A better damping method for superelement support structure modelling

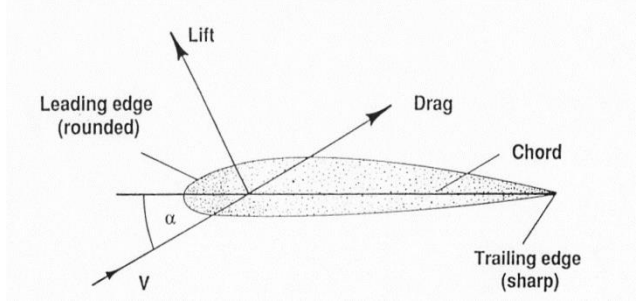
Will Collier

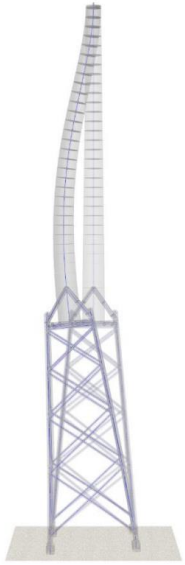
1st October 2019

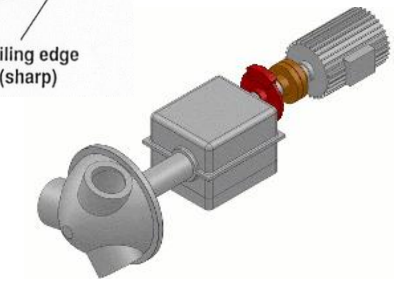
Outline

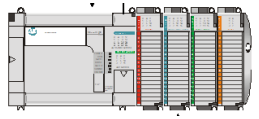
- Introduction and problem statement
- Method: specify damping on support structure natural modes
- Results

