EX 2

Analysis and development of structures in reinforced concrete

Name: ______________________________

Introduction

Objective

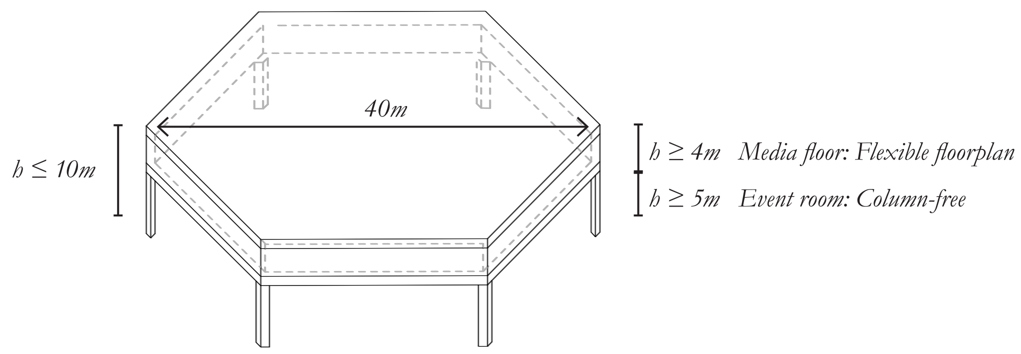
The exercises of Structural Design III deepen the understanding of the relationship between force, form and material with the help of graphic statics. These exercises illustrate the design process of a structure built from one of the main building materials: steel, reinforced concrete, timber and masonry. We will look at the following design 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 material properties.

For further reading, the following literature is recommended:

- Script «Tragwerksentwurf III-IV», Page 1 - 24: Erläuterungen zum Konstruieren in Stahlbeton
- Script «Tragwerksentwurf III-IV», Page 80 - 84: Erläuterungen zum dreidimensionalen Tragwerkskonzept vom Wohnhaus Forsterstrasse
- Script «Tragwerksentwurf III-IV», Page 139 - 152: Materialanhang zum Beton, Stahlbeton und Spannbeton

Architectonical conditions

The following architectonical conditions are given: The height of the building does not exceed 10 meters. The event room on the ground floor is column-free and has a minimal height of 5 meters. The upper floor for media representatives has a flexible floorplan with a minimal height of 4 meters.

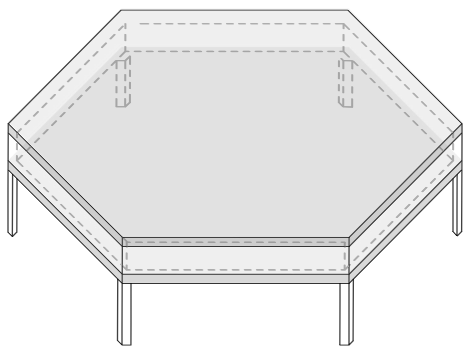


Pre-dimensioning

The table on page 1 of the attachement «Lasten und Kennwerte» offers reference values for the slenderness of structures.
Below are three different initial thoughts for the roof construction. Evaluate with the help of the table if these initial thoughts fulfill the architectonical conditions.

