Optimizing Reliability using BECAS - an Open-Source Cross Section Analysis Tool

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www.becas.dtu.dk
Optimizing Reliability

• Many components of a wind turbine are designed based on loads that are derived using an aeroelastic model of the turbine (e.g. HAWC2).
• Underestimating the real loads will lead to premature failure!
• The aeroelastic model usually relies on beam theory to describe various parts of the turbine.
• In case of the blades, determining the parameters of the beam model proves difficult.
• This is due to:
  – complex geometry
  – multiple, arbitrarily oriented, anisotropic materials
  – coupling stiffness terms

real structure -> beam model -> aeroelastic model -> loads

BECAS - an open-source cross section analysis tool
**BECAS - an Open-Source Cross Section Analysis Tool**

- BECAS is a general purpose cross section analysis tool.
- BECAS determines the stiffness and mass properties of an arbitrary beam cross section, while accounting for all the geometrical and material induced couplings.
- BECAS is based on the theory originally presented by Giavotto et al.\(^1\)
- BECAS was developed by José Pedro Blasques (DTU Wind Energy) and Boyan Lazarov (DTU Mechanical Engineering).
Theory

For a linear elastic beam there exists a linear relation between the vector of cross section forces and moments $\theta$, and the resulting strains and curvatures $\psi$:

$$\theta = K\psi$$

$$\begin{bmatrix}
T_x \\
T_y \\
T_z \\
M_x \\
M_y \\
M_z \\
\end{bmatrix}
= 
\begin{bmatrix}
K_{11} & K_{12} & K_{13} & K_{14} & K_{15} & K_{16} \\
K_{21} & K_{22} & K_{23} & K_{24} & K_{25} & K_{26} \\
K_{31} & K_{32} & K_{33} & K_{34} & K_{35} & K_{36} \\
K_{41} & K_{42} & K_{43} & K_{44} & K_{45} & K_{46} \\
K_{51} & K_{52} & K_{53} & K_{54} & K_{55} & K_{56} \\
K_{61} & K_{62} & K_{63} & K_{64} & K_{65} & K_{66} \\
\end{bmatrix}
\begin{bmatrix}
\tau_x \\
\tau_y \\
\tau_z \\
\kappa_x \\
\kappa_y \\
\kappa_z \\
\end{bmatrix}$$

This cross section stiffness matrix is what BECAS computes!
Theory

- shear stiffness x-direction
- shear stiffness y-direction
- extensional stiffness
- bending stiffness about x-axis
- bending stiffness about y-axis
- torsional stiffness
Theory

- It is assumed that the cross section deformation is defined by a superimposition of the rigid body motions and warping deformations.
- The cross section is discretized using two dimensional finite elements to interpolate the 3D warping deformations.
- Application of the principle of virtual work yields the finite element form of the cross section equilibrium equations.
- These equations allow to determine the resulting vector of strains and curvatures for a given vector of cross section forces and moments.
- If 6 vectors of strains and curvatures are determined for 6 “unit loads”, the 6x6 cross section stiffness matrix $K$ can be determined.

$$\begin{align*}
E \frac{\partial u}{\partial z} + R \frac{\partial \psi}{\partial z} &= 0 \\
R^T \frac{\partial u}{\partial z} + A \frac{\partial \psi}{\partial z} &= \frac{\partial \theta}{\partial z} \\
Eu + R\psi &= (C - CT) \frac{\partial u}{\partial z} + L \frac{\partial \psi}{\partial z} \\
R^T u + A\psi &= -L^T \frac{\partial u}{\partial z} + \theta
\end{align*}$$
Theory

- From the cross section stiffness matrix the location of various centers can be computed.

shear center

$$K_{45} = K_{54} = 0$$
Example: Analysis of a Wind Turbine Blade

finite element shell model → shellexpander (python program) → BECAS input files → BECAS → cross section stiffness matrices → finite element beam model
Example: Analysis of a Wind Turbine Blade

- Eigenfrequencies obtained from the BECAS-based beam model match the results from the original finite element shell model.

\[ f_1 = 0.580 \text{ Hz} \quad f_2 = 0.957 \text{ Hz} \]
\[ f_3 = 1.640 \text{ Hz} \quad f_4 = 3.080 \text{ Hz} \]
Outlook: Stress Recovery

- The cross section forces and moments coming from a beam model can be used to compute the local 3D stresses for each cross section.

- In the process of being validated.
- Will be part of a future release of BECAS.
Why choose BECAS?

• Many other cross section analysis tools are available – why choose BECAS?
  – BECAS is open source! It is distributed as Matlab® source code.
  – Alternatively it is available as a compiled version, which does not require a Matlab license.
  – The BECAS license is free of charge for academic use.
  – BECAS has been validated extensively and comes with a comprehensive user’s manual.
  – BECAS is fast, when used with the free SuiteSparse package.
  – Integrated with HAWC2
Thank you.

Further information?

BECAS Webpage:  www.becas.dtu.dk

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Literature

