Design of Wind Energy Systems
Tutorial 4: Load Calculation and Design

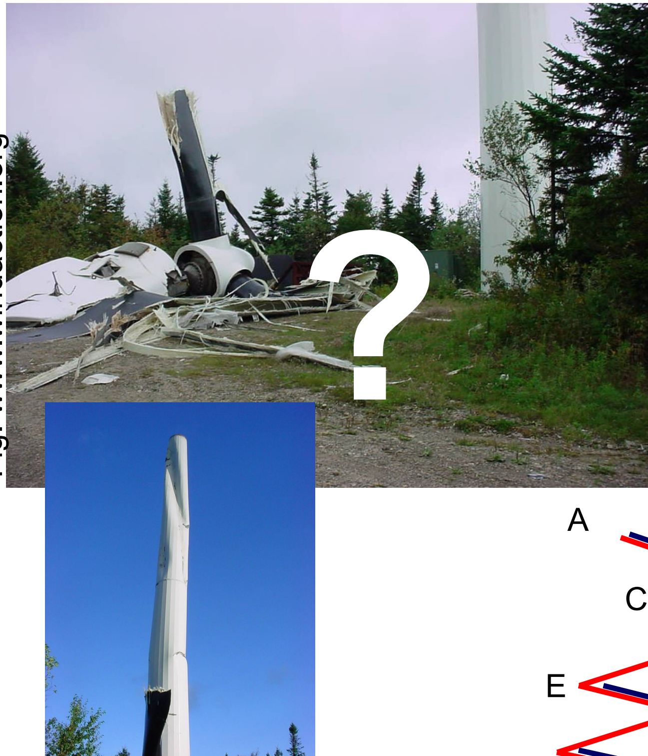
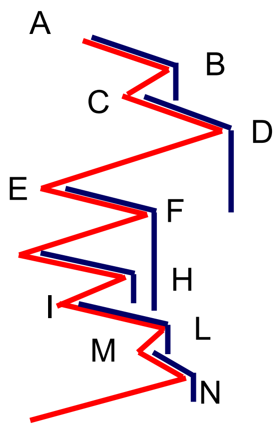


Fig. www.windaction.org



Exercise 1:

- **Definition of possible critical events to consider in the load calculation**

Exercise 2:

- **Definition of the number of cycles in a time series using the “rain flow” approach**

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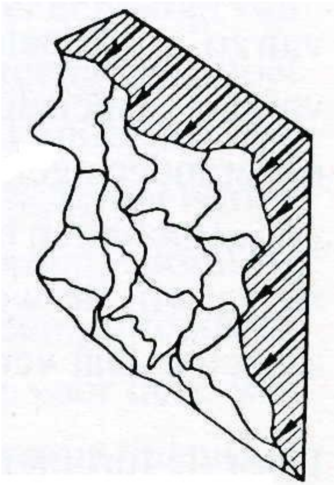
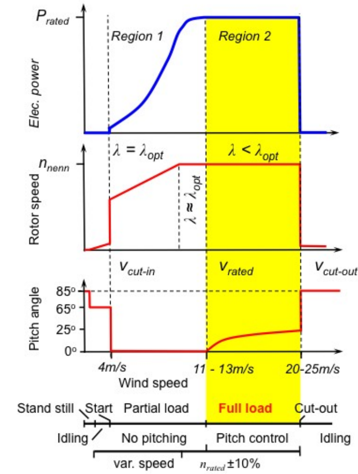
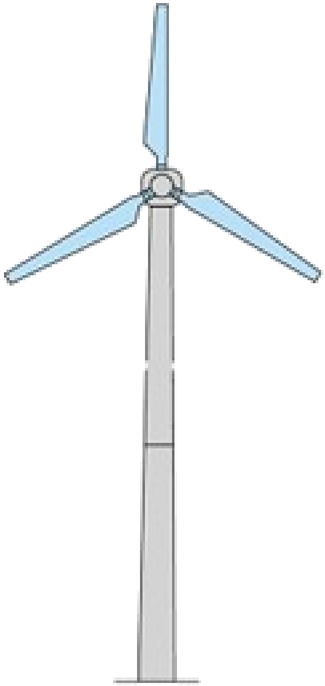
Origin of design load cases



