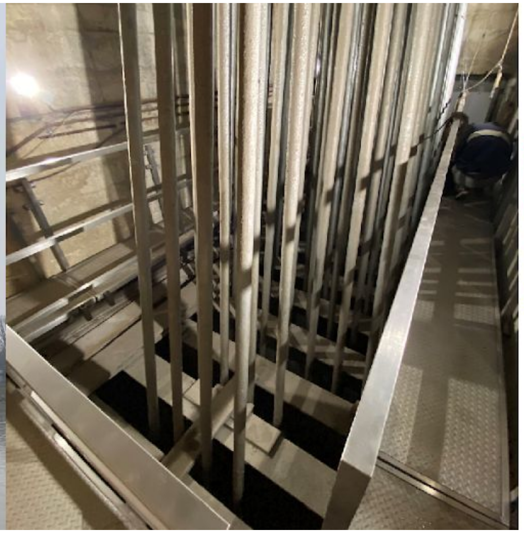
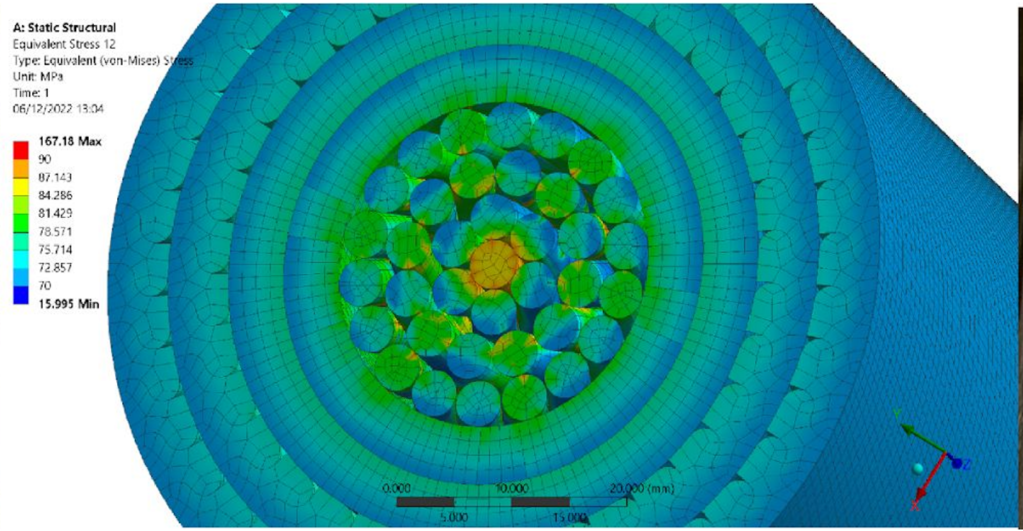




Diagnostics of prestressed ropes after multiannual operation – SNP Bridge, Bratislava, Slovakia

Tomáš Koščo, Matúš Margetin, Vladimír Chmelko

11th INTERNATIONAL SYMPOSIUM ON STEEL BRIDGES

11. - 13. September 2024

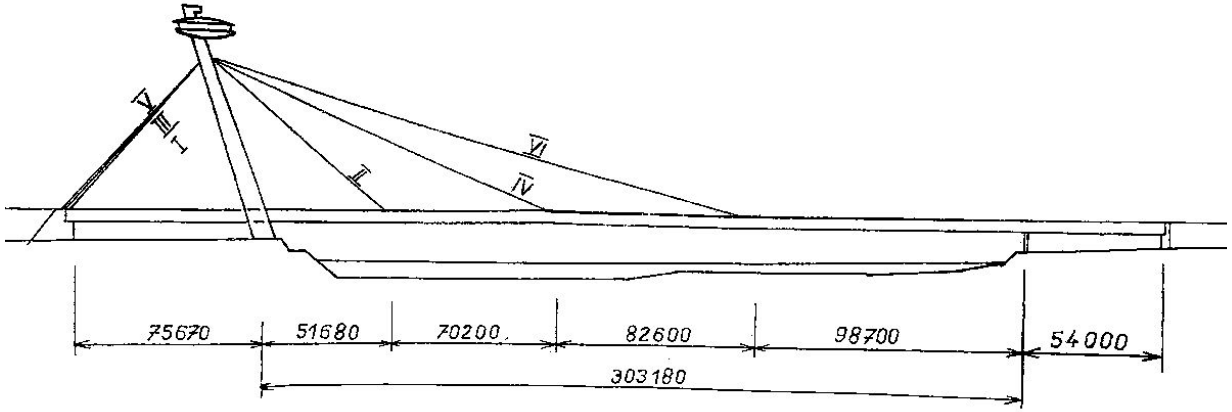
SLOVAK UNIVERSITY OF TECHNOLOGY IN BRATISLAVA

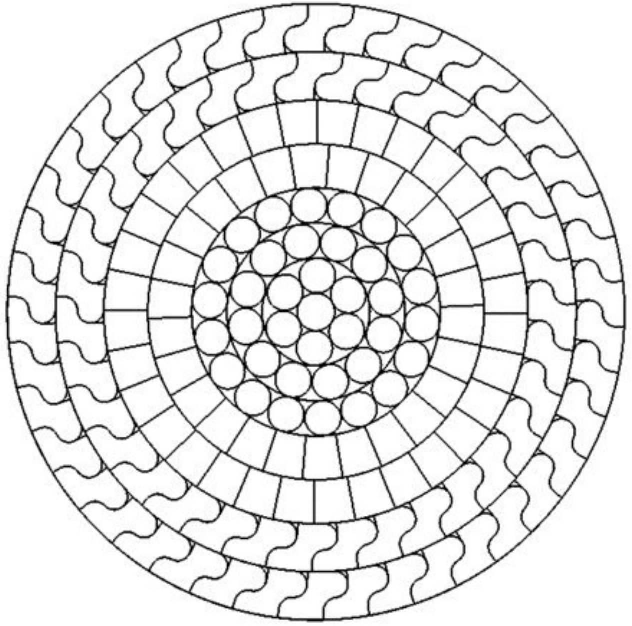
STEEL BRIDGES PRAGUE 2024

CONTENT

- SNP Bridge in Bratislava, Slovakia
- Analysis of the material
- Cable tension estimation
- Rope tension estimation
- FEM Simulation of a rope
- Summary

