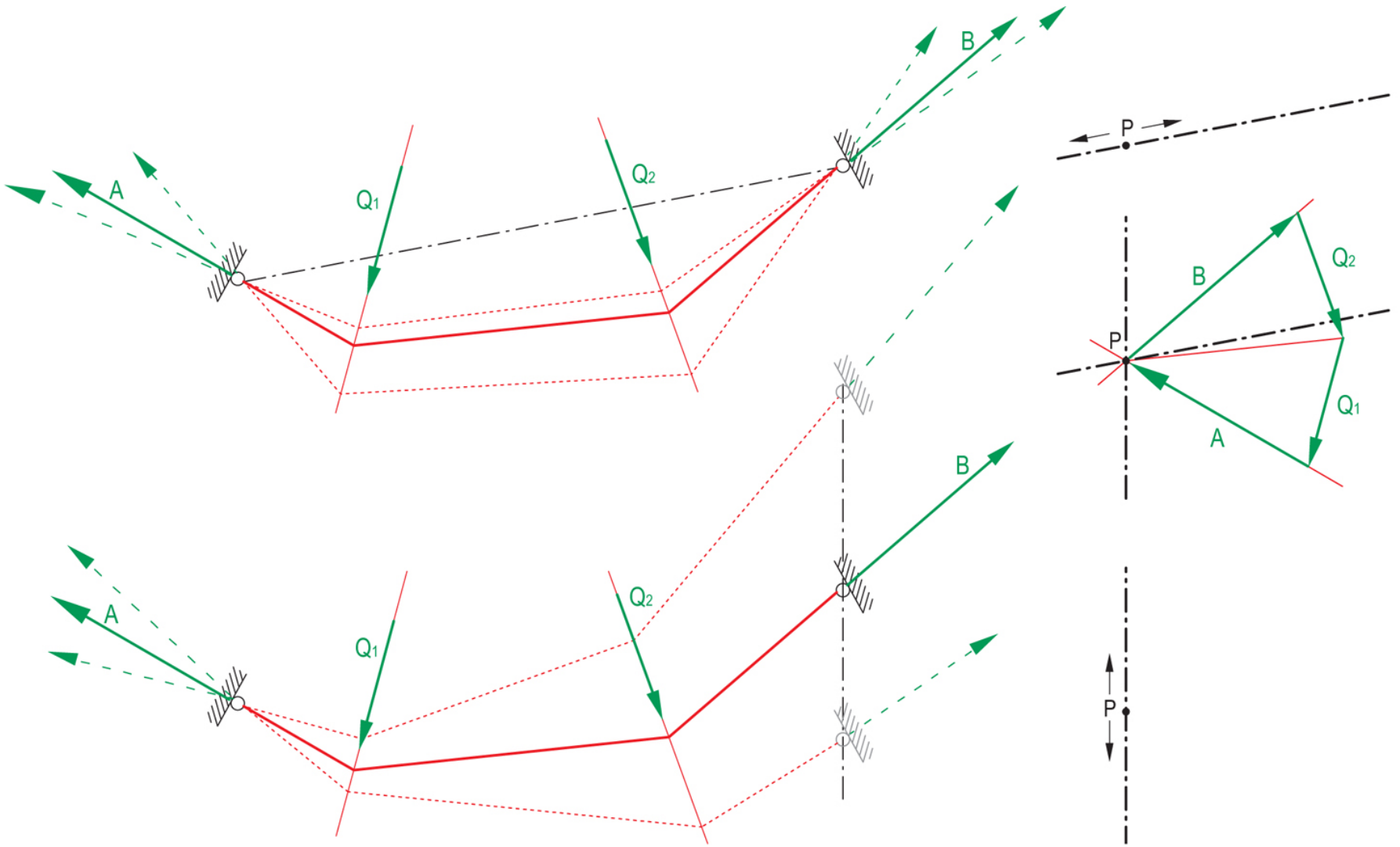
Step 2: construct support forces S_1 & S_2

