

Introduction Objective

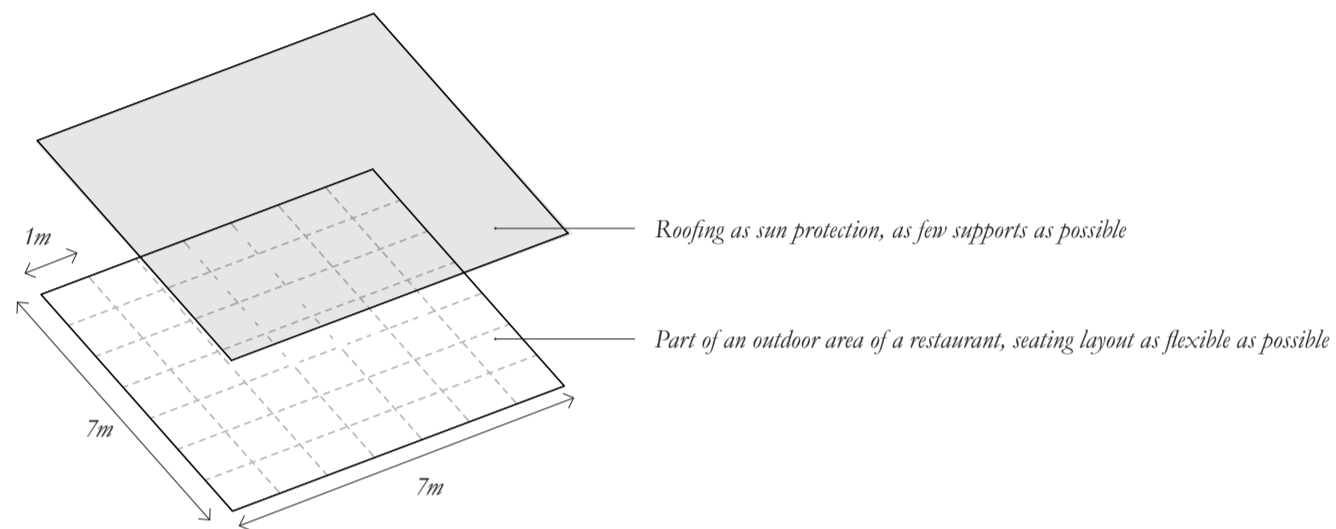
The exercises of Structural Design III deepen the understanding of the relationship between force, form and material with the help of graphic statics. These exercises illustrate the design process of a structure built from one of the main building materials: steel, reinforced concrete, timber and masonry.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

- Script «Tragwerksentwurf III-IV», Seite 43 - 54: Erläuterungen zum Konstruieren mit Holz
- Script «Tragwerksentwurf III-IV», Seite 167 - 181: Materialanhang zu Holz
- Faustformel, Seite 80 - 84: Erläuterungen zum Werkstoff Holz

Architectural conditions

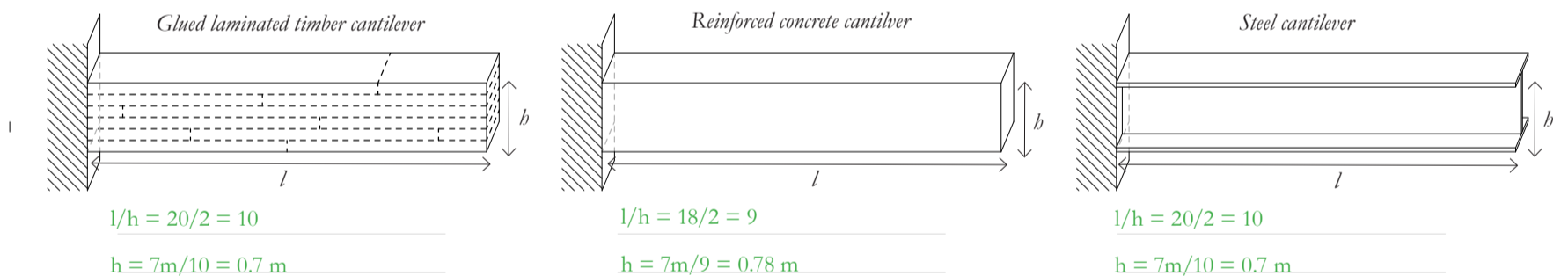
The following architectural conditions are given: 7*7 meters of the outside area of a restaurant should be covered with a light roof to provide shading. The roof structure should be made of wood and supported by as few columns as possible to grant flexible seating.



Pre-dimensioning of cantilevers

The table on page one of the appendix «Lasten und Kennwerte» shows economical values of slendernessratios for different kinds of structures. In the previous exercise, these have already been applied to reinforced concrete beams and plates and are in this exercise adapted to cantilever beams.

In the following, cantilevers with the same dimensions, however built out of different materials, are shown. Estimate the cantileverheights h needed, in order to span a roof structure over the entire restaurant area while avoiding the use of columns. For this, the ratios for beams shown in the appendix have to be adapted in the right manner.

