Offshore Summer School

Offshore Environment and Loads
Mechanical Loads

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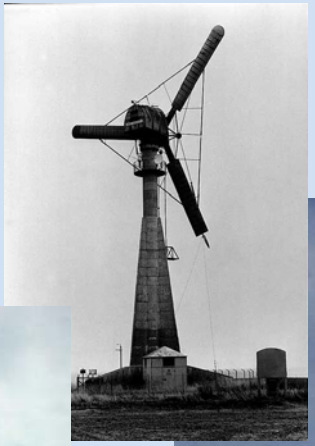
fk-wind
University of Applied Sciences Bremerhaven

Historical Development

wood

wood/steel



steel

1982
CRP

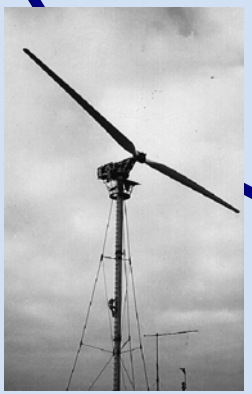
1984

1984
3MW

1991
3MW

1995
1,5MW Series

2006
6MW



1957
GRP

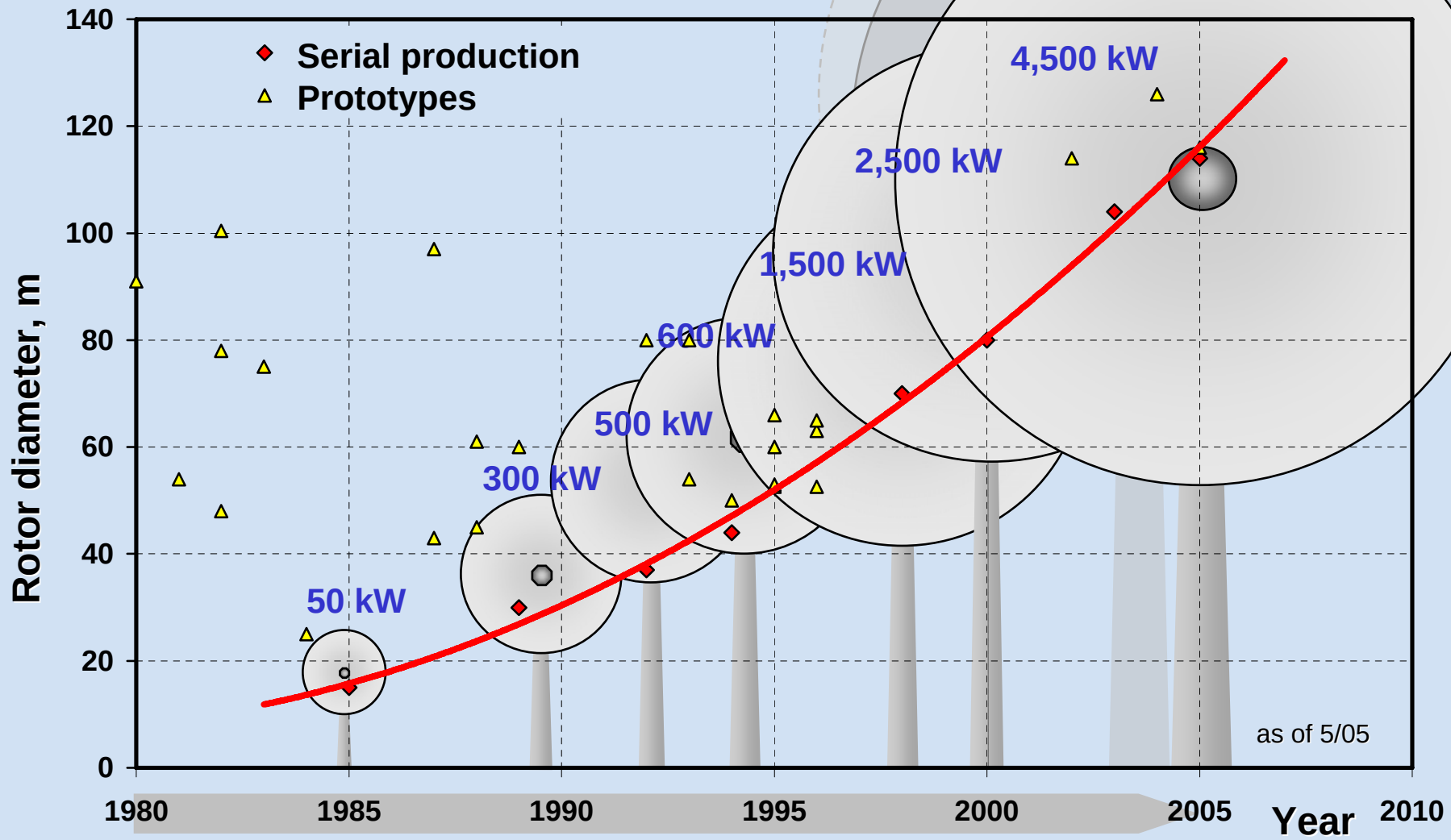
The first German wind farm 1956

Ref: DFVLR

The first off shore turbine ?

Ref: DFVLR

Development of the size



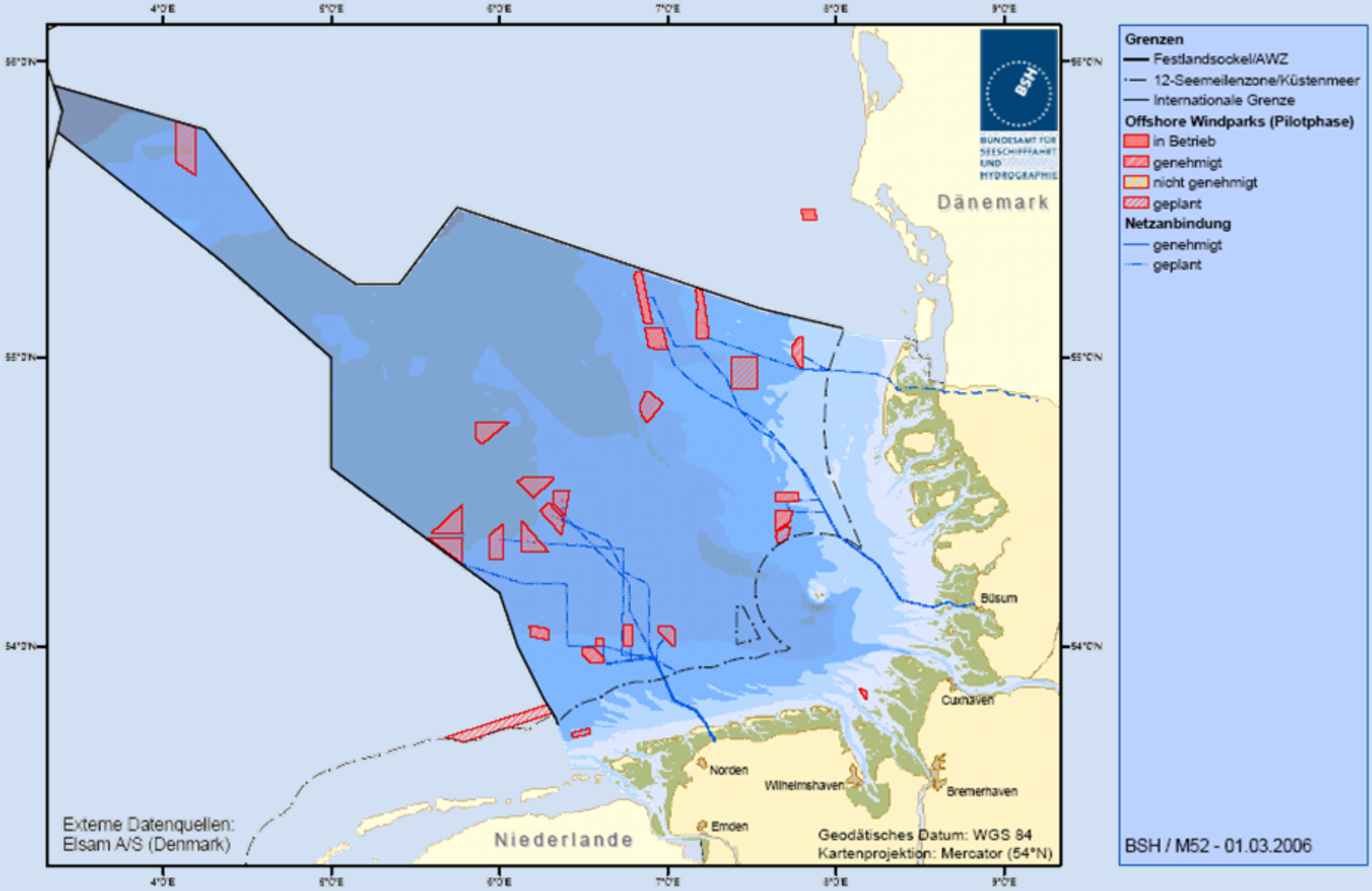
Wind energy technique uses multi disciplinary engineering

- Meteorology
- Aerospace engineering
- Electrical engineering
- Mechanical engineering
- Control engineering
- Economics
- Energy techniques
- Environmental engineering
- Civil engineering
- Measurement techniques
- Acceptance

