NORDEX-ACCIONA Windpower: Seismic Loading Analysis

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Agenda

1 Nordex-Acciona Windpower Overview

2 Wind farm in Seismic areas

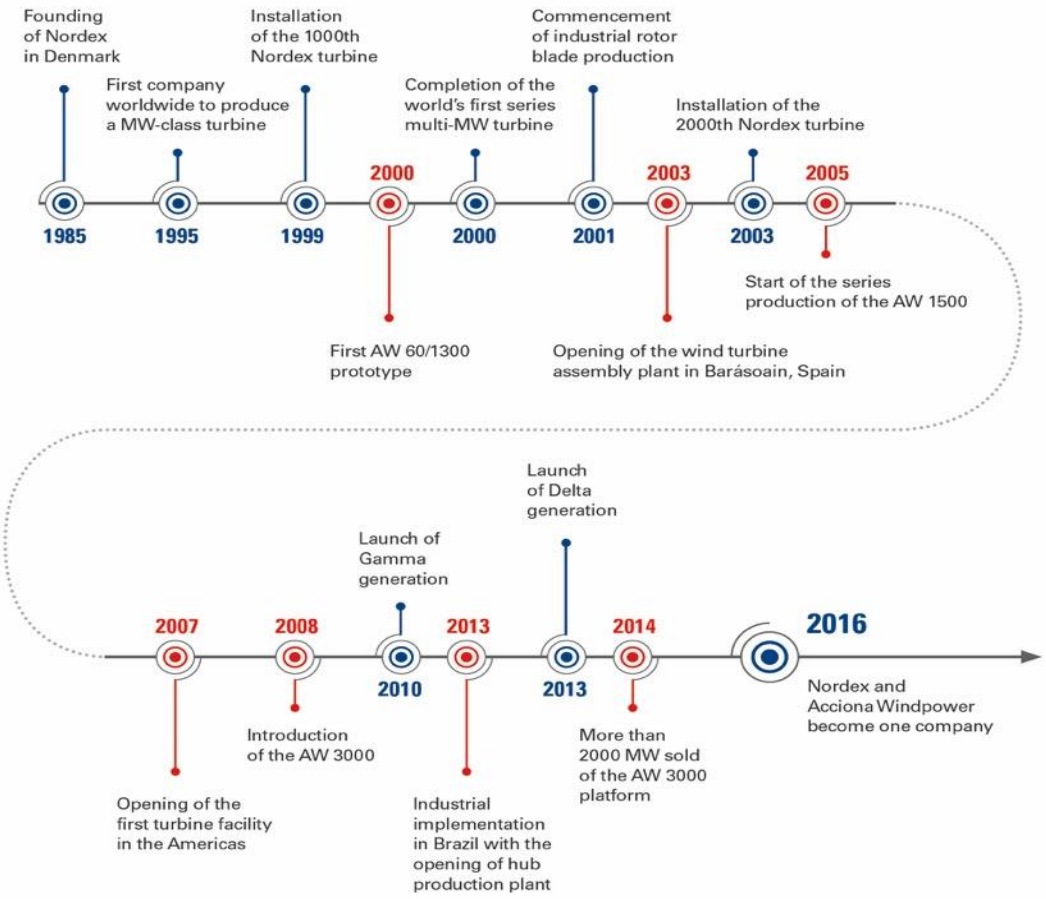
3 Standards and guidelines

4 Vertical seismic calculation with Bladed

5 Conclusions

Nordex-Acciona Windpower Overview