Step 3: construct inner forces in force plan

Step 4: use this inner forces to construct inflection points

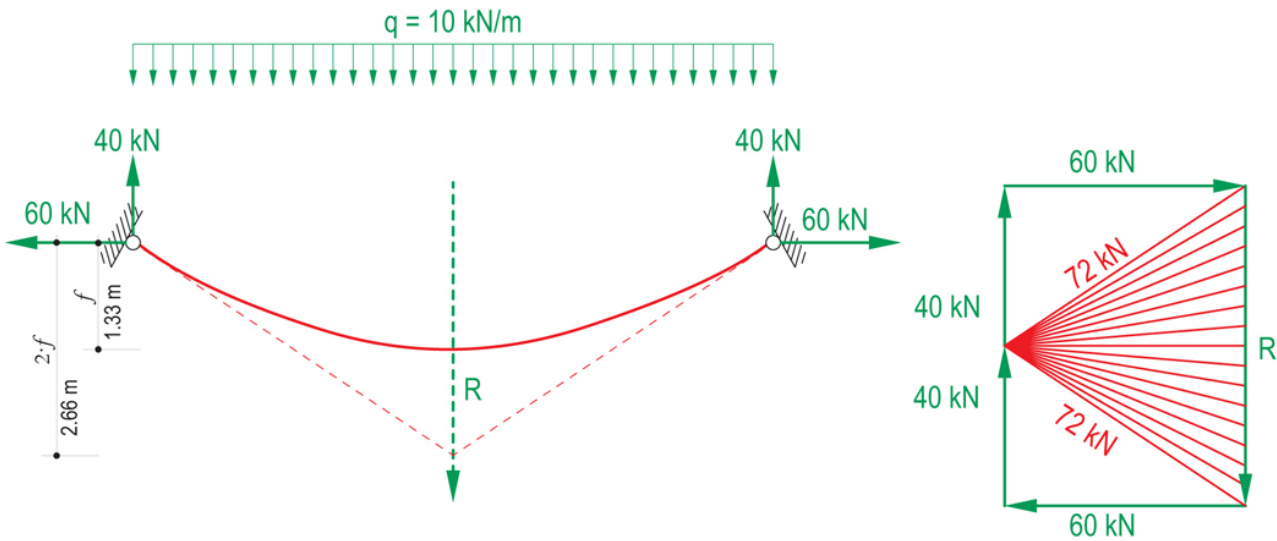
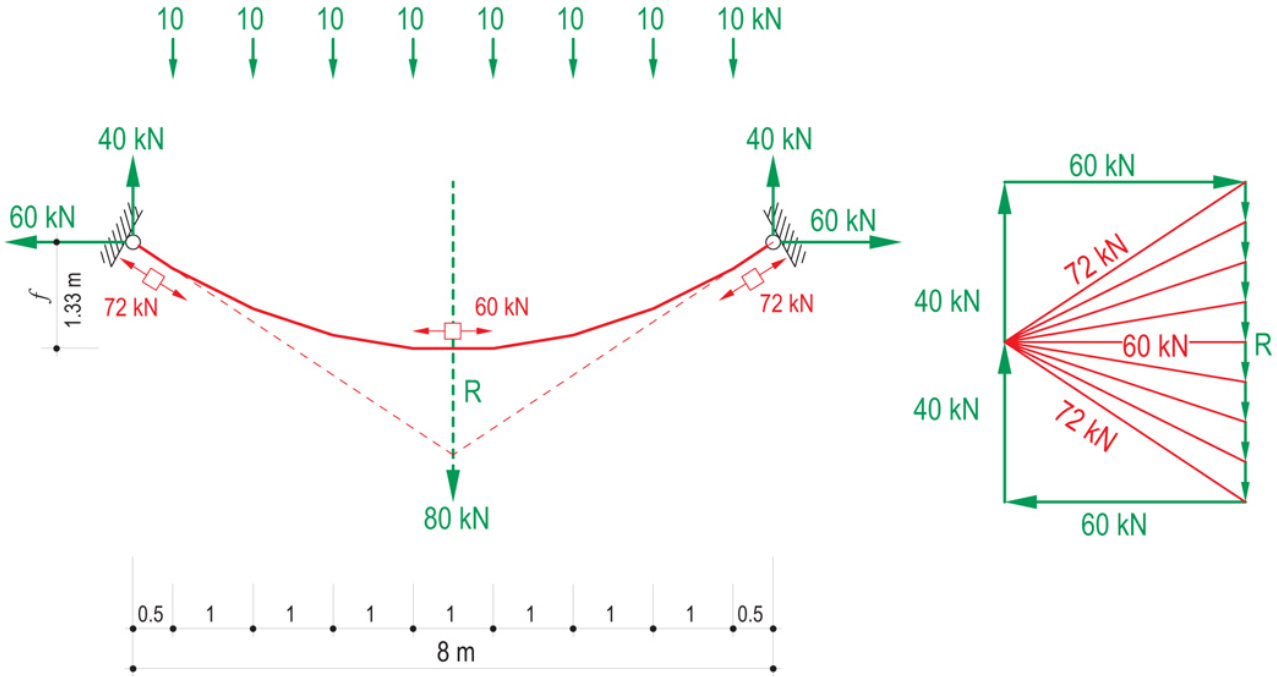
Step 5: use inflection points to construct cable