Wind energy technique uses multi disciplinary engineering

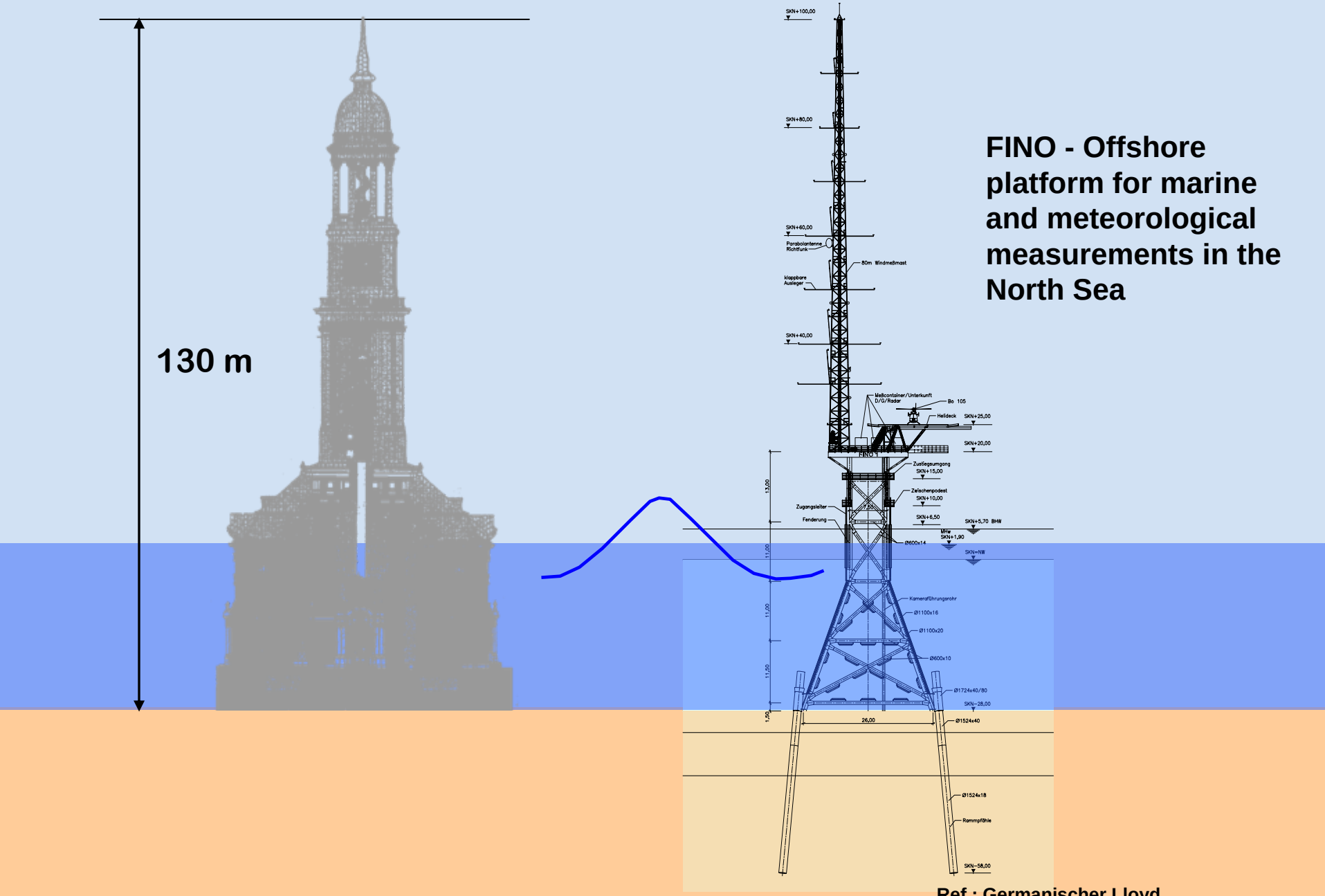
in combination with offshore-techniques

Planned North Sea wind farms

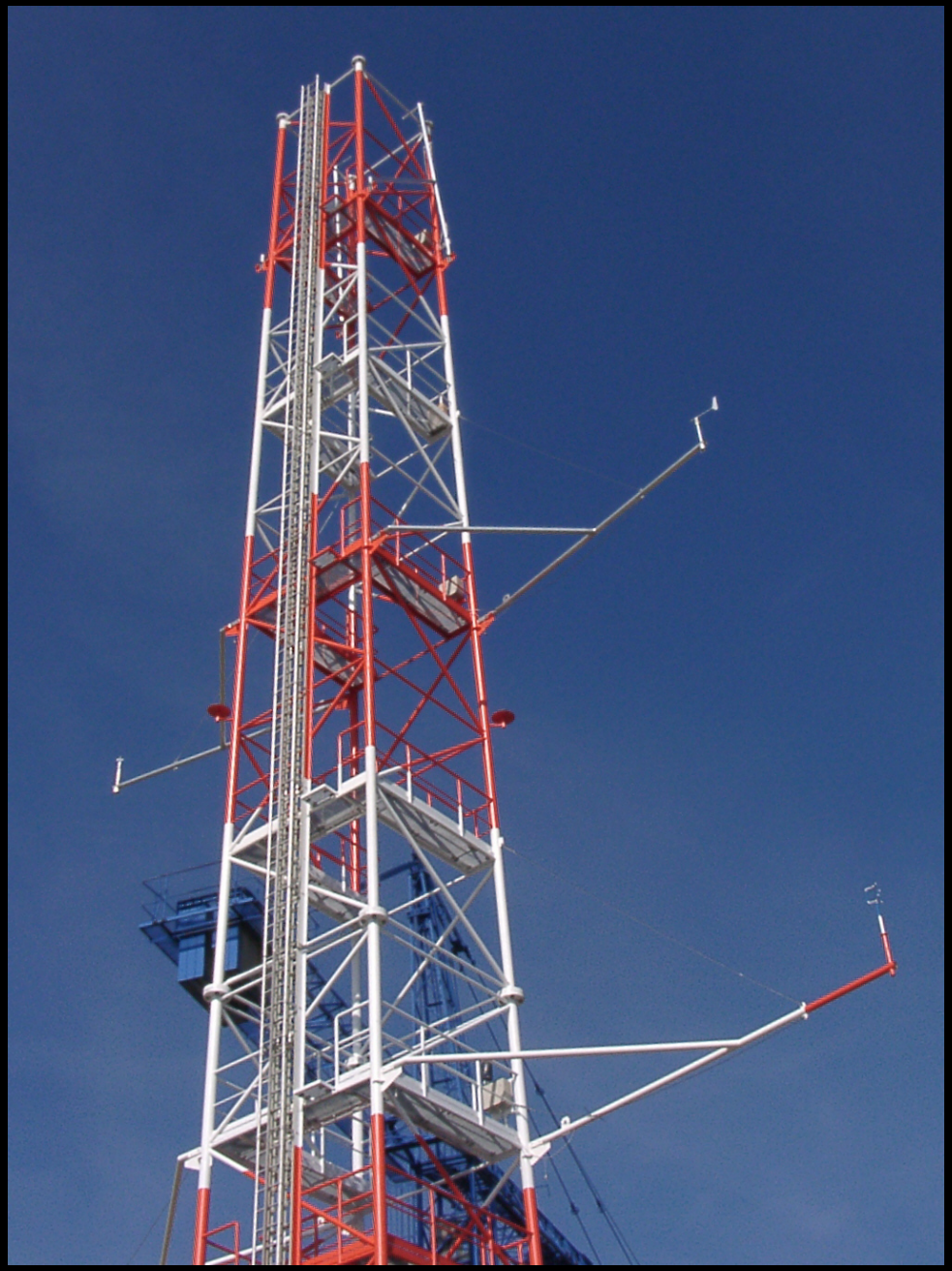


http://www.bsh.de/de/Meeresnutzung/Wirtschaft/CONTIS-Informationssystem/index.jsp

FINO - Offshore platform for marine and meteorological measurements in the North Sea

