



# Systematic modelling of wind turbine dynamics and earthquake loads on wind turbine tower and foundation

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WVEC 2005 Melbourne (U. Ritschel)



# Overview



- **Windrad Engineering GmbH**
- **Load Simulations and Design Process**
- **Simulation Code „SI-WEC“**
- **Earthquake Loads on Wind Turbines**

# Company



- Founded** : **September 2002**
- Homepage** : [www.windrad-engineering.de](http://www.windrad-engineering.de)
- Team** : **5, interdisciplinary (engineers, physicist, mathematician)**
- Motivation** : **Larger and more complex wind turbines require more detailed analyses; more “computational engineering“; trend towards outsourcing of R&D tasks; trend towards renewable energies**

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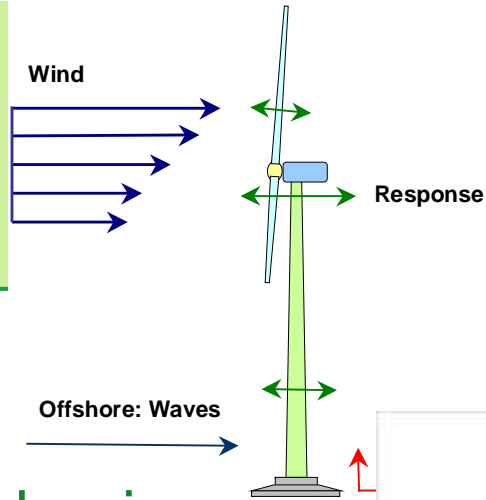
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WWEC



# Company

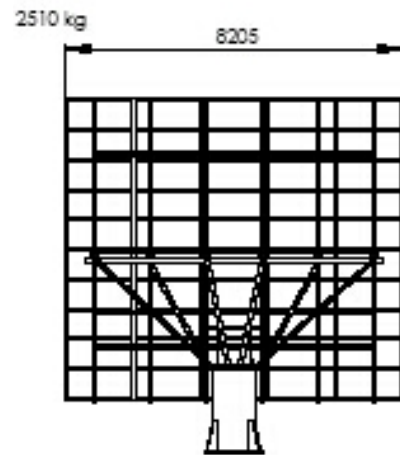
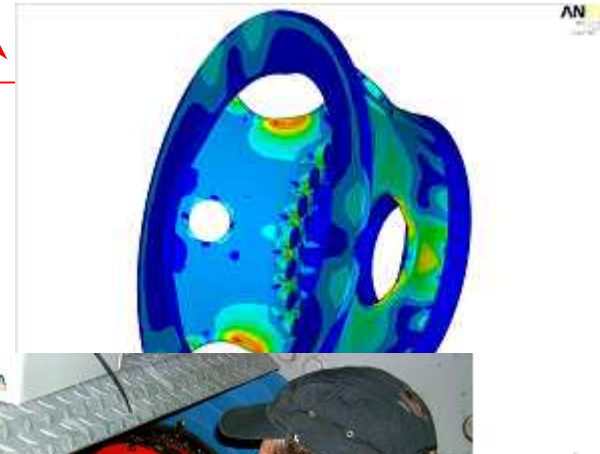


Simulation

Structural mechanics

Measurement

Special machines



ANSICHT [1:100]



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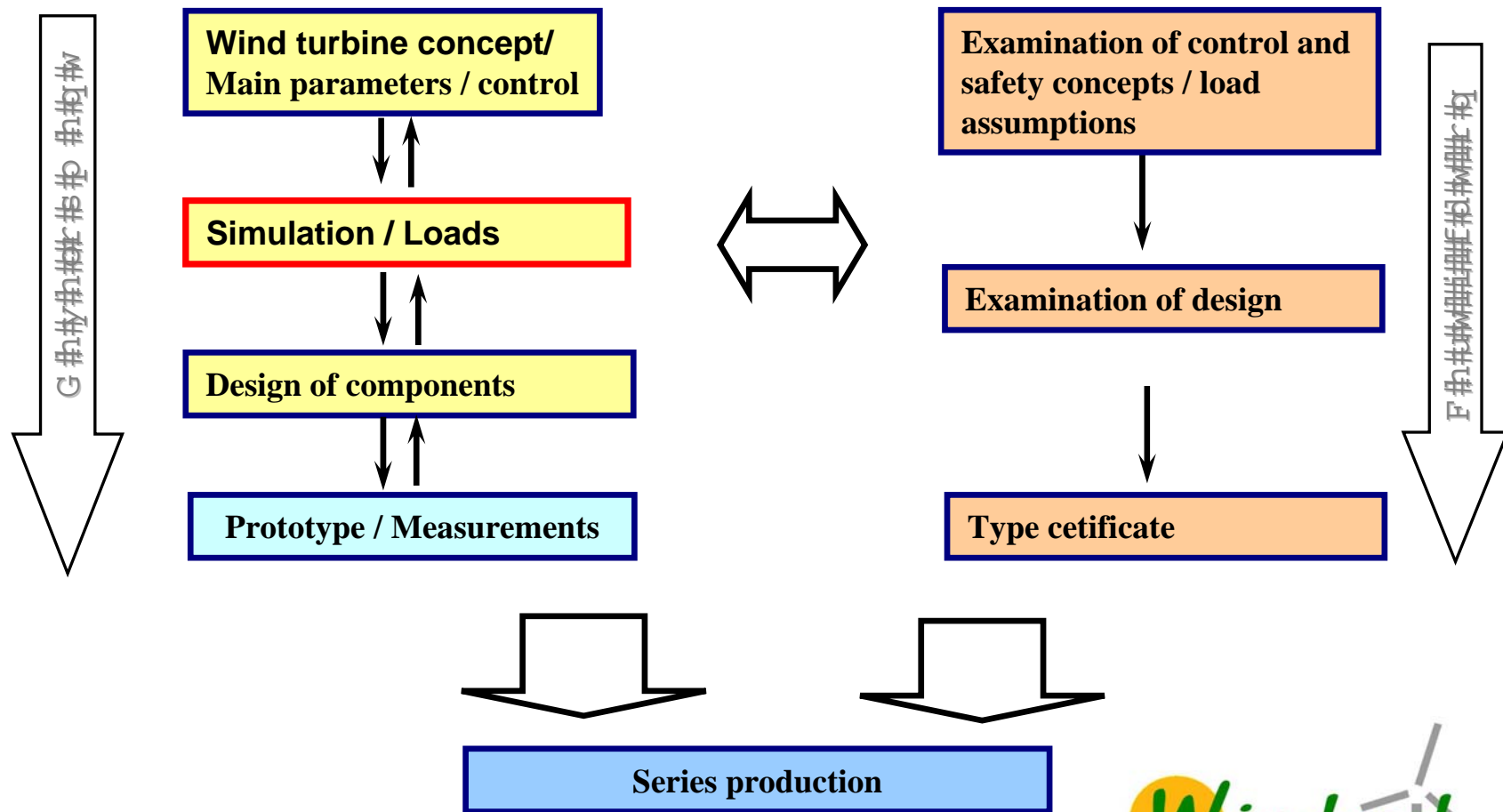


