# Himmelhausmattesteg, rope net suspension bridge, Switzerland

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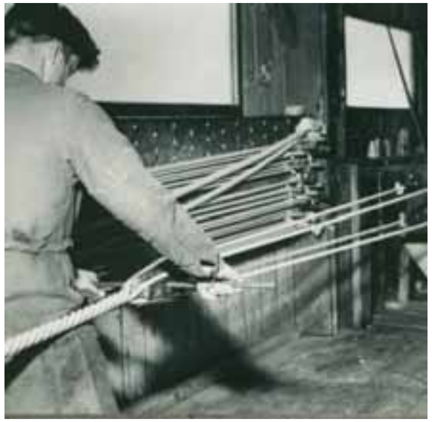
*(Presentation based on Burgdorfer Brückenbautag 2022; Bau und Wissen)*

# Rope Engineering from Emmental, Switzerland

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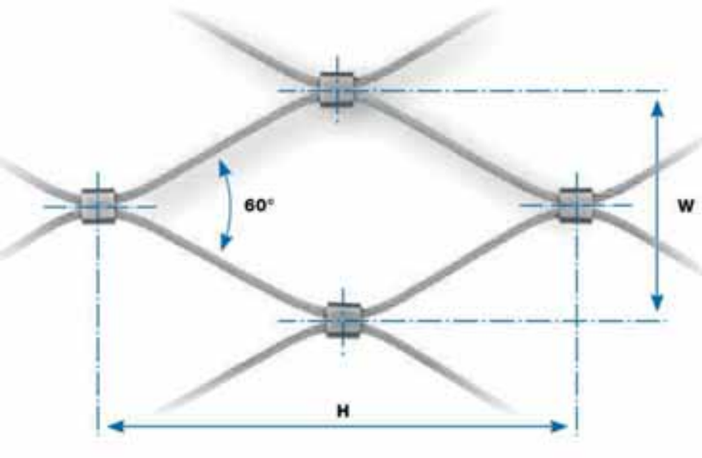
# **Rope net** | Rope net structures





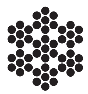
### Rope net

- Opening angle: $\alpha$
- Mesh geometry: $W; H$
- Net rope Ø
- Node type: with sleeves / sleeveless
- Steel grade: rope 1570-EN1.4401 / sleeves EN1.4404

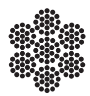
Nodes



Ø 1.0 / 1.5 / 2 / 3 mm



Ø 1.5 / 2 mm



Ø 3–5 mm

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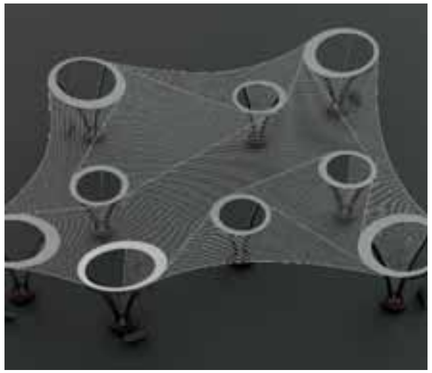
# **Applications** | Rope net structures

## Zoo enclosures

## Greening structures

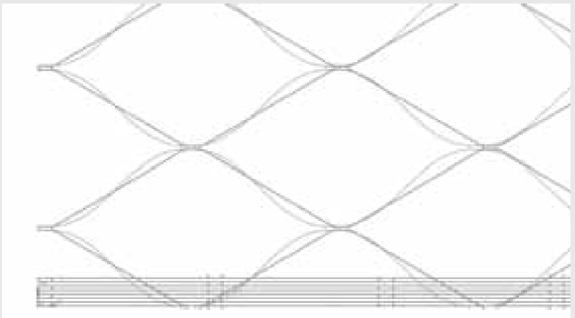


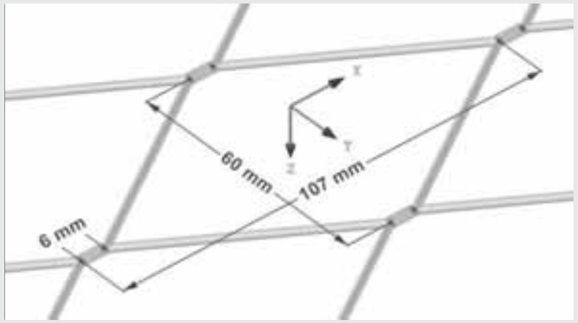
## Safety structures

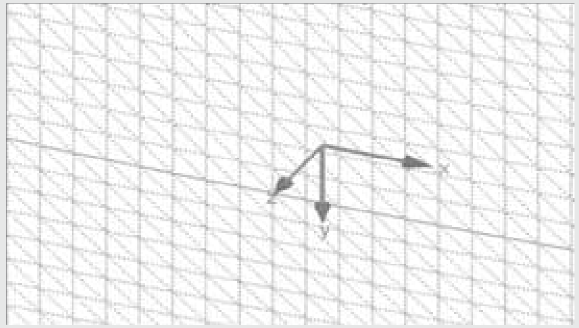
## Bridge constructions

# **Modeling** | Rope Net Structures

| 1. Method - "Real" ropes | 2. Method - "Ideal" ropes | 3. Method - Orthotropic membrane |
|---|---|---|
| • Beam elements with a real, representative bending stiffness<br>• Rope deviation at the sleeve or tensioning process is taken into account | • Ideal, straight rope elements<br>• Simplified geometry in the tensioned stage | • Orthotropic membrane with linear-elastic material model |





| | | |
|---|---|---|
| **Strengths / Weaknesses** | | |
| + Exact determination non-linearity of the single mesh-diamond | - Simplification of the single mesh-diamond with linear-elastic material model | + Reduced effort for form finding<br>- For point loads |
| **Applications** | | |
| • Detailed investigations: Initial stressing in the tensioned stage, local stress analysis around sleeves | • Loads in plane or perpendicular to the network plane | • Structural system modeling of large-scale spatial free-forms, basis for patterning |

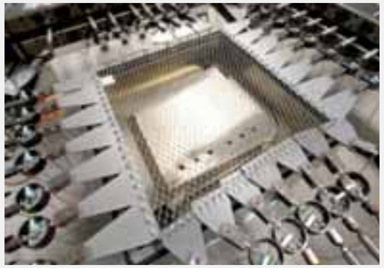
[Drayer D.; Jakob AG]

# **Dimensioning** | Rope net structures

For quasi-static loads

STIFFNESS

**Tests**
Uniaxial or biaxial tests



*[Biax-DEKRA]*

**Calibration FE model**
Isolated rope net structure → adaptation $EA_{net\ rope}$ from initial stressing stage

**FE - SIMULATION**

**Empirical determination $k_e$**
by node test / test lacing rope

**Verification**
acc. to EN1993-1-11[2010];(6.2)

$$f_{Rd,net\ rope} = \frac{f_{min} * k_e}{1.5 * \gamma_R}$$

RESISTANCE

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# **Applied actions** | Rope net structures

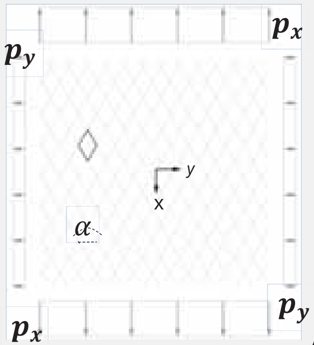
QUASI - STATIC

DYNAMIC

### Initial Stressing

$p$ dependent on net structure, net application

$$p_y\{\alpha, 60°\} = {}^{1}/_{3}\, p_x$$




### Wind

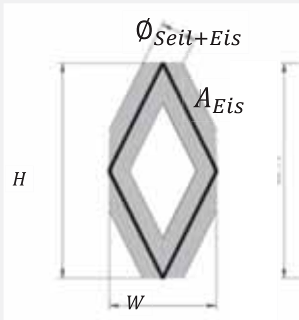
$c_f$ - based on wind tunnel tests

Dependent on net type (rope-Ø., mesh size, node type)