Wind

Control System



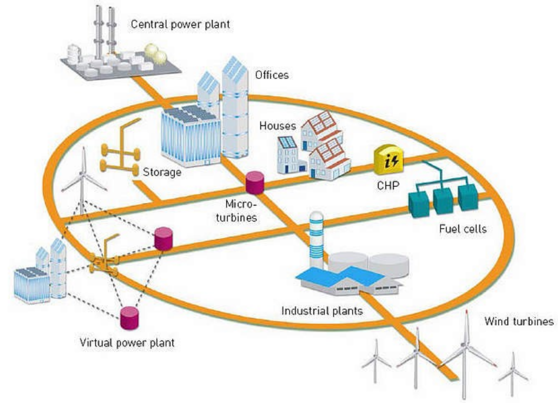


External Environment

(c) Alexander McNair

Failures

Grid



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Assignment 1

Please fill the following table with the events or operations you think you should consider in the load calculation e.g. for wind speed/direction. Add also the relative consequences and the wind turbine component that would be most affected.

	Event/Operation	Consequence
Wind		
WT System		
Environment		

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Assignment 1: solution

Please fill the following table with the events or operations you think you should consider in the load calculation e.g. for wind speed/direction. Add also the relative consequences and the wind turbine component that would be most affected.

	Event/Operation	Consequence
Wind	•Gusts •Extreme change in the wind direction •Extreme/normal wind speed •Extreme/normal turbulence intensity •Partial/full wake •Normal/extreme shear	•Pitch control action •Yawed inflow •Different loading condition •Different fatigue cycles •Non-symmetric loads on the swept area
WT System	•Start/stop •Idling •Yaw control one blade pitch failure •Pitch control failure •Emergency stop •Power production	•Inertial loads •Non-symmetric loads on the swept area •Over-speed •High inertial loads, increase of temperature in the nacelle •Operational loads
Environment	•Earthquake •Extreme/normal waves •Grid failure •Lightening •Transport/Assembling •Icing •Salty atmosphere	•Over-speed •Thermal stresses

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Fatigue (I)

Ultimate loads are not enough to ensure the reliability of a component.

Loads much lower than the design loads may cause the collapse of a component when cyclically repeated a certain amount of times.

Microscopically small defects in components after cyclic loading may deteriorate to cracks which slowly grow until they lead to the fatigue failure of component.

Evaluation of the number of cycles per year:

- For each wind speed interval I_p a ten minutes series of the stresses relative to most loaded sections is recorded.
- Stress cycles are counted according to the cycle mean amplitude σ_{mi} and range σ_{rj}

(note: sometimes only the range is taken into account)

- The number count of the same stress cycle $\sigma_{mi,rj}$ found for different wind conditions are added together
- From the probability density function of the wind speed the number of cycles per year $n_{i,j}$ is estimated
- Stress cycles from operational loads are added to $n_{i,j}$ (e.g. start, stop)

Fatigue (II)

Evaluation of the material lifetime from the Palmgren-Miner rule:

The damage D evaluated form the sum of the stress cycles $n_{tot,ij}$ given in the lifetime T, normalized with the number of cycles N_{ij} leading to failure for cyclic loading with the stresses σ_{mi} and range σ_{rj} found in the S-N curve or Wöhler curve of the considered material, has to be lower than 1.

$$D = \sum_{i,j} \frac{n_{tot}(\sigma_{mi}, \sigma_{rj})}{N_{ij}} = \sum_{i,j} \frac{T \cdot n_{ij}}{N_{ij}} < 1$$