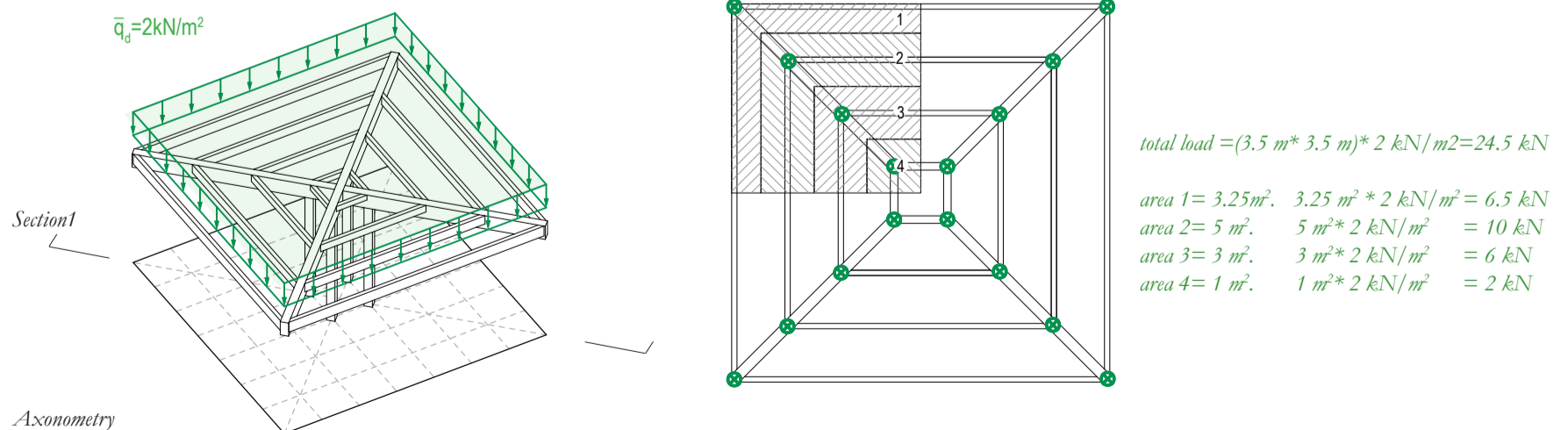


Hint: Anhang «Lasten und Kennwerte» S.1

Working with projections and three-dimensional structures

Develop an initial design for the roof. Simplified external forces are used for this gluelam structure and other external forces can be neglected. Demonstrate amount of force on tributary areas 1, 2, 3, 4 (drawing at right); and then use a force-diagram to determine the magnitude of the internal forces for the structural elements and given load case shown below (section at the bottom left). Use the colours red for tension, blue for compression and green for the support forces.

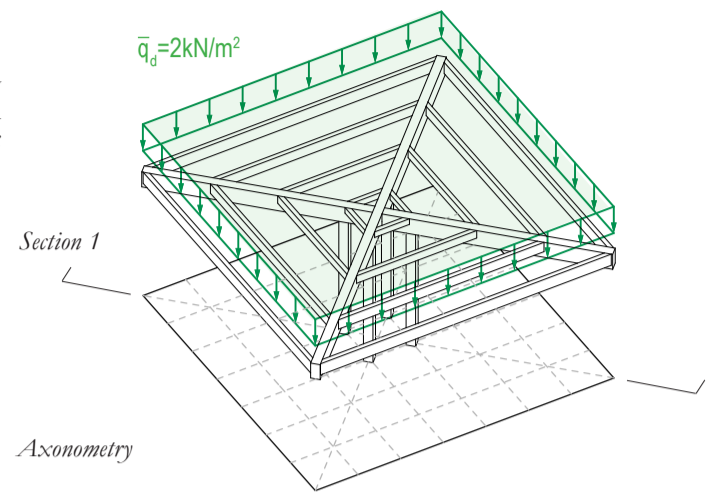
Hint: Exercises SD 3 on Steel & Reinforced concrete



Task 1 Transfer of vertical forces: design variation 1

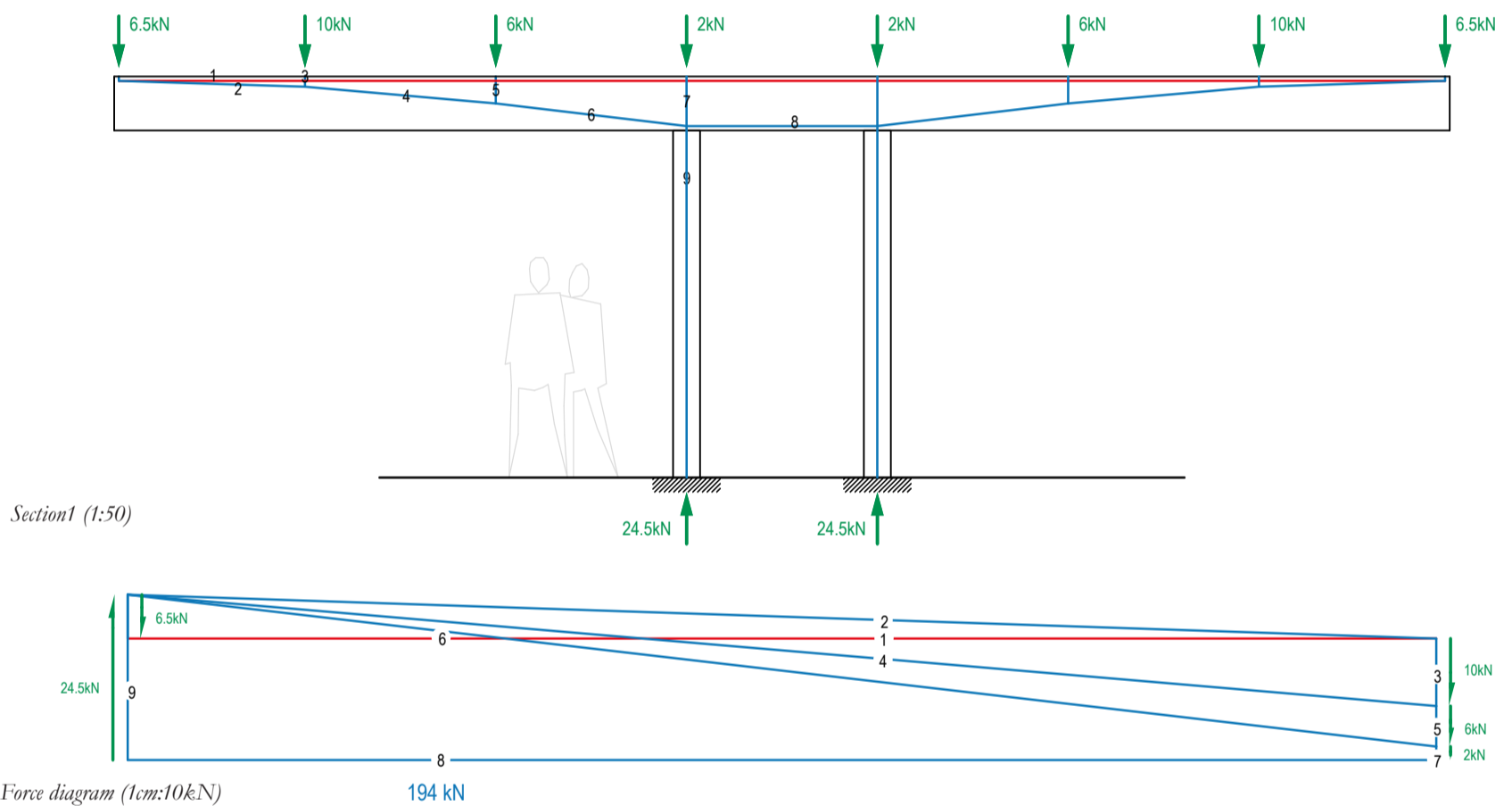
The roof is supported on a cantilevering glulam structure.

