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Operational Analysis of a Structure with Intermittent Impact

Submission #14282

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Outline

- Motivation
- Structure Configurations & Testing
- Finite Element Model
- Operational Deflection Shapes Implementation
- ODS Results
- Conclusions

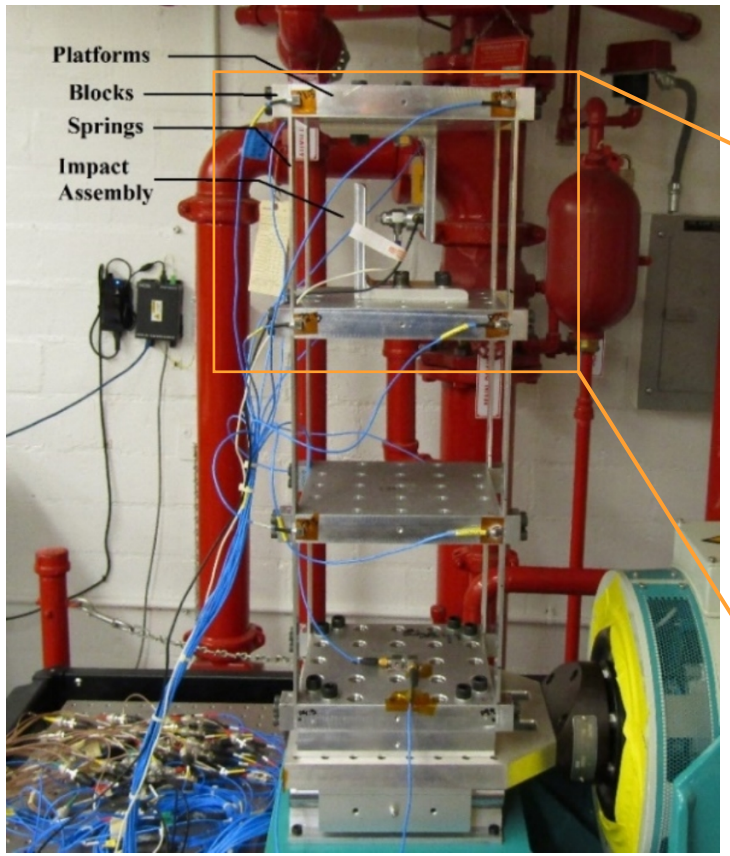
Motivation

- Modal parameters give key insight regarding structural response to dynamic excitation
  - Also are an important step in model validation and calibration
- Modal testing is not always a priority
- Vibration data can be used to *estimate* modal parameters when modal testing not possible
- We do this by calculating operational deflection shapes (ODS)
  - However, nonlinear response and high level of excitation may affect these predictions

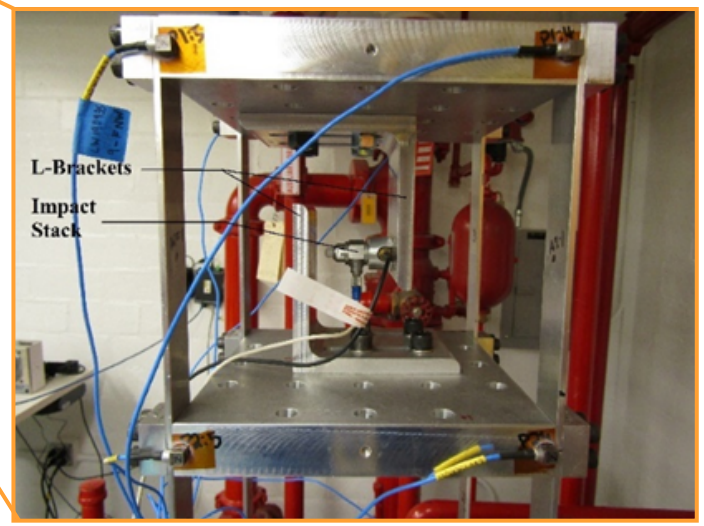
We are using an academic structure to investigate the effects of intermittent impact and varying levels of excitation on ODS!

Structure Configurations and Testing

Structure designed to respond with intermittent impact and was vibration tested at various excitation levels (0.57 Grms to 3 Grms)

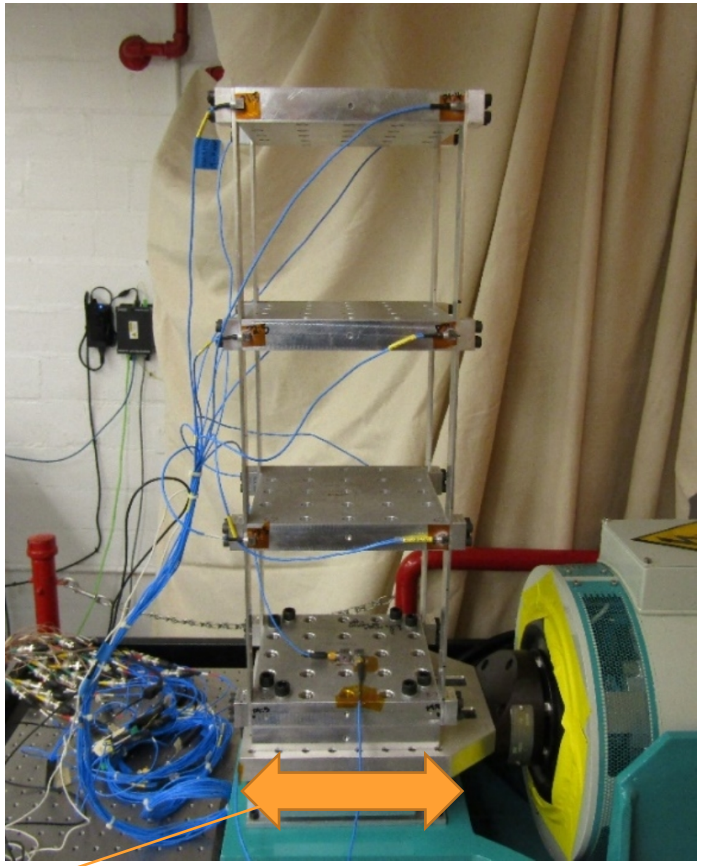


Structure with impact assembly



Closeup of impact assembly

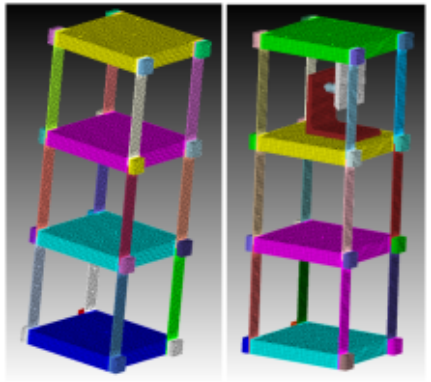
Direction of vibration



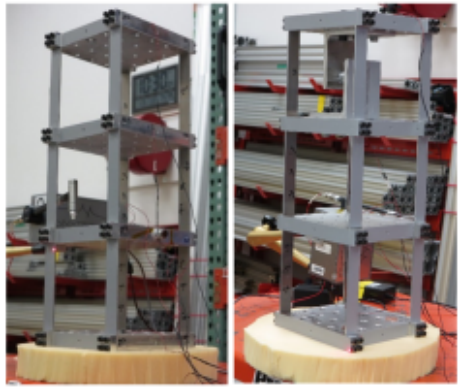
Structure without impact assembly

Finite Element Model Calibration

- Ideally modal testing would be done to serve as “true” mode shapes and frequencies
- Ironically, schedule didn’t allow for this
- Instead we compared to finite element model
  - Used existing LDV modal data for structure in free-free boundary condition to calibrate the FEM