SNP BRIDGE BRATISLAVA, SLOVAKIA





ROPE CROSS-SECTION

CHEMICAL COMPOSITION - SPECTROMETRY

BELEC Compact Port HLC
MASS SPECTROMETER

ANALYSED SURFACE

CHEMICAL ELEMENT	C (%)	Si (%)	Mn (%)	Cu (%)	Cr (%)	Mo (%)	Ni (%)
	0.848	0.269	0.520	0.178	0.570	0.105	0.115
CHEMICAL ELEMENT	V (%)	Ti (%)	Co (%)	W (%)	Nb (%)	Al (%)	P, S(%)
	0.045	0.070	0.101	0.12	0.047	0.057	0.05

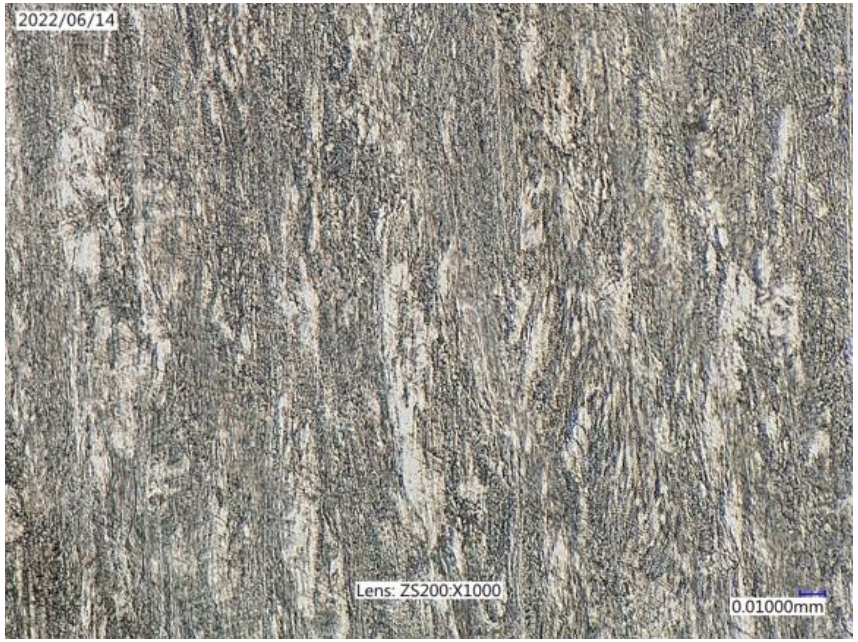
CHEMICAL COMPOSITION OF THE ROPE

ANALYSIS OF THE MATERIAL

KEYENCE VHX 6000

MICROSCOPE

MAGNIFIED 500x



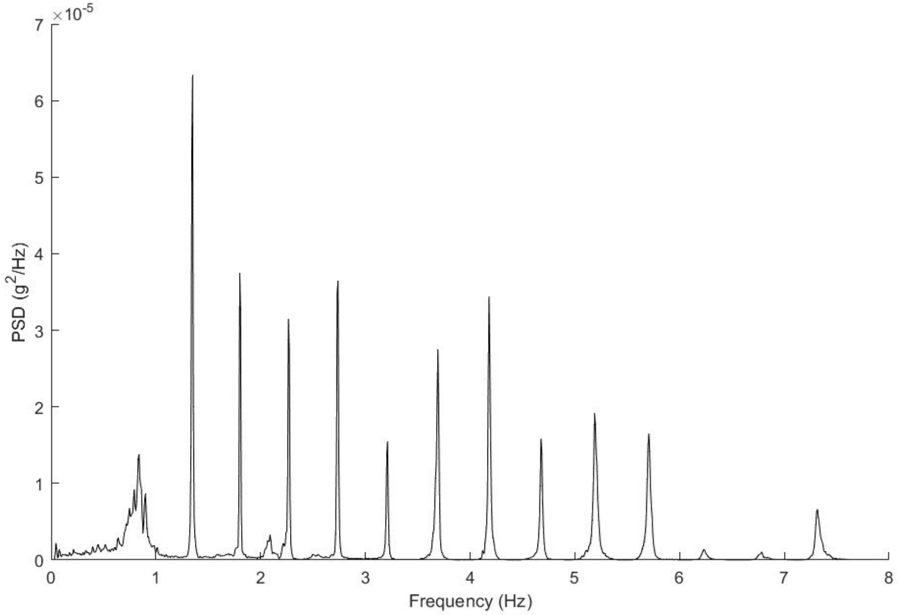
MAGNIFIED 1000x

MICROSTRUCTURE OF THE ROPE

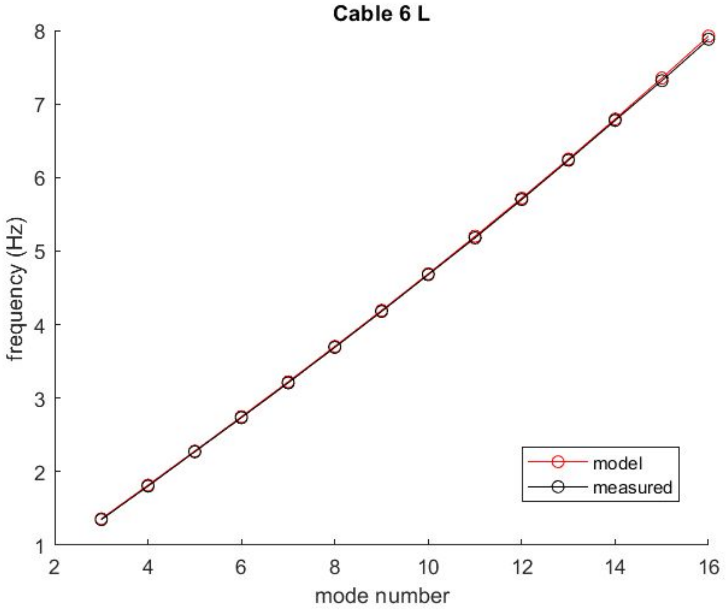
SORBITIC STRUCTURE WITH NO INVESTIGATED DEGRADATION (SEGREGATION),
PATENTED STEEL WITH ESTIMATED STRENGTH ABOUT **1370 MPa**

