Frequency Domain Fatigue

in the Design of Support Structures for Offshore Wind Turbines

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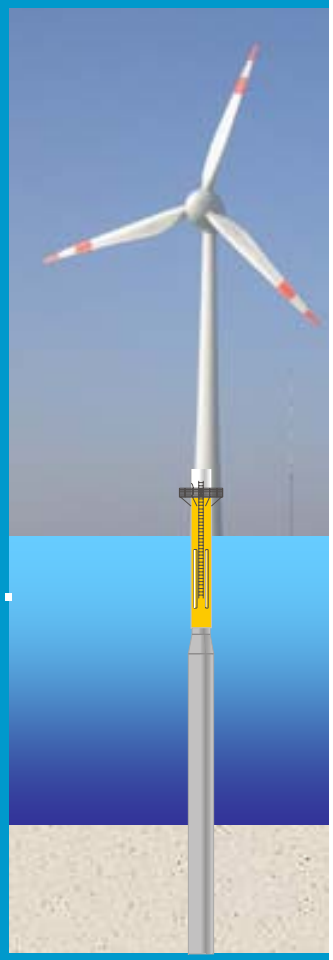
Larger turbines, deeper water

- Blyth: 0.47 Hz → 2 sec. period
- E112, 500t: 0.20 Hz → 5 sec. period
- waves: periods between 3 and 10 sec.



Fatigue is and will increasingly be a design driver

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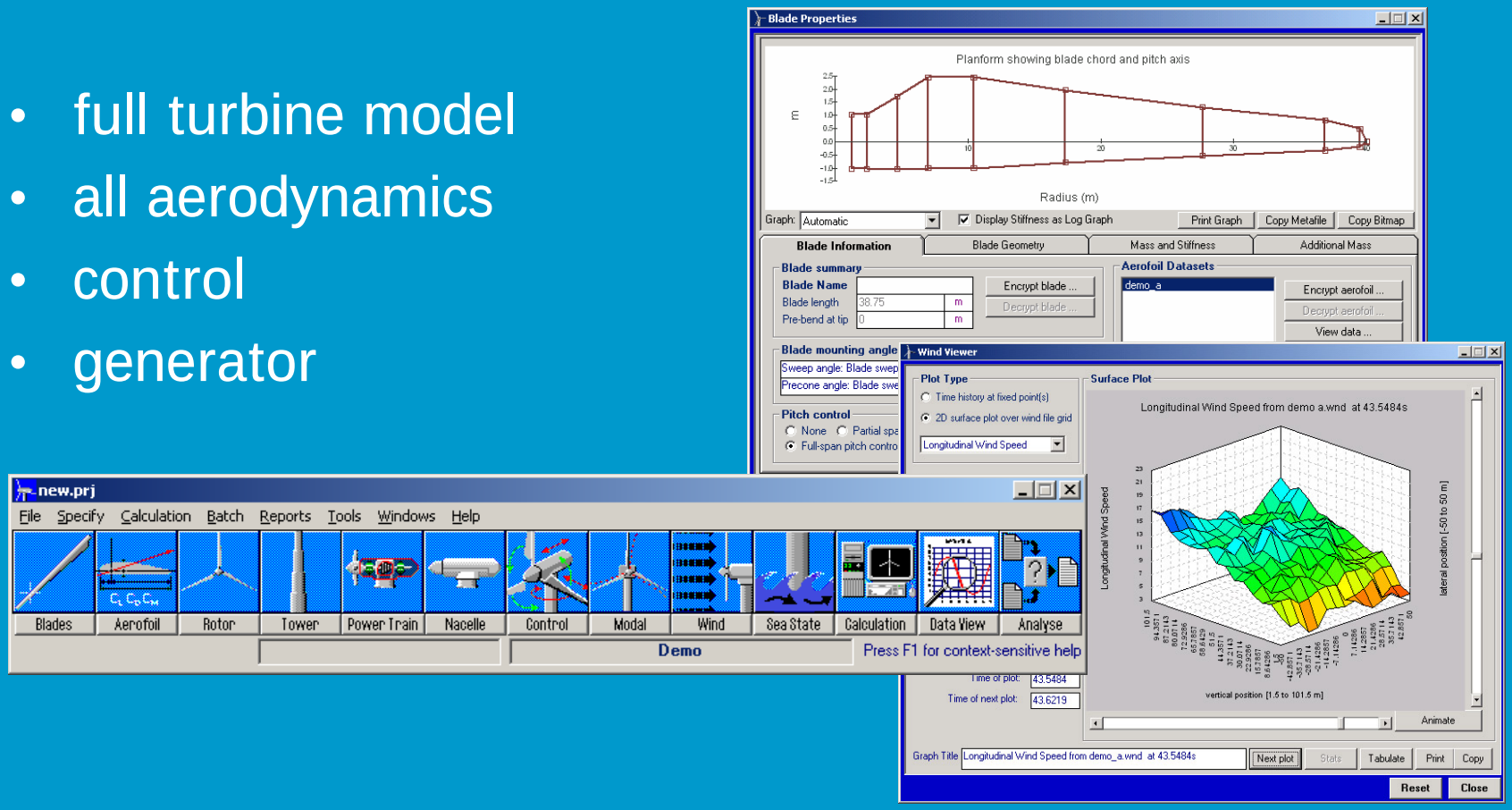
Current method: Time Domain

