Submission No. 10142

Error localization examples: Looking for a needle in a haystack

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Objectives

- To discuss an application of an Error Localization Algorithm (ELA) for model calibration of finite element models

- To discuss implementation by comparing results for two examples with known answers

- To compare model changes using a standard approach and ELA

What is the ELA process?

- Process starts with a nominal mass M and stiffness K

$$K\Phi = M\Phi\Lambda$$

- Where Φ and Δ are the nominal mode shapes and eigenvalues.
- The ELA corrected model is

$$(K + \Delta K)\Psi = (M + \Delta M)\Psi\Omega$$

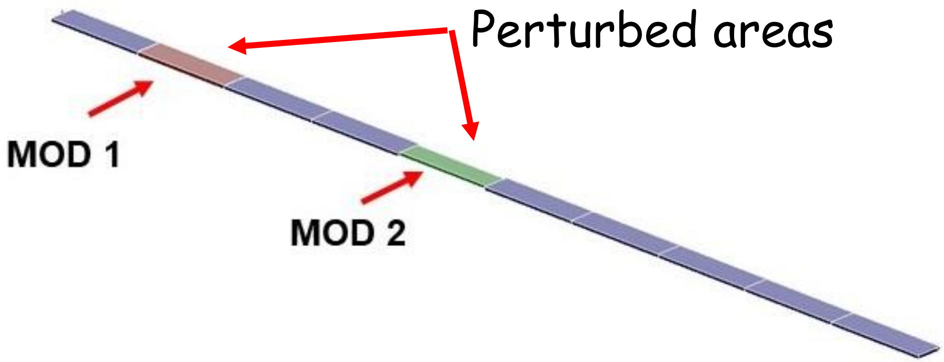
- Where Ψ and Ω are the measured mode shapes and eigenvalues.
- Under certain conditions the ELA corrected model matches the test data exactly

Degrees of freedom affected by ΔM and ΔK are the error zones

General comments about ELA

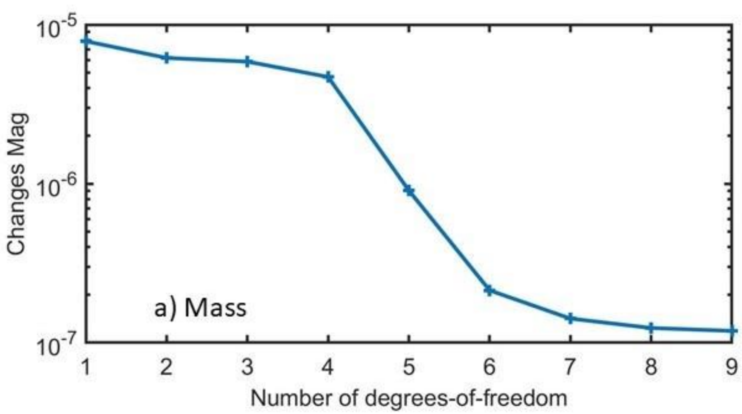
- The ELA approach was initially proposed in: Horta, L.G., and Reaves, M.C.: "An implementation of error localization algorithms for model calibration of dynamical systems." Published on-line 06 May 2020. SN Applied Sciences (2020) 2:1027, https://doi.org/10.1007/s42452-020-2744-x
- Under certain conditions ELA is effective in locating problem areas in finite element models using modal data
- Error localization is an extremely difficult task that can fail for many reasons –is not a panacea for all model ills-
- ELA uses measured mode shapes and frequencies to compute mass and stiffness corrections to match the test data
- MATLAB software for partitioning of the FEM using ELA has been developed to work with MSC solution 200
- FEM partitioning often produce large number of design variables
- FEM partitioning is ideally suited for use with commercial software