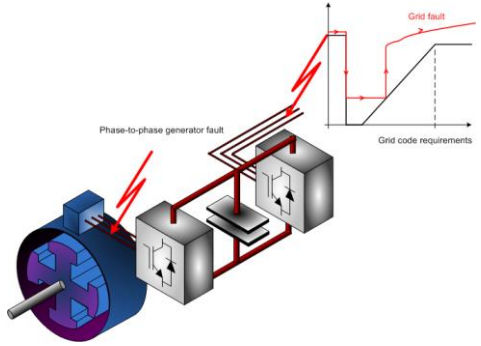
Introduction to Bladed



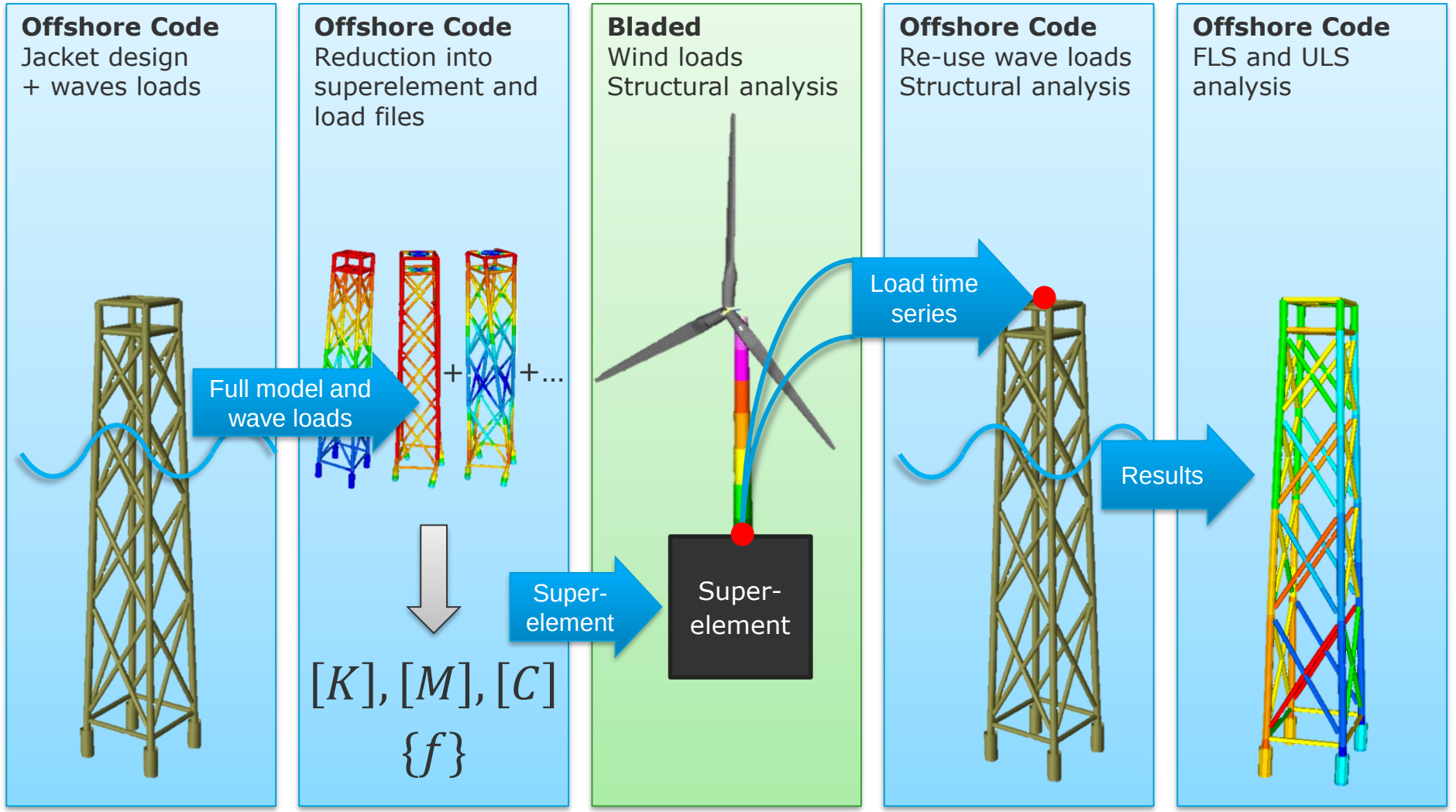




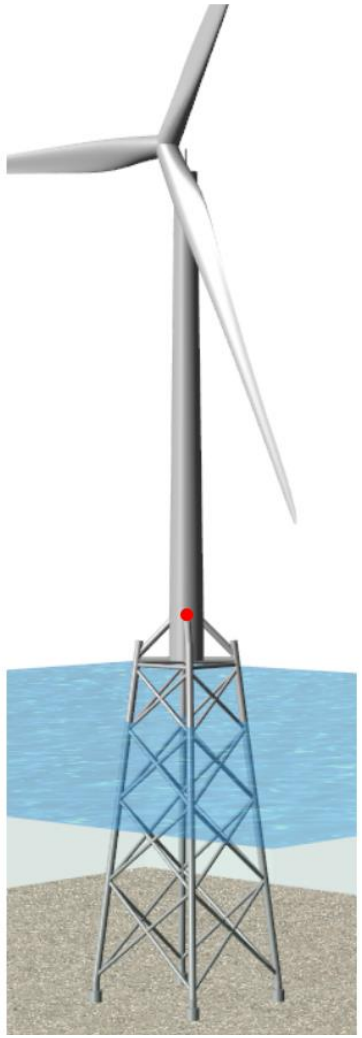




Superelement modelling

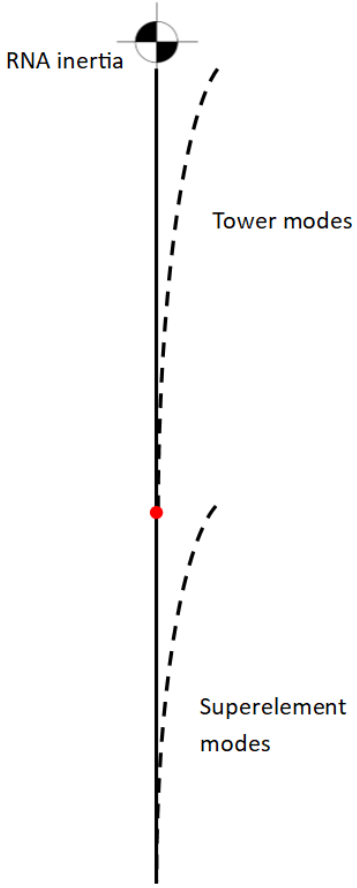


Modal basis



Component modes

(defined on sub-components)