Help: File «Lasten und Kennwerte» P.1 →

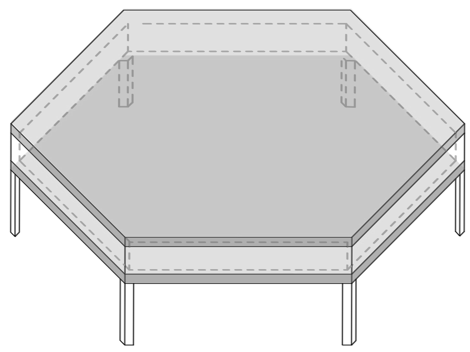
Slabs in reinforced concrete



l/h = 20 bis 25

-> h = l/25 = 40m/25 = 1.6m

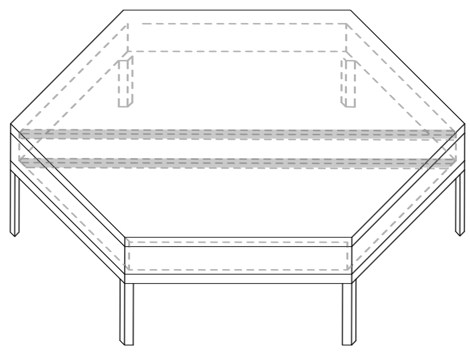
Slabs in prestressed concrete



l/h = 28 bis 35

-> h = l/35 = 40m/35 = 1.14m

Beam in prestressed concrete

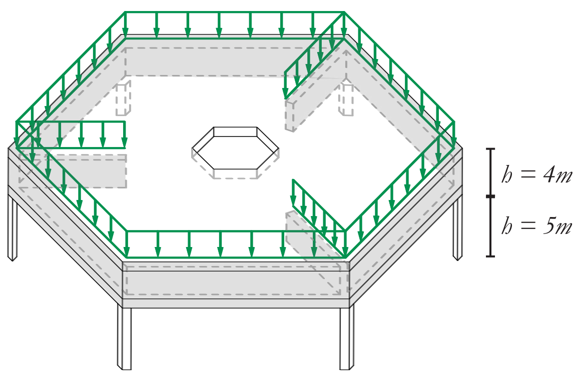


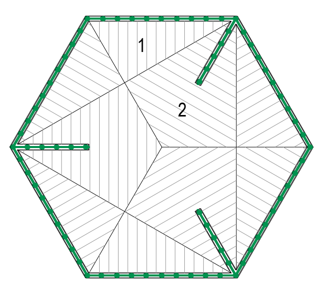
l/h = 12 bis 18

-> h = l/18 = 40m/18 = 2.22m

Idea for the structural design

It is decided to install walls (10m * 4m * 0.3m) on the media floor in order to reduce the span and thus the thickness of the roof structure to 50 cm. In the following tasks you will develop and analyze different variants of this decision. Calculate the dead load as well as the live loads applied on the structure (illustration on the left). Then calculate the forces in all load-bearing walls (illustration on the right).





Help: area of hexagon: (3√3 l²)/ 2 l: length of a side* →

Deadload of slabs and walls

Specific weight of reinforced concrete of 25 kN/m³

Slab's volume: 2(1040 m² * 0.5 m thickness)=1040 m³

Periphery walls' volume: 6(4 m*20 m* 0.3m thickness)=144 m³

Interior walls' volume: 3(4 m*10 m* 0.3m thickness)=36 m³

G_d = 1.35 (25 kN/m³*(1040 m³+144 m³+36 m³))= 41175 KN

Live load of lower slab (nutzlasten)

Q_d=1.5 (1040 m² (area of slab)*3 kN/m² (Versammlungsraum))=4680 kN

Live load of upper slab (snow load)

Snow load in Zurich: 1.2 kN/m²

$Q_{d,snow}$=1.5 (1040 m²*1.2 kN/m²)=1872 kN

$G_d + Q_d + Q_{d,snow}$ = 41175+4680+1872≈47730 kN

Area of surface 1 = 1/2 of area of surface 2 = 1/12 of total surface

Calculation of the tributary load for all load bearing walls

Amount of load on each periphery wall=47730 /12= 3977.5 kN ≈4000 kN

Amount of load on each interiour wall= 47730 /6= 7955 kN ≈8000 kN

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Task 1 Transfer of vertical loads: design variation 1

