Experimental & Computational studies of nominally similar structures

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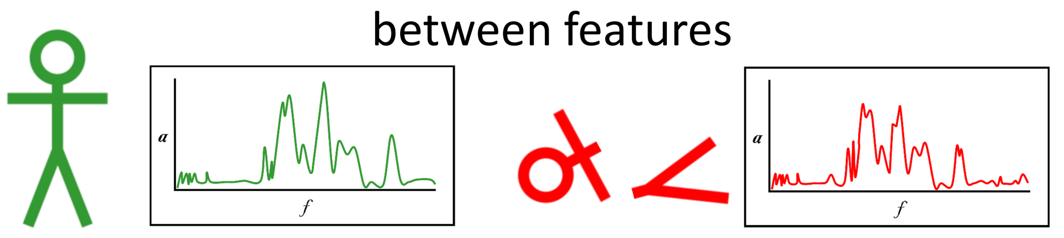
S. Walker. Thanks to C. Lord, K. Worden, N. Dervilis, E. Papatheou

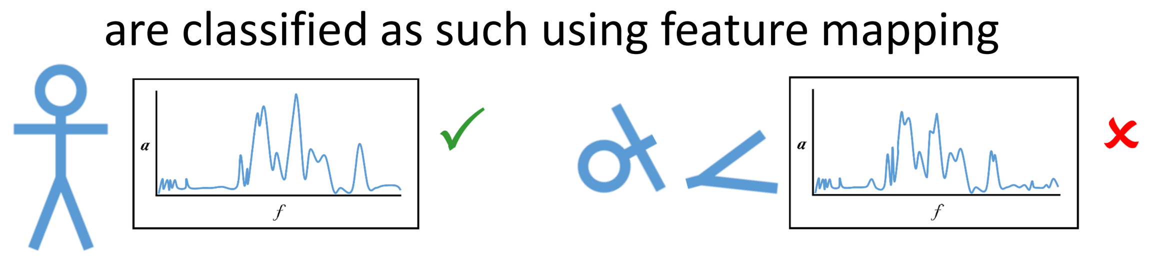
Dynamics Research Group

Data-based SHM

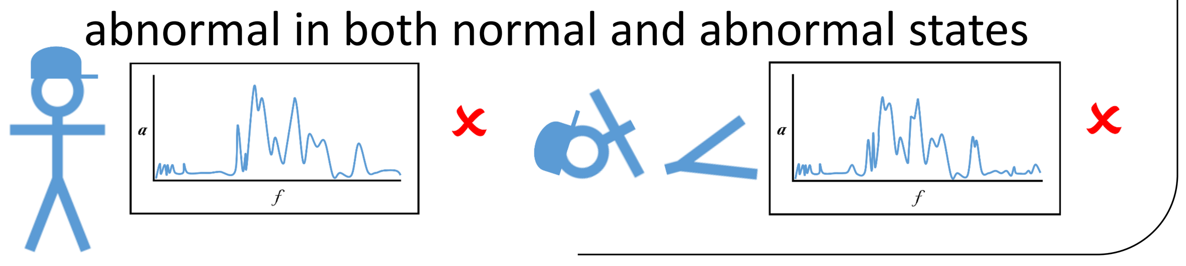
Data gathered on a structure in normal and abnormal states. Feature extraction & classification used to map between features



Future normal and abnormal cases of the same structure are classified as such using feature mapping



Previously unseen similar structure would be classified as abnormal in both normal and abnormal states

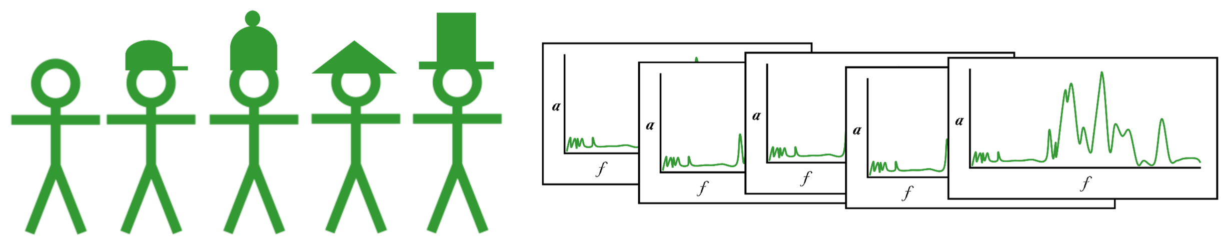


Population-based Structural Health Monitoring (SHM) offers the opportunity to monitor populations of structures (e.g. turbine arrays) without requiring prior knowledge of the damaged states of all structures