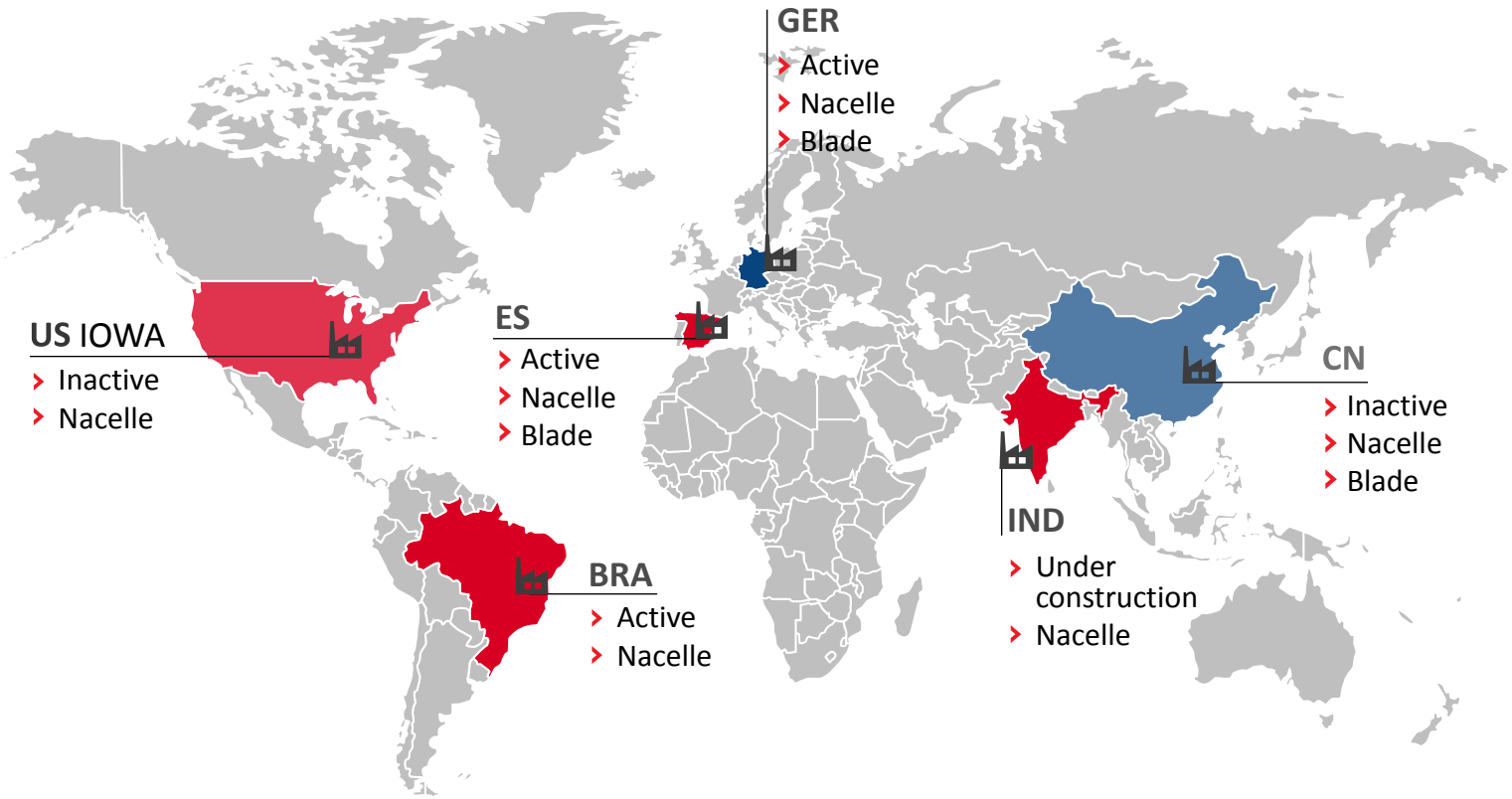
- WHO WE ARE
  We have come a long way



Nordex-Acciona Windpower Overview

- WHERE WE ARE
  Joint company profile - Production footprint

GOOD GEOGRAPHIC FIT FOR PRODUCTION PURPOSES



Manufacturing site | **N:** Nacelle manufacturing | **B:** Blades manufacturing | * Tower design with on-site manufacturing not displayed