# Company



- Wind turbine manufacturers
- Component suppliers (towers, bearings,...)
- Wind farm developers
- Other engineering consultants

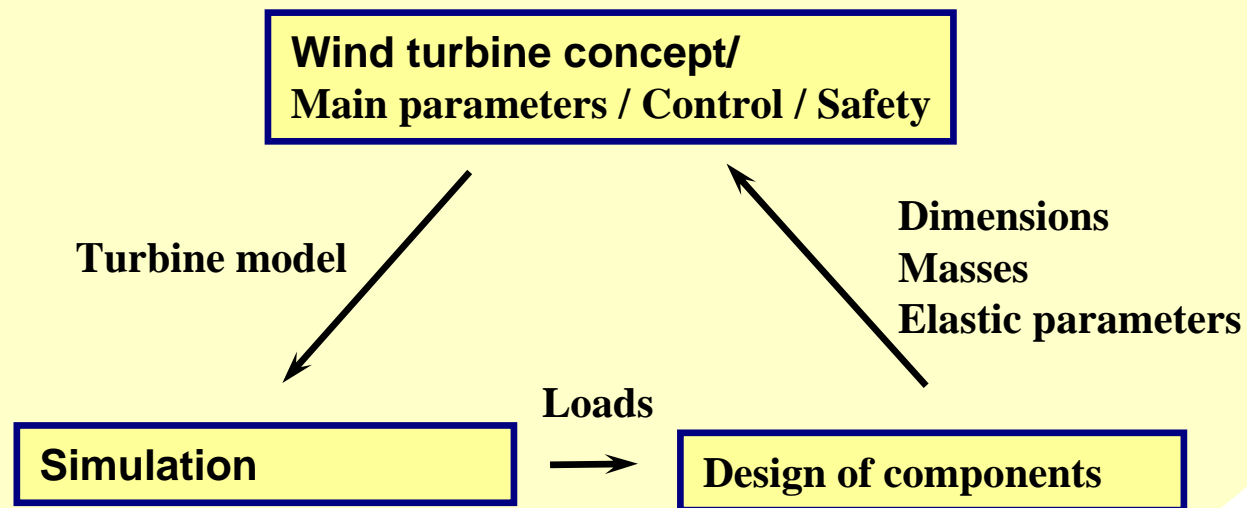
# Load Simulations and Design Process



# Load Simulations and Design Process



## Virtual Prototype





# Load Simulations and Design Process



## Preprocessing

- Create turbine model
- Generate wind, waves, earthquake
- Create load cases (according guide lines GL, IEC, ...)



## Simulation

- Compute aerodynamic forces
- Compute reaction of elastic structure
- Aeroelastic simulation



## Postprocessing

- Determination of extreme loads (sectional forces, moments)
- Determination of fatigue loads
- Documentation

# Load Simulations and Design Process



## Load calculation according to current standards

- Simulation of 30-40 hours real time, 300-400 load cases
- Normal operation, starts, stops, failure, extreme wind, etc.
- **Wind: turbulence, height variation, ...**
- **Offshore: waves, ice, ... > 500 load cases**
- **Earthquakes: ground acceleration, effects on foundation**



- **Determination of extreme values of 500-1000 state variables and loads**
- **Calculation of fatigue loads and extrapolation to 20 years**
- **1-2 GB of data for one run**

