Design tool for steel lattice towers

ANGELHY Workshop / Webinar (08.12.2020)

CWE Center for Wind and Earthquake Engineering
RWTH AACHEN UNIVERSITY

2 Projects (past/present):

- The present results are taken from two IGF-projects
  - „OpDiWind“
  - „HyTower“

of „*FOSTA – Forschungsvereinigung Stahlanwendungen e.V.*“

- Main results in today‘s context:
  - Design tool for dimensioning and for optimization of lattice towers

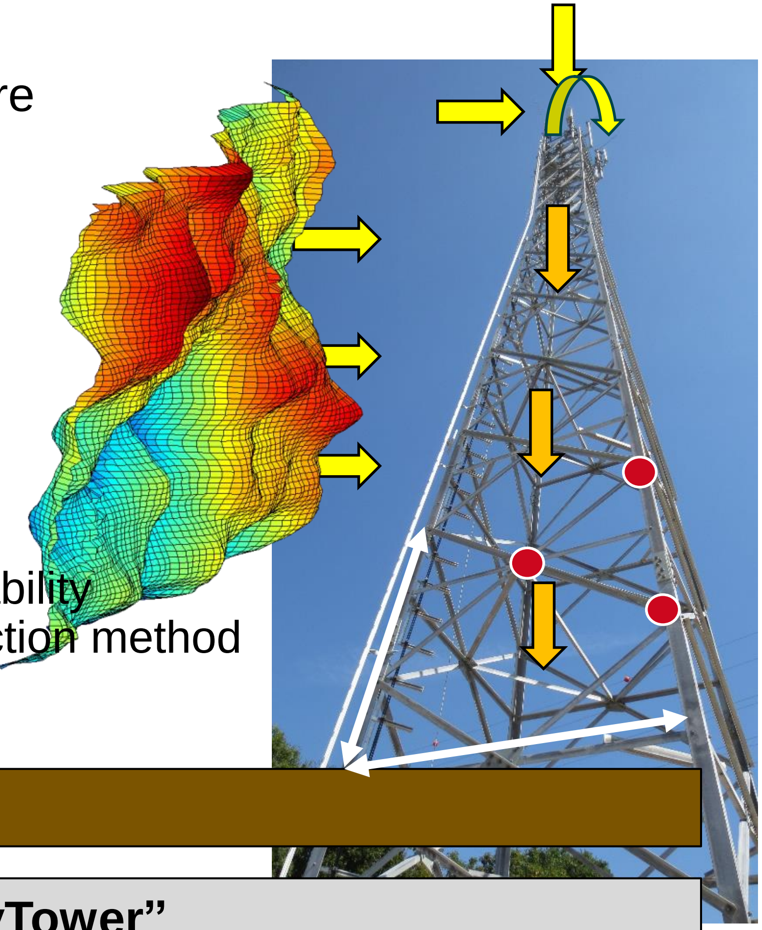
1. How is the truss structure designed ?

Target:

- Determination of an „optimal“ truss structure

Procedure Design of lattice towers

- Definition of the structure
  - Topologie, cross-sections,…
- Determination of realistic load effects
  - Wind loads,
- Proof of safety (dimensioning) and/or servicability
- Choice of a permantly cost-effective construction method



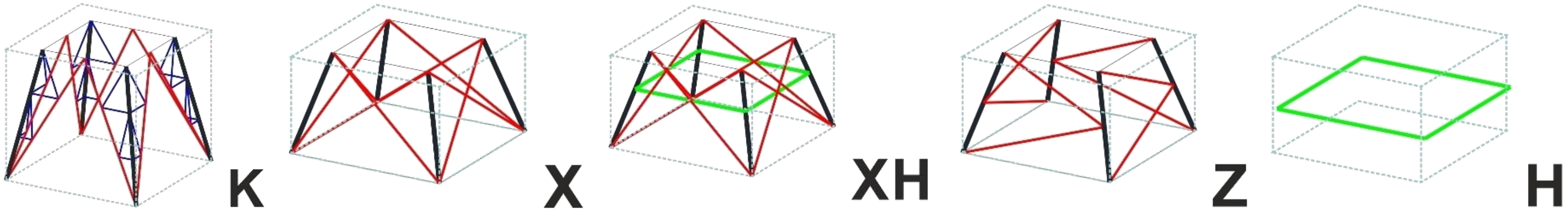
► **Optimization by hand hardly possible**

