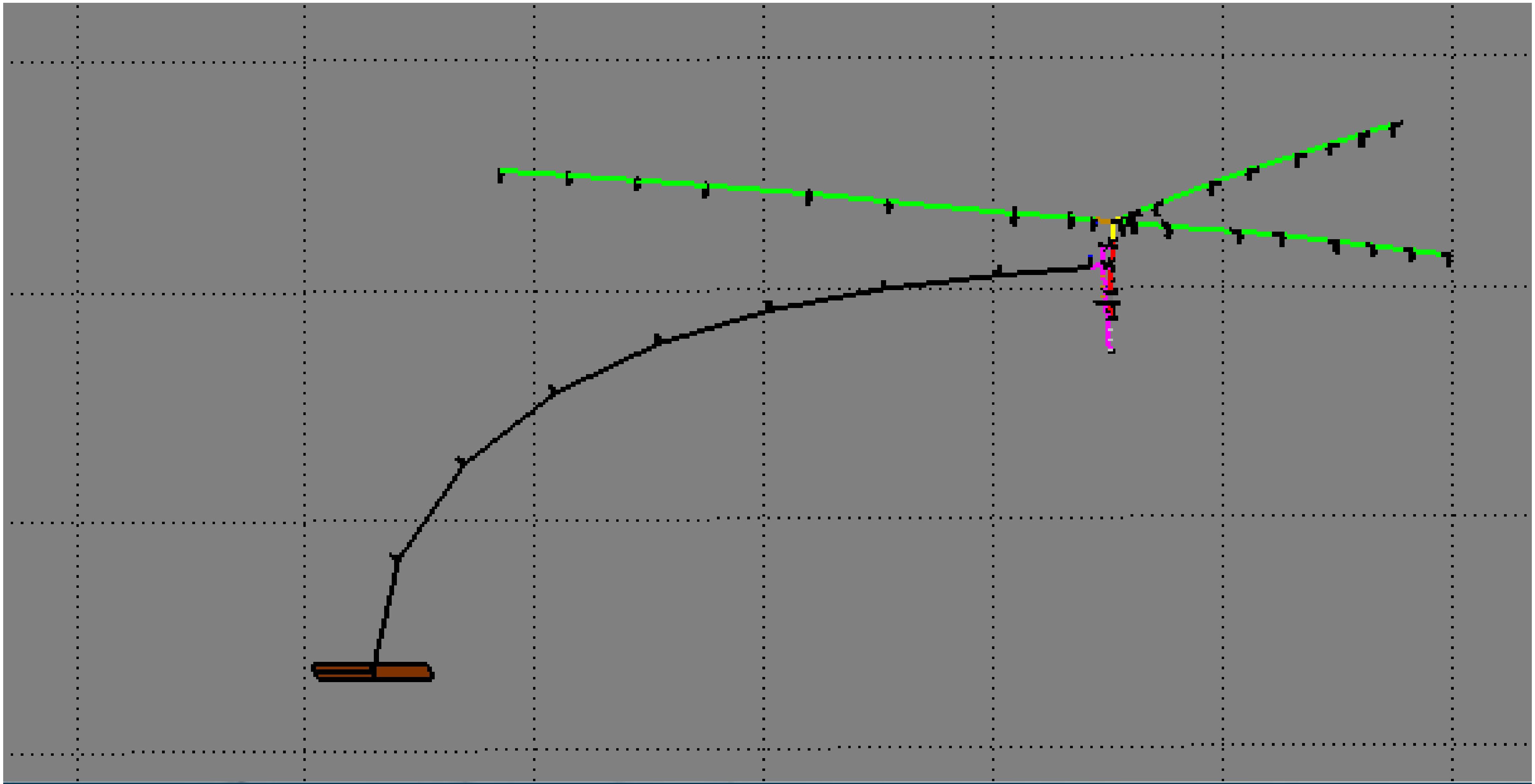


Monopile as part of aeroelastic code BHawC

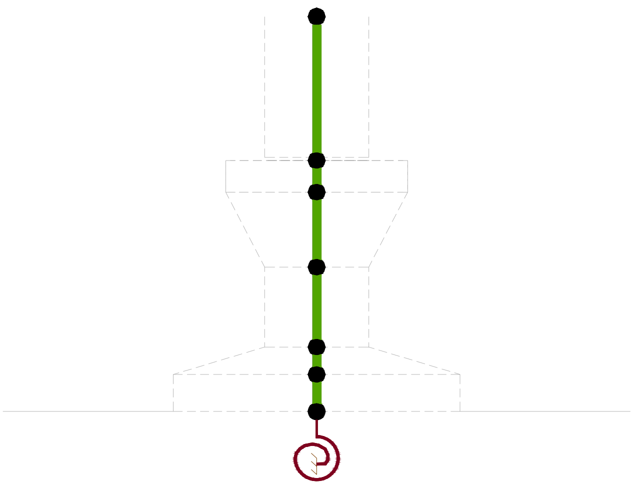
PRESENTATION OUTLINE

- SWP offshore aeroelastic model techniques
- BHawC non-linear aeroelastic code
- Integrated monopile
- Case study