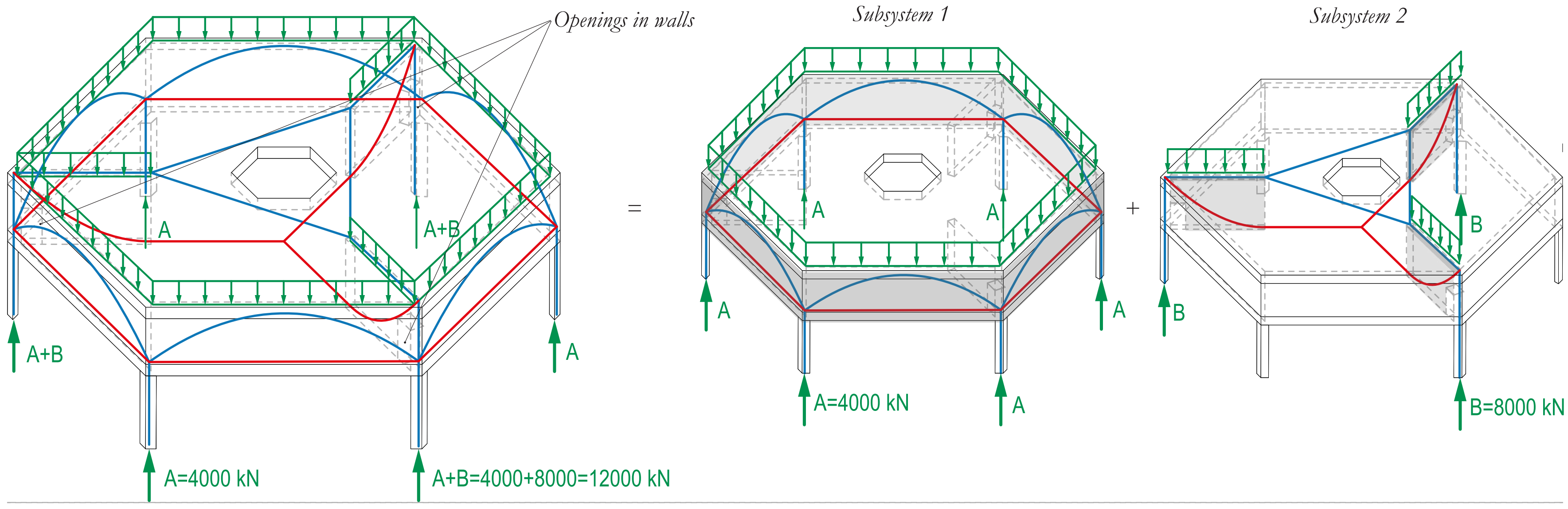
The Structure is a slab-wall system supported on 6 columns.

1a Global equilibrium & qualitative forceflow

Help: «Script TE 3-4» P.83, «Faustformeln» P.243 →

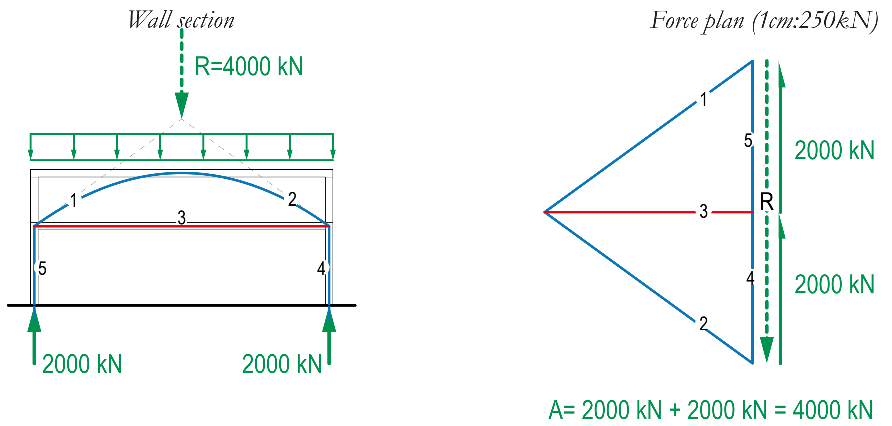
In order to better understand the force flow in a complex three-dimensional structure, it is possible to subdivide it into seperate subsystems acting together for forming a global equilibrium state.

In the axonometry drawings below, draw a possible qualitative force flow as well as the reaction forces for the given load case.
Use the two given subsystems (subsystem 1: periphery walls and subsystem 2: interior walls) in order to develop the three-dimensional qualitative force-flow in 2 steps.
Use the colours red for tension, blue for compression and green for the reaction forces in the supports.