► **Softwaretool from “OpDiWin” and “HyTower”**

1. Definition of the structure

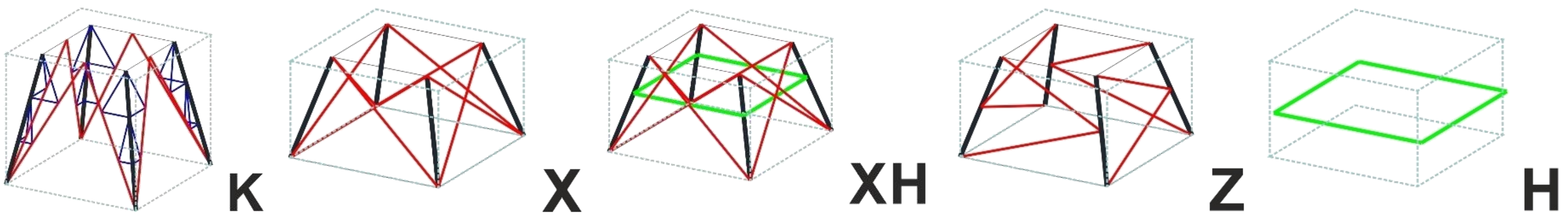
How can an optimization of lattice towers be done?

1. **Paramterized generation of the topology**

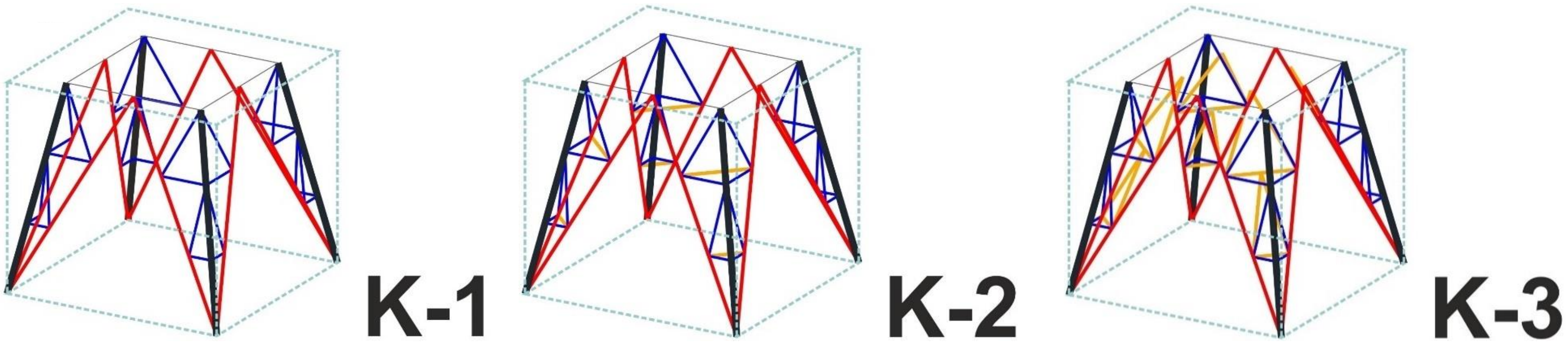


How can an optimization of lattice towers be done?