### Wind with ice

After iced surface (icing coating)
*SIA 261;Tab.72/73*

and state duration
*DIN EN1991-1-4/NA.B.5*

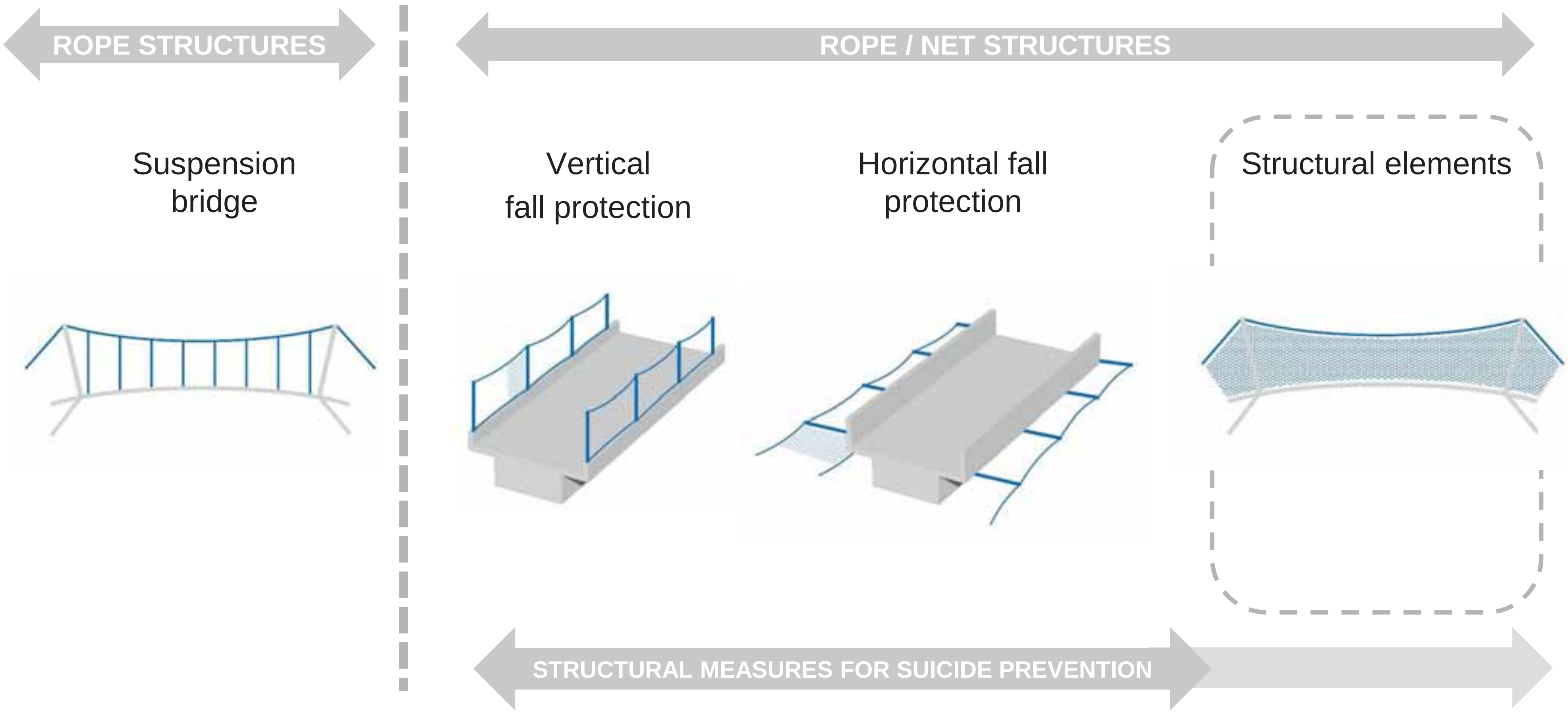



### Snow

Reduction value in relation to standard values for closed surfaces

### Falling bodies

# **Bridge construction** | Rope / net structures



# **Himmelhausmattesteg** | Case study

Trubschachen, 2020
Slow traffic bridge (pedestrian and cycle bridge)

