CABLE MESH AS STRUCTURAL SUBSTITUTE FOR LIGHTWEIGHT FOOTBRIDGES

TEXTILE ROOFS 2024, BERLIN . 30.4.2024

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

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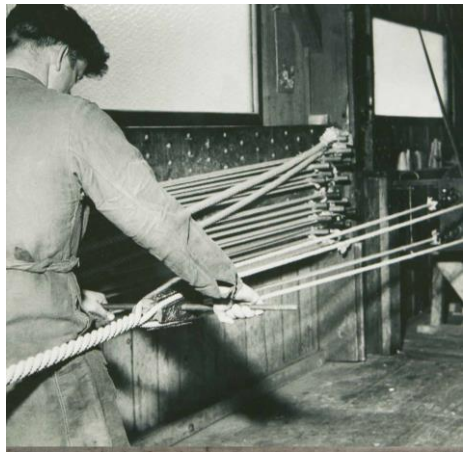
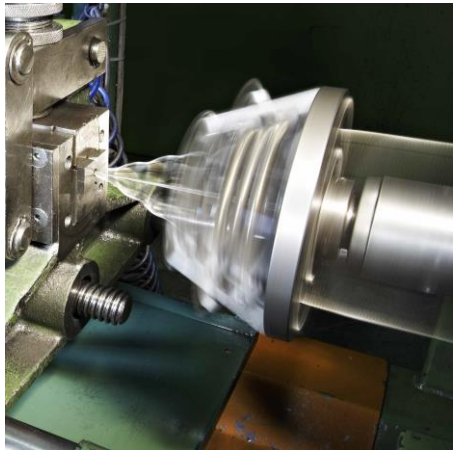
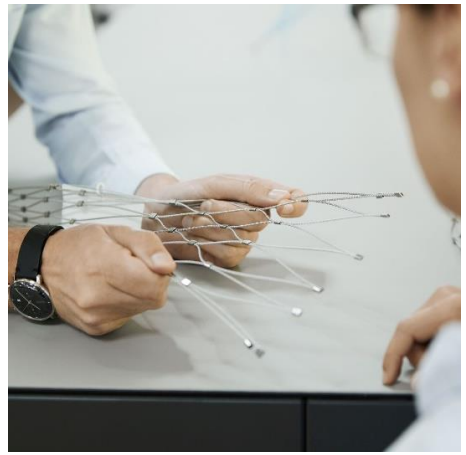
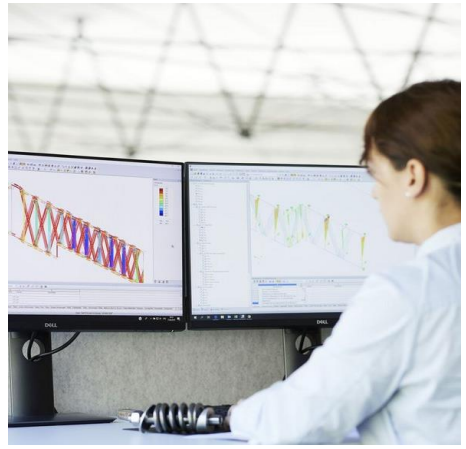
Rope Systems

JAKOB AG | Rope engineering from Emmental, Switzerland









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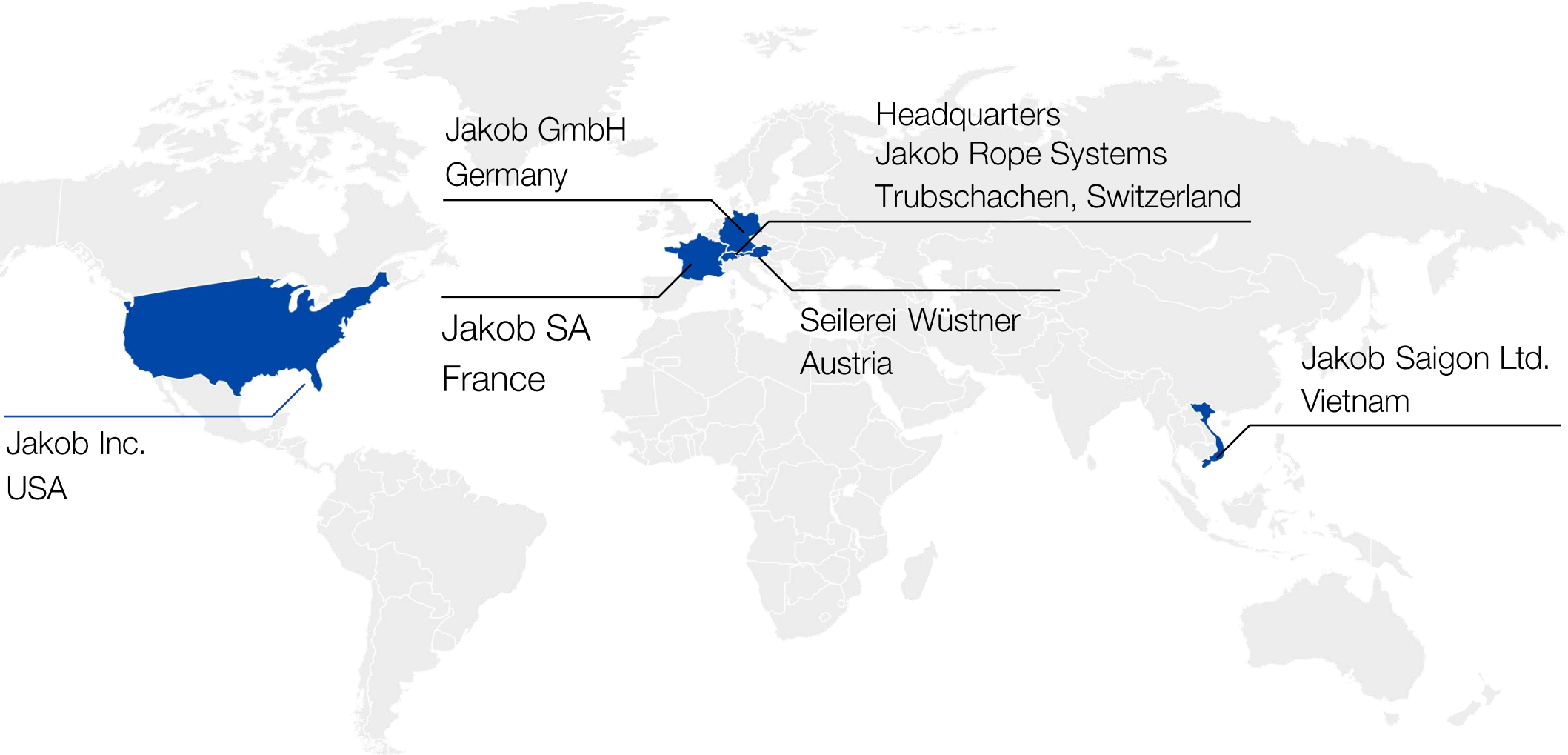
JAKOB AG | Worldwide support



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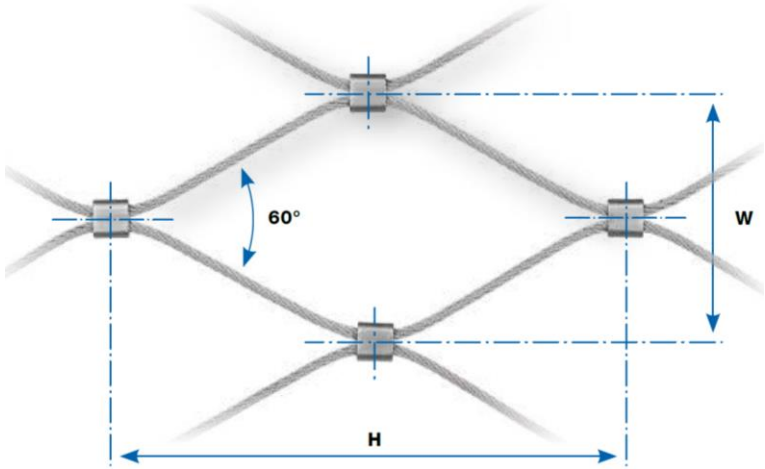
Rope net | Rope net structures




Allgemeine bauaufsichtliche Zulassung/ Allgemeine Bauartgenehmigung

Nummer: Z-14.7-557

Geltungsdauer vom: 5. Januar 2022 bis: 5. Januar 2027

Antragsteller: Jakob AG 3555 Trubschachen SCHWEIZ

Gegenstand dieses Bescheides: Seilnetzkonstruktionen Jakob Rope Systems Webnet

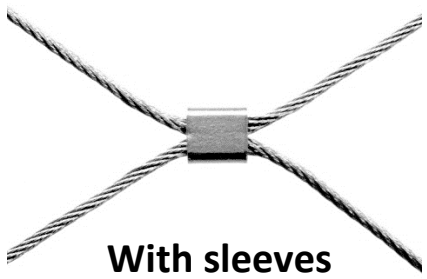
Der oben genannte Regelungsgegenstand wird hiermit allgemein bauaufsichtlich zugelassen/genehmigt.
Dieser Bescheid umfasst acht Seiten und 16 Anlagen.
Der Gegenstand ist erstmals am 5. Januar 2012 allgemein bauaufsichtlich zugelassen worden.