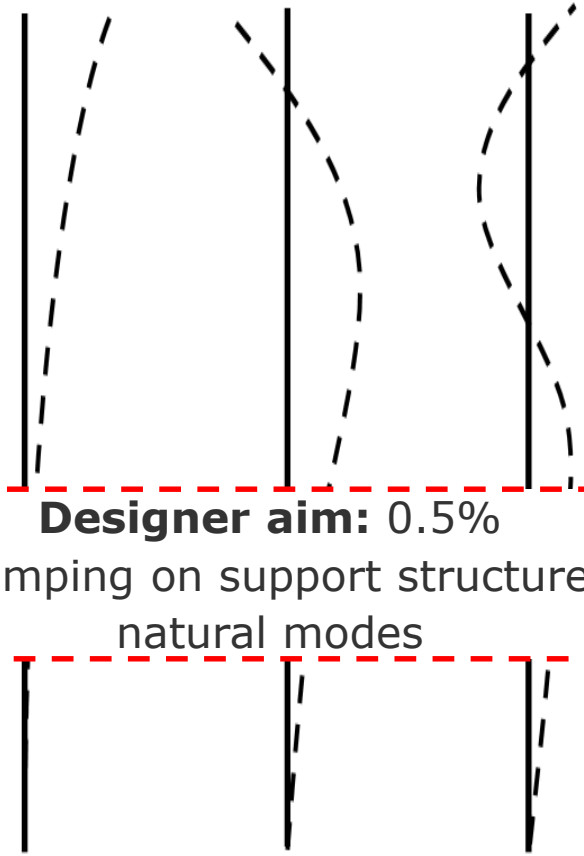
0.5% modal damping

Rayleigh damping

0.5% on 1st and 5Hz mode

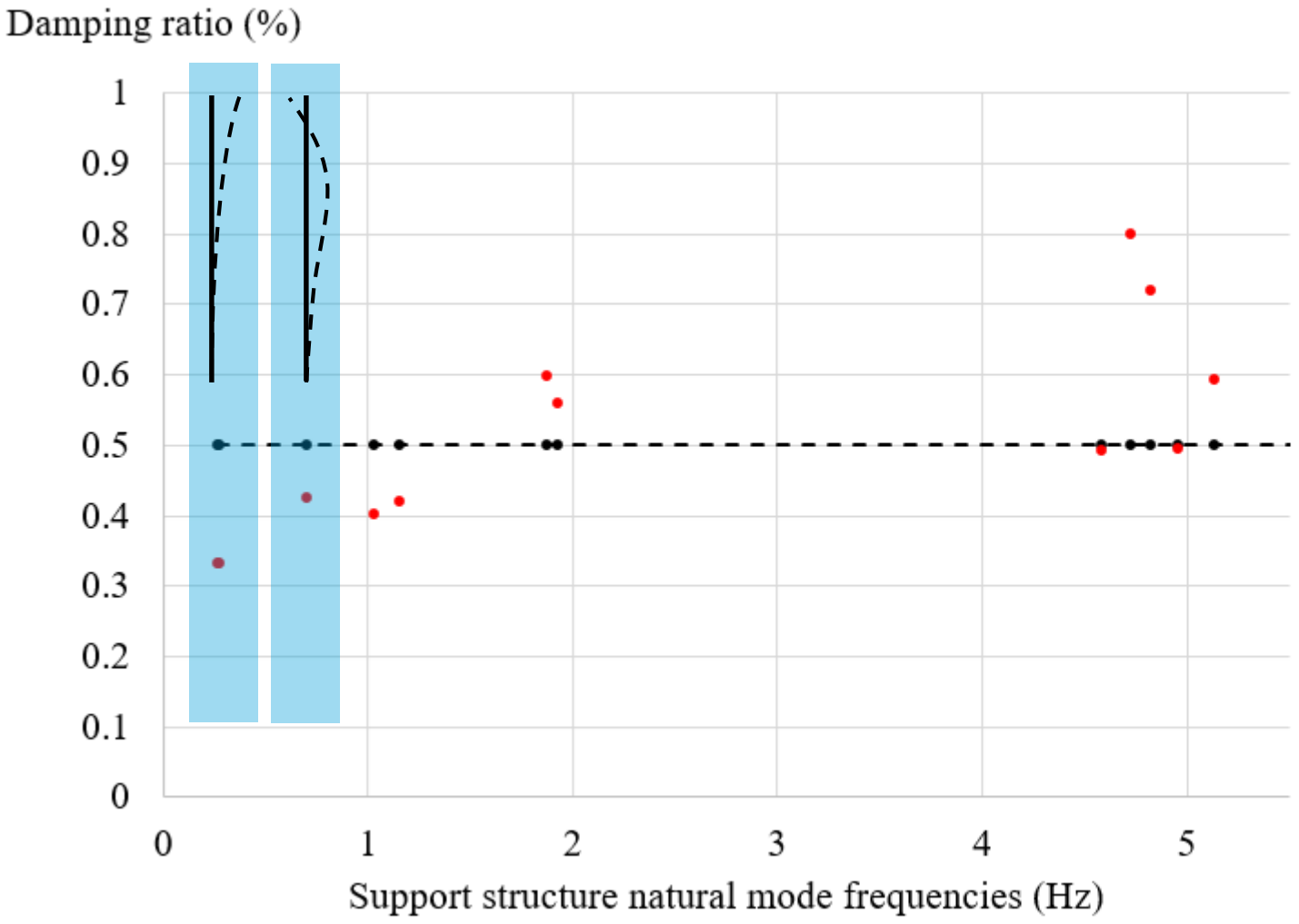
Natural modes

(free vibration modes)