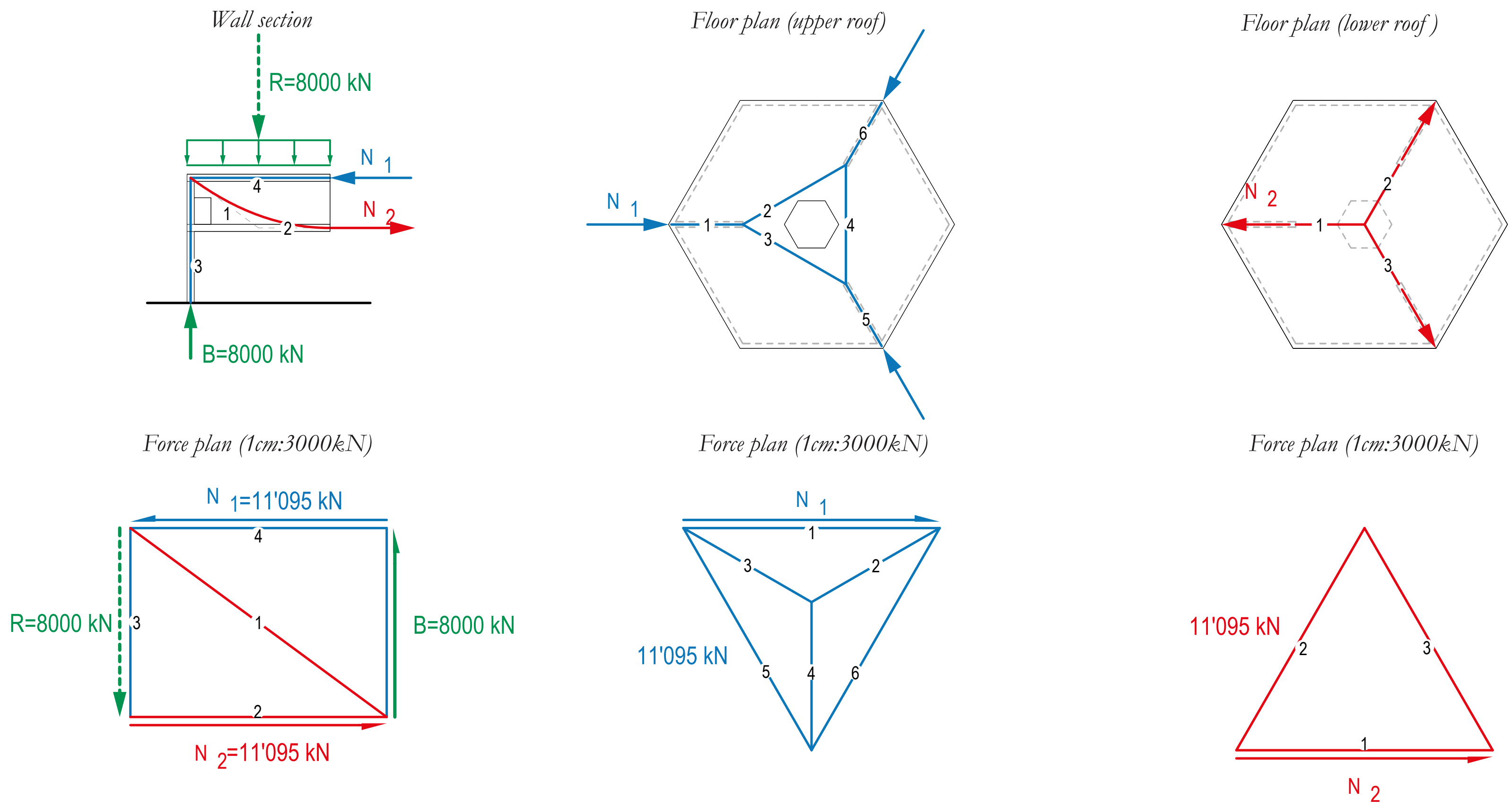


1b Quantitative forceflow

Subsystem 1



Subsystem 2



1c

Is there only one possible path of internal forces within the structure?

A three-dimensional structure that has more than three supports is statically indeterminate. This means that there are multiple solutions for the reaction forces in the supports and therefore there are many possible flows of internal forces within the structure. Accordingly, you are free to chose the amount of force going to each of the supports in a plausible way.

