Analysis and development of structures in steel

Name: ______________________

Introduction

Objective

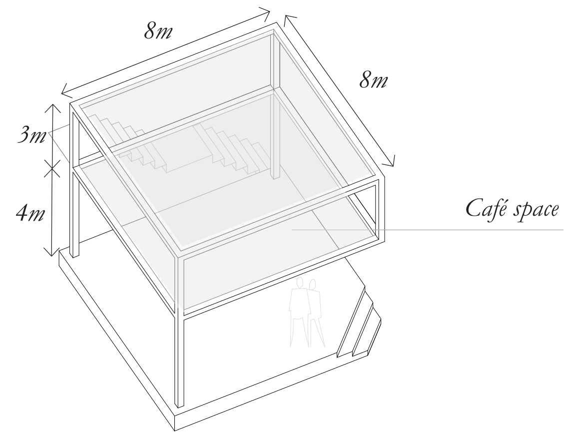
The exercises of Structural Design III deepen the understanding of the relationship between force, form and material with the help of graphic statics. These exercises illustrate the design process of a structure built from one of the main building materials: steel, reinforced concrete, timber and masonry. We will look at the following steps: brief discussion of the concept, calculation of the relevant loads, global equilibrium, internal force flow, variations of typology-topology-geometry, design for both vertical and horizontal loads and dimensioning.

For further reading, following literature is recommended:

- Script «Tragwerksentwurf III-IV», Page 27 - 40: Erläuterungen zum Konstruieren in Stahl
- Script «Tragwerksentwurf III-IV», Page 95 - 107: Erläuterungen zur dreidimensionalen Raumbildung in Stahl
- Script «Tragwerksentwurf III-IV», Page 155 - 163: Materialanhang zum Baustahl
- Faustformel, Page 75 - 79: Erläuterungen zum Werkstoff Stahl
- Faustformel, Page 131 - 133: Erläuterungen zum Kräfteverlauf in Scheiben mit Öffnungen

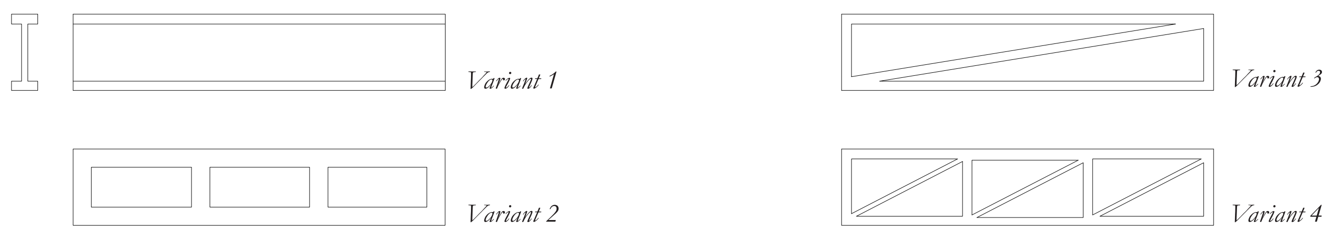
Architectural conditions

The following architectural conditions are given: A space for a Café is designed above the 8*8 meter platform. To be usable as a covered area for the customers, the room is situated 4 meters over the platform. In the corner of this platform there are 3 steps, preventing the building to have a colomn there. The final project should rest on colomns on the other 3 corners.



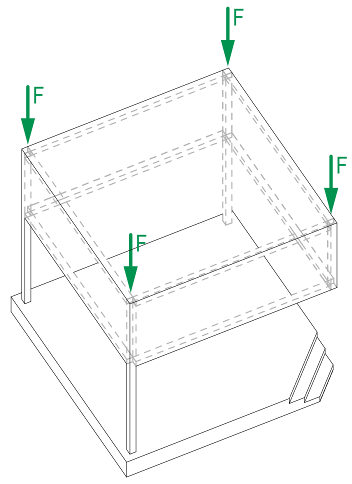
Console girder possibilites

Consider different possibilities how the structure of the Café could be composed. Discuss how the variants of the continuous girder, Vierendel girder and truss , shown in the sketches below, influence the weight as well as the spatial and architectural qualities of the structure.