- full turbine model
- all aerodynamics
- control
- generator



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Current method: Time Domain

- loads are non-linear: related to V^2
- rotating system
- all details should be incorporated

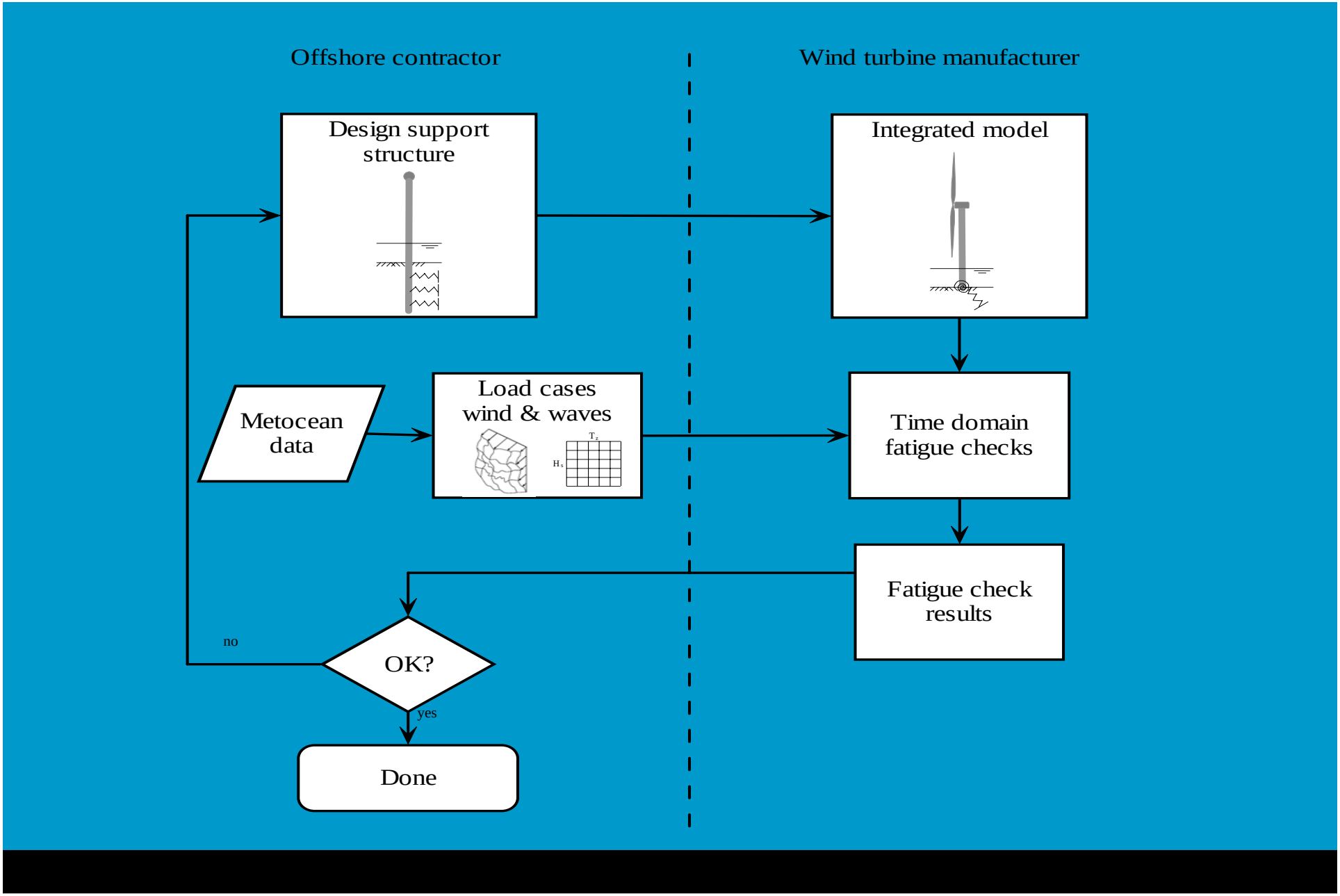
- > 100 load combinations of wind and waves
- 5 x 20 minutes or 1 x 60 min, expert opinions differ

