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Experimental Application of Boundary Condition Compensation Map (From Field to Laboratory Response)

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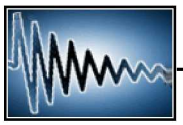
Motivation

- *Laboratory vibration tests typically mimic field environment dynamics*
- *<u>Any</u> difference between the boundary conditions change the dynamic characteristics of the device under test*



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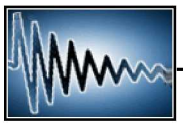
Field Environment

https://share-ng.sandia.gov/news/resources/news_releases/images/2017/TTR_FlyBy.jpg



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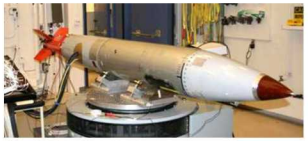

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Laboratory Test

https://www.sandia.gov/news/publications/lab_accomplishments/articles/2016/nuclear-weapons-engineering.html

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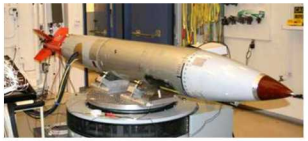

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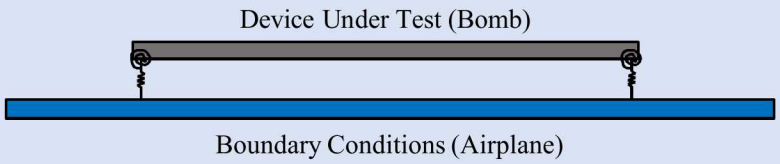
Airplane ≠ Shaker Fixture

Motivation

- *Two beam assembly used to demonstrate the problem*

Field Environment



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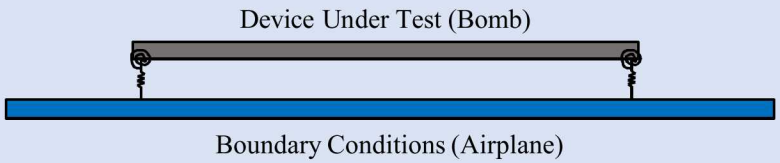
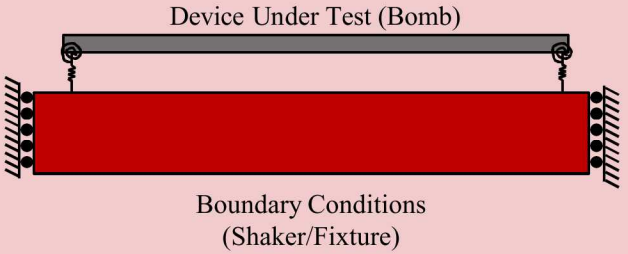
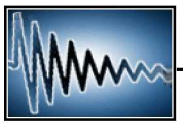