1d

What are the advantages of using post-tensioning?

Post-tensioning is one of most common ways to prestress structural elements often built in reinforced concrete such as beams and slabs. Post-tensioning is used to prevent cracks from appearing in the mass of concrete. It also allows beams and slabs to be thinner.

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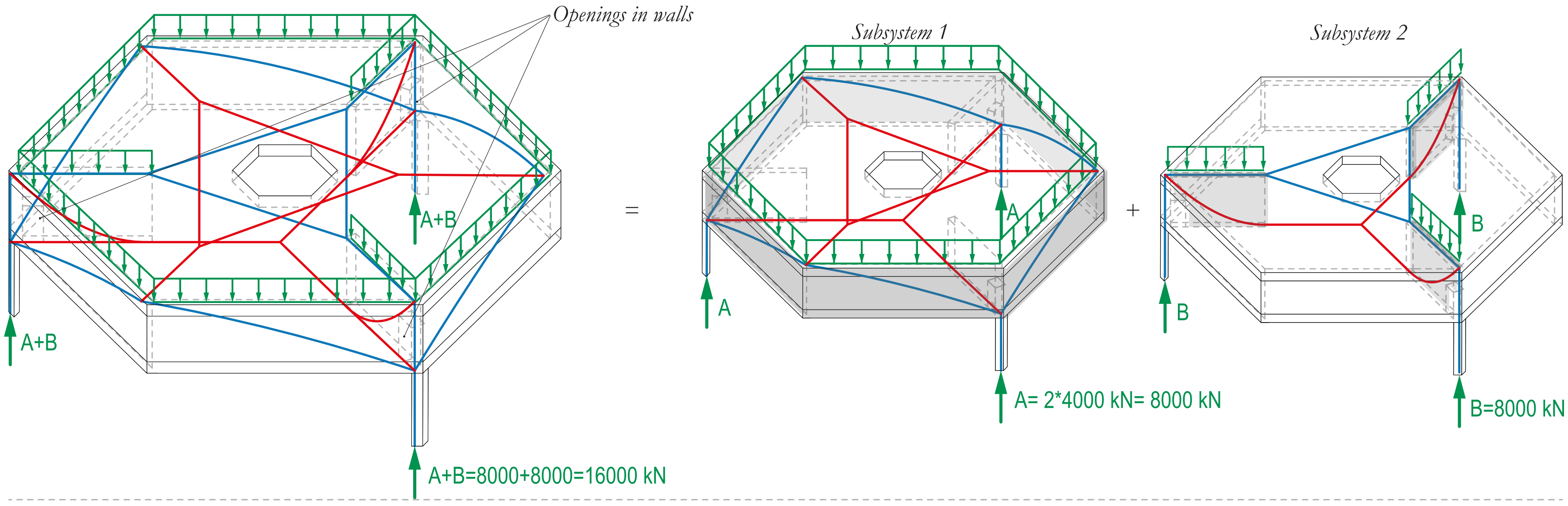
Task 2 Transfer of vertical loads: design variation 2

The Structure is a slab-wall system supported on 3 columns.