DIBt

Rope net

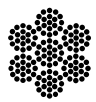
- Opening angle: α
- Mesh geometry: W; H
- Net rope Ø
- Node type: with sleeves / sleeveless
- Steel grade: rope 1570-EN1.4401 / sleeves EN1.4404

Nodes



Ø 1.0 / 1.5 / 2 / 3 mm

Ø 1.5 / 2 mm



Ø 3–5 mm

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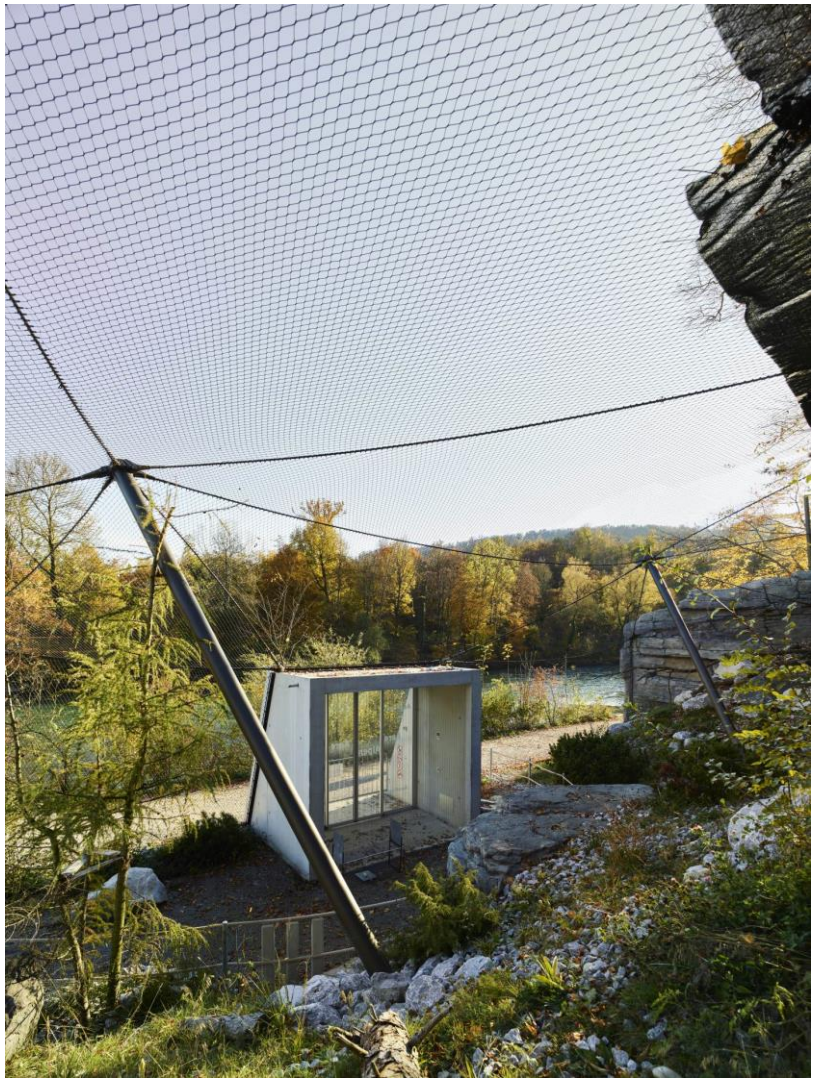
Applications | Zoo Enclosures

Enclosure Aarealpen Dählhölzli, Berne, Switzerland . 2019



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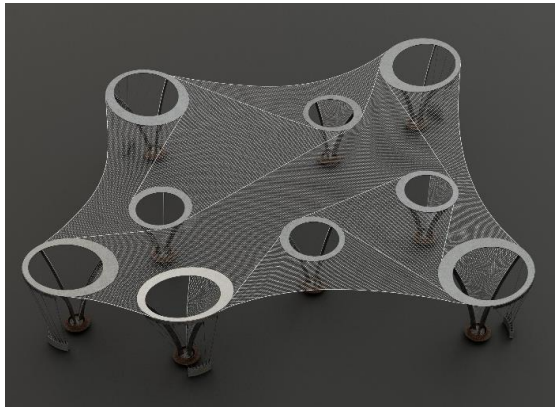
Applications | Green Structures

Amthausplatz Solothurn, Switzerland



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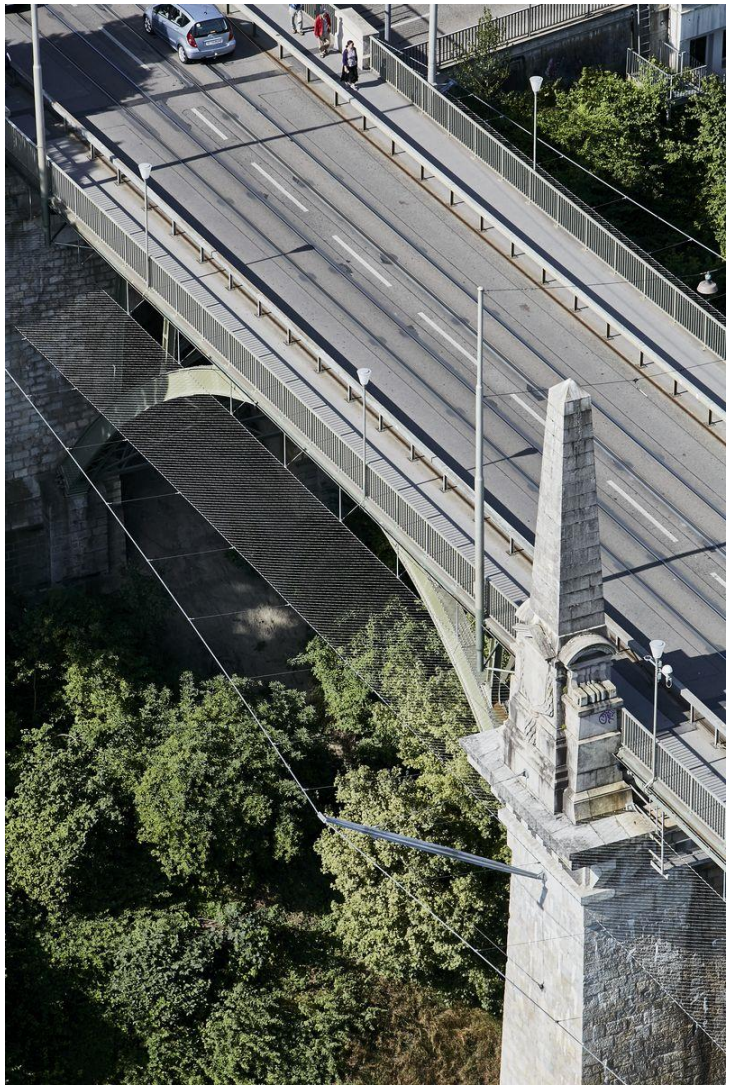
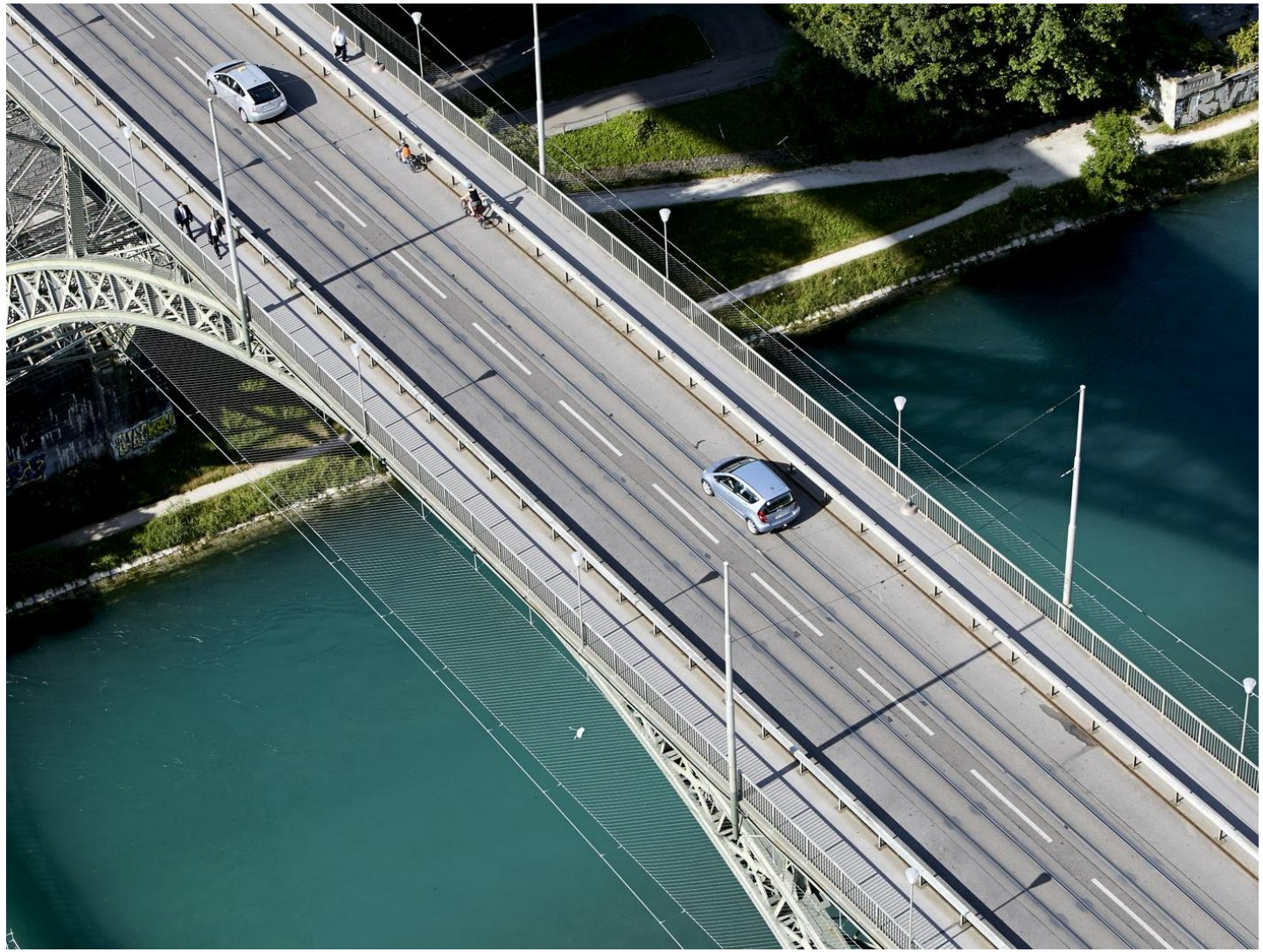
Applications | Safety Structures

Suicide Prevention Structure Kornhausbrücke Berne, Switzerland . 2015





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Applications | Bridge Constructions