# Simulation Code „SI-WEC“



## „Simulation of Wind Energy Converters“

- Existing codes (Bladed, Flex5,...) multy body simulation with flexible parts; fixed maximum number of DOF (blade/tower modes)
- Other alternatives MBS or FEM too slow

### Motivation for new code:

- Requirements of e.g. building standards partly not fulfilled
- Aerodynamic model, numerical procedures limited accuracy
- No updates, no support (Flex5)
- Expensive / source code not available (Bladed)

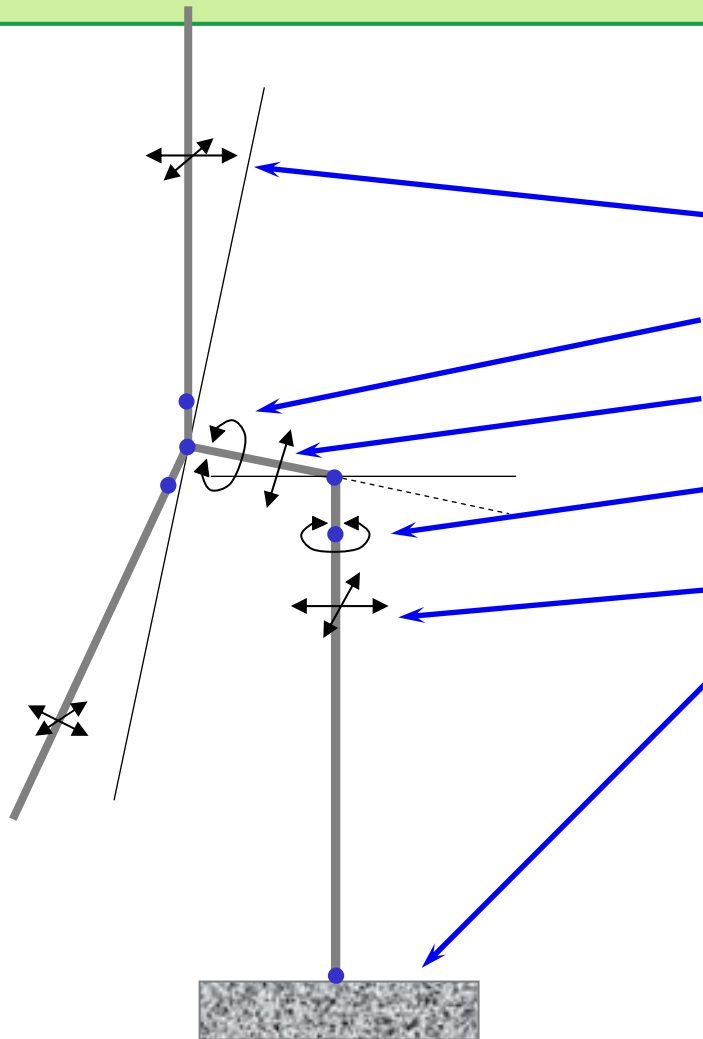
## Simulation Code „SI-WEC“



**Aims for development (supported by TIFA-363):**

- **Start from scratch, use efficient algorithms from comp. mech. (✓)**
- **User-definable number of DOF (✓)**
- **Strictly modular design (✓)**
- **Fast new ODE solver, effective error control, variable DOF (✓)**
- **Detailed on-shore foundation model (acc. To Hsieh/Lysmer) (✓)**
- **Improved aerodynamic model (in progress)**
- **Offshore modul (in progress)**
- **Final aim: Create a software (including pre- and postprocessing) for fast and accurate WEC simulation**