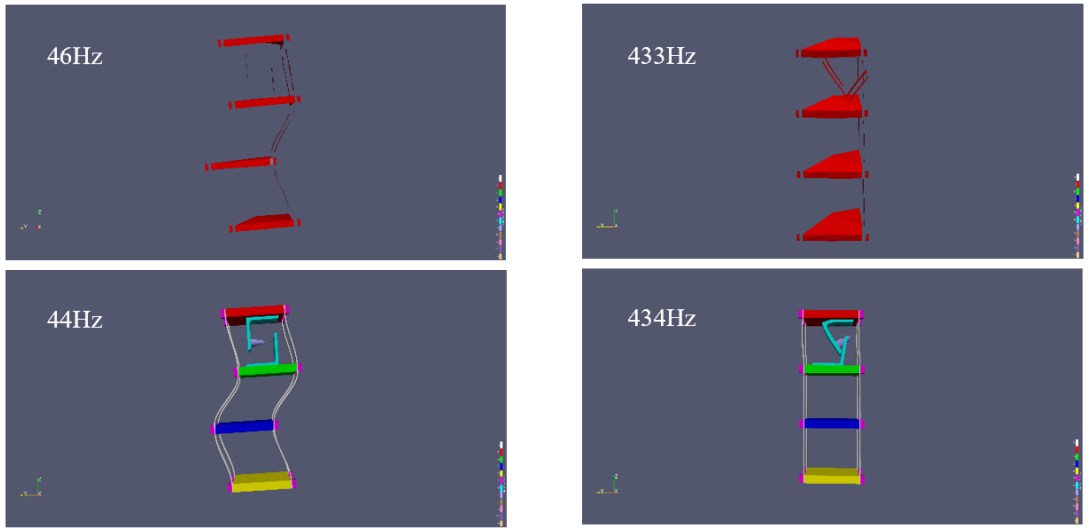
Finite Element Models

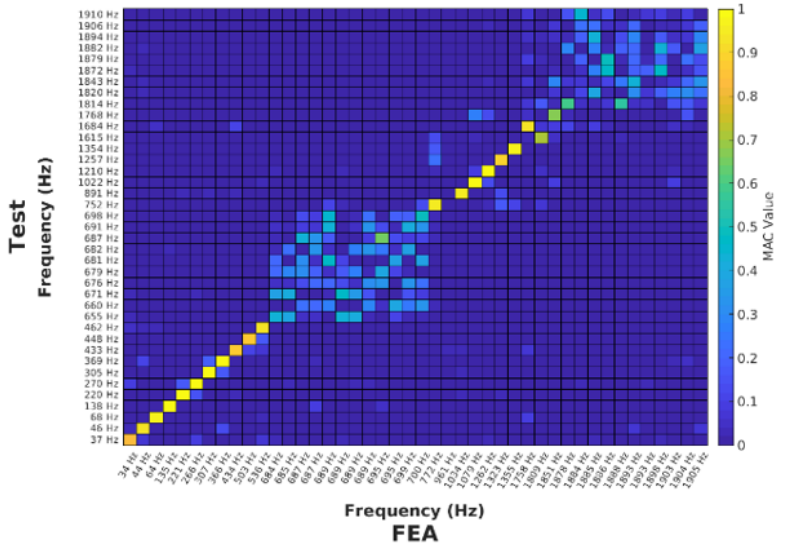


Free-Free Modal Test

Modal Test Mode Shapes

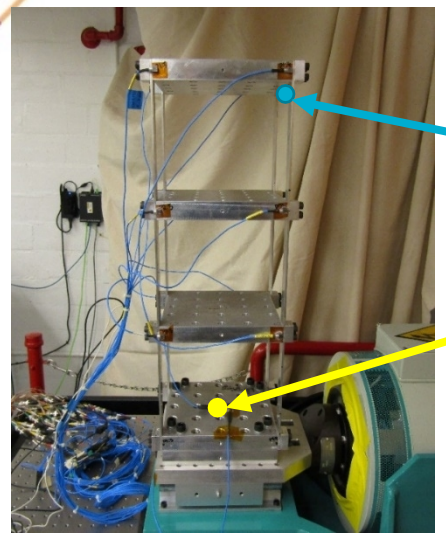
FEM Mode Shapes





MAC showing model calibration

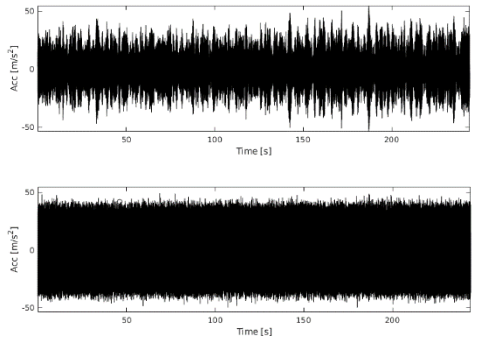
ODS Calculation Process



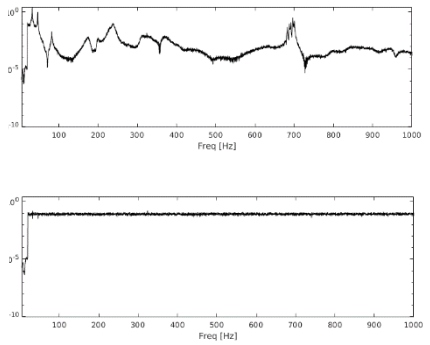
Response Node

Reference Node

Time Response

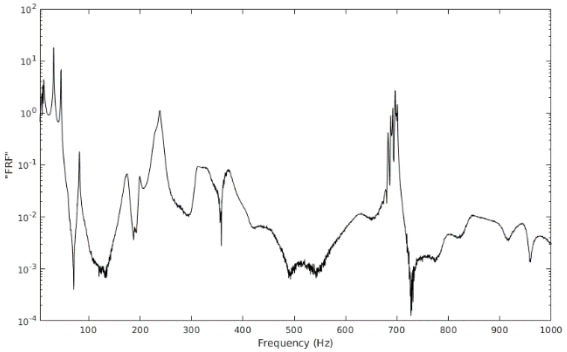


Frequency Response

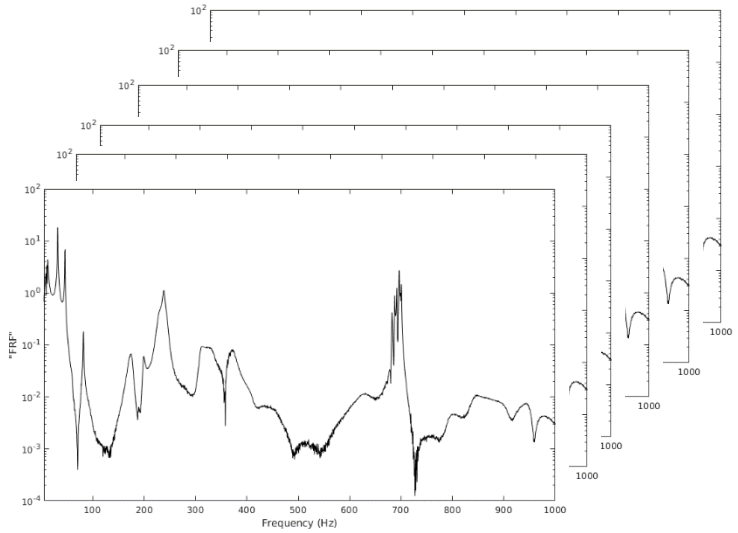


Averaged

Transfer Function aka "FRF"