TENSION ESTIMATION by VIBRATION METHOD

MODAL SHAKER on the CABLE 6



PSD 15 MINUTE MEASUREMENT



FREQUENCY vs MODE NUMBER

TENSION ESTIMATION by VIBRATION METHOD

$$m\frac{\partial^2 y(x,t)}{\partial t^2} + EI\frac{\partial^4 y(x,t)}{\partial x^4} - T\frac{\partial^2 y(x,t)}{\partial x^2} = 0$$

STRING THEORY

$$\boldsymbol{T} = 4\boldsymbol{m}\boldsymbol{L}^2\left(\frac{\boldsymbol{f}_n}{\boldsymbol{n}}\right)^2$$

- NEGLECTS BENDING STIFFNESS
- HINGED ENDS

EULER-BERNOULI BEAM THEORY

$$\boldsymbol{T} = 4\boldsymbol{m}\boldsymbol{L}^2\left(\frac{\boldsymbol{f}_n}{\boldsymbol{n}}\right)^2 - \frac{\boldsymbol{EI}}{\boldsymbol{L}^2}(\boldsymbol{n\pi})^2$$

- INCLUDES BENDING STIFFNESS
- BENDING STIFFNESS IS **UNKNOWN**
- ASSUMES HINGED ENDS

FANG-WANG - PRACTICAL FORMULA

$$\boldsymbol{T} = 4\pi^2\boldsymbol{m}\boldsymbol{L}^2\frac{\boldsymbol{f}_n^2}{\boldsymbol{\gamma}_n^2} - \frac{\boldsymbol{EI}}{\boldsymbol{L}^2}\boldsymbol{\gamma}_n^2$$

- INCLUDES BENDING STIFFNESS
- BENDING STIFFNESS IS **UNKNOWN**
- FIXED ENDS
- [FANG, 2012]

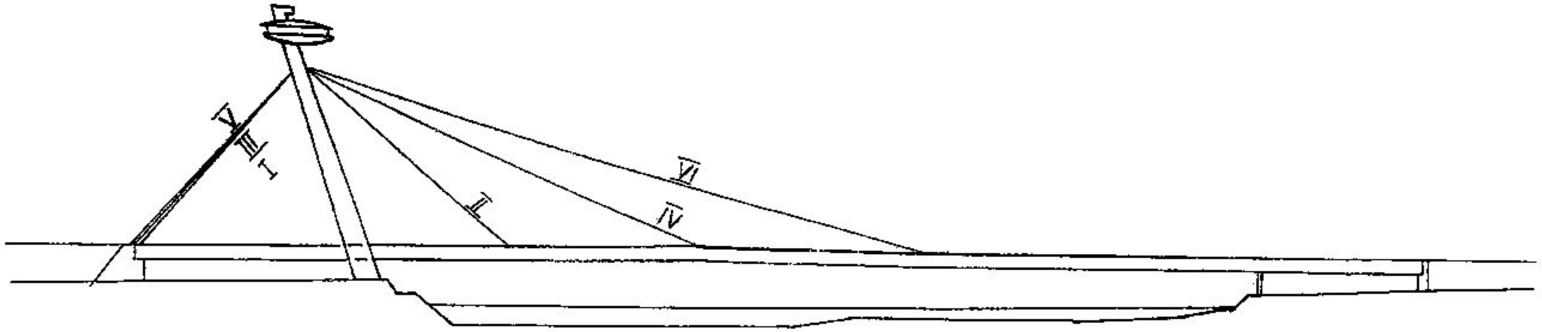
ESTIMATION OF BENDING STIFFNESS

$$f_n = \sqrt{\frac{\pi^2 EI}{4\rho A L^4} n^4 + \frac{T}{4\rho A L^2} n^2}$$

$$min\, F(EI, T) = \sum_n \left\{ \left(\frac{\pi^2 EI}{4\rho A L^4} n^4 + \frac{T}{4\rho A L^2} n^2 \right) - (f_n^m)^2 \right\}^2$$

HIGHER ORDER VIBRATION METHOD [YAMAGIWA, 2000]