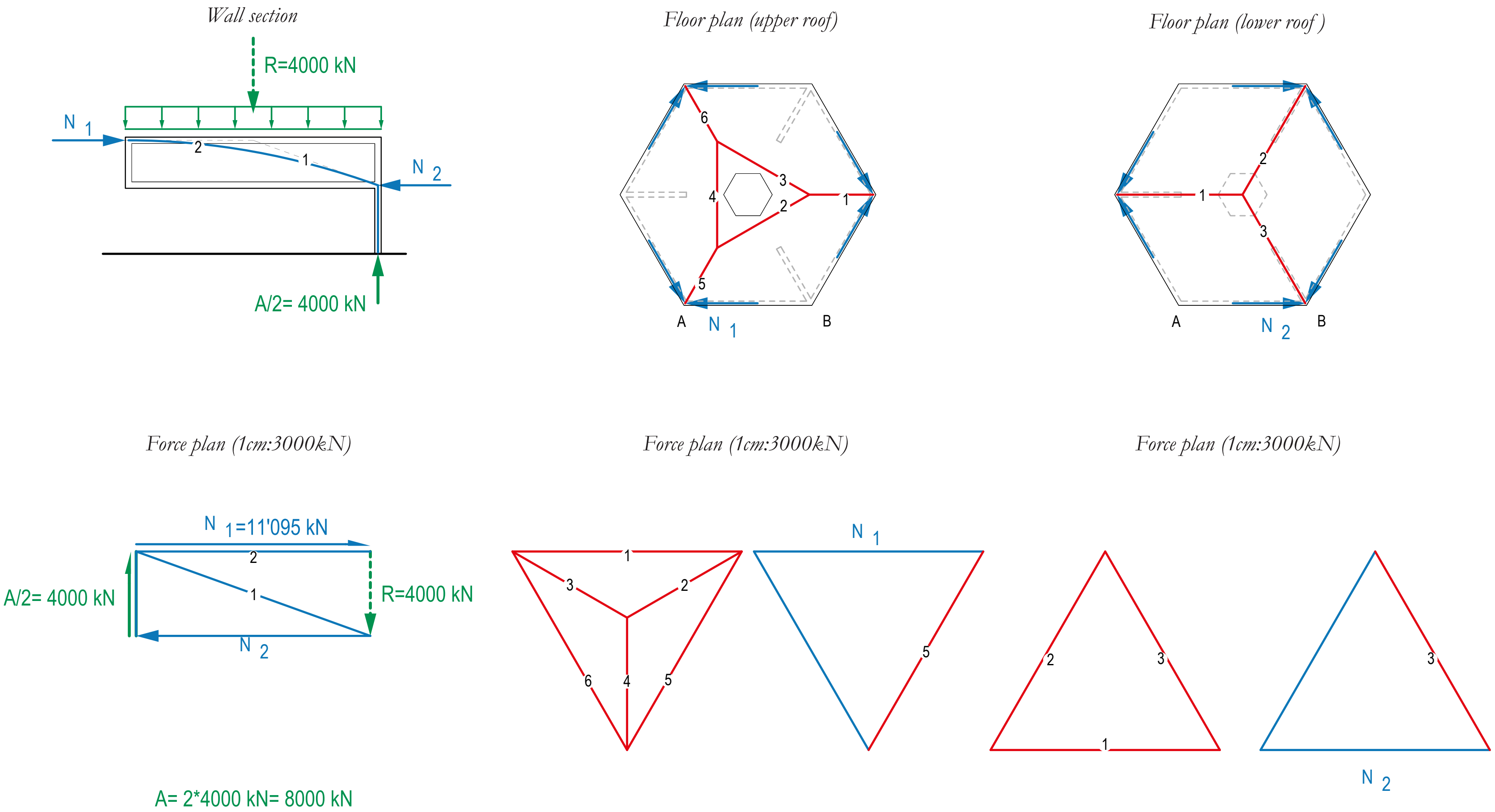
2a Three dimensional qualitative forceflow

To obtain a flexible floor plan, the numbers of columns are reduced to only 3. Draw in the axonometry drawings below, a possible qualitative force flow as well as the reaction forces for the given load case. Use the two given subsystems (periphery walls and interior walls) in order to develop the three-dimensional qualitative force-flow in 2 steps. Use the colours red for tension, blue for compression and green for the reaction forces in the supports.



2b Quantitative forceflow

Subsystem 1



Subsystem 2

Forces in this subsystem are qualitatively and quantitatively equal to the subsystem 2 of the previous page (Task 1a).

2c Dimensioning of elements

Determine the cross-sectional area of a column. Reinforced concrete C25/30 is used.