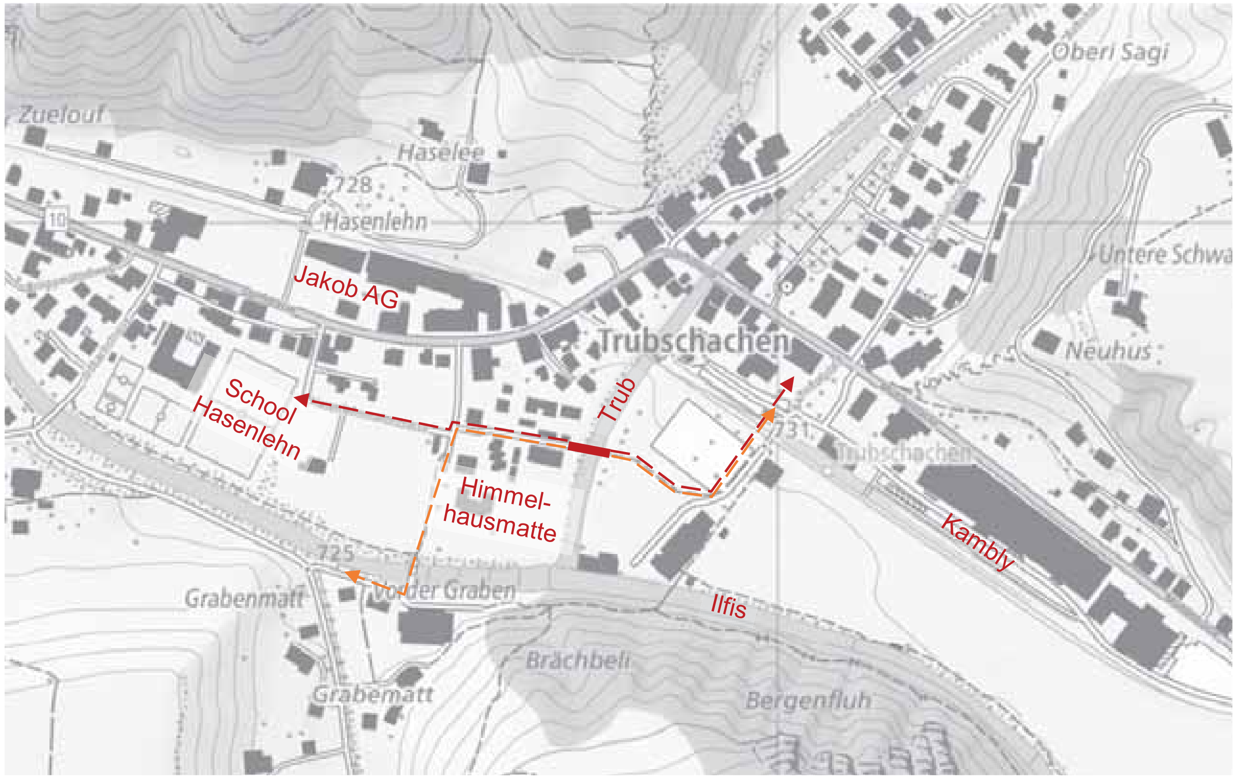



*fig.: Situation; [maps.geo.admin.ch]*

Client:
**Municipality of Trubschachen**

Design / Engineering; supply rope / net construction:
**Jakob AG**

Design of foundation:
**Wüthrich Ing. AG**

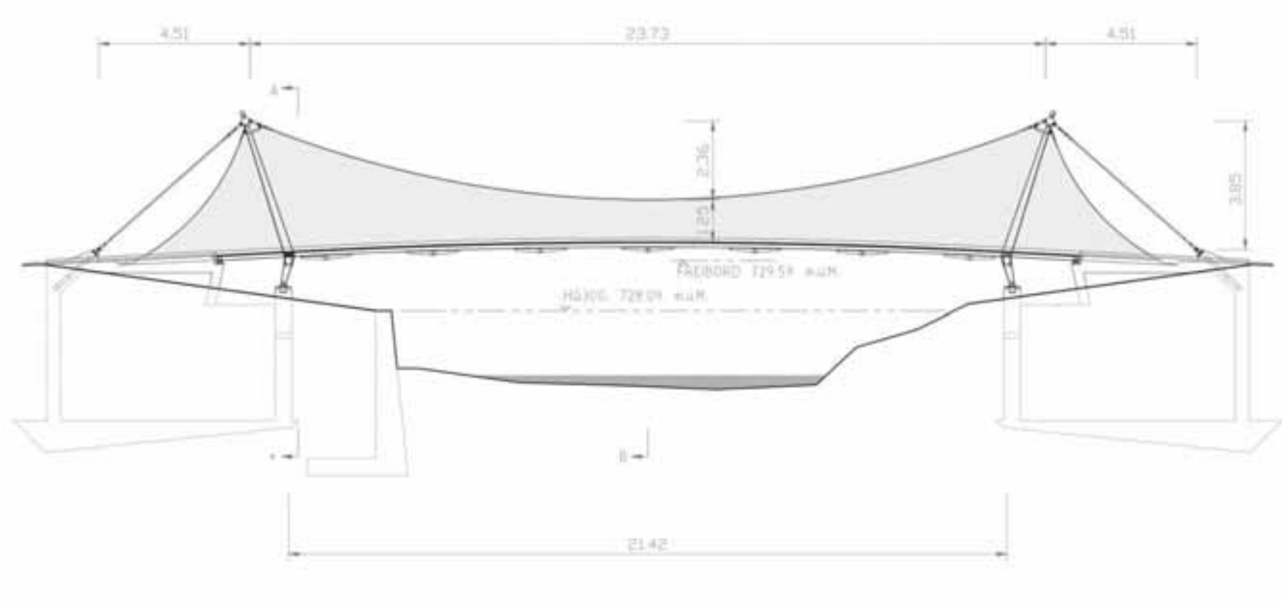
Contractor:
**Thuner AG**

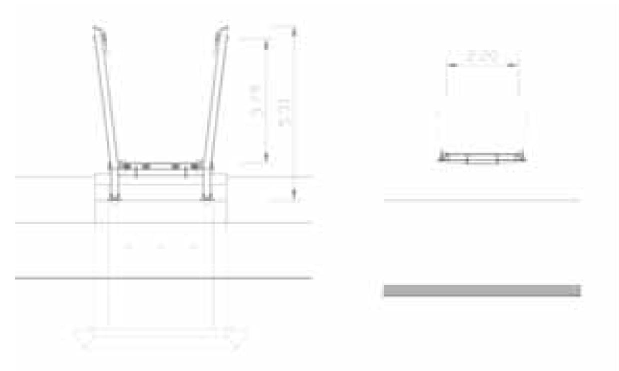
Steel and metal supplier:
**Von Niederhäusern AG**

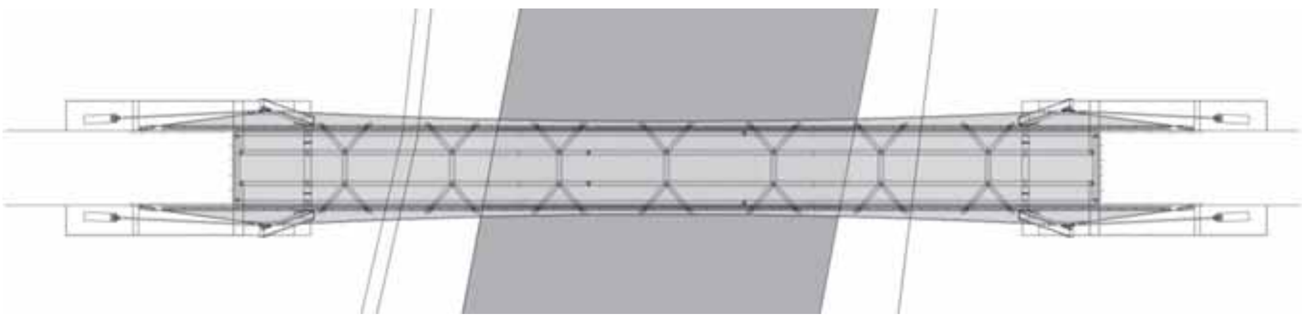
Footpath to school - Hasenlehn

Regional cycle routes

# **Structural design approach** | Himmelhausmattesteg



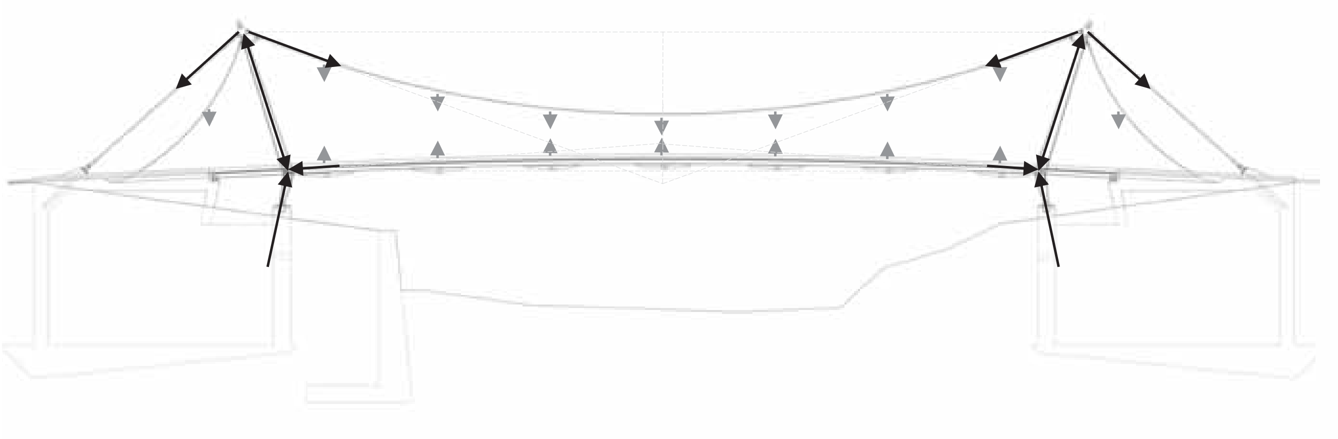





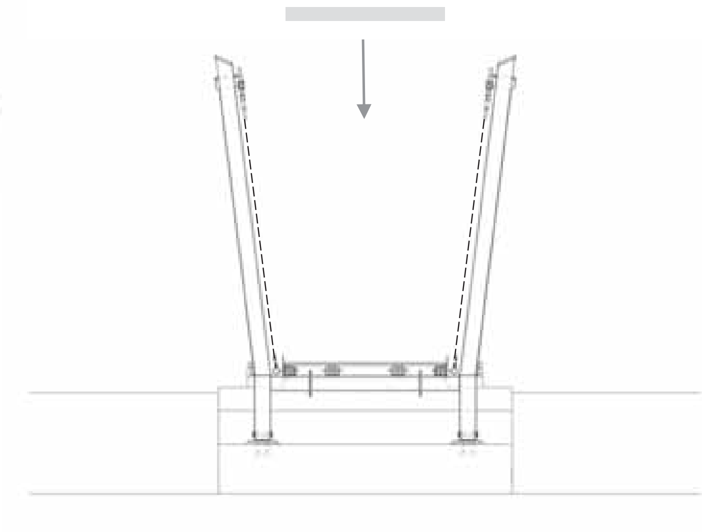
| **Requirements** | |
|---|---|
| Live load | $4\ {}^{kN}/_{m^2}$ |
| Tractor - snow removal | $50\ kN$ |
| | |
| **Geometry** | |
| Bridge length, width | 25.7 m, 2.2 m |
| Free span $l$ | 21.4 m |
| Rope sag $f$ | 2.4 m $\left({}^{f}/_{l} = {}^{1}/_{10}\right)$ |
| Height pylons | 5.3 m |

# **Structural design approach** | Himmelhausmattesteg

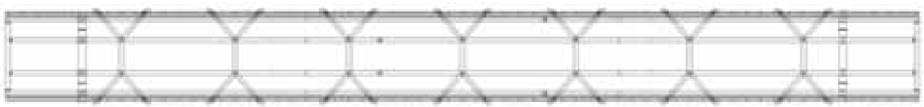
Tensioning of suspension cable to bridge girder → **system stiffness**