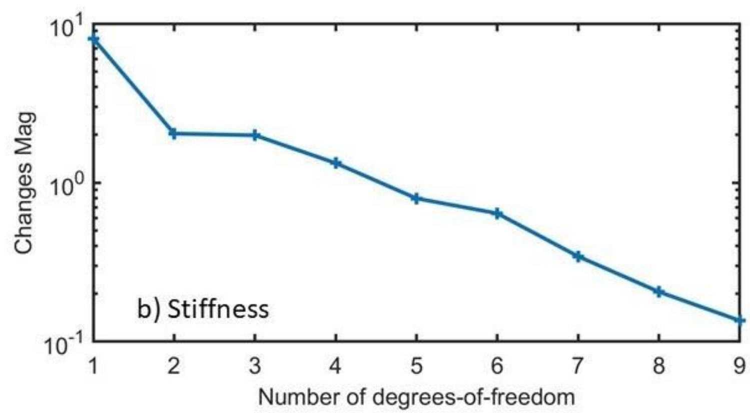
Example No. 1: Clamped Beam



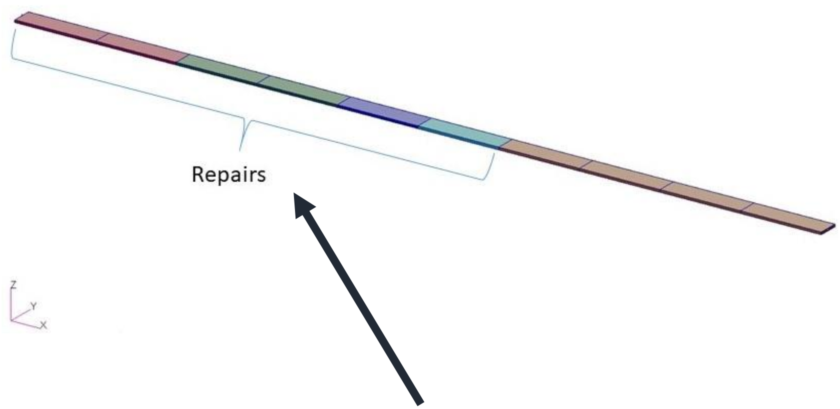
Test Setup
10 test shapes
18 sensors y and z