Offshore aeroelastic model techniques

SIEMENS

- Gravity based concrete structure
  - Shallow water
  - Stiff structure
  - High soil strength
  - Preloaded soil
- Model method
  - Timoschenko beam elements
  - Translational and rotational soil spring



Offshore aeroelastic model techniques

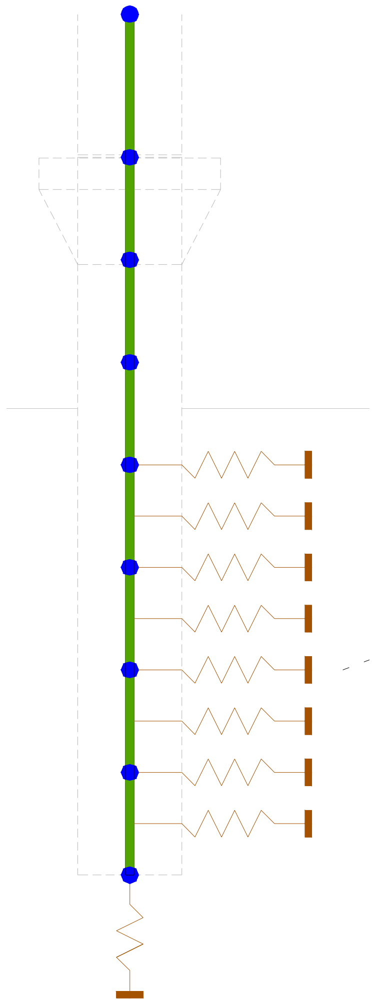
SIEMENS

- Monopile foundation
  - Shallow and deeper water
  - Flexible structure
  - Soil strength variation
  - Unloaded soil
- Model method 1
  - Part of monopile with beam elements
  - Equivalent fixation point

Offshore aeroelastic model techniques

SIEMENS

- Monopile foundation
  - Shallow and deeper water
  - Flexible structure
  - Soil strength variation
  - Unloaded soil
- Model method 1
  - Part of monopile with beam elements
  - Equivalent fixation point
- Model method 2
  - Full monopile with beam elements
  - Non-linear soil springs