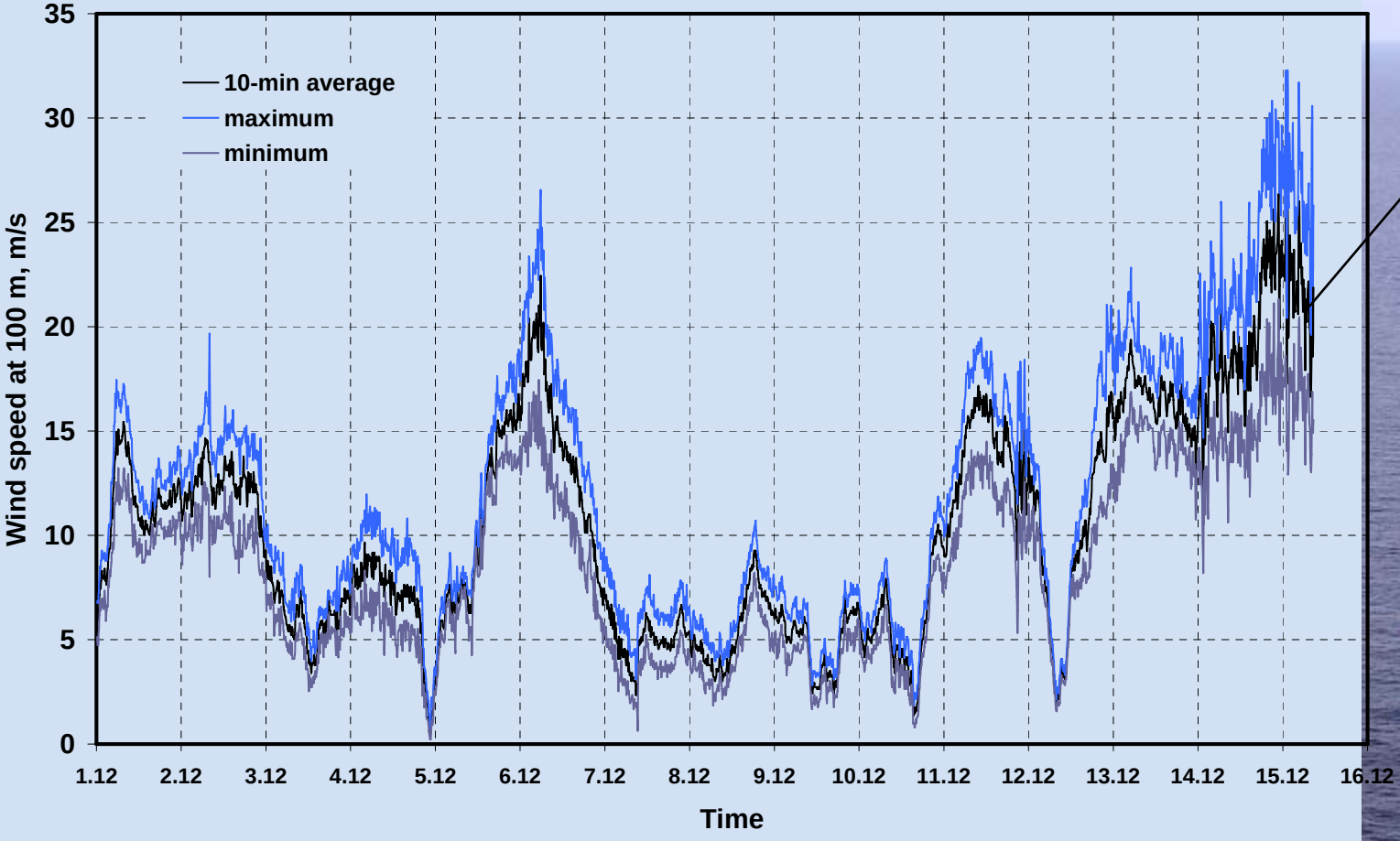


Ref.: Germanischer Lloyd



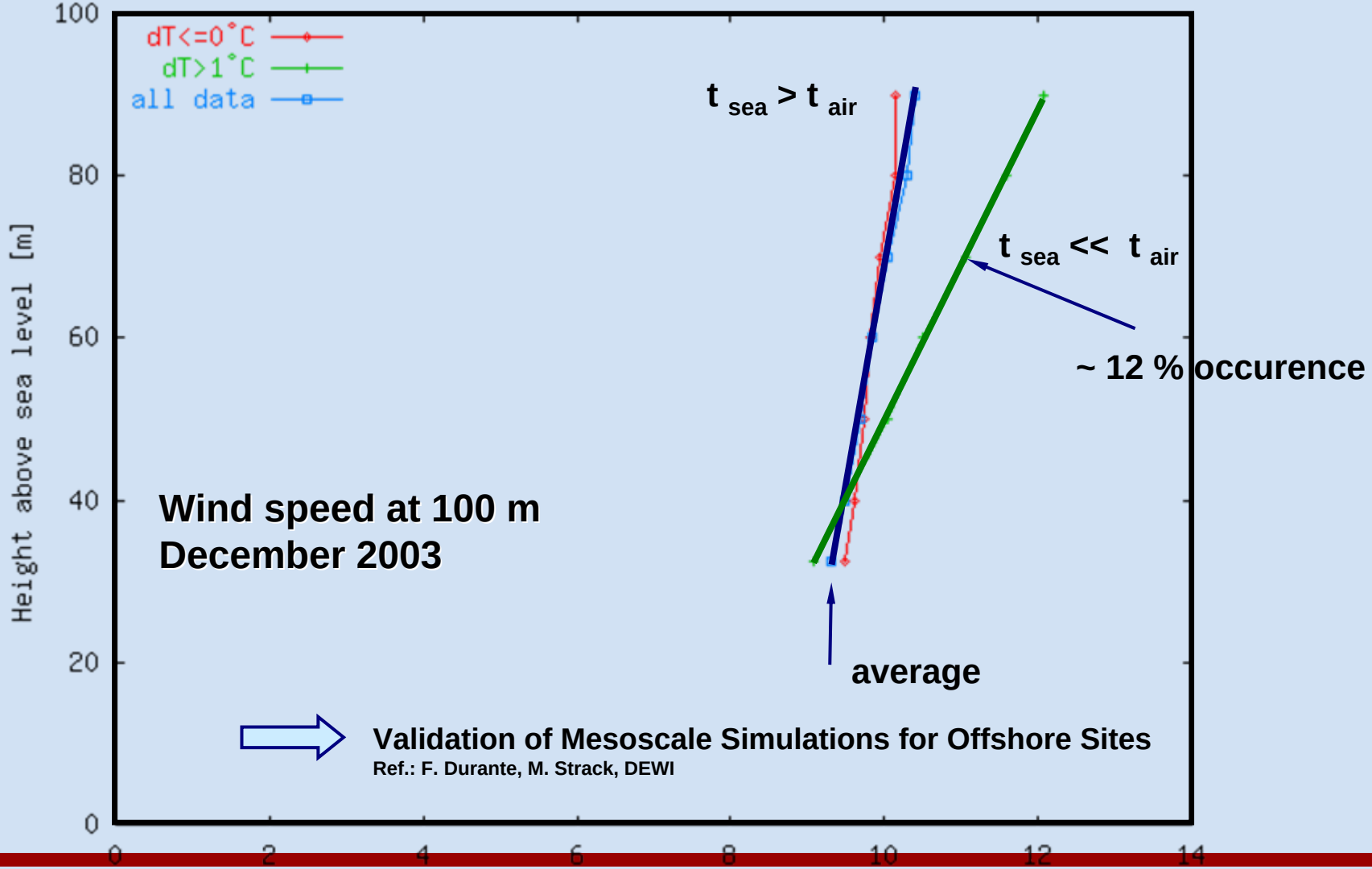
Ref: DEWI

FINO Platform

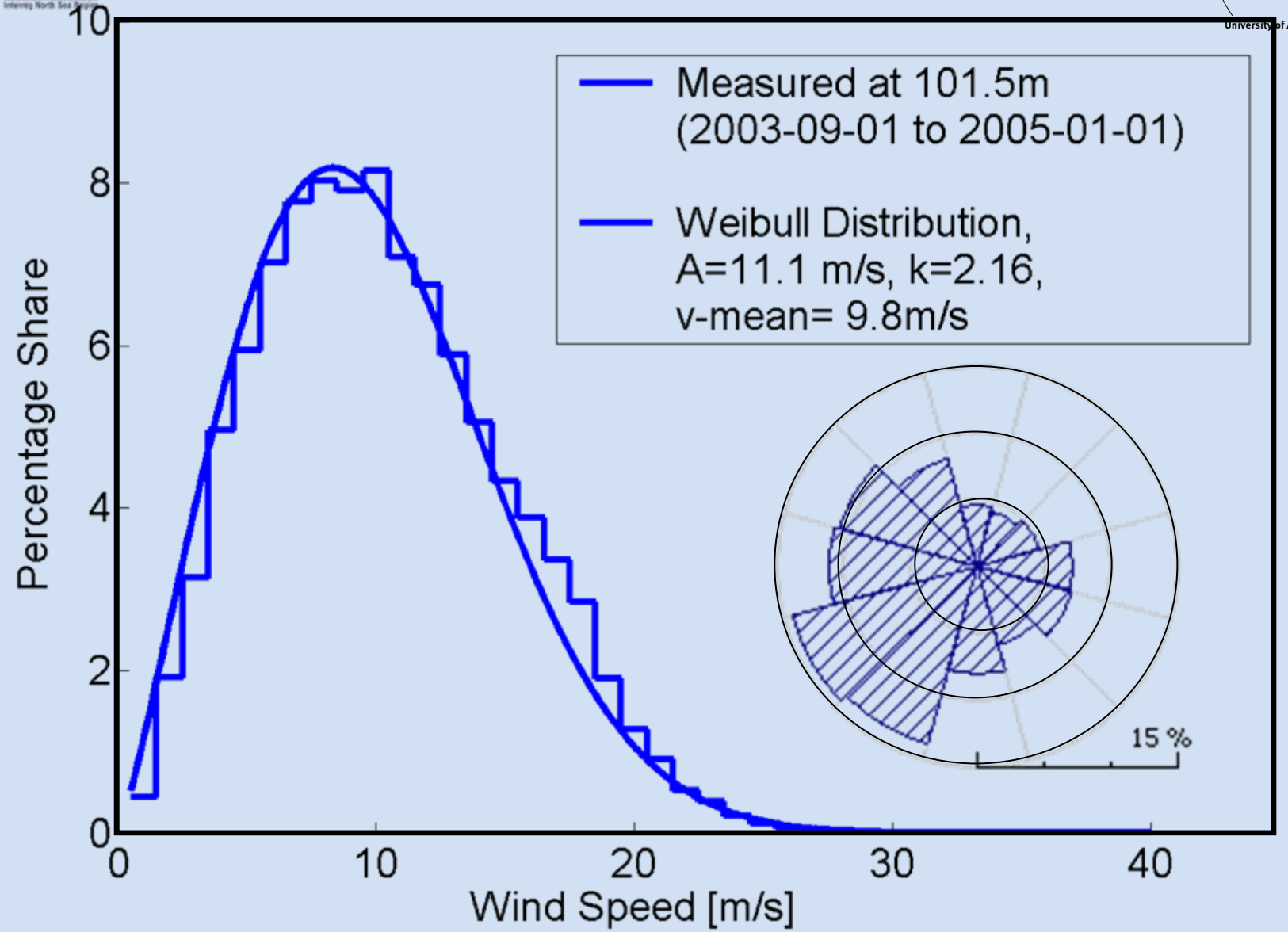


Wind speed in 100 m, measured in December 2003

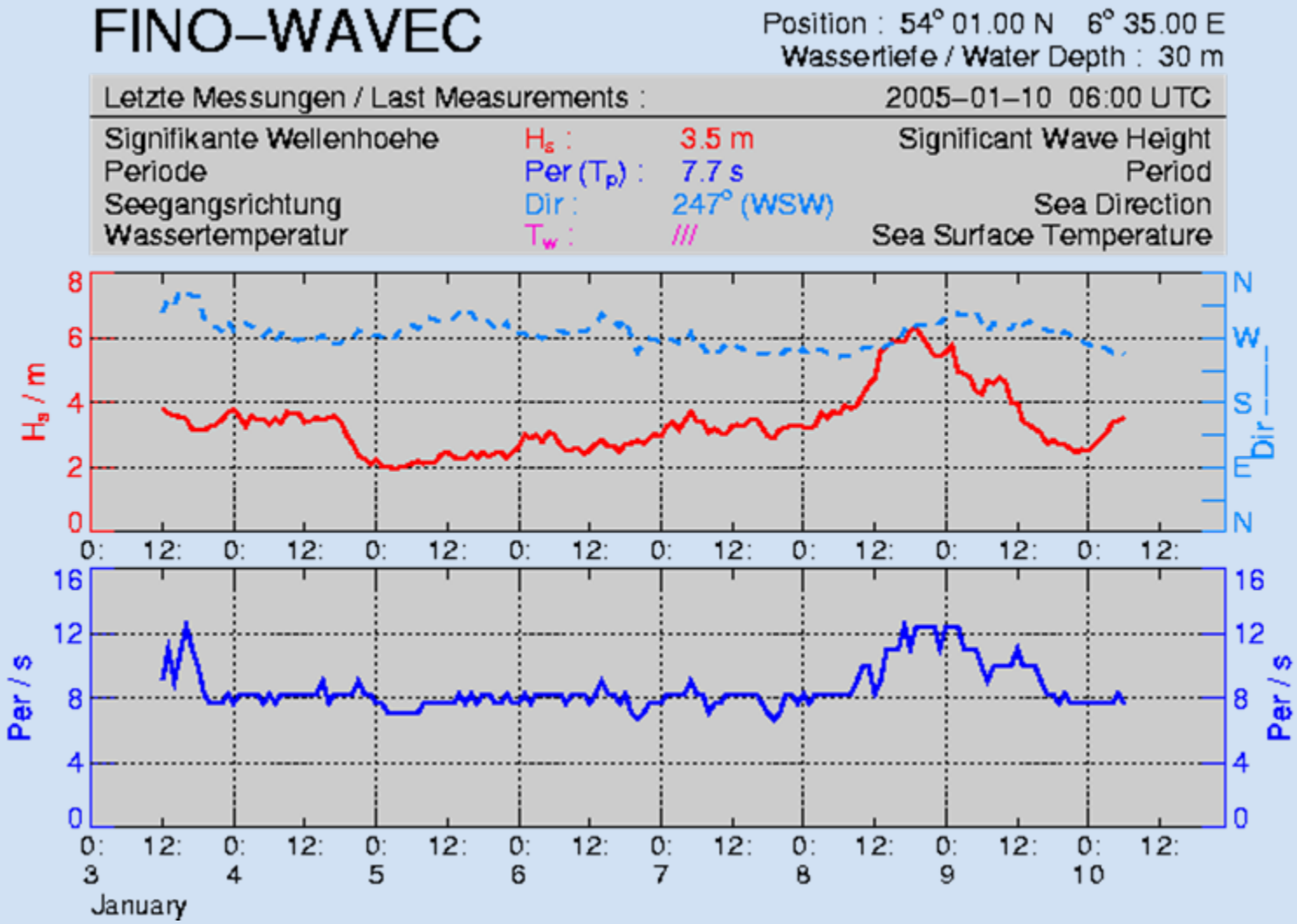
The difference between water and air temperature is the main driving force for the wind profile



Validation of Mesoscale Simulations for Offshore Sites
Ref.: F. Durante, M. Strack, DEWI


Measured at 101.5m
(2003-09-01 to 2005-01-01)
Weibull Distribution,
A=11.1 m/s, k=2.16,
v-mean= 9.8m/s
15 %
Percentage Share
Wind Speed [m/s]
0
2
4
6
8
10
0
10
20
30
40

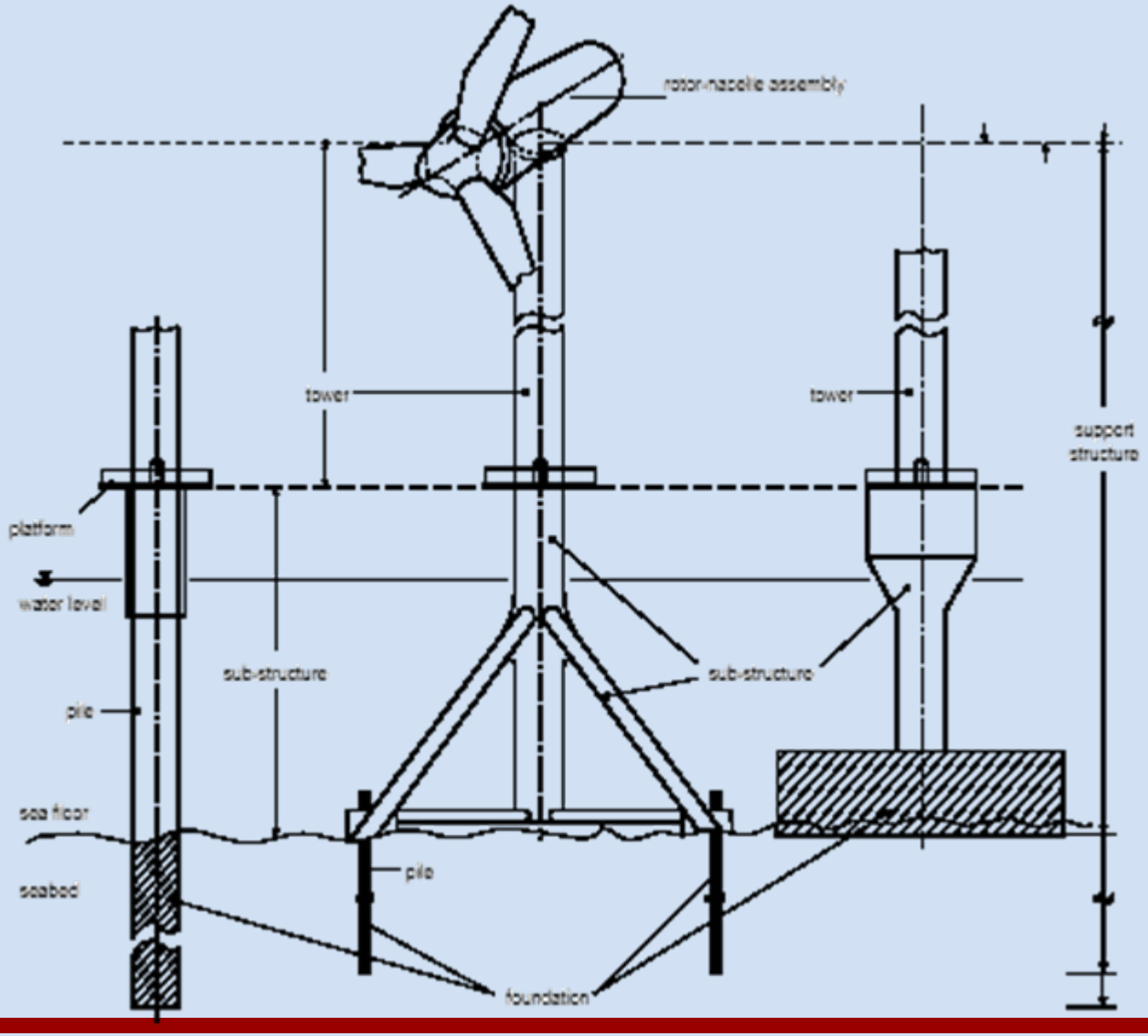
Wave height measuremets



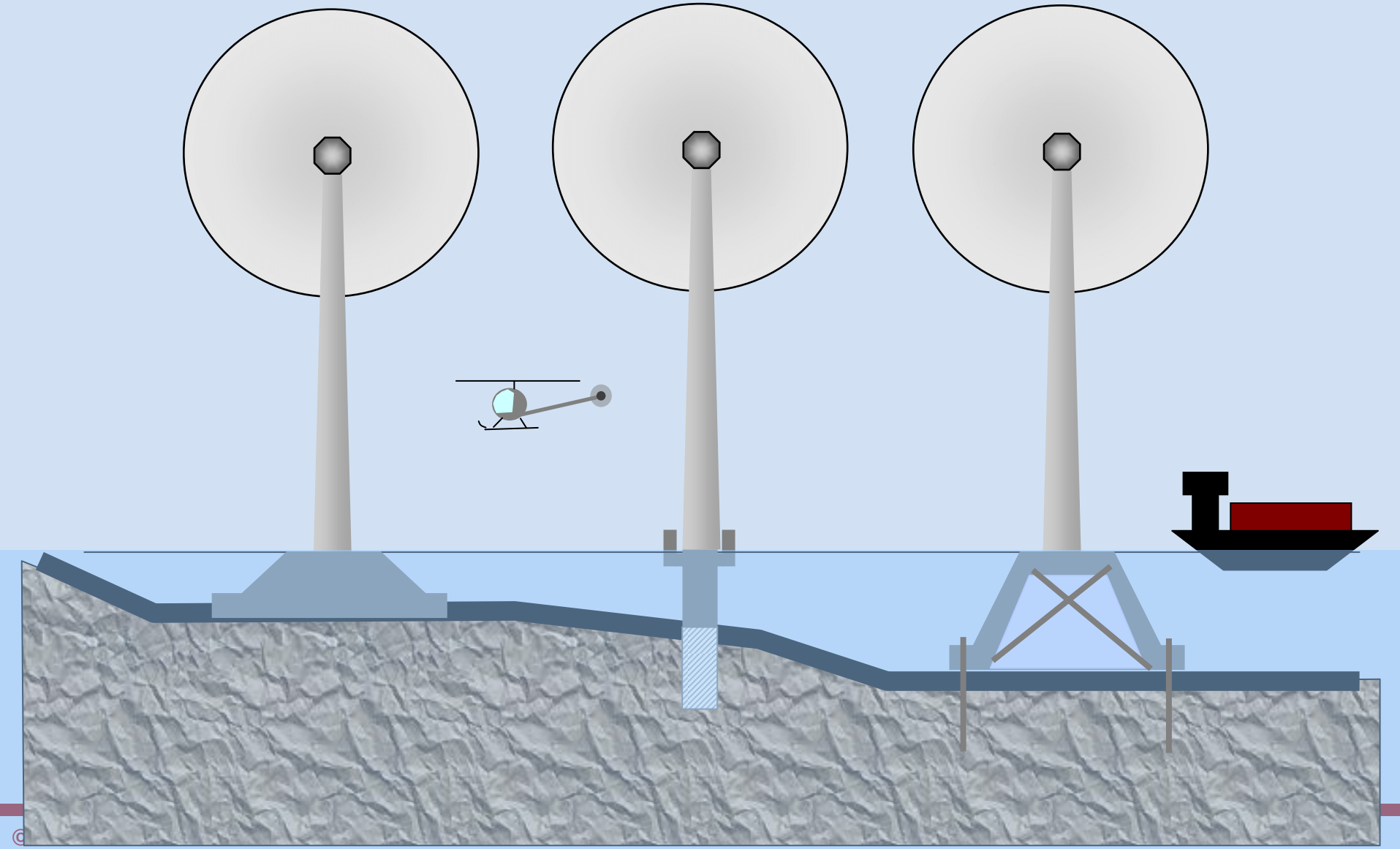
Use of offshore techniques

External Conditions	➔	Requirements
● Difficult access	➔	High technical availibility over the entired life time
● Corrosive environment	➔	Adequate corrosion protection
● Increased mechanical loads	➔	Optimised wind turbine techique
● Special foundations	➔	Optimised foundations concerning serial production, logistics and lifetime
● Difficult erection	➔	Optimised logistic and erection to use the short season for offshore design
● Long power lines	➔	Effective transmission of high power via sea cables
● Grid connection	➔	Availability of grid connection points with sufficient capacity

Main parts of an offshore wind turbine



Foundations for offshore wind turbines



©

Design Requirements for Offshore Wind Turbines

For an offshore wind turbine the definition of wind turbine classes in terms of wind speed and turbulence parameters remains appropriate as the basis of design of the rotor - nacelle assembly.

A further wind turbine class S is defined for use when special wind or other external conditions or a special safety class are required by the designer and/or the customer.

The foundation, sub-structure and tower of the offshore support structure shall require class S design.

Design Requirements for Offshore Wind Turbines IEC 61400 - 3

For the rotor - nacelle assembly, the wind conditions assumed for design may be site specific or as defined in IEC 61400-1

Wind Turbine Classes

Table 1 - Basic parameters for wind turbine classes[1]

Wind Turbine Class		I	II	III	S
V_{ref}	(m/s)	50	42,5	37.5	Values Specified by the Designer
A	I_{ref} (-)	0,16			
B	I_{ref} (-)	0,14			
C	I_{ref} (-)	0,12			

In Table 1, the parameter values apply at hub height and

V_{ref} is the reference wind speed average over 10 minutes,

A designates the category for higher turbulence characteristics,

B designates the category for medium turbulence characteristics,

C designates the category for lower turbulence characteristics and

I_{ref} is the expected value of the turbulence intensity[2] at 15 m/s.

The design lifetime for wind turbine classes I to III shall be at least 20 years.