1. Paramterized generation of the topology

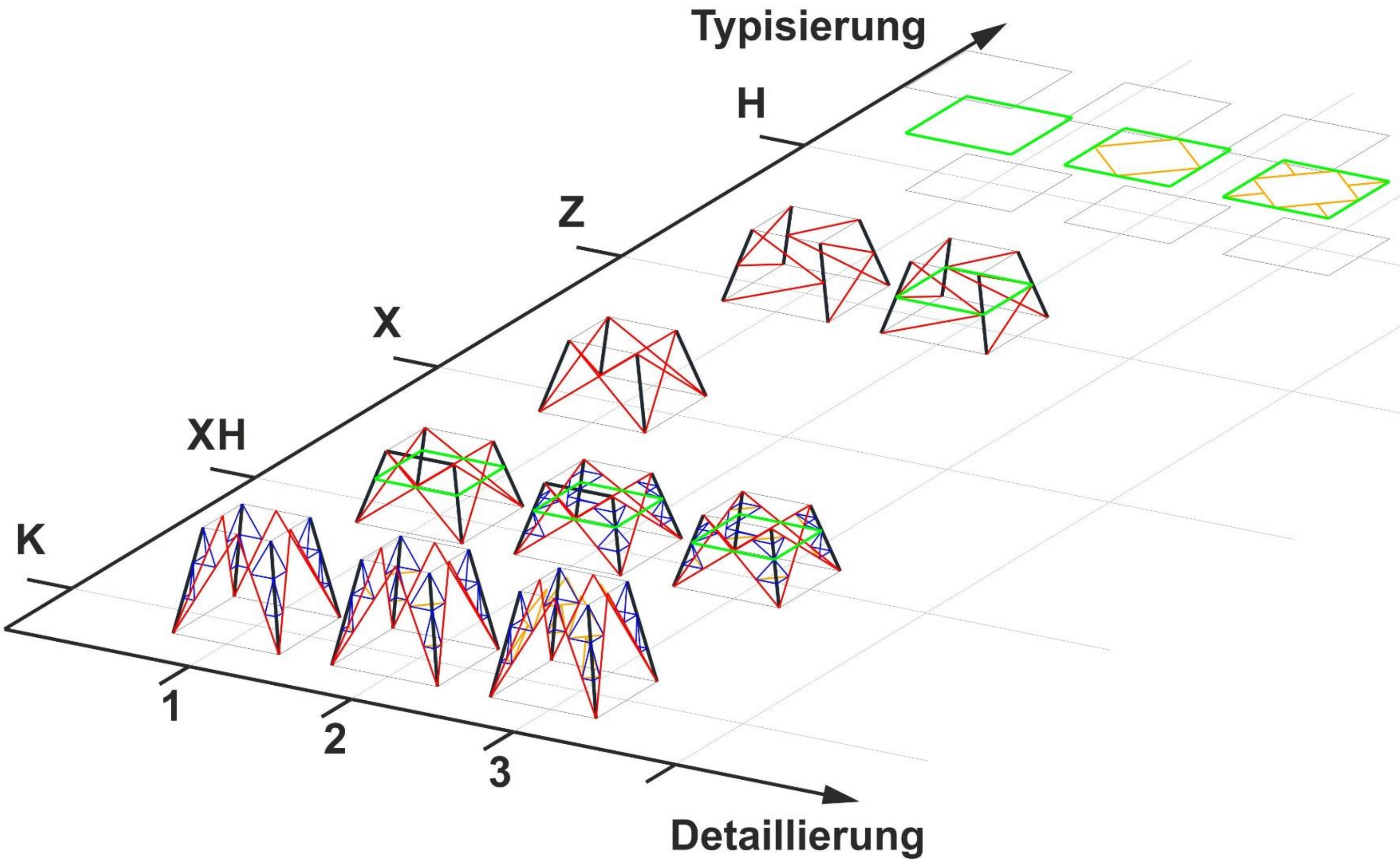


Details

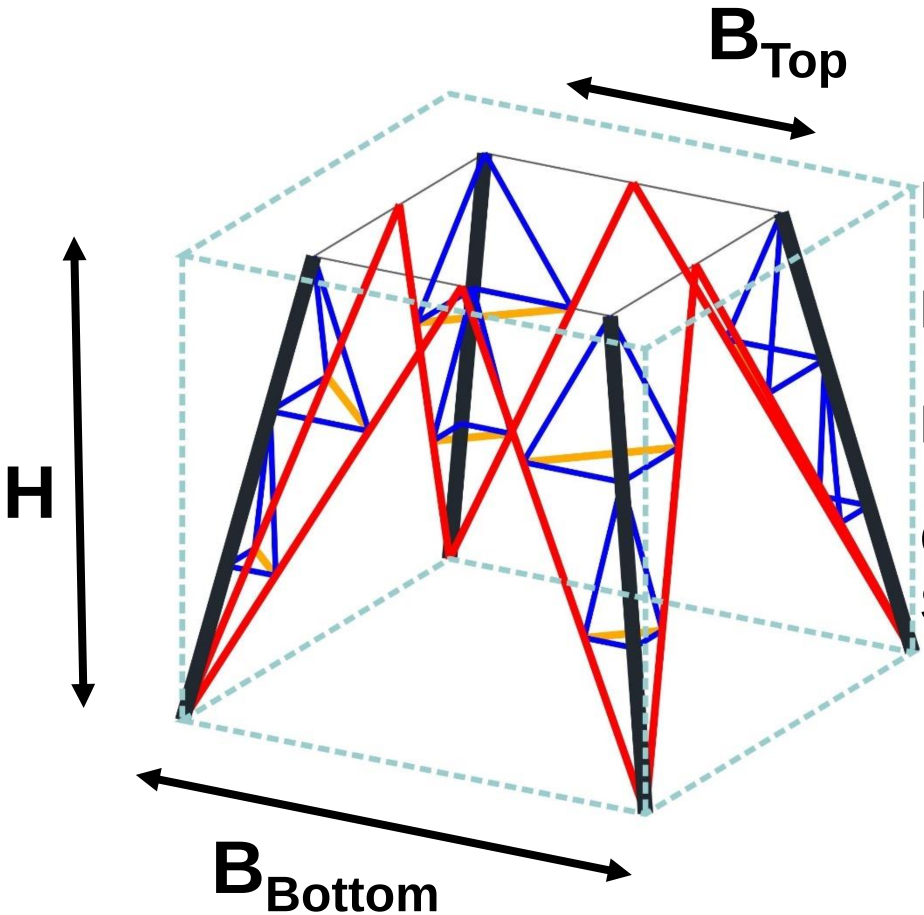


Parametirization of the topolgy

1.