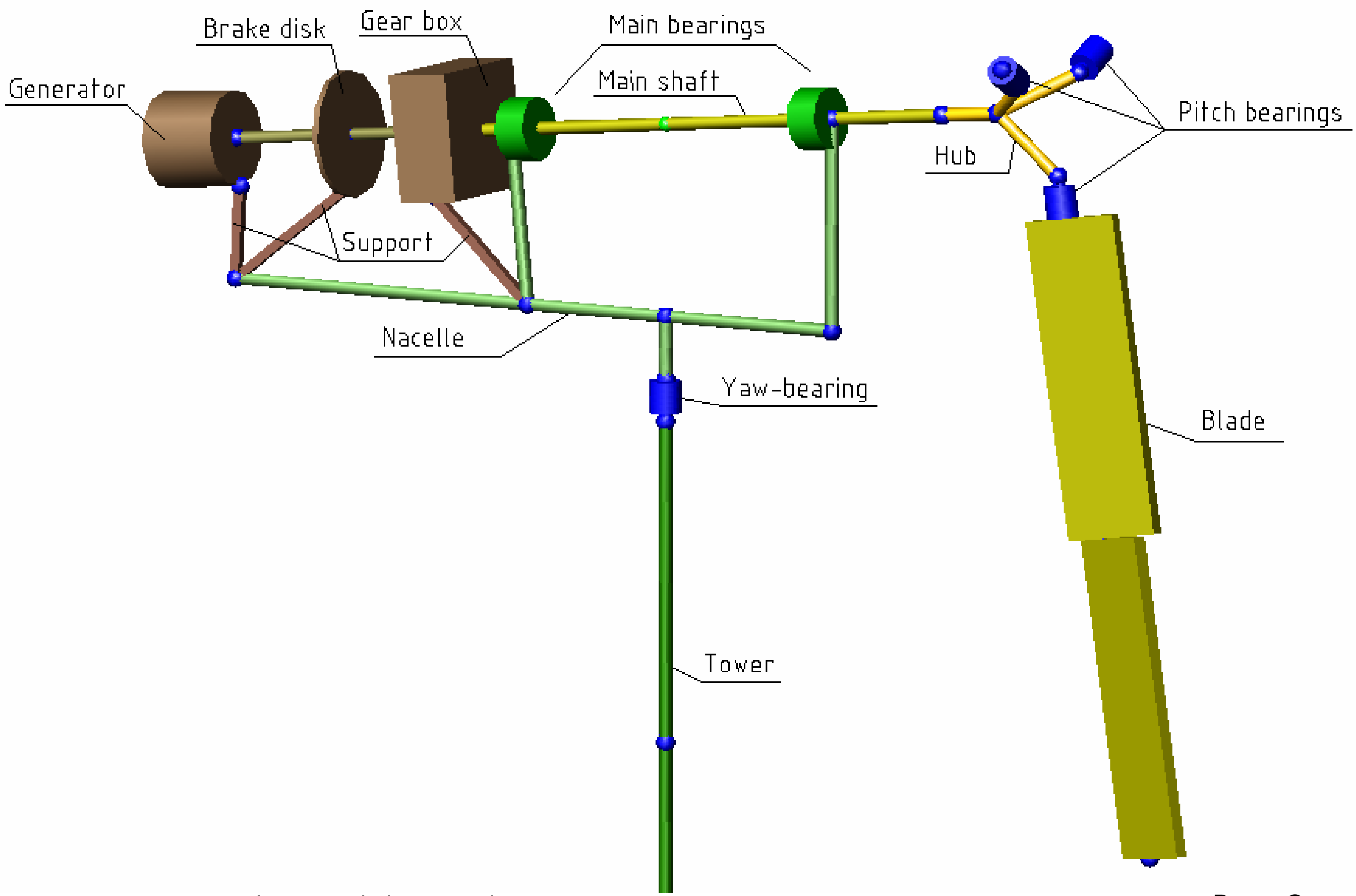
BHawC - Development

SIEMENS

- **BHawC: B**ONUS ENERGY **H**orizontal **a**xis **w**ind turbine **C**ode
  - Jørgen Thirstrup Petersen
  - Rune Rubak
- Development milestones
  - 02 / 2003: Static non-linear simulation
  - 10 / 2003: Dynamic non-linear simulation
  - 08 / 2004: Comparison with HawC 2.3MW CombiStall® turbine
  - 04 / 2005: IEC design load calculation
  - 08 / 2005: Basic load verification on 2 turbines
  - ?? / ????: Detailed load verification
- Performance
  - Calculates with 0.2·realtime on PC