Equilibrium cable



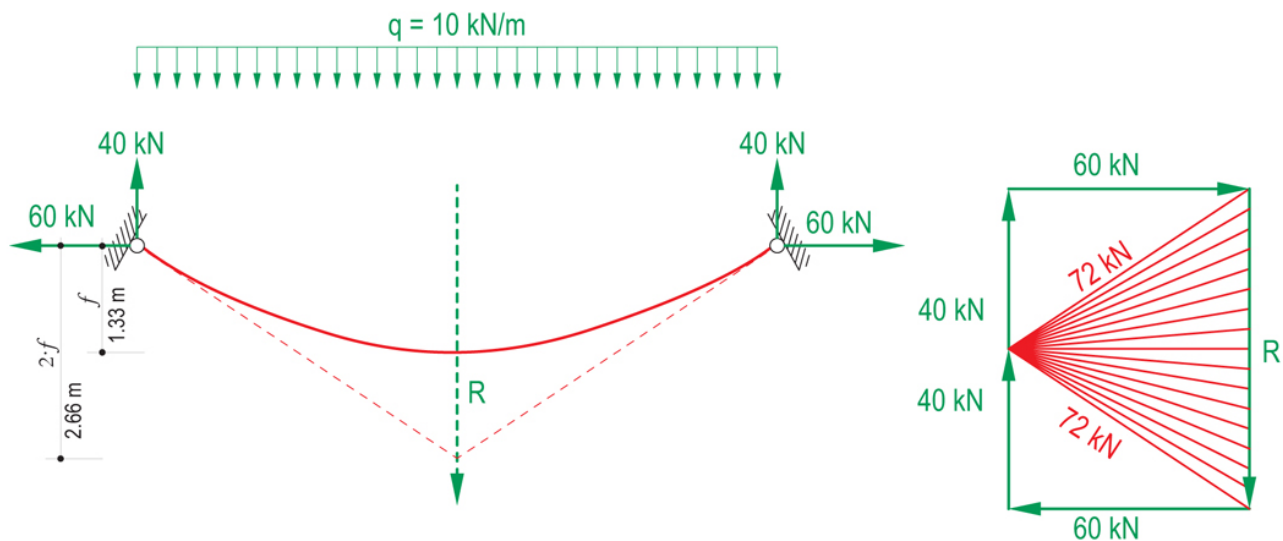
reciprocal relationship between form of cable and forces at support