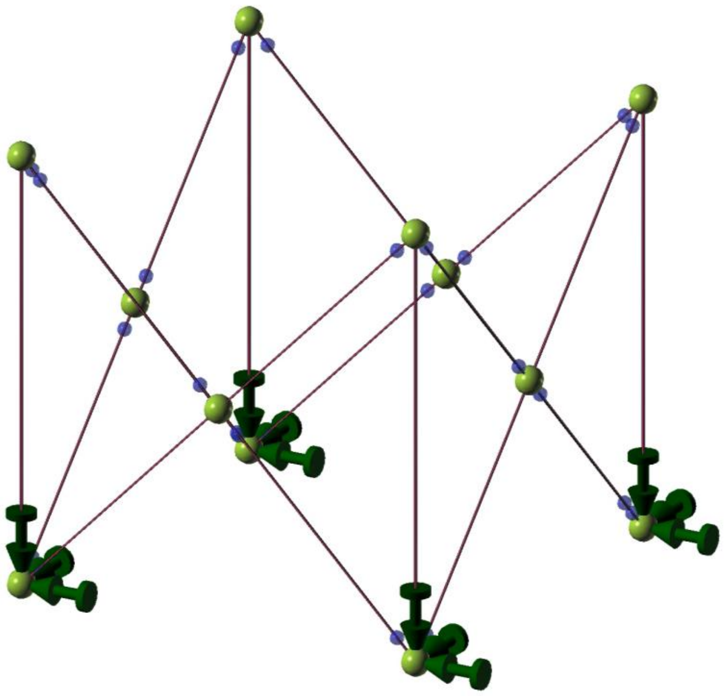


Parametirization of the topolgy

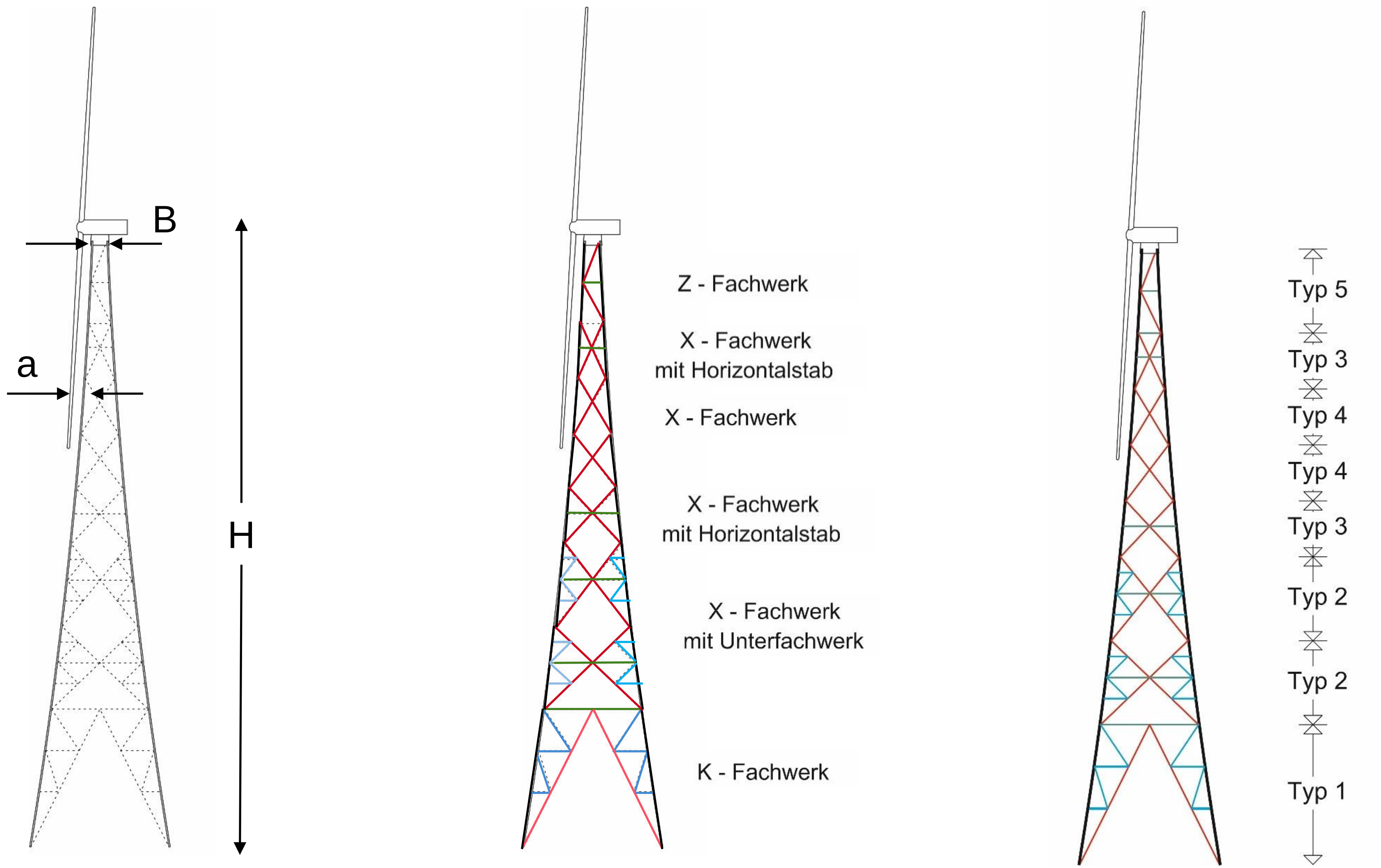


- Different Profile types
- Different Profile dimensions
- Different Section dimensions
- Connection
- Steel grade
- …

Parametirization of the topolgy