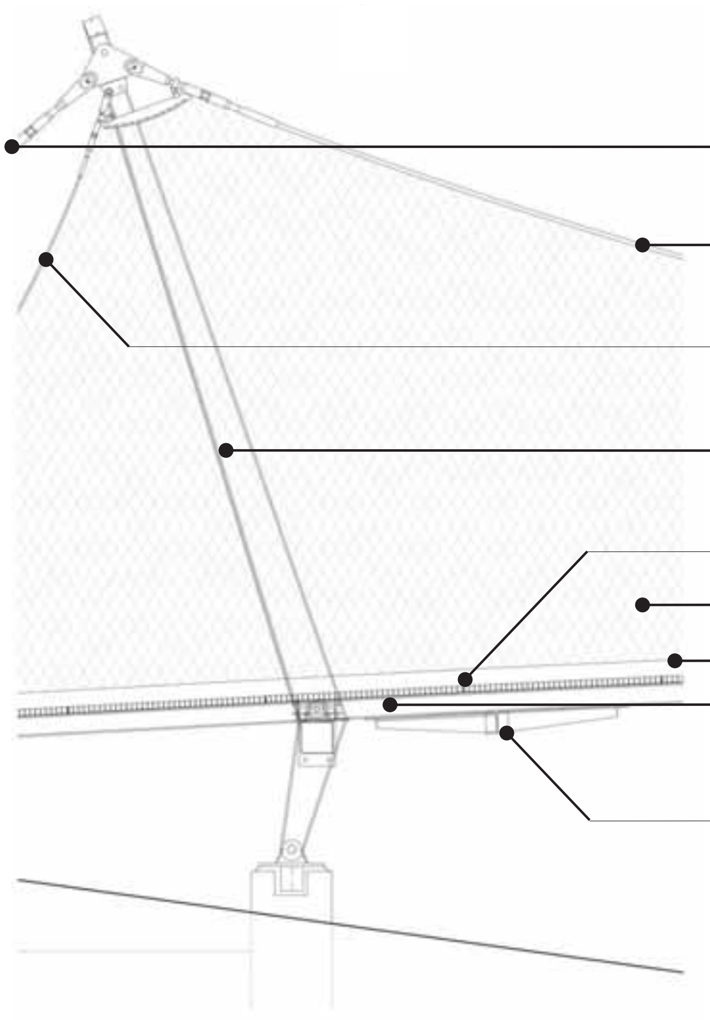
Geometry of pylons→ **plane rope net, lift in bridge girder**



Double Y-bracing → **horizontal bracing, reduction of span rope net beams**



## **Structural description** | Himmelhausmattesteg



Forte **M36** tie-back rod; 1570; 1.4401

Forte ø**26**-OSS; 1570; 1.4401

Forte **Ø12**-OSS; 1570; 1.4401

Welded hollow section; 115x230 → 285x230, t12; S355

Grating; 40x4; S235

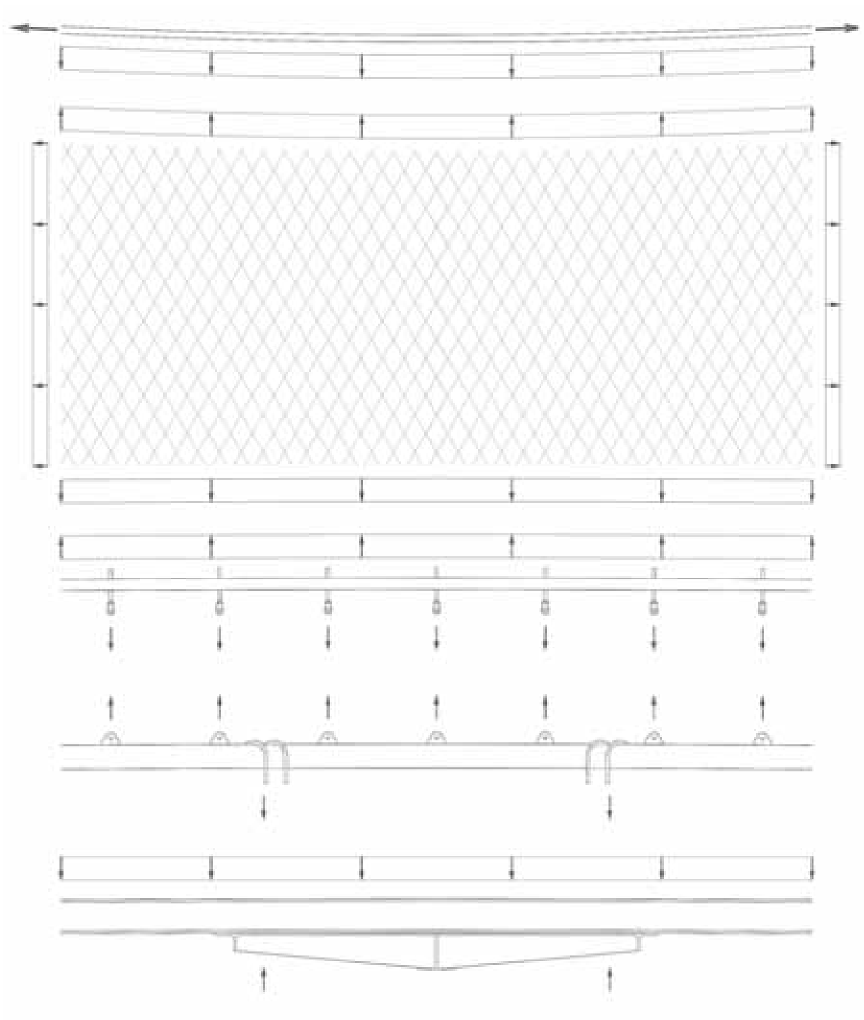
WEBNET; ø**3 - W80** with sleeves; V24; 1.4401/4

Curb-angle profile L 160x80x10, S235

4 x **HEA140**; S355

Cross bracing: 4 x HEA140 - twin boom INP tapered; S355

# **Tectonics** | Himmelhausmattesteg



Suspension rope

Rope net

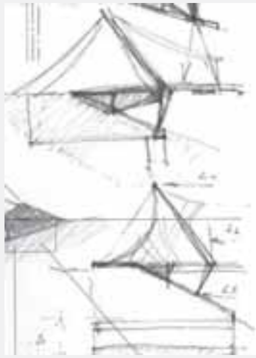
Railing (adjustable)

Bridge girder longitudinal tube (electr. cable)

Bridge girder with cross bracing

# **Dimensioning** | Himmelhausmattesteg

**Structural design**



**Geometry**
- Qualitative form-finding
- Modification

**FE Modeling**
- Form-finding
- Mesh - "Ideal Ropes"
- Stiffness assignment

**Design-Checks**
- Component dimen-sioning

**Workshop planning**
- Patterning net
  Confection lengths rope

**Stiffness adjustment**
- Uniaxial test rope net
- Deformation measurement of bridge girder

**Mesh modeling**
Method 2 - "Ideal" ropes, scale factor 4

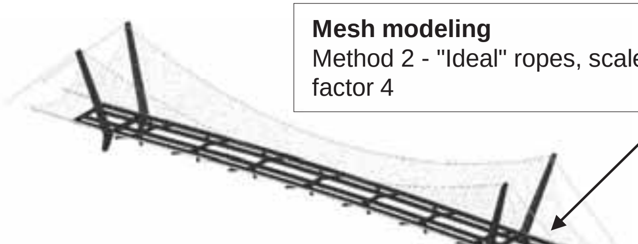
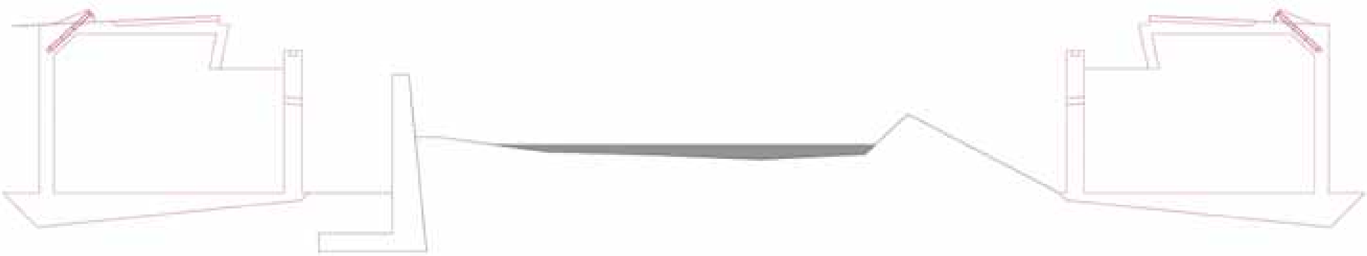