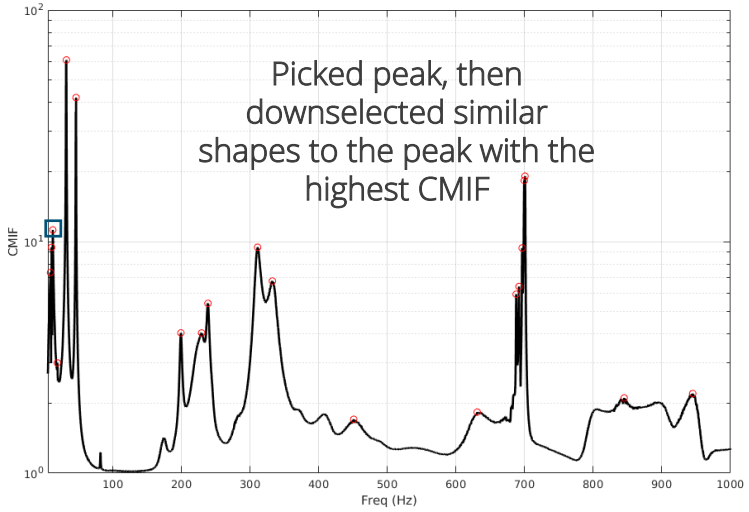


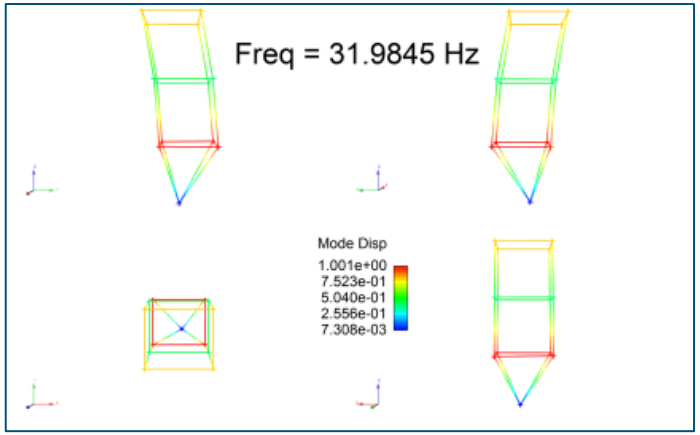
"FRF" at each measurement location



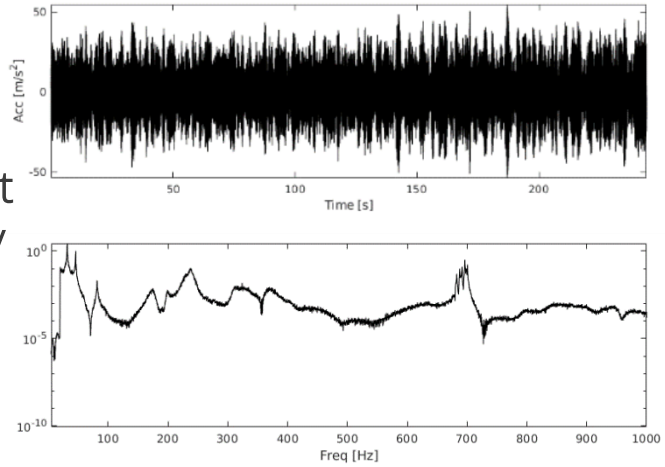
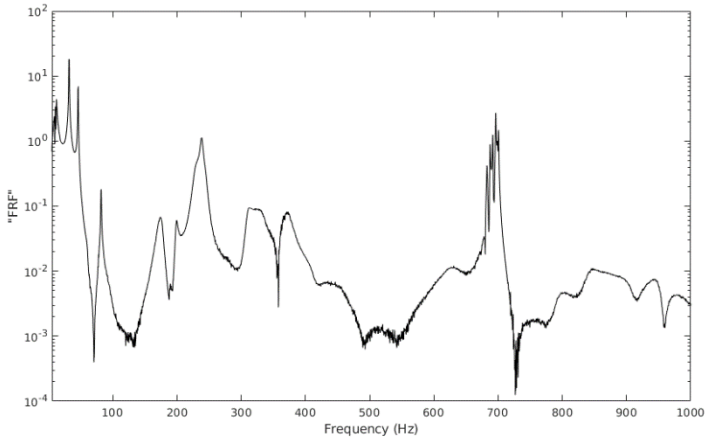
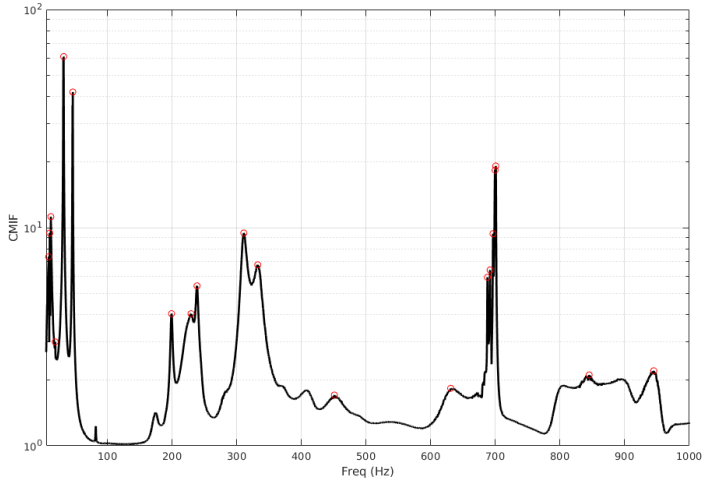
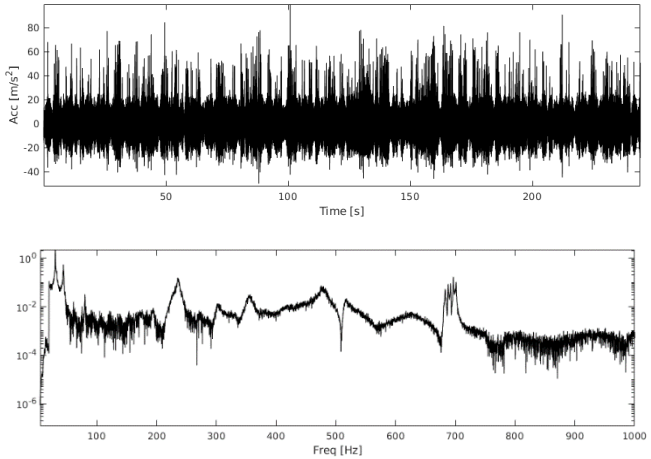
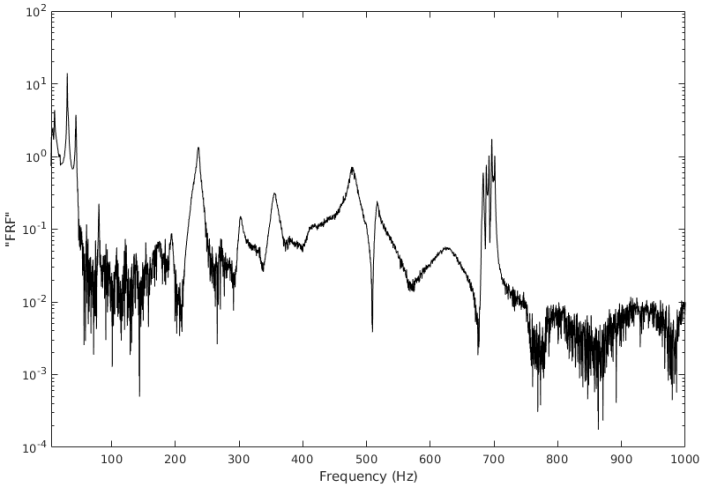
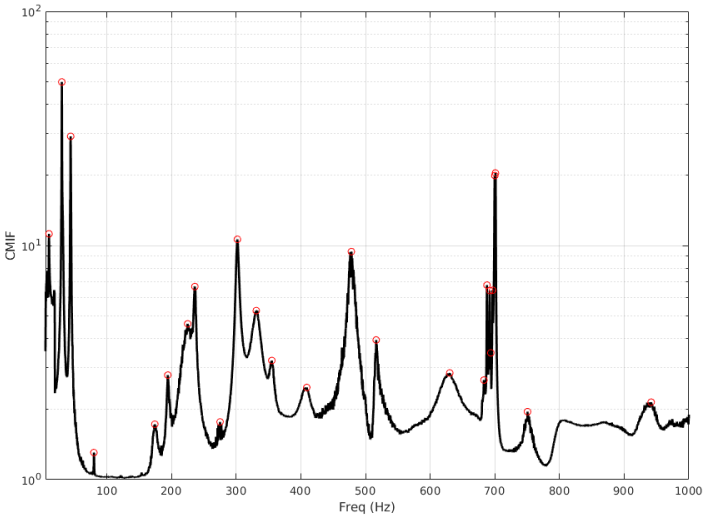
SVD