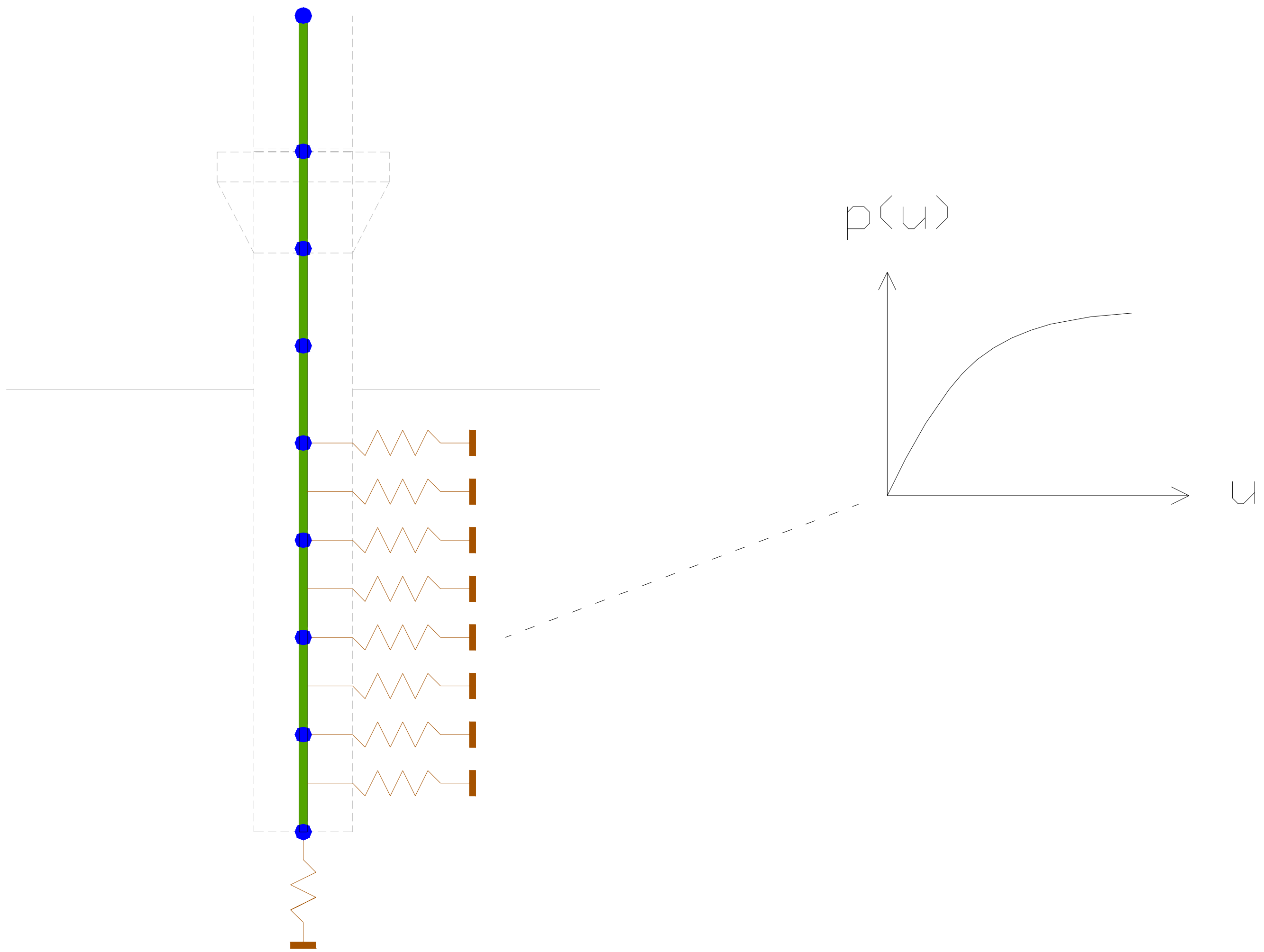
BHawC – Structural model turbine

SIEMENS



BHawC – Integrated monopile model

SIEMENS



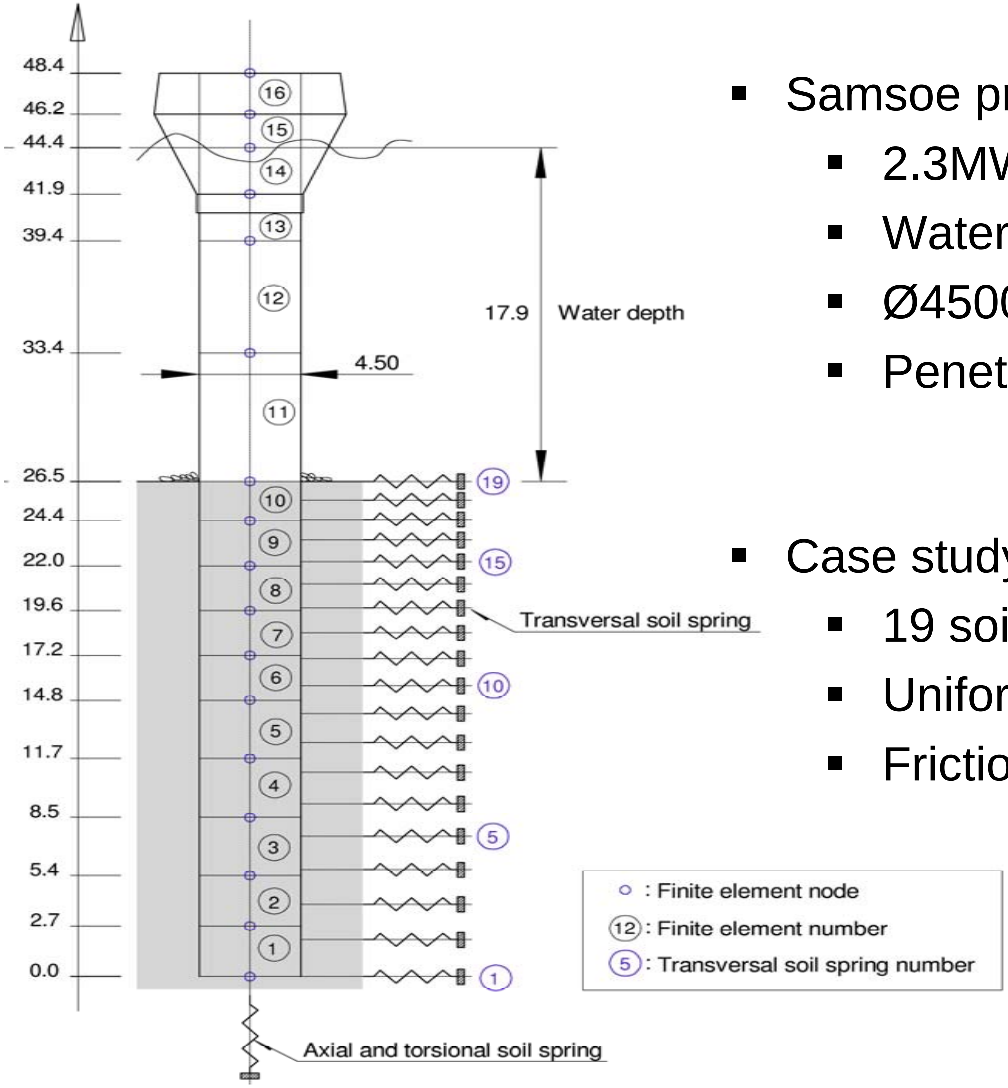
BHawC – Load models

SIEMENS

- Aerodynamic blade loads
  - BEM
  - Yaw correction
  - Tower shadow
  - Dynamic inflow
  - Dynamic stall model
- Nacelle and tower aerodynamic loads
- Wave loads
- Gravity loads