*fig.: beam model*

*fig.: beam model, net i forces N [kN];* $LC\{G + P + Q\}$

# **Construction process** | Himmelhausmattesteg

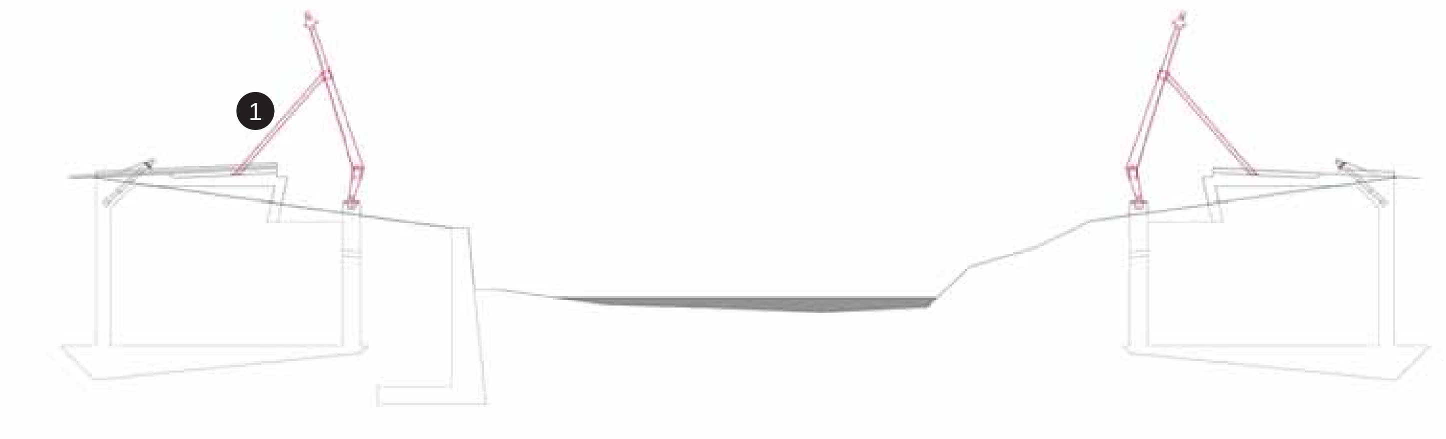
Step 1



- Creation of access, installation site
- Foundation

# **Construction process** | Himmelhausmattesteg

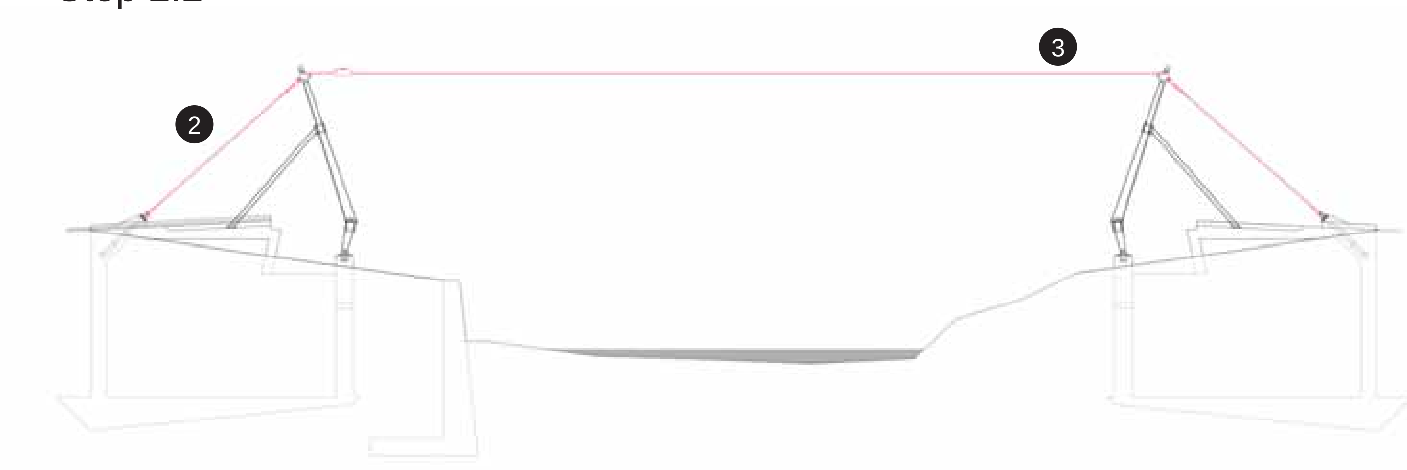
Step 2.1




- Erecting pylons with auxiliary struts ❶

# **Construction process** | Himmelhausmattesteg

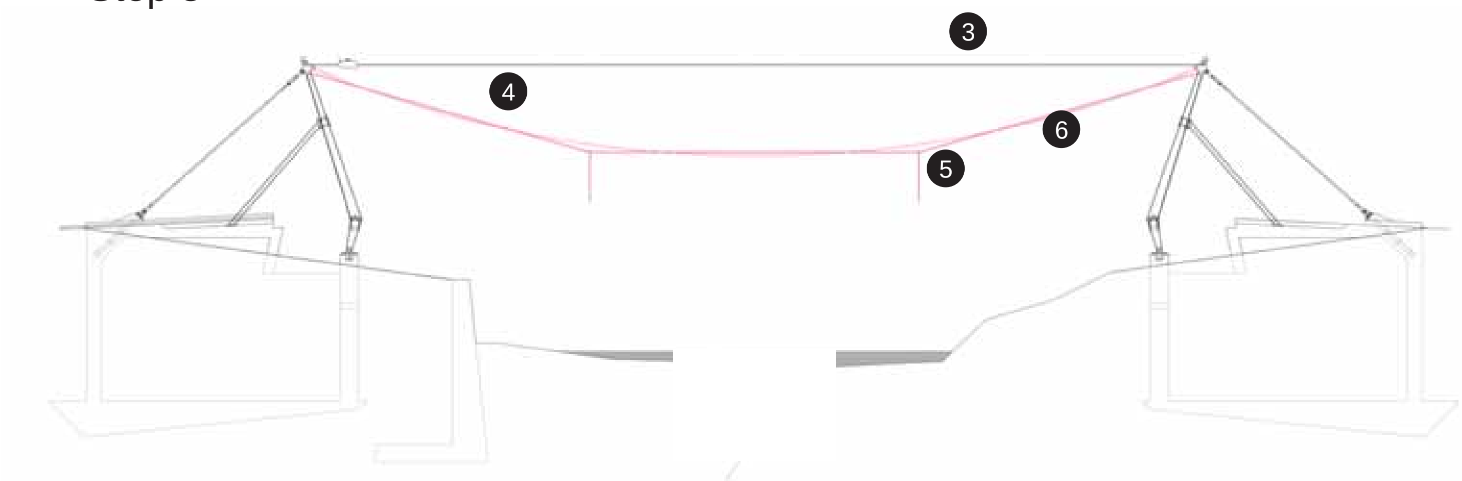
Step 2.2

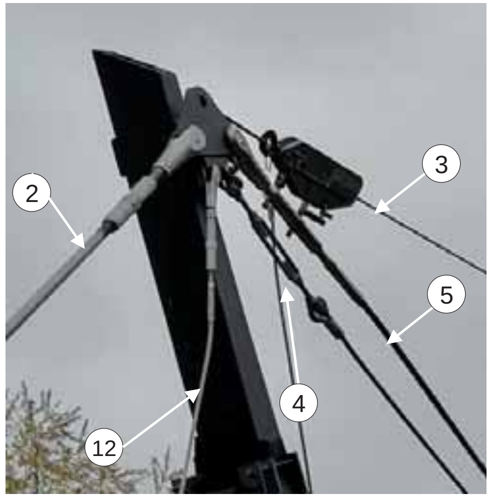



- Mounting tie-back rods ❷
- Horizontal pylon coupling cable ❸
- Adjustment pylon alignment