ELA computed mass and stiffness changes to match the test





Example No. 1: ELA identified zones for repairs

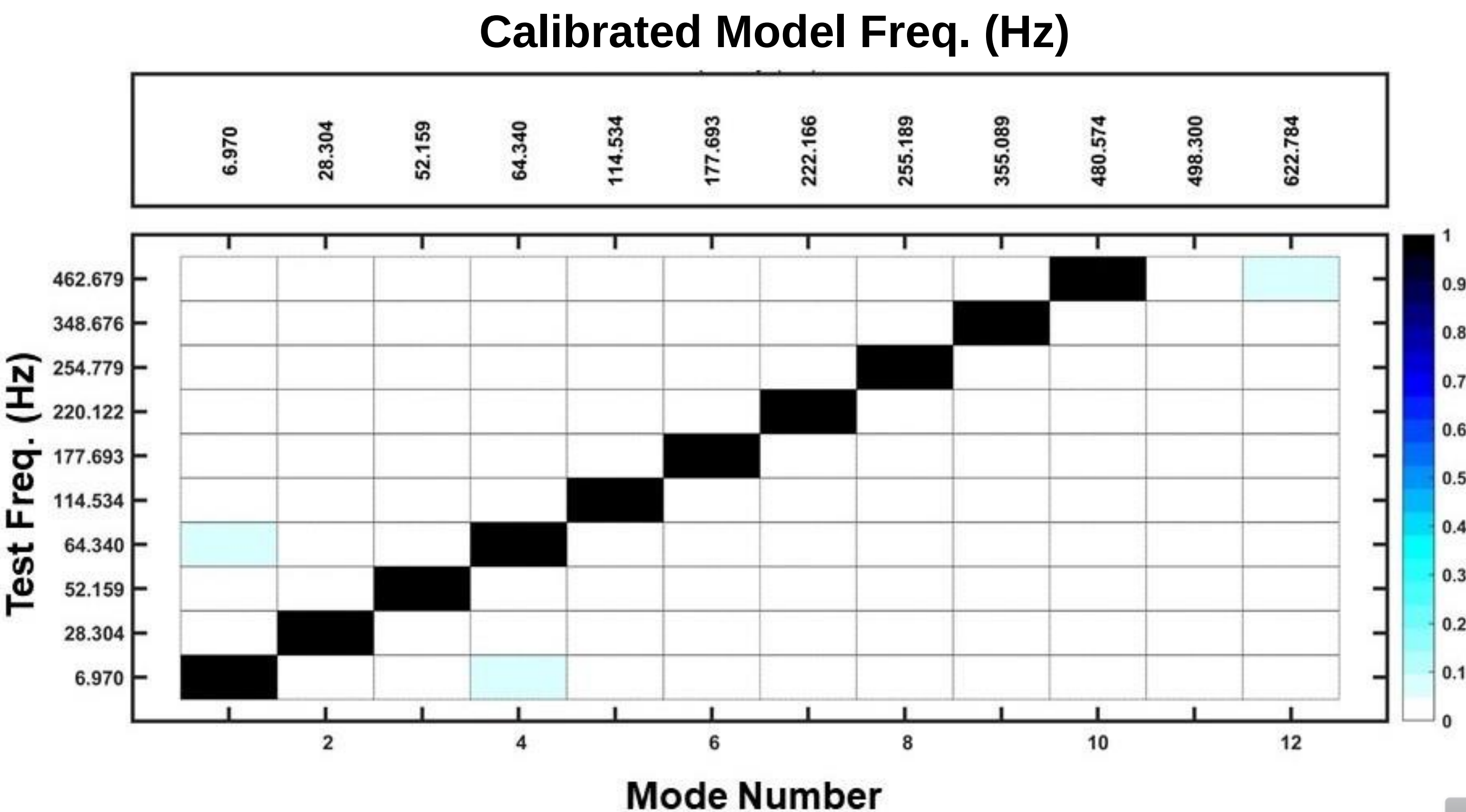


ELA identified zones needing mass and stiffness corrections

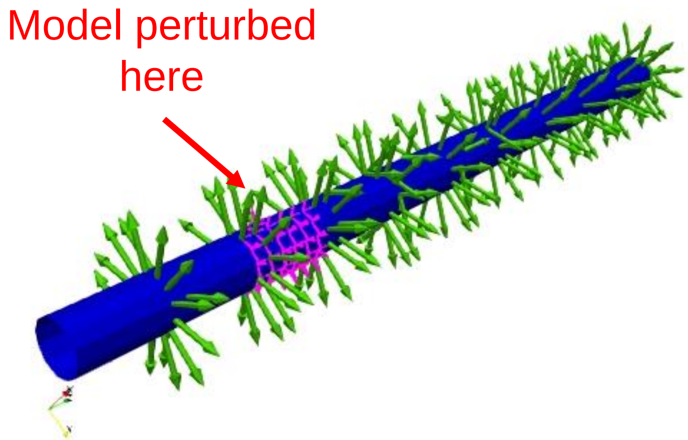
FEM partitioned into 4 zones
Parameter List

Par No.	Zone ID	Units	Nominal Value	Label	Cal. Value
1	555001	in^2	0.1250	A	0.1179
2	1110001	in^2	0.1250	A	0.1248
3	1665001	in^2	0.1250	A	0.1250
4	2220001	in^2	0.1250	A	0.1435
5	555001	in^3	0.0002	I1	0.0002
6	1110001	in^3	0.0002	I1	0.0002
7	1665001	in^3	0.0002	I1	0.0002
8	2220001	in^3	0.0002	I1	0.0002
9	555001	in^3	0.0104	I2	0.0083
10	1110001	in^3	0.0104	I2	0.0104
11	1665001	in^3	0.0104	I2	0.0083
12	2220001	in^3	0.0104	I2	0.0083
13	555001	in^3	0.0006	J	0.0006
14	1110001	in^3	0.0006	J	0.0006
15	1665001	in^3	0.0006	J	0.0006
16	2220001	in^3	0.0006	J	0.0006