External conditions

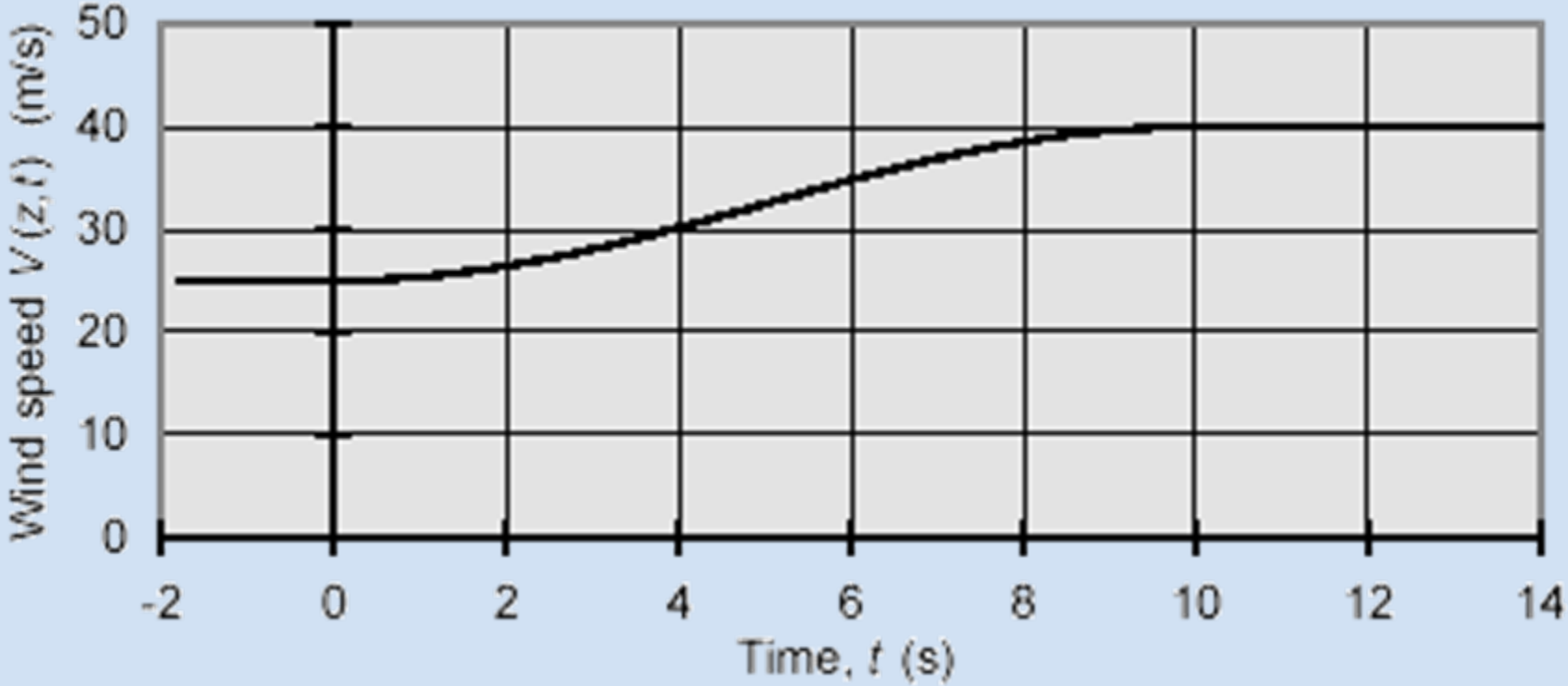
Wind conditions

- Normal wind conditions
- Wind speed distribution
- The normal wind profile model
- Normal turbulence model

Extreme wind conditions

- Extreme wind speed model
- Extreme operating gust
- Extreme turbulence model
- Extreme direction change
- Extreme coherent gust with direction change
- Extreme wind shear

External conditions



Example of extreme coherent gust amplitude for ECD

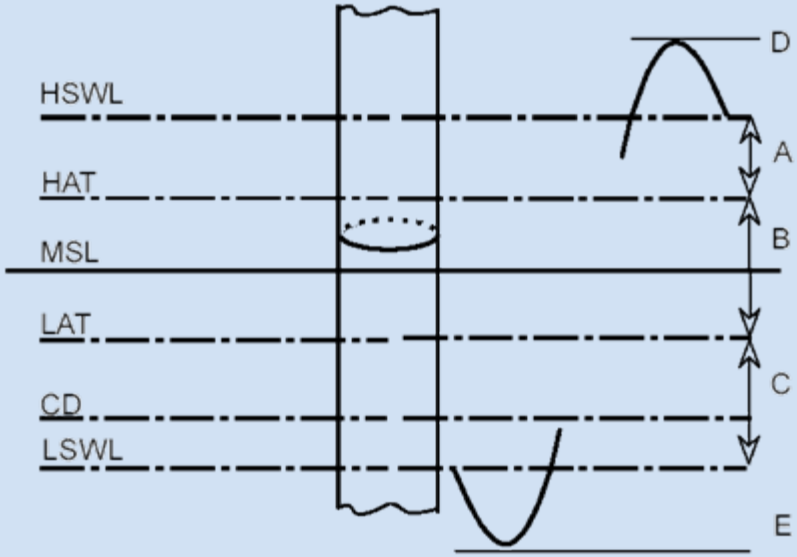
Other environmental conditions to be taken into account :

- air temperature
- humidity
- air density
- solar radiation
- rain, hail, snow and ice
- chemically active substances
- mechanically active particles
- salinity causing corrosion
- lightning
- seismicity causing earthquakes
- water density
- water temperature
- traffic

Marine conditions

- Waves
  - Normal sea state
  - Severe sea state
  - Extreme sea state
- Sea currents
  - Sub surface currents
  - Wind generated, near surface currents
  - Breaking wave induced surf currents
- Water level
- Marine growth
- Scour and overall seabed movement

Example: Definition of water levels



HSWL	highest still water level
HAT	highest astronomical tide
MSL	mean sea level
LAT	lowest astronomical tide
CD	chart datum (often equal to LAT)
LSWL	lowest still water level
A	positive storm surge
B	tidal range
C	negative storm surge
D	maximum crest elevation
E	minimum trough elevation

Loads on Off-shore Wind turbines

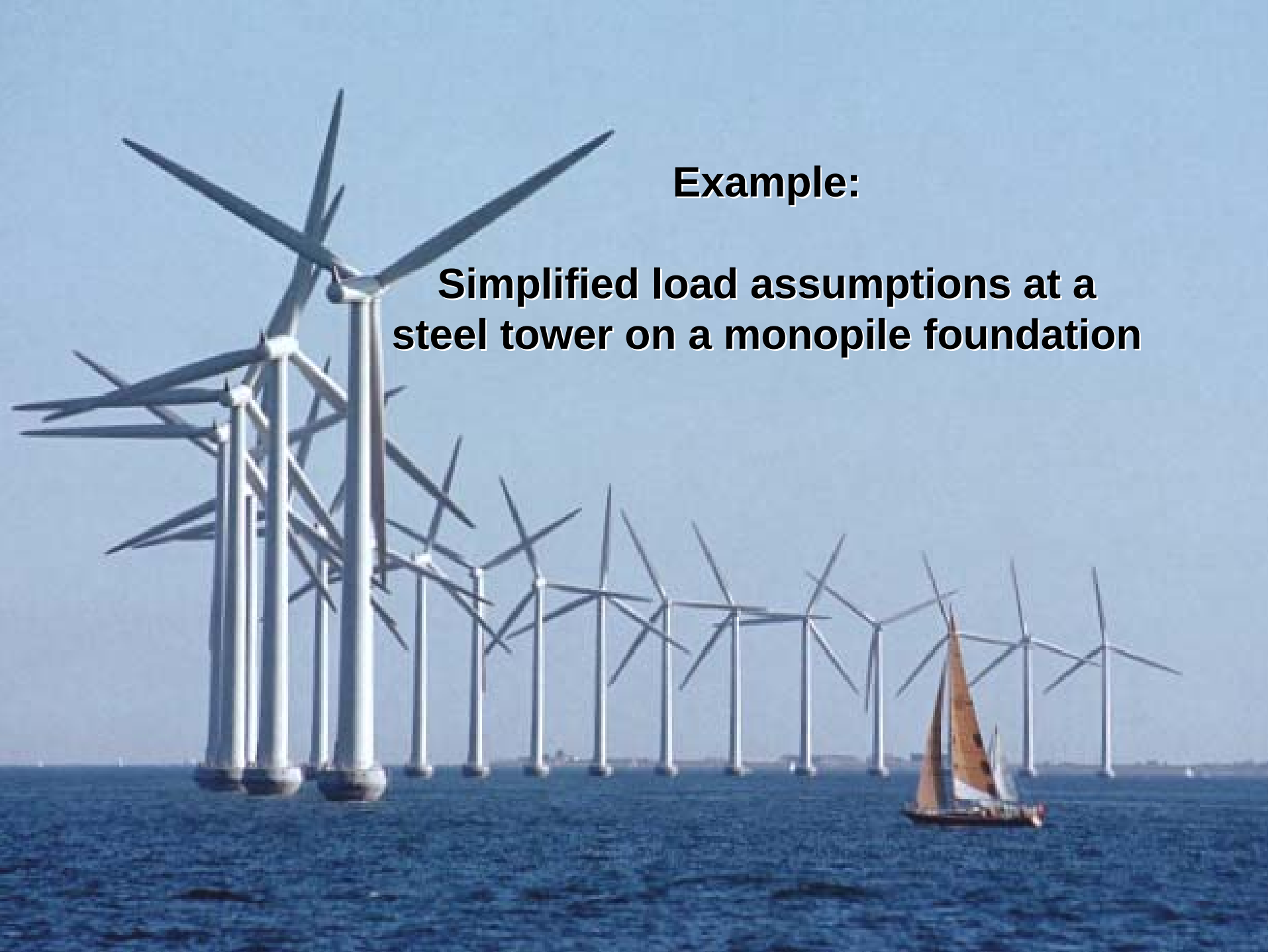
- Gravitational and inertial loads
- Aerodynamic loads
- Actuation loads
- Hydrodynamic loads
- Sea ice loads
- Other loads

Load cases

- Normal design situations and appropriate normal or extreme external conditions
- Fault design situations and appropriate external conditions
- Transportation, installation and maintenance design situations and appropriate external conditions

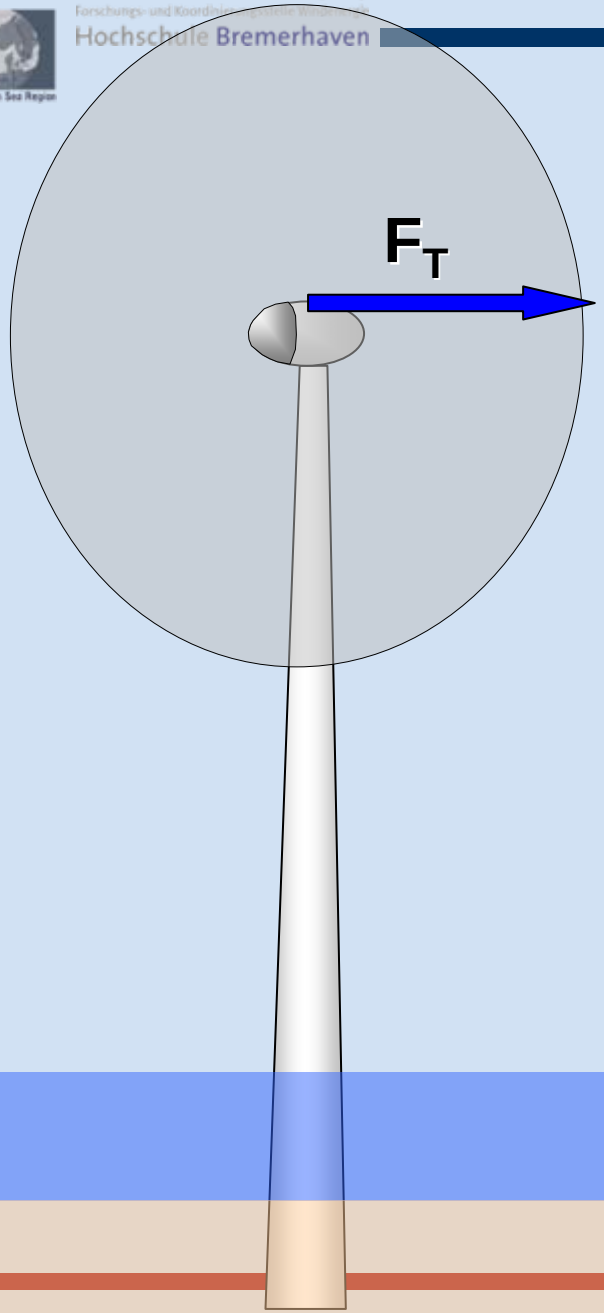
both, ultimate and fatigue loads have to be taken into account

Ref.: IEC 61400 – 1 ed 3 Design requirements



Example:

Simplified load assumptions at a steel tower on a monopile foundation



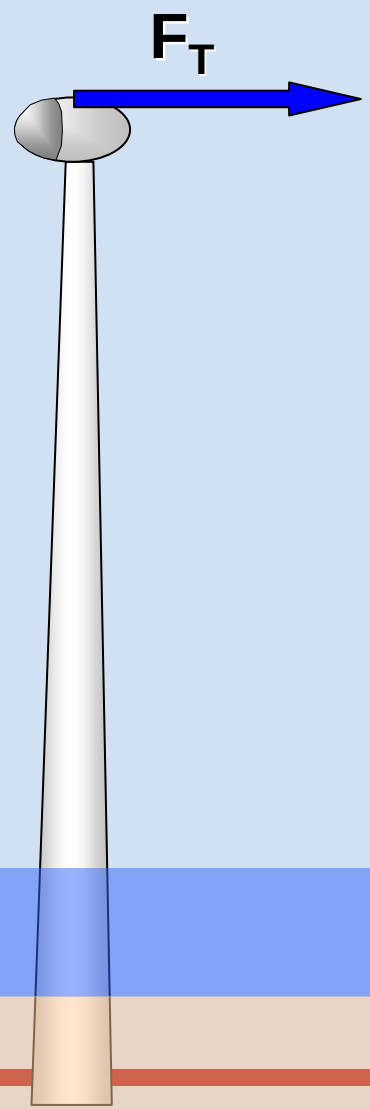
Aerodynamic loads due to wind speed and operation (simplified)

F_T rotor thrust

e.g. affected by:

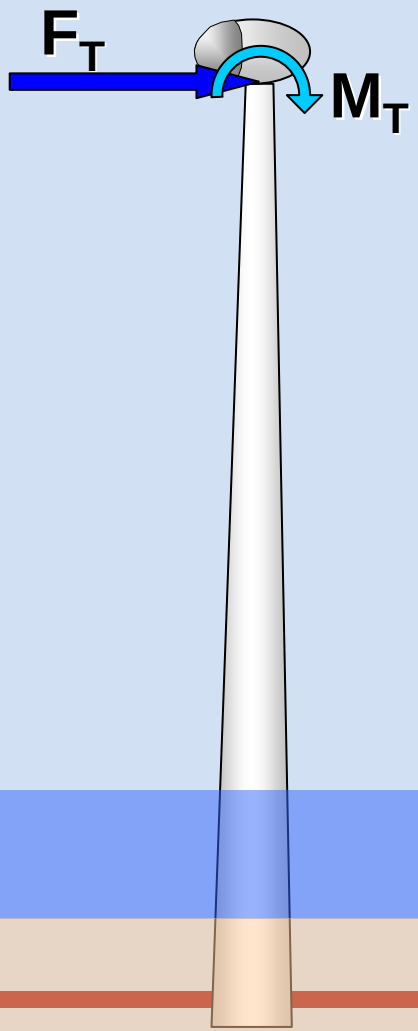
wind (spatiotemporal)
wind direction
wind gradient

rotor blade control
rotor speed



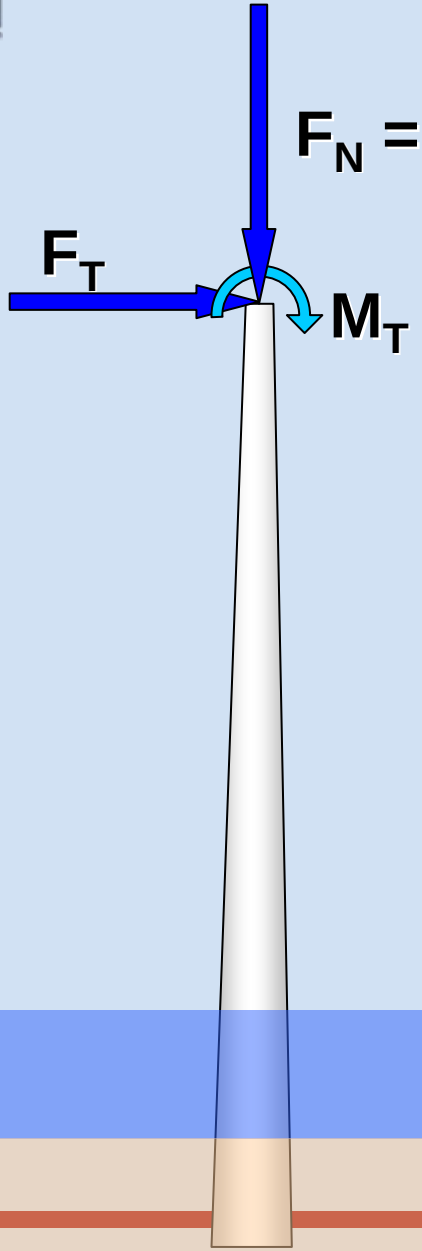
Aerodynamic loads due to wind speed and operation (simplified)

F_T rotor thrust



Aerodynamic loads due to wind speed and operation (section forces at tower head)

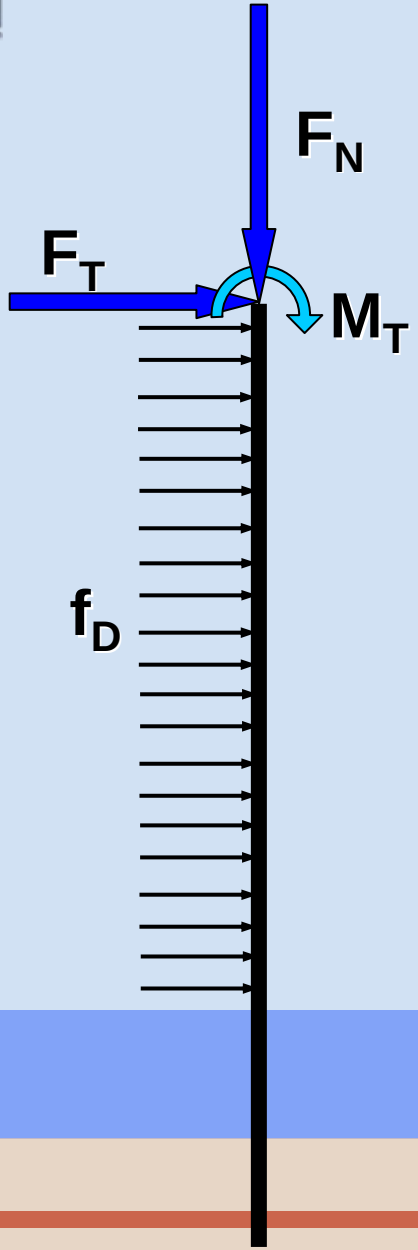
F_T rotor thrust
M_T tilt moment at tower head
M_{Tz} yaw moment at tower head
(not shown)



more tower head loads

F_N gravity force from the nacelle at the tower head
(Assumption: c.o.g. of nacelle acting centrically)

m_N mass of nacelle



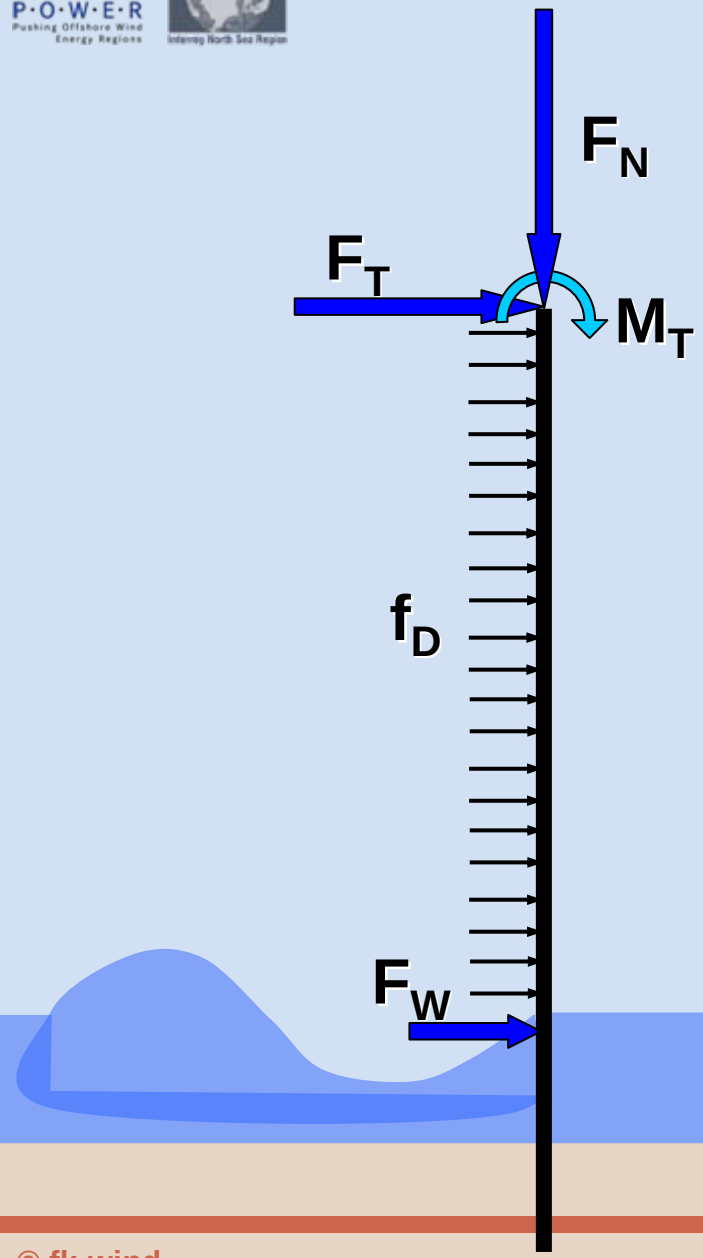
aerodynamic wind induced tower loads

f_D wind loads acting at tower, line load f(z)

(ass.: constant vs z)