Parametirization of the topolgy



Realistic wind load

Wind tunnel investigations

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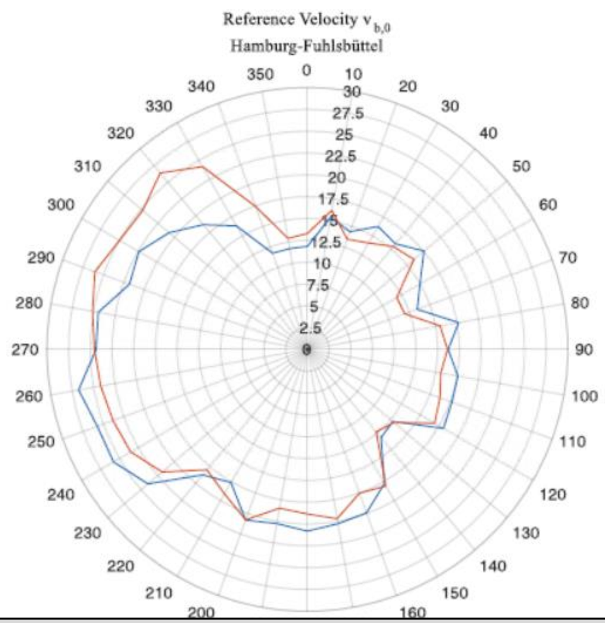
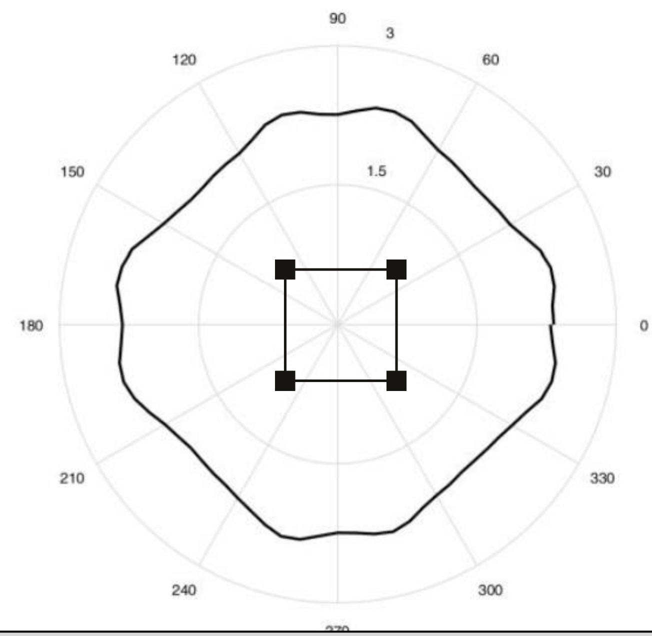
How can an optimization of lattice towers be done?