Himmelhausmattesteg Trubschachen, Switzerland . 2020

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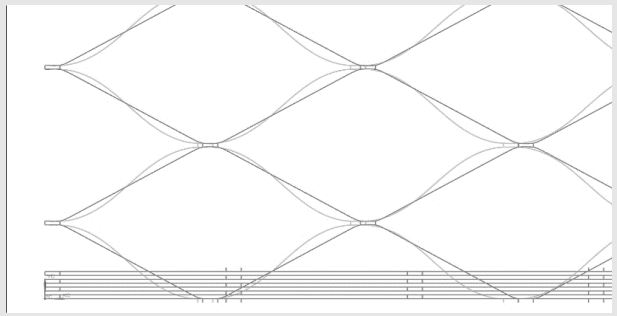
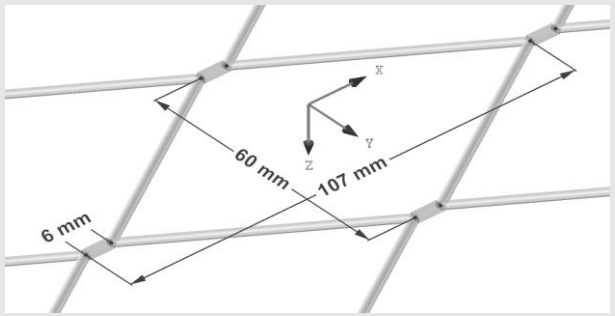
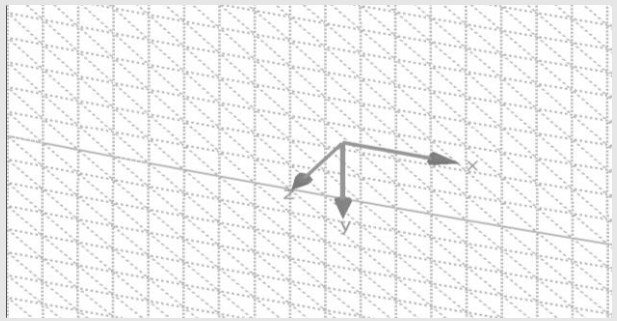
Modeling | Rope net Structures

1. Method - "Real" ropes	**2. Method - "Ideal" ropes**	**3. Method - orthotropic membrane**
• Beam elements with a real, representative bending stiffness • Rope deviation at the sleeve or tensioning process is taken into account	• Ideal, straight rope elements • 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 - 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]

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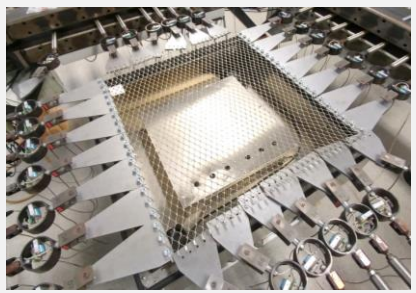
Dimensioning | Rope net structures

For quasi-static loads

STIFFNESS

Tests
Uniaxial or biaxial tests



[Biax-DEKRA]

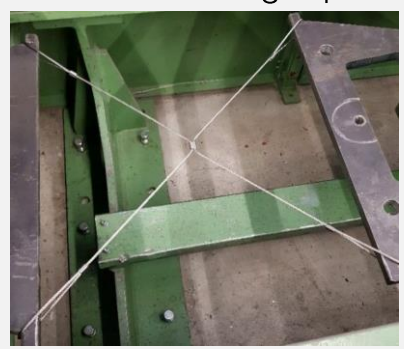
Calibration FE model
Isolated rope net structure → adaptation $EA_{net\ rope}$ from initial stressing stage

FE - SIMULATION

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

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

Empirical determination k_e
by node test / test lacing rope



RESISTANCE

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Applied actions | Rope net structures

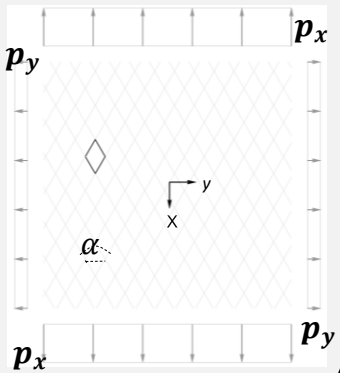
QUASI - STATIC

DYNAMIC

Mains voltage

p dependent net structure, net application

$p_y\{\alpha, 60°\} = {}^1/_3\, p_x$



Wind

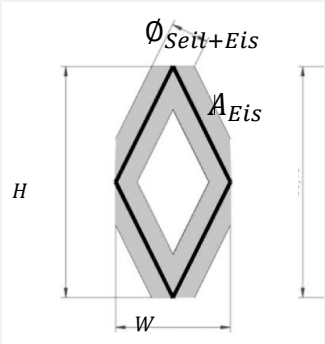
c_f - based on wind tunnel tests

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

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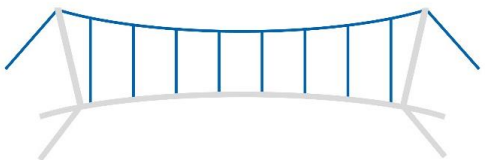
Bridge construction | Rope / net structures

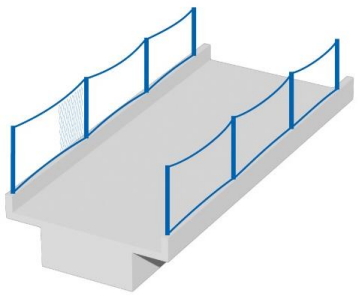
ROPE STRUCTURES

ROPE / NET STRUTURES

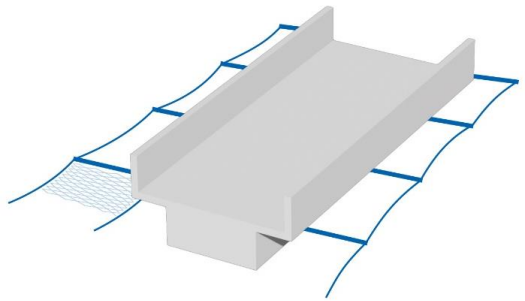
Suspension bridge



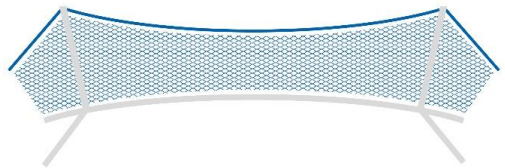
Vertical fall protection



Horizontal fall protection



Structural elements



STRUCTURAL MEASURES FOR SUICIDE PREVENTION

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Himmelhausmattesteg | Case study

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

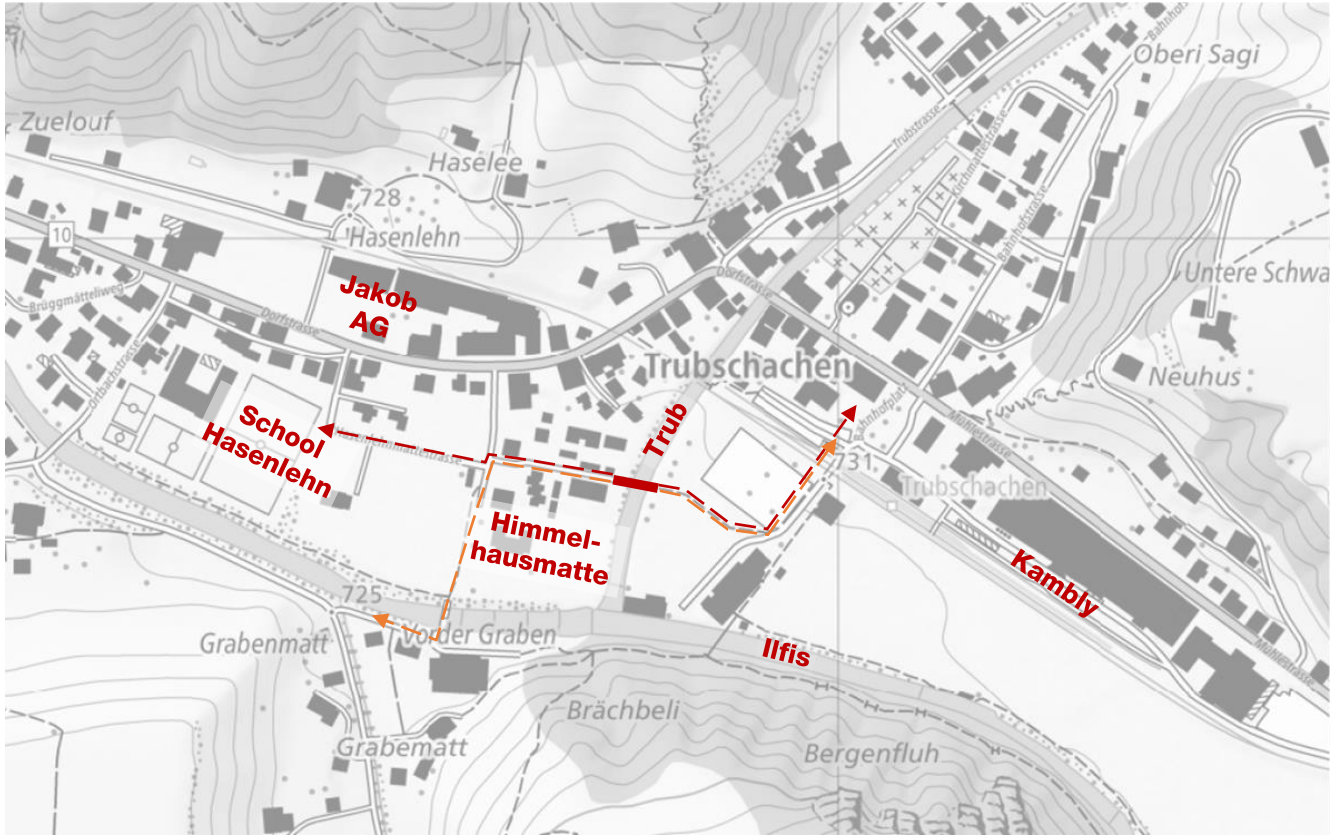

fig.: Situation; [maps.geo.admin.ch]