Example No. 1: Cross-orthogonality of test and calibrated model

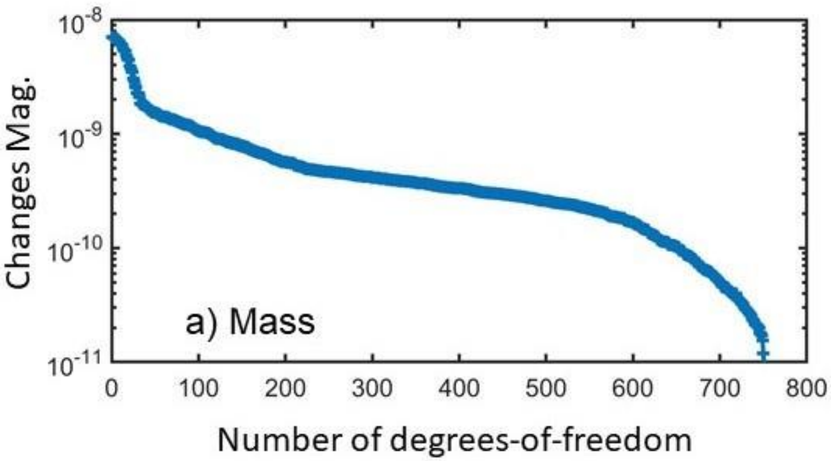


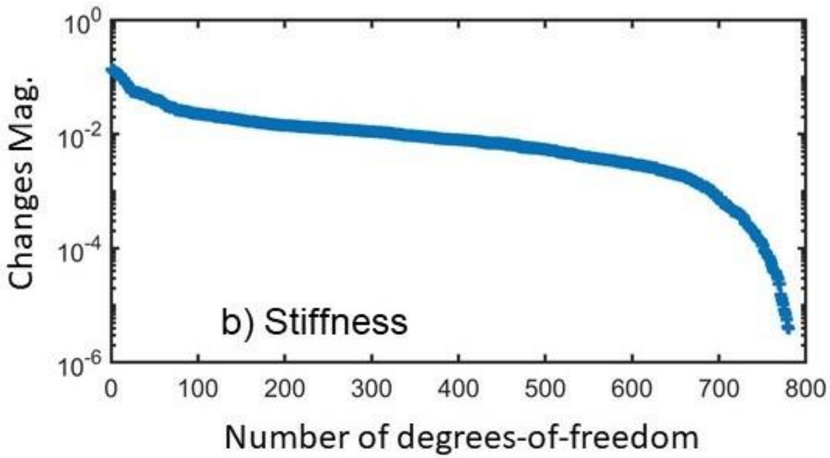
Example No. 2: Cantilever tube



Test Setup
6 modes
209 sensors

ELA Mass and stiffness corrections





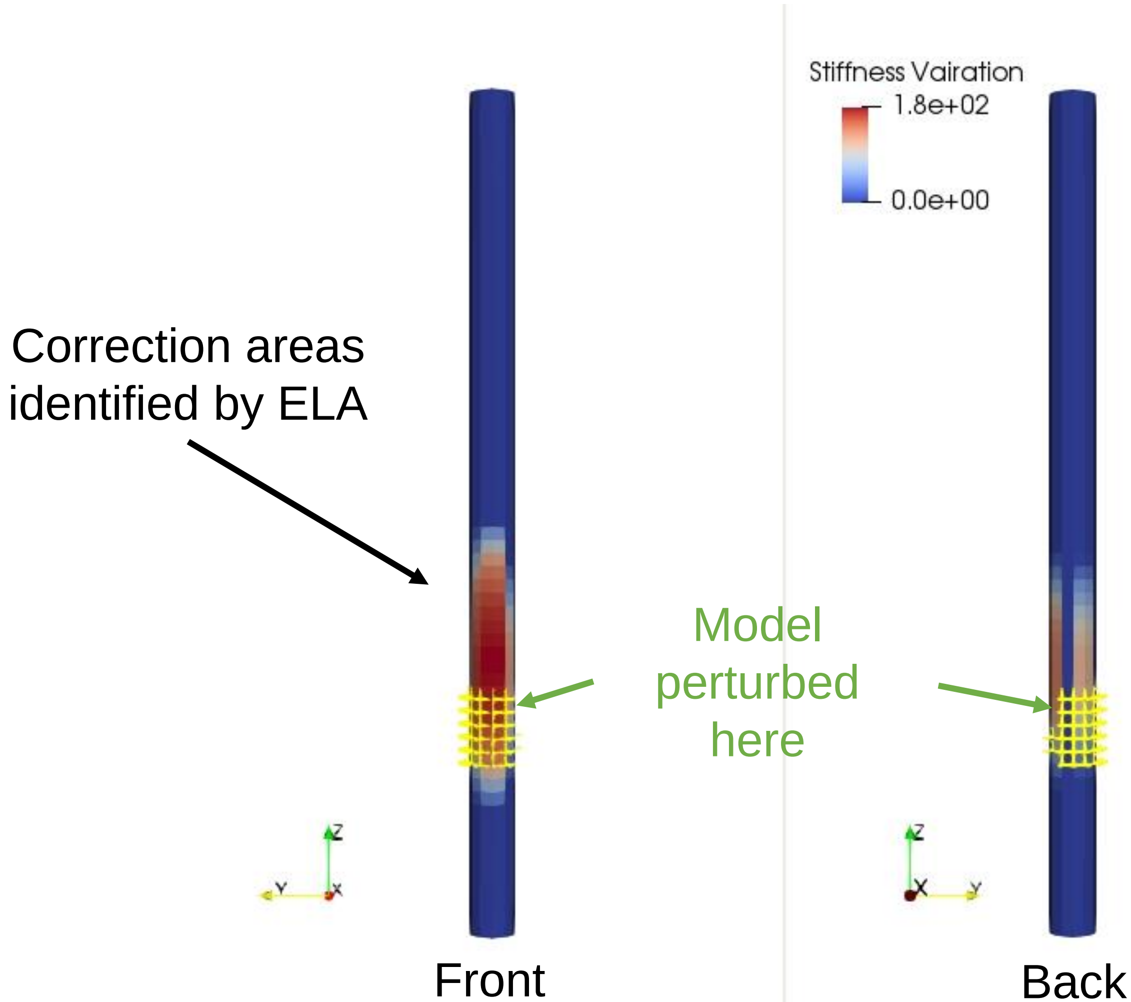
Example No. 2: Model frequencies

Mode	Perturbed Model Freq. (Hz)	Nom. Model Freq. (Hz)	Nom. Freq. Error (%)	Cal-1 Freq. (Hz)	Cal-1 Freq. Error (%)	Cal-2 Freq. (Hz)	Cal-2 Freq. Error (%)
1	53.8	54.4	1.0	53.8	-0.1	53.7	-0.3
2	58.6	61.1	4.1	58.7	0.2	59.1	0.8
3	334.0	332.6	-0.4	333.2	-0.2	334.5	0.1
4	368.6	367.1	-0.4	367.8	-0.2	366.7	-0.5
5	527.6	529.0	0.3	527.9	0.1	532.8	1.0
6	536.8	538.5	0.3	537.1	0.0	535.0	-0.3
7	543.1	546.9	0.7	543.6	0.1	543.7	0.1
8	551.5	555.8	0.8	551.9	0.1	547.2	-0.8