Designer aim: 0.5% damping on support structure natural modes

Damping

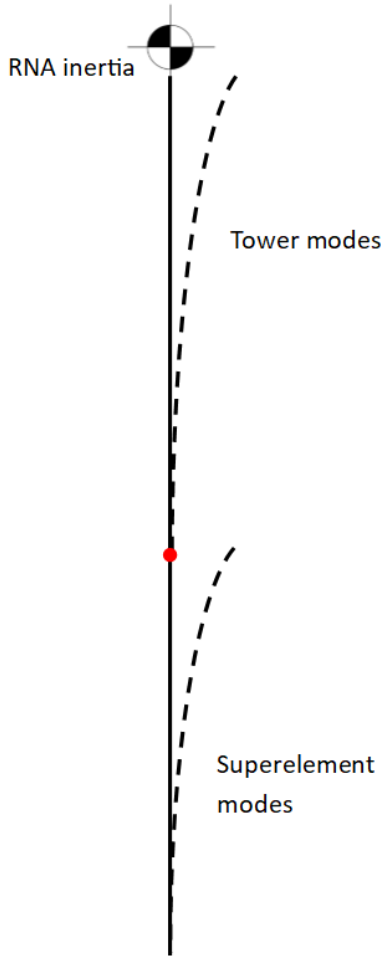


Target 0.5% damping

Component mode damping method

– Calculated by linearising the model (Campbell diagram calculation)

Superelement damping



Modal damping for tower modes

$$[C_T] = 2\begin{bmatrix} \frac{\zeta_1 K_{T11}}{\omega_1} & & \\ & \frac{\zeta_2 K_{T22}}{\omega_2} & \\ & & \ddots \end{bmatrix}$$

Superelement damping from FD

$$[C_{SE}] = a_0[M_{SE}] + a_1[K_{SE}]$$

Support structure damping:

$$[C_{SS}] = \begin{bmatrix} [C_{SE}] & [0] \\ [0] & [C_T] \end{bmatrix}$$

- Superelement damping has no cross-terms
- C_{SE} does not take account of inertia of tower and RNA

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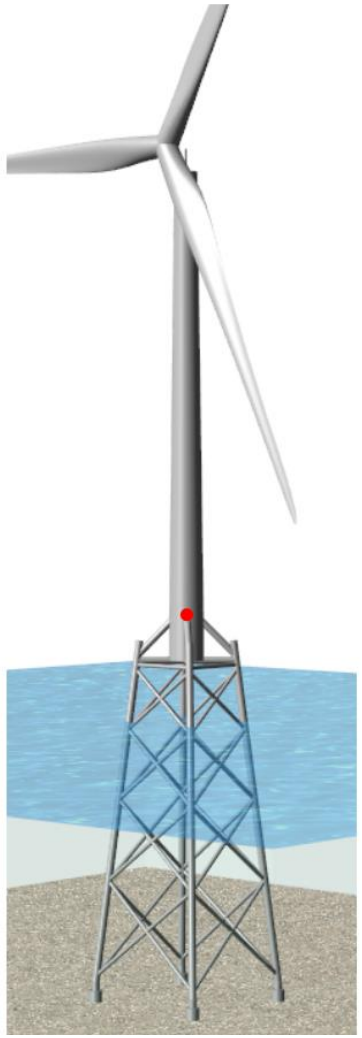
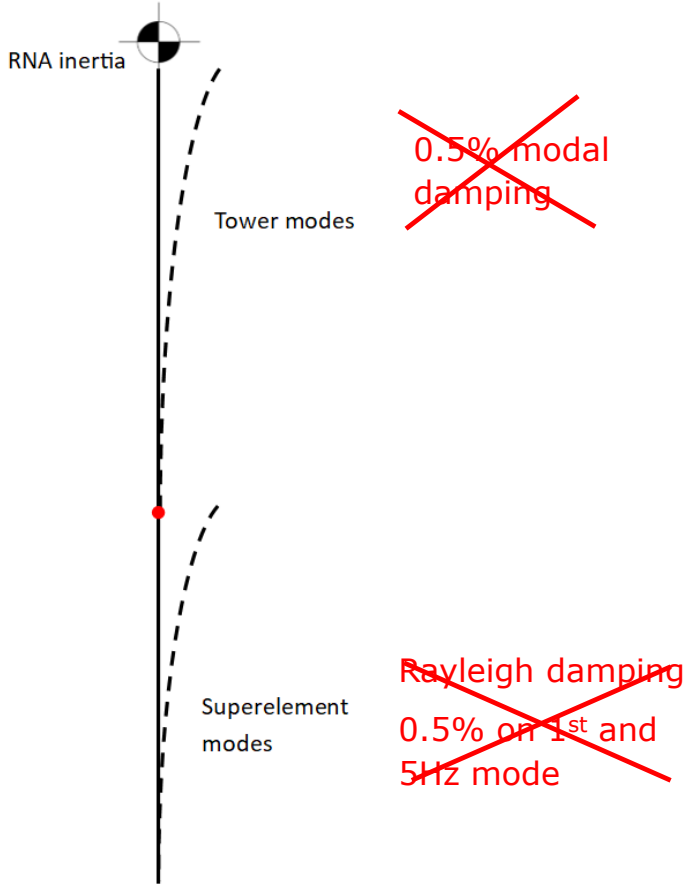
Modal basis