- total time for 1 fatigue check: 12 - 24 - 48 hours

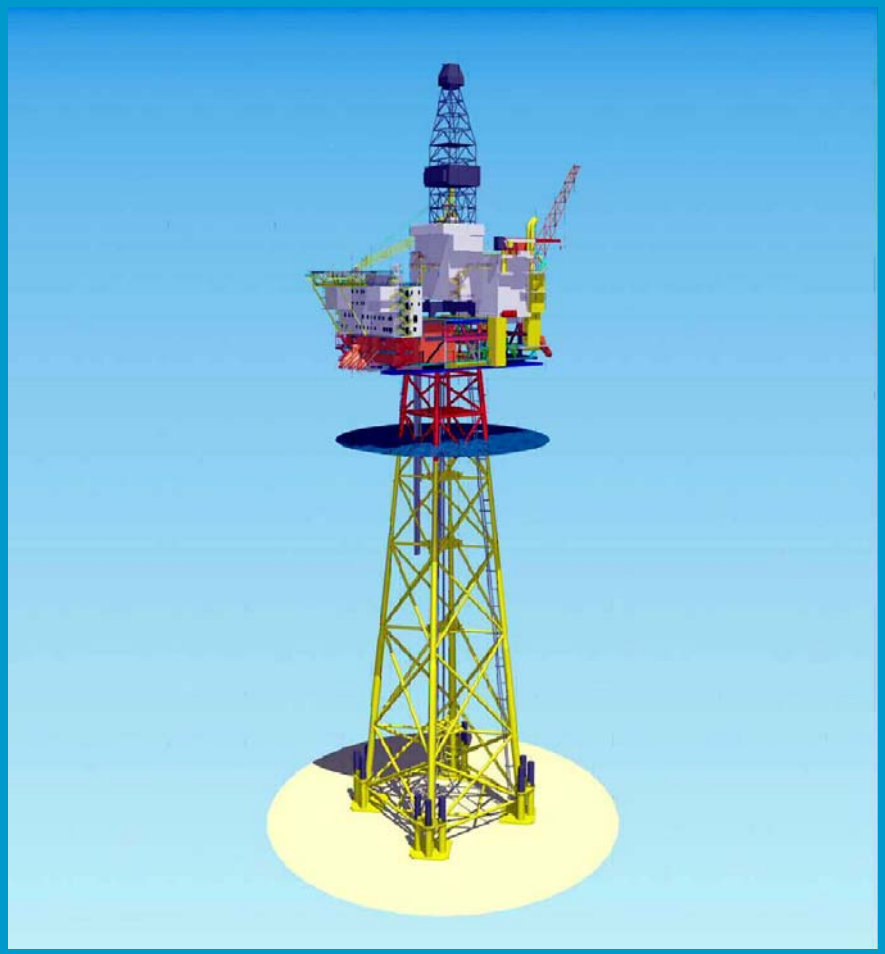
Current method: Time Domain

- Offshore contractor does not have specialist software
- Turbine manufacturer reluctant to share details

- No real optimisation of support structures
- Insufficient mutual understanding
- Site specific optimisation very difficult


Offshore contractor
Wind turbine manufacturer
Design support structure
Integrated model
Metocean data
Load cases wind & waves
Time domain fatigue checks
Fatigue check results
no
OK?
yes
Done

Offshore: Frequency Domain



- nat. freq.: 0.25 Hz
- also fatigue driven
- main loading: waves

- Morison equation:
- $F = C_d A u^2 + C_m B u$

- Also non-linear!!

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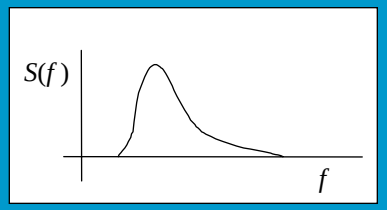
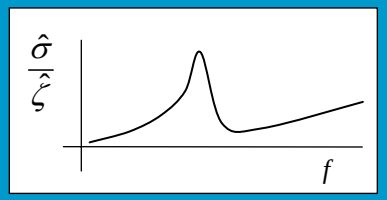
Offshore: Frequency Domain

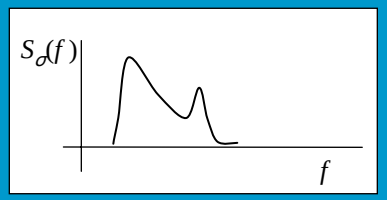
wave spectrum



transfer function



response spectrum



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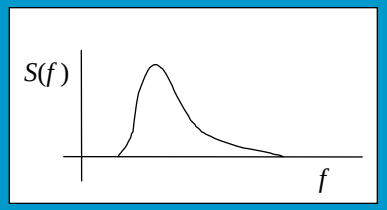
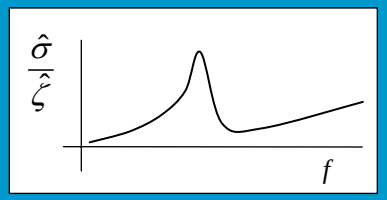
Offshore: Frequency Domain

H_s [m] / T_z [s]	0 - 1	1 - 2	2 – 3	3 – 4	4 – 5	5 - 6	6 - 7	7 - 8	Sum:
6.5 - 7.0									0
6.0 - 6.5								0.1	0.1
5.5 - 6.0							0.1	0.1	0.2
5.0 - 5.5							0.1	0.1	0.2
4.5 - 5.0							1		1
4.0 - 4.5							4		4
3.5 - 4.0						4	5		9
3.0 - 3.5						19	0.1		19.1
2.5 - 3.0					0.1	38			38.1
2.0 - 2.5					27	43			70
1.5 - 2.0				0.1	115	5			120.1
1.0 - 1.5				6	220	1			227
0.5 - 1.0				236	145	1			382
0.0 - 0.5	1		1	113	14	0.1	0.1		129.2
Sum:	1	0	1	355.1	521.1	111.1	10.4	0.3	1000