By inverting the above equation it is possible to evaluate the lifetime T of the material:

$$T = \frac{1}{\sum_{i,j} \frac{n_{ij}}{N_{ij}}}$$

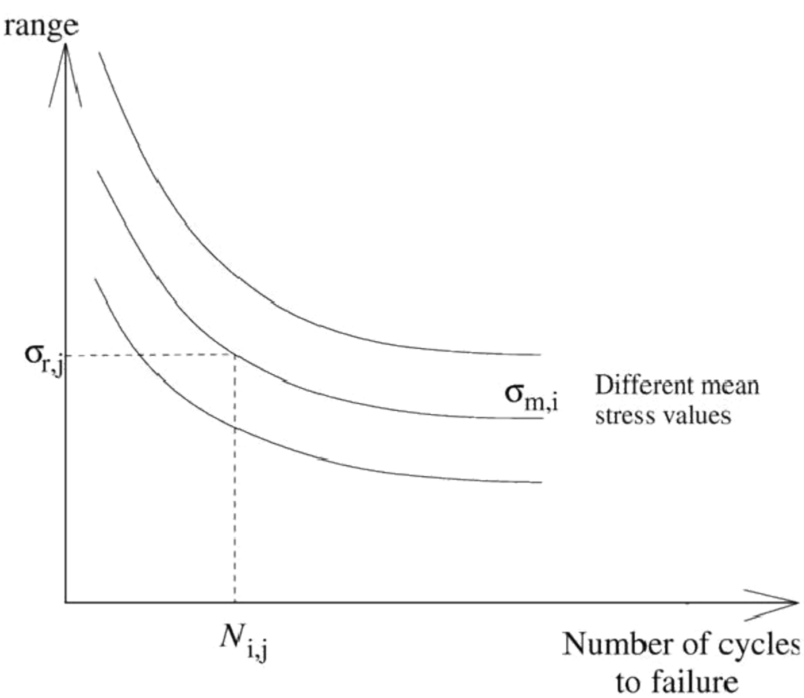

Fig. Hansen 2008

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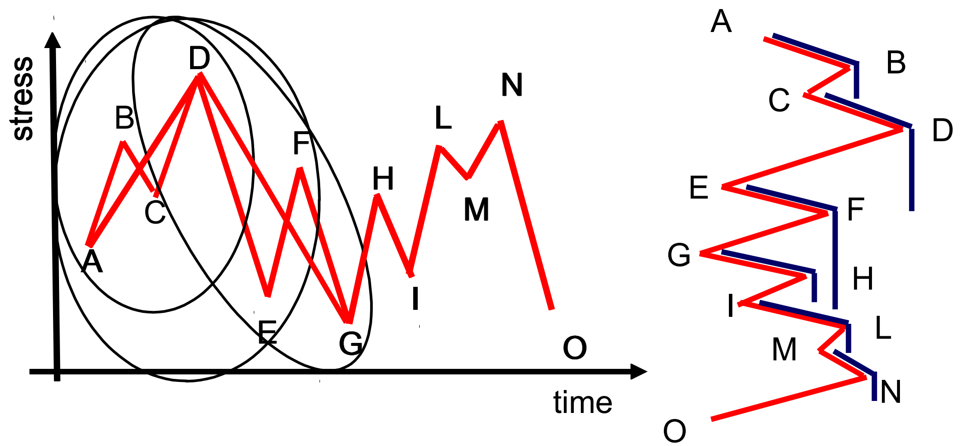
Rain-flow count method

Counts the stress cycles imaging that the peaks as well as the troughs of a time series rotated by 90 degree define the surface line of a pagoda roof where the rain is dropping from. Half cycles are counted when:

- a rain flow from a peak (trough) reaches the end of the time history or an other peak (trough)
- the considered peak (trough) is followed by a trough (peak) at least of the same amplitude