You decide to first explore a plane structure made out of horizontal glulam beams. The previously calculated external point loads can be applied along the diagonals of the structure. The internal forces are then determined using two different models. Use the color red for tension, blue for compression and green for the external forces.



1a Determination of the internal forces with the help of an arch-cable-structure

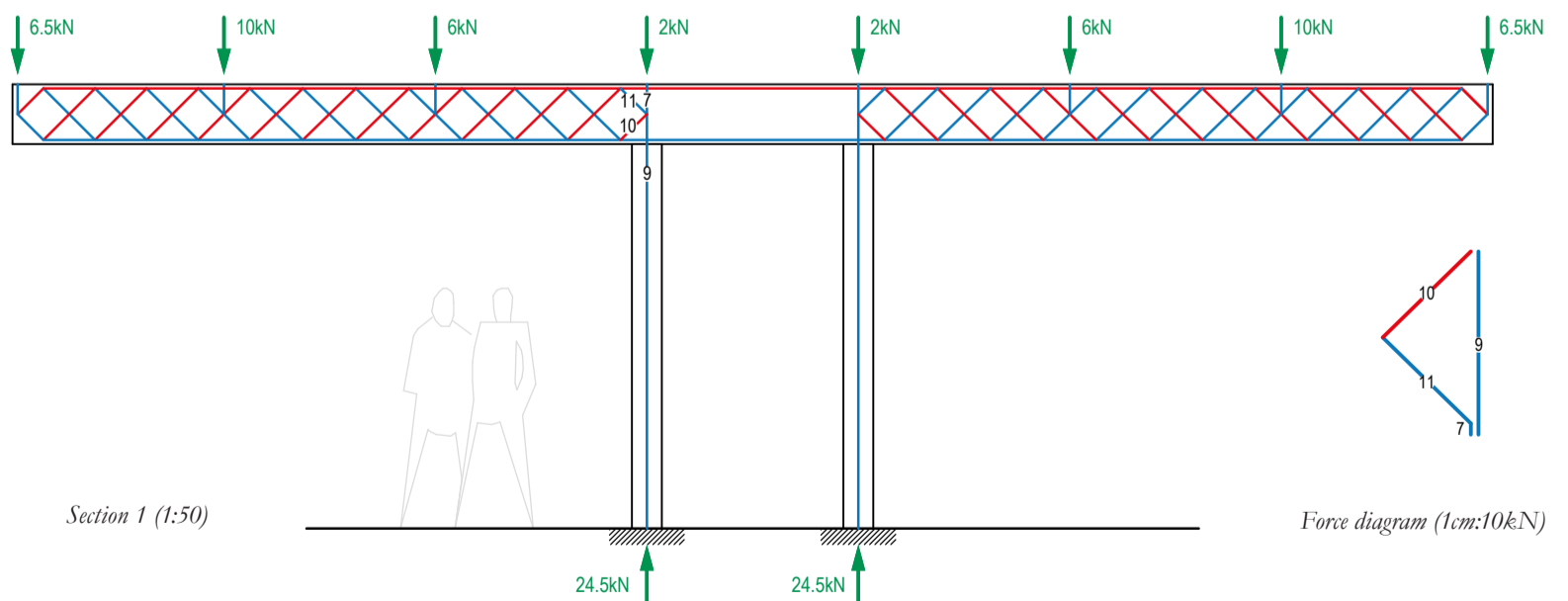
Use a force-diagram based on an arch-cable structure to determine the magnitude of the internal and support forces in the structural elements for the load case calculated above. Use the colours red for tension, blue for compression and green for the support forces.



1b Determination of the internal forces with the help of a truss-like stress field

Hint: «Skript TE 2» P.27-38, «Skript TE 3-4» P.46-47

Design a force-diagram with the help of a stress field and determine the magnitude of the diagonals with the largest internal forces. Use the colours red for tension, blue for compression and green for the support forces. Note: The grey lines in the beam indicate the line of action of the internal forces.