Help: File «Lasten und Kennwerte» P.4 →

$A_{c,netto,\,erf} = -D_d / f_{cd}$ = 16'000'000 / 16.5 =969'700 mm²

√969'700 mm² = 985 mm. 2h' +985 mm=h (h': Betonüberdeckung= 0.1 h). h= 1231 mm

Help: «Skript TE 3-4» p.17, diagram 17, Concrete cover

Determine if buckling occurs. Square full-profiles are used. To simplify, the critical lenghts can be assumed to be the actual lenght of the element. (l_{cr}=l)

Help: File «Lasten und Kennwerte» P.9

l_{cr}/h = 5'000 mm/1231 mm = 4.06 (Wert 1). $- D_d / A_c * f_{cd}$ = 16'000'000 / 1231mm*1231mm*16.5 = 0.63 (Wert 2).

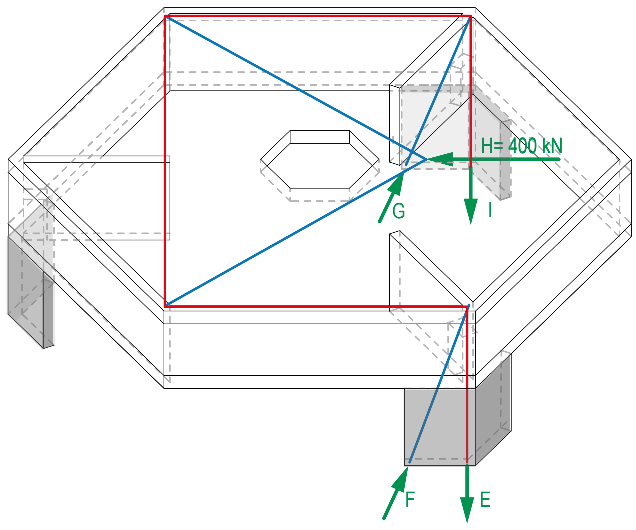
Find the intersection of these 2 values on the graph „ langzeit" of the rectangular cross-section of „knickkurven". The intersection point shows the value of ω . We consider the ω curve which is „above" the intersecting point. With the value of ω in this new curve, we calculate the amount of reinforcement needed to avoid buckling.

Task 3 Transfer of horizontal forces

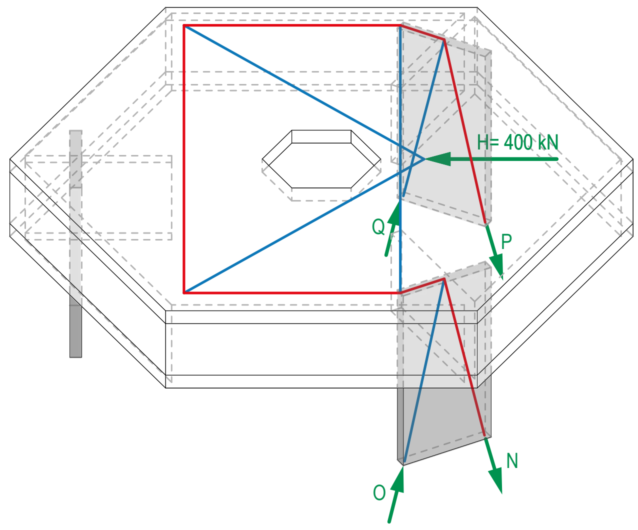
3a Evaluate the structure of the previous page with the case of horizontal forces. Discuss possible improvements to achieve adequate stability under horizontal forces.

3b Below are two possible solutions to achieve horizontal stability. Draw a possible force flow for both variants under horizontal forces. Use the colours red for tension, blue for compression and green for the support forces.

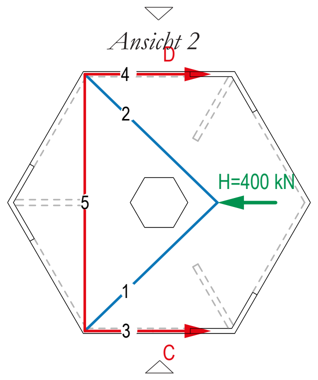
Variant 1



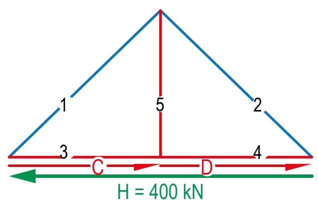
Variant 2



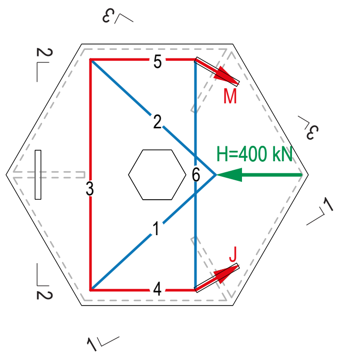
Floor plan (upper roof)