# Simulation Code „SI-WEC“



## Degrees of Freedom

Blades flap, edge, N modes

Drive train rotation + torsion, 2 DOF

Nacelle tilt, 1 DOF

Tower torsion, 1 DOF

Tower bending 2 directions, N modes

Foundation 6 DOF

e.g. with 2 blade + 3 tower modes

$\Sigma = 28$  DOF ; speed about 1 : 10

# Earthquake Loads on Wind Turbines

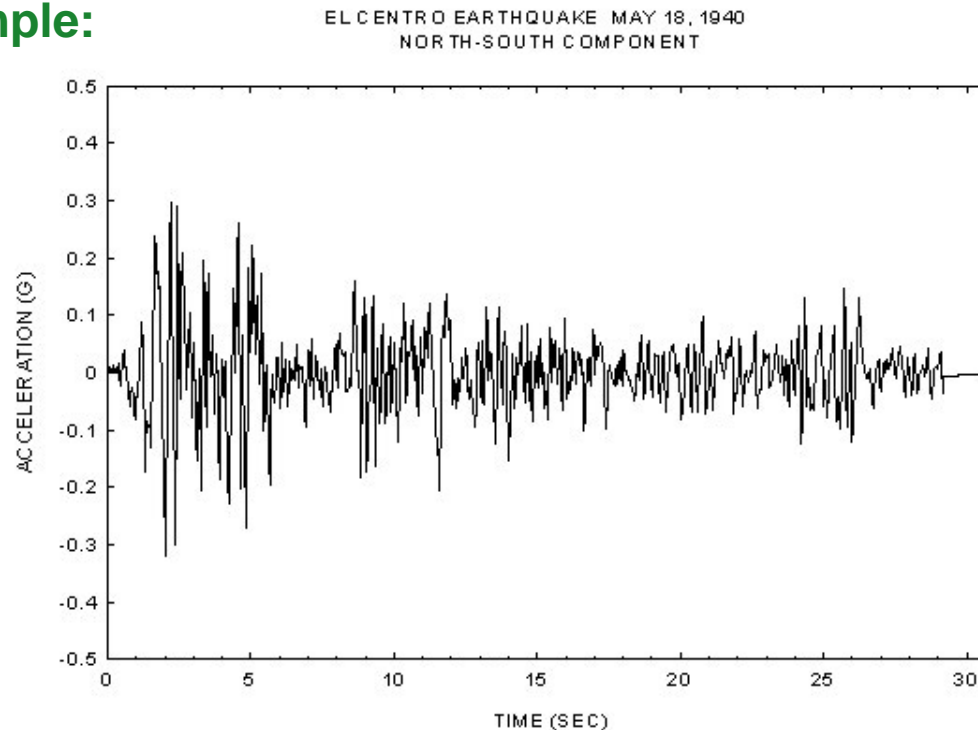


- Many wind farms in areas with strong earthquakes (Japan, China, ...)
- Earthquake: ground motion leads to structural vibrations and loads, earthquake loads should not exceed design loads
- Consequence: earthquake loads have to be calculated in order to assess whether a given wind turbine is suitable for a site or whether design modifications are necessary

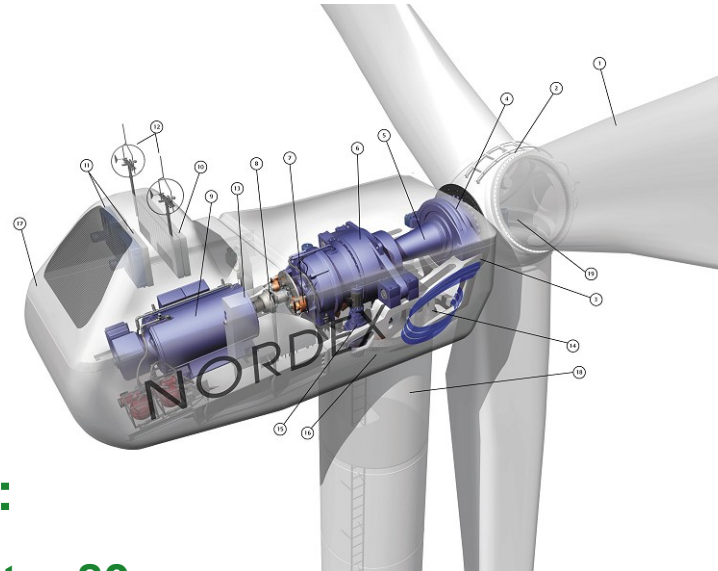
# Earthquake Loads on Wind Turbines



- Classification of earthquake by peak ground acceleration
- Example: Ryuyo-Cho (Japan) with peak acceleration of 0.3 g (on average once during 475 years, MM scale IX, Richter scale ~ 7)
- Example:



# Earthquake Loads on Wind Turbines



## Nordex N80:

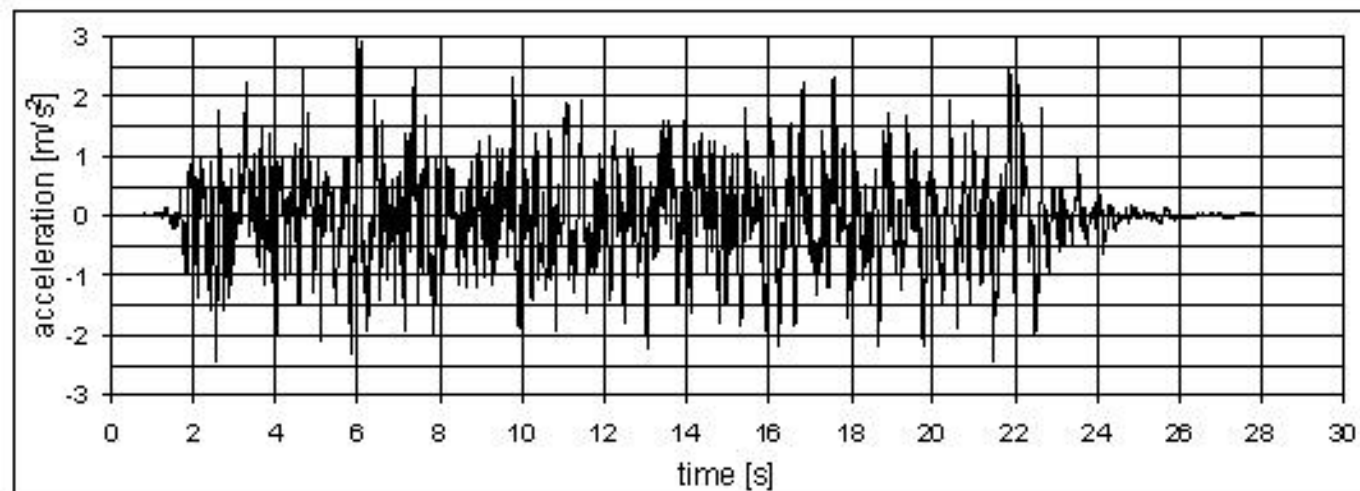
- Rotor diameter 80 m
- Rated power 2500 kW, variable speed, pitch-regulated
- Hub height Ryuyo Cho 60 m
- Certified for IEC1A site