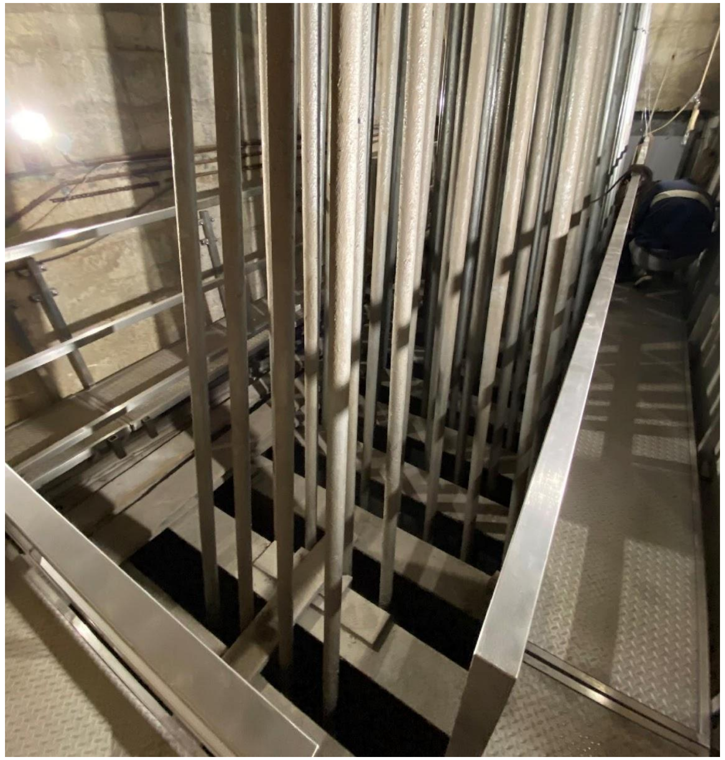
CABLE MEASUREMENTS



Cable	String Theory [MN]	Beam theory (hinged ends)[MN]	Fang (fixed ends) [MN]
1	8.904	9.0050	8.1636
2	9.290	9.0827	8.1802
3 R	16.127	15.8365	14.650
3 L	16.477	16.3023	15.014
4 R	22.201	22.3574	20.658
4 L	22.579	22.3574	20.868
5 L	25.342	24.8416	21.562
6 R	21.632	21.6588	20.222
6 L	21.632	21.6588	20.222

ESTIMATED TENSION FORCES

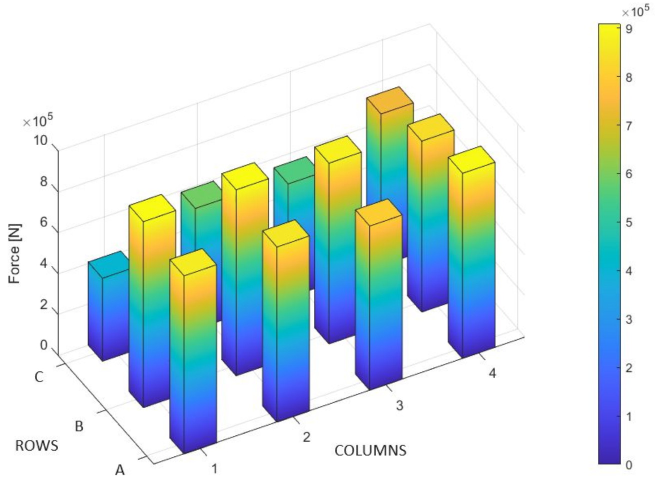
ROPE MEASUREMENTS



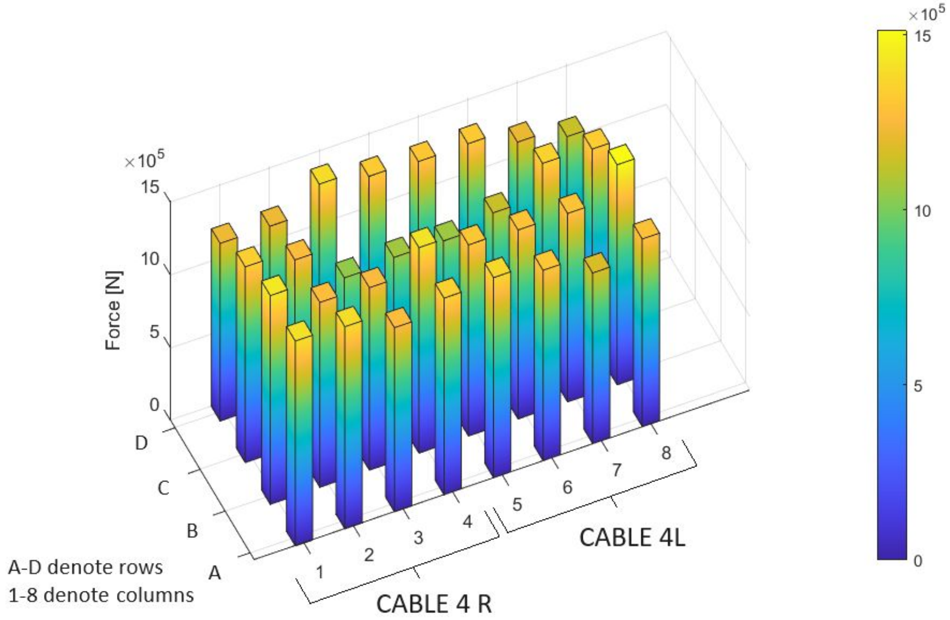
ANCHORING CHAMBER

ACCELEROMETERS on ROPES

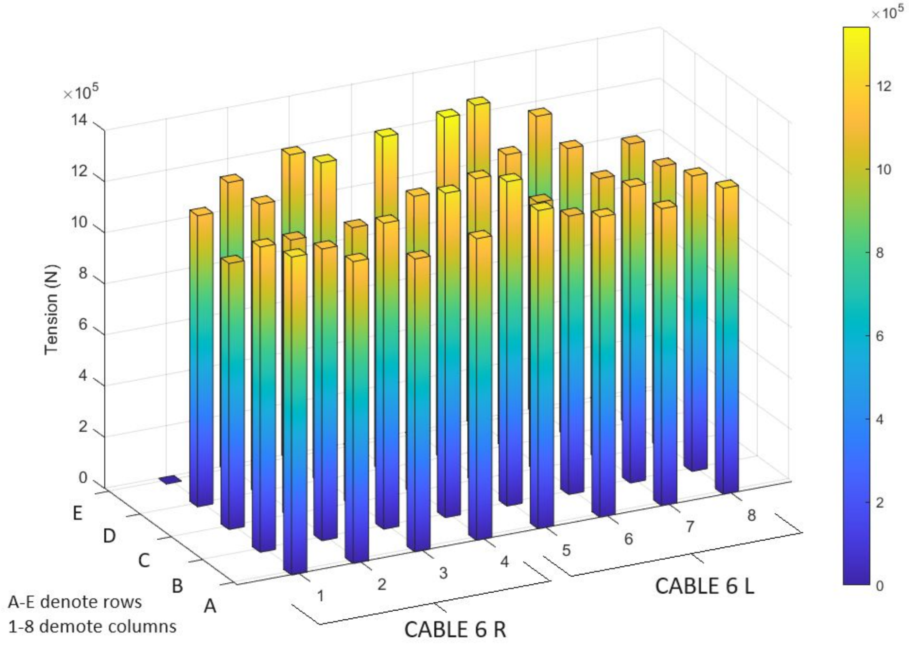
ROPE MEASUREMENTS - TENSION DISTRIBUTION