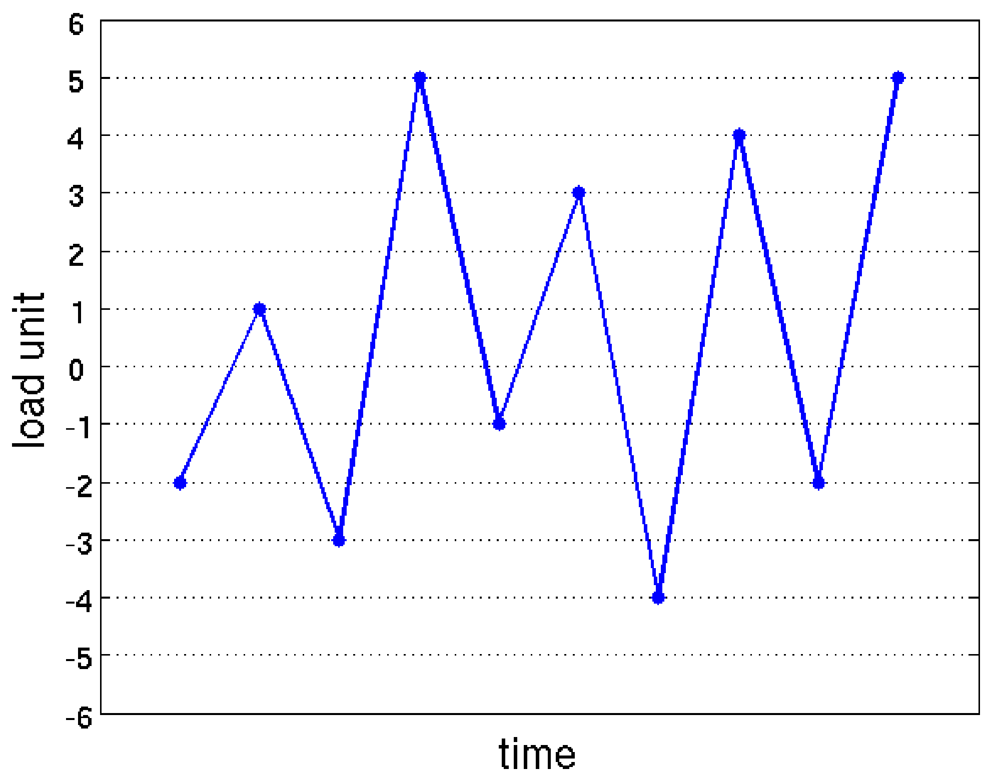


Algorithms

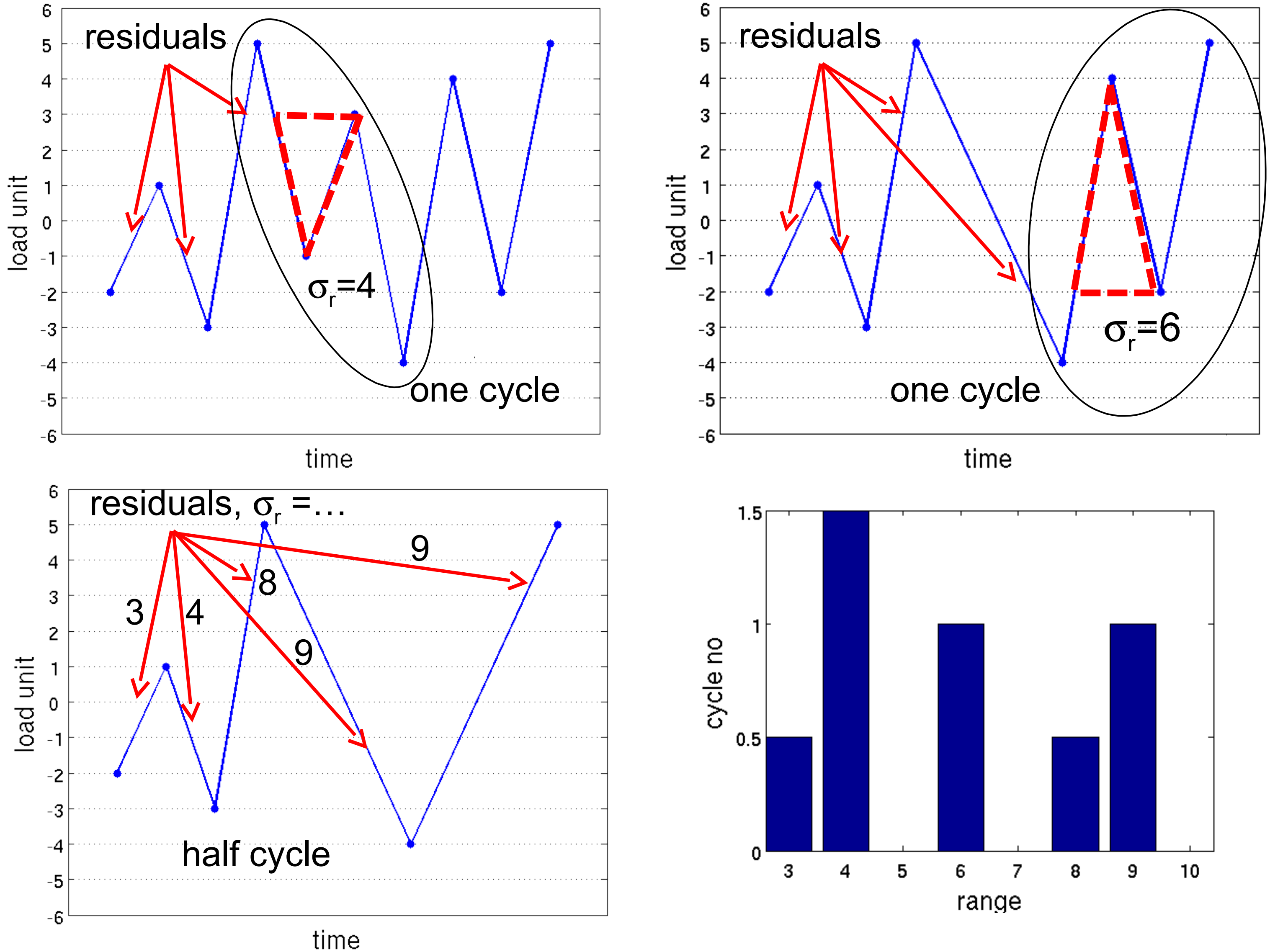
1. Reduce the time series to peaks and troughs
2. Consider the first group of 4 data S_i, S_{i+1}, S_{i+2} S_{i+3}
3. The pair range $|S_{i+1}-S_{i+2}|$ is counted as cycle and the relative data dismissed if the pair is totally included in