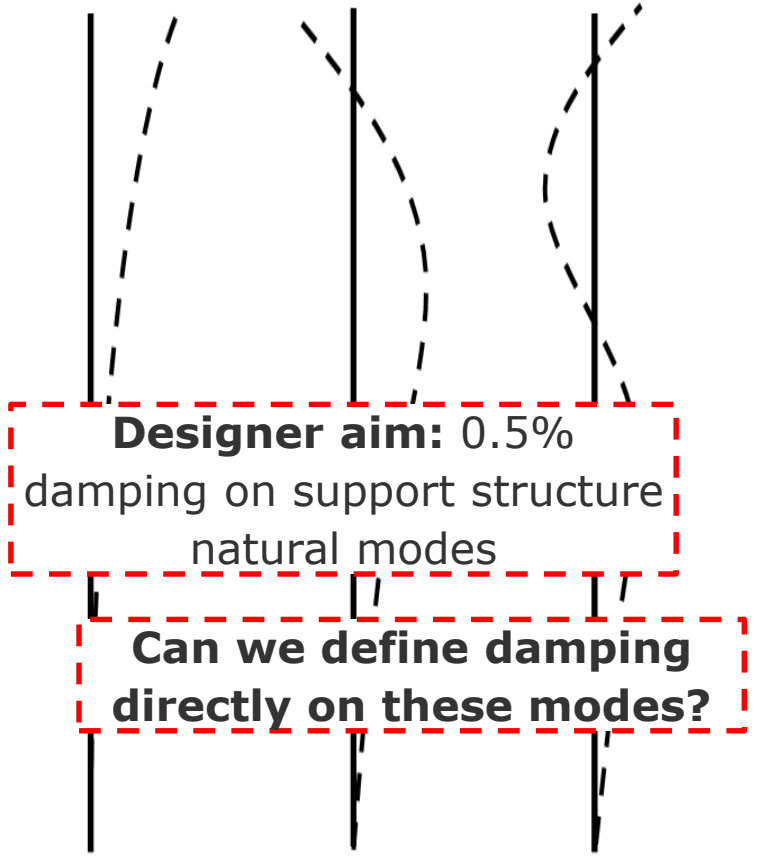
Component modes

(defined on sub-components)