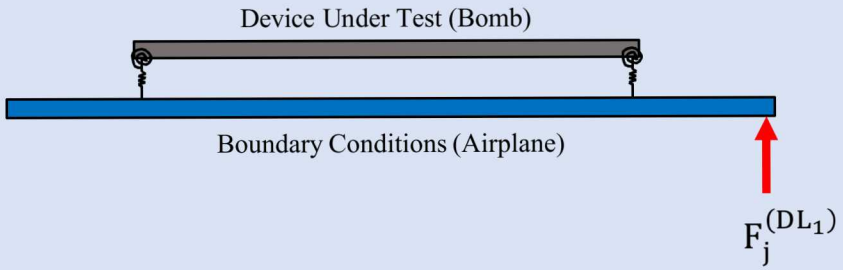
Laboratory Test





Motivation

Reference Excitation Location



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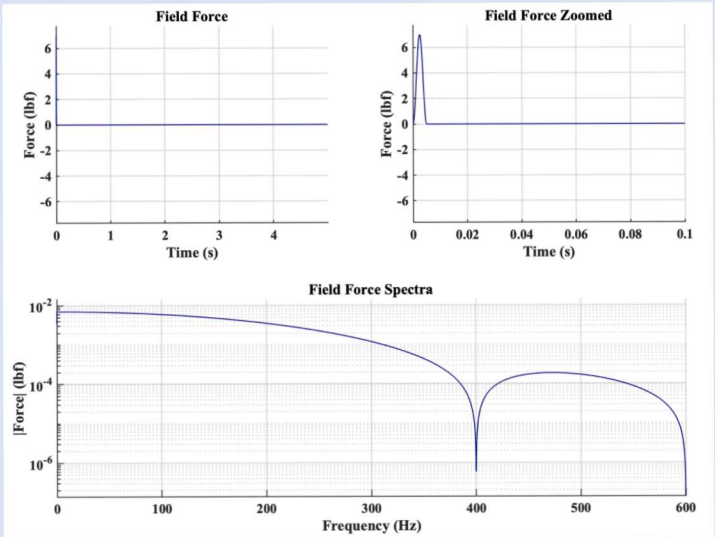

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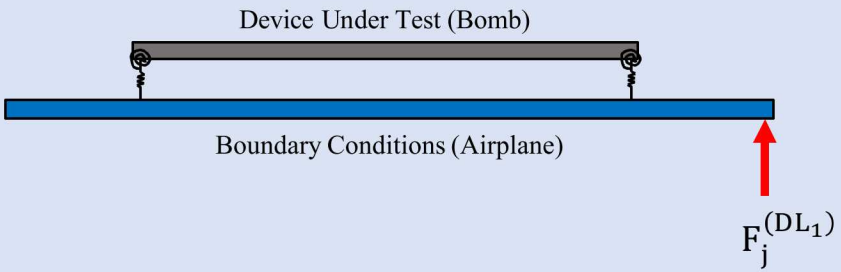

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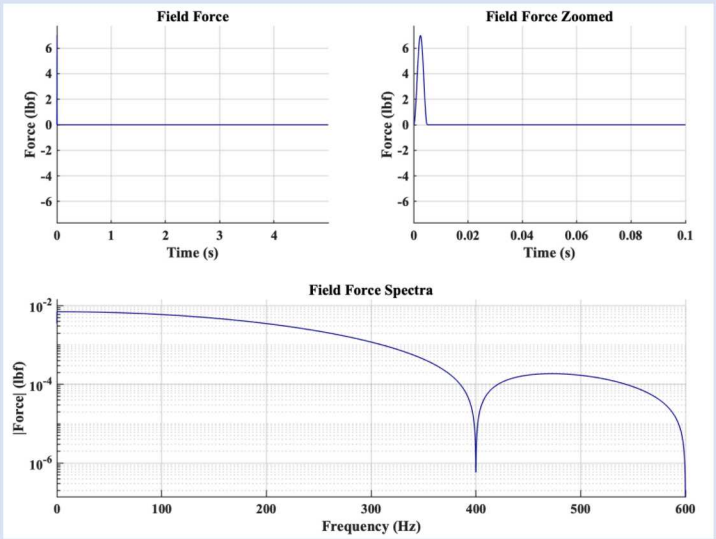
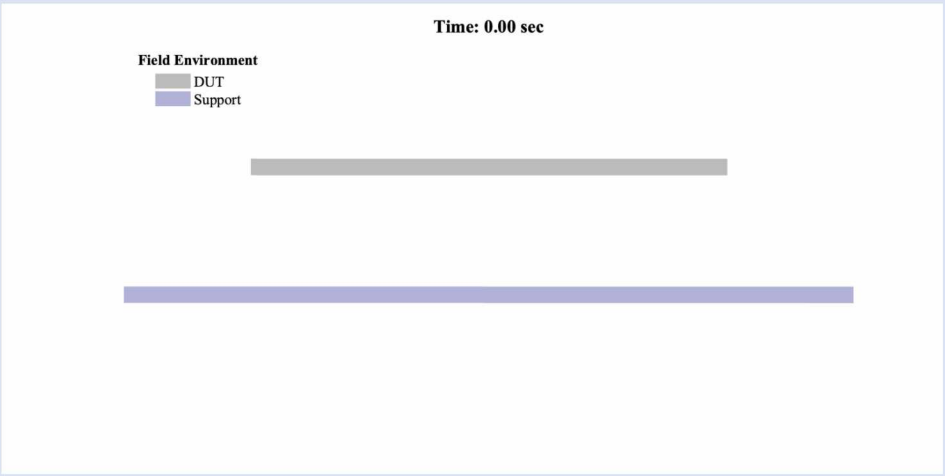
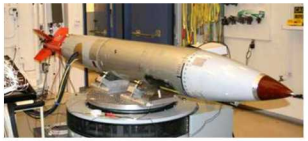


