Re-powering Structures via Simulation & Monitoring

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1 Introduction – Problem Statement

Infrastructure carries the resources and networks ensuring our mobility, safety, health and economic development. Against popular belief, structures comprise breathing organisms that continually evolve and are exposed to hazards and ageing. We exploit the synergy of **Simulation** (Modeling) & **Observation** (Monitoring) for assessing the Health of Infrastructure systems & meeting expected demands.

A significant part of existing infrastructure in developed countries is reaching or has exceeded the end of its life-expectancy. Catastrophic events like the Minnesota bridge collapse have increased awareness and posed an abrupt wake up call.

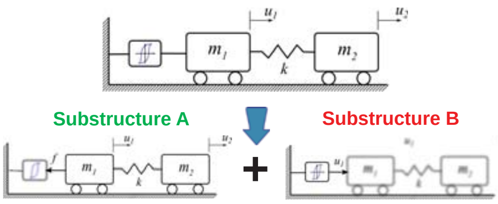
We need means for assessing the condition of existing systems, predicting their residual life and possibly extending this. We need ways to shield or strengthen defect systems, and we do need a plan as to how to look for short or long-term threats. Finally, we need tools for optimally managing the operation and maintenance of these systems, cutting down on costs while ensuring safety.

UK's State of Nation, ICE

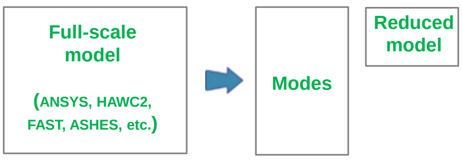
Fig. 1. In recent report cards issued by civil engineering societies in the US and Europe, infrastructure scores embarrassingly low grades, while every new report urges for significant investment for avoiding economic loss and meeting expected demands.

2 Forward Engineering: accelerating computation

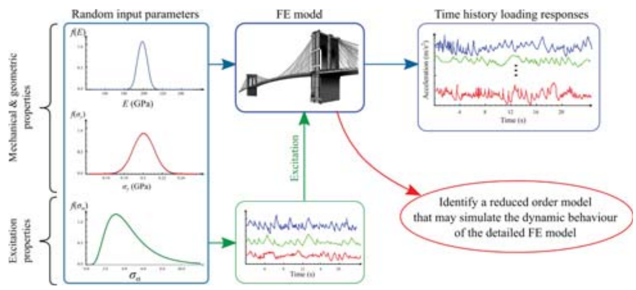
(a) Apply **substructuring**



(b) Perform **model reduction**



(c) Utilize **surrogates / metamodels**



Reduced model → **ARX model** →

$$y[t,\xi] + \sum_{i=1}^{na} \alpha_i(\xi) y[t-i] = \sum_{i=0}^{nb} \beta_i(\xi) u[t-i] + e[t]$$

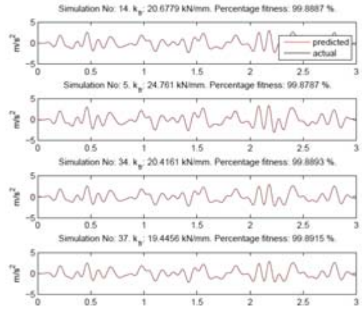
Metamodel →

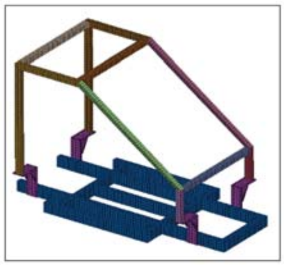
$$\alpha_i(\xi) = \sum_{j=1}^{p} \alpha_{ij} S_{j,k}(\xi, \boldsymbol{\delta}_\alpha)$$

$$\beta_i(\xi) = \sum_{j=1}^{p} \beta_{ij} S_{j,k}(\xi, \boldsymbol{\delta}_\beta)$$

3 Case study

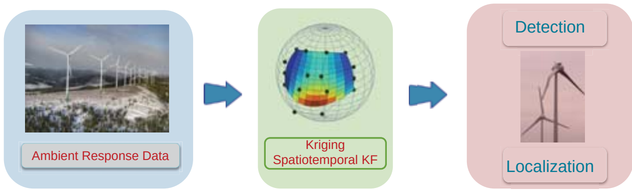
- ✓ Full BETA FE model: 46000 DOFs
- ✓ Reduced model: 54 DOFs
- ✓ 50 simulations (stiffness realizations)
- ✓ input: road induced force
- ✓ output: suspension acceleration