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

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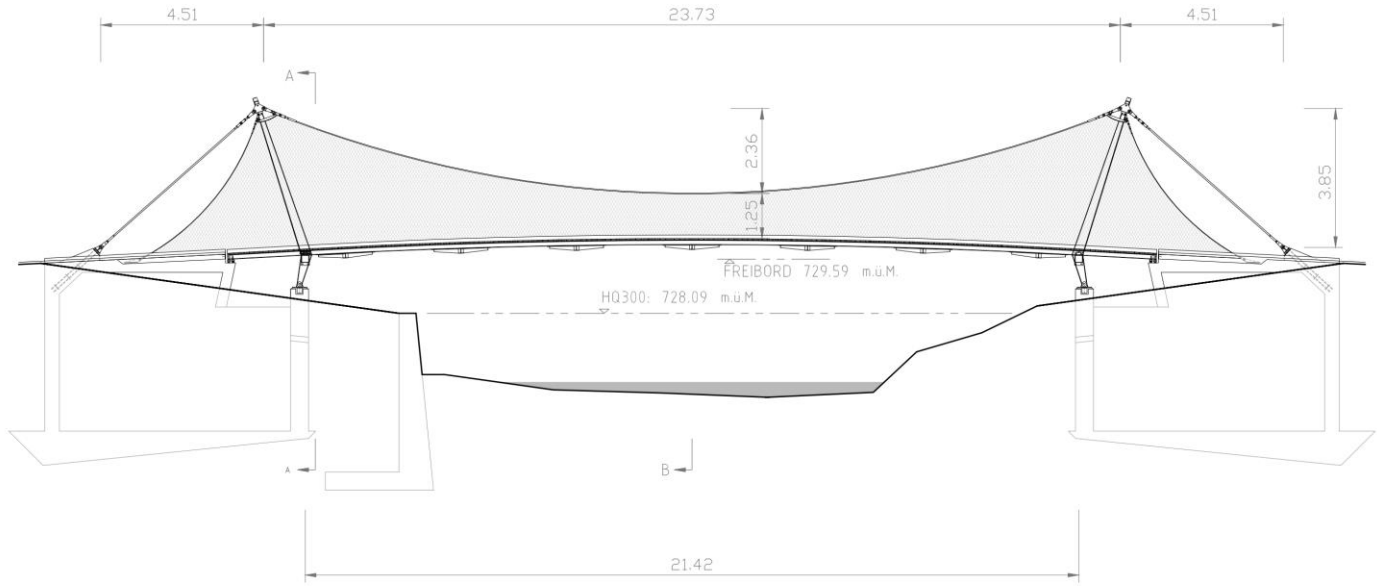
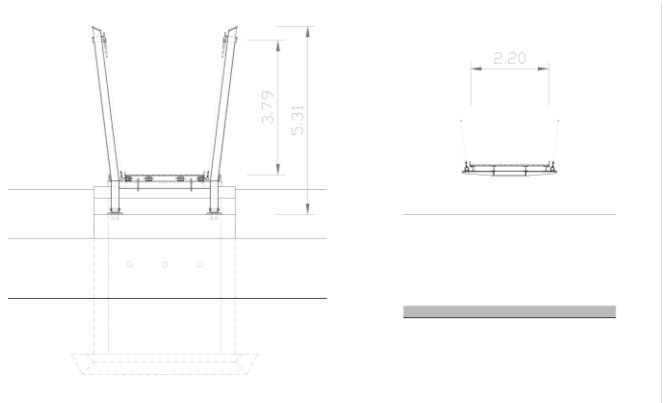
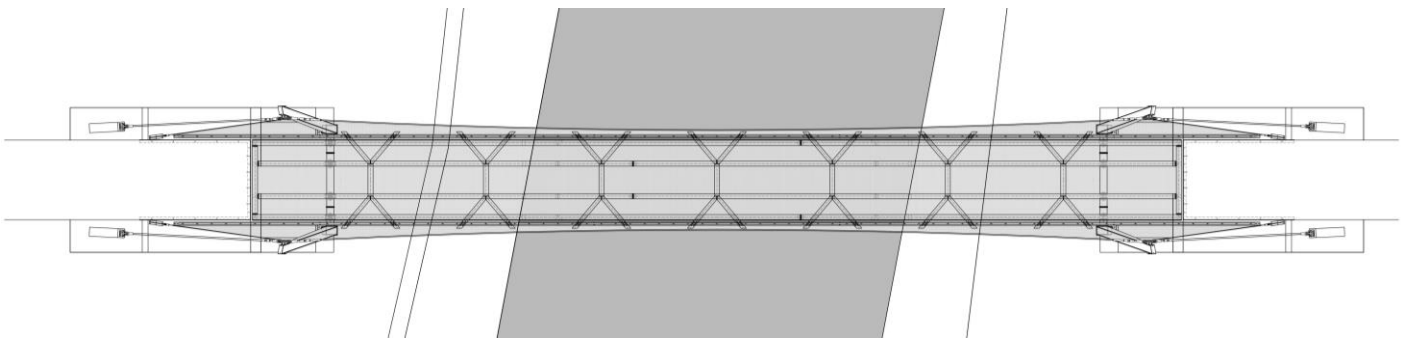
Structural design approach | Himmelhausmattesteg







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

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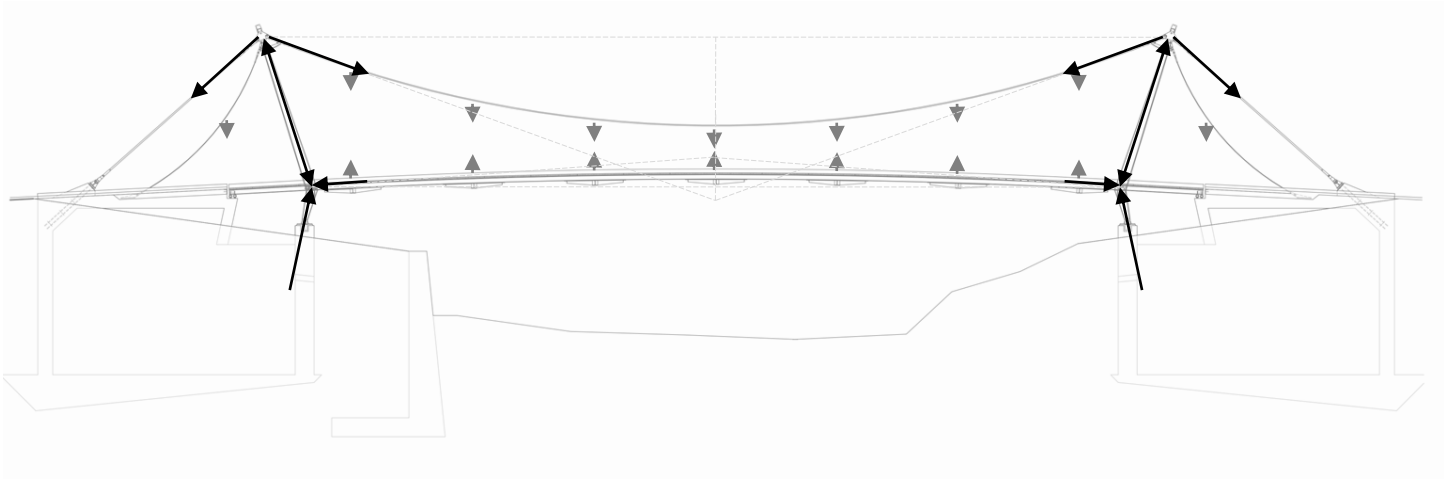
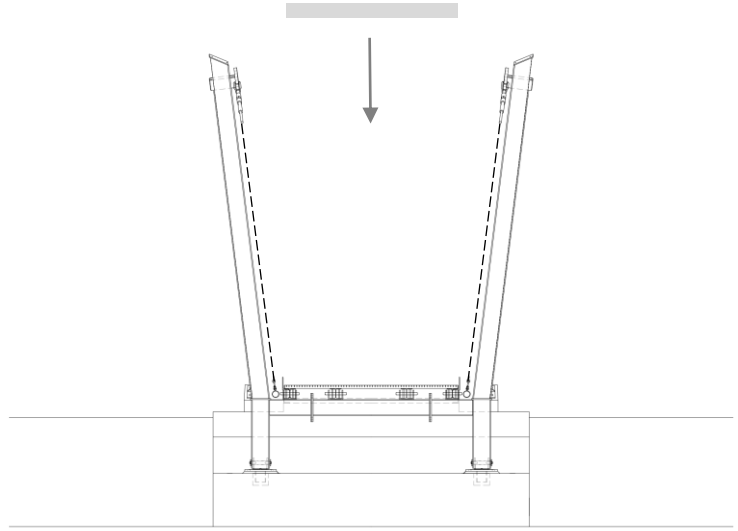
Structural design approach | Himmelhausmattesteg

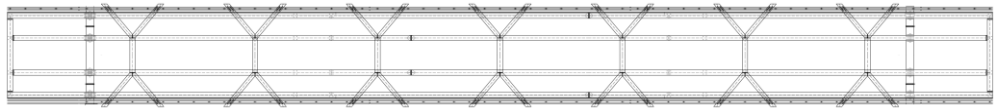
Tensioning of suspension cable to bridge girder → **system stiffness**