Nordex-Acciona Windpower Overview

- WHERE WE ARE
  Track Record

acciona Windpower
Installed capacity:
5,928.10 MW

NORDEX
Installed capacity:
14,842.95 MW

Total installed capacity: **20,771.05 MW**

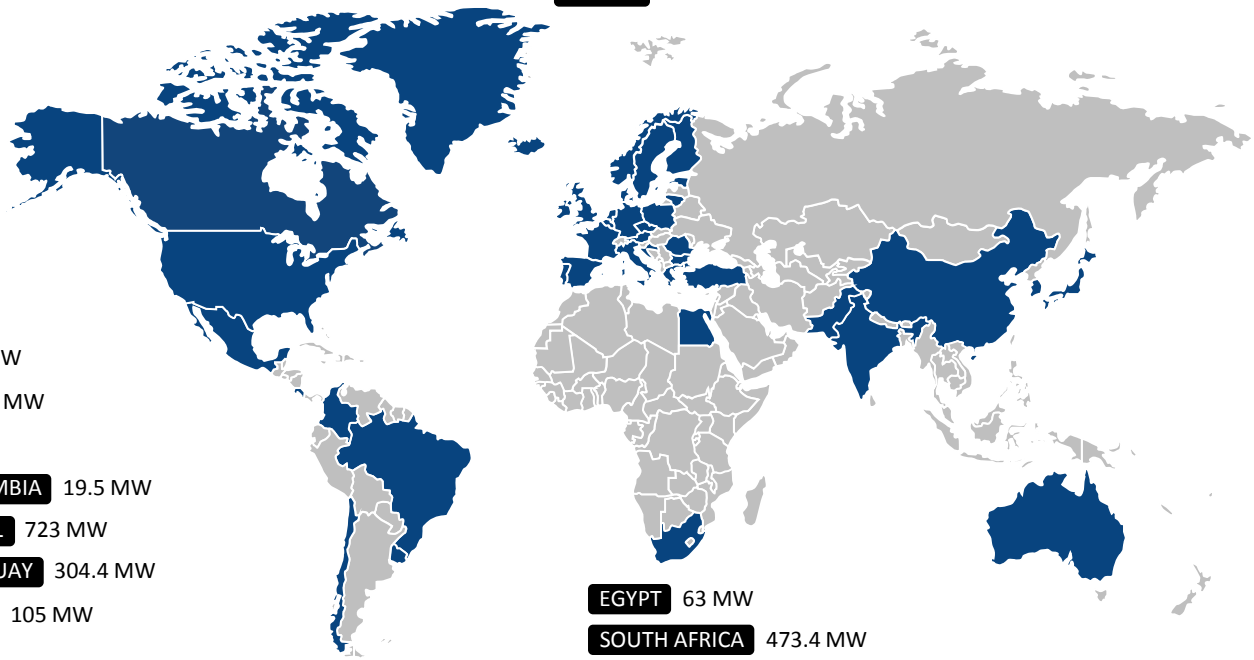
SPAIN 1,913.3 MW
FRANCE 1,625.35 MW
PORTUGAL 402.1 MW
ITALY 669.1 MW