Reference Response



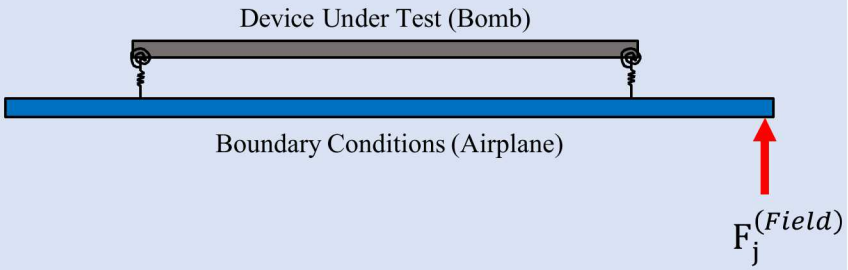
Reference response, try to match in laboratory

Motivation



How can the laboratory test system be excited to replicate the DUT field environment dynamics?

Field Environment



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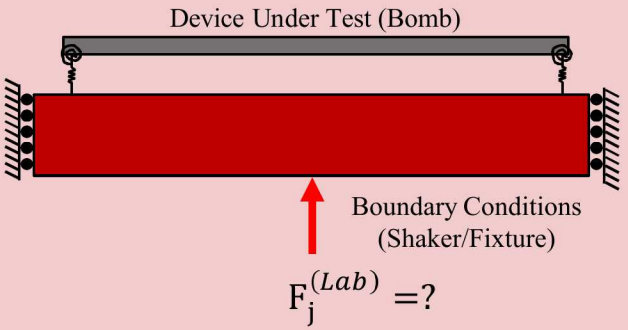

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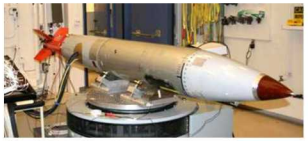

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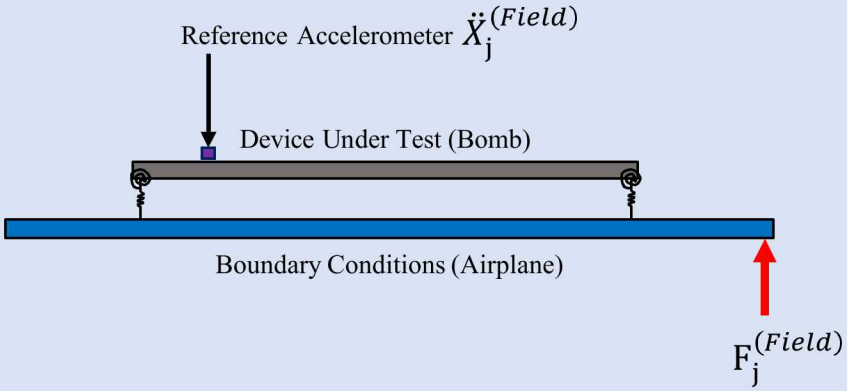