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



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



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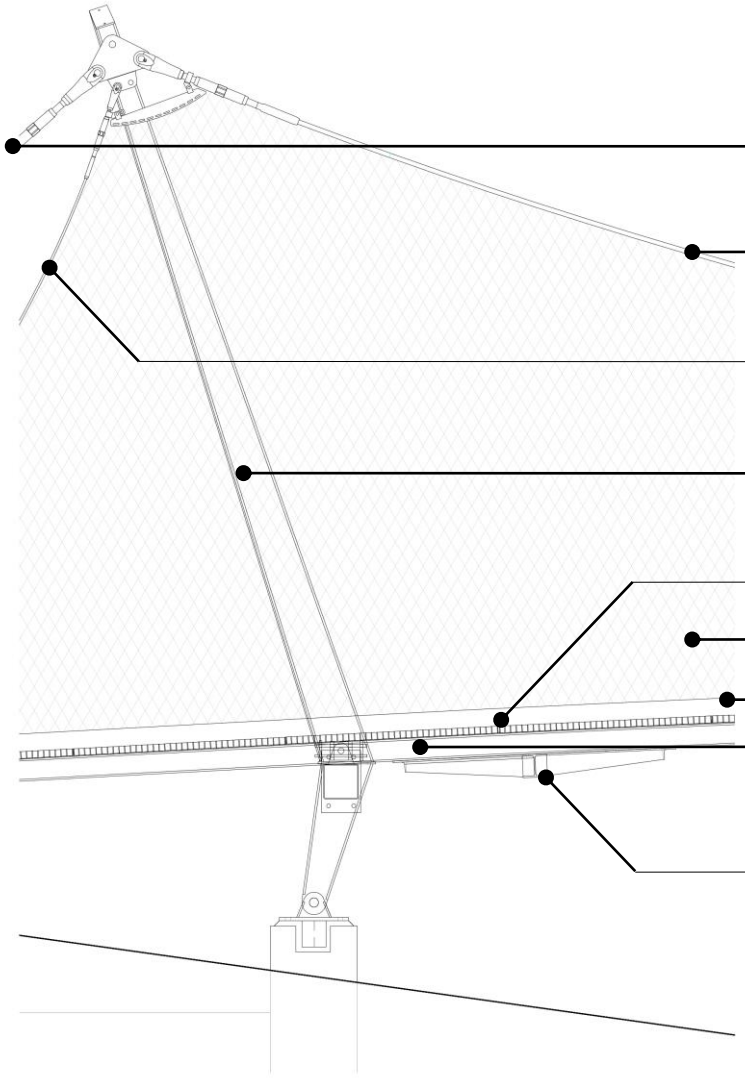
Structural description | Himmelhausmattesteg



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

Steel: 8'500 kg, gratings: 2'800 kg

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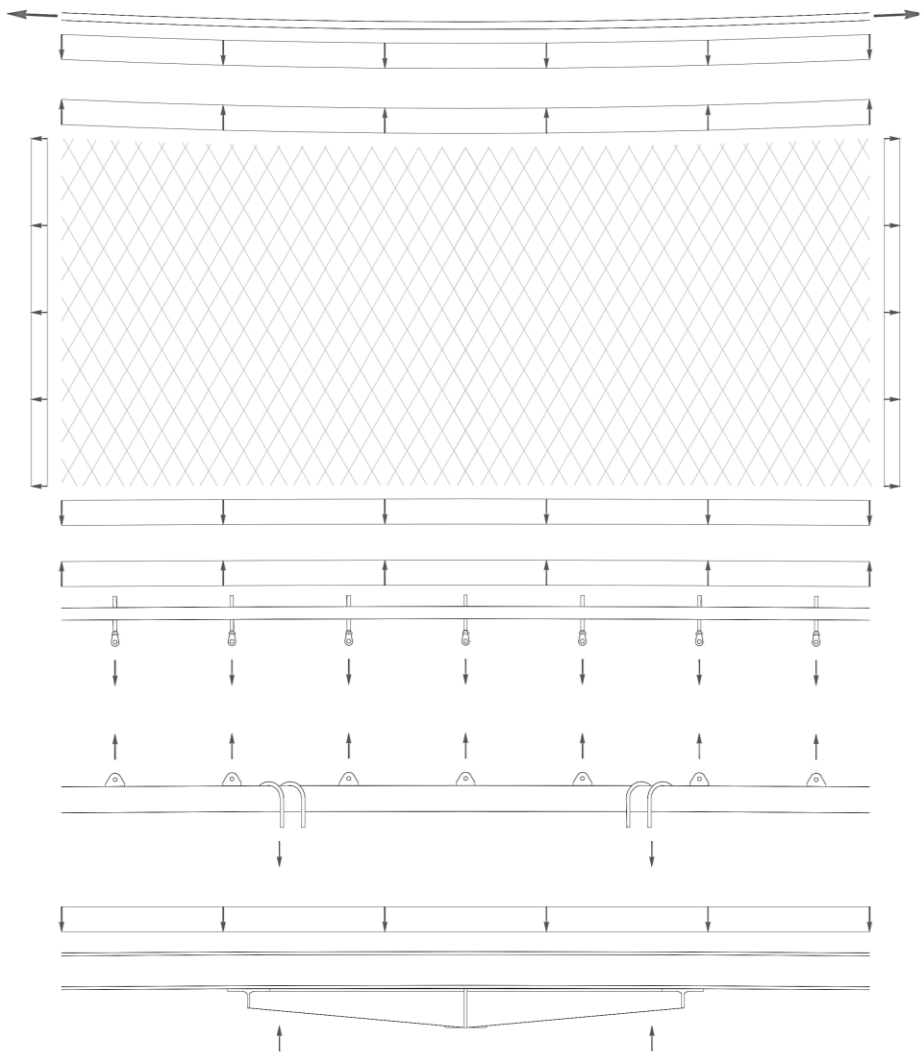
Tectonics | Himmelhausmattesteg



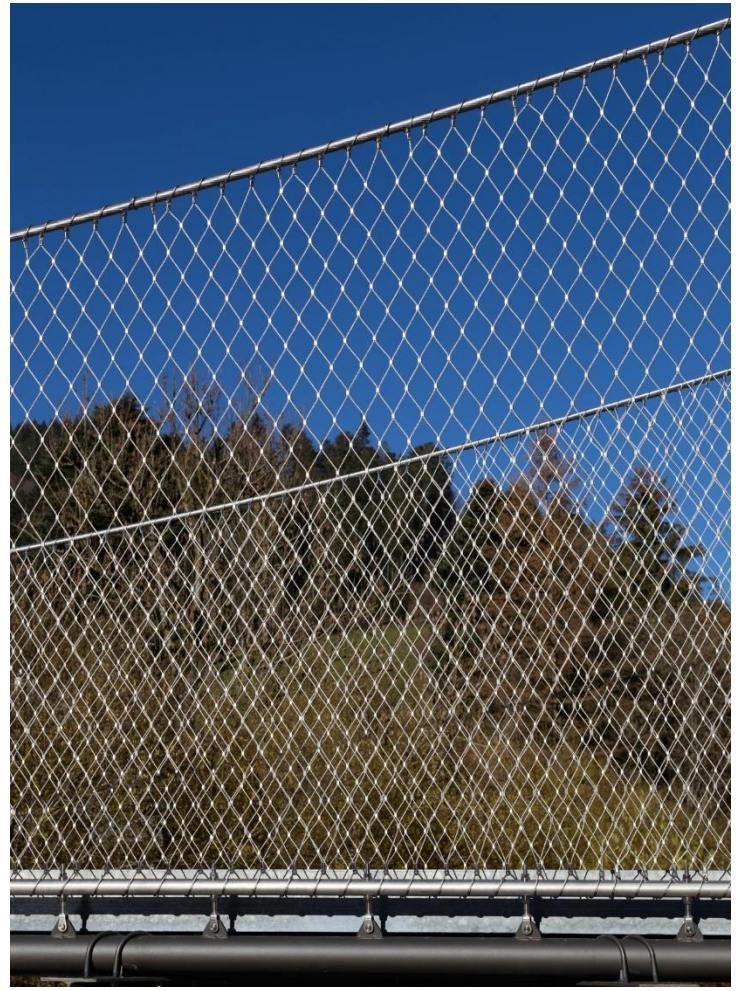
Suspension rope

Rope net

Railing (adjustable)

Bridge girder longitudinal tube (electr. cable)

Bridge girder with cross bracing



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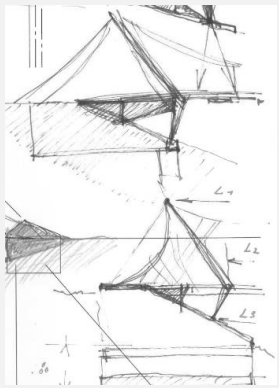
Dimensioning | Himmelhausmattesteg

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
- 1- axial test rope net
- Deformation measurement of bridge girder

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

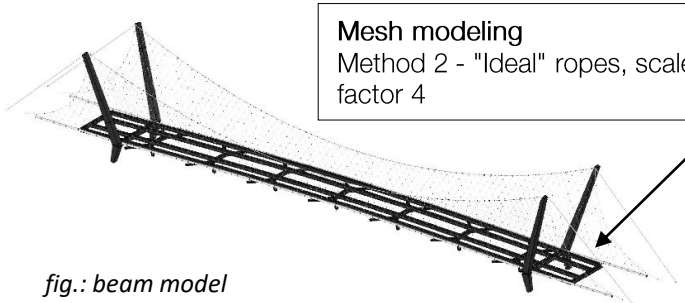


fig.: beam model

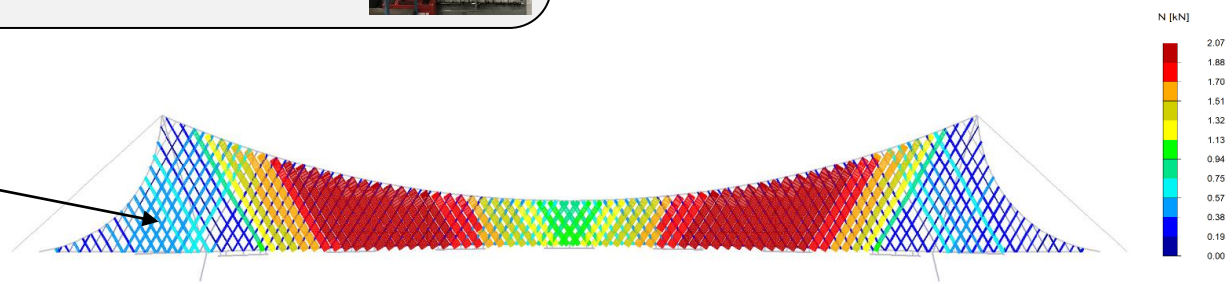


fig.: beam model, net i forces N [kN]; $LC\{G + P + Q\}$

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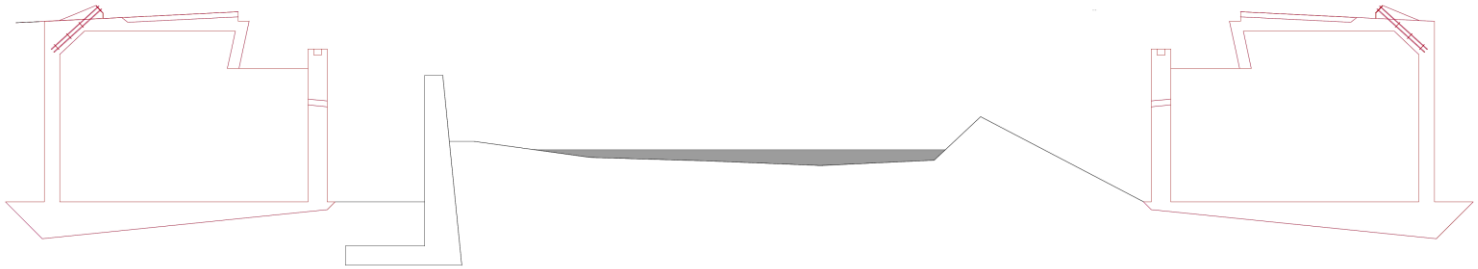
Construction process | Himmelhausmattesteg