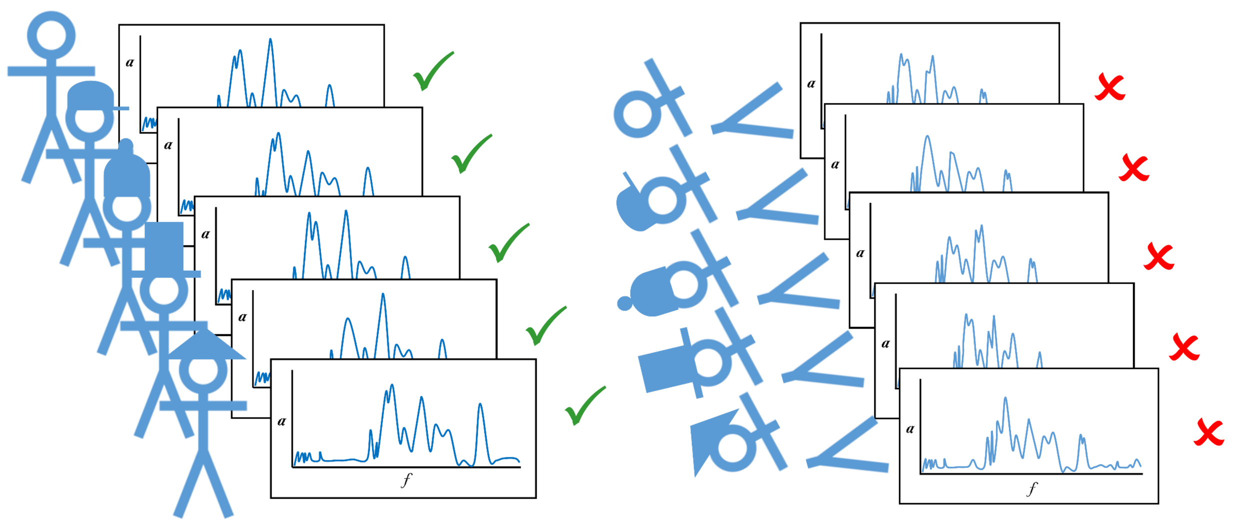
To this end, we aim to experimentally test a population of structures, build a Finite Element (FE) model, understand the variation between normal states in nominally similar structures, and test the potential of pseudo-damage.

Population-based SHM

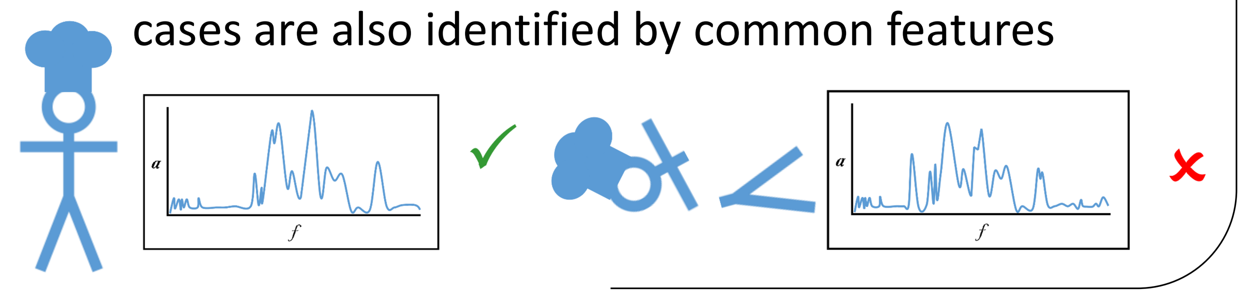
Common features of normal cases are identified from a population of similar structures



Previously unseen abnormal cases are classified as such by their variation from the population of normal cases