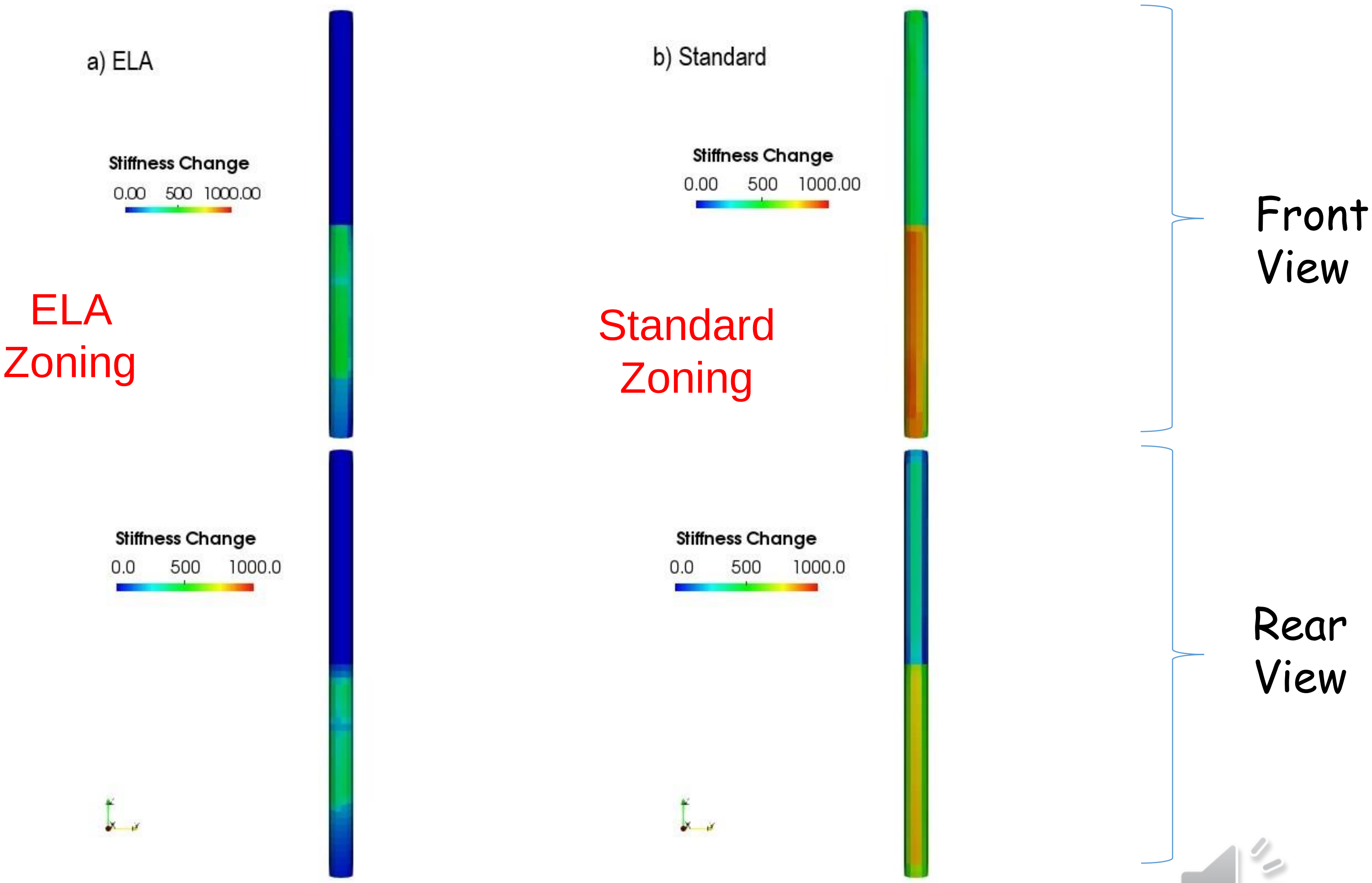
(Cal-1) ELA zoning (Cal-2) STD zoning

Note:
Cal-1 model calibrated using ELA zoning
Cal-2 model calibrated using standard zoning