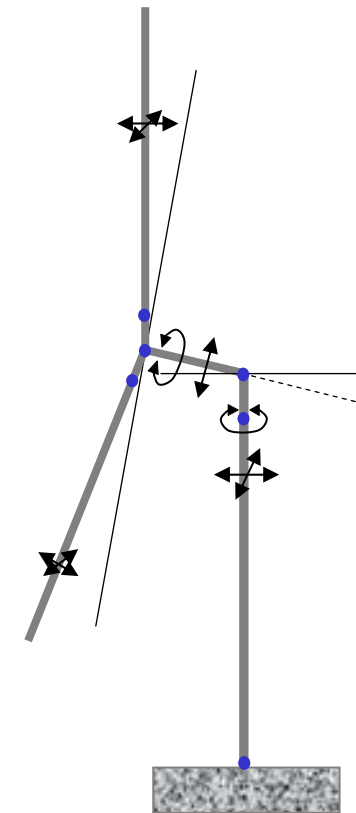
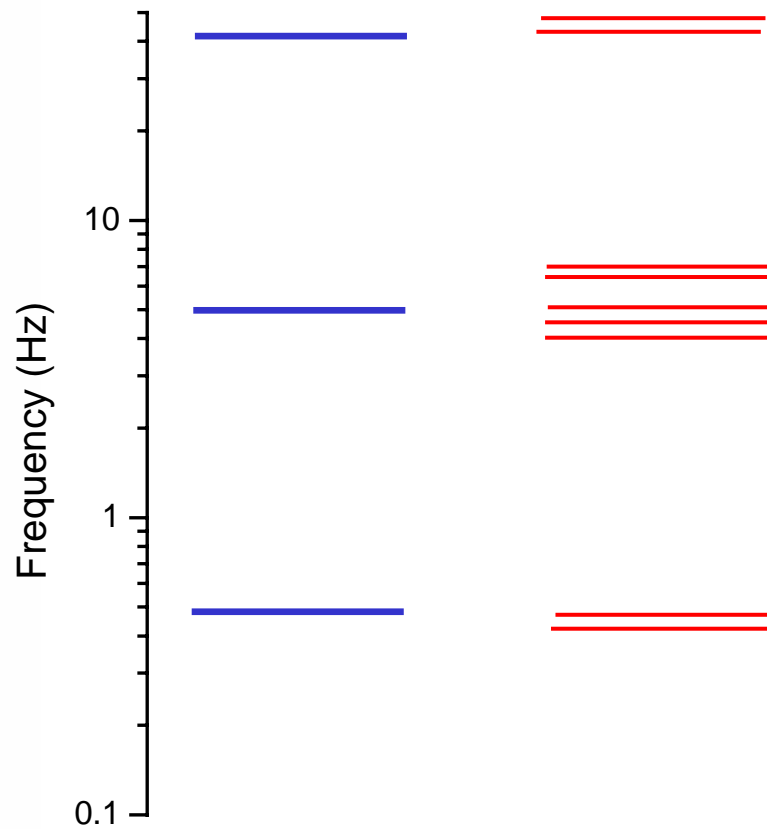
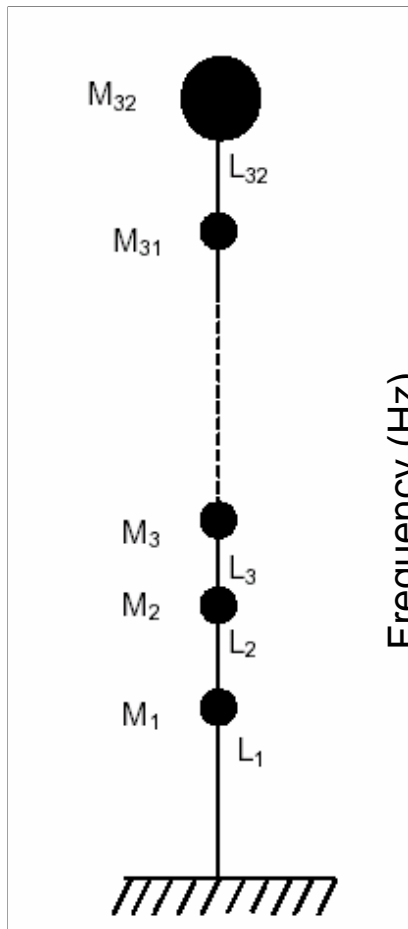
# Earthquake Loads on Wind Turbines



- Generate 3-D realistic synthetic accelerograms
- Specified in standards e.g. Eurocode 8 ...
- Include accelerograms in SI-WEC as ground acceleration