within S_i and S_{i+3} otherwise the index i is increased by 1 (repeat till possible)
4. The remaining ranges are considered individually as half cycles

Assignment 2

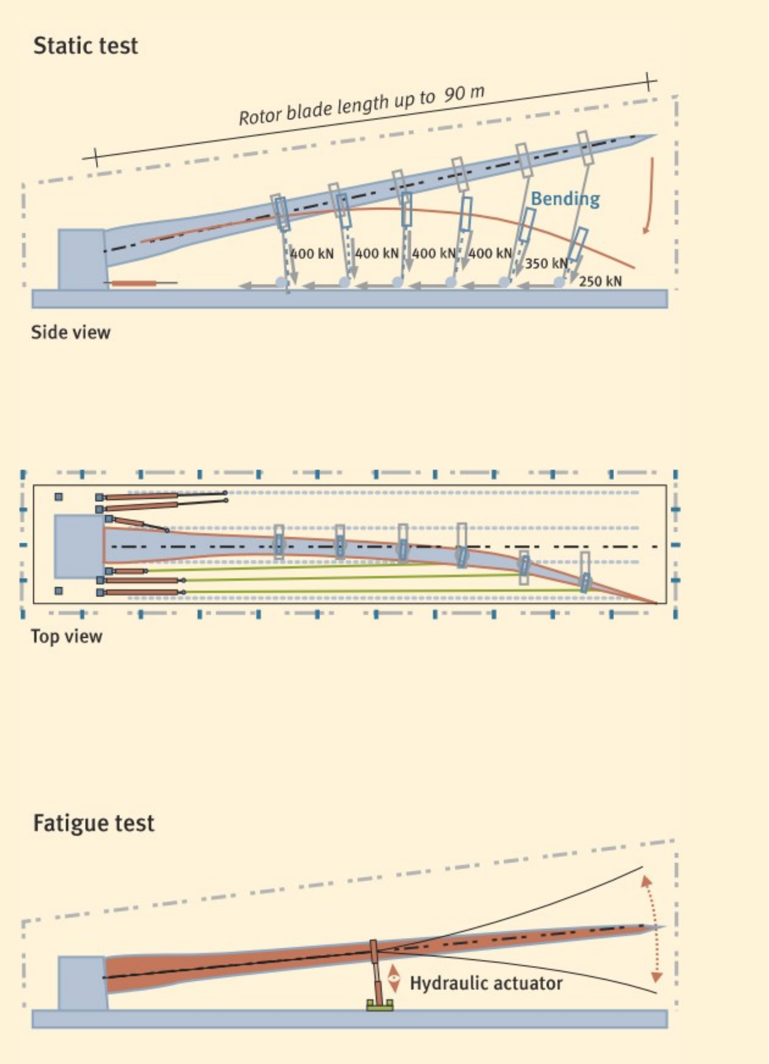
For the given data series defines the occurring range cycles and count their frequency according to the rain-flow method.