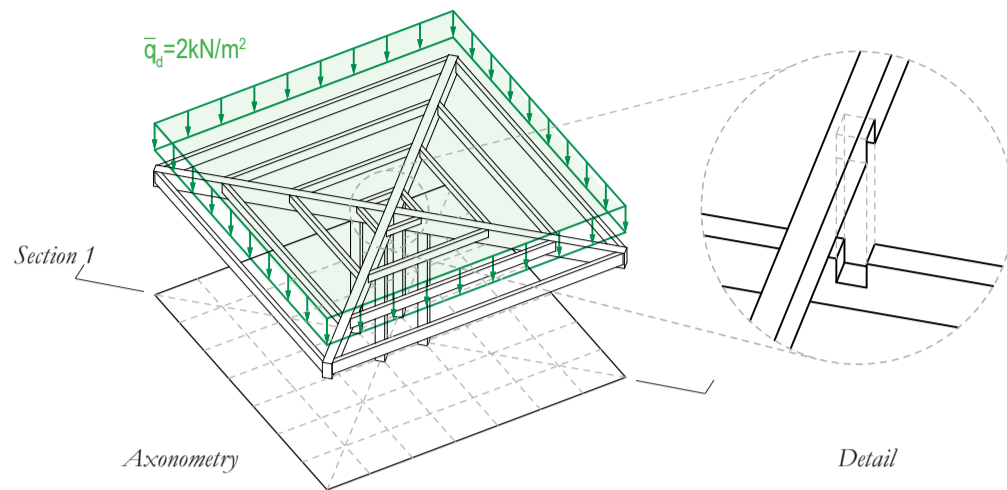


1c Relations between form, force and material

Hilfe: «Skript TE 3-4» S.47, Anhang «Lasten und Kennwerte» S.5

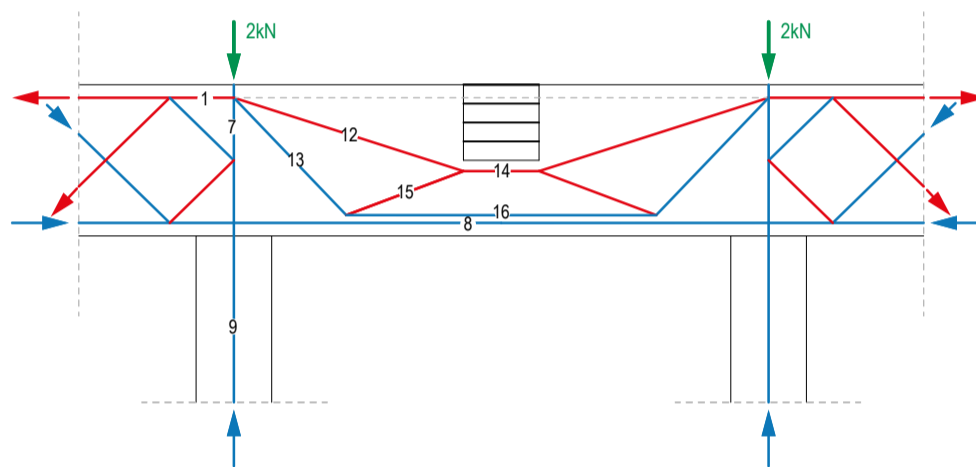
Examine the load-bearing capacity of the diagonal with the largest internal force from the results of task 1b. Note: The cross-sectional area of the beam is 40 x 20cm. Largest internal force of the diagonal is 16.5kN (10 and 11); Thickness beam: $200\text{mm} \cdot \sqrt{2} = 283\text{mm}$; Area $283\text{mm} \times 200\text{mm} = 56600\text{mm}^2$; $\sigma = 16500\text{N} / 56600\text{mm}^2 = 0.29\text{ N/mm}^2 < 1.8\text{ N/mm}^2$ (Strength of glulam below 45°)

Task 2 Analysis of the connection detail between the crossed, diagonal main beams

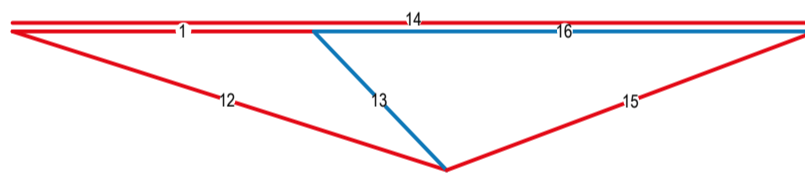


2a Determination of the internal forces in the «lower» main beam detail

Design a possible force-flow for the detail of the «lower» main beam. Create a force flow based on an arch-cable structure to determine the magnitude of the internal forces for given load case. Use the colours red for tension, blue for compression and green for the support forces.
 Note: The grey lines in beam indicate the possible force-flow determined in 1b.