Idea for the structural design

You decide to use steel trusses and reinforced concrete slabs (25cm) for the structure. In the following tasks you will analyse different design variants considering this choice. But, before that, calculate the loads of the building and distribute them to the four corners as shown in the drawing below.
Hint 1: Consider the dead loads of both the concrete slab and the steel beam.
Hint 2: To calculate the weight of the steel beams, consider the slenderness (Script TWE II, Table 14).
Hint 3: Find the value of the live load in eQUILIBRIUM/courses/Structural Design III/Lasten und Kennwerte.
Hint 4: Note that the value for the snow load in the city of Zurich is 1.2 kN/m².



Dead load of the reinforced concrete slab
Specific weight of reinforced concrete: 25kN/m³
Slab's surface: 8*8 = 64m²
2 slabs * 64m²: 2*64m² = 128m²
Total weight of slabs (thickness of 0.25 m): 128m²*0.25m*25kN/m³ = 800 kN

Dead load of the steel girder
With the maximum value for the slenderness ℓ/h of a steel girder of 20 (from script TWE II, table 14.1), a girder height of at least 400 mm results for a span of 8m: An IPE 200 profile with a height of 400 mm is selected.
The specific load of this beam is 66 kg/m. (equilibrium website /Stahlprofile /page (IPE).
106m (Annahme)* 66kg/m ≈ 7000kg = 70 kN
G_d = 1.35*(800 kN reinforced concrete + 70 kN steel) ≈ 1175 kN

Live load of the lower roof
Live load (Café): 5 kN/m² (Equilibrium website/Lasten und Kennwerte/Page 1/12)
Surface: 8m*8m = 64m²
Q_d = 1.5*(5 kN/m²*64m²) = 480 kN

Live load of the upper roof
Snow load in Zurich: 1.2 kN/m²
Roof surface = 8m*8m = 64m²
$Q_{d,snow}$ =1.5*(1.2 kN/m²*64m²) ≈ 115 kN

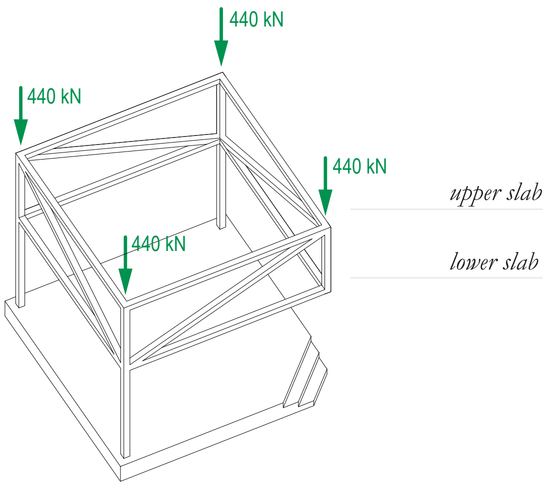
$Q_{d,tot}$ = G_d + Q_d + $Q_{d,snow}$ = 1175+480+115 ≈ 1770kN
F every corner = 1770/4 ≈ 440 kN

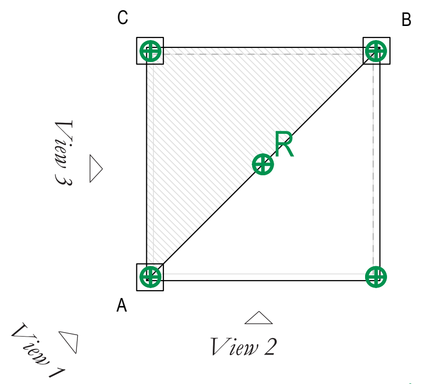
Task 1 Transfer of vertical loads: design variation 1

The structure is designed as a three-dimensional cantilevering truss.

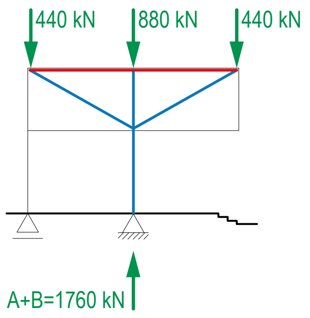
1a Global equilibrium & qualitative forceflow

The following axonometric drawing shows a possible structure for carrying the vertical loads calculated in the last page (440 kN on each corner). Draw a possible internal force-flow and determine with the help of force diagrams the magnitude of the forces in the structural members as well as in the supports for the indicated load case. Use the colours red for tension, blue for compression and green for the support forces.