UK 1,357.2 MW
IRELAND 581.2 MW
GERMANY 3,584.35 MW
POLAND 446.25 MW

ROMANIA 100 MW
CZECH REPUBLIC 12 MW
BULGARIA 7.7 MW
CROATIA 30 MW
GREECE 124.85 MW

NORWAY 150 MW
SWEDEN 435.1 MW
FINLAND 344.1 MW
DENMARK 151.85 MW

BELGIUM 57.5 MW
NETHERLANDS 271.9 MW
ESTONIA 18.4 MW
LITHUANIA 115.2 MW



CANADA 203 MW
USA 2,211.55 MW

MEXICO 895.5 MW
COSTA RICA 49.5 MW

COLOMBIA 19.5 MW
BRAZIL 723 MW
URUGUAY 304.4 MW
CHILE 105 MW

EGYPT 63 MW
SOUTH AFRICA 473.4 MW

TURKEY 1,521.8 MW
PAKISTAN 299.5 MW
INDIA 57.85 MW
CHINA 1,053.1 MW
JAPAN 73.1 MW
SOUTH KOREA 64.5 MW

AUSTRALIA 238.5 MW

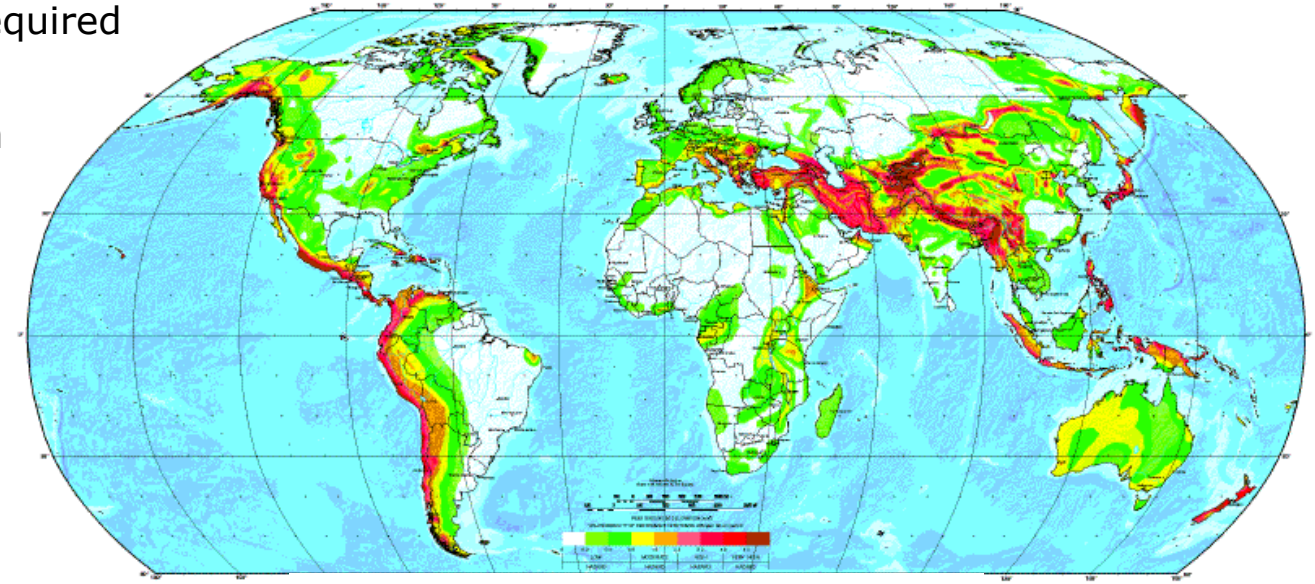
OTHERS 11.7 MW


Nordex Turbines

El Perdón wind farm (20 MW) in Navarre (Spain). The first one installed by the Group (1994-1996)

Wind farm in Seismic areas

- Most earthquakes are small
- Large earthquakes are rare => significant risk of damage to civil structures.
- The return period is often measured in hundreds or thousands of years
- Some wind farms are installed in seismic active regions: China, India, California, Mexico, Chile, Peru,…
- Seismic analysis is only implemented in the design process if the site is in regions of highly seismic hazard or if it is required by local authorities.
- Wind energy developers in earthquake-prone regions can mitigate this risk with appropriate:
  - Design margins
  - Site selection
  - Insurance



