3D Beam element for FSI-simulation of flow around turbine blades

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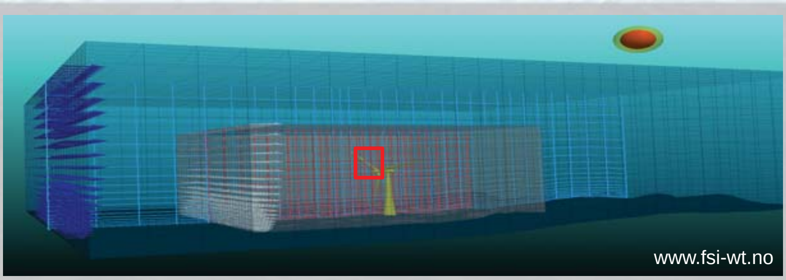
INTRODUCTION

We present here a nonlinear 3D beam formulation applicable for fluid-structure interaction (FSI) of wind turbine blades. The nonlinear 3D beam formulation is derived from a 3D continuum, where large-deformation kinematics and the St. Venant-Kirchhoff constitutive law are assumed. The initial configuration may be curved and twisted. The beam is intended for two different FSI-approaches:

Semi 3D: The strip theory approach using 2D CFD
Full 3D: Here the fluid flow is computed using 3D CFD



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3D BEAM GEOMETRY

The NREL 5MW blade is defined as a series of cross-section airfoils at various points along the blade axis. Corresponding cross-sectional beam stiffness data are given and can be used directly. Alternatively we may make a full 3D model of the blade and compute the cross sectional stiffness data by integration. The nonlinear 3D beam handles non-symmetric cross-sections – which is common for turbine blades.

Figure 1: 3D turbine blade geometry may be generated by lofting the given cross-sections

HILBER-HUGHES-TAYLOR α-METHOD

Numerical damping is crucial to avoid unphysical oscillations in computed results. The Hilber-Hughes-Taylor (HHT) α-Method is the most popular time integration scheme for nonlinear beams, where the numerical damping is controlled by the value of α.

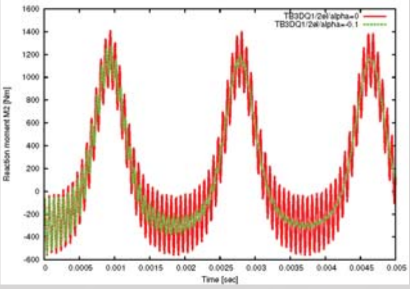

Figure 1: The computed reaction moment **with** and **without** numerical damping.

CONCLUSION

IFEM Beam is a versatile nonlinear 3D beam element applicable for FSI-simulations of offshore wind turbines.

NONLINEAR 3D BEAM FORMULATION

The nonlinear 3D beam formulation is derived from a 3D continuum, where large-deformation kinematics (Green-Lagrange strain tensor and second Piola-Kirchhoff stress tensor) and the St. Venant-Kirchhoff constitutive law are assumed.

- We may use Lagrange polynomials or Splines.
- The local element kinematics are based on both Timoshenko and Bernoulli assumptions, considering both low-order and higher-order terms in second-order approximations of the Green-Lagrange strains.
- Account for membrane, bending, transverse shear and torsional effects.
- Linearly varying cross section along the beam axis that may be non-symmetric.
- Consistent inertia and dynamic tangent stiffness are derived that allows for arbitrarily large motions and achieve second order convergence in the Newton iterations.

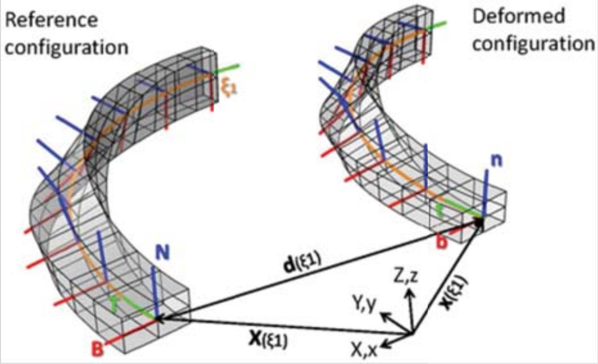

Figure 2: The beam element in the reference (left) and deformed (right) configuration, showing the local coordinate system. Six DOFs per node.

VERIFICATION EXAMPLE

To verify the implemented nonlinear 3D beam formulation in IFEM we solved a double cantilever beam problem (point load at midpoint) and compared the computed displacement, velocity and acceleration with ABAQUS.

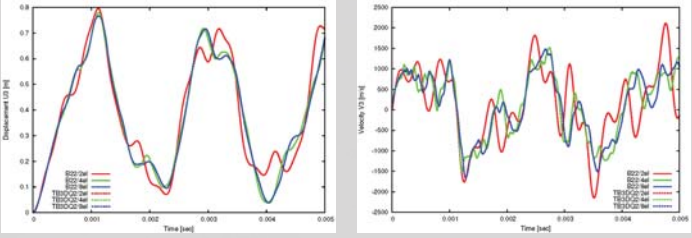

Figure 3: The tip displacement (left) and velocity (right) for p=2.
The results from IFEM and ABAQUS coincides very well!

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