Direction dependent gust velocity pressure and force coefficients

Wind speed



Force coefficient



► **wind tunnel tests performed**

► **more informations: next presentation**

Dimensioning

accoding to standards

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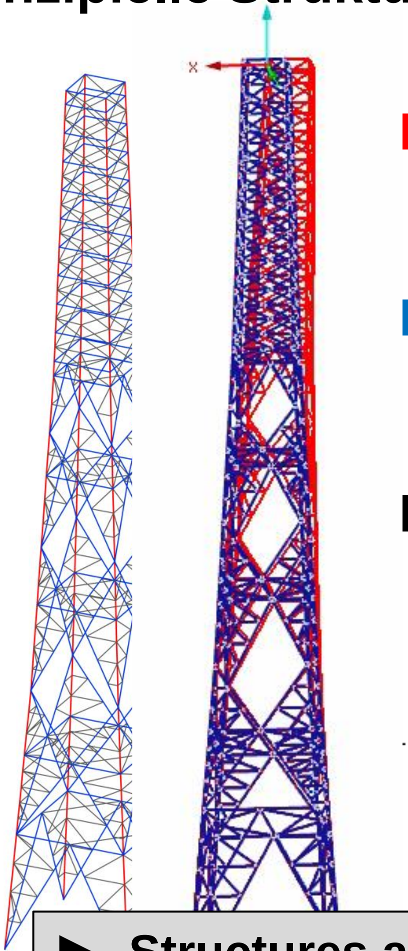
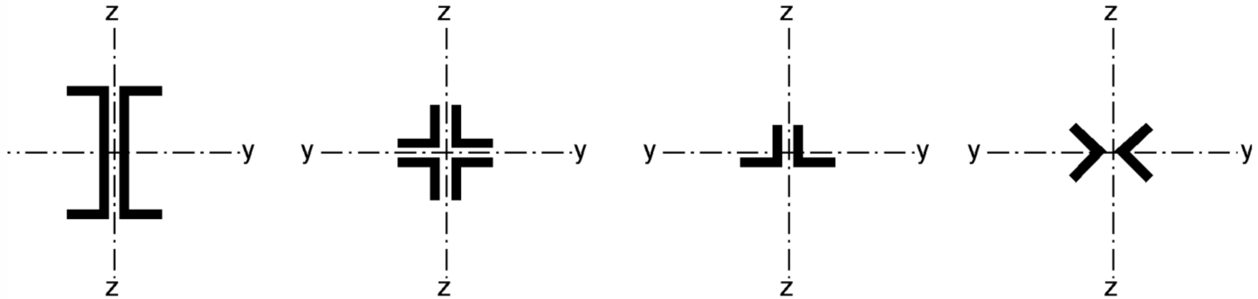
Prinzipielle Struktur von Gittertürmen



- **Leg members**: Steel components that are the main load-bearing components of the structure.

- **Primary bracing:** components necessary for the transfer of loads in addition to leg members, reduce buckling length of other elements

- **Secondary bracing:** Components to reduce the buckling length of other elements



► **Structures at risk of stability**

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08.12.2020

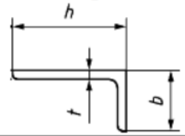
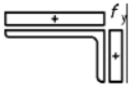
Dimensioning

Verification EC-3-1 in comparison with EC-3-3-1

Cross-section classification

EC3-1

Table 7.3 — Maximum width-to-thickness ratios for compression parts (sheet 3 of 3)

Refer also to "Outstand flanges" (see sheet 2 of 3)	Angles 	Does not apply to angles in continuous contact with other components
Stress distribution across section (compression positive)		
Class 3	$\frac{h}{t} \leq 15\,\varepsilon$ and $\frac{b+h}{2t} \leq 11{,}5\,\varepsilon$	
Circular and elliptical hollow sections		

EC3-3-1

8.2.1 Special provisions for angle sections and members

(1) <RCM> The class of the cross section should be determined according to table 7.3 of EN 1993-1-1 using maximum width to thickness ratio $(h-2t)/t$ instead of h/t.

Verification EC-3-1 in comparison with EC-3-3-1

Buckling **EC3-1**

$$N_{b,Rd} = \frac{\chi N_{Rk}}{\gamma_{M1}}$$

8.3.1.1 Buckling resistance

$$\bar{\lambda} = \sqrt{\frac{N_{Rk}}{N_{cr}}}$$

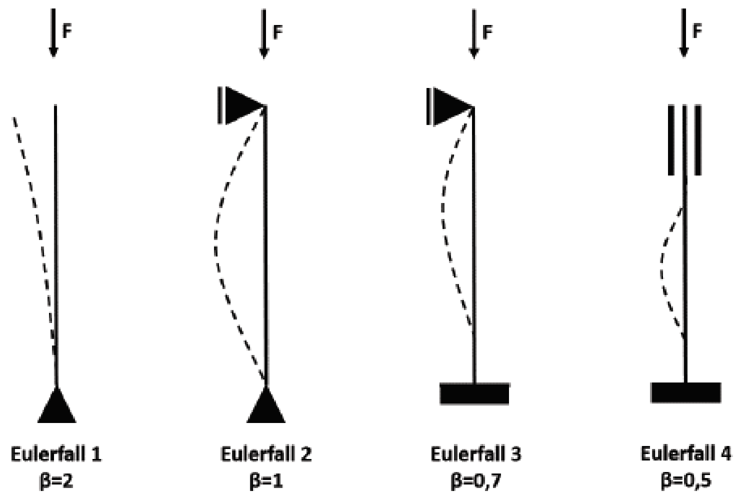
$$\bar{\lambda} = \frac{L_{cr}}{i}\frac{1}{\lambda_1}$$ for Class 1, 2 and 3 cross-sections