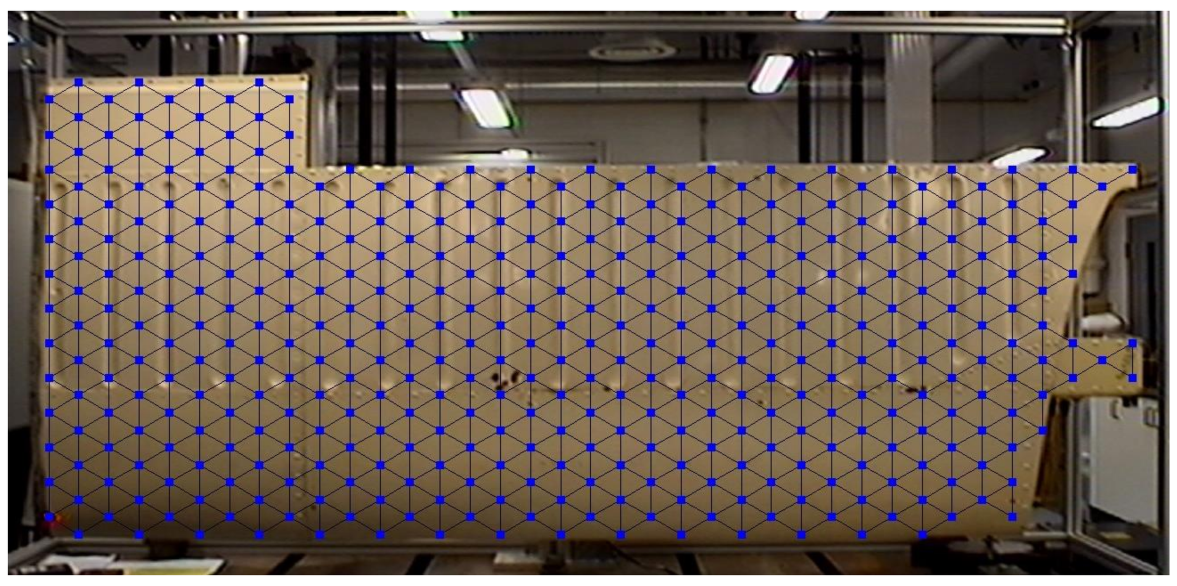


Previously unseen similar structure normal and abnormal cases are also identified by common features



Experimental testing

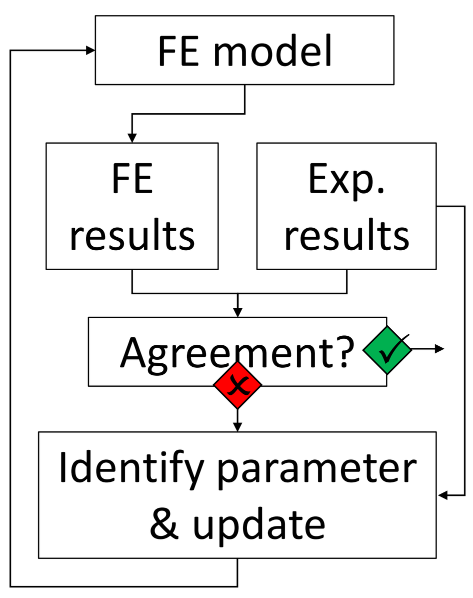
Population of 6 aircraft tailplane structures tested on both surfaces with and without two masses of *pseudo-damage* (total of 36 result cases).



Structures hung on springs and excited (0-1000Hz white noise) on rear surface. Data captured by Scanning Laser Doppler Vibrometer over 400 surface points