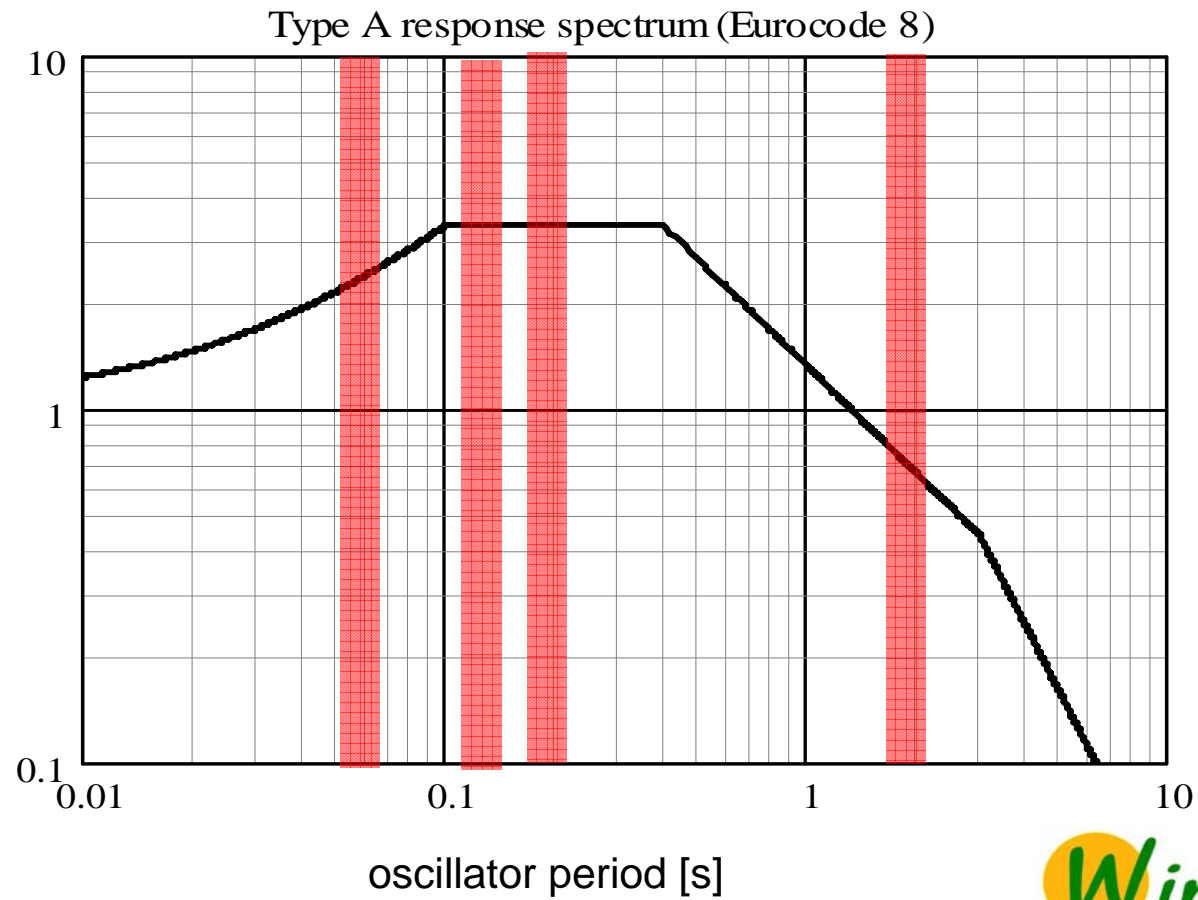


# Earthquake Loads on Wind Turbines



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# Earthquake Loads on Wind Turbines



# Earthquake Loads on Wind Turbines



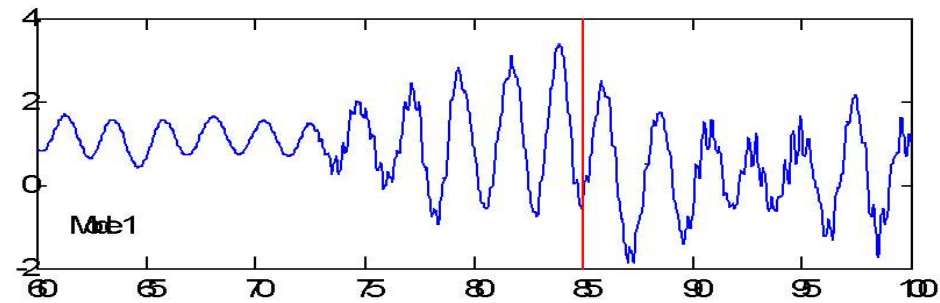
## We need for earthquake analyses

- Detailed description of tower / foundation dynamics
- To be consistent with building standards (85% of mass,  $\geq 3$  modes)
- Detailed picture of machine and blade loads
- Reliable results for accelerations in the nacelle