Example No. 2 : Comparison of ELA versus perturbed area



Example No. 2: Comparison of improvement areas using standard and ELA zoning



Lesson: two calibrated models can have significantly different stiffness changes

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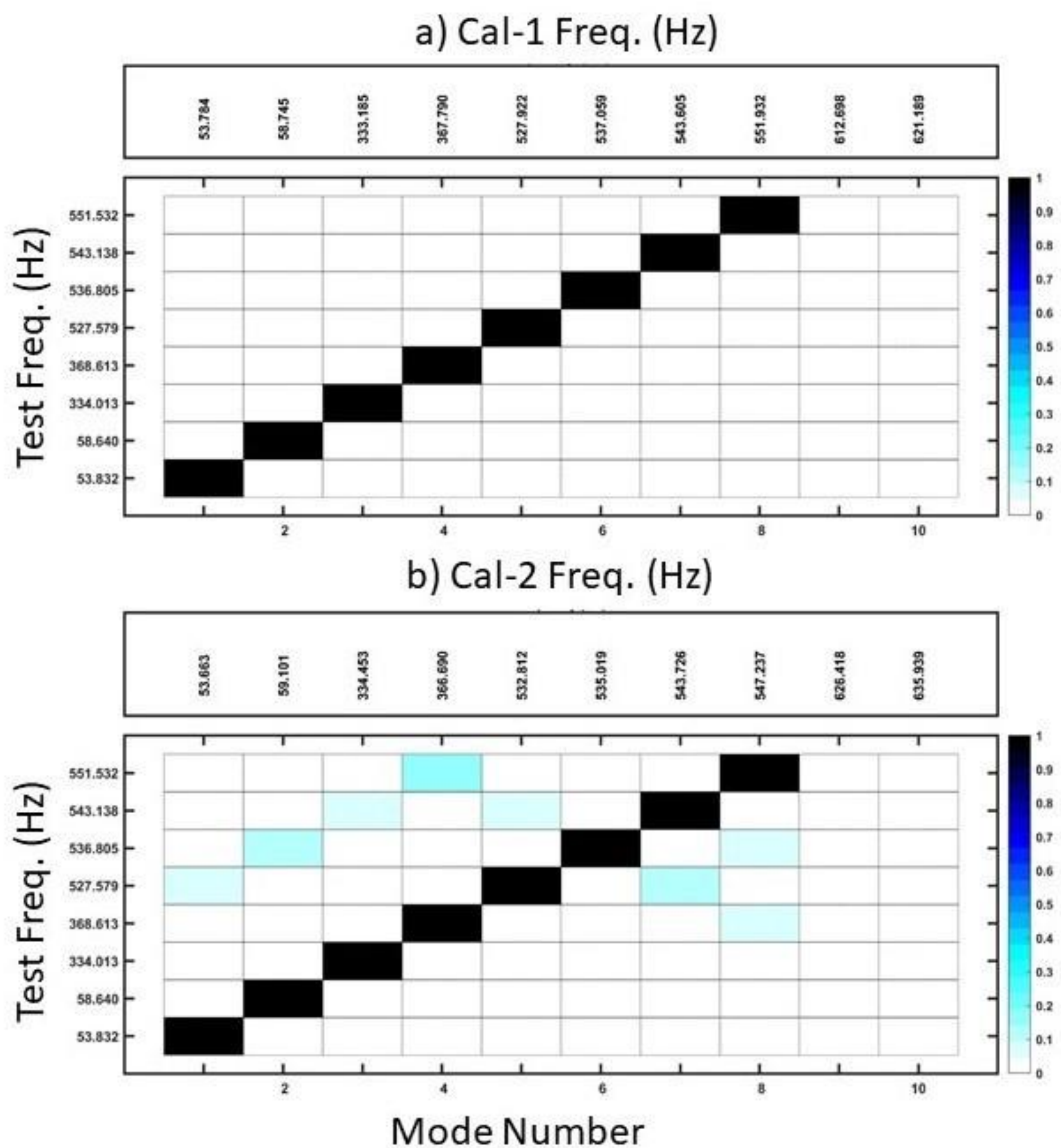
(Cal-1) ELA zoning (Cal-2) STD zoning

Note:
Cal-1 model calibrated using ELA zoning
Cal-2 model calibrated using standard zoning

Example No. 2: Cross-orthogonality for two calibrated models

ELA Zoning

Standard Zoning



Concluding remarks

- ELA approach provides, for the first time, a way to determine FEM problem areas directly from measured data
- The ELA process can identify corrections in both mass and stiffness
- Efficacy of the ELA process has been demonstrated using problems with known answers
- Implementation of actual model changes can be turned over to commercial model update tools
- Model calibration is a non-deterministic problem that can lead to many different acceptable solutions
- Example problem showed two calibrated models with similar calibration metrics but with drastically different model changes