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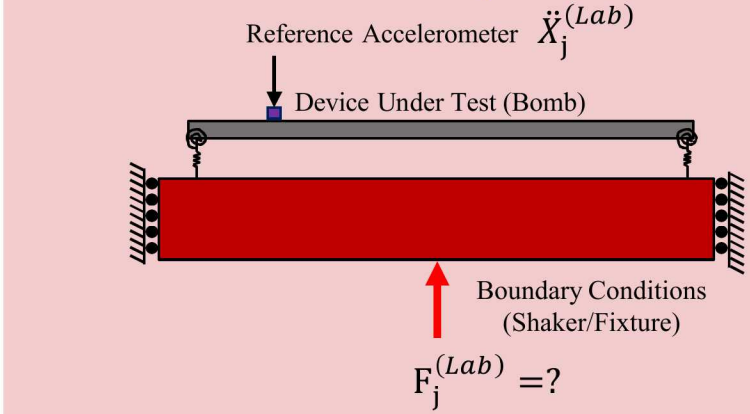

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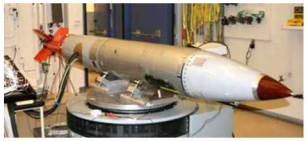

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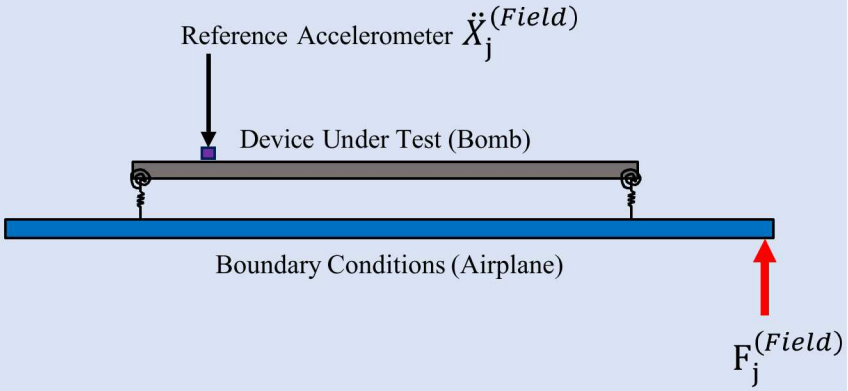

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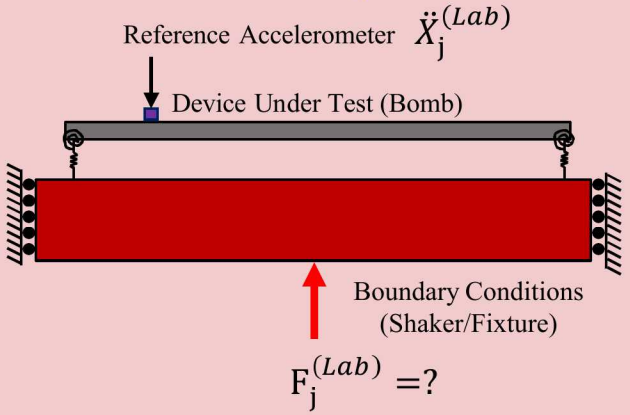

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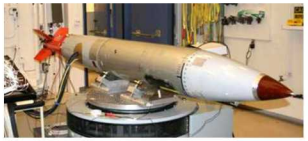

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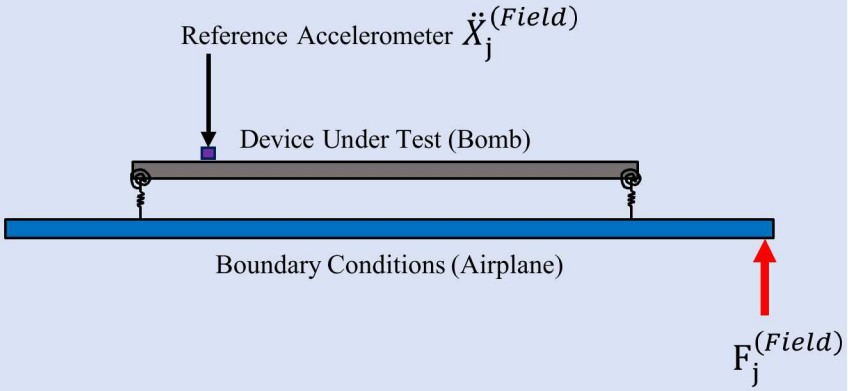