Case study - Description

SIEMENS

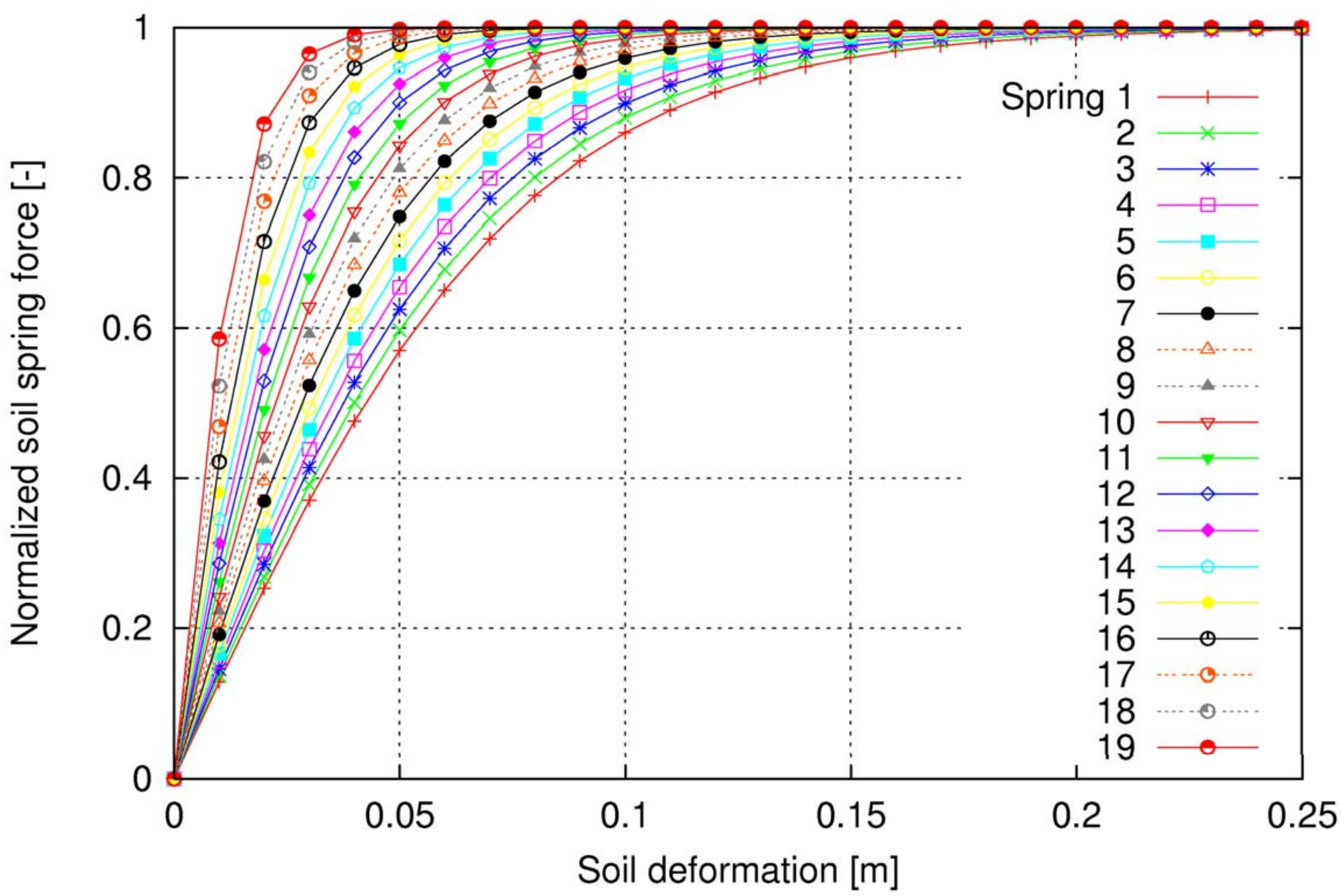


- Samsoe project basis
  - 2.3MW turbine - CombiStall® regulation
  - Water depth 17.9 m
  - Ø4500 monopile
  - Penetration depth 26.5 m

- Case study
  - 19 soil springs
  - Uniform sand assumed
  - Friction angle 24°, 30° and 36°