Assignment 2: solution



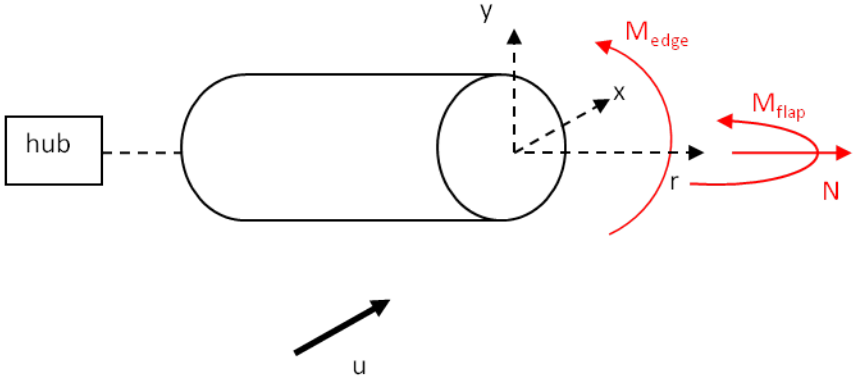
Structural test on blades

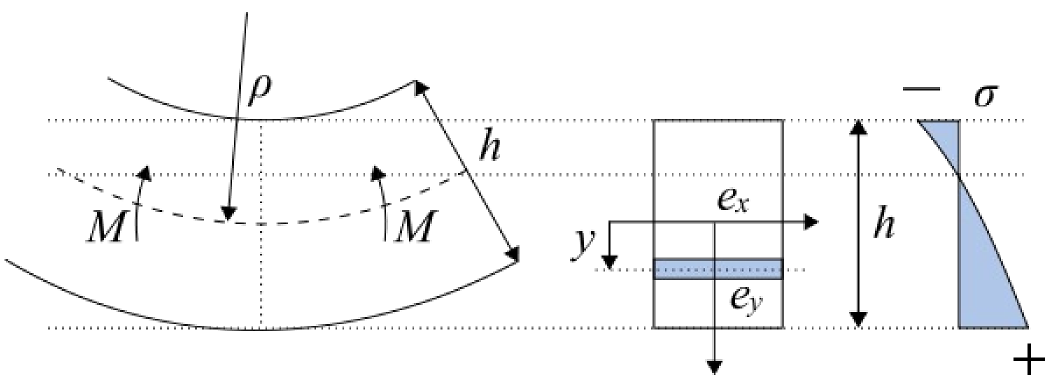


Exitation at the structure at the eigenfrequency of the blade

(c) Fraunhofer IWES

Home assignment





- De Saint Venant beam model
- Sections do not deform while bending
- Main inertial axis