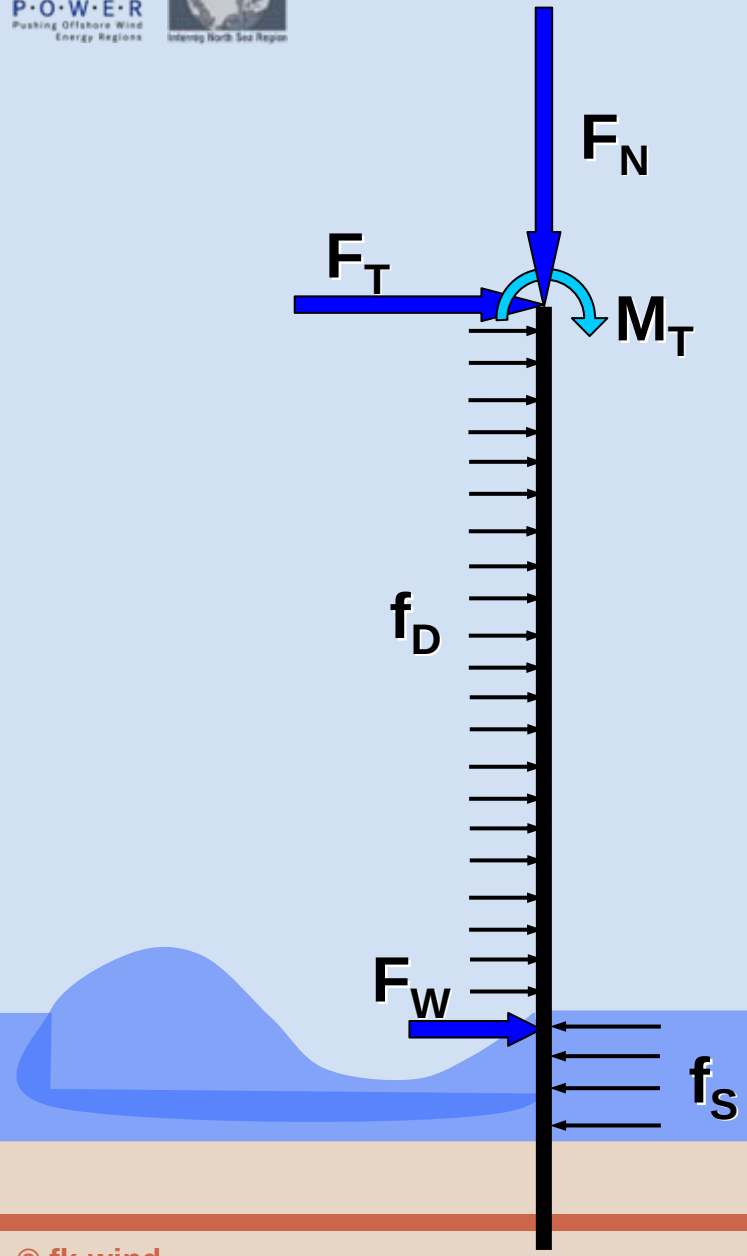
F_D aerodynamic drag at a tower section

$$F_D = \rho/2 \cdot v^2 \cdot c_d \cdot A$$



wave loads

F_W wave and ice loads

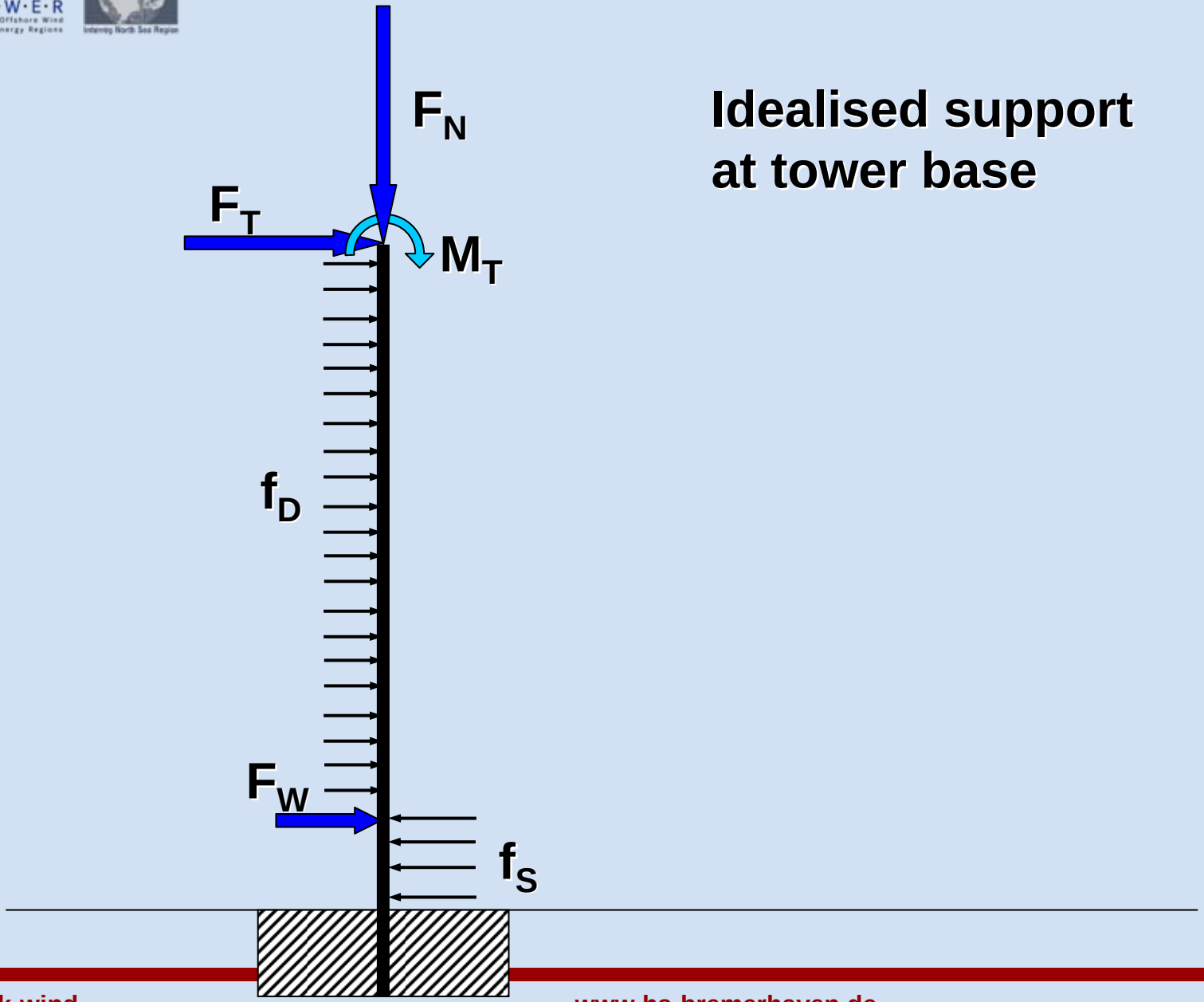


water current

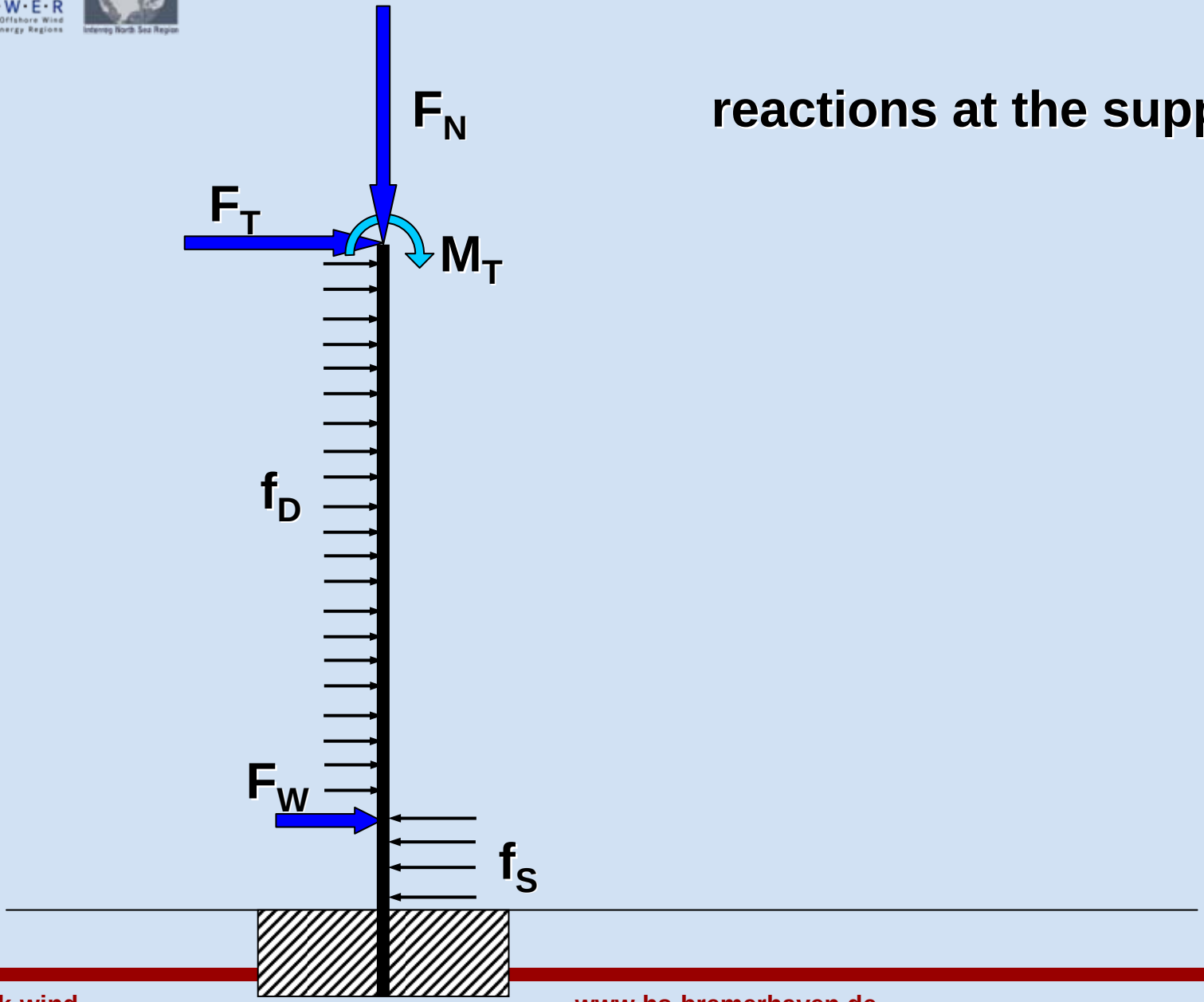
f_S drag of water current line load f(z)

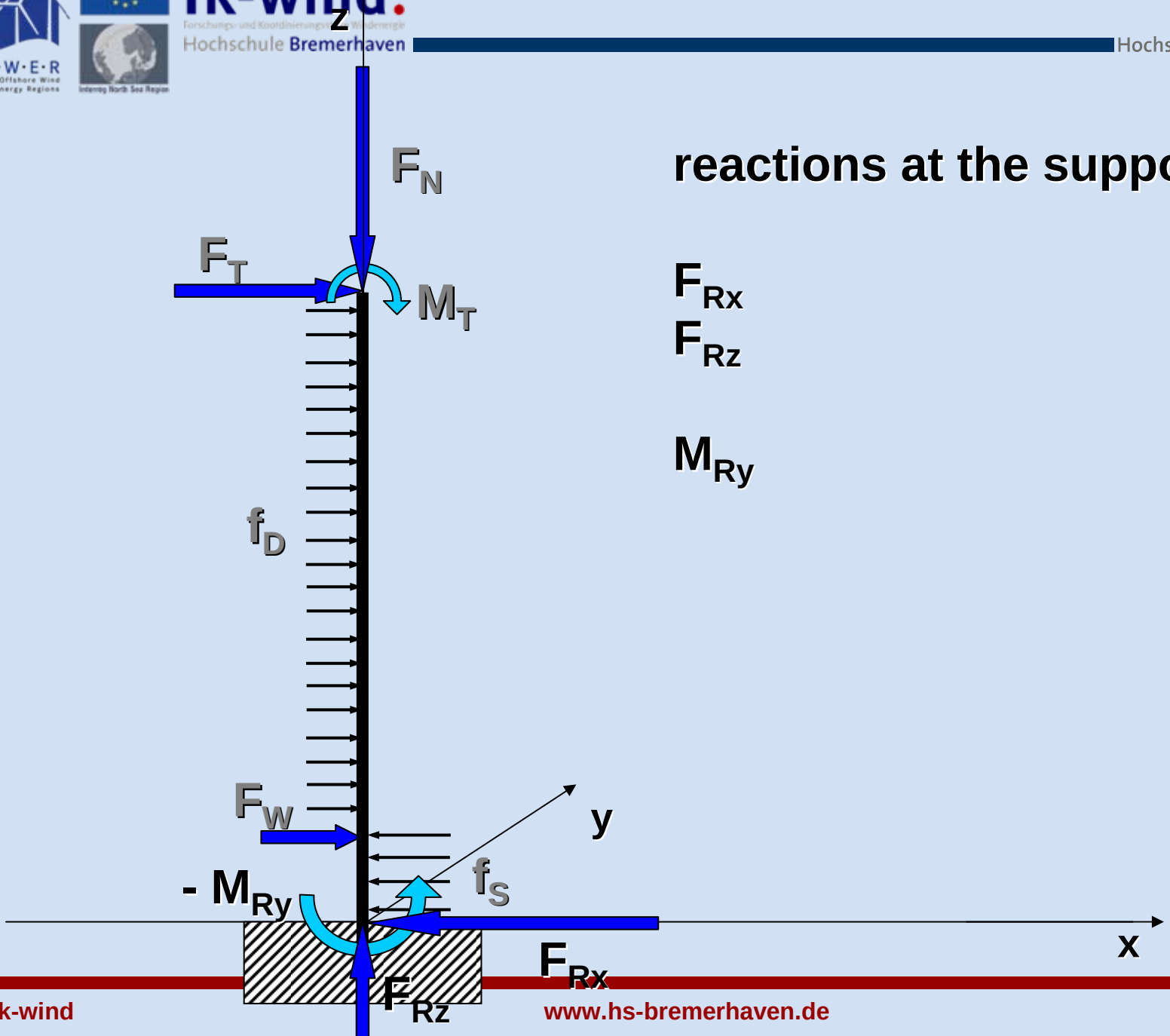
(ass: constant vs z)

Idealised support at tower base



reactions at the support



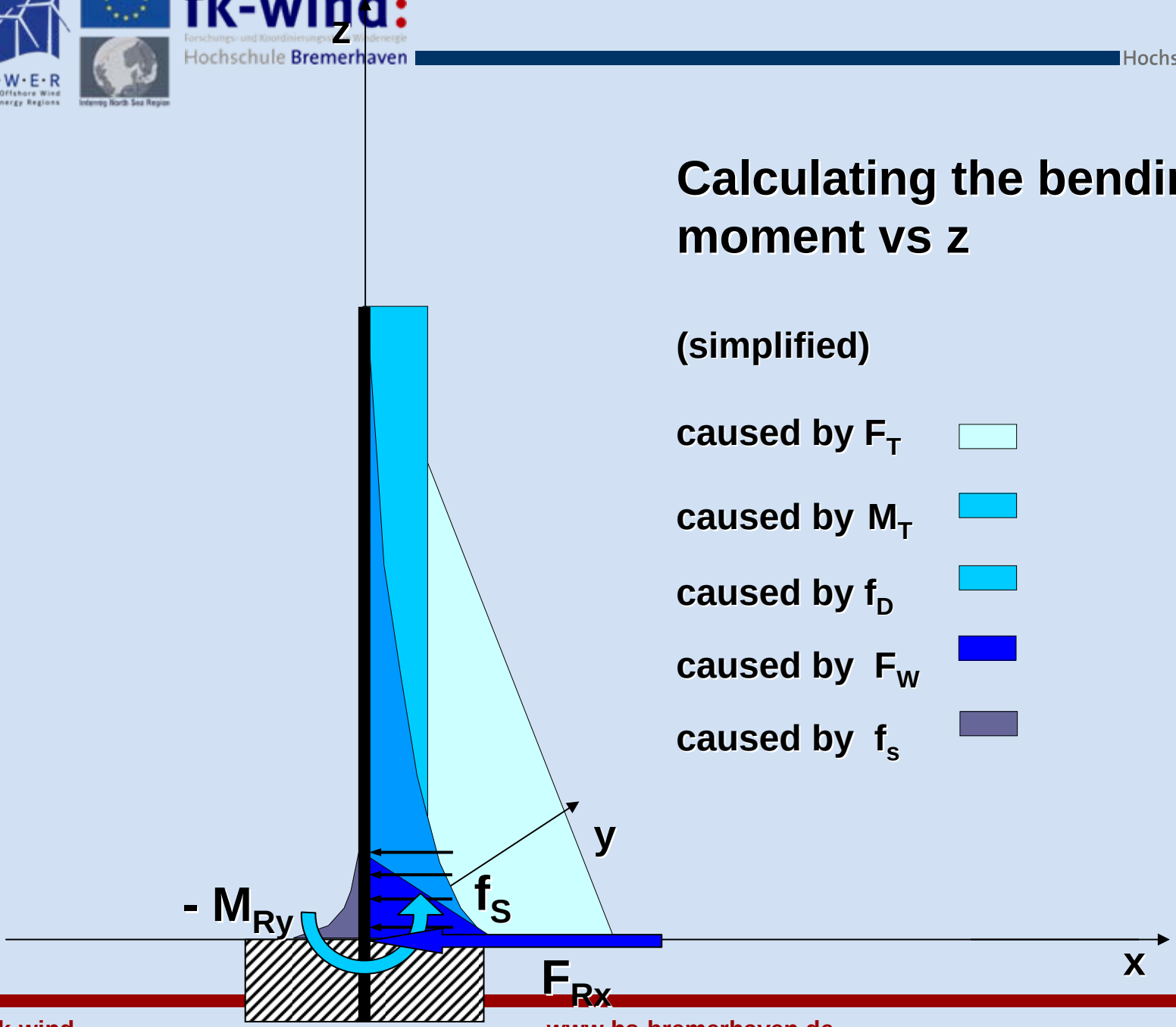


reactions at the support

F_{Rx}
F_{Rz}

M_{Ry}

Calculating the bending moment vs z



(simplified)