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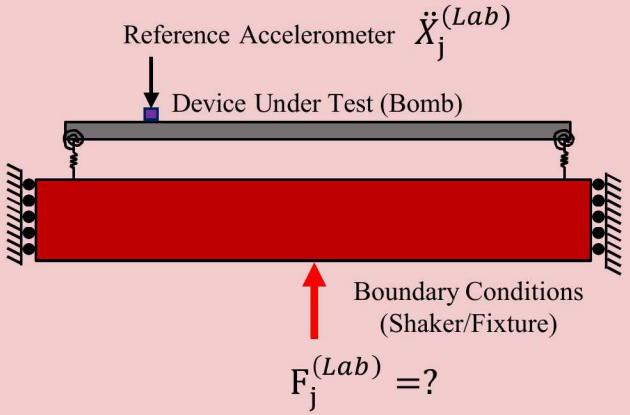

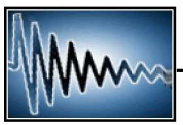

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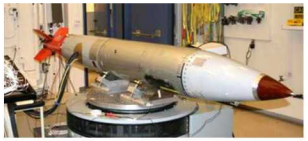

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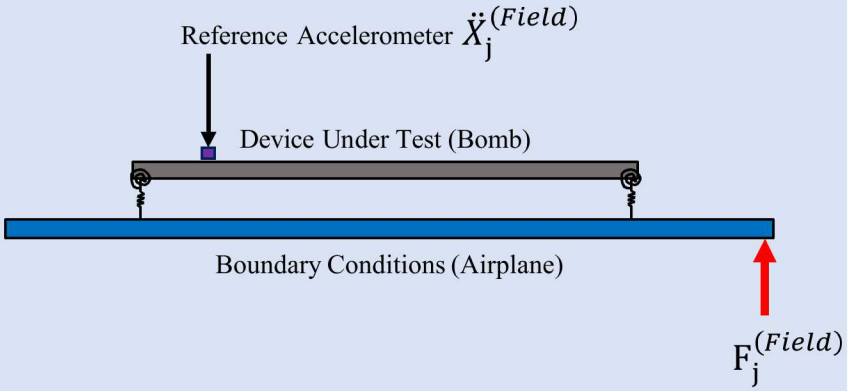

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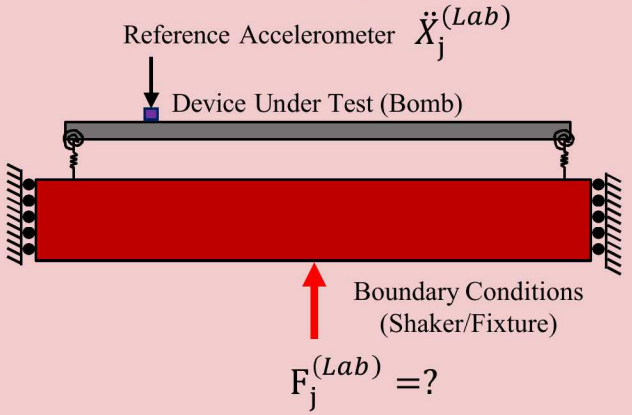