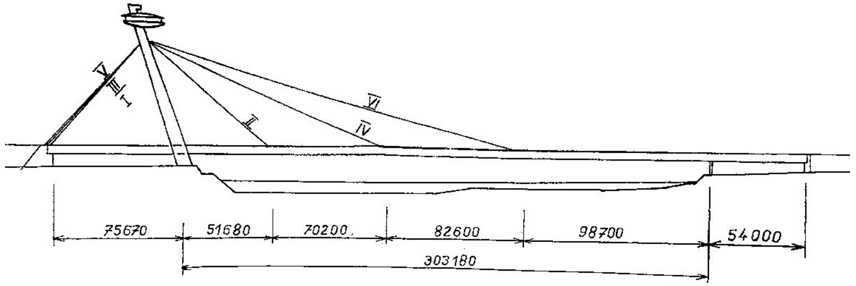
CABLE 2



CABLE 4



CABLE 6



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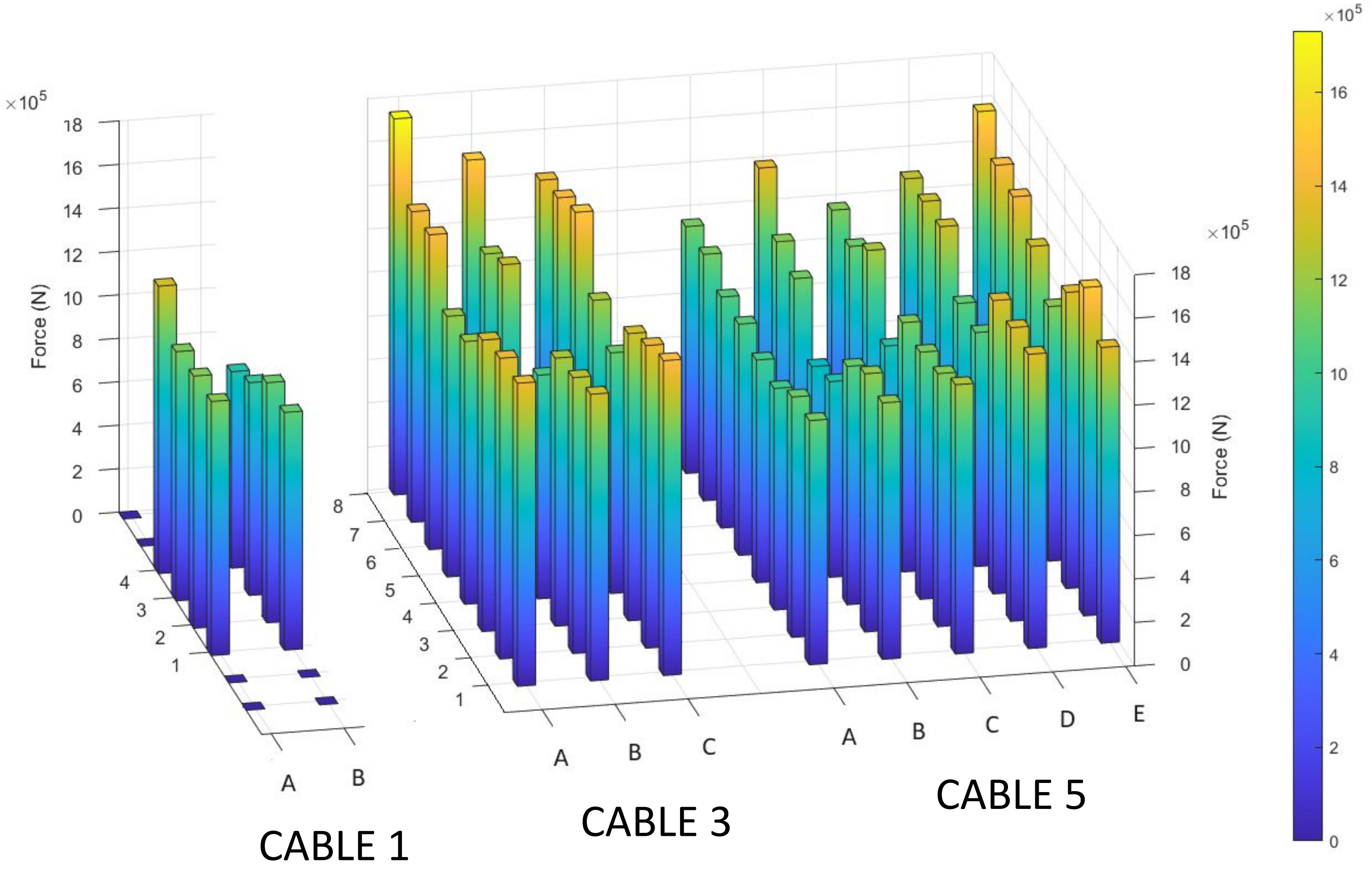
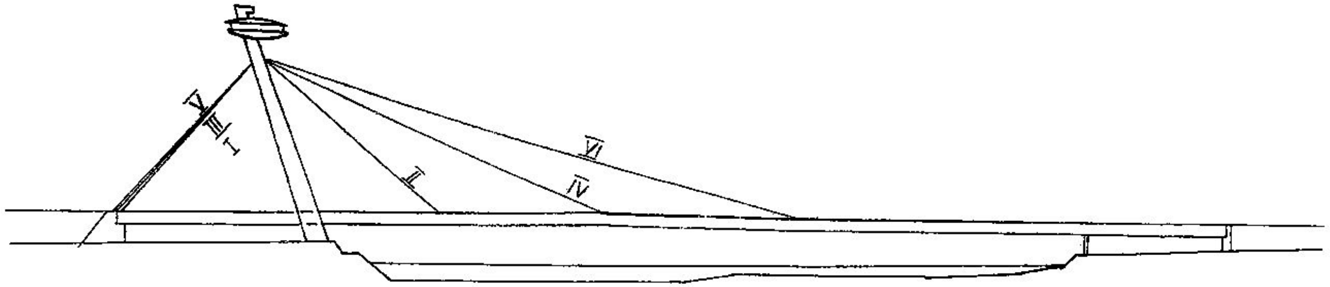
ROPE MEASUREMENTS - TENSION DISTRIBUTION