Equilibrium cable





Alvaro Siza: Expo-Pavilion
Lisbon, Portugal, 1998





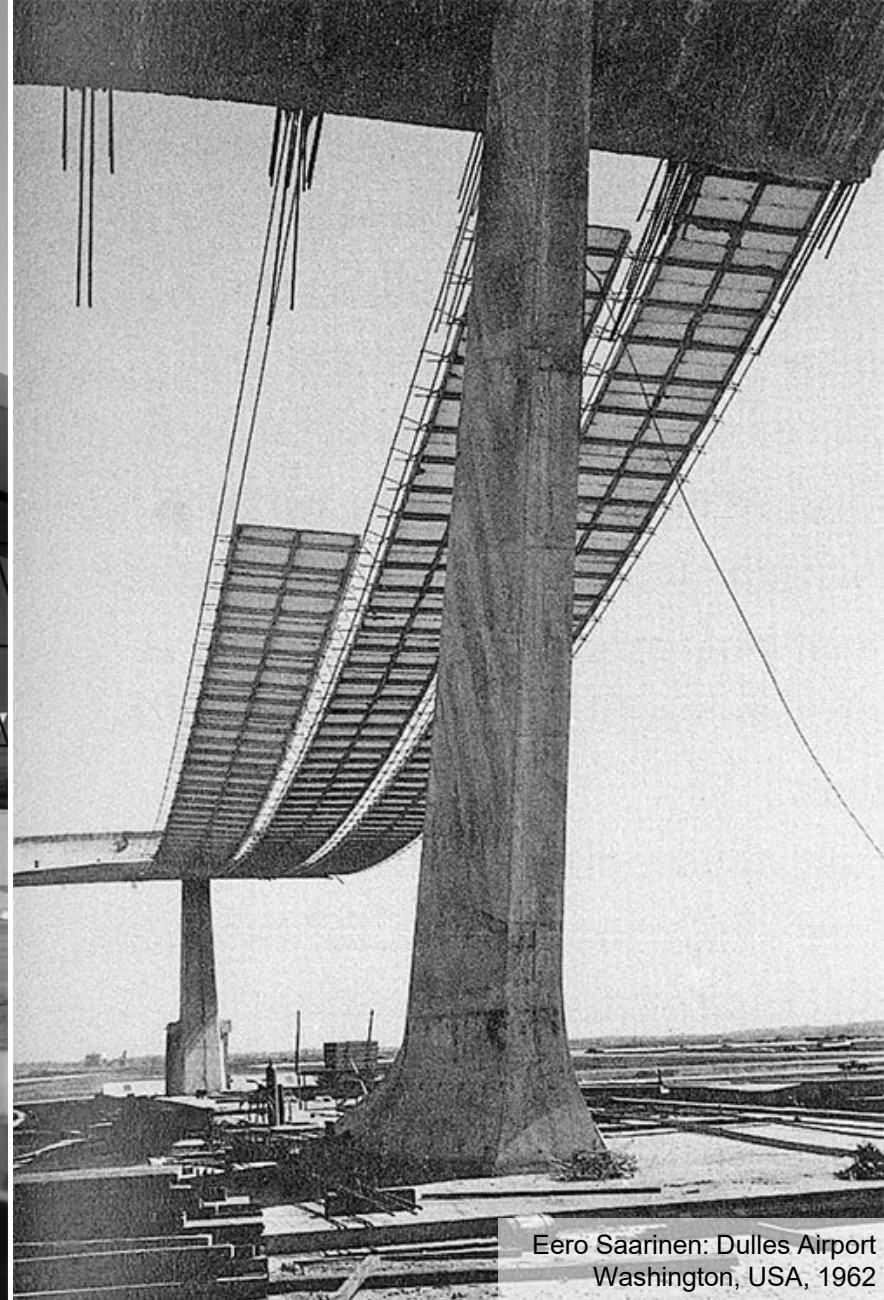
Alvaro Siza: Expo-Pavilion
Lisbon, Portugal, 1998



Alvaro Siza: Expo-Pavilion
Lisbon, Portugal, 1998



Eero Saarinen: Dulles Airport
Washington, USA, 1962

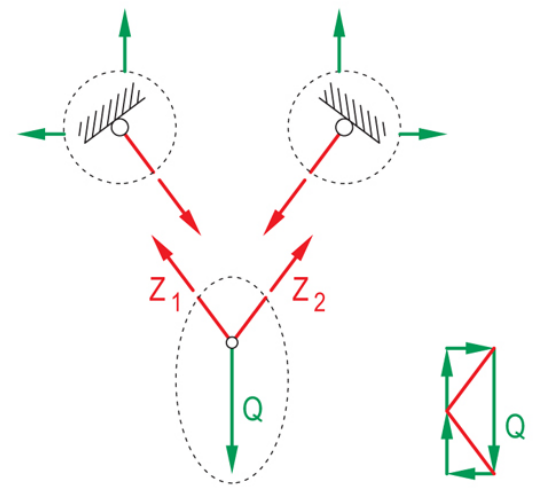
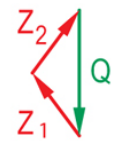
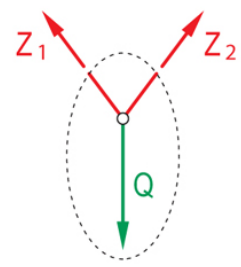
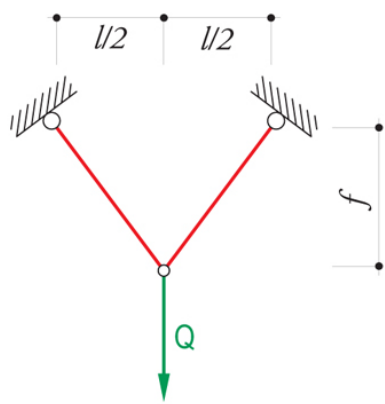