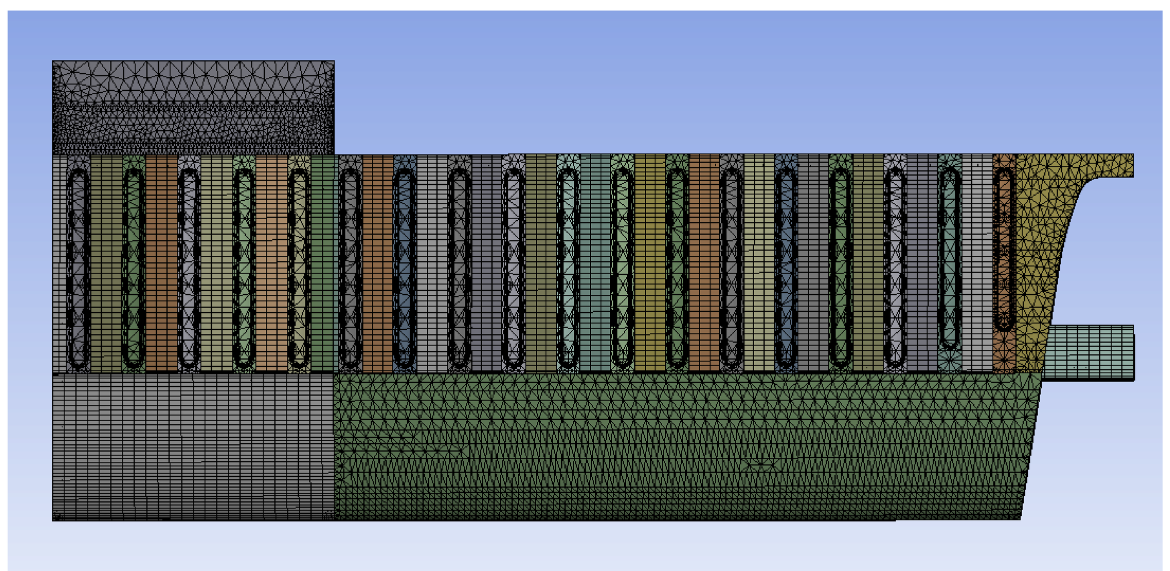
Since ω=√k/m, we aim to simulate the effect on natural frequency of a reduction in structural stiffness (as caused by damage) by adding mass

In a complex structure with global and local modes, Model updating allows the use of experimental data to update FE model mass, stiffness and damping matrices.



A material property (e.g. Young's Modulus) is selected and experimental data is used to incrementally update the computational model