Natural modes

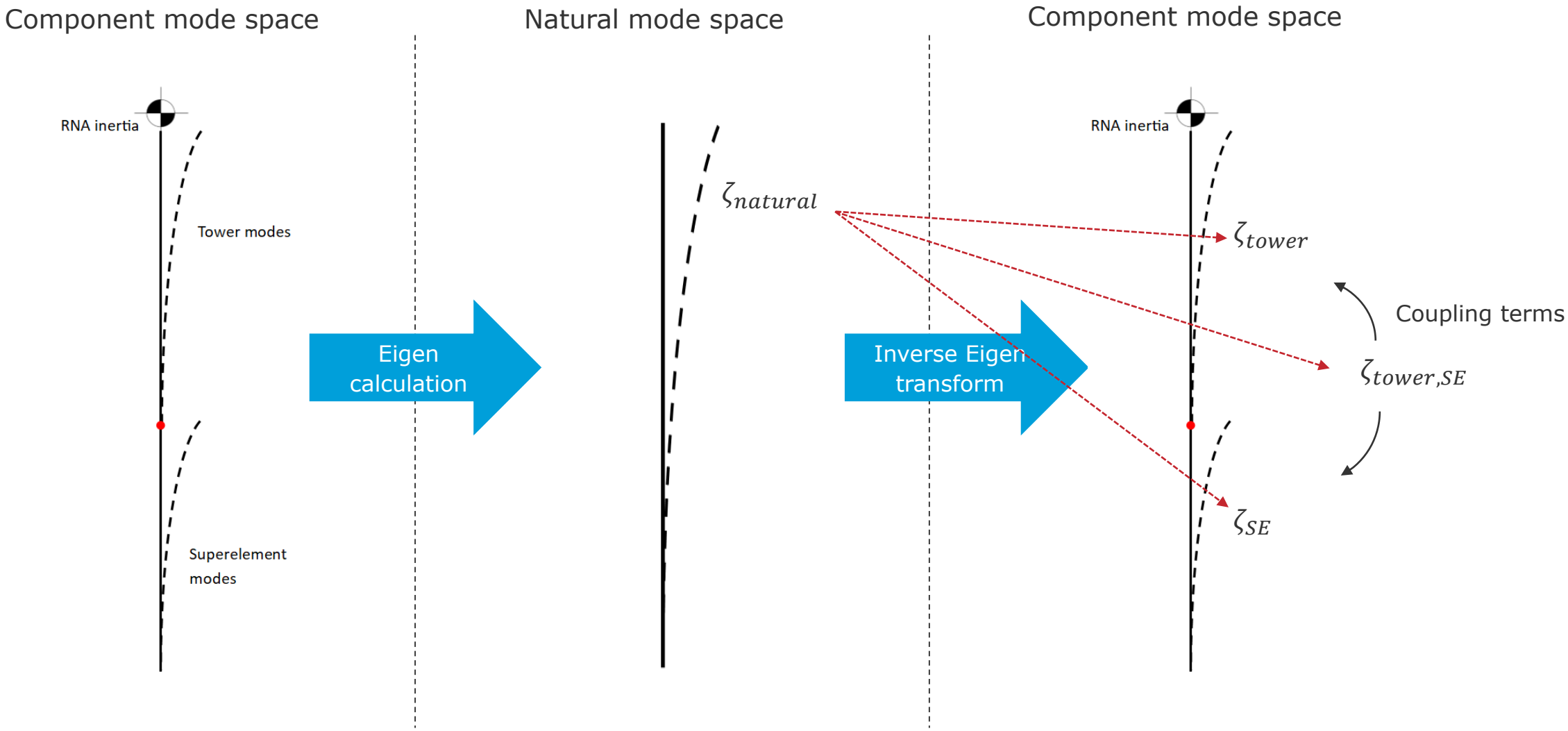
(free vibration modes)



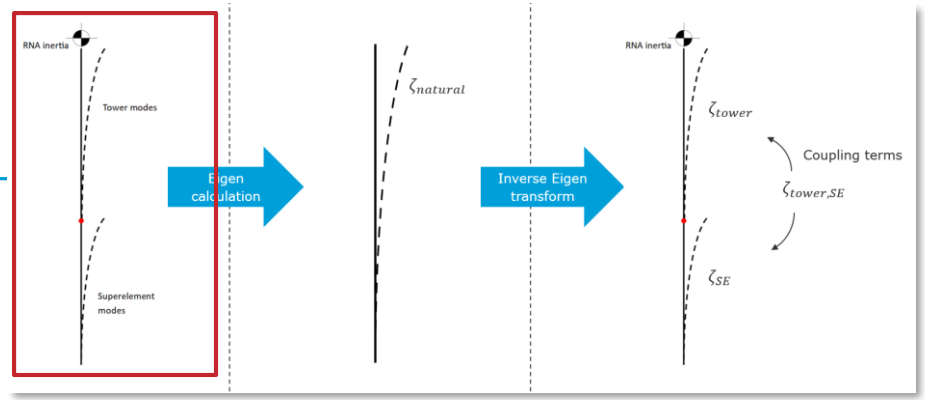
Designer aim: 0.5% damping on support structure natural modes

Can we define damping directly on these modes?

Damping calculation procedure



Natural mode damping



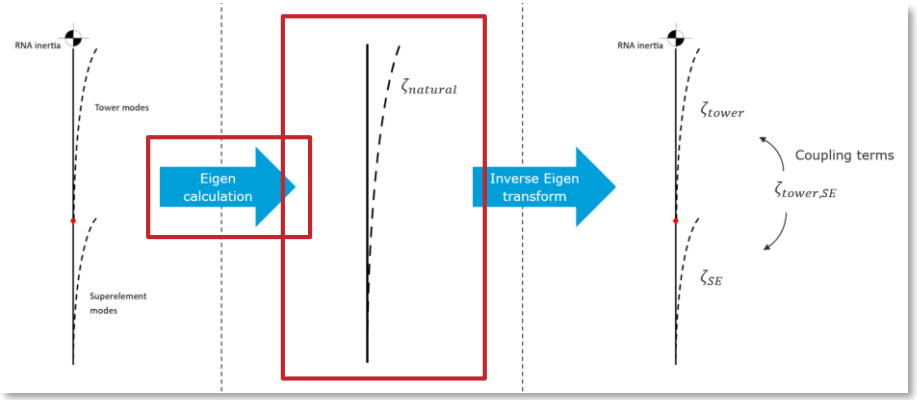
Start with component mode properties:

Mass and stiffness

$$[M_{SS\ component}] = \begin{bmatrix} [M_{SE}] & [0] \\ [0] & [M_T] \end{bmatrix}$$

$$[K_{SS\ component}] = \begin{bmatrix} [K_{SE}] & [0] \\ [0] & [K_T] \end{bmatrix}$$

Natural mode damping



Calculate natural modes of support structure:

$$[K_{SScomponent}]\{\psi_i\} = \omega_i^2[M_{SScomponent}]\{\psi_i\}$$

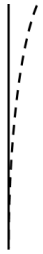
Solve Eigen problem

ψ_i are the mode shape vectors

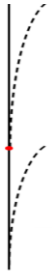
Natural mode shapes in terms of component modes

ω_i are modal angular frequencies (rad/s)

Calculate natural mode matrices:

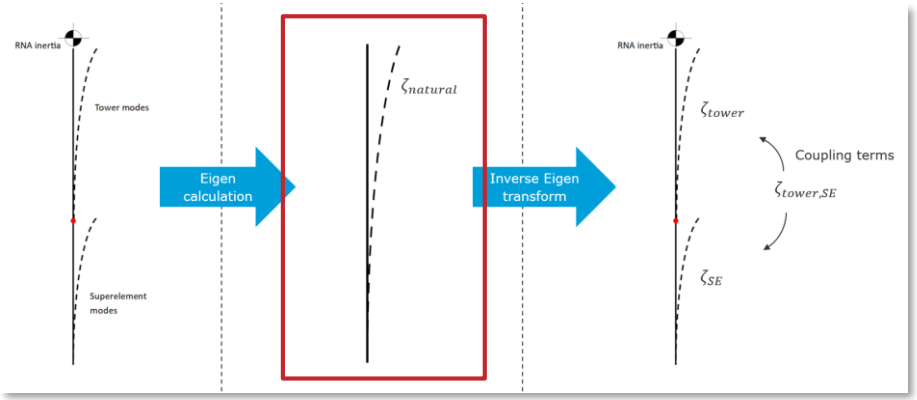


$$[K_{SSnatural}] = [\Psi^T][K_{SScomponent}][\Psi]$$
$$[M_{SSnatural}] = [\Psi^T][M_{SScomponent}][\Psi]$$



Ψ is natural mode shapes in terms of component modes

Natural mode damping



Specify damping on the natural mode properties:

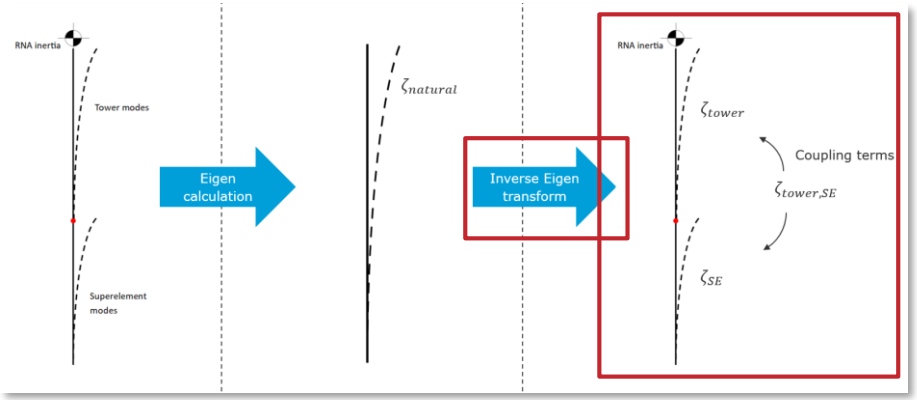
Proportional damping: $[C_{SSnatural}] = a_0[M_{SSnatural}] + a_1[K_{SSnatural}]$

Modal damping:

$$[C_{SSnatural}] = 2\begin{bmatrix} \frac{\zeta_1 K_{SSnatural_{11}}}{\omega_1} & & \\ & \frac{\zeta_2 K_{SSnatural_{22}}}{\omega_2} & \\ & & \ddots \end{bmatrix}$$