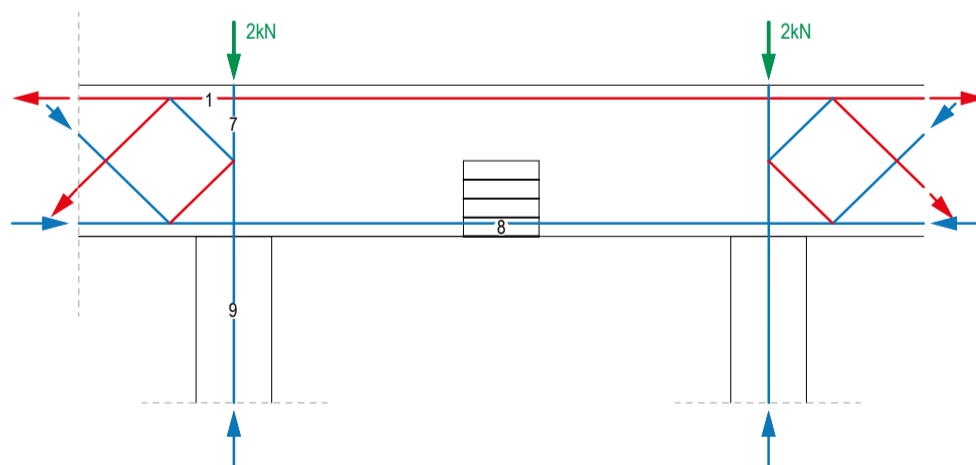
Detail of the lower main beam (1:20)



Force diagram (1cm:50kN)

2b Determination of the internal forces in the «upper» main beam detail

Design a possible force-flow for the detail of the «upper» main beam. Use the colours red for tension, blue for compression and green for the support forces.
 Note: The grey lines in beam indicate the possible force-flow determined in 1b.



Detail of the upper main beam (1:20)

2c Relations between form, force and material

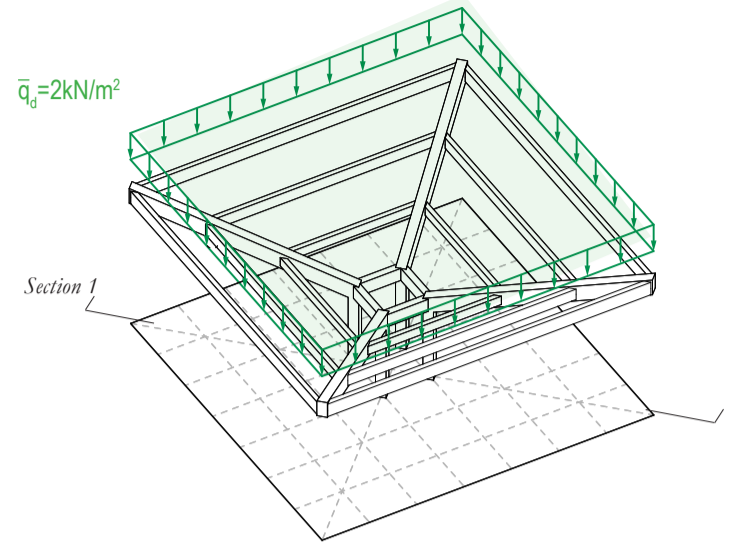
Evaluate if the compressive forces in the «upper» main beam can be guided through the crossed glulam beams. Pay attention to the anisotropy of the wood (different characteristics parallel or perpendicular to the grain). Note: The cross-sectional area of the beam is 40 x 20cm. How is it possible to increase the load bearing capacity of this detail?

Compressive force: 194 kN; Height 20cm x width 20cm = 40000mm²; Tension: 194'000 / 40'000 = 4.85 N/mm² > 1.9 N/mm² (compressive force perpendicular to the grain) -> Glulam beam would fail: Increase of the load-bearing capacity with steel pins through the crossing beams which are arranged parallel to the compressive forces.

Hint: PDF file «Lasten und Kennwerte» P.5 →

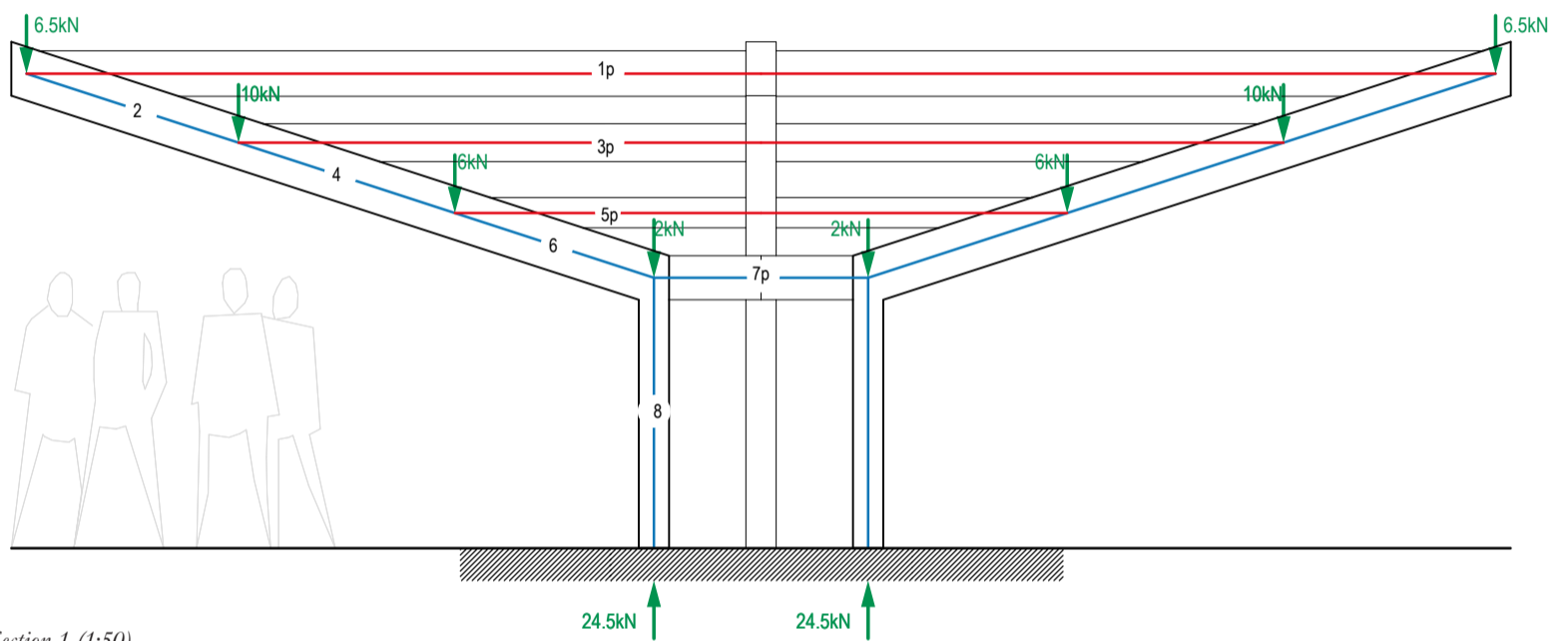
Task 3 Transfer of the vertical forces: design variation 2