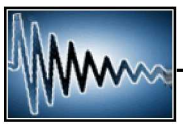

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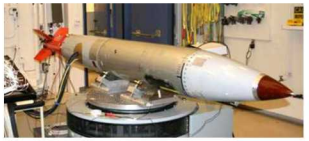
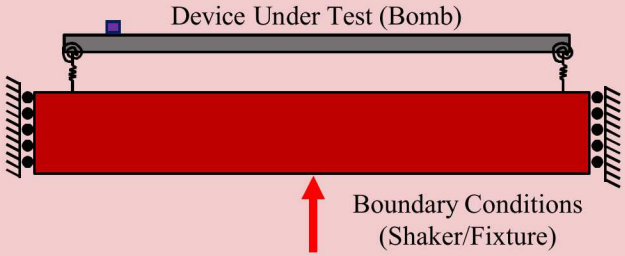
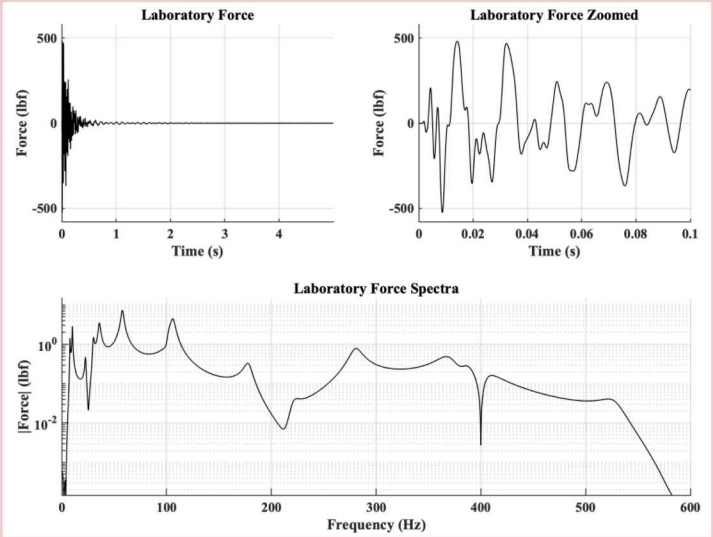


Reference Excitation Location



Excitation Force



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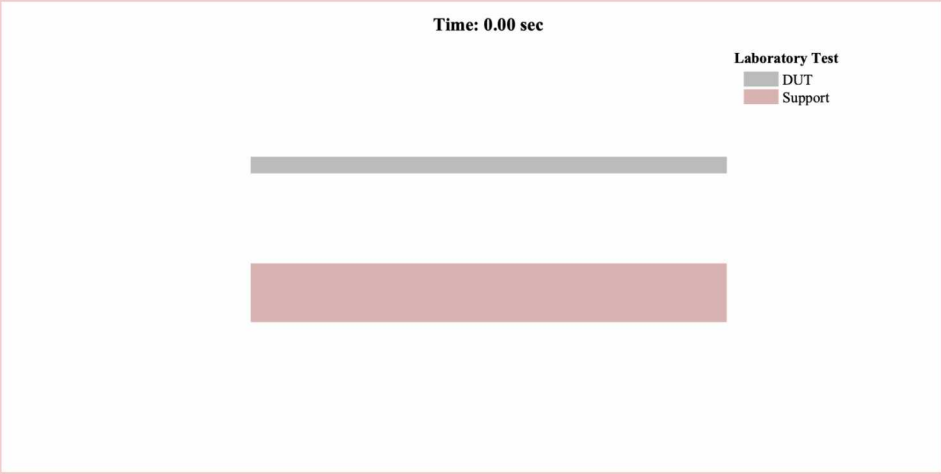