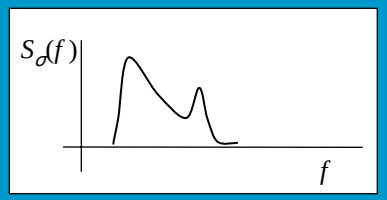
wave spectrum



transfer function



response spectrum



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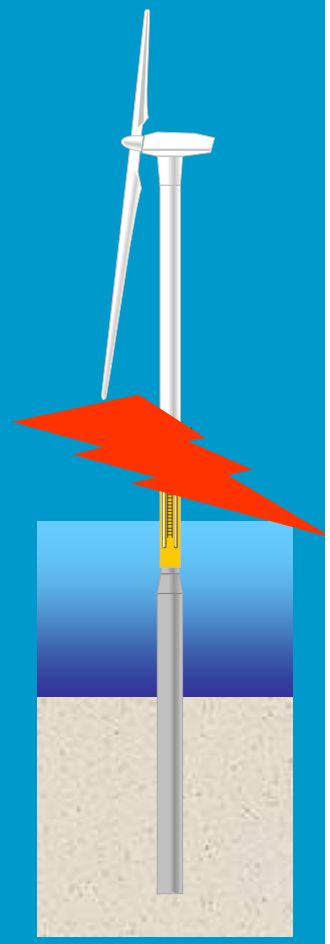
Frequency Domain Calculations

- Calculating time for full scatter diagram, > 100 cases:
  10 s. to 1 minute
- Easy optimisation

New method

Goal:

- Make frequency domain fatigue method
- Restricted information transfer
- But enough to be accurate
- Enhance mutual understanding



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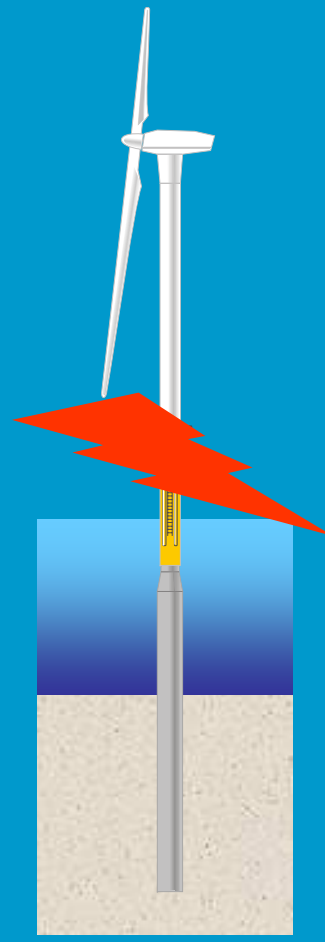
New method

Requirement:

- Leave contractual boundaries
- Shift boundary to bearing



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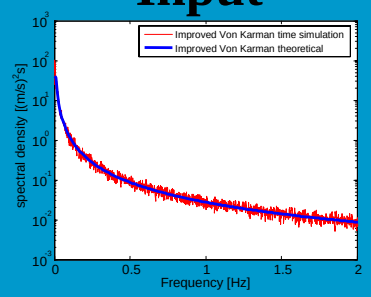
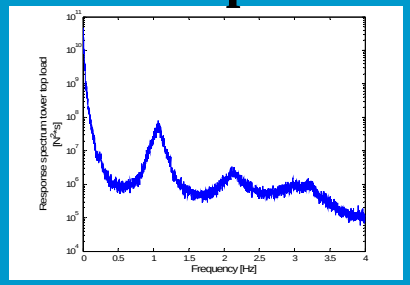
Turbine modelling

- Full time domain
- all wind speed classes: 4, 6, 8 .. 26 m/s
- rigid support: no dynamics
- find tower top force
- transfer to frequency domain