The roof is supported on a spatial glulam structure.

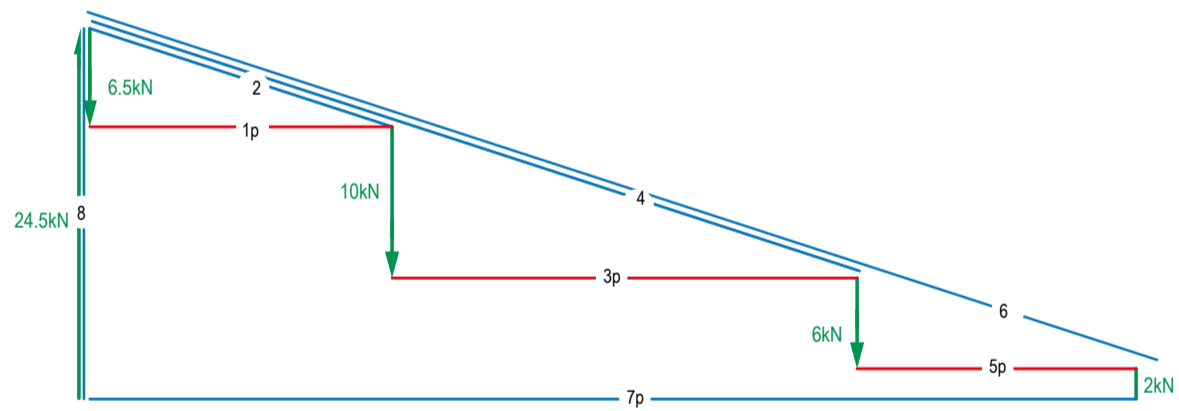


3a Determination of the internal forces

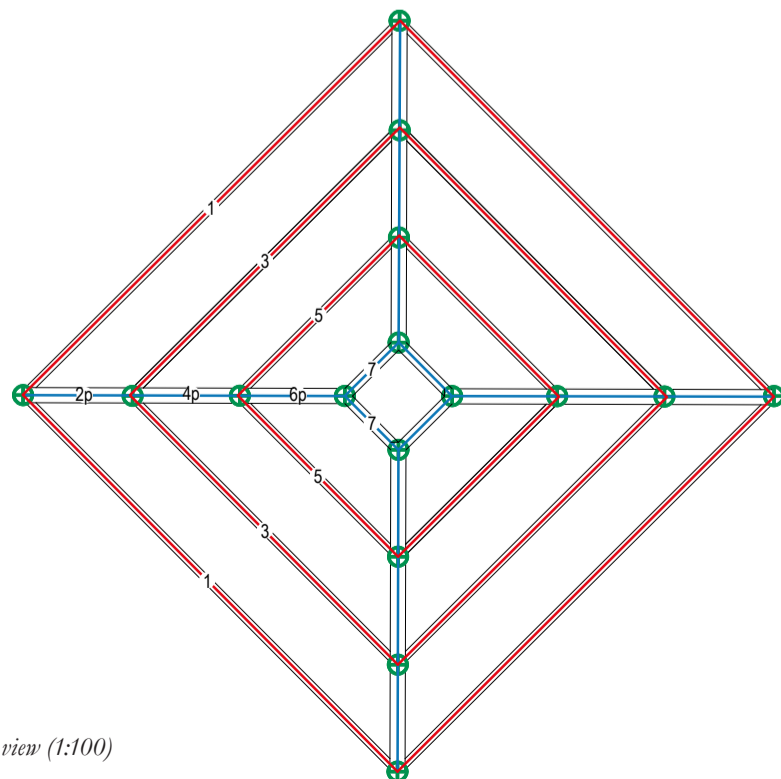
Determine the magnitude of the internal and supporting forces of the spatial structure shown below using a force plan based on an arch-cable structure. Use the colors red for tension, blue for compression and green for the external forces.