# **Construction process** | Himmelhausmattesteg

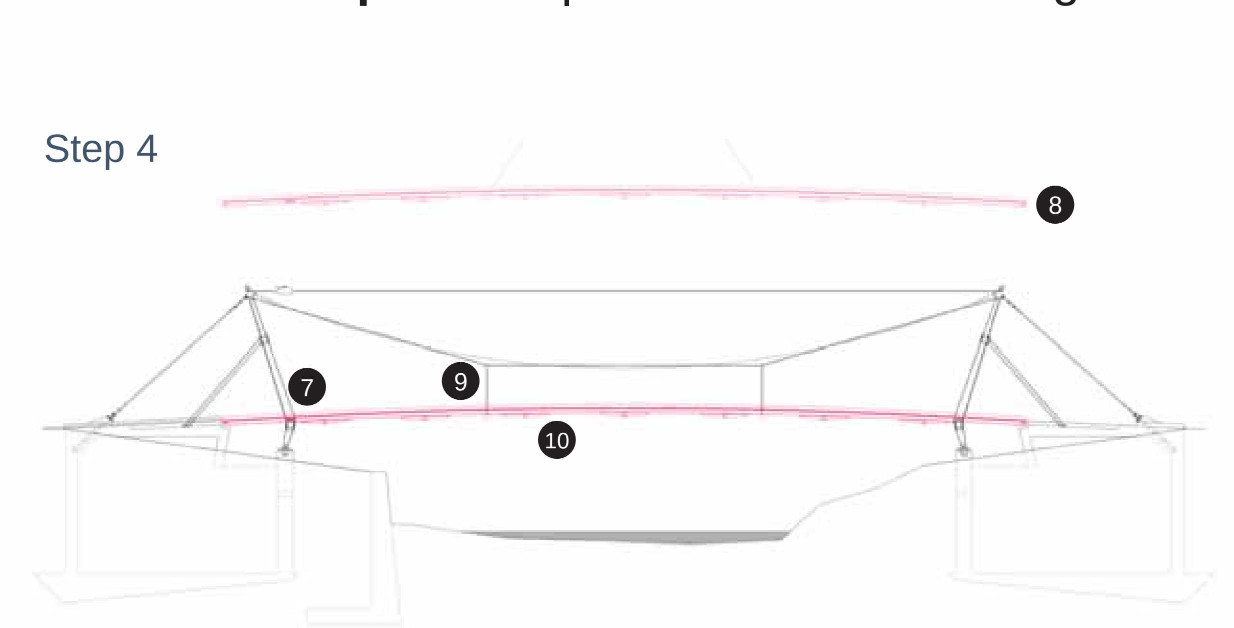
Step 3




- Mounting temporary suspension ropes ④ with hangers ⑤ pull in along ③
- Installation of suspension ropes (temporary laterally tensioned) ⑥

# **Construction process** | Himmelhausmattesteg

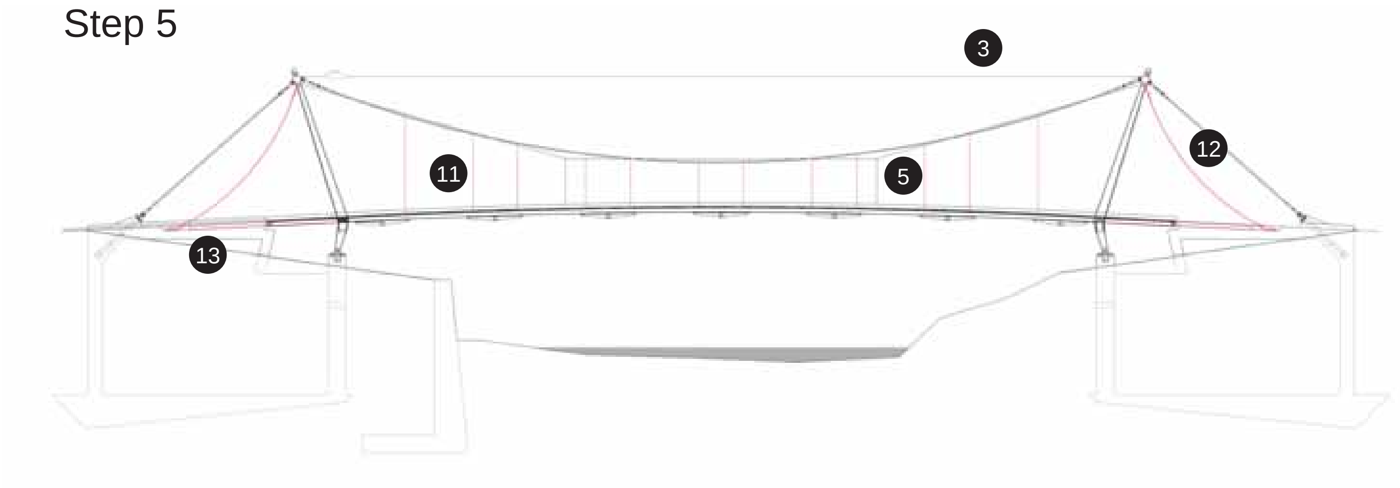


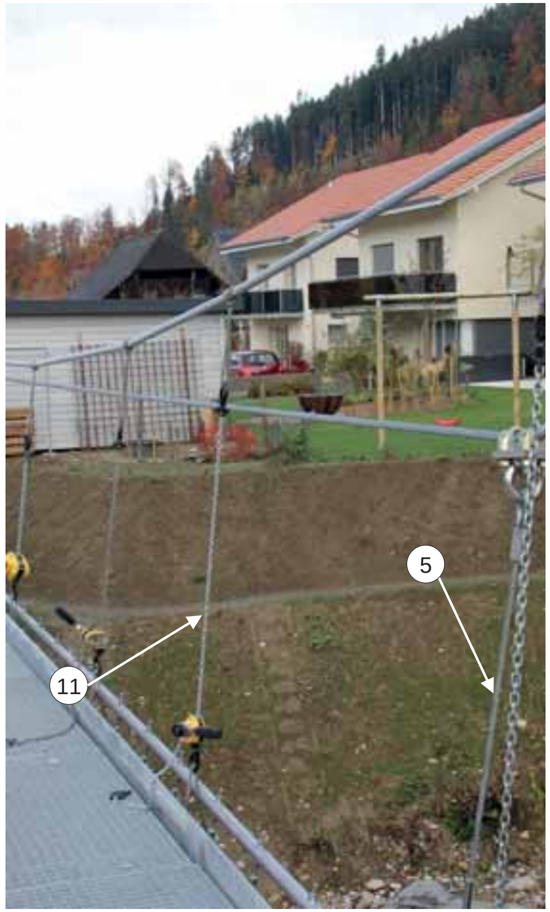


- Longitudinal adjustment of pin connection at pylon locations
- Attachment of bolts at connection bridge girder - pylon 7
- Lifting bridge girder with mobile crane 8
- Coupling to temporary cable structure 9
  - Connecting hangers to auxiliary lifting beams 10
  - Applying tension to hanger / geometry check
  - Relieving the load on the mobile crane
- Approval of accessibility of bridge girders for further assembly steps