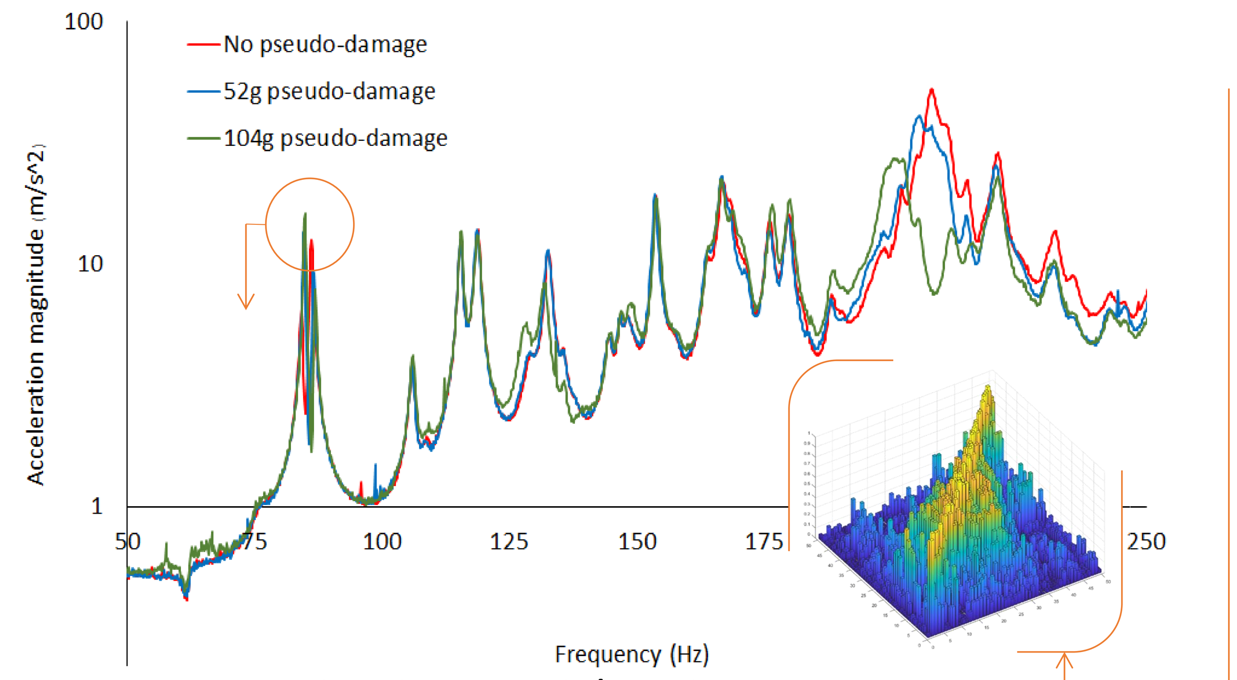
FE Model



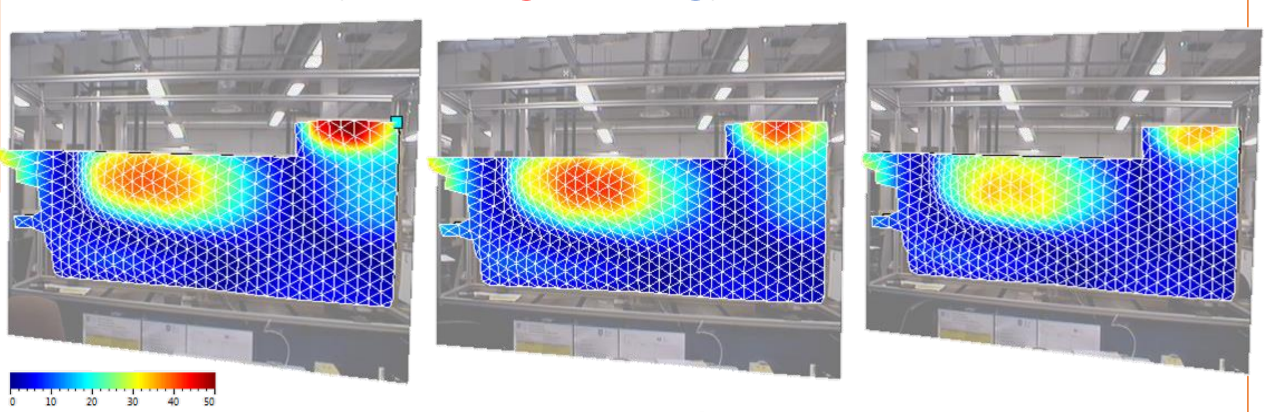
Model constructed in ANSYS 18.2. Initial model based on estimated internal structure and material properties. *Model updating* based on these parameters may yield closer agreement between experimental and FE results

Pseudo-damage results

Experimental Frequency Response Functions (FRFs) show close correlation between undamaged and pseudo-damage cases. Damage appears to decrease modal frequencies:



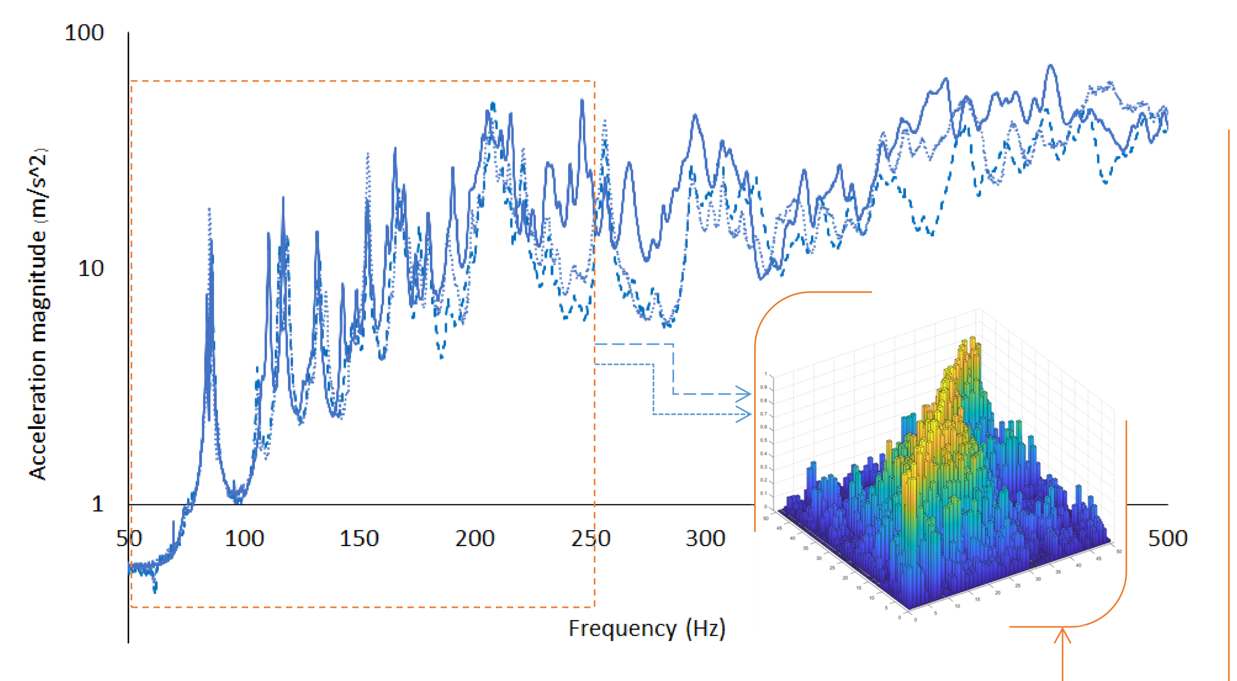
MAC (undamaged / 52g) > 0.9



Acceleration magnitude (m/s²). Mode 1: 86-87Hz
(l-r) undamaged, 52g pseudo-damage, 104g pseudo-damage

Population results

Significant variation in nominally identical structure FRFs at high frequency (sample of 3 undamaged structures):



MAC (similar structures: 0-250Hz) > 0.8

Modal Assurance Criterion (MAC) allows comparison of modes between experiments and FE models, or between structures.

For modal vectors $\{\varphi_m\}$ and $\{\varphi_e\}$:

MAC=1 ⟶ Full correspondence

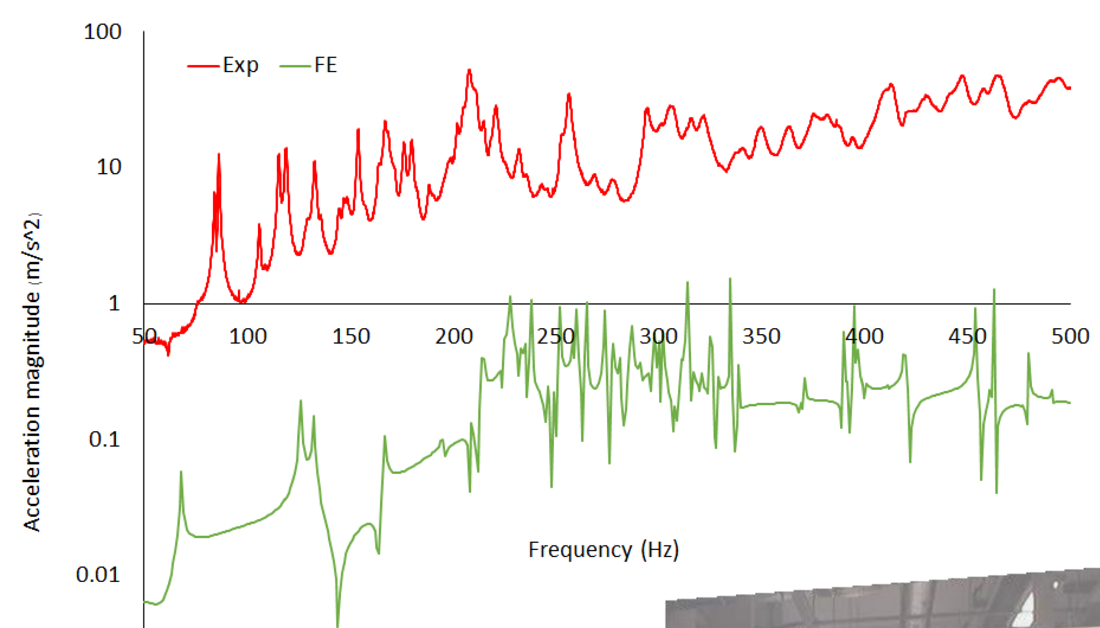
MAC=0 ⟶ Zero correspondence

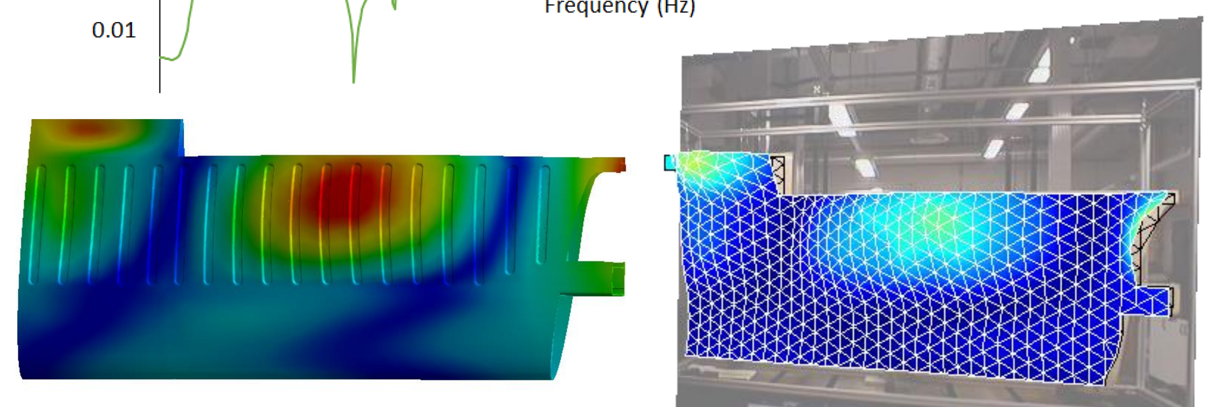
$$MAC(\{\varphi_e\},\{\varphi_m\}) = \frac{|\{\varphi_e\}^T\{\varphi_m\}|^2}{(\{\varphi_e\}^T\{\varphi_m\})(\{\varphi_m\}^T\{\varphi_e\})}$$

MAC was used to study variation between similar structures within the population, and between undamaged and pseudo-damaged structures.

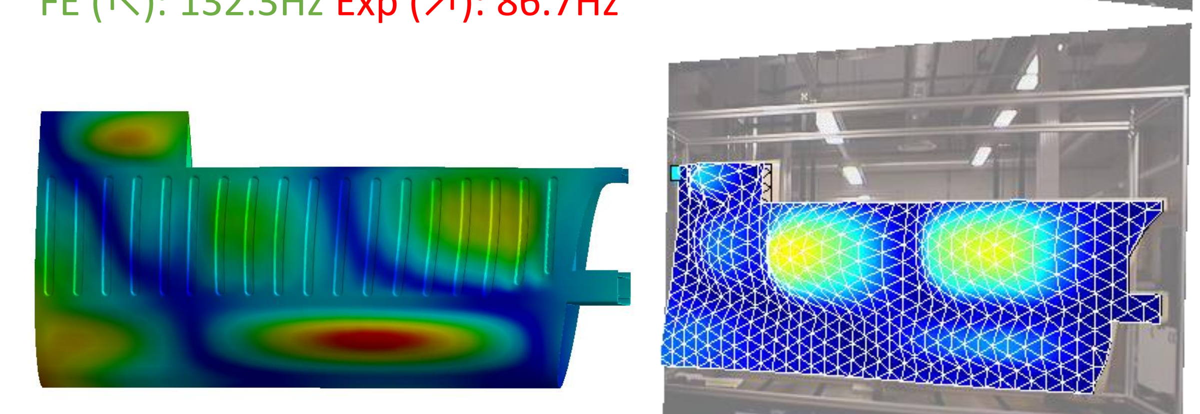
Modal comparison

Experimental and FE model results were compared by *MAC*, mode shape and FRF comparison:

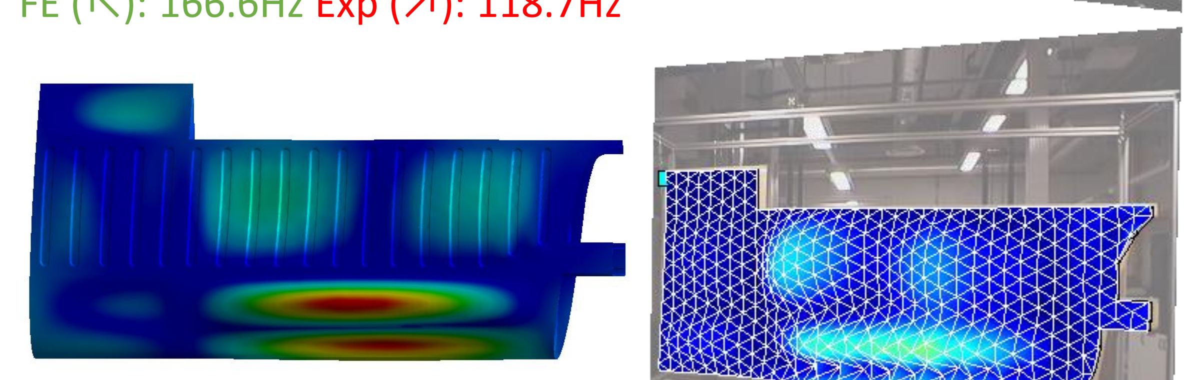




Mode 1
FE (↖): 132.3Hz Exp (↗): 86.7Hz



Mode 2
FE (↖): 166.6Hz Exp (↗): 118.7Hz

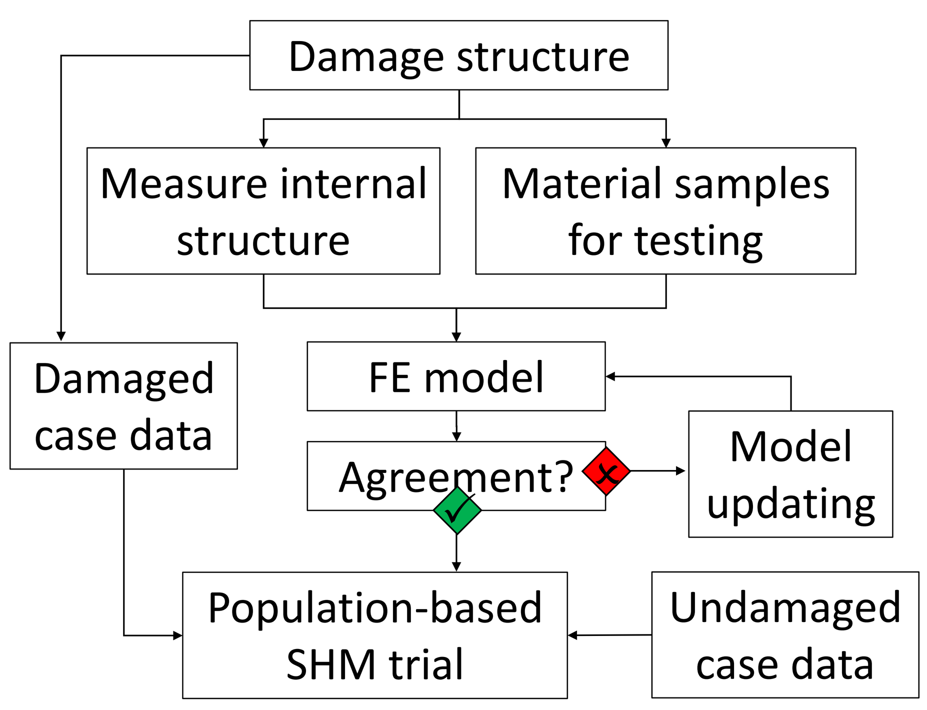


Mode 3
FE (↖): 194.9Hz Exp (↗): 132.7Hz

Conclusions

FE / Experimental correlation is currently low

This is due to a lack of material properties and internal structure data. By incrementally damaging a structure we hope to collect this data:



Incremental damage tests will also allow validation of pseudo-damage results.

Damaged, undamaged and pseudo-damaged data will ultimately be used to test the population-based SHM concept