Case study – Description

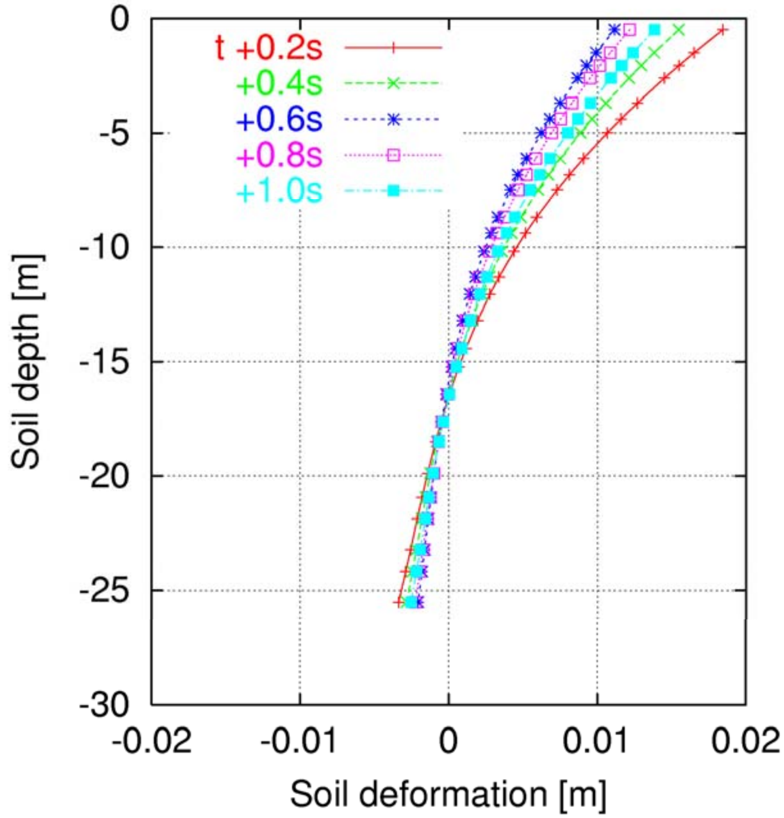
SIEMENS

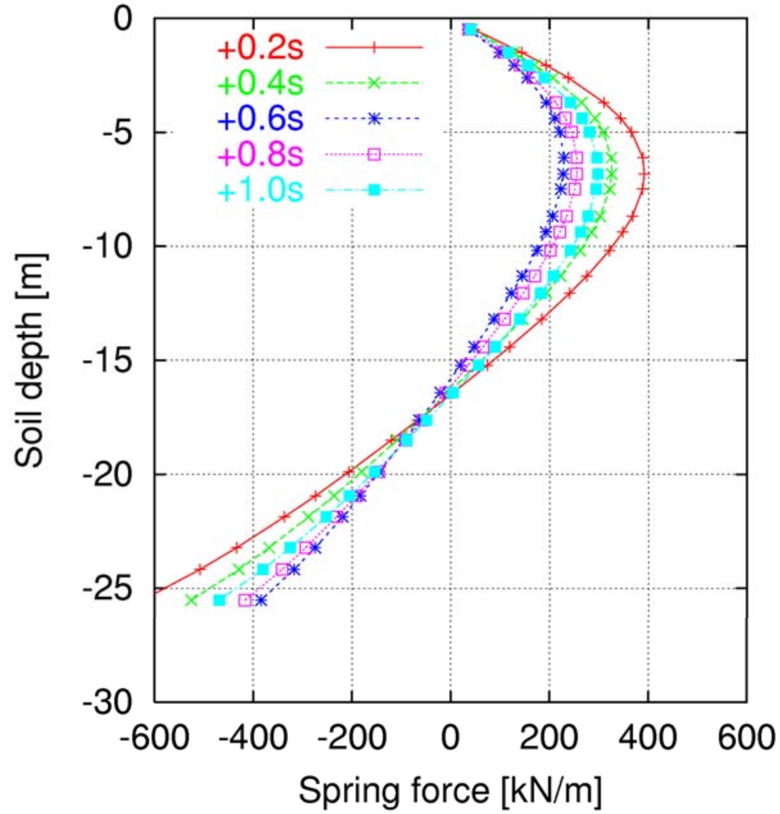


Case study – Results

SIEMENS

- Snapshots of longitudinal deformation and soil spring force

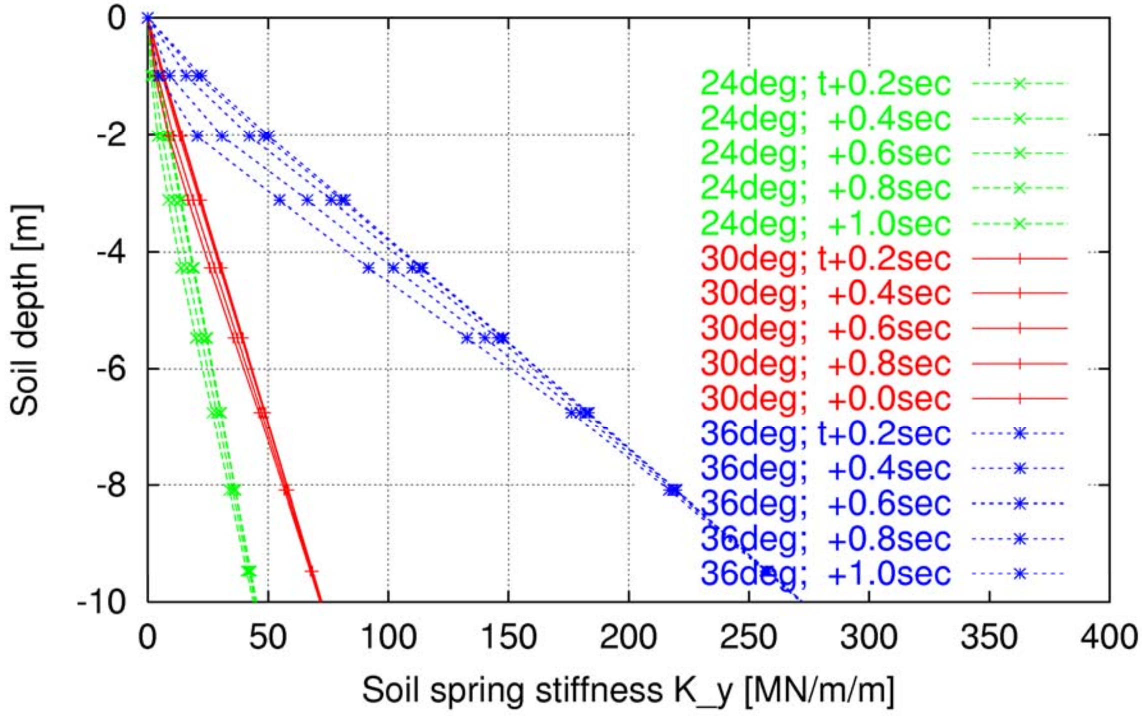




Case study – Results

SIEMENS

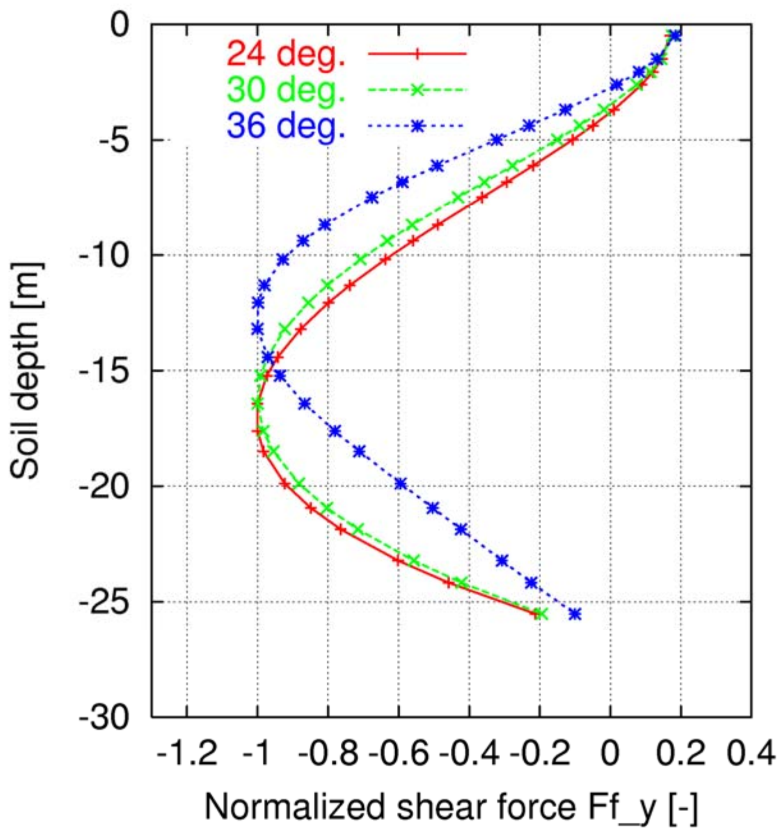