# **Construction process** | Himmelhausmattesteg

Step 5

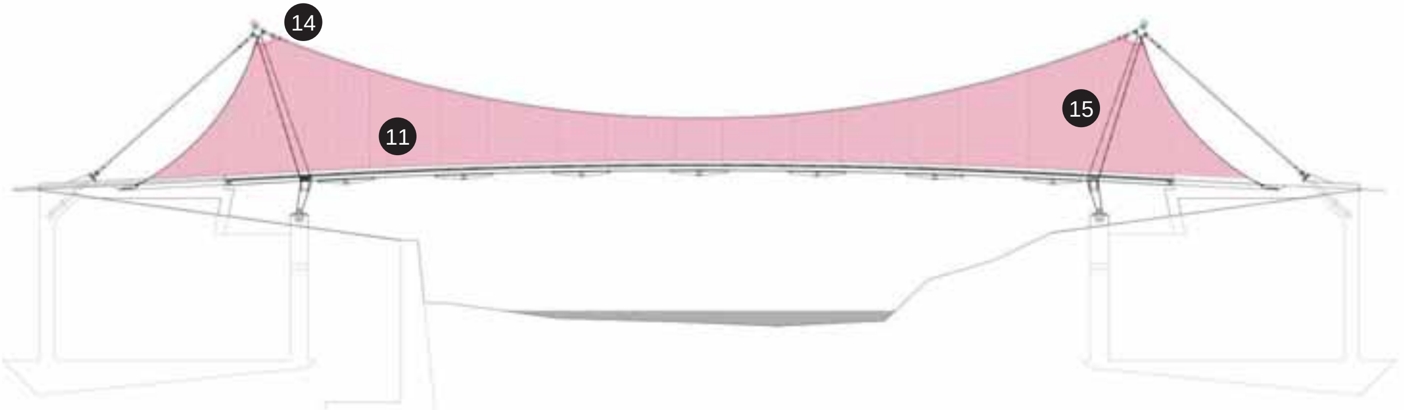


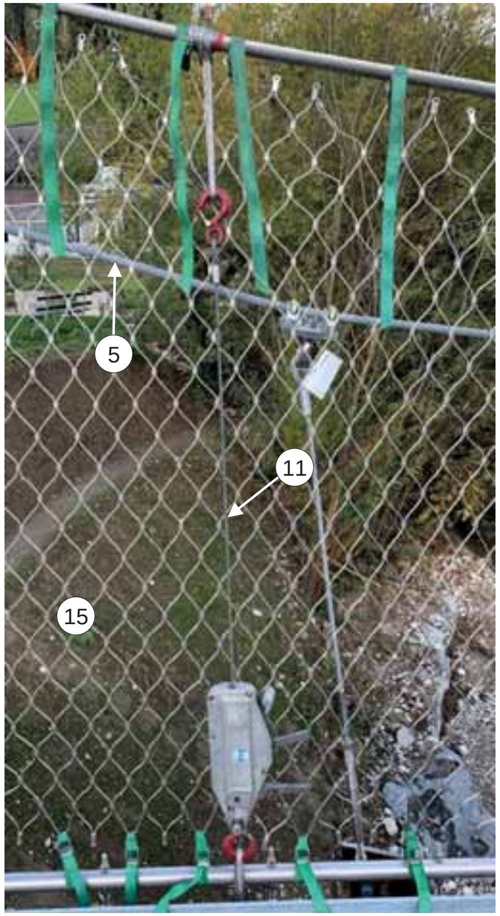




- Disassembly auxiliary struts
- Dismantling pylon coupling cable 3
- Assembly chain hoists / Habegger hoists
    - Tensioning chain hoists 11
    - Relieving temporary suspension ropes 5
    - Re-tensioning chain hoists 11
- Assembly net tie-back rope 12
- Assembly edge tube extension 13

# **Construction process** | Himmelhausmattesteg

Step 6



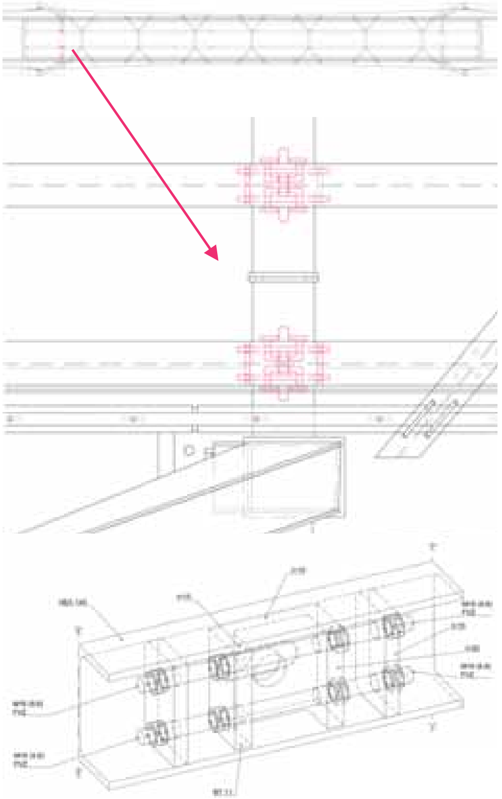

- Attachment of components for net edge structure (14)
- Alignment and temporary tensioning of the nets (15)
- Attachment of rope net tensioning elements / tension belts
- Unloading chain tension members (11)
- Lacing rope net
- Dismantling temporary rope net tensioning elements
- Dismantling chain hoists