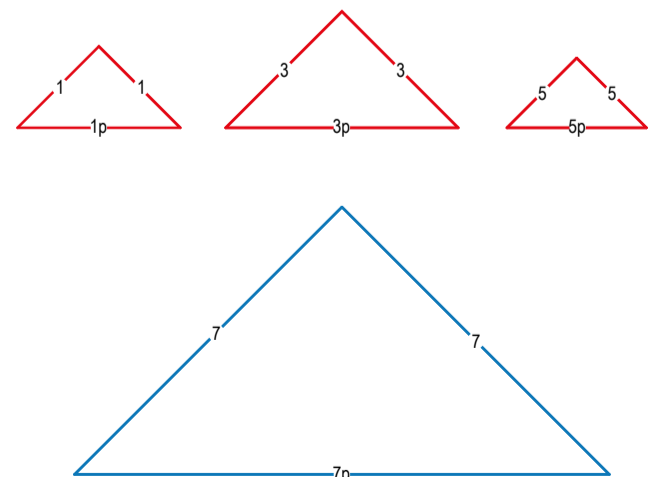
Section 1 (1:50)



Force diagram (1cm:5kN)

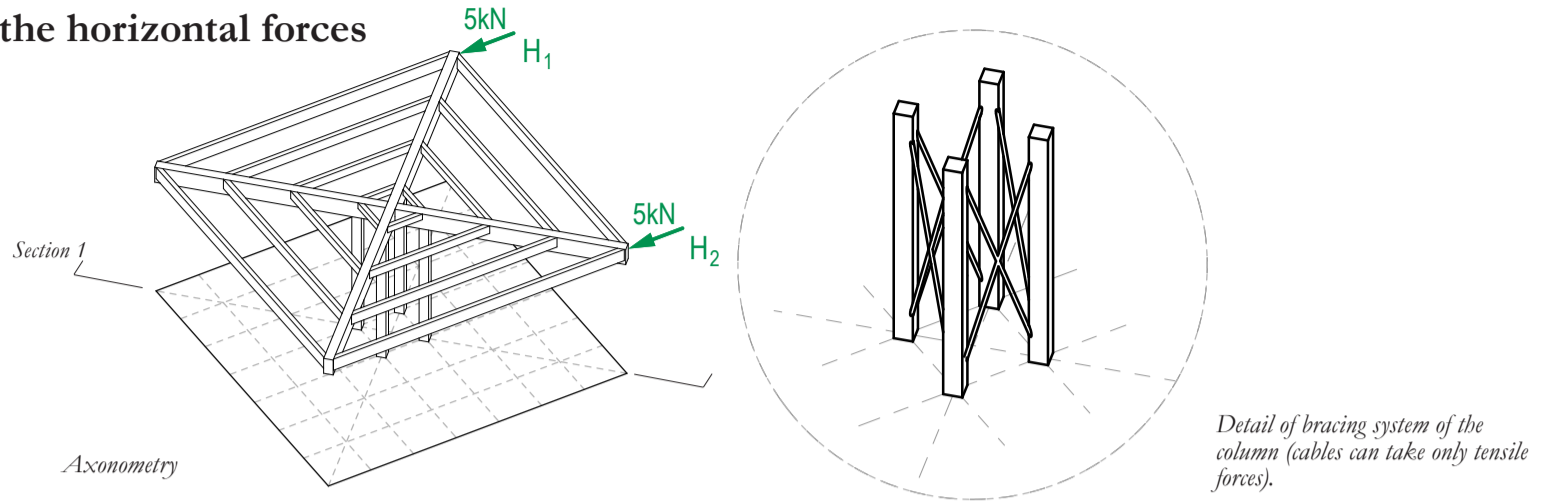


Top view (1:100)



Force diagram (1cm:10kN)

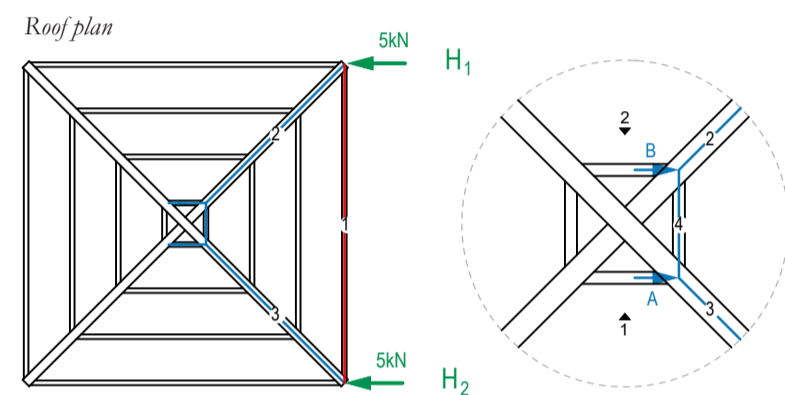
Task 4 Transfer of the horizontal forces



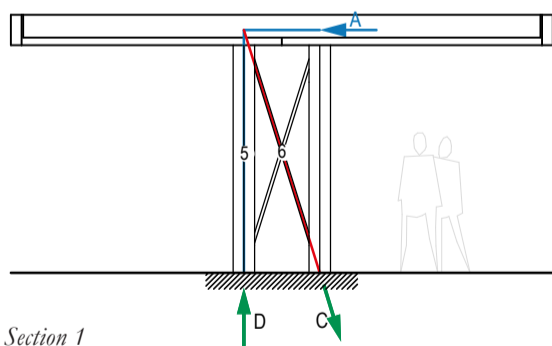
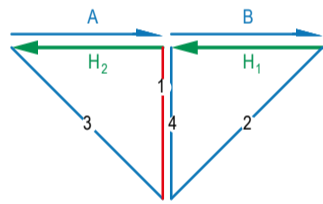
4a Determination of the internal forces under horizontal forces

Examine the force-flow under the influence of a symmetrical horizontal wind load of 5kN (structure at left). Investigate the transfer of this horizontal force from the roof into the supports. Develop a possible internal force-flow in the roof as well as in the load bearing structural members and determine with a force-diagram the magnitude of the support forces. Use the colours red for tension, blue for compression and green for the support forces.