Input



Output



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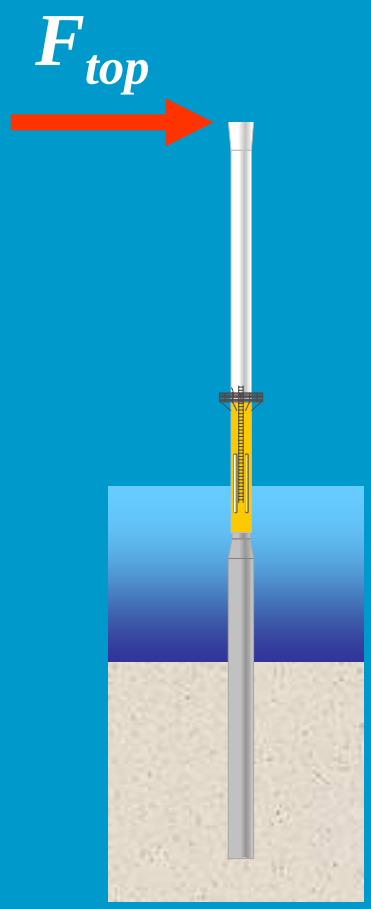
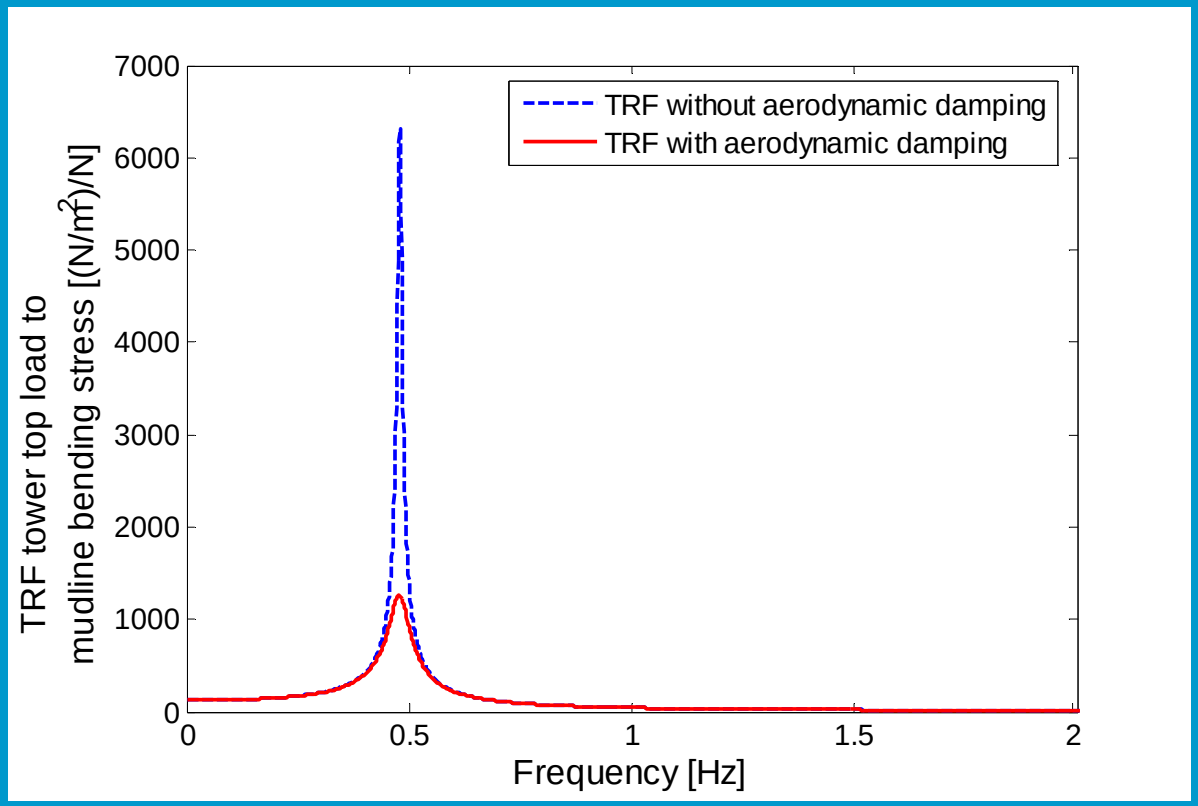
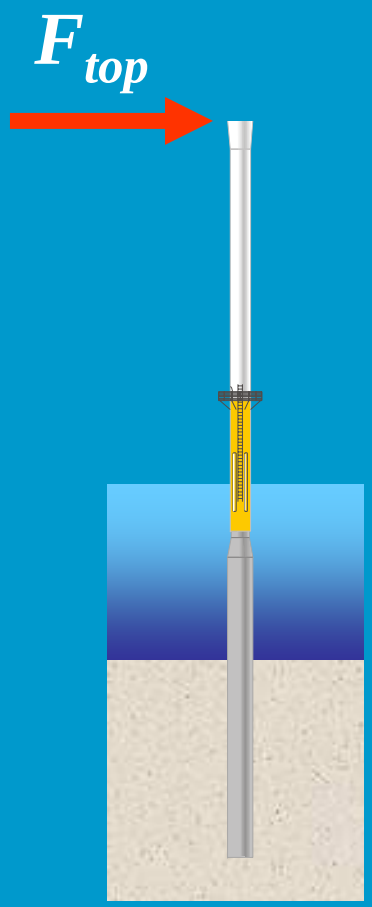
Tower modelling (1/2)

- any FEM program
- select 1 or several spots
- make transfer function for tower top load



Add aerodynamic damping





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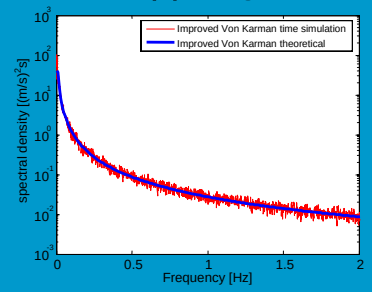
Frequency domain wind stress

