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

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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

![Diagram showing the process from real structure to loads through beam and aeroelastic models.](image-url)
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 $\psi$:

$$\theta = K\psi$$

where

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

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
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

\[ \kappa_z = 0 \]

elastic center

elastic axes orientation

\[ K_{45} = K_{54} = 0 \]
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.

\[ f_1 = 0.580 \text{ Hz} \]
\[ f_2 = 0.957 \text{ Hz} \]
\[ f_3 = 1.640 \text{ Hz} \]
\[ f_4 = 3.080 \text{ Hz} \]
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