Natural mode damping

Transform natural mode damping back to component modes:



$$[C_{SScomponent}] = [\Psi^T]^{-1}[C_{SSnatural}]\,[\Psi]^{-1}$$

Includes effect of tower and RNA inertia

Coupling terms

Defined on component modes:

$$[C_{SS\ component}] = \begin{bmatrix} \begin{bmatrix} C_{SE} \end{bmatrix} & \begin{bmatrix} 0 \end{bmatrix} \\ \begin{bmatrix} 0 \end{bmatrix} & \begin{bmatrix} C_T \end{bmatrix} \end{bmatrix}$$

Defined on natural modes:

$$[C_{SS\ component}] = \begin{bmatrix} \begin{bmatrix} C_{SE}{}' \end{bmatrix} & \begin{bmatrix} C_{T-SE} \end{bmatrix} \\ \begin{bmatrix} C_{SE-T} \end{bmatrix} & \begin{bmatrix} C_T{}' \end{bmatrix} \end{bmatrix}$$

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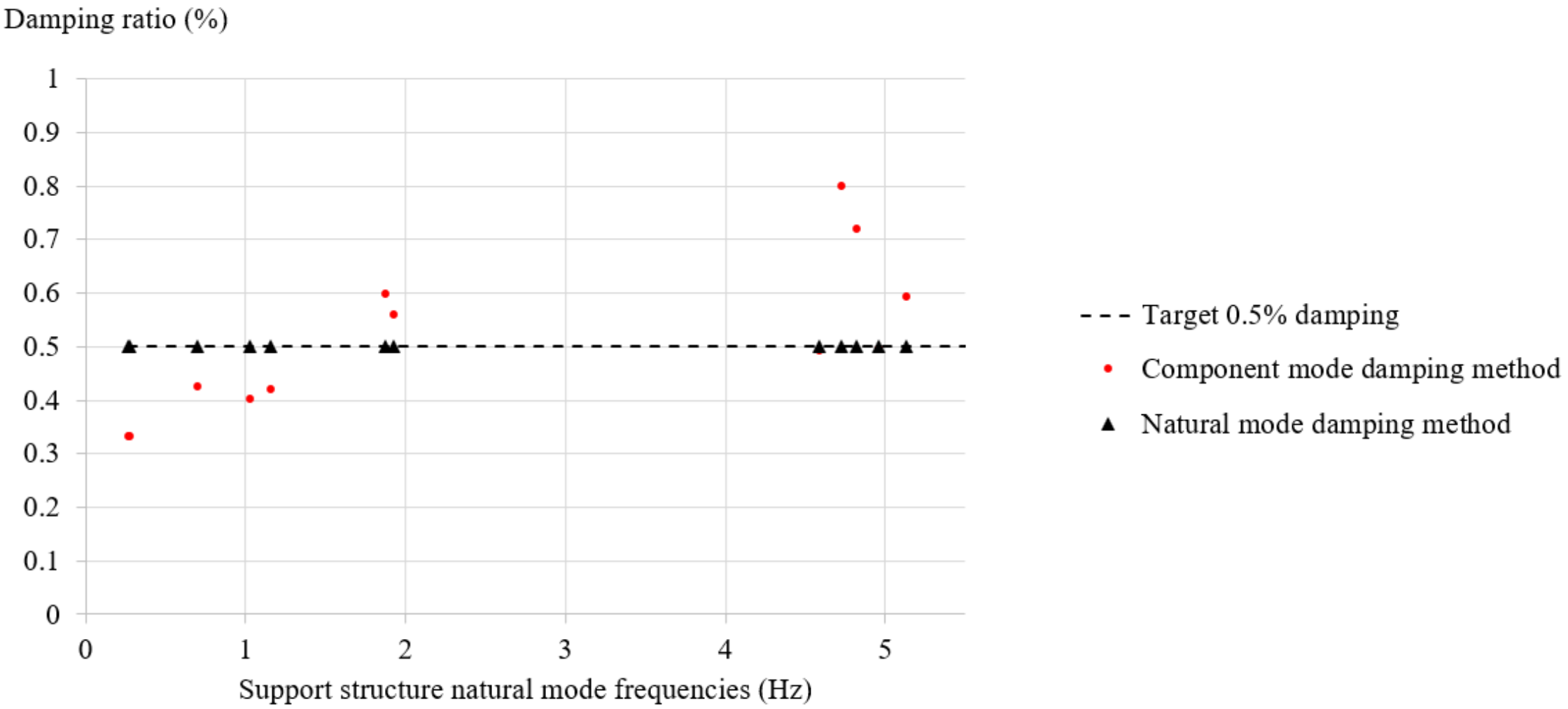
Results: Natural mode damping vs component mode damping



Summary

- Using industry standard approaches, achieving target support structure damping is tricky
- New approach defined with damping specified on support structure natural modes
- Damping is calculated automatically on tower and superelement, including coupling terms
- New approach exactly achieves desired damping ratios

Thank you

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