GLOBAL SEISMIC HAZARD MAP

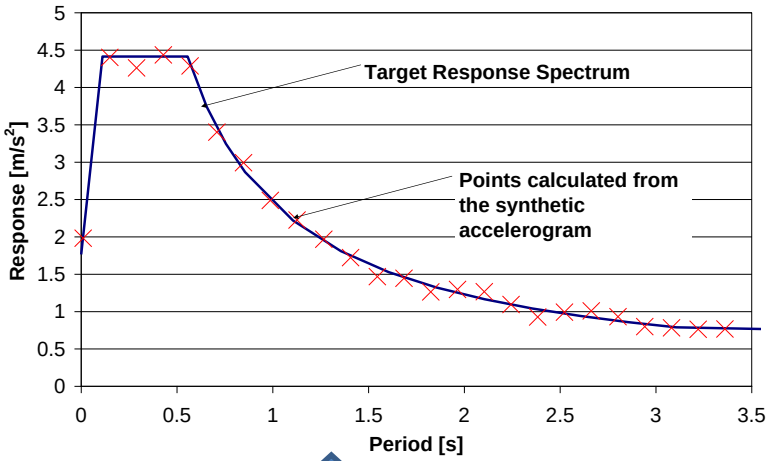
Standards and guidelines

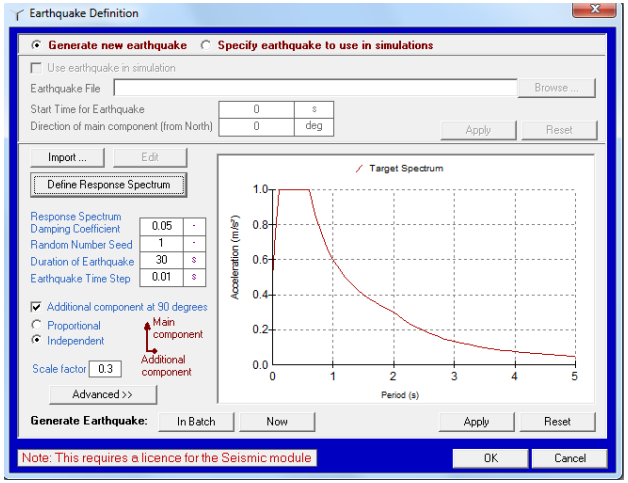
- Three main standards or guidelines provide direct guidance for seismic loading of wind turbines:
  - **Guidelines for Design of Wind Turbines (Risø, 2001)**
  - **Guideline for the Certification of Wind Turbines (GL, 2010)**
  - **IEC 61400-1 Ed.3: Wind turbines - Part 1: Design requirements (IEC, 2005).**
- Also there are building codes, can be used to inform earthquake analysis of wind turbines, but do not directly address wind turbines:
  - **Local building codes of each country**
  - **DIN EN 1998, Eurocode 8, Design of structures for earthquake resistance**
  - **American Petroleum Institute (API): Recommended Practice for Design and Construction of Fixed Offshore Platforms, PR 2A, chapter 2.3.6: Earthquake, Washington, 2000.**

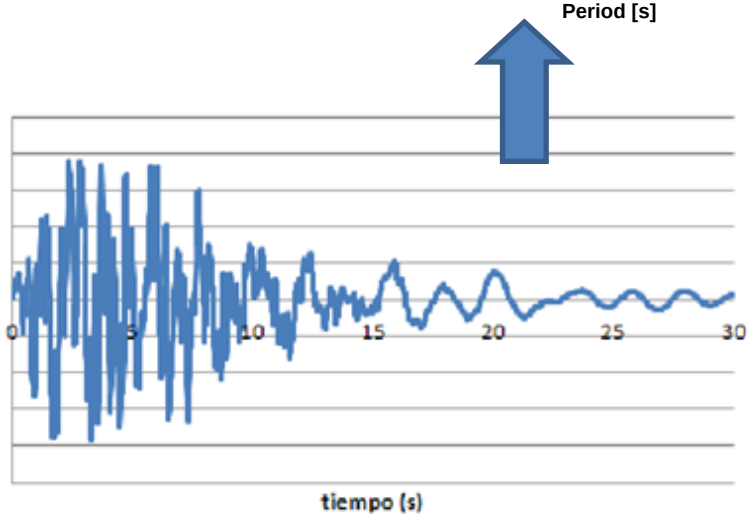
Vertical seismic calculation with Bladed

Generation Accelerograms in Bladed 4.3

- The Bladed calculation is in the time domain:
- Iterative process to calculate the accelerogram:
  - Define a target response spectrum
  - Compute response spectrum
  - Compare against Target Response Spectrum
  - Check convergence criteria
  - Scale in the frequency domain
  - Peak correction