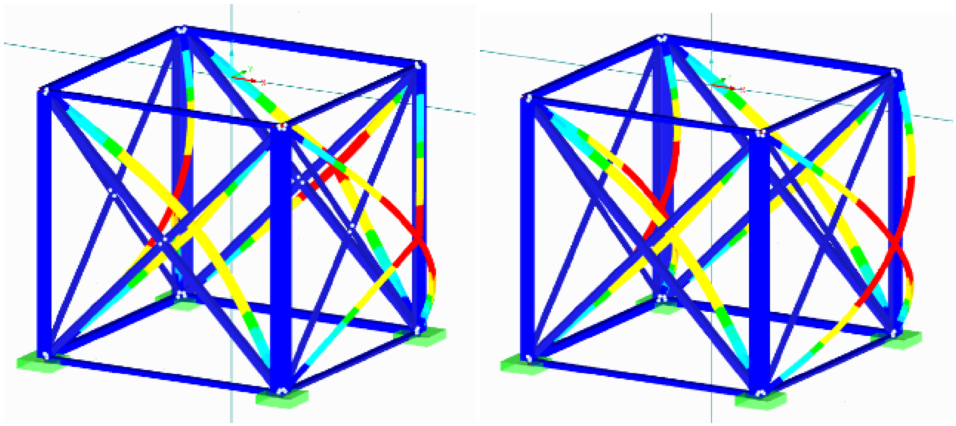
$$\bar{\lambda} = \frac{L_{cr}}{i}\frac{\sqrt{\frac{A_{eff}}{A}}}{\lambda_1}$$ for Class 4 cross-sections

Dimensioning

Verification EC-3-1 in comparison with EC-3-3-1

Buckling **EC3-3-1**





Verification EC-3-1 in comparison with EC-3-3-1

Buckling **EC3-3-1**

$$N_{b.Rd} = \frac{\chi A f_y}{\gamma_{M1}}$$ for class 1,2 and 3 cross section

$$N_{b.Rd} = \frac{\chi A_{eff} f_y}{\gamma_{M1}}$$ for class 4 cross sections

$$\bar{\lambda}_{\text{eff}} = k\bar{\lambda} \qquad \bar{\lambda} = \frac{\lambda}{\lambda_1};$$

(3) <RCM> For single angle members which are not connected rigidly at both ends (at least with two bolts, if bolted), the design buckling resistance defined in C.1(1) should be reduced by a reduction factor η.

NOTE <POS> The reduction factor η can be defined in the National Annex. The following values are recommended:

- $\eta = 0{,}8$ for single angle members connected by one bolt at each end;
- $\eta = 0{,}9$ for single angle members connected by one bolt at one end and continuous or rigidly connected at the other end.

Verification EC-3-1 in comparison with EC-3-3-1

Buckling **EC3-3-1**

C.2 Effective slenderness factor *k*

(1) <PER> In order to calculate the appropriate generalised slenderness of the member, the effective slenderness factor k may be determined according to the structural configurations.

a) *Leg members*

k should be obtained from table C.1.

a) *Diagonal bracing members*

k should be determined taking account of both the bracing pattern (see Figure C.1) and the connections of the bracing to the legs. In the absence of more accurate information values of k should be obtained from table C.2.

b) *Horizontal bracing members*

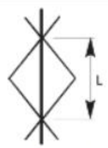
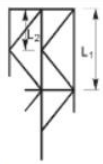
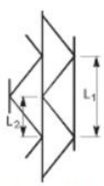
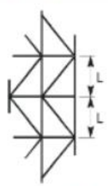
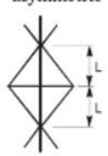
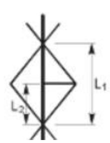
In the case of horizontal members of *K* bracing without plan bracing (see C.4.10) that have compression in one half of their length and tension in the other, the effective slenderness factor *k* for buckling transverse to the frame determined from table C.2, should be multiplied by the factor k_1 given in table C.3 depending on the ratio of the tension load, N_t, to the compression load N_c.

Dimensioning

Verification EC-3-1 in comparison with EC-3-3-1

Buckling **EC3-3-1**

Table C.1 — Effective slenderness factor k for leg members

Symmetrical bracing			Unsymmetrical bracing			
Section	∟ (3)	+ ● ○	Section	∟ (3)		+ ● ○
Axis	v - v	y - y	Axis	v - v	y - y	y - y
 Case (a) Primary bracing at both ends	$0,8+\frac{\bar{\lambda}}{10}$ but ≥ 0,9 and ≤ 1,0	1,0 (1)	 discontinuous top end with horizontals  Case (d) Primary bracing at both ends	$1,2\left(0,8+\frac{\bar{\lambda}}{10}\right)$ but ≥ 1,08 and ≤ 1,2 on L_2 (2)	$1,2\left(0,8+\frac{\bar{\lambda}}{10}\right)$ but ≥ 1,08 and ≤ 1,2 on L_1	1,0 on L_1 (1)
 asymmetric  symmetric Case (b)	$0,8+\frac{\bar{\lambda}}{10}$ but ≥ 0,9 and ≤ 1,0	1,0 (1)				

...