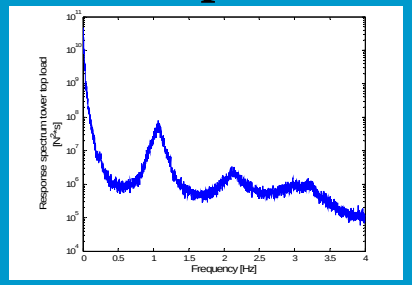
Input

Wind

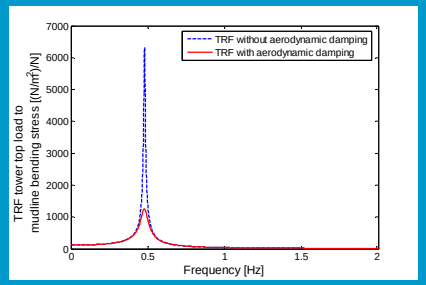


TRF

TRF top force

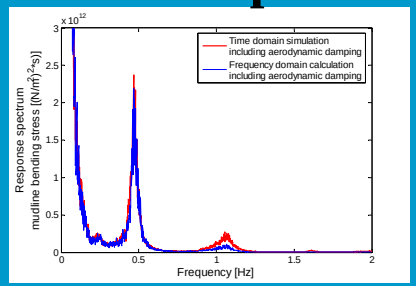


TRF stress



Output

Stress response



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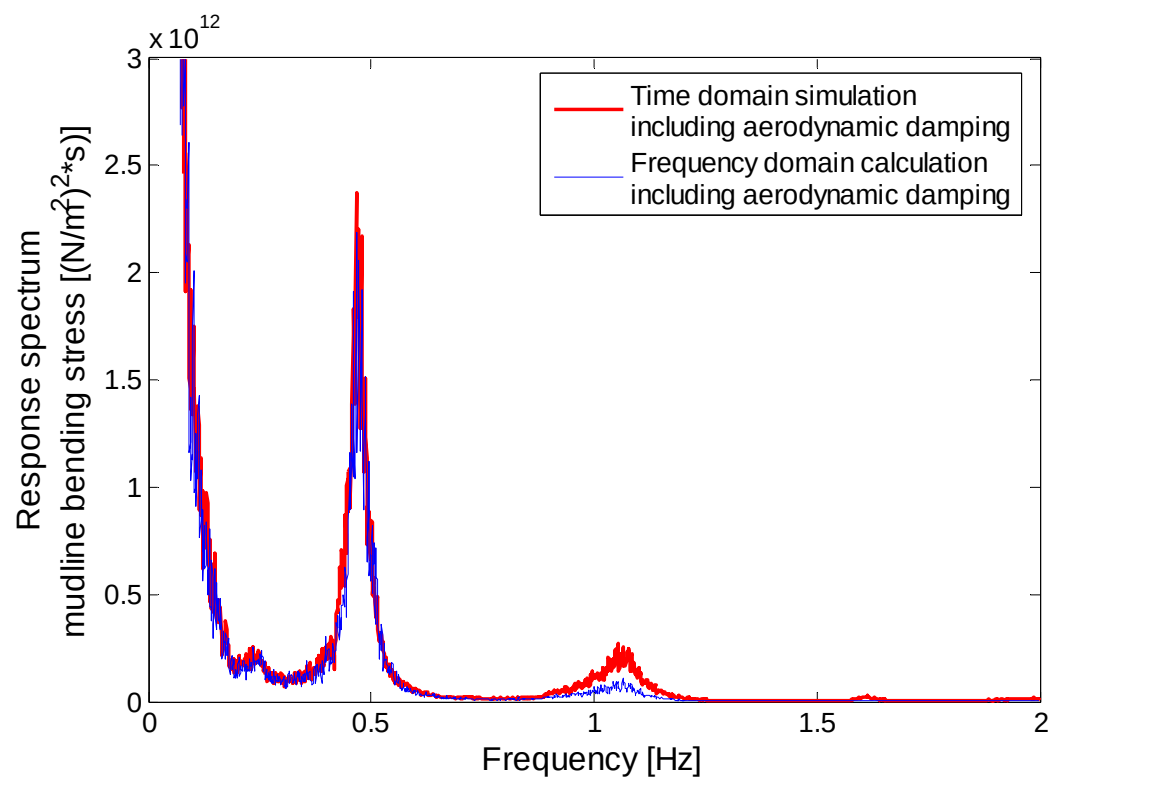
Compare FD - TD

- perfect match
- small deviation at 3P



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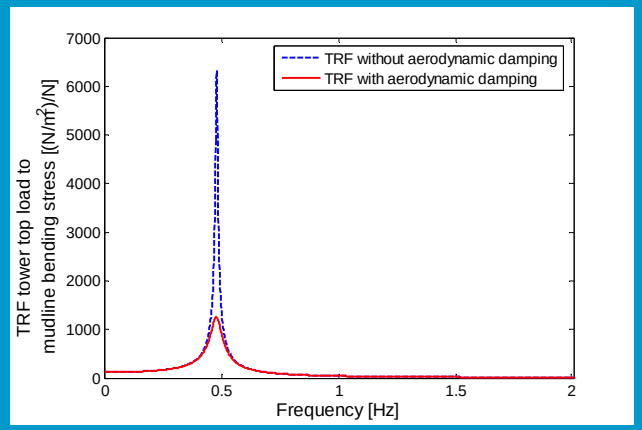
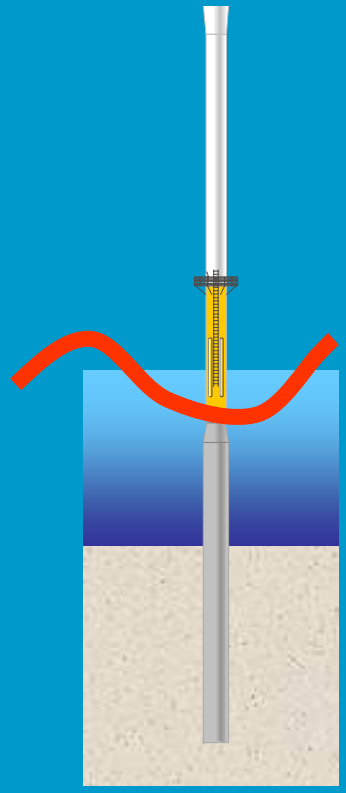
Tower modelling (2/2)

- same FEM program
- select 1 or several spots
- make transfer function for wave load

again:

aerodynamic damping





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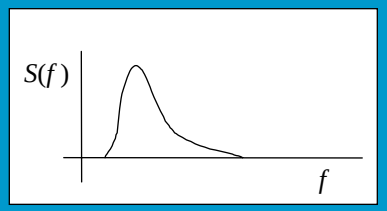
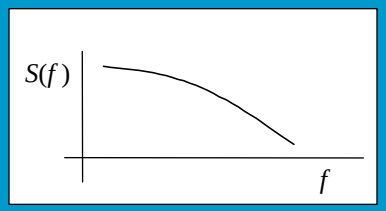
Combining