- Snapshots of soil spring stiffness

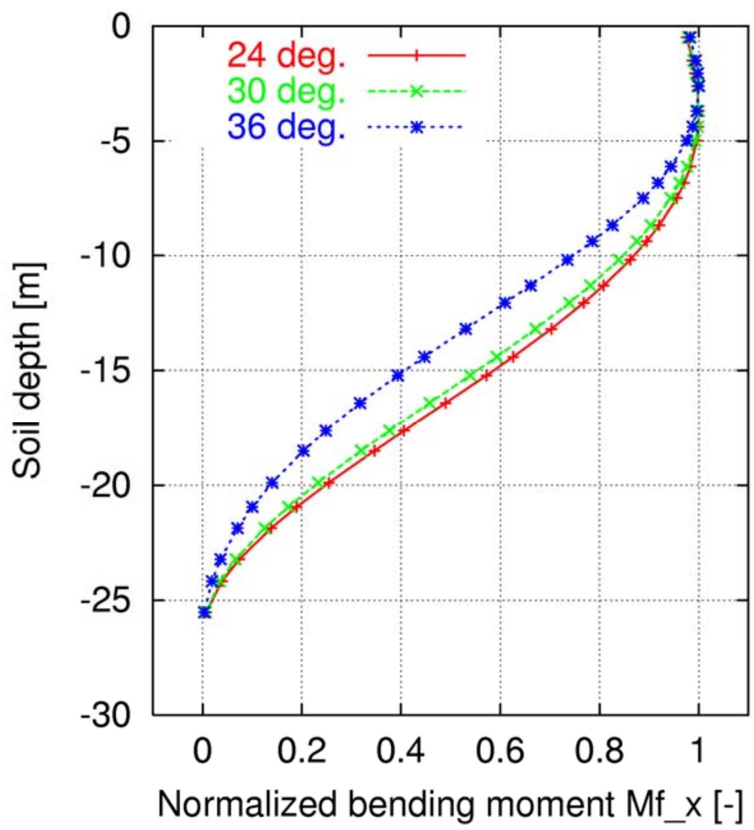


Case study – Results

SIEMENS

- Shear force and bending moment





Case study - Results

SIEMENS

- Main changes in natural frequencies

Modeshape	Friction angle		
	24°	**30°**	**36°**
1st tower	-3%	Baseline	+6%
2nd rotor tilt	-6%	Baseline	+13%
2nd rotor yaw	-7%	Baseline	+13%