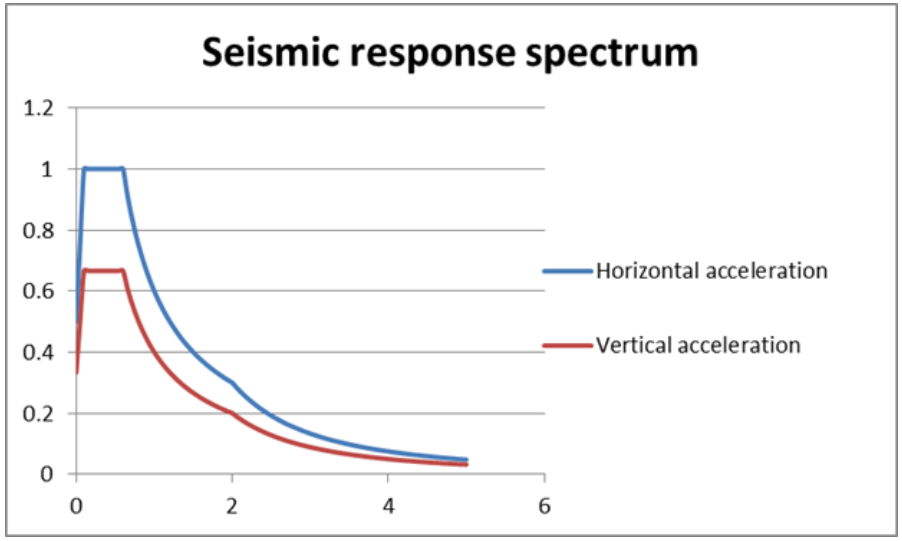




Vertical seismic calculation with Bladed

Combination Horizontal + Vertical spectrum: Eurocode 8

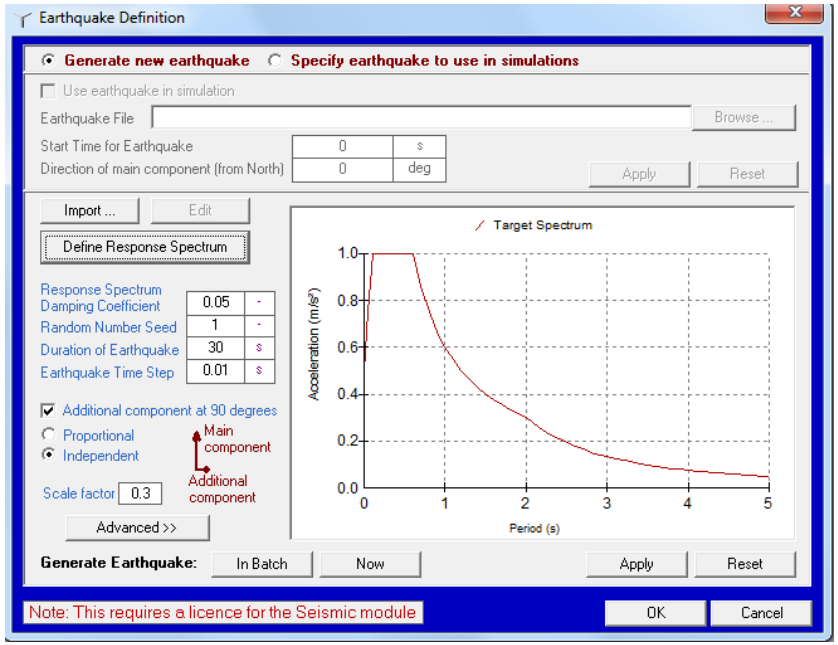
- 4.3.3.5 Combination of the effects of the components of the seismic action
  - 4.3.3.5.1 Horizontal components of the seismic action
    - *E*Edx "+" 0.30 *E*Edy
    - 0.30 *E*Edx "+" *E*Edy
  - 4.3.3.5.2 Vertical component of the seismic action
    - *E*Edx "+" 0.30 *E*Edy "+" 0.30 *E*Edz
    - 0.30 *E*Edx "+" *E*Edy "+" 0.30 *E*Edz
    - 0.30 *E*Edx "+" 0.30 *E*Edy "+" *E*edz



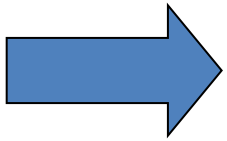
Vertical seismic calculation with Bladed