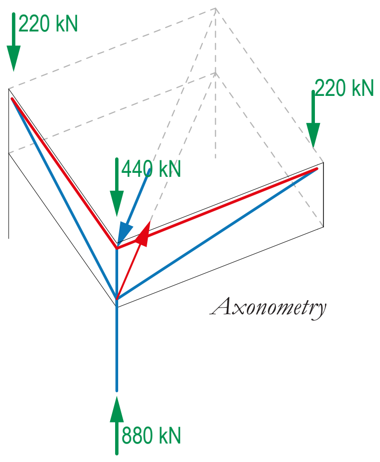




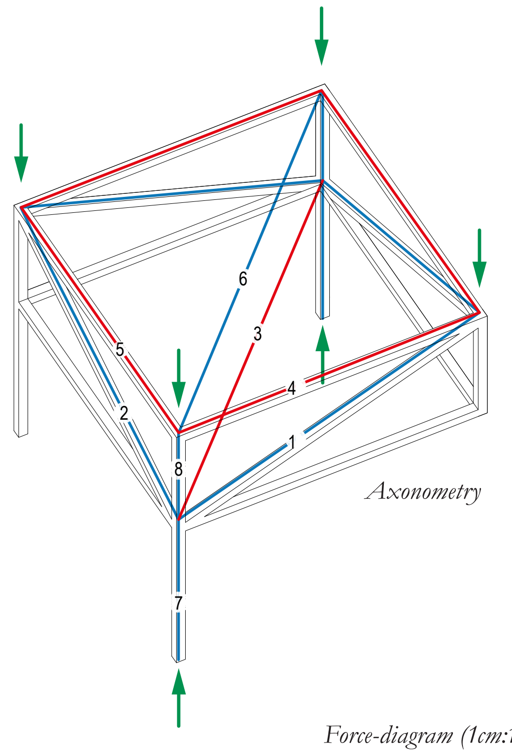
Plan



View 1



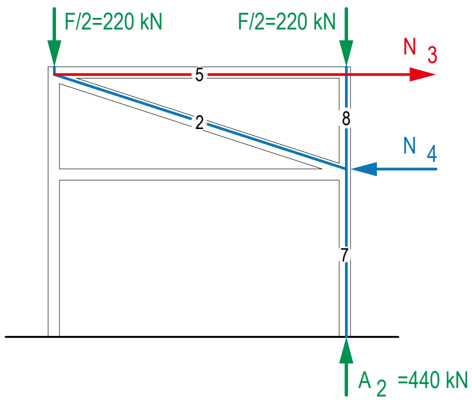
Axonometry



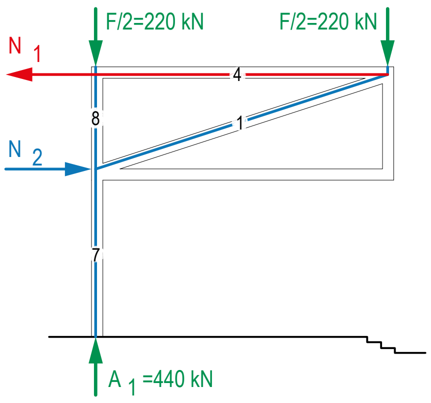
Axonometry

1b Quantitative forceflow

View 3

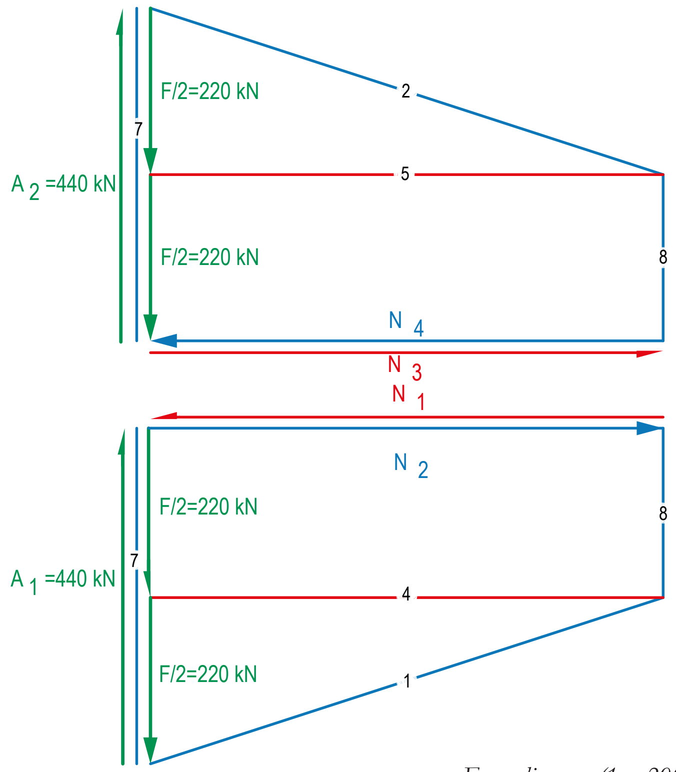


View 2

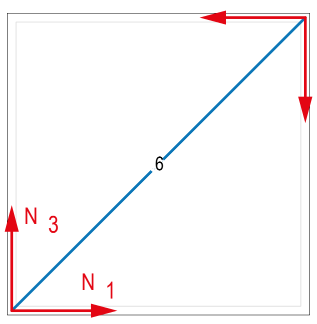


$A = A_1 + A_2 = 440 + 440 = 880$ kN

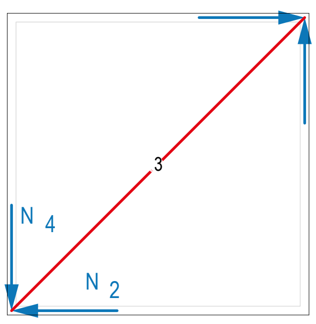