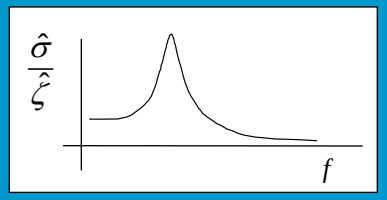
wave spectrum

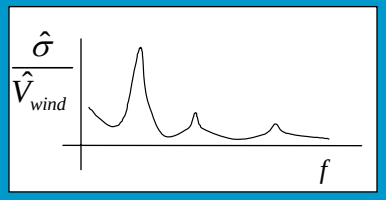




wind spectrum

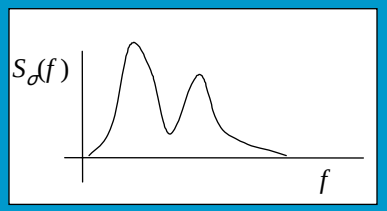
transfer function

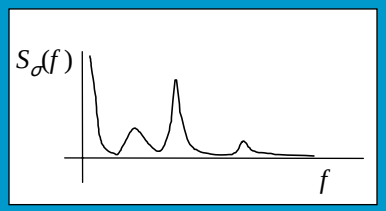




transfer function

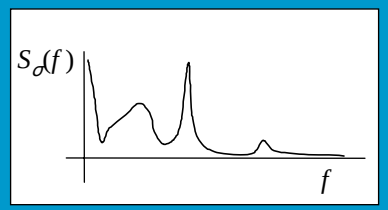
response spectrum





response spectrum

+



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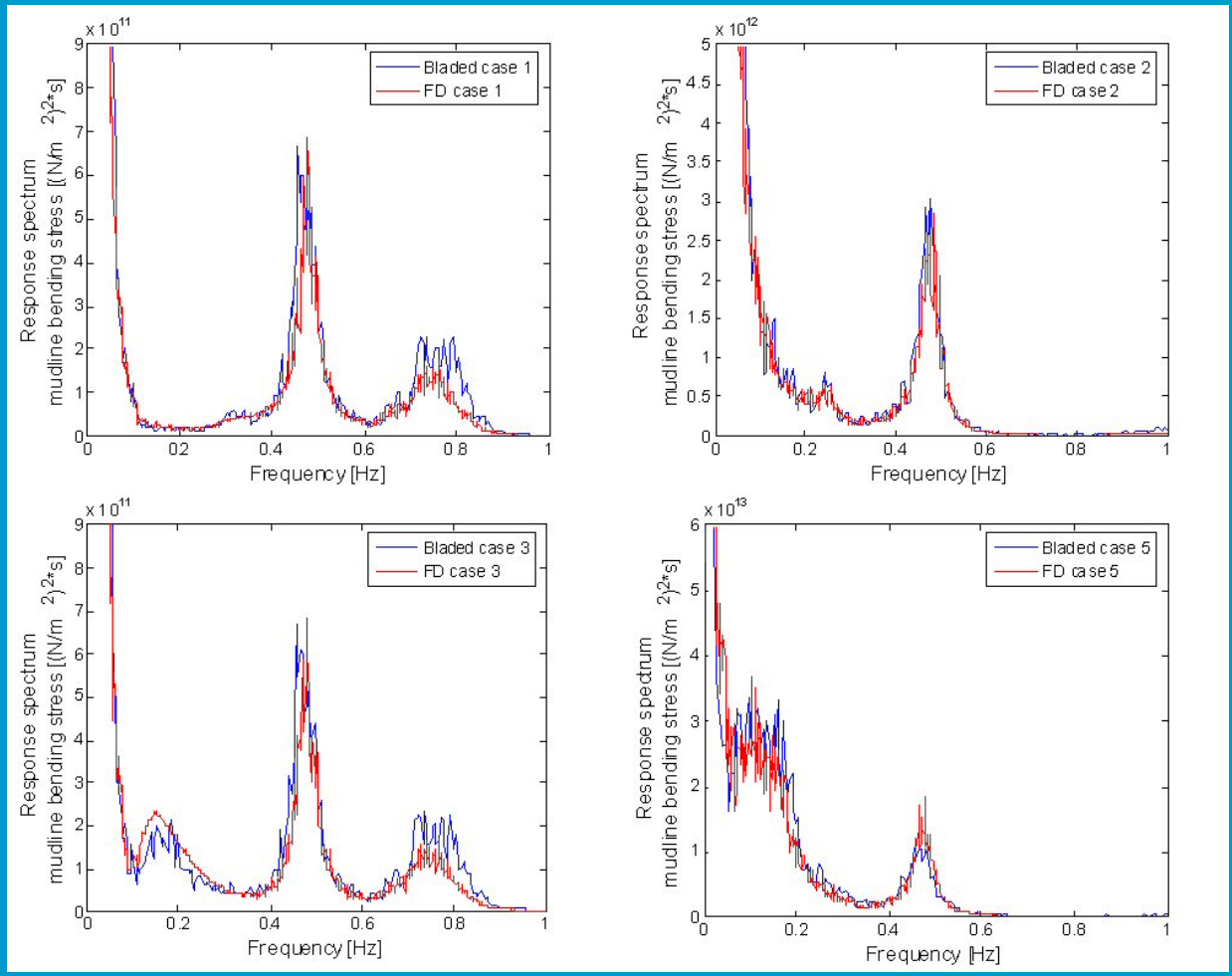
Validation: Blyth