Horizontal + Vertical spectrum generation in Bladed 4.3

- Calculate the spectrum horizontal direction
- Calculate the spectrum vertical direction
- New file .qke , there are only two changes:
  - Add the line NDOF 6 to the *.qke file
  - Add a further 4 columns of data corresponding to the remaining DoF
- The order of DoFs is (in global coordinates): X, Y, Z, X-rot, Y-rot, Z-rot




```
POINTS        3000
TSTEP  0.01000000
    0.000000     0.000000
   -0.112093    -0.126859
    0.462325    -0.118394
    0.262743    -0.119340
    0.368637    -0.132403
    0.307178    -0.142032
    0.340905    -0.139117
    0.301058    -0.133785
    0.315934    -0.125451
    0.188863    -0.120925
    0.207988    -0.118165
```



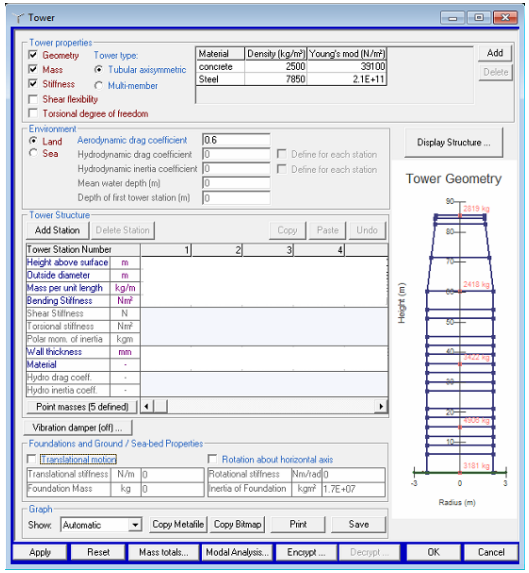
```
POINTS        3000
TSTEP  0.01000000
NDOF 6
    0.000000     0.000000     0.000000     0.000000  0  0
   -0.112093    -0.126859    -0.481636     0.000000  0  0
    0.462325    -0.118394    -0.156665     0.000000  0  0
    0.262743    -0.119340    -0.266870     0.000000  0  0
    0.368637    -0.132403    -0.163013     0.000000  0  0
    0.307178    -0.142032    -0.190699     0.000000  0  0
    0.340905    -0.139117    -0.102082     0.000000  0  0
    0.301058    -0.133785    -0.128333     0.000000  0  0
    0.315934    -0.125451    -0.037813     0.000000  0  0
    0.188863    -0.120925    -0.083695     0.000000  0  0
    0.207988    -0.118165    -0.043981     0.000000  0  0
```

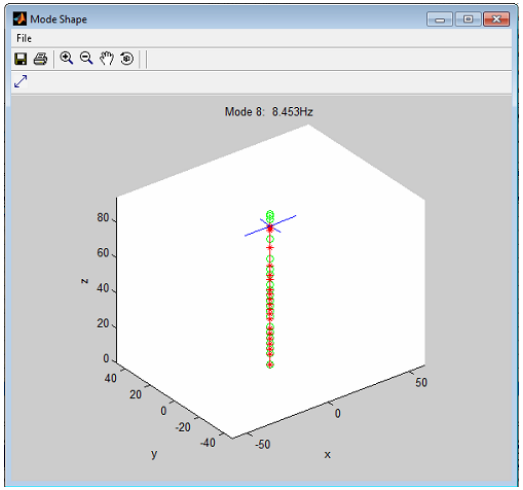
Vertical seismic calculation with Bladed