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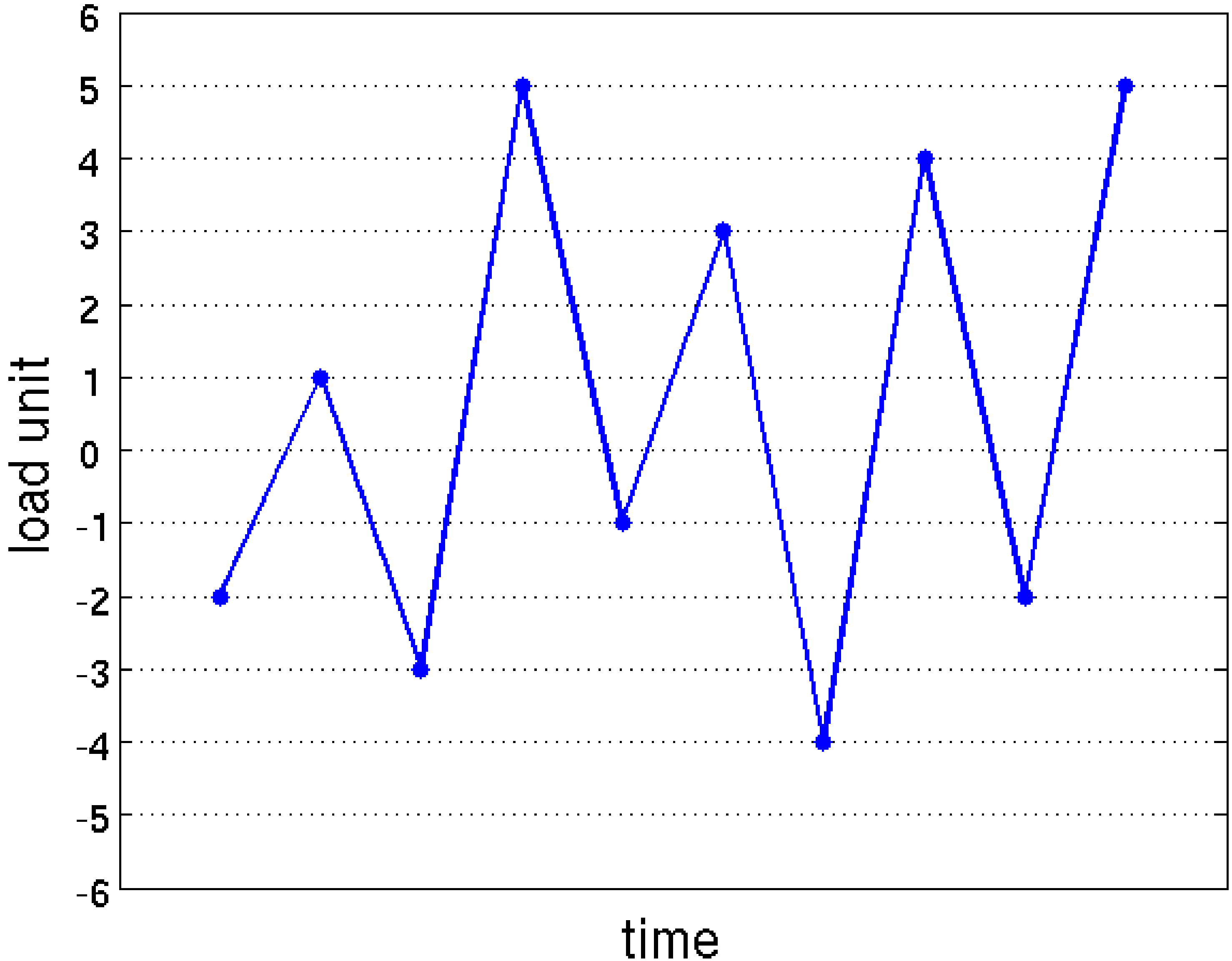

6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
load unit
time