Eero Saarinen: Dulles Airport
Washington, USA, 1962

Principle of Duality

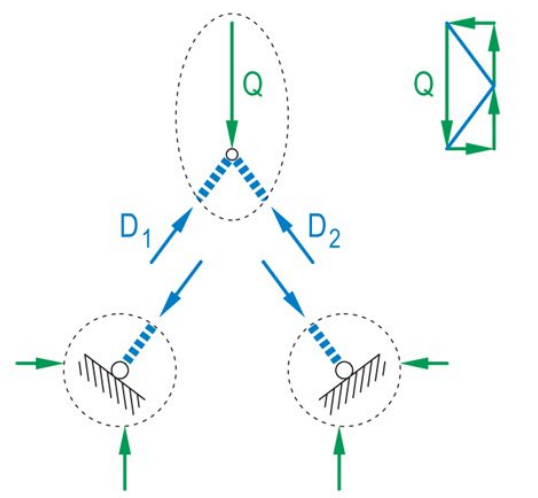
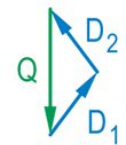
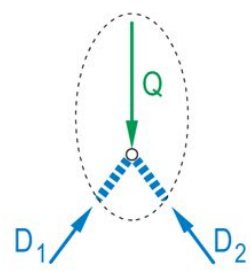
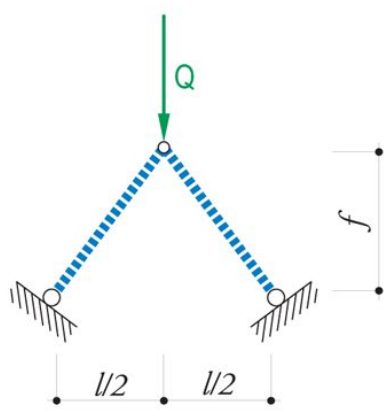
cable

only tension as inner forces



arch

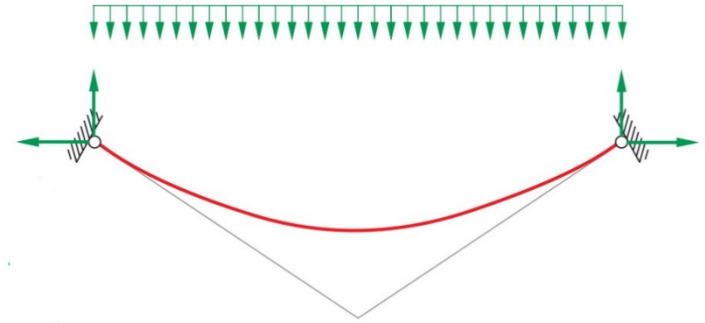
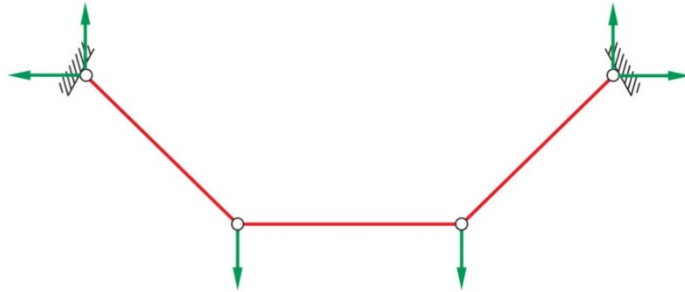
only compression as inner forces