CABLE vs ROPE MEASUREMENTS



Cable	String Theory (MN)	Beam Theory (hinged ends) (MN)	Fang-Wang (MN)	Sum of ropes (MN) min/max
1	8.904	9.0050	8.1636	8.432 / 8.881
2	9.290	9.0827	8.1802	8.035 / 9.269
3 R	16.127	15.8365	14.650	14.701 / 15.452
3 L	16.477	16.3023	15.014	15.401 / 16.190
4 R	22.201	22.3574	20.658	18.389 / 20.684
4 L	22.579	22.3574	20.868	18.164 / 20.435
5 L	25.342	24.8416	21.562	23.010 / 24.076
6 R	21.632	21.6588	20.222	21.591 / 23.442
6 L	21.632	21.6588	20.222	21.616 / 23.471

Koščo, T., Margetin, M., Chmelko, V., Šulko, M., Bridge cable tension estimation using the vibration method, Structures, 2024

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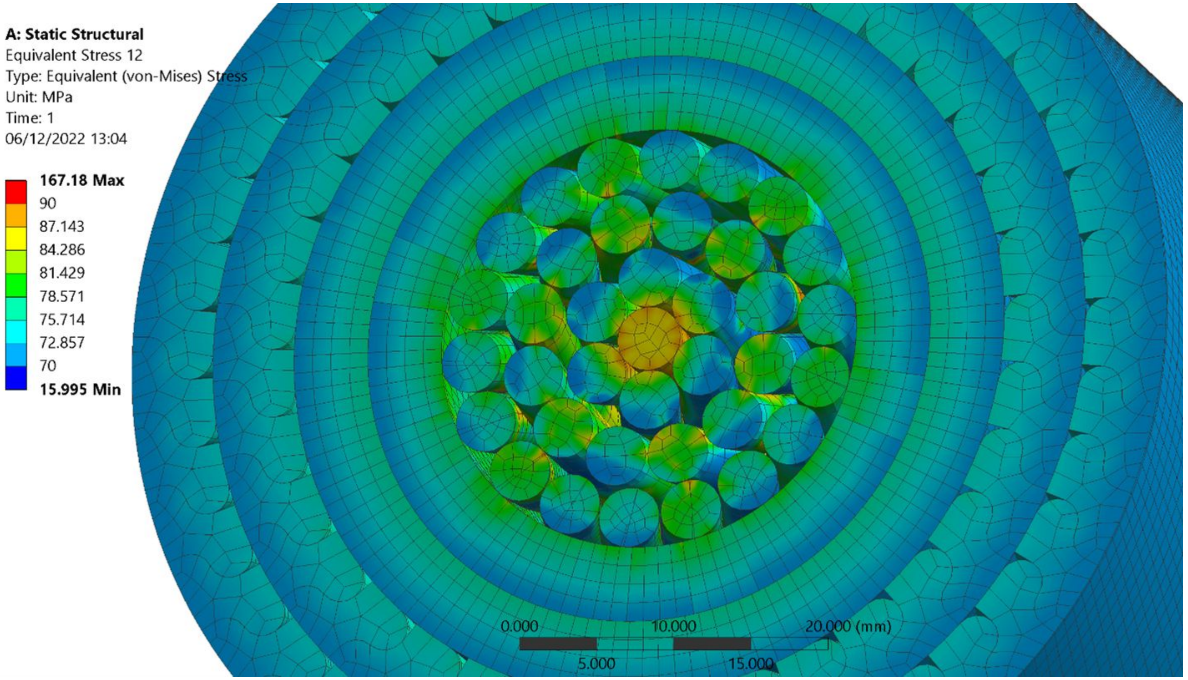
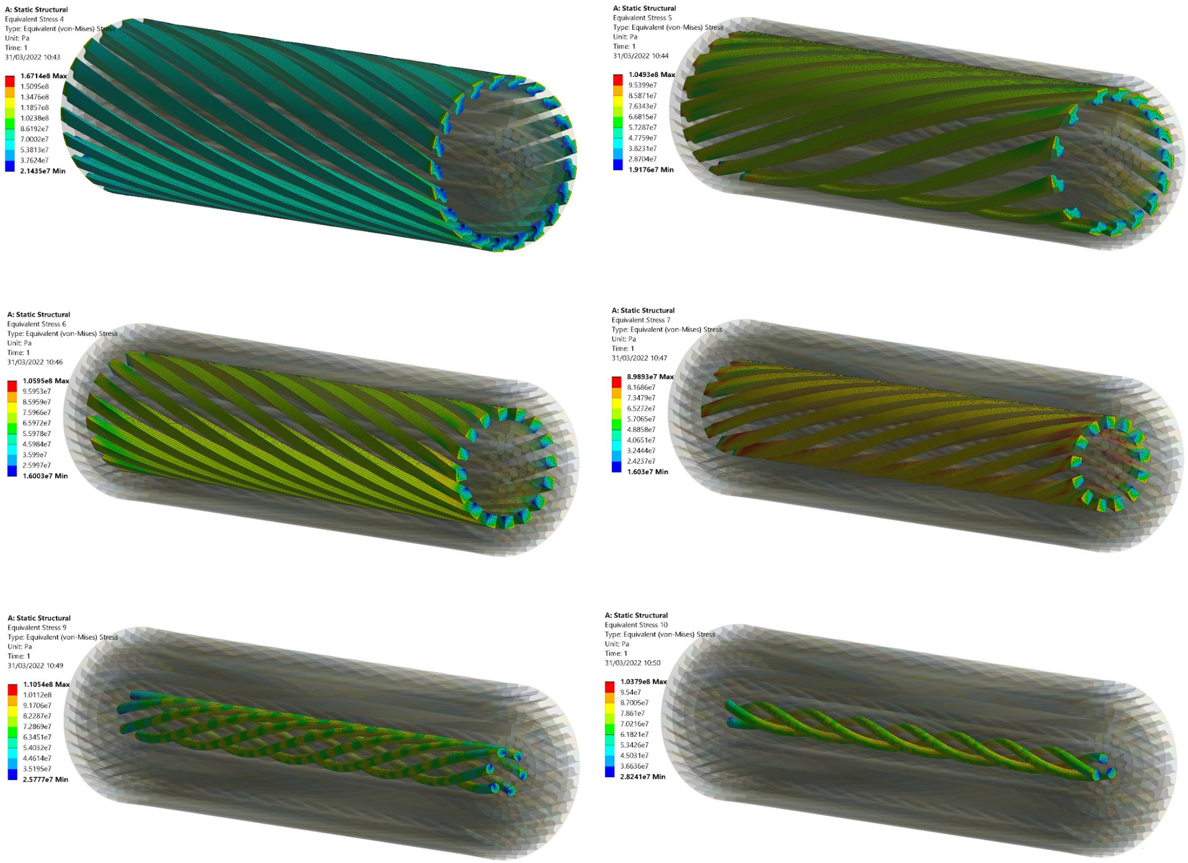
FEM SIMULATION - TENSION