Case study – Fatigue loads

SIEMENS

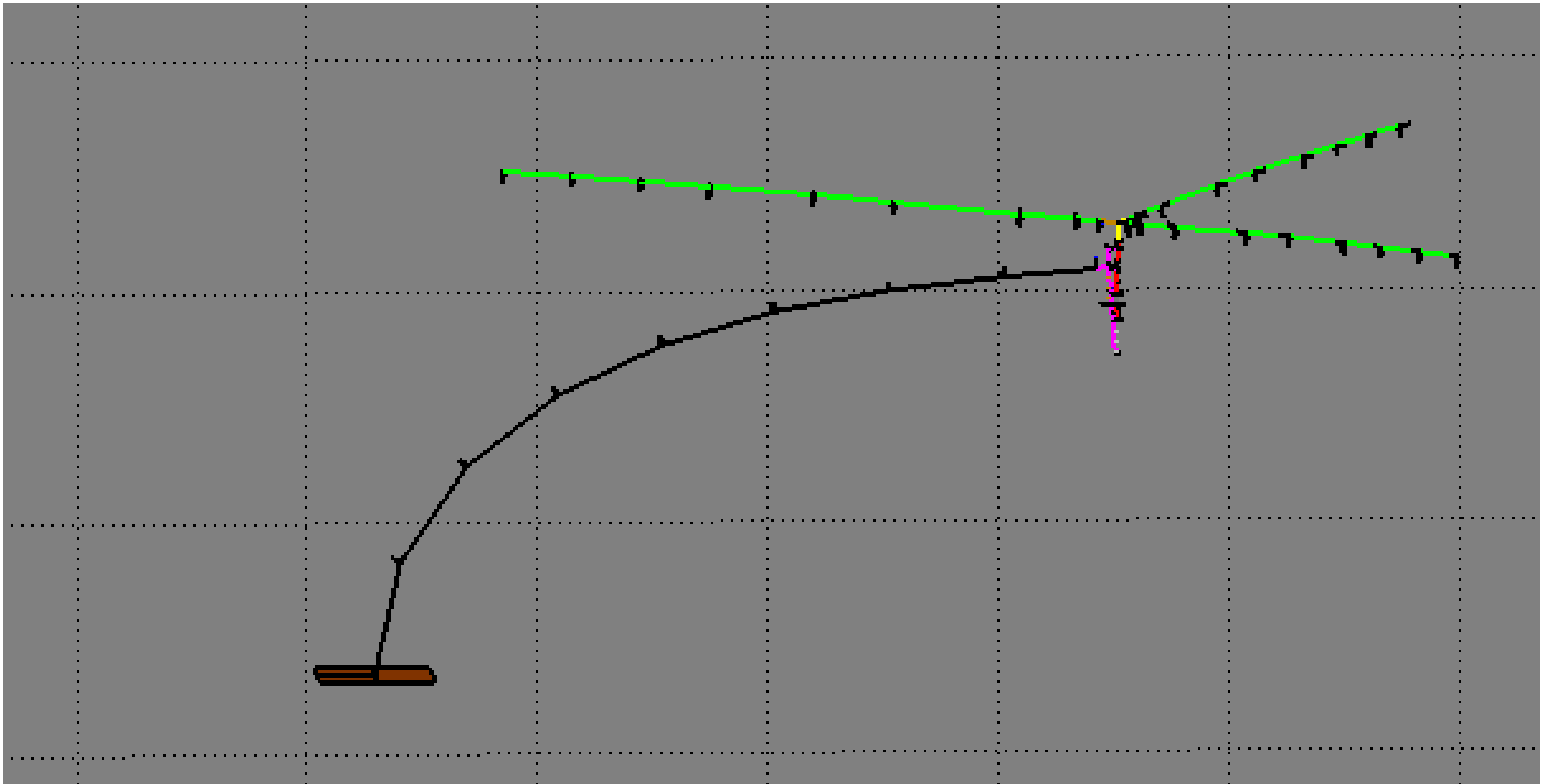
- Impact on lifetime fatigue loads
  - Based on 5, 10, 15, 20 and 25 m/s

Bending moment	Friction angle		
	24°	**30°**	**36°**
Mudline	+24%	Baseline	-19%
Tower base	+30%	Baseline	-24%
Shaft-hub flange	-1%	Baseline	+5%
Blade flapwise	+1%	Baseline	+3%
Blade edgewise	+0%	Baseline	+40%

Summary

SIEMENS

- Aeroelastic code BHawC
  - Non-linear FEM model of turbine
  - Integrated monopile model
- Improvements with monopile model
  - Cross section forces available below mudline
  - Mode shapes and natural frequencies
  - Fatigue load estimation improved
- Further developments
  - Soil stiffness and damping models
  - Effect on extreme loads
  - Load verification



Monopile as part of aeroelastic code BHawC

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