Complex Mode Indicator Function (CMIF)



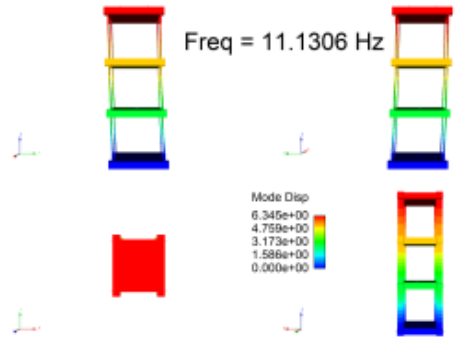


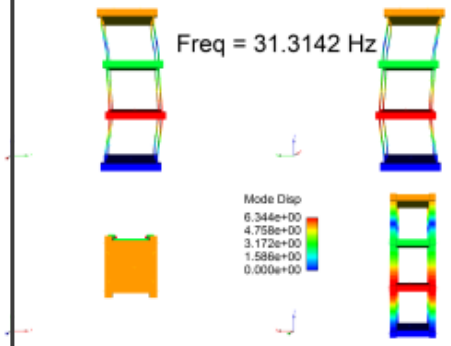
CMIF Comparison

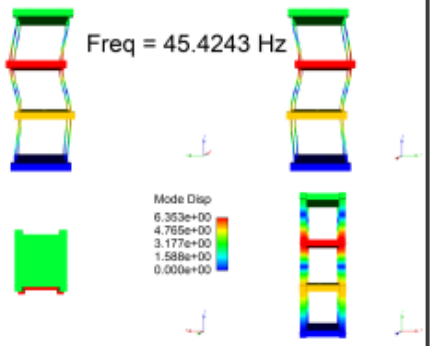
	Measurement	"FRF"	CMIF
No Impact Assembly			
Impact Assembly			

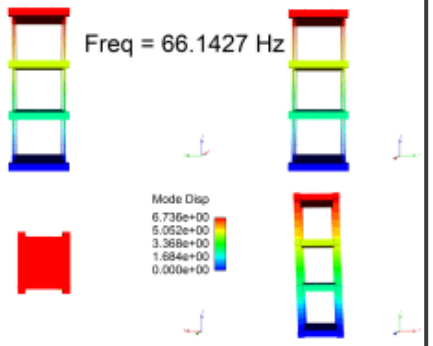
ODS vs. FEM Shapes – No Impact Assembly (1.5 Grms)

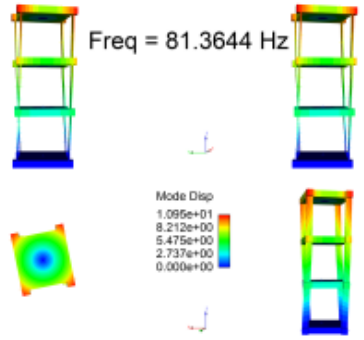
FEM

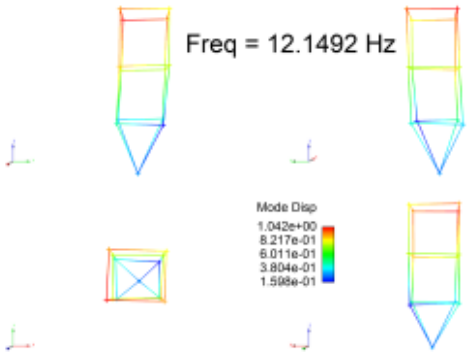


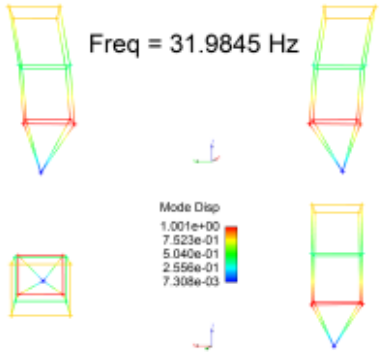


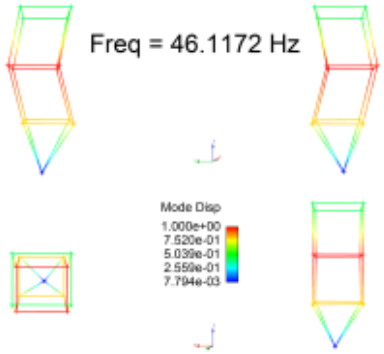












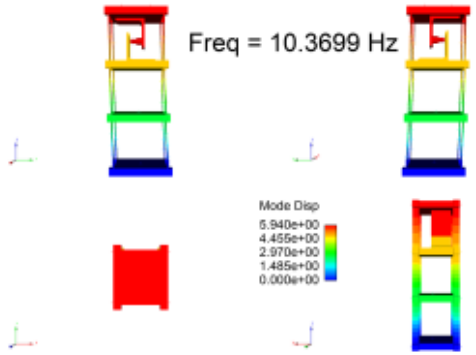
NO CORRESPONDING ODS

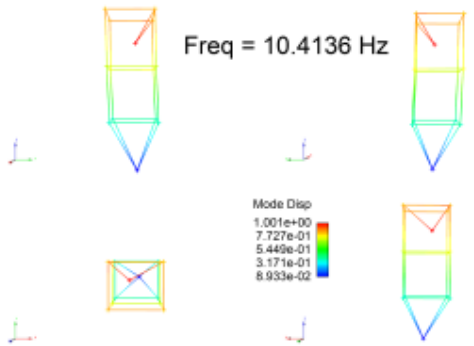
NO CORRESPONDING ODS

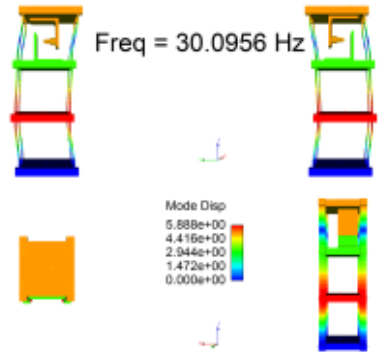
ODS

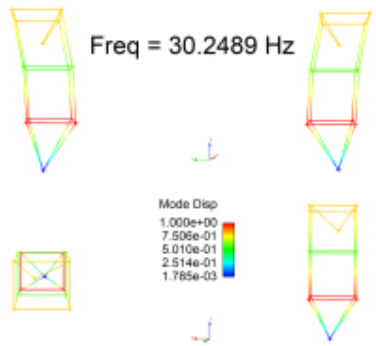
ODS vs. FEM Shapes – With Impact Assembly (1.5 Grms)