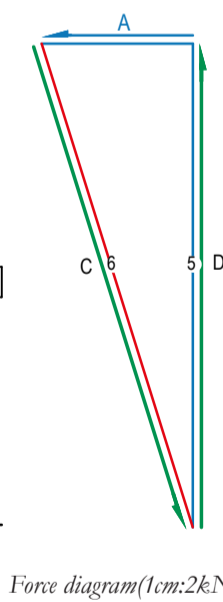
Since the proposed structure does not work under the non-symmetrical load case, another bracing pattern is proposed for the roof (Structure at right). Investigate the transfer of this horizontal force from the roof into the supports.



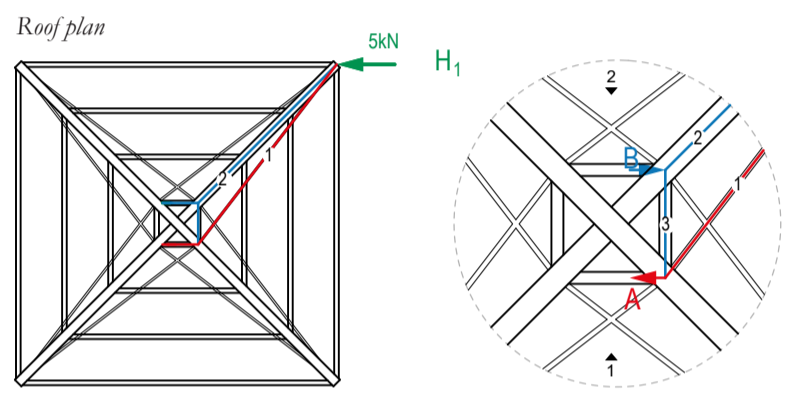
Force diagram (1cm:2kN)



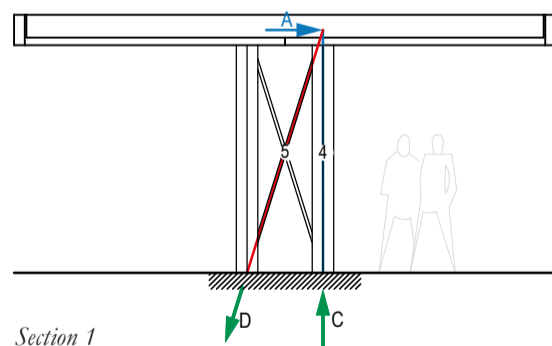
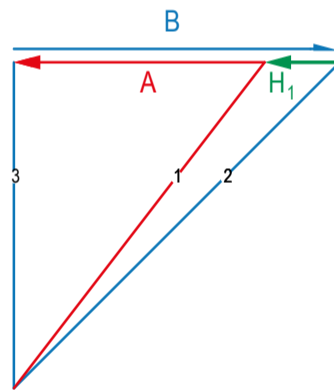
Section 1



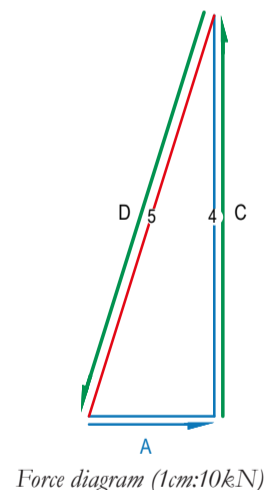
Force diagram (1cm:2kN)



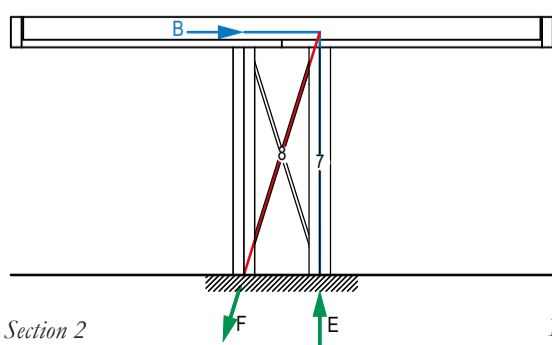
Force diagram (1cm:5kN)



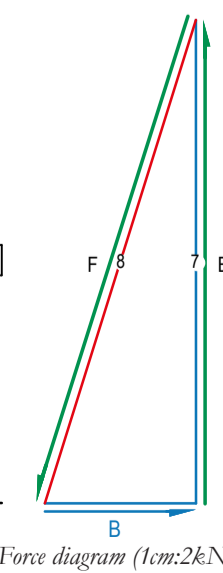
Section 1



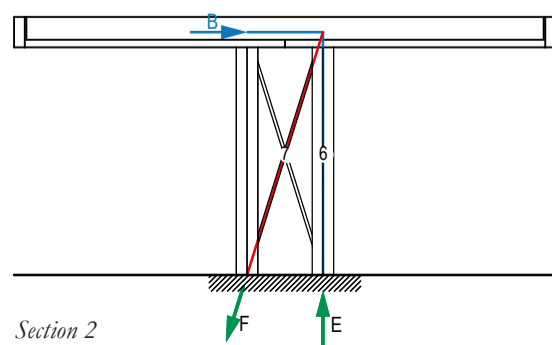
Force diagram (1cm:10kN)



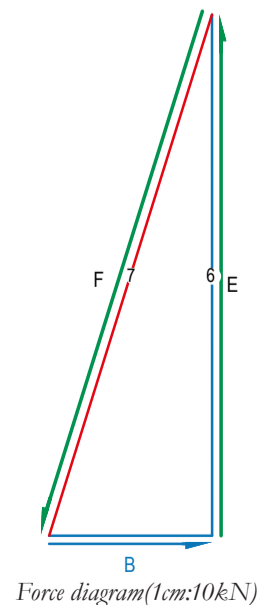
Section 2



Force diagram (1cm:2kN)



Section 2



Force diagram (1cm:10kN)