Force-diagram (1cm:100kN)



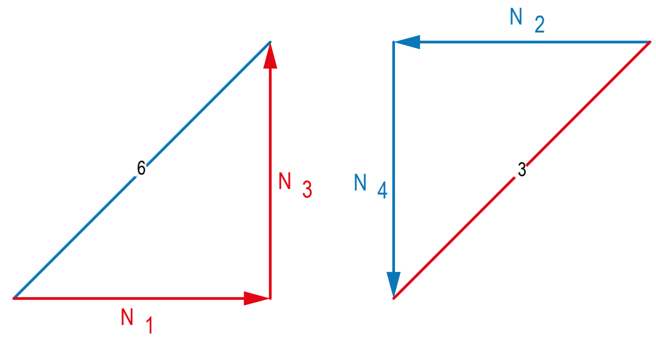
Floor plan (upper slab)



Floor plan (lower slab)



Force-diagram (1cm:200kN)



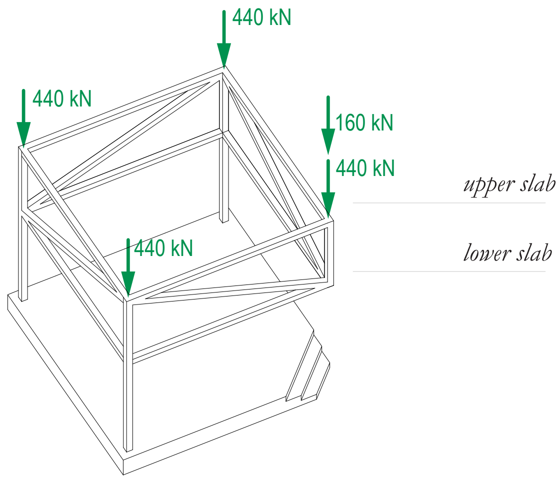
Name: ____________________

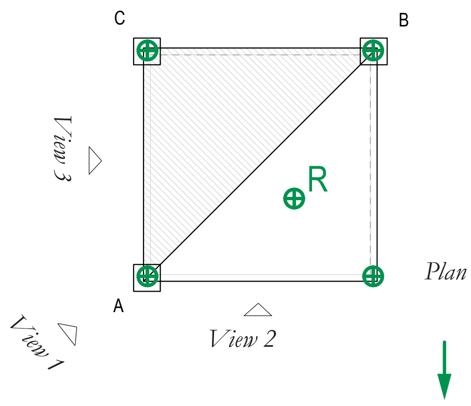
Task 2 Transfer of vertical loads: design variation 2

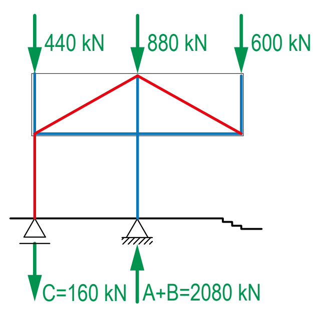
The structure is designed as a three-dimensional cantilevering truss