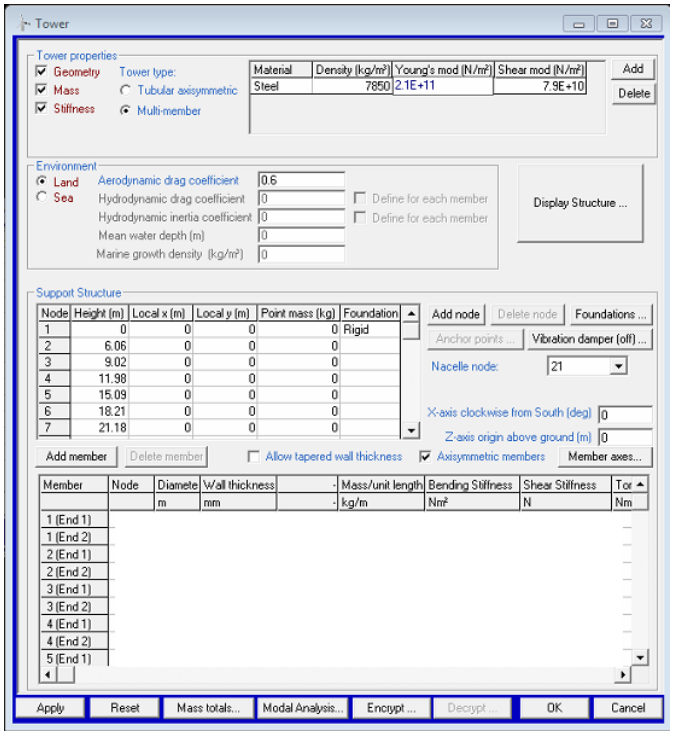
Tower Model

- Tower Tubular axisymmetric:
- No Vertical modes

- Tower multi-member
- Axial stiffness definition => Vertical modes
- Offshore support structure license necessary



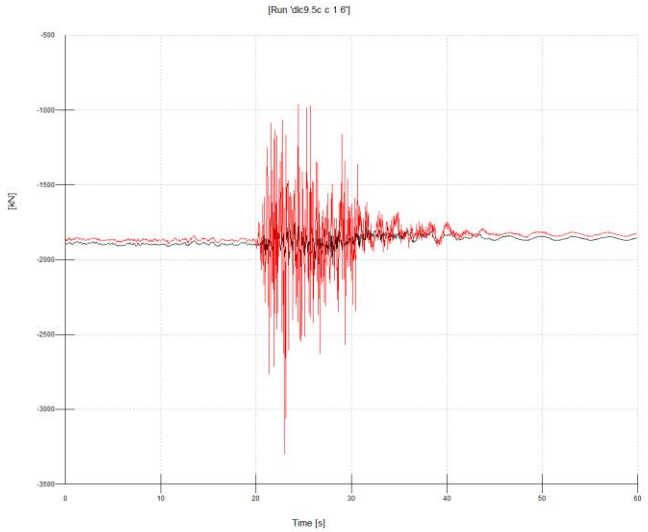




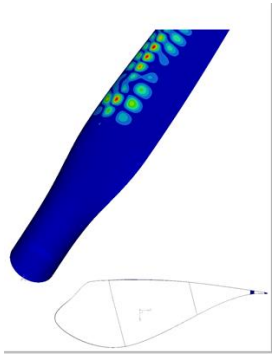
Vertical seismic calculation with Bladed

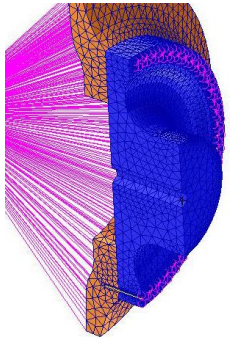
Results

- Important differences between Horizontal vs Horizontal + Vertical and taking into account the vertical mode of the tower.
  - Tower Fz
  - Hub Fz
  - Blade Fz
- No driving sensors



- Revision in some components
  - Foundations
  - Verification tower buckling
  - Hub-Main shaft bolted joined
  - Verification blade buckling





Conclusions

- The assessment of the seismic loads is important in some locations.
- The response spectrums are defined by the local codes.
- The guideline GL2010 recommends some seismic load cases to calculate
- Bladed is an adequate tool to calculate the seismic and aero elastic loads coupled
- The vertical mode of the tower has influence in the vertical earthquake
- The vertical spectrum has influence in the Fz: Not driving sensor, but attention should be taken.

Thanks for your attention

Together
on the same course

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