Quantity	Symbol	Value	Unit
Frame material density	E	2.1×10^{11}	N/m
Frame material modulus	ρ	7850	kg/m^3
Wheelset mass	m_w	16	kg
Wheelset stiffness	k_w	35	N/m
Wheelset damping	c_w	0	Ns/m
Suspension stiffness	k_s	22	N/m
Suspension damping	c_s	5	Ns/m
Uncertain stiffness	k_{fr}	$\sim \mathcal{N}(22, 6)$	N/m
Road profile	r_{fr}	$\sim \mathcal{N}(0, 7 \times 10^{-3})$	m

4 Inverse Engineering: damage localization



Step 1: Kriging $\boldsymbol{y}(\boldsymbol{s},t) = \boldsymbol{\pi}^T(\boldsymbol{s})\, \boldsymbol{\alpha}(t) + \sigma^2 Z(t)$

Step 2: KF for $\boldsymbol{\alpha}(t)$

$$\hat{\alpha}[t+1|t] = \mathbf{H}\hat{\alpha}[t|t]$$
$$\hat{\mathbf{P}}[t+1|t] = \mathbf{H}\hat{\mathbf{P}}[t|t]\mathbf{H}^T + \mathbf{JQJ}^T$$
$$\hat{y}(\mathbf{s}, t+1|t) = \boldsymbol{\pi}^T(\mathbf{s})\hat{\alpha}[t+1|t]$$

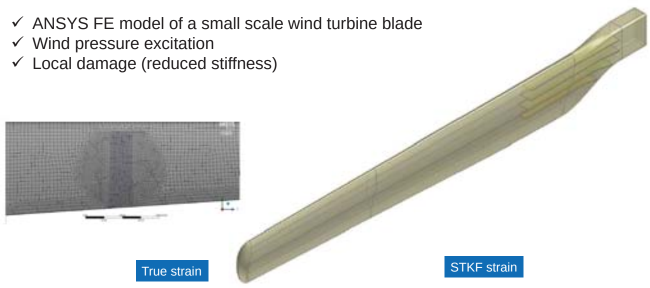
PREDICT

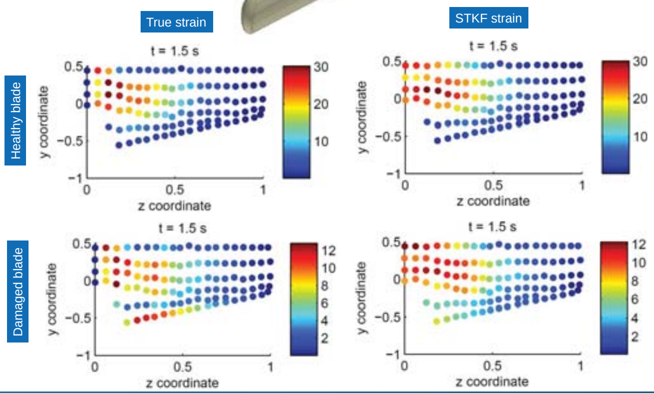
$$\hat{\alpha}[t|t] = \hat{\alpha}[t|t-1] + \mathbf{K}\left(\mathbf{Z}[t] - \boldsymbol{\Phi}\hat{\alpha}[t|t-1]\right)$$
$$\hat{\mathbf{P}}[t|t] = \hat{\mathbf{P}}[t|t-1] - \mathbf{K}\boldsymbol{\Phi}\hat{\mathbf{P}}[t|t-1]$$
$$\hat{y}(\mathbf{s}, t|t) = \boldsymbol{\pi}^T(\mathbf{s})\hat{\alpha}[t|t] + \mathbf{c}_v^T(\mathbf{s})\mathbf{C}_{Z,0}^{-1}\mathbf{Z}[t]$$

UPDATE

5 Case study

- ✓ ANSYS FE model of a small scale wind turbine blade
- ✓ Wind pressure excitation
- ✓ Local damage (reduced stiffness)





7 References

1. Dertimanis et al., ECCOMAS 2016, pp. 6316-6327, 2016.
2. Ou et al., IALCCE 2016, pp. 355-364, 2016.

Partners