caused by F_T

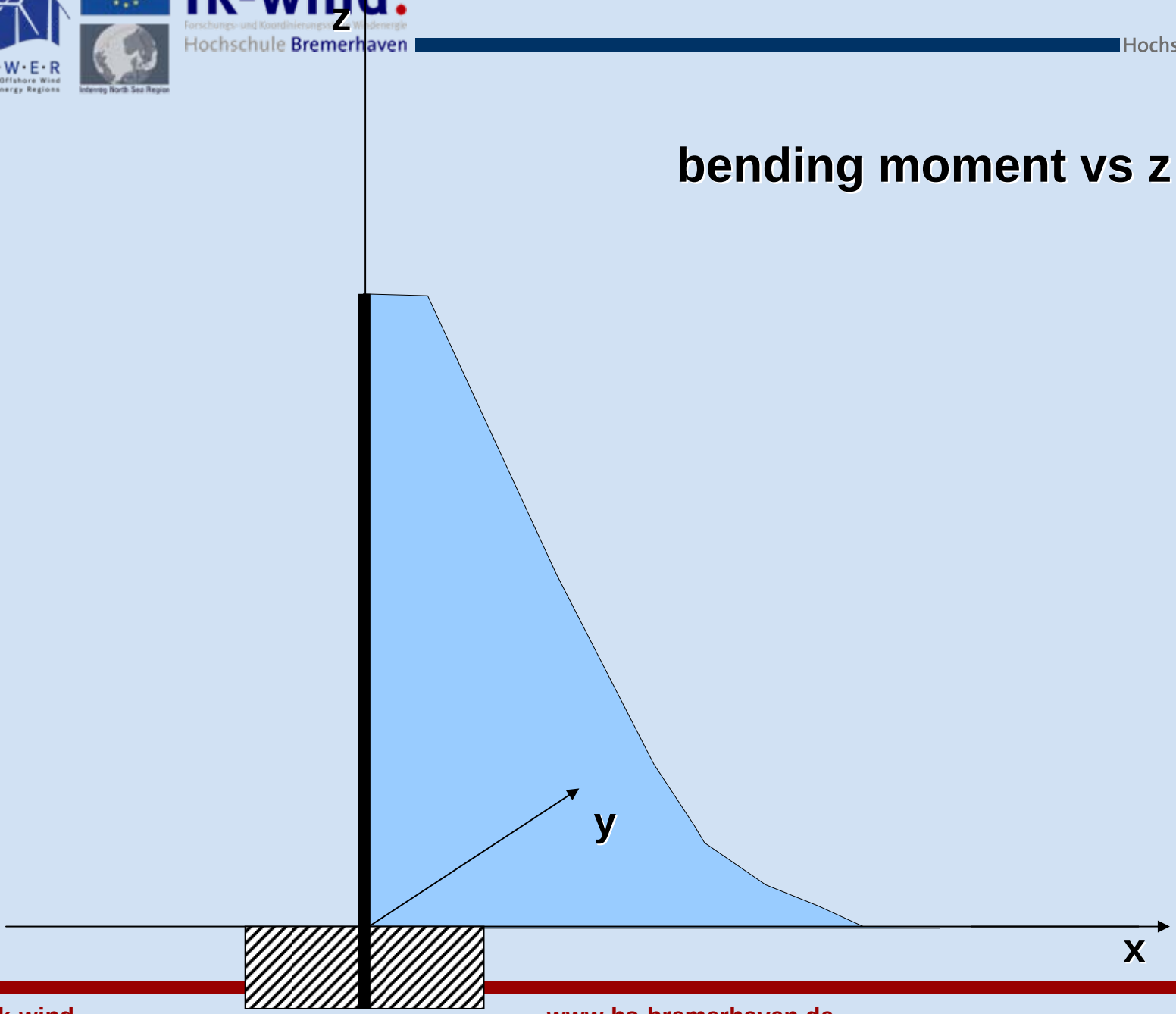
caused by M_T

caused by f_D

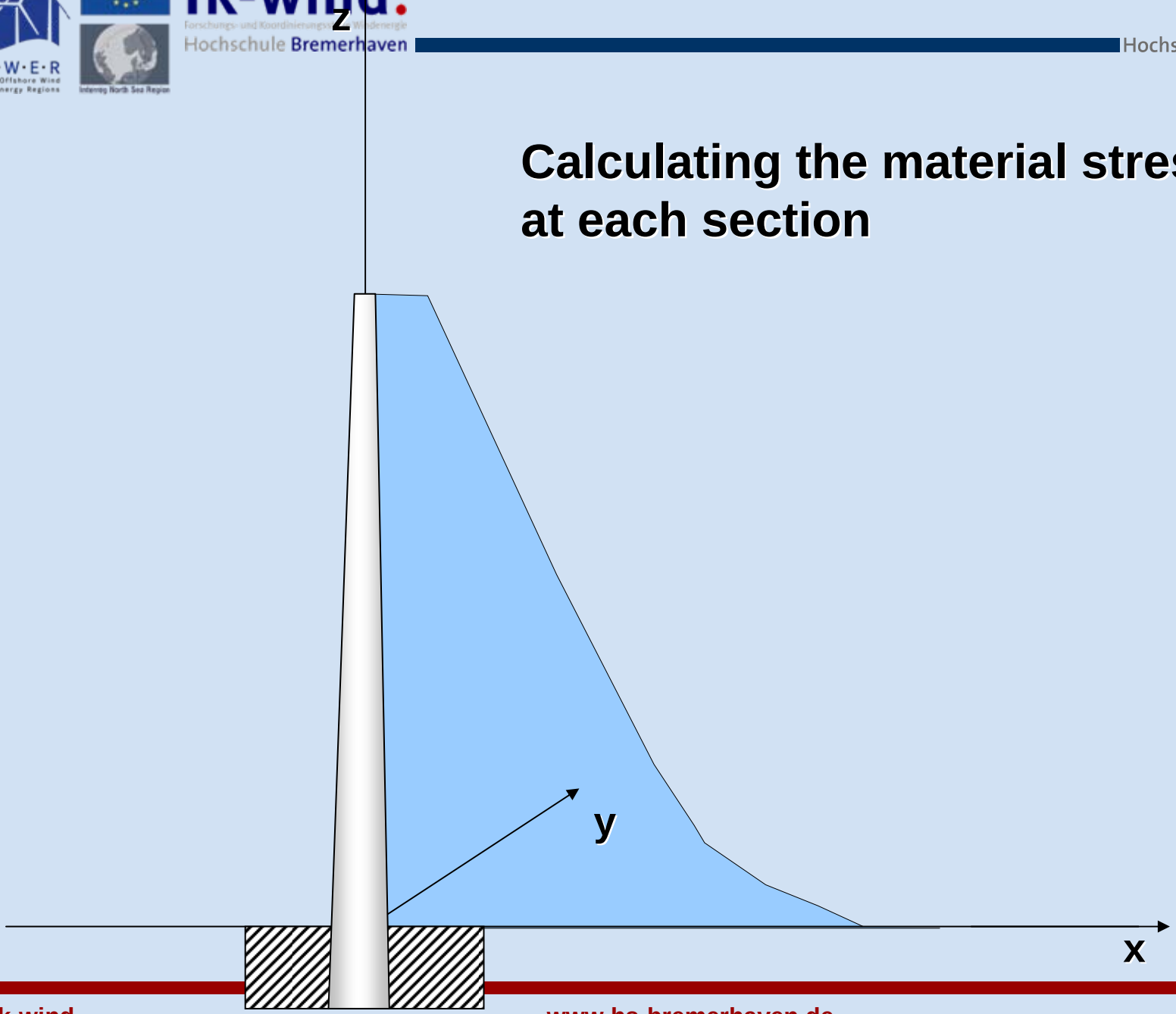
caused by F_W

caused by f_s

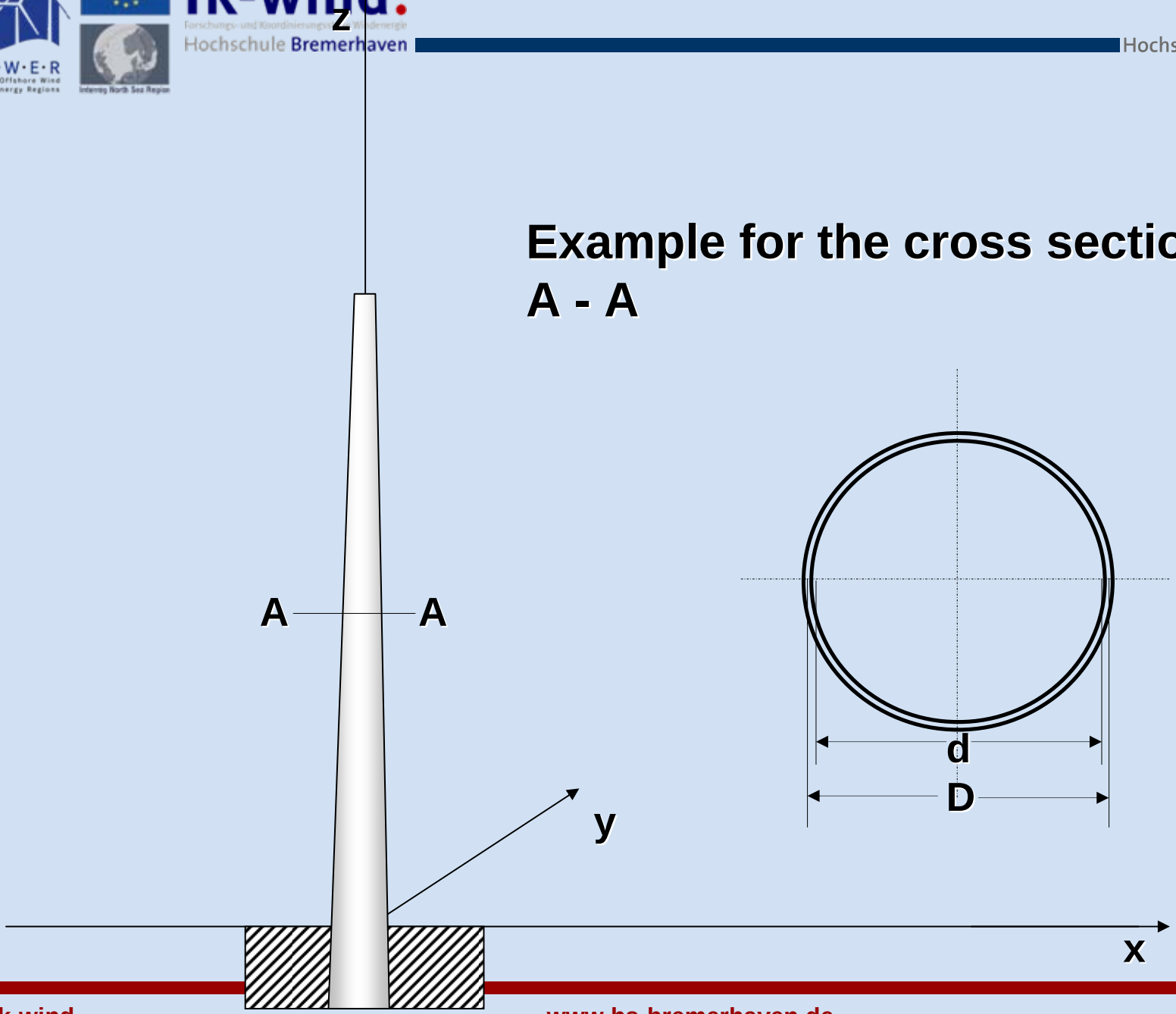
bending moment vs z



Calculating the material stress at each section

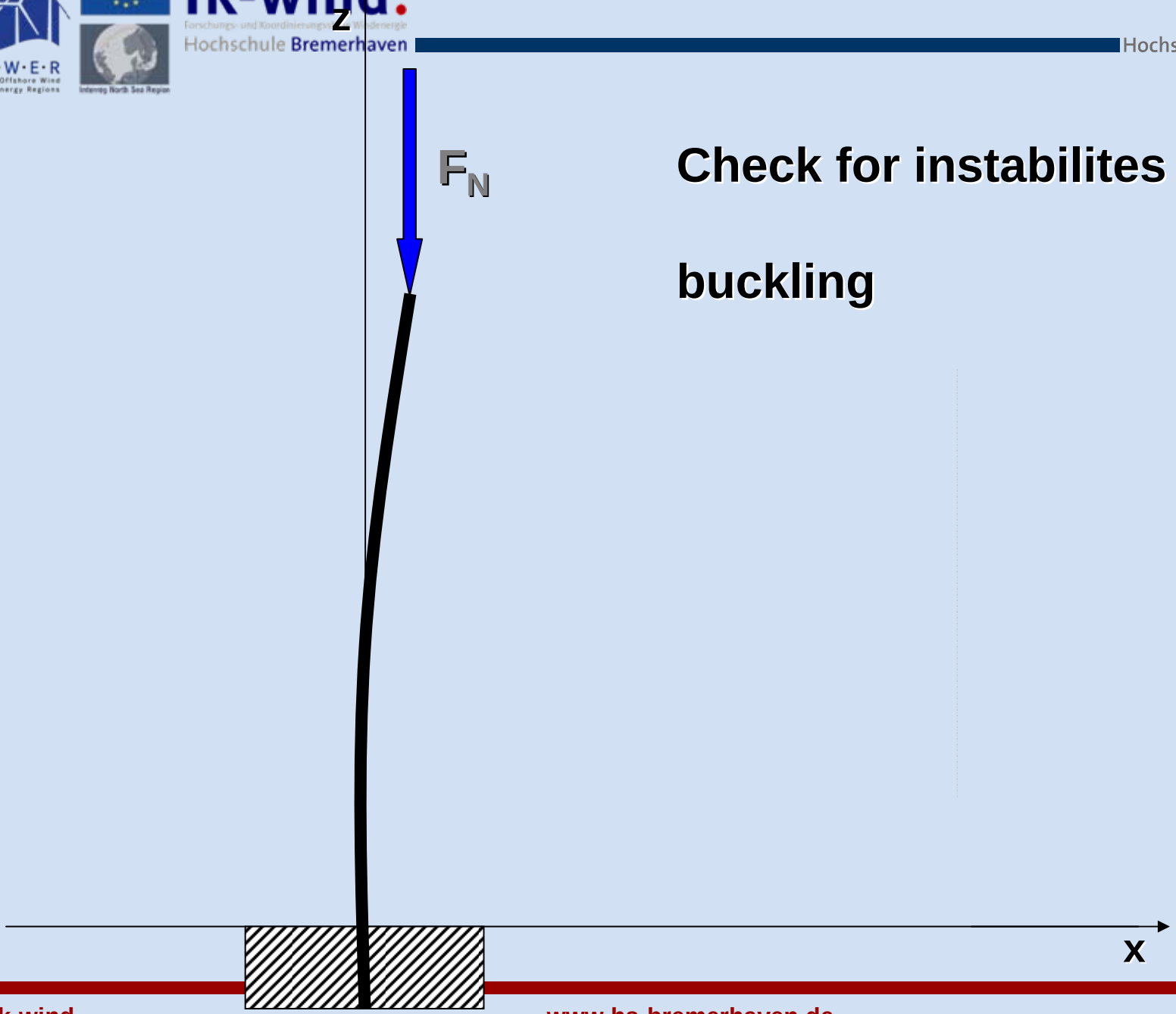


Example for the cross section A - A



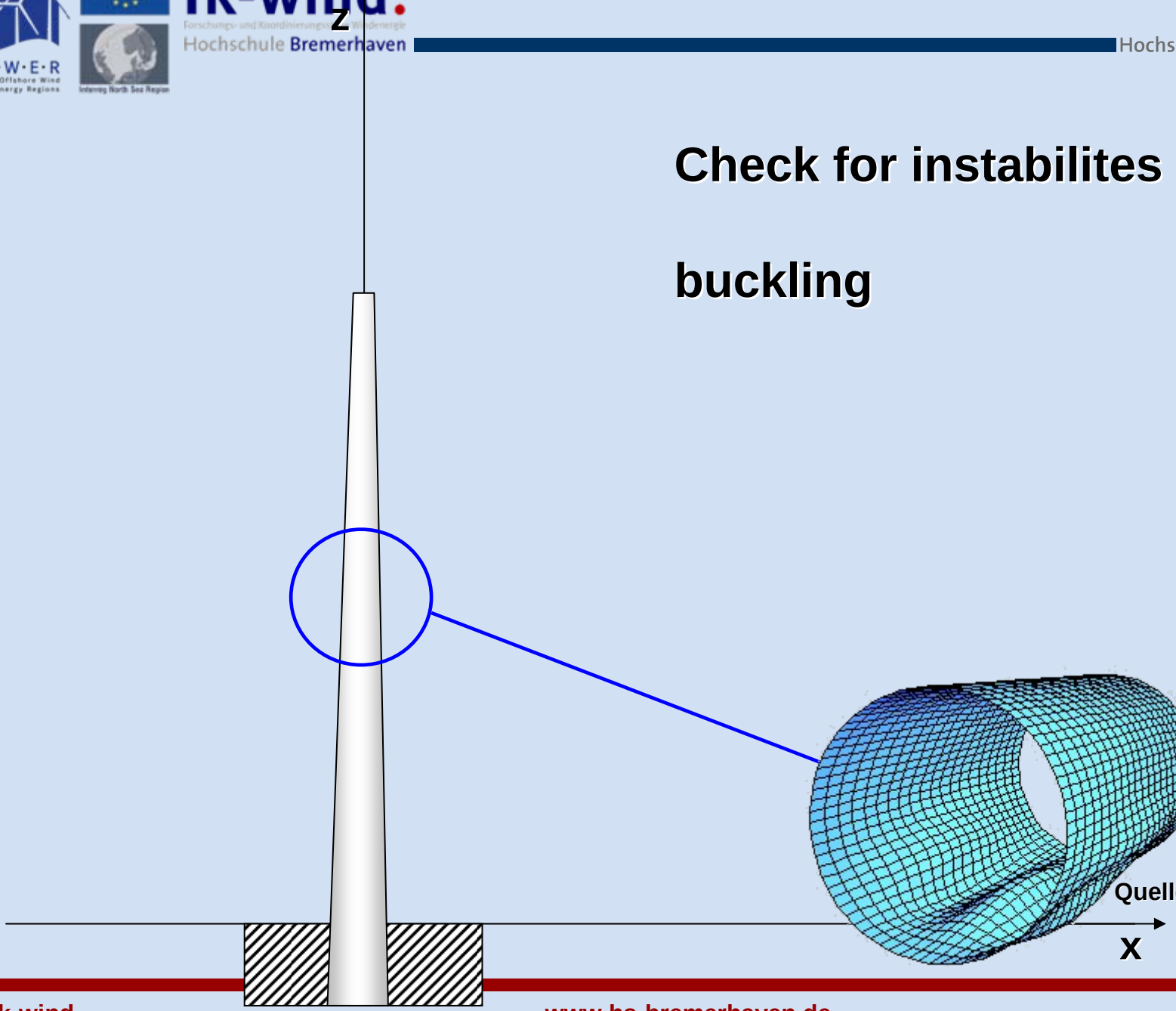
Check for instabilites

buckling



Check for instabilites

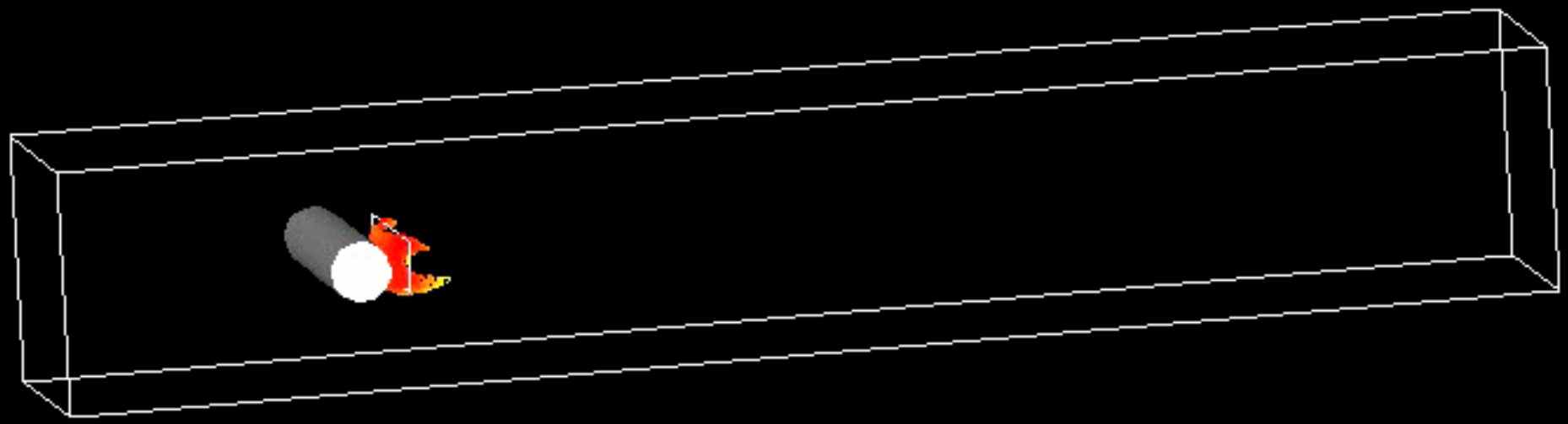
buckling



Quelle: www.sofistik.de

Quelle: Internet