2a Global equilibrium & qualitative forceflow

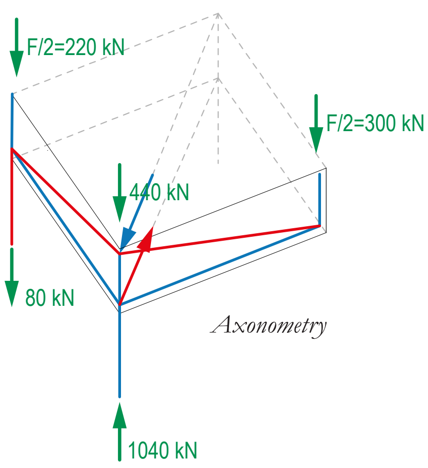
Besides the changed arrangement of the diagonals, some mechanical installations need to be placed on the rooftop, above the missing column. These installations will apply a punctual load of 160 kN on this corner, which influences the behaviour of the structure. Draw a possible internal force-flow and determine with the help of force diagrams the magnitude of the forces in the structural members aswell as in the supports for the indicated load case. Use the colours red for tension, blue for compression and green for the support forces.

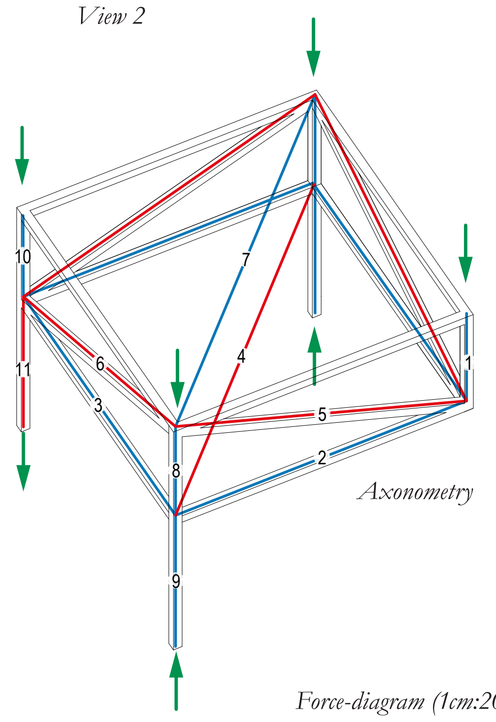




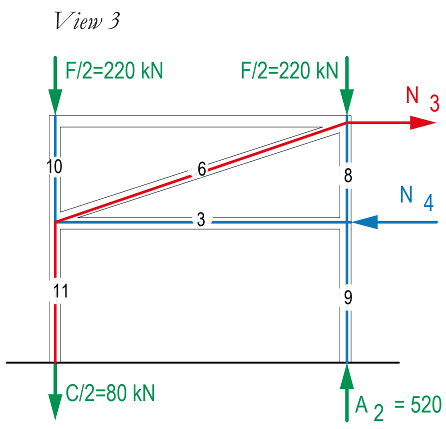


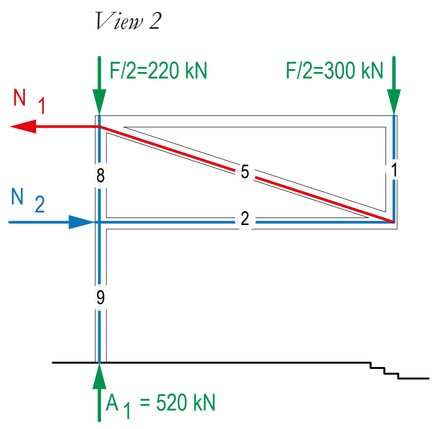
View 1





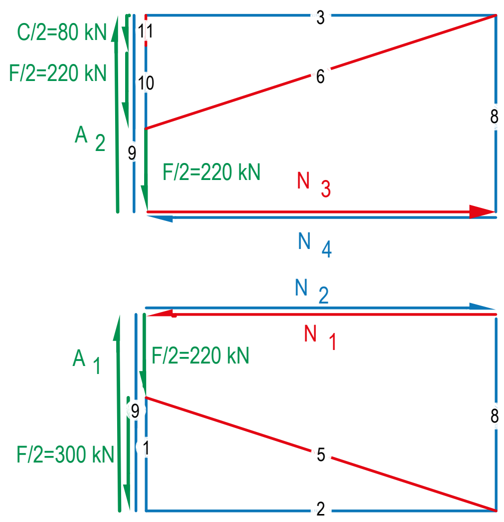
2b Quantitative forceflow