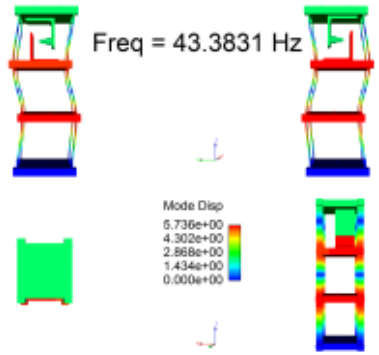
FEM

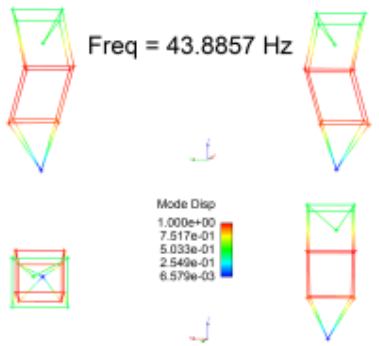


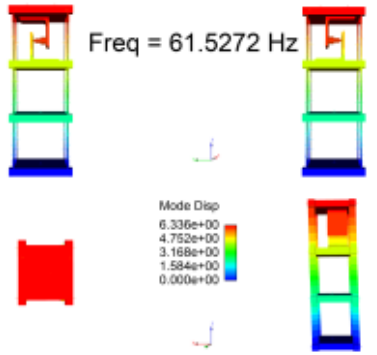




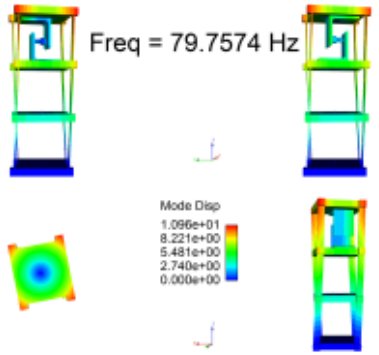


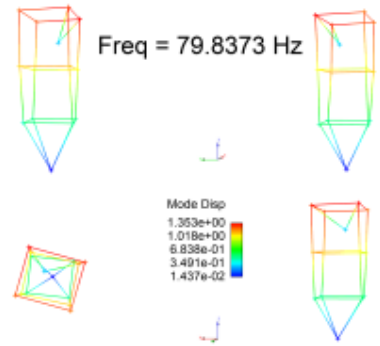






NO CORRESPONDING ODS





ODS

ODS vs. Finite Element Model

- Tables show ODS that are consistent with FEM mode shapes
- Note that ODS for structure WITH impact assembly has fewer missing mode predictions

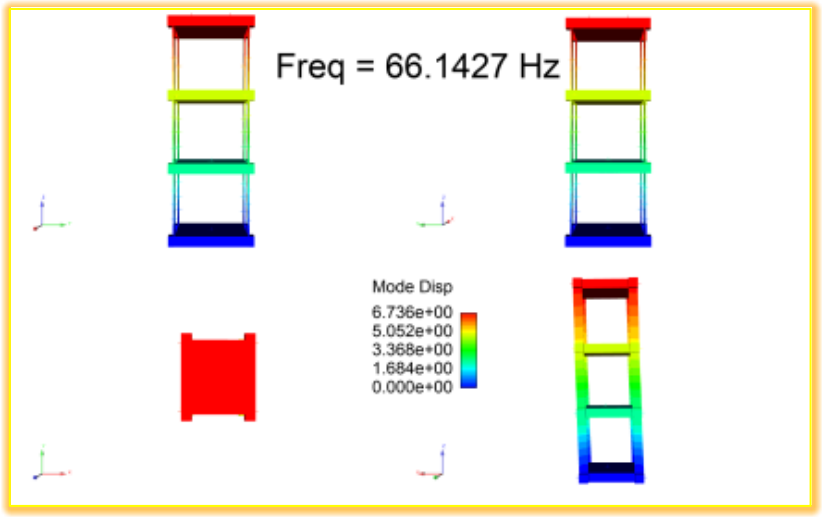


Table 4 High consistency frequencies for structure with impact assembly

-	Finite Element Model	ODS: 0.57Grms	ODS: 0.95Grms	ODS: 1.06Grms	ODS: 1.5Grms	ODS: 2.12Grms	ODS: 3Grms
Modal Frequencies (Hz)	10			11	10	10	11
	30	30	30	30	30	30	30
	43	43	44	43	44	44	44
	62						
	80	80	80	80	80	80	80
	192	195	195	195	194	194	193
	235	236	236	236	236	236	236
	302	303	302	302	302		301
	355	357	356	356	355	353	
	460						
	486	480	479	480	478	478	476
	531						
	684-700	683-701	683-701	683-701	683-701	683-701	683-701
	711	752	752	752	751	750	748
	821						

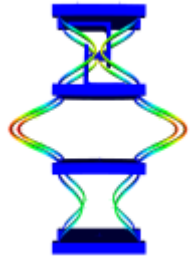
WITH Impact Assembly

Table 5 High consistency frequencies for structure without impact assembly

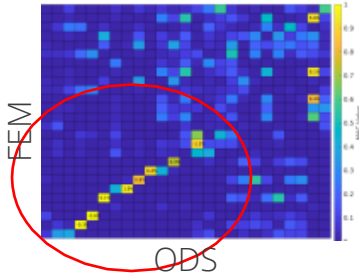
-	Finite Element Model	ODS: 0.57Grms	ODS: 0.95Grms	ODS: 1.06Grms	ODS: 1.5Grms	ODS: 2.12Grms	ODS: 3Grms
Natural Frequencies (Hz)	11						11
	31	31	32	31	32	31	31
	45	46	46	46	46	46	46
	66						
	81			82		82	82
	198	200	199	199	199	198	198
	237	238	238	238	238	239	239
	315	313	312	311	311	310	311
	361						
	510						
	684-700	688-701	688-701	688-701	688-700	688-700	688-700
	803						
	831	846	846	843	845	844	842

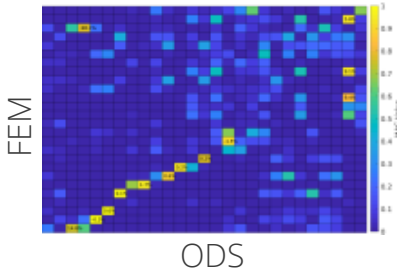
WITHOUT Impact Assembly

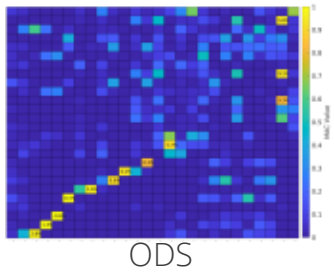
ODS vs. FEM Modal Assurance Criterion (MAC) Plots