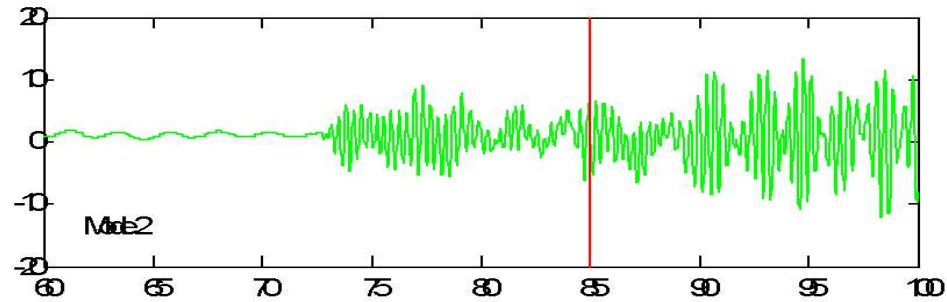
# Earthquake Loads on Wind Turbines



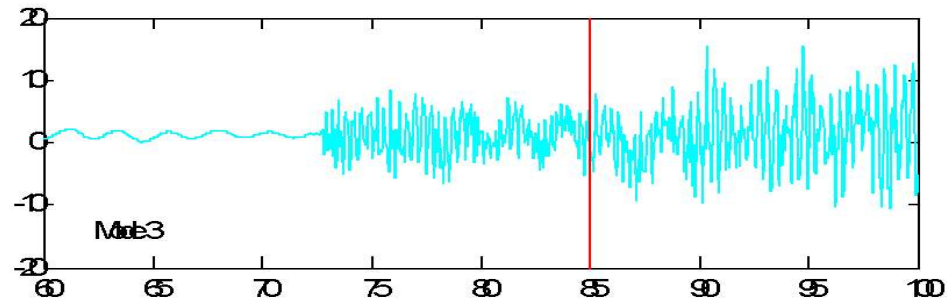
1. Mode



2. Mode



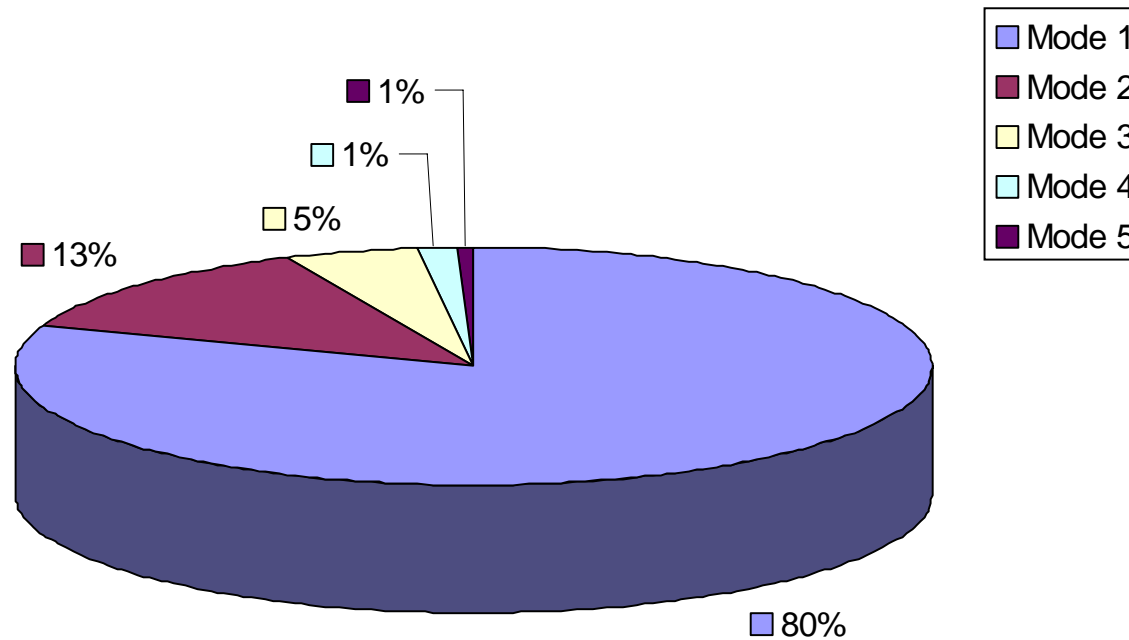
3. Mode



# Earthquake Loads on Wind Turbines



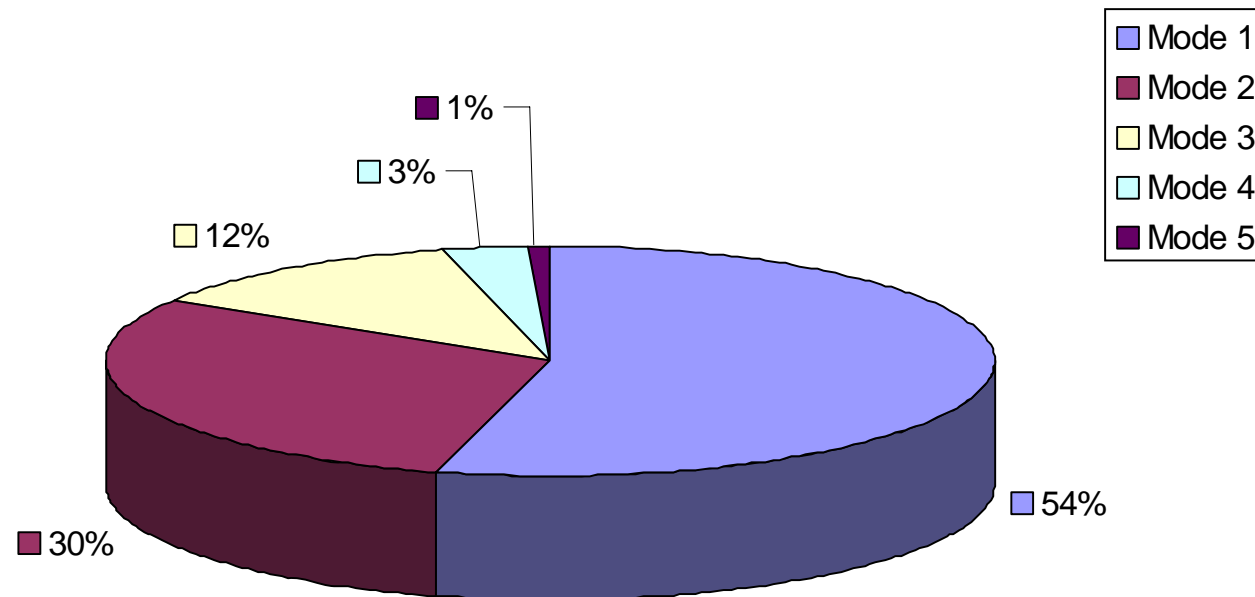
Modal Energy Distribution of Tower production at rated wind speed