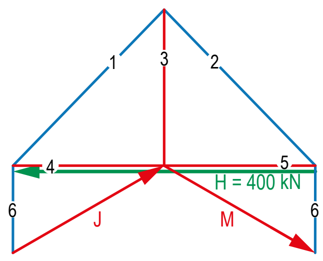
Force plan (1cm:100kN)



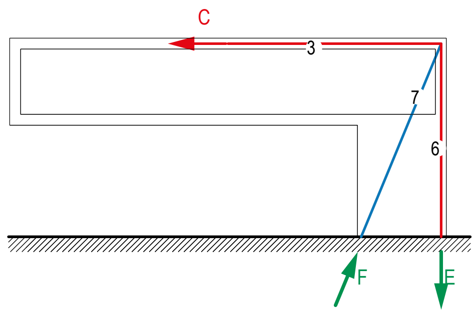
Floor plan (lower roof)



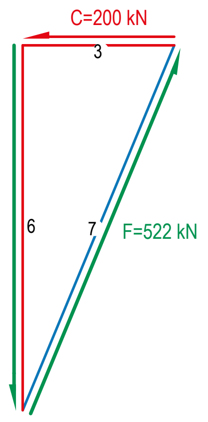
Force plan (1cm:100kN)



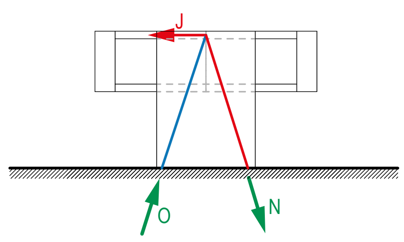
View 1



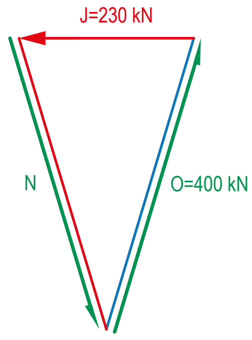
Force plan (1cm:100kN)



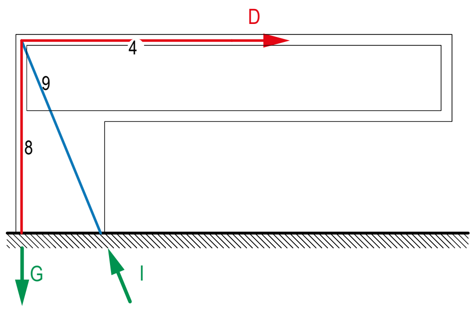
Section 1-1



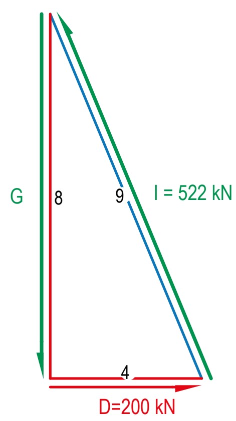
Force plan (1cm:100kN)



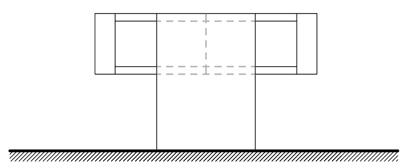
View 2



Force plan (1cm:100kN)

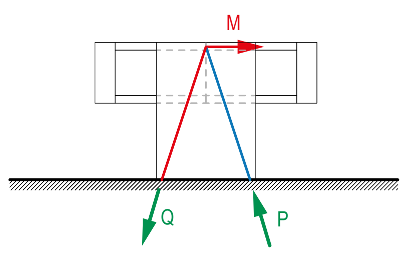


Section 2-2



Force plan (1cm:100kN)

Section 3-3



Force plan (1cm:100kN)