- EU-project OWTES
- Vestas V66, fully measured
- full model in Bladed by Garrad-Hassan
- assistance of Vestas
- model checked with measurements

Validation: Blyth



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Validation: Blyth

- very good comparison
- wave influence low
- nearly no resonance
- fatigue not really an issue

- only turbine to get data from

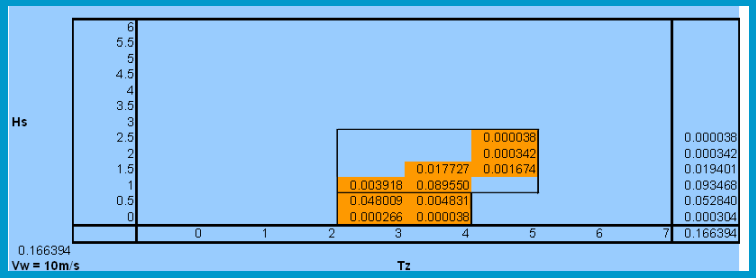
- apply on real design with more fatigue

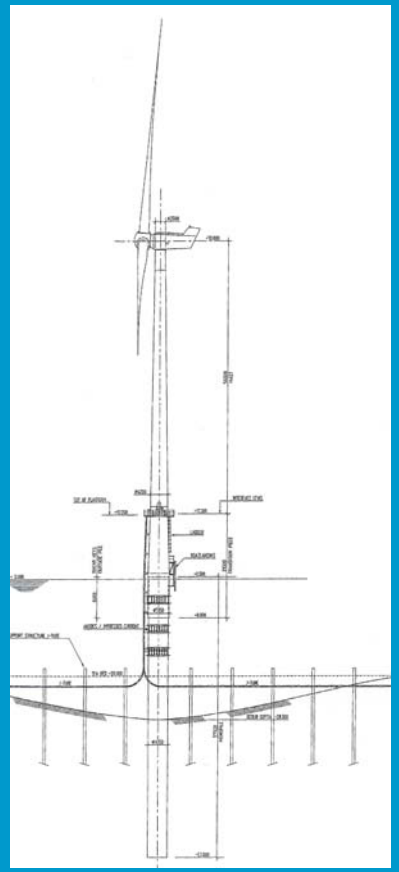
Design comparison: Egmond

- design of NM92
- 2.75 MW turbines
- nat. freq.: 0.31Hz
- NM92 abandoned
- Available for study

Design comparison: Egmond

- wave scatter diagram per wind speed
- 112 cases
- full TD simulation
- FD calculation





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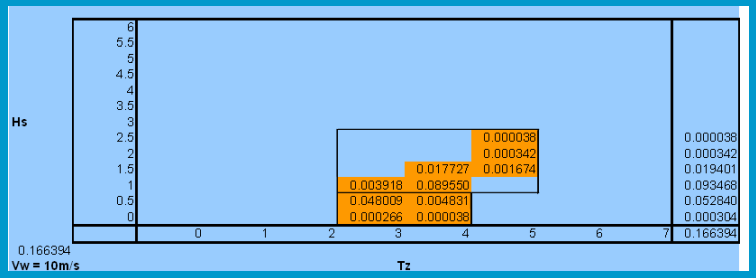
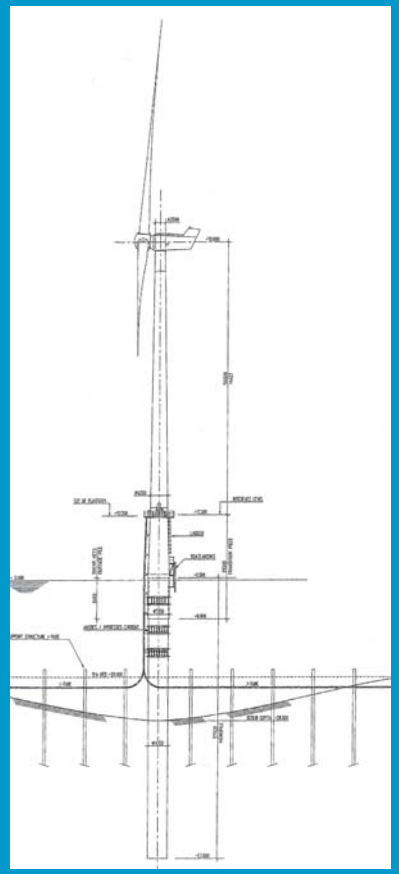
Design comparison: Egmond

Outcome:

- TD: $D_{life,\ 20\ years} = 0.56$
- FD: $D_{life,\ 20\ years} = 0.52$





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Conclusions

- The method works!
- Effective separation of support structure and turbine
- Enabling offshore contractor to optimise structure

- Fast checking (1 minute)
- Enhancing understanding

Outlook

- Current design check of V90 design at Egmond
- Adjusting contractor's tools
- Improvement of aerodynamic damping calculation
- Testing for tripods and jackets
- Full PhD thesis available from January 2006