ROPE CROSS-SECTION



STRESS DISTRIBUTION in the CROSS-SECTION

HIGHEST STRESS is **8% HIGHER** THAN the AVERAGE STRESS

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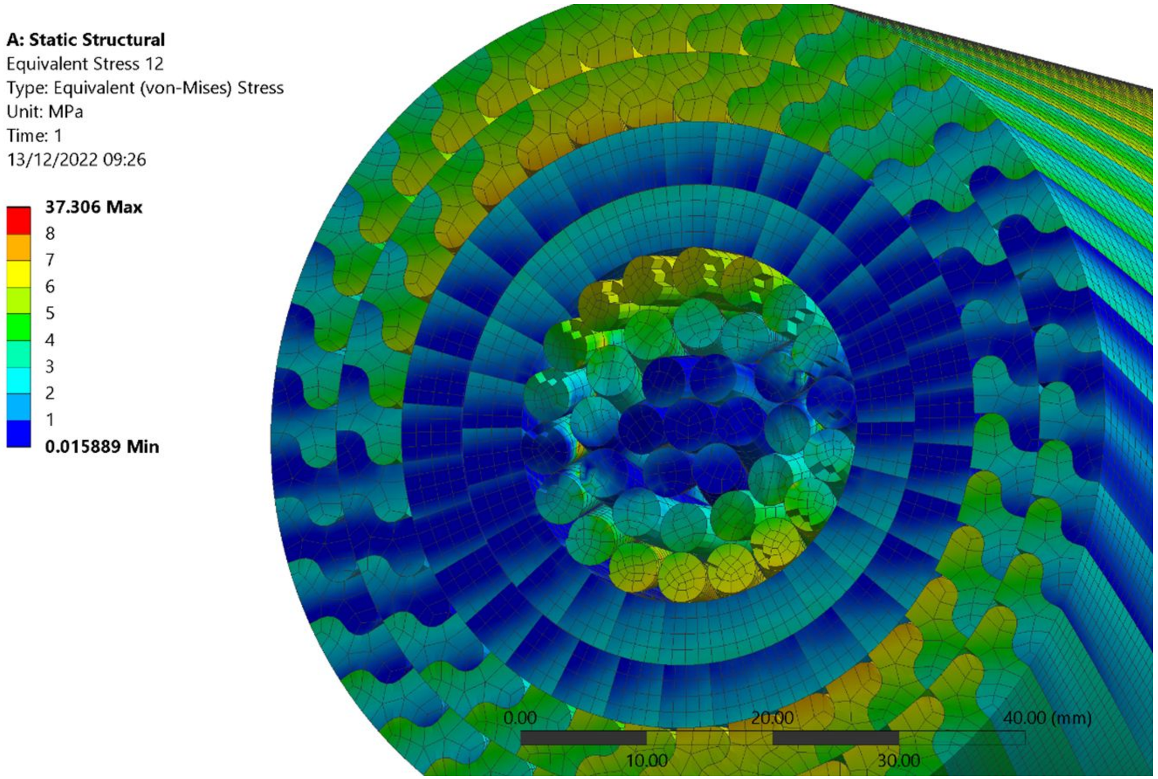
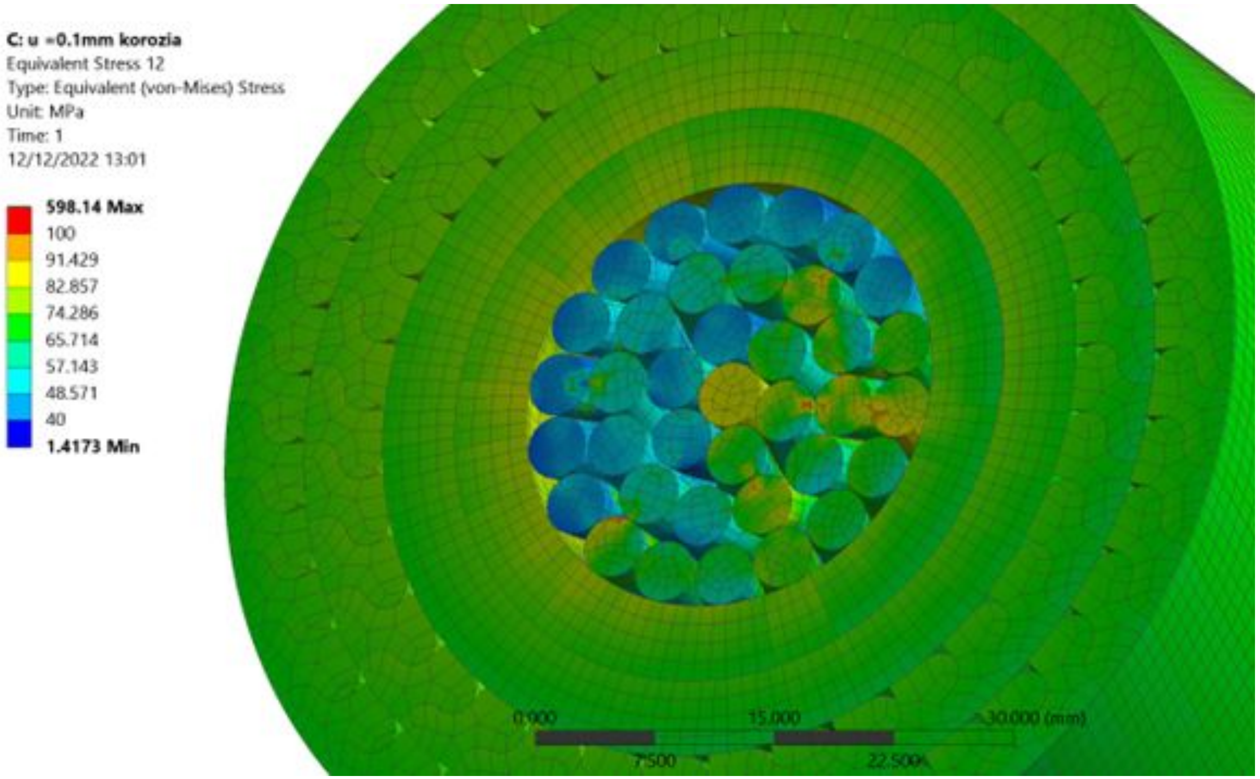
FEM SIMULATION – BENDING / CORROSION