Step 1



- Creation of access, installation site
- Foundation

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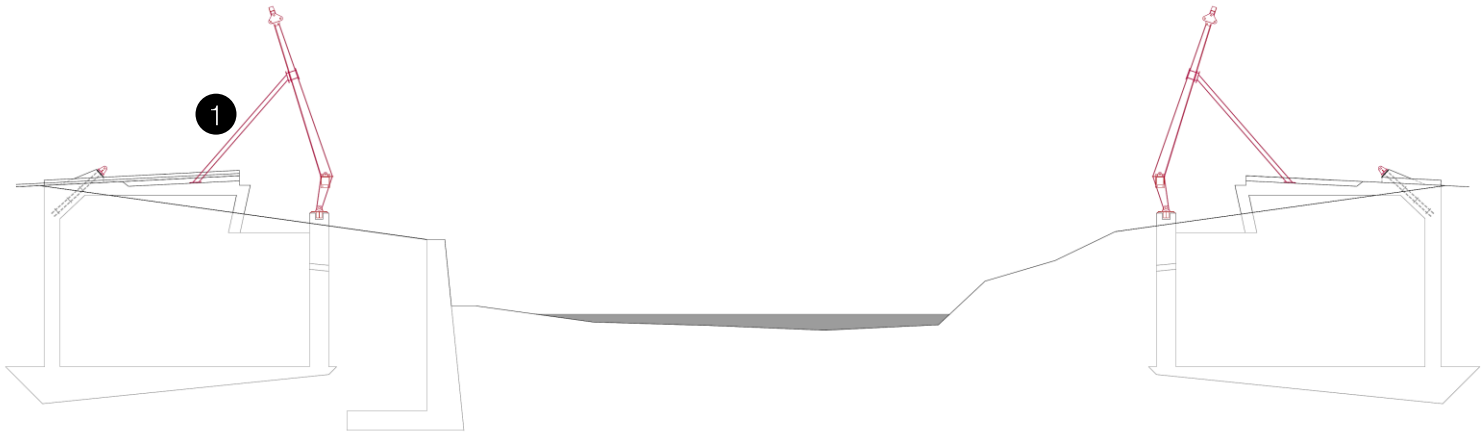
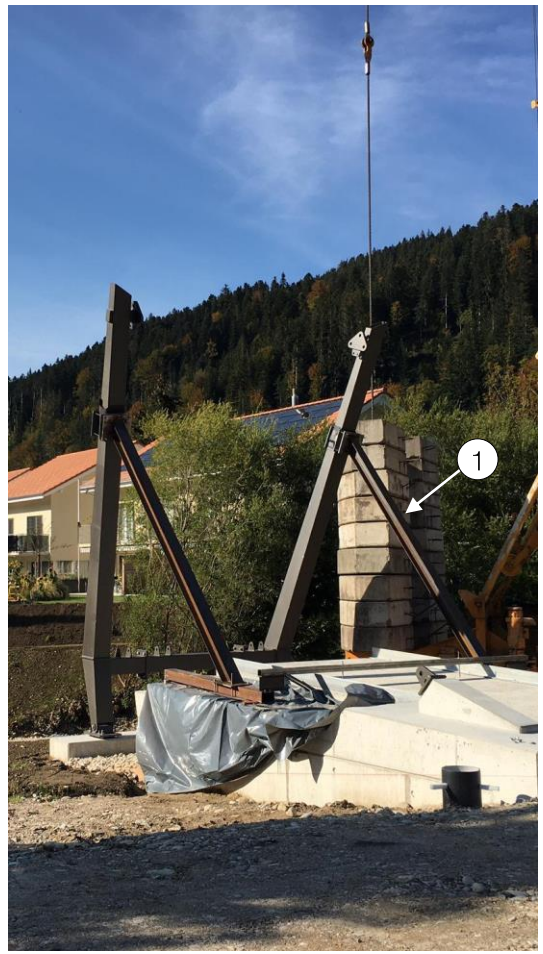
Construction process | Himmelhausmattesteg

Step 2.1



- Erecting pylons with auxiliary struts 1



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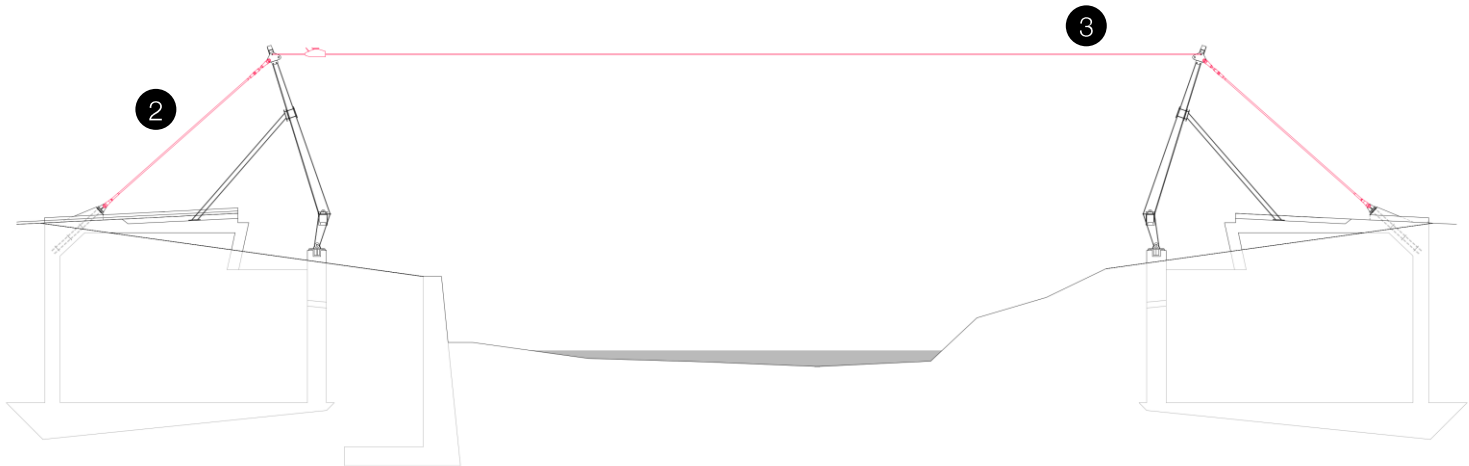
Construction process | Himmelhausmattesteg

Step 2.2



- Mounting tie-back rods 2
- Horizontal pylon coupling cable 3
- Adjustment pylon alignment

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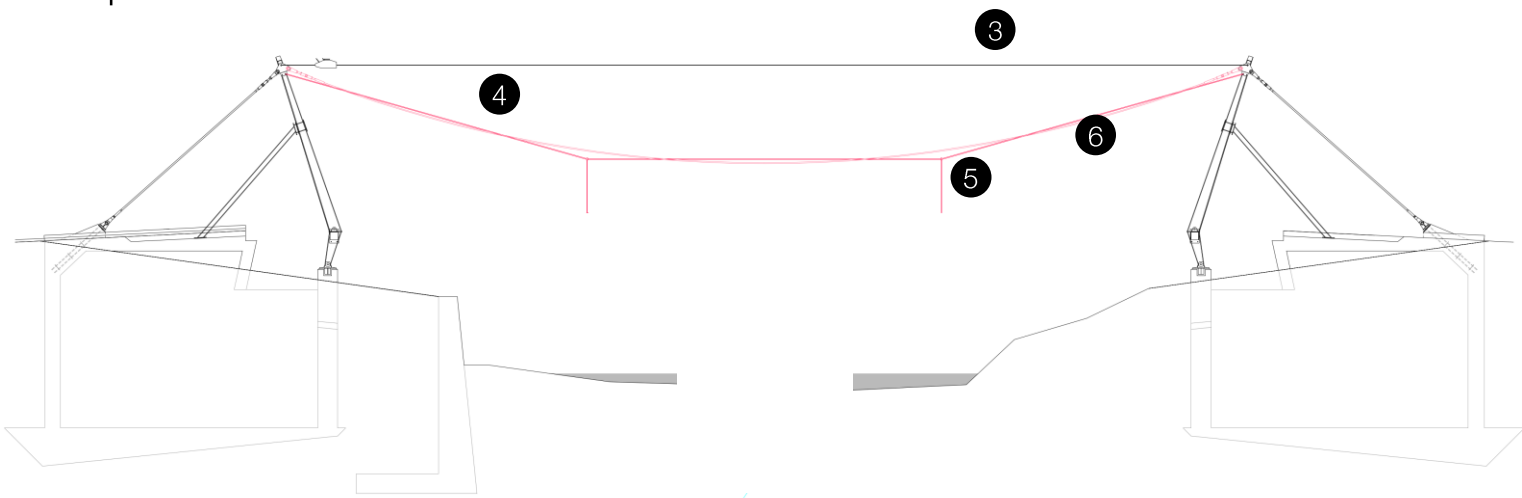
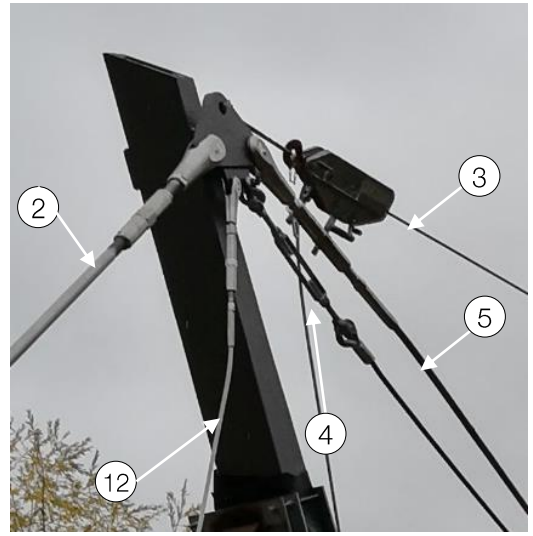
Construction process | Himmelhausmattesteg