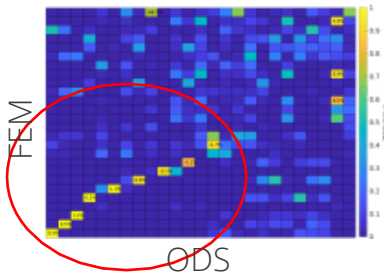


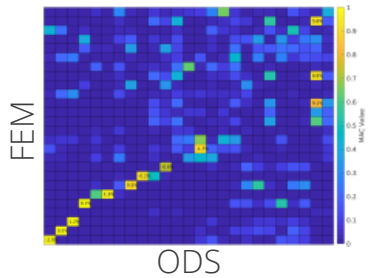
WITH

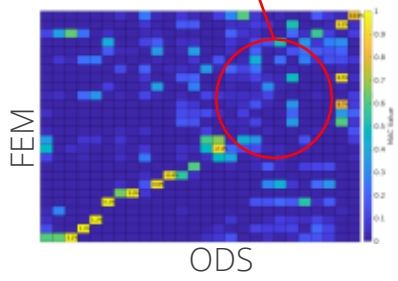






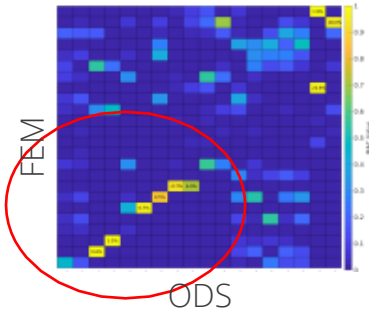


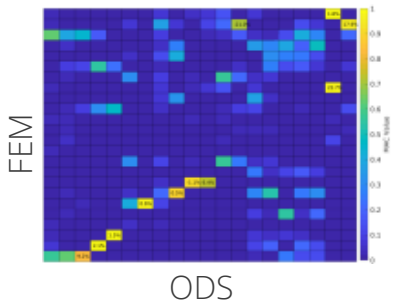


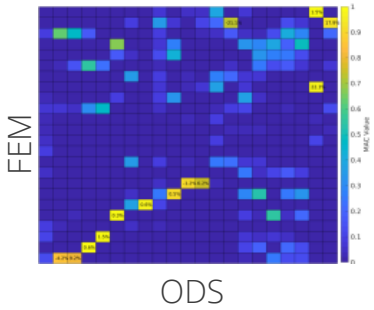


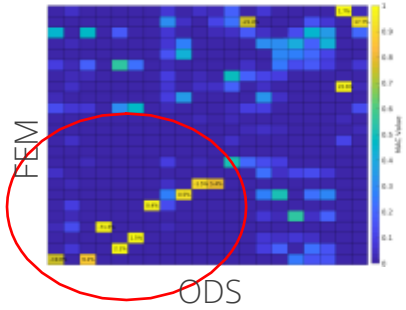
0.57 Grms | 0.95 Grms | 1.06 Grms | 1.5 Grms | 2.12 Grms | 3 Grms

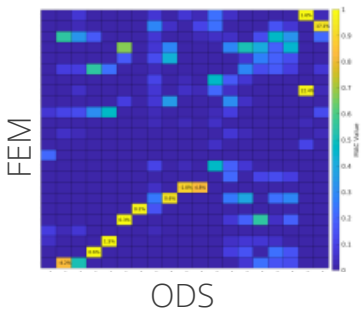
WITHOUT

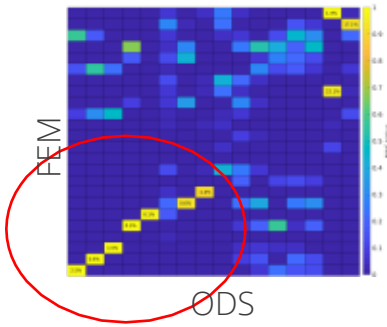










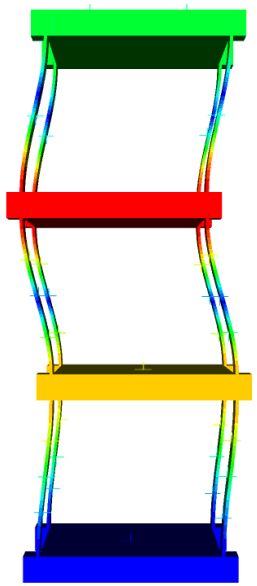


Note: Section with no consistency are spring bending modes, which weren't able to be predicted by ODS since we didn't have sensors on springs

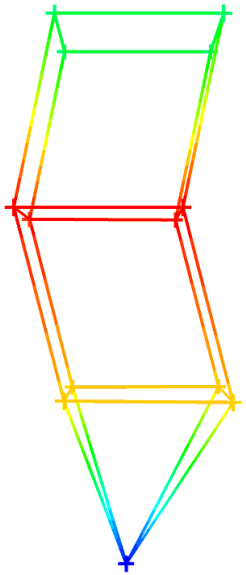
ODS vs. FEM – Representative Mode Shapes

Generally, modes shapes that were successfully predicted by ODS were predicted quite accurately (shape and frequency both very close to model)