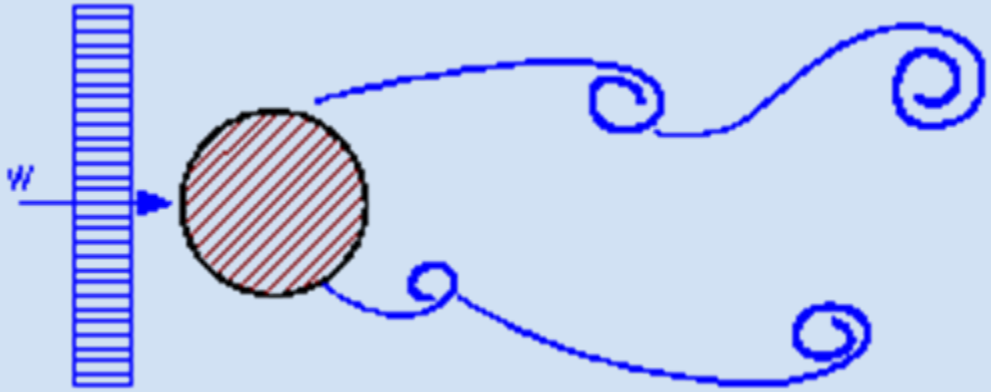
Dynamics of the tower
Example: Check for vortex induced vibrations

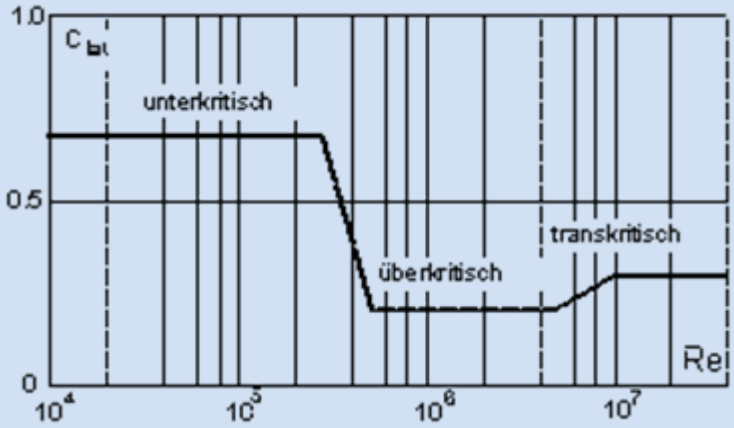


Ref: www

Dynamics of the tower

Example: Check for vortex induced vibrations





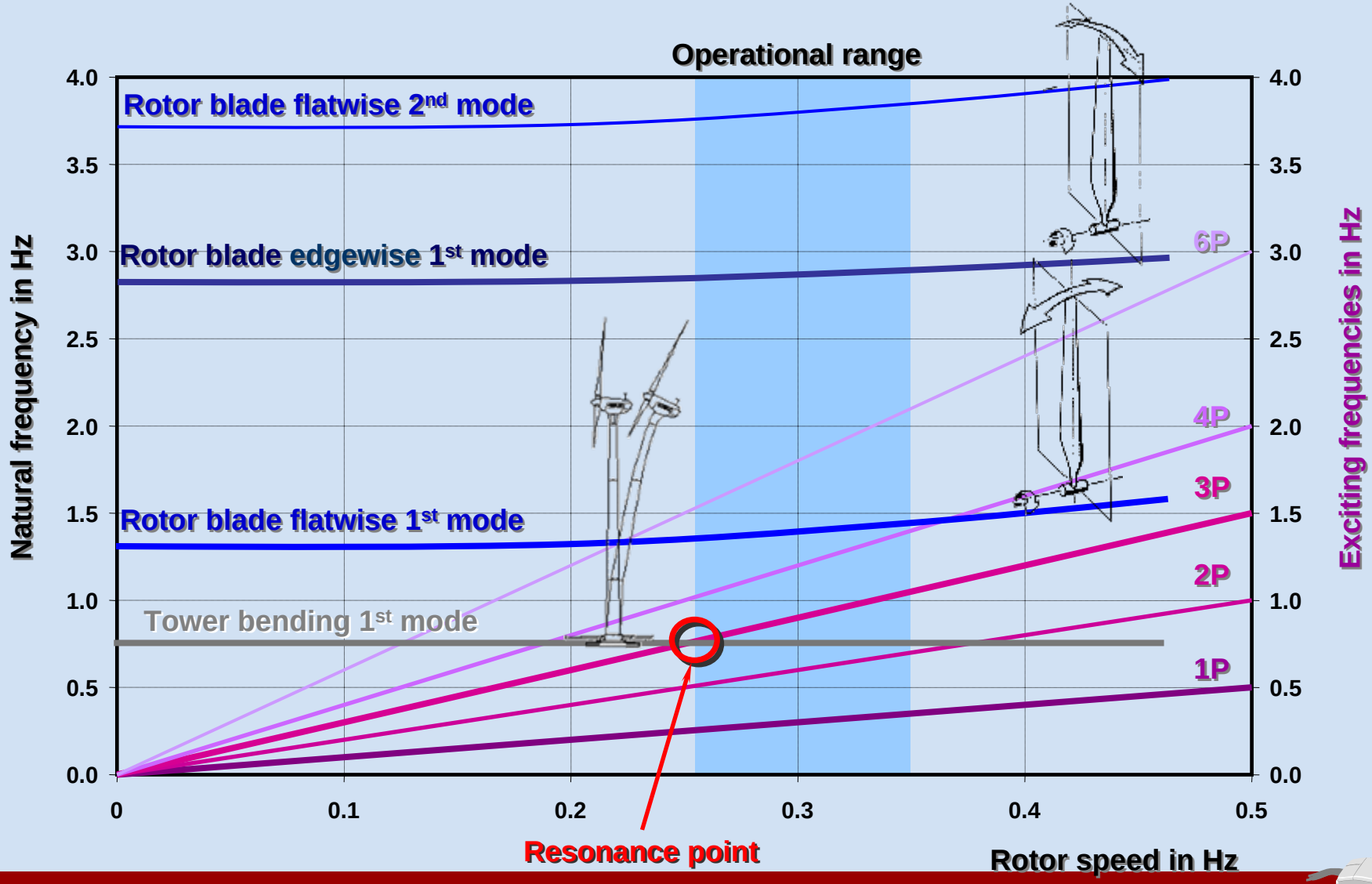
At chimneys:
„Anti-Karman spirals“

Dynamics of the tower

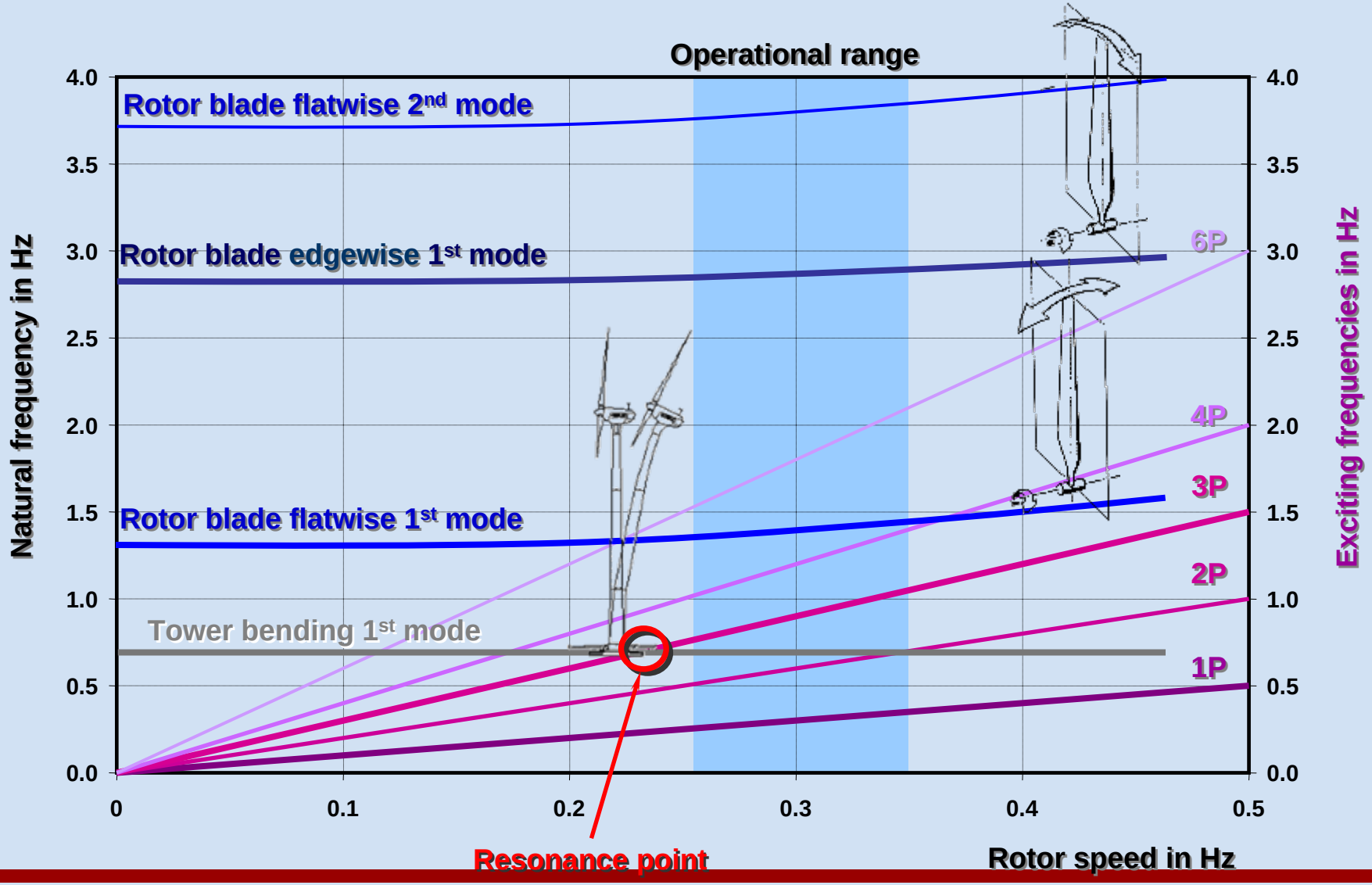
Example: Check for vortex induced vibrations

Quelle: http://www.middelgrunden.dk

the Campbell-Diagram



the Campbell-Diagram



Thank you for your attention