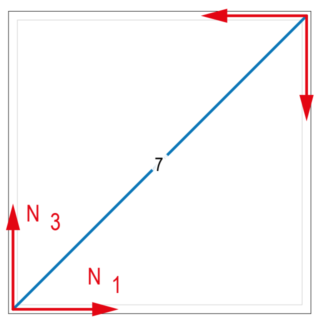


A = A 1 + A 2 = 520 + 520 = 1040 kN

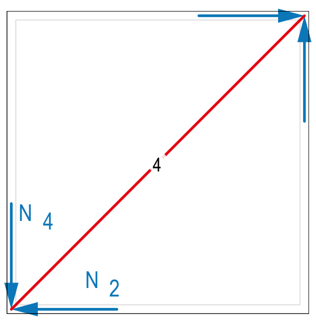
Force-diagram (1cm:200kN)



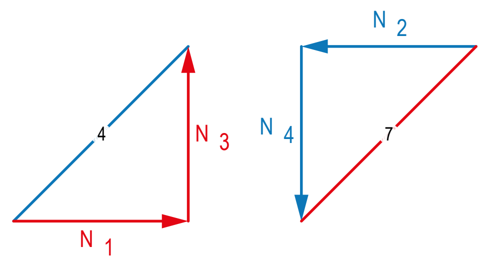
Floor plan (upper slab)



Floor plan (lower slab)



Force-diagram (1cm:400kN)



2c Dimensioning of elements

Determine the cross-sectional area of the diagonal tension elements. Determine with the help of the table *(Equilibrium Website/Stahlprofile/Seite 9/9 (ROR)* appropriate pipe corss-sections (Steel: S 235)

Element = 970 kN

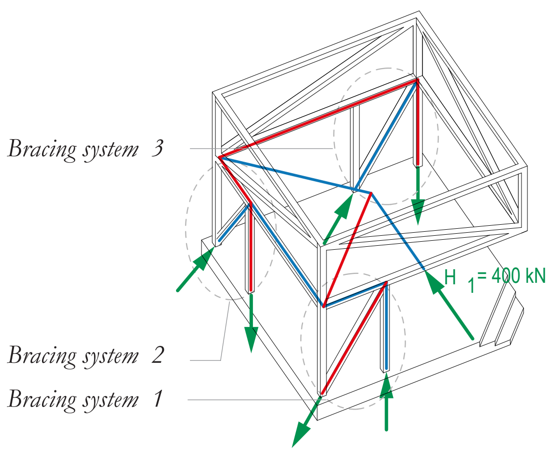
$A_{req} = N_d / f_{s,d}$ = 970'000 N / (235/1.05) N/mm² ≈ 970'000 N / 224 ≈ 4331 mm²

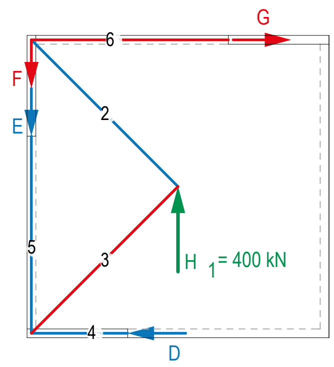
ROR: d=152.4 mm, t=10.0 mm

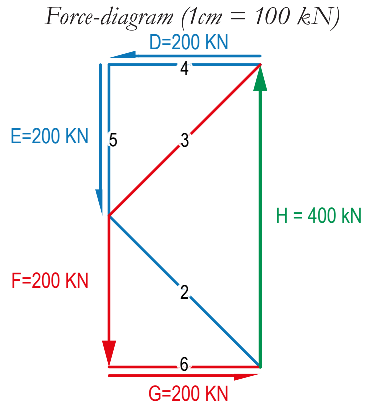
Task 3 Determination of the internal forces in the structure under horizontal forces