Step 3





- Mounting temporary suspension ropes ❹ with hangers ❺ pull in along ❸
- Installation of suspension ropes (temporary laterally tensioned) ❻

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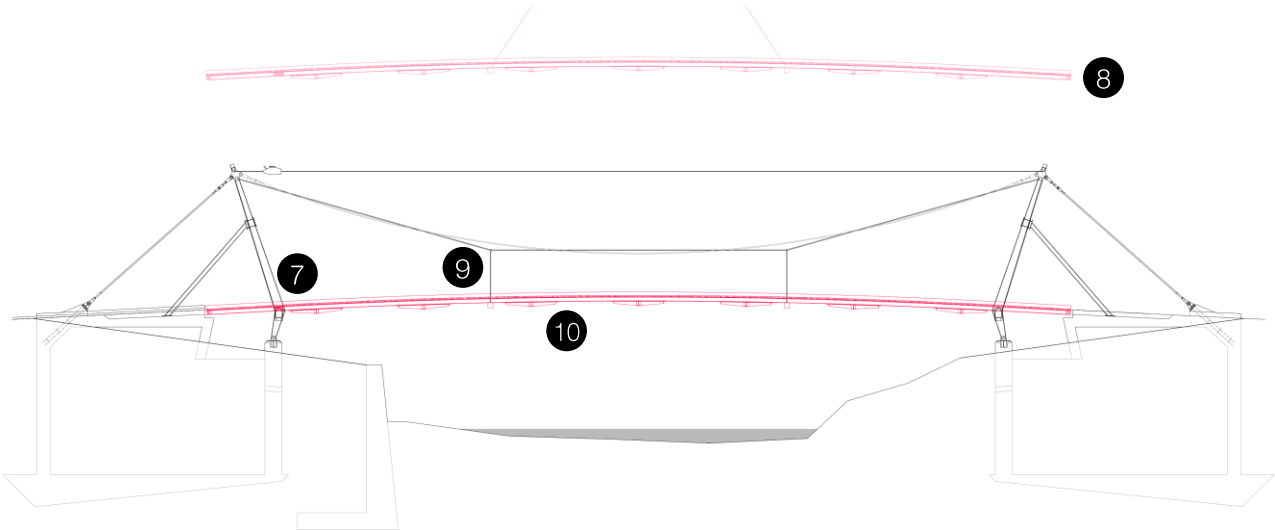
Construction process | Himmelhausmattesteg

Step 4



- 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

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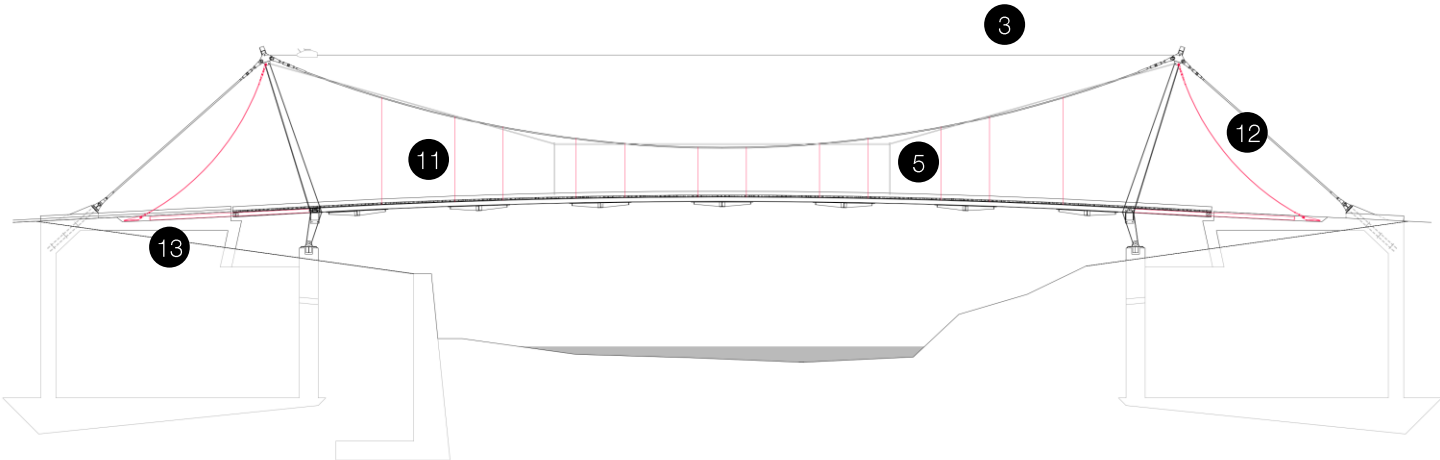
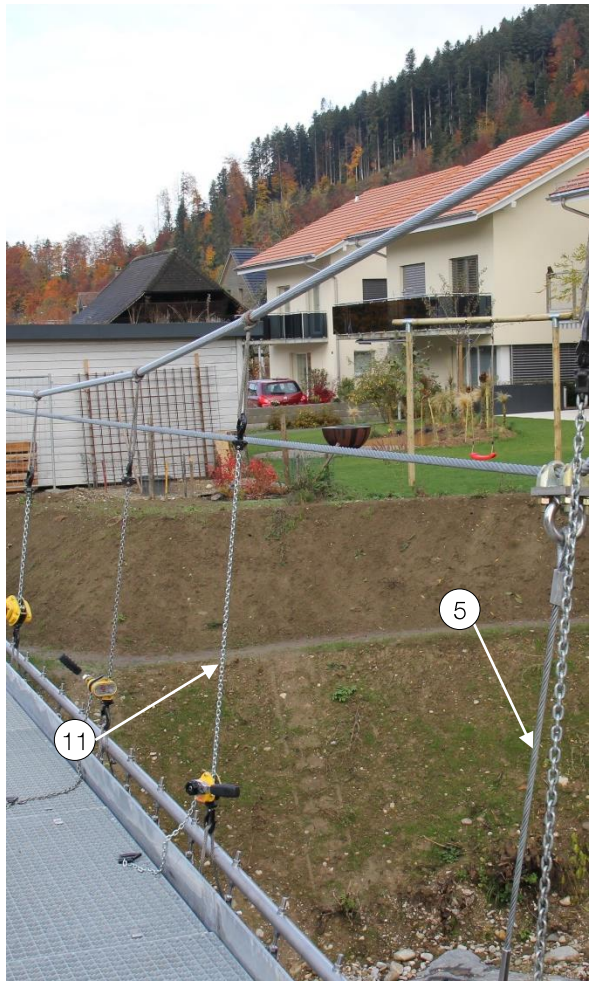
Construction process | Himmelhausmattesteg

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



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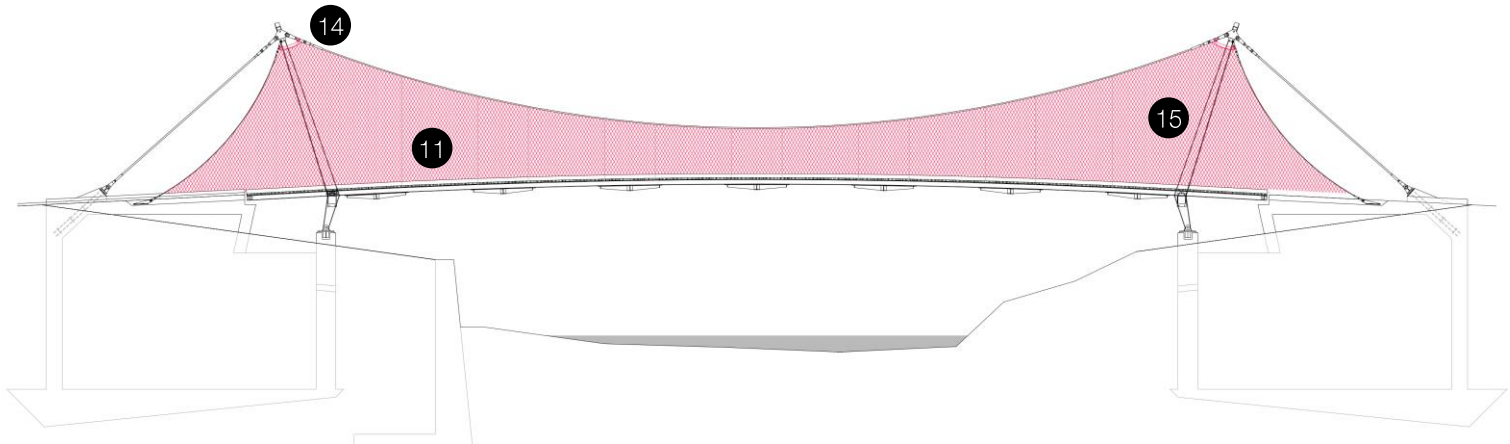
Construction process | Himmelhausmattesteg

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

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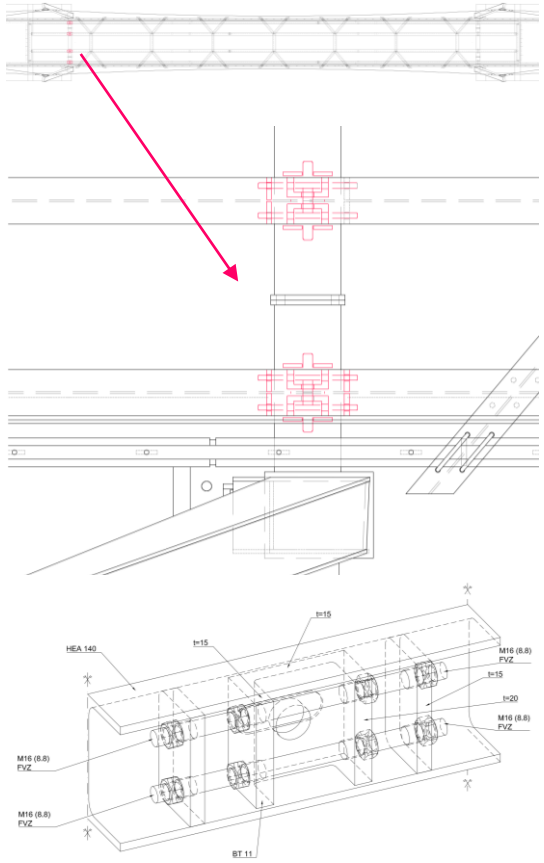
Constructive design | Himmelhausmattesteg

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

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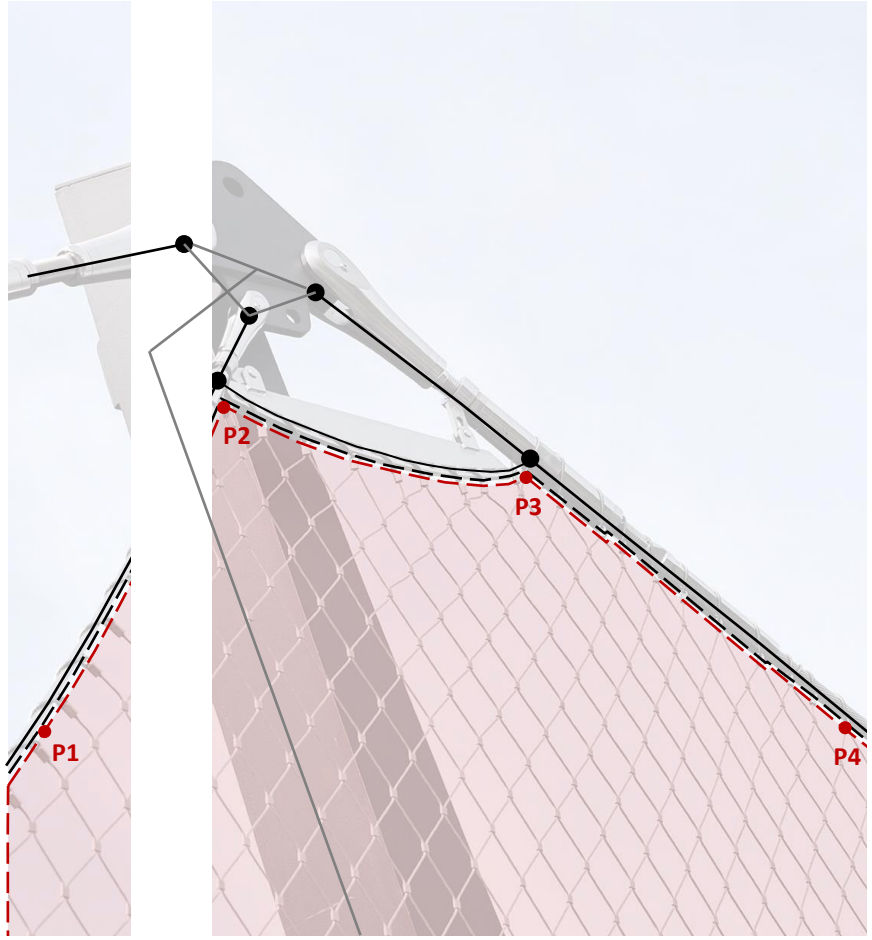
Patterning | Himmelhausmattesteg



FE structural model

constr. deduction

Patterning

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

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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 medium / minimum $a_{limit,vertical} \leq 1.0$
Marching	vertical vibration	2.2	critical	-	not acceptable
Running	vertical vibration	2.8	critical	-	not acceptable

- Number of pedestrians: 9 + 1 persons -> 0.2 P/m2 (TC2)
- Quiescent vibration: FE model: 2.7 Hz

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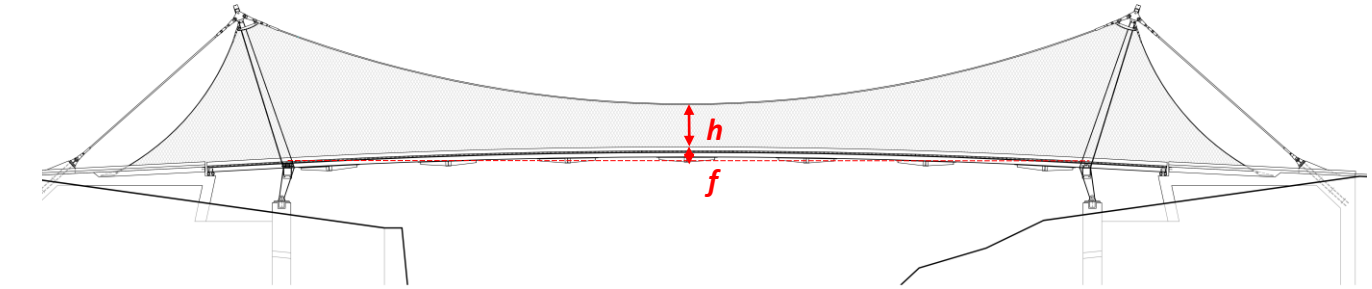
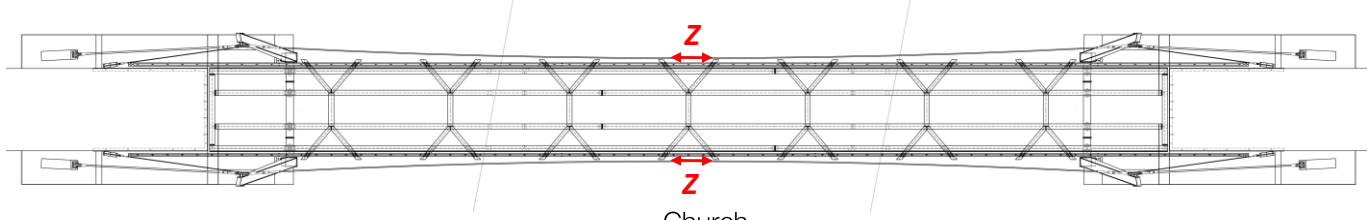
Monitoring | Himmelhausmattesteg

Measurement	Location	Z [kN]		h [mm]		f [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



Ilfis



Church

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Construction costs | Himmelhausmattesteg

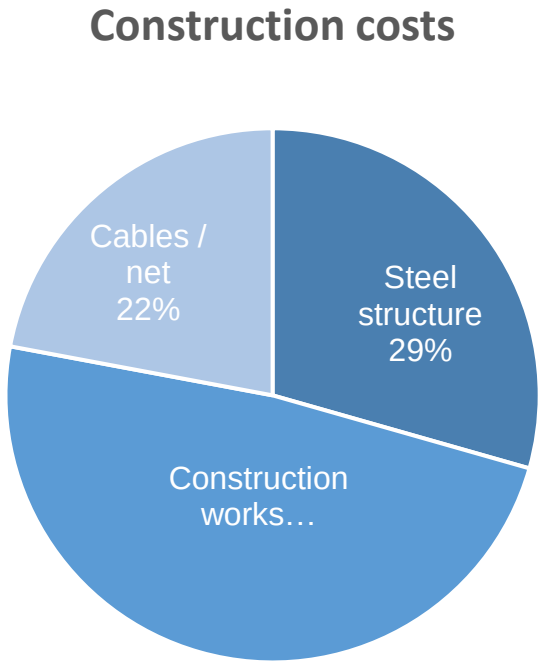
(Erection 2020)

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/m²
based on bridge length $l = 26\ m$	9 500 EUR/m

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



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What's next? | Small spans

Webnet bridge Parco via Pico Lugano, Switzerland . 2022
Span: 15 m

Jakob Rope Systems for HINNEN playground equipment

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What's next? | Big spans

Structural porposal suspension bridge Disentis, Switzerland . 2024
Span: 270 m

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

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

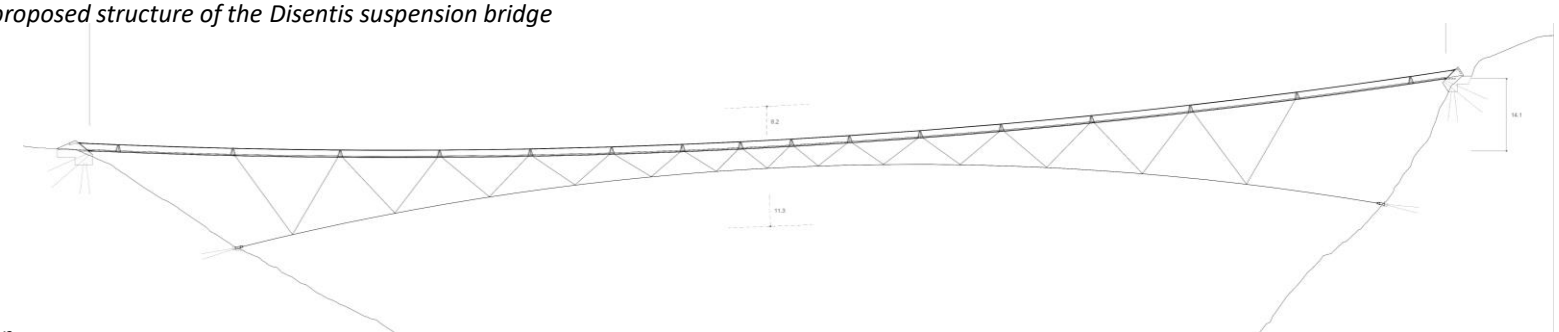

fig.: longitudinal elevation

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