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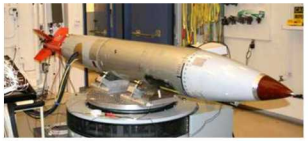
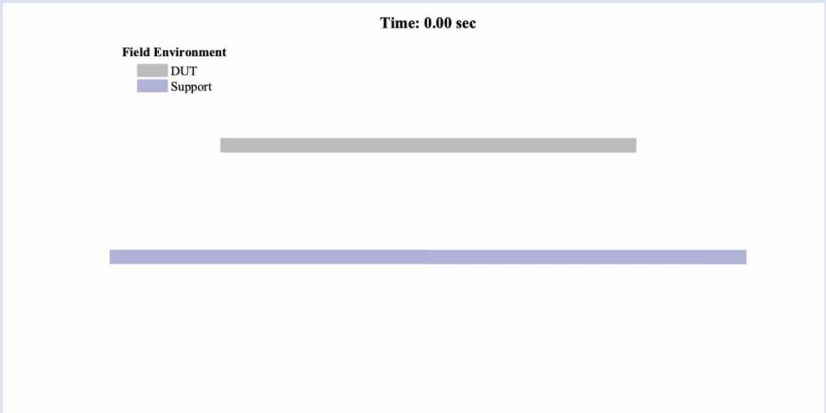
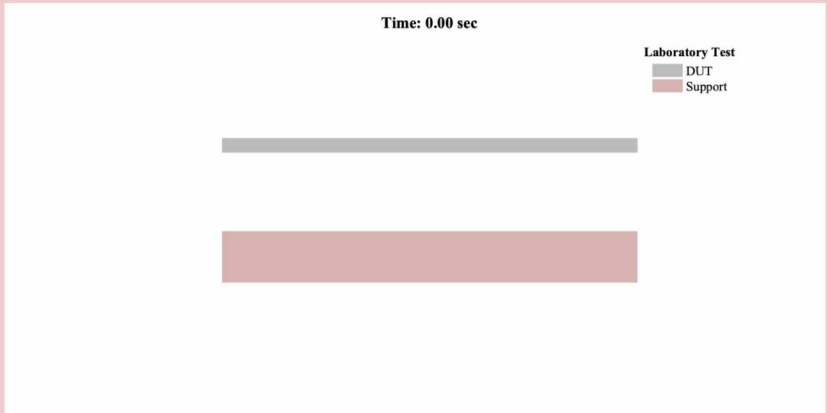


Field Environment Response



Matched Laboratory Test Response



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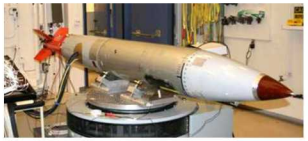

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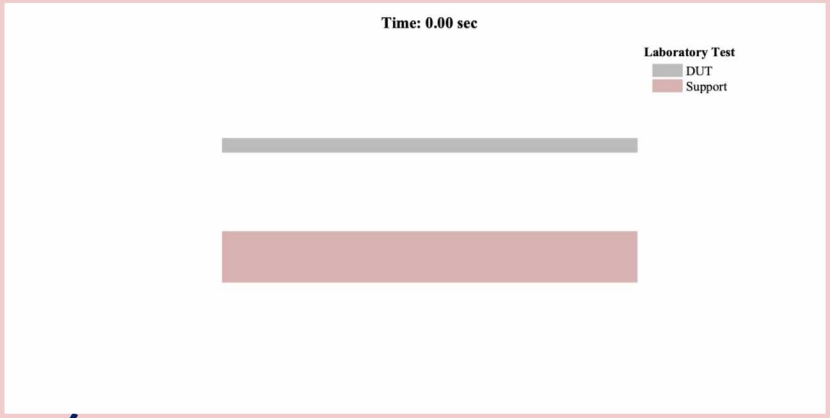

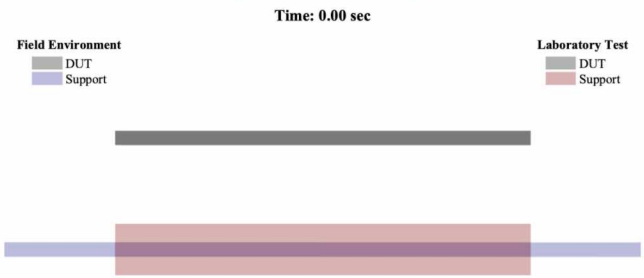

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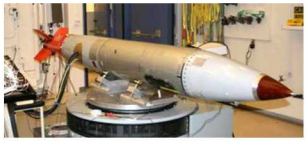

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