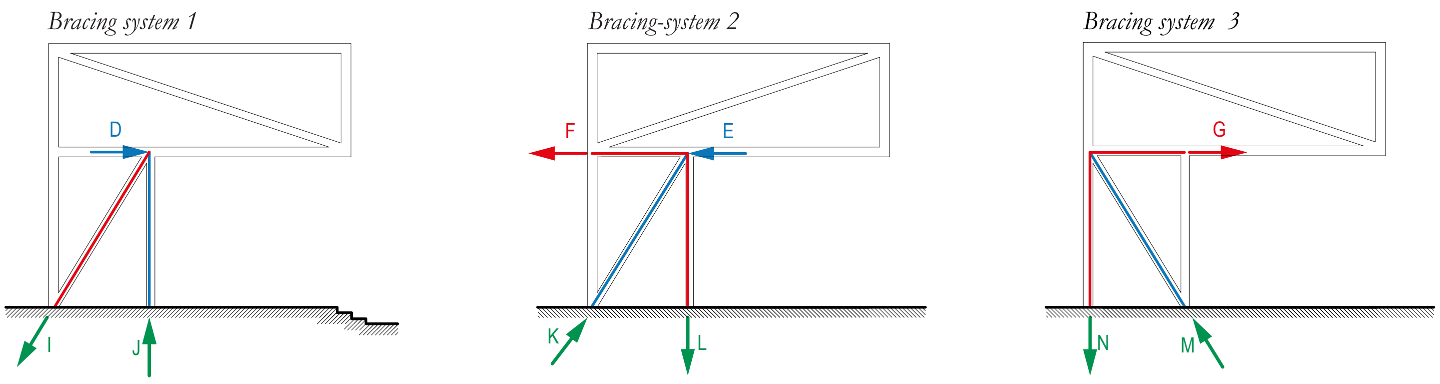
3a Quantitative analysis of forceflow in lower slab

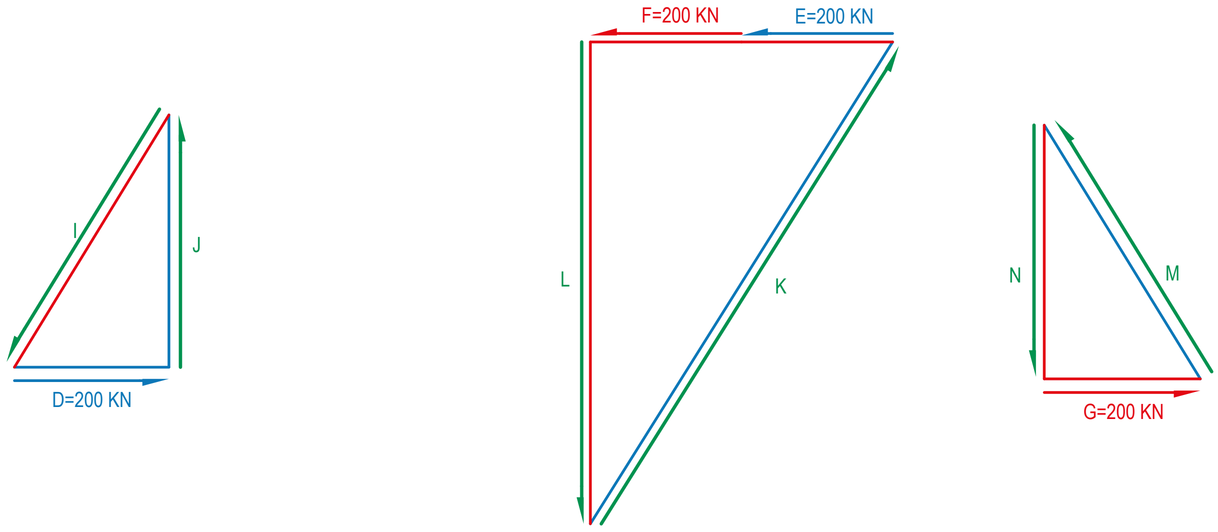
Discuss the stability of the structure under the influence of horizontal forces in the lower slab, draw a possible force-flow and calculate the internal forces using the force diagram. The axonometry below shows a possible bracing solution in order to guarantee the stability of the structure under the influence of horizontal forces acting in the lower slab. Use the colours red for tension, blue for compression and green for the support forces.











3b Quantitative analysis of forceflow in upper slab

Discuss the stability of the structure under the influence of horizontal forces in the upper slab, draw a possible force-flow and calculate the internal forces using the force diagram. The axonometry below shows a possible bracing solution in order to guarantee the stability of the structure under the influence of horizontal forces acting in the upper slab. Use the colours red for tension, blue for compression and green for the support forces.