WITHOUT Impact Assembly

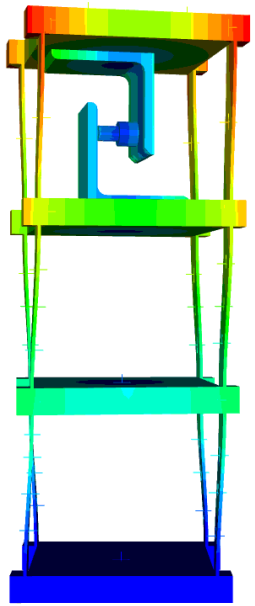


45 Hz

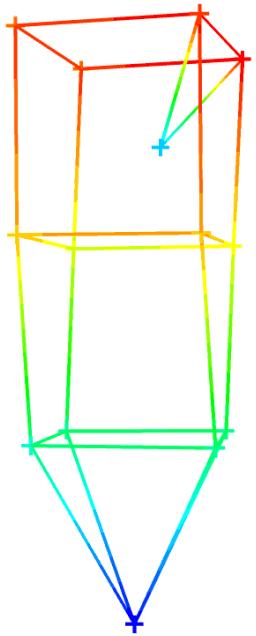


46 Hz

WITH Impact Assembly



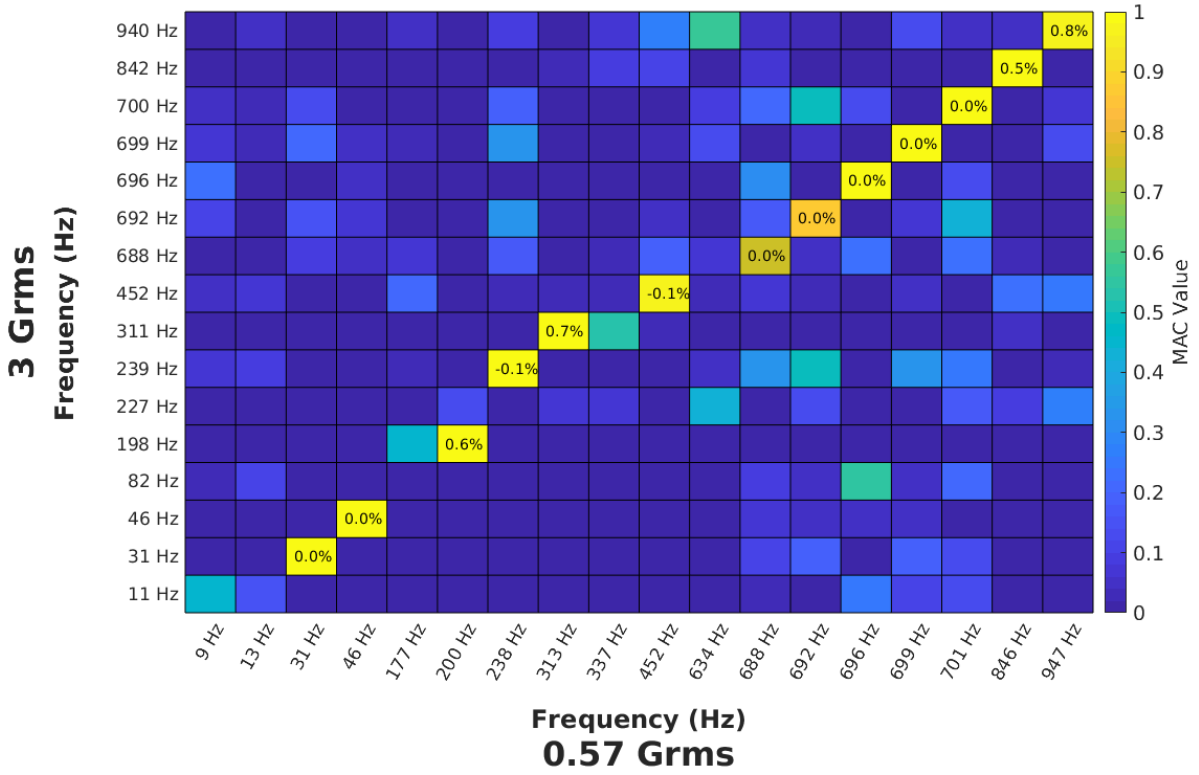
80 Hz



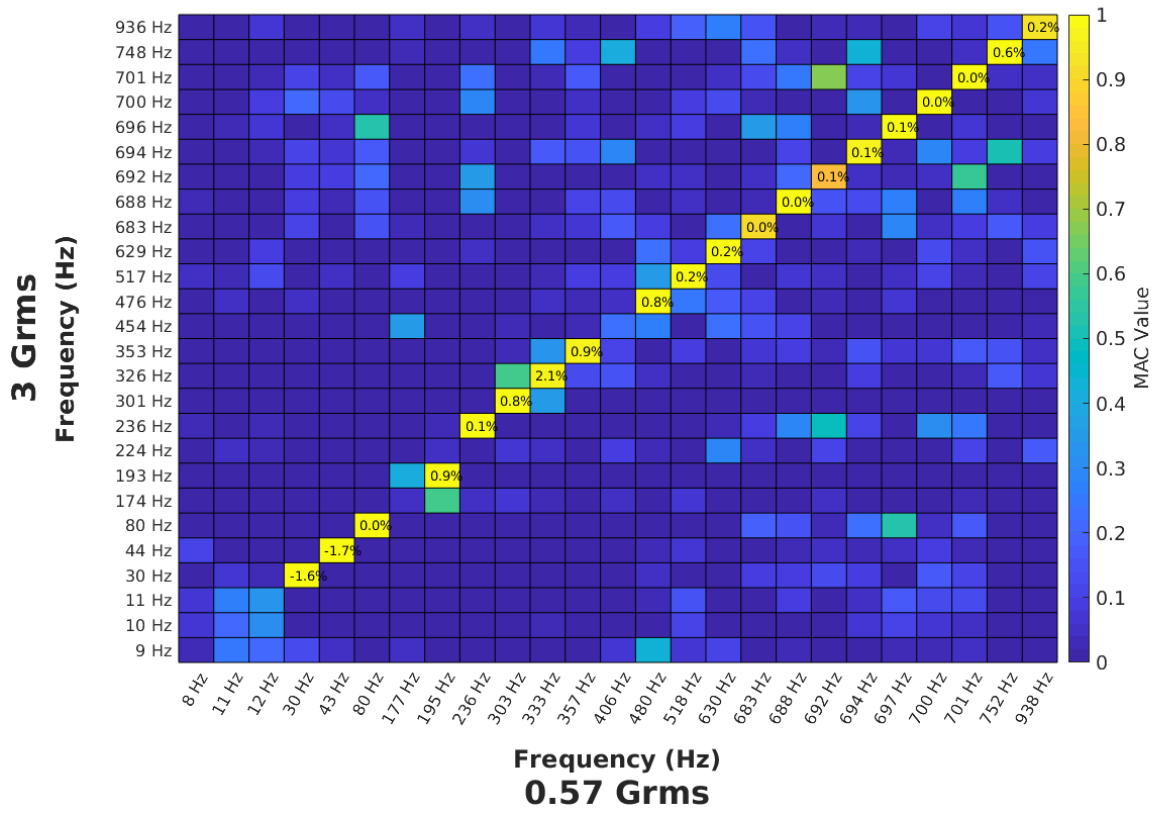
80 Hz

ODS Consistency – High/Low Excitation

WITHOUT IMPACT ASSEMBLY



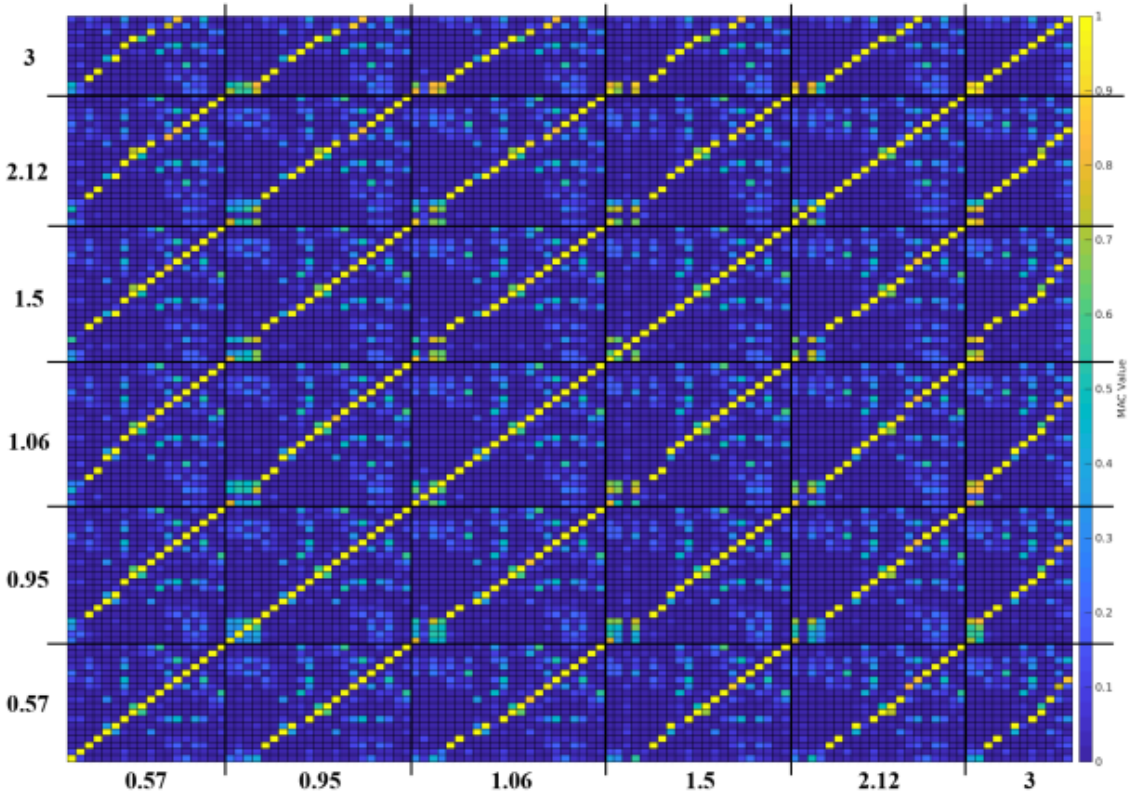
WITH IMPACT ASSEMBLY



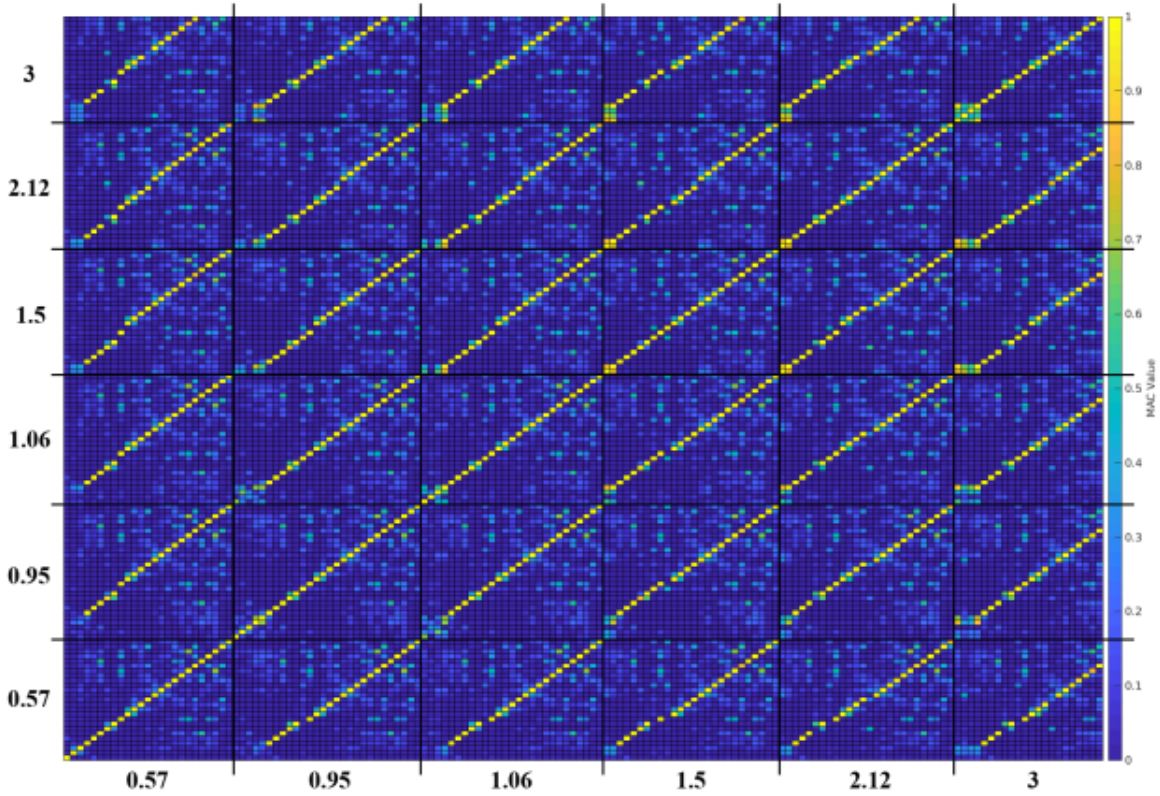
ODS Consistency – BIGMAC

Plots show degree of consistency between ODS predicted mode shapes across excitation level

- Generally, we note *higher* consistency across excitation level WITH impact assembly than WITHOUT
- Possibly due to different response characteristics from impact and asymmetry



WITHOUT Impact Assembly



WITH Impact Assembly

Conclusions

- ODS results are limited by excitation characteristics and sensor placement
  - Frequency content and excitation direction are important!
- Impact assembly results in *slightly better* prediction of modal parameters
  - BUT, it also results in prediction of additional shapes due to additional response peaks
- Increasing excitation level appears to have slightly positive effect on modal predictions
  - Possibly due to enhanced response peaks
  - If possible, use multiple excitation levels!
- Ultimately, intermittent impact and varying levels of excitation DID NOT result in vastly different results → Promising, BUT need better baseline modal data to say for sure!

References

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[7] Sierra SD Team, *Sierra SD,* SAND2022-12518, 2022.

Questions?

Backup Slides

ODS vs. Finite Element Model

- Here, tables show all ODS alongside FEM results -> false predictions included
- Note that ODS for structure WITH impact assembly has more shapes not consistent with FEM mode shapes
  - Due to extra CMIF peaks resulting from impact