Principle of Duality

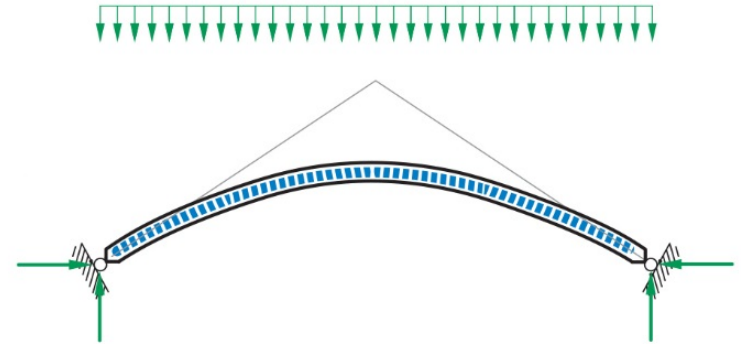
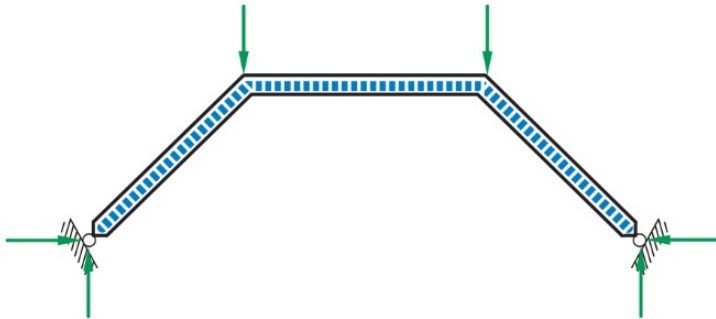
cable

only tension
as inner forces



arch

only compression
as inner forces



Principle of Duality

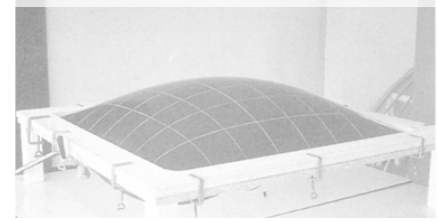


Antoni Gaudi: hanging model
Sagrada Família, Barcelona, Spain
around 1889



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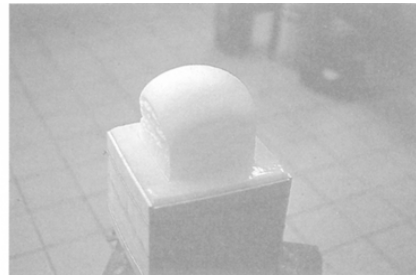
Principle of Duality



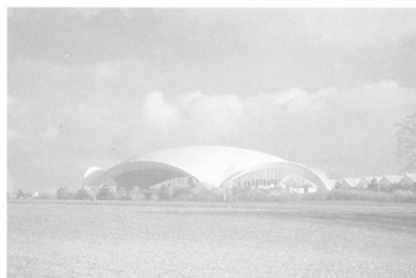
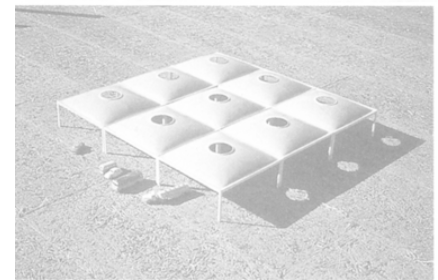
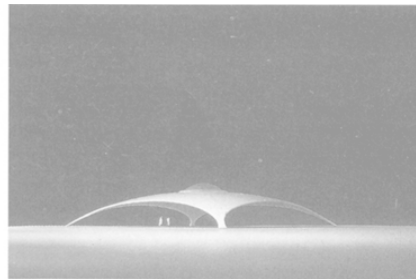
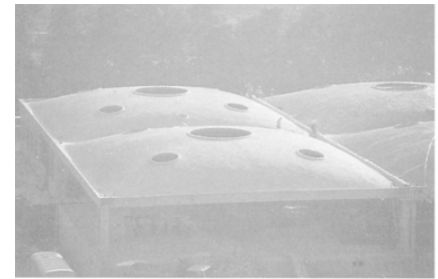
Pneumatic Membrane