Table C.2 — Effective slenderness factor k for bracing members

(a) Single and double bolted angles

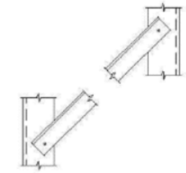
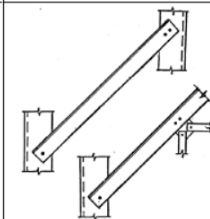
Type of restraint	Examples	Axis	k
Discontinuous both end (i.e. single bolted at both ends of member)		v-v	$0,7+\frac{0,35}{\bar{\lambda}_v}$
		y-y	$0,7+\frac{0,58}{\bar{\lambda}_y}$
		z-z	$0,7+\frac{0,58}{\bar{\lambda}_z}$
Continuous one end (i.e. single bolted at one end and either double bolted or continuous at other end of member)		v-v	$0,7+\frac{0,35}{\bar{\lambda}_v}$
		y-y	$0,7+\frac{0,40}{\bar{\lambda}_y}$
		z-z	$0,7+\frac{0,40}{\bar{\lambda}_z}$
			$0,7+\frac{0,35}{...}$

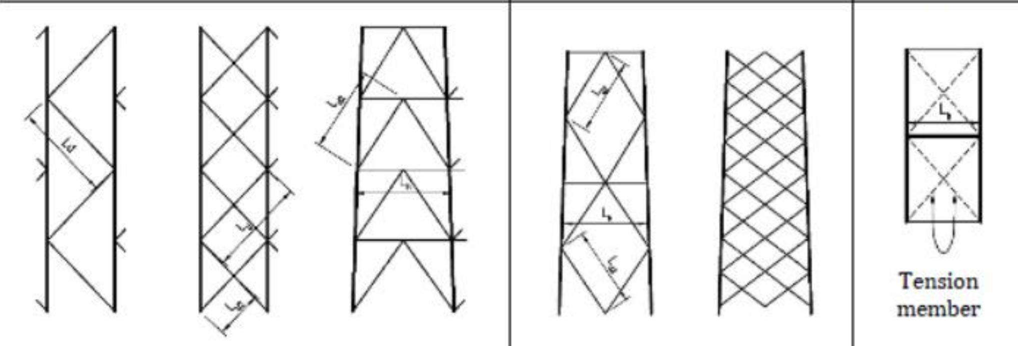
Table C.3 — Modification factor (k_1) for horizontal of K brace without plan bracing

Ratio $\frac{N_t}{N_c}$	Modification factor, k_1
0,0	0,73
0,2	0,67
0,4	0,62
0,6	0,57
0,8	0,53
1,0	0,50
A value of 1,0 applies when the ratio $\frac{N_t}{N_c}$ is negative (i.e. when both members are in compression).	

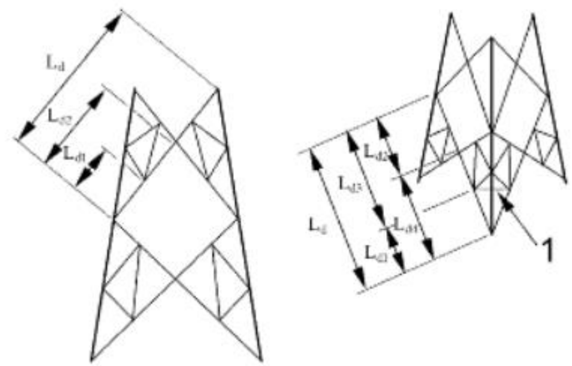
Dimensioning

Verification EC-3-1 in comparison with EC-3-3-1

Buckling length **EC3-3-1**



Typical primary spacing patterns					
parallel or tapering			usually tapering		usually parallel
I Single lattice $L_{d1} = L_d$	II Cross bracing $L_{d1} = L_{d2}$	III K-bracing $L_{d1} = L_{d2}$	IV Discontinuous bracing with continuous horizontal intersections $L_{d1} = L_{d2}$	V Multiple lattice bracing	VI Tension bracing
Typical secondary bracing patterns (see also Figure C.2)				NOTE The tension members in pattern VI are designed to carry the total shear in tension, e.g.	



(a) [IIB]

(b) [IIC]
Cross bracing with diagonal co
members

Parametrisierte Erzeugung der Topologie

Verification EC-3-1 in comparison with EC-3-3-1

Buckling **EC3-3-1**

▶ **Verifications implemented in the softwaretool**