Table 2 Resonant frequencies of structure with impact assembly from finite element model and ODS

-	Finite Element Model	ODS: 0.57Grms	ODS: 0.95Grms	ODS: 1.06Grms	ODS: 1.5Grms	ODS: 2.12Grms	ODS: 3Grms
Modal Frequencies (Hz)	**10**	8	7	6	**10**	**10**	9
	30	11	8	9	**30**	**30**	10
	43	12	12	**11**	**44**	**44**	**11**
	62	**30**	13	**30**	**80**	**80**	**30**
	80	**43**	**30**	**43**	174	175	**44**
	192	**80**	**44**	**80**	**194**	**194**	**80**
	235	177	**80**	175	225	225	174
	302	**195**	175	**195**	**236**	**236**	**193**
	355	**236**	**195**	227	275	301	224
	460	**303**	228	**236**	**302**	329	**236**
	486	333	**236**	**302**	331	**353**	**301**
	531	**357**	**302**	331	**355**	408	326
	684-700	406	332	**356**	409	443	353
	711	**480**	**356**	408	**478**	**478**	454
	821	516	408	**480**	516	517	**476**
		630	**479**	518	630	628	517
		683-701	518	628	683-701	683-701	629
		752	628	683-701	**751**	**750**	683-701
		938	683-701	**752**	942	934	**748**
			752	938			936
			937				

WITH Impact Assembly

Table 3 Resonant frequencies of structure without impact assembly from finite element model and ODS

-	Finite Element Model	ODS: 0.57Grms	ODS: 0.95Grms	ODS: 1.06Grms	ODS: 1.5Grms	ODS: 2.12Grms	ODS: 3Grms
Natural Frequencies (Hz)	**11**	9	8	8	9	8	**11**
	31	13	11	11	10	11	**31**
	45	**31**	12	12	12	12	**46**
	66	**46**	**32**	**31**	19	**31**	**82**
	81	177	**46**	**46**	**32**	**46**	**198**
	198	**200**	175	**82**	**46**	**82**	227
	237	**238**	**199**	175	**199**	**198**	**239**
	315	**313**	230	**199**	229	228	**311**
	361	337	**238**	230	**238**	**239**	452
	510	452	**312**	**238**	**311**	**310**	688-700
	684-700	634	335	**311**	332	330	**842**
	803	688-701	450	335	451	453	940
	831	**846**	634	409	631	688-700	
		947	688-701	633	688-700	**844**	
			846	688-701	**845**	940	
			946	**843**	945		
				946			

WITHOUT Impact Assembly