Hanging Form



Flow Form

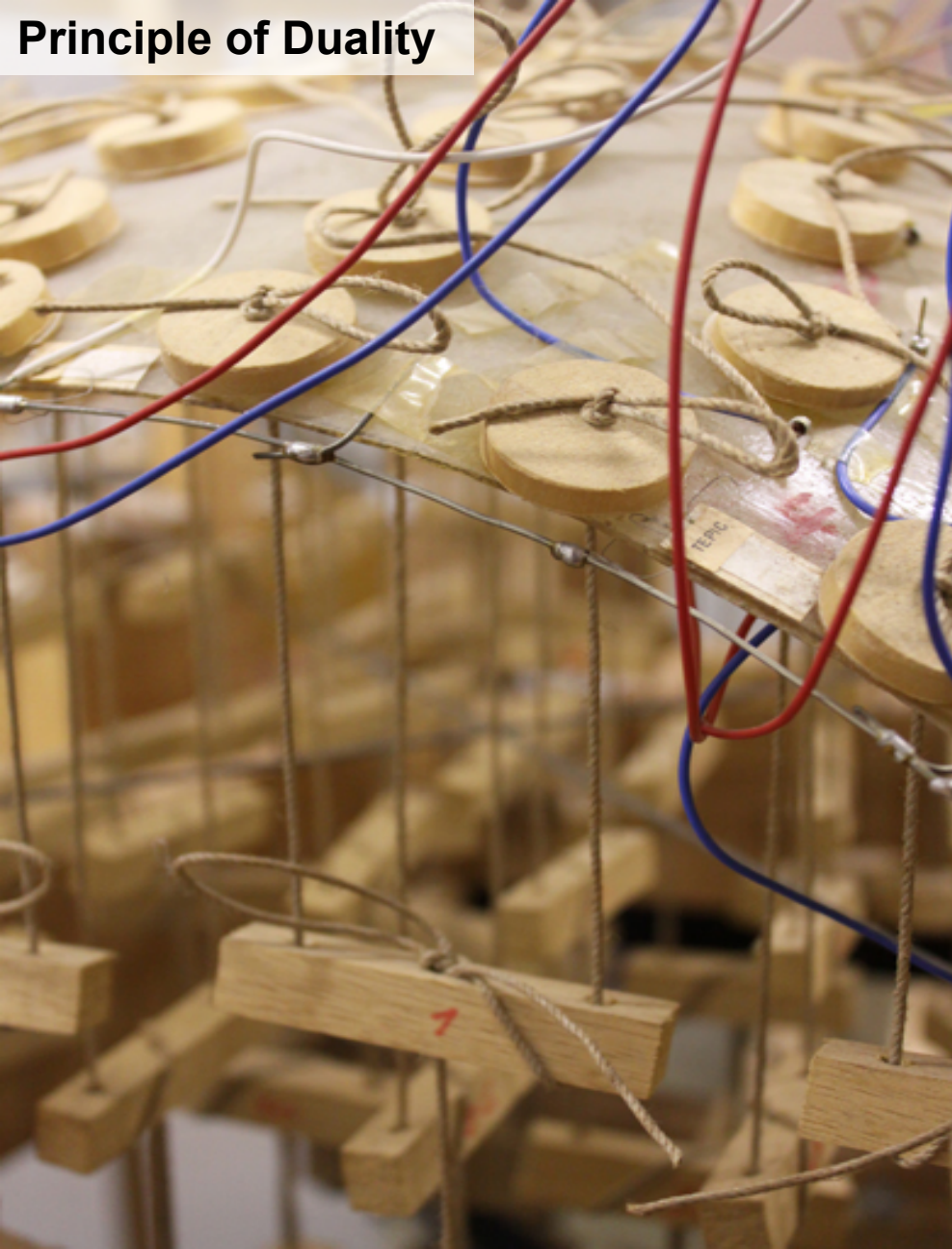


Heinz Isler: New Shapes of Shells
IASS Conference, Madrid, 1955



Heinz Isler: experimental setup for form-finding of hanging forms

Principle of Duality



Heinz Isler: experimental setup for form-finding of hanging forms



Heinz Isler: study of variations

Principle of Duality



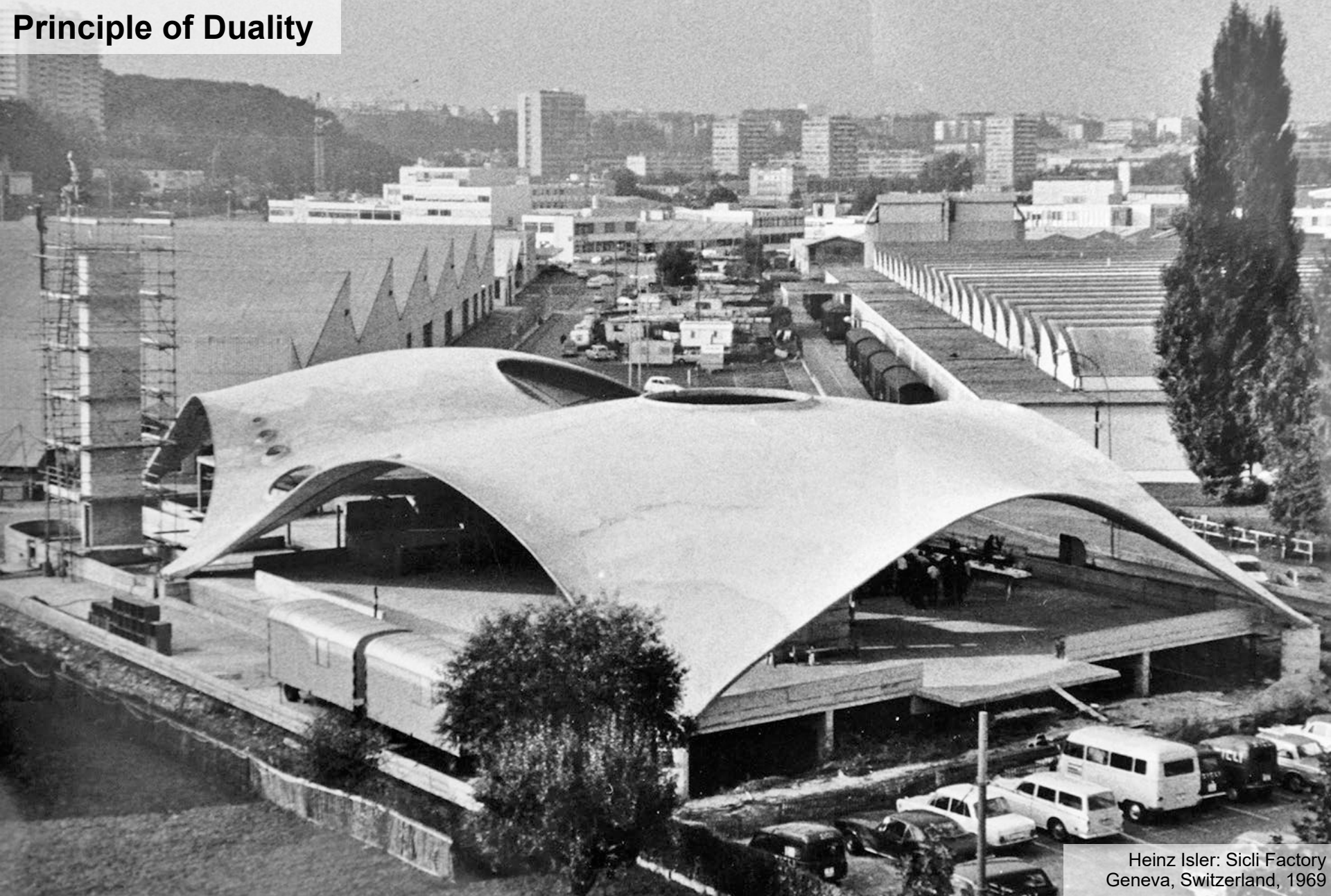
Heinz Isler: Wyss Garden Center
Solothurn, Switzerland, 1962

Principle of Duality



Heinz Isler: Gasstation
Deitingen, Switzerland, 1968

Principle of Duality



Heinz Isler: Sici Factory
Geneva, Switzerland, 1969

Inner Forces

tension

compression

inner forces act upon material

form & inner forces are coupled

cable as tension-only structure

arch as compression-only structure

principle of duality

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Exercise 2.1

Construct a cable (a) and an arch (b) as equilibrium solution for the given three forces F_1 , F_2 and F_3 . How is the form changing if F_1 is doubled?

location plan



F_1



F_2



F_3