# **Constructive design** | Himmelhausmattesteg

## Adjustment devices

Adjustment devices for mounting

Adjustment devices for long-term effects regarding loss of clamping force



Adjustment for the bridge girder

## Net set up

Blocking sleeve on binding rope
@ 6th eyelet = approx. 500 mm

Net corner design, reduction of force peaks

# **Patterning** | Himmelhausmattesteg

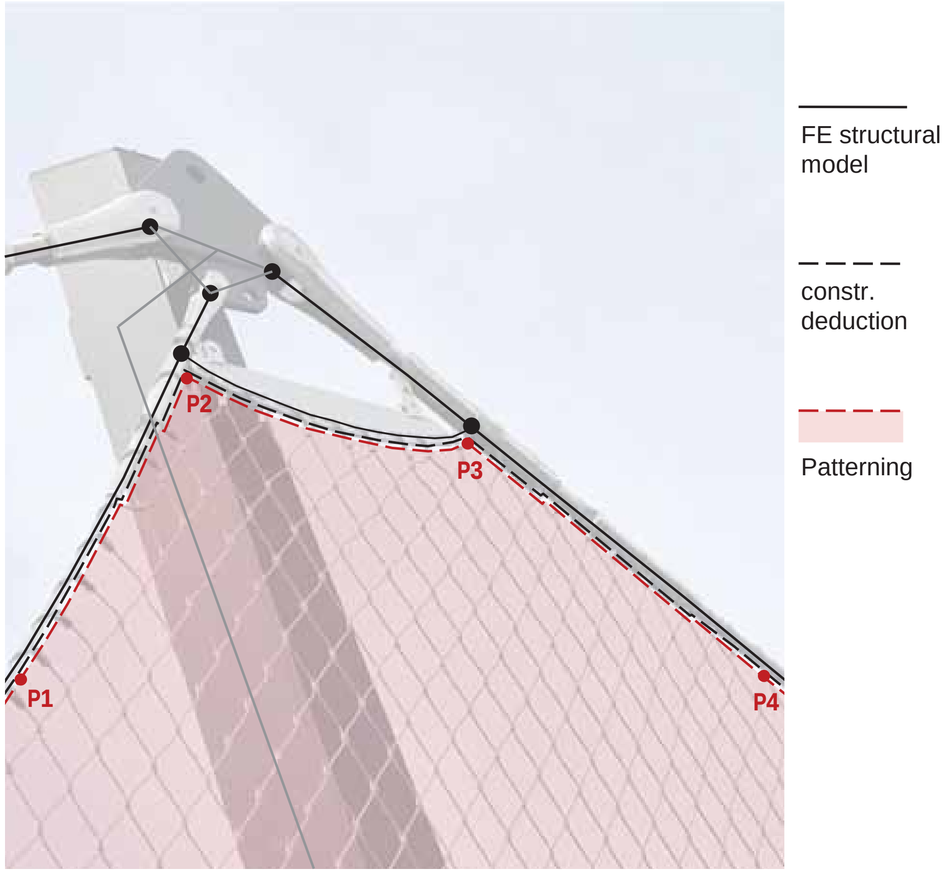



*fig.: patterning, schematic figure*

## Structural Design

**Patterning**
- 2D flattening based on shape form-finding $LF\{G + P\}$
- Labeling, markings supported with FE software

**Constructive deduction**
Combination of FE software and manually

## Production Planning

**Patterning drawing**

**Workshop drawings**
Basis for cutting net ropes / net production

## **Dynamic behavior** | Himmelhausmattesteg

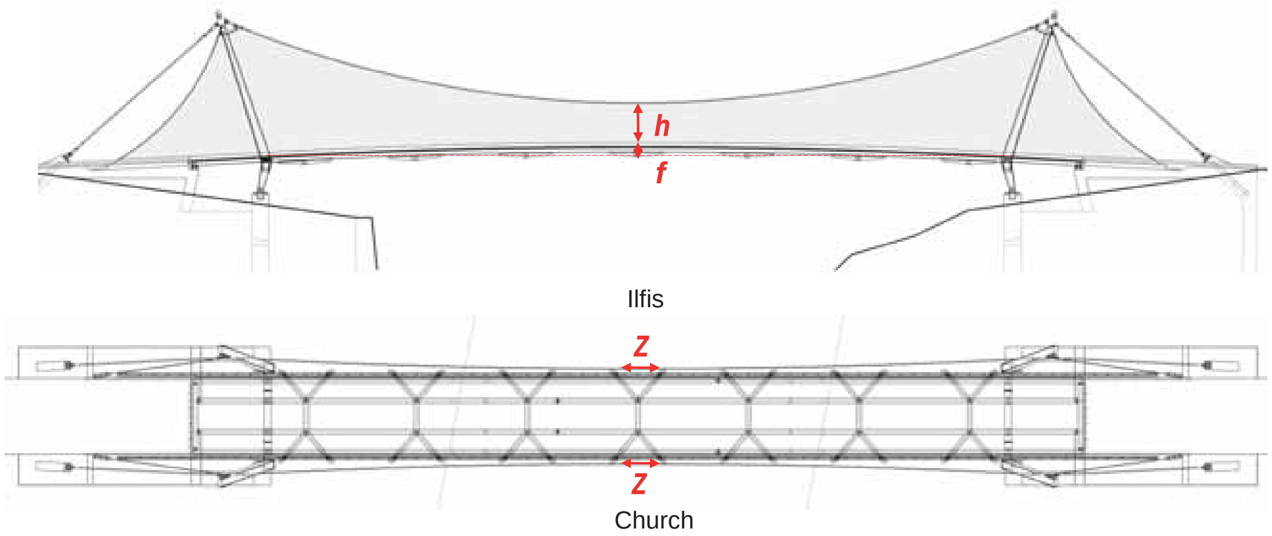
| | | Natural frequency *[Hz]* | *HIVOSS, [a]* | *a* $\left[\frac{m}{s^2}\right]$ | *HIVOSS, [a]* |
|---|---|---|---|---|---|
| Walking | vertical vibration | 2.9 | not critical | 1.0 | CL 2-3<br><br>medium / minimum $a_{limit,vertical} \leq 1.0$ |
| Marching | vertical vibration | 2.2 | critical | - | not acceptable |
| Running | vertical vibration | 2.8 | critical | 16 | not acceptable |

- Number of pedestrians: 9 + 1 persons -> 0.2 P/m$^2$ (TC2)
- Stand-by vibration: FE model: 2.7 Hz

# **Monitoring** | Himmelhausmattesteg

| Measurement | Location | Z<br>[kN] | | h<br>[mm] | | f<br>[mm] | | |
|---|---|---|---|---|---|---|---|---|
| 02.11.2020 | Church | 74 | | | | | | Construction stage, side ready laced |
| 02.11.2020 | Ilfis | 78 | | | | | | |
| 23.02.2021 | Church | | | 1155 | | 303 | | Calibrating bridge after completion |
| 23.02.2021 | Ilfis | | | 1146 | | 295 | | |
| 10.08.2022 | Church | 69.4 | 94 % | 1153 | 100 % | 301 | 99.8 % | Unloaded (2 persons) |
| 10.08.2022 | Ilfis | 70.6 | 91 % | 1147 | 100 % | 280 | 100.1 % | |

*fig.: Tractel Dynarope, rope force measuring device*



# **Construction costs** | Himmelhausmattesteg

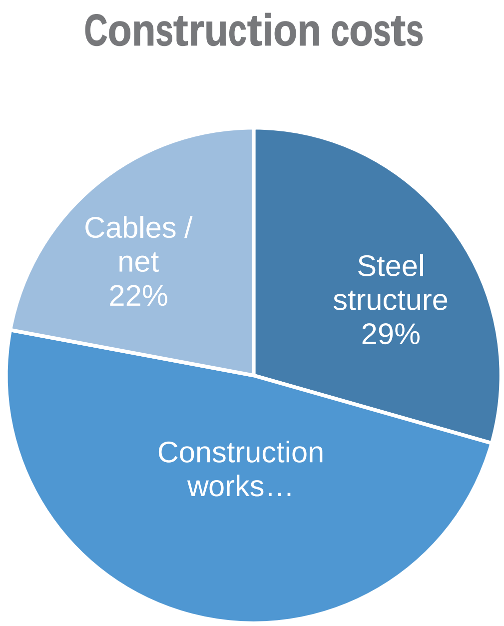
(Erection 2020)

| | |
|---|---|
| Steel structure (incl. installation) | 72 000 EUR |
| Construction works | 120 000 EUR |
| Ropes / nets (incl. installation) | 55 000 EUR |
| | 247 000 EUR |

Key figures

| | |
|---|---|
| based on bridge area $A = 58\,m^2$ | 4 300 EUR/m$^2$ |
| based on bridge length $l = 26\,m$ | 9 500 EUR/m |

| | |
|---|---|
| Alternative conventional suspension bridge | ~ – 10 000 EUR |
| + Fall protection<br>Connections suspension / hangers (26 pcs.) | ~ + 30 000 EUR |
| - Net area, reduction of net installation costs | ~ - 20‘000 EUR |



## **Sustainability** | Himmelhausmattesteg

| | |
|---|---|
| **Necessity** | safer way to school, crossing river for pedestrian / cyclist |
| **Minimization** | only structural elements, light-weight structure |
| **Regenerability** | only by melting |
| **Robustness** | by used material, constructive design |
| **Reuseability** | design approach to use standard components (possibility of sea freight → $C0_2$ - impact)<br>***design-to-disassembly*** |
| **Multifunctionality** | use for pupils/pedestrians/cyclists, power supply cables |
| **Adaptability** | use of bolted connections and open cross-sections (except pylons) |
| **Light-weight structure** | steel: 8'500 kg, gratings: 2'800 kg |

## **What's next? |** Small spans

Webnet bridge in Lugano - Parco via Pico, 2022
Span: 15 m

Jakob Rope Systems for HINNEN playground equipment

## **What's next?** | Big spans

Structural proposal suspension bridge Disentis, 2024
Span: 270 m

JV – Jakob Rope Systems. Von Rotz&Wiedemar. Pfeifer

*fig.: Visualizations of the proposed structure of the Disentis suspension bridge*

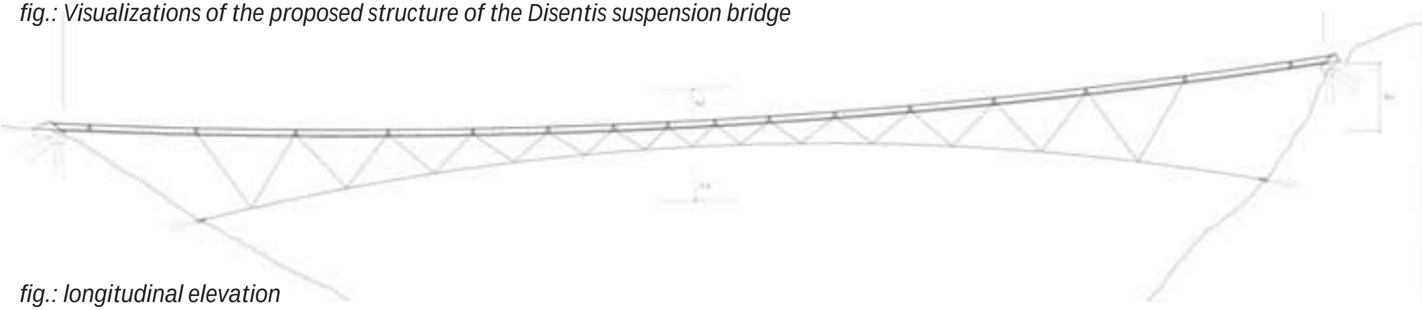


*fig.: longitudinal elevation*

# Bridges with Webnet in NL

HANS JANSEN STAALKABELS







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## Literature

[1] Wagner R; Bauen mit Seilen und Membranen, chapter 3.3; Beuth Verlag GmbH, 2016.
[2] Hivoss, RFS2-CT-2007-00033; Human induced vibrations of steel structures; Guide for the design of pedestrian bridges; 10.9.2008.