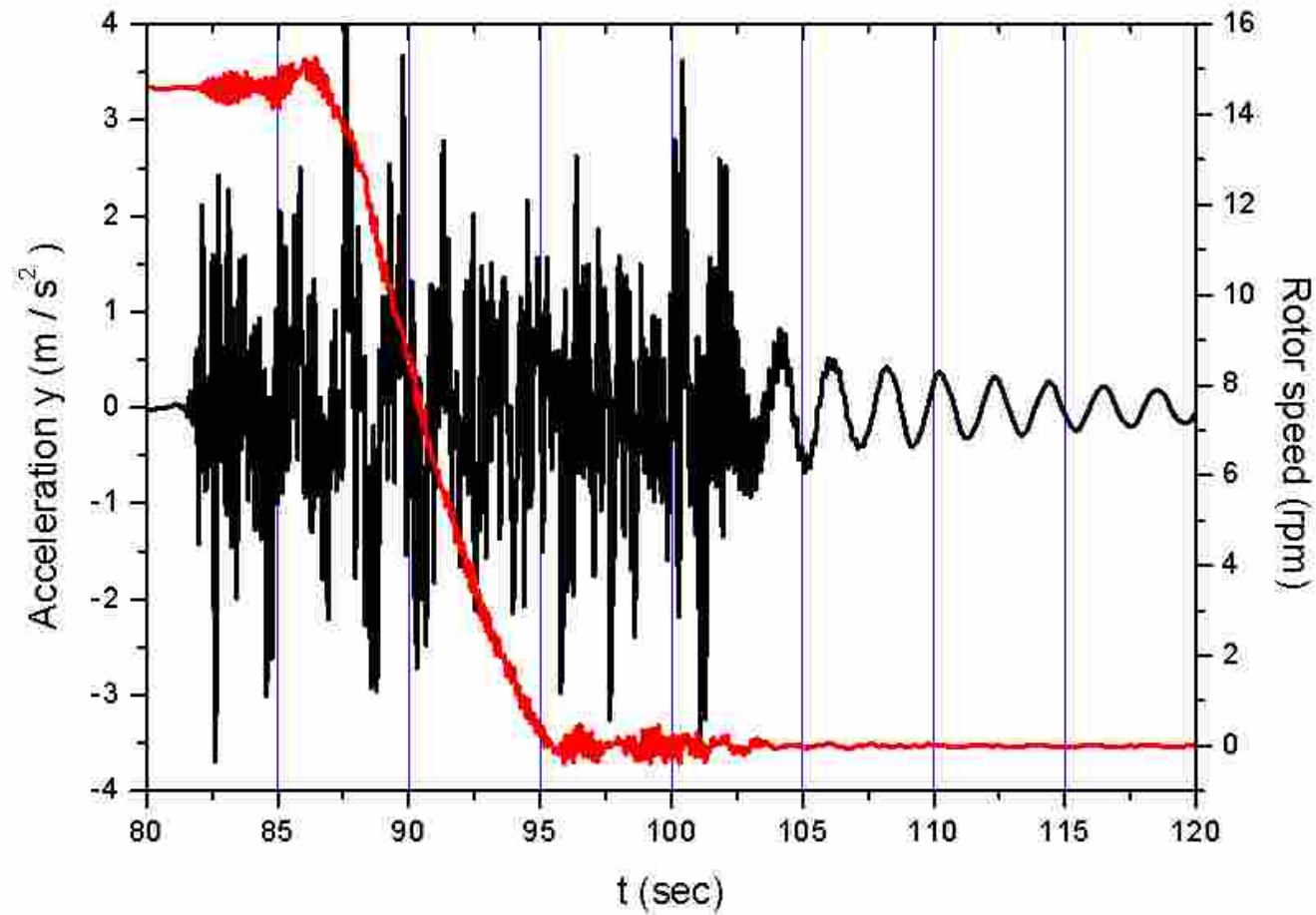
# Earthquake Loads on Wind Turbines



Modal Energy Distribution of Tower during earthquake



# Earthquake Loads on Wind Turbines





# Earthquake Loads on Wind Turbines



## With SI-WEC

- Synthetic accelerograms according to various standards
- Requirements of standards for analysis of tower/foundation loads can be fulfilled (85 % of system mass, at least 3 tower modes)
- Accurate results for modes of the system
- Accurate results for tower/foundation dynamics and loads
- Detailed picture of machine and blade loads obtained

# Outlook



- Completion of aerodynamics
- And pre- and post-environment
- Validation with measurements / User interface
- Offshore foundations



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