BENDING IN HINGES (542.5 MPa)



CORROSION OF INTERNAL WIRES
(8% CROSS SECTION REDUCTION)
17% STRESS INCREASE

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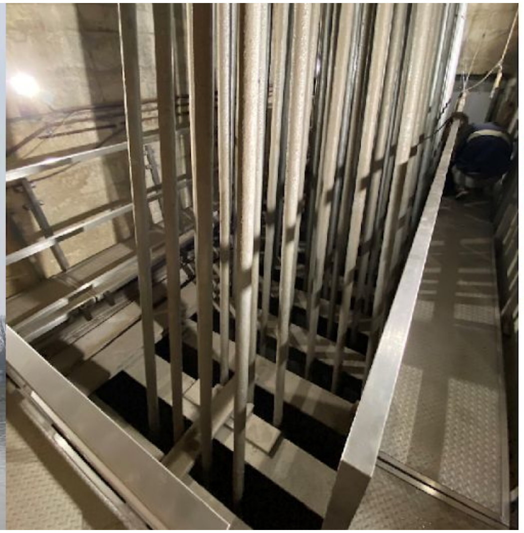
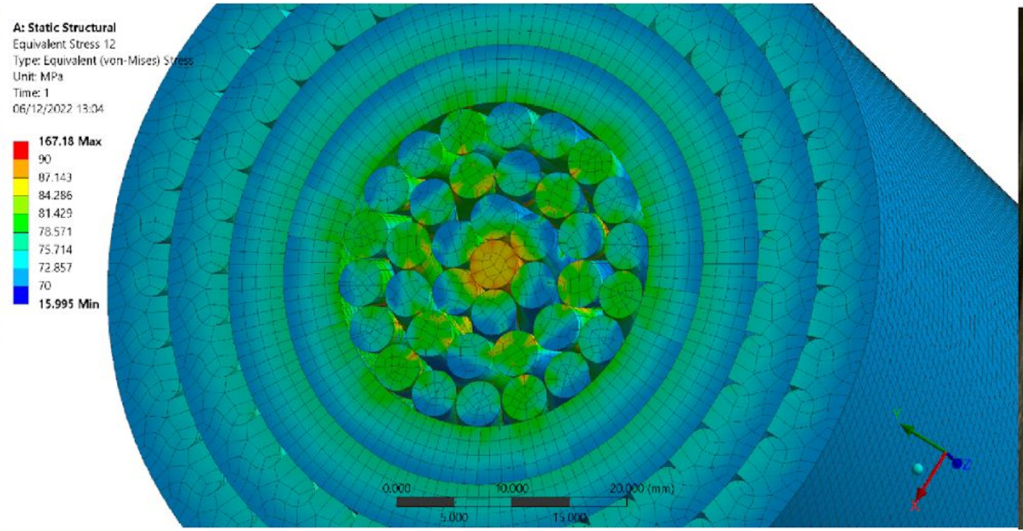
SUMMARY

- Material strength of around 1370 MPa was estimated.
- Cable and rope tension has been estimated using vibration method, AVERAGE STRESS 330 MPa (24% of strength).
- FEM analysis of tensile loading of the rope was performed, highest stress is 8% higher than the average stress
- FEM analysis of bending, 542.5 MPa (40% of strength)
- FEM analysis of corrosion





THANK YOU FOR YOUR ATTENTION

Tomáš Koščo, Matúš Margetin, Vladimír Chmelko

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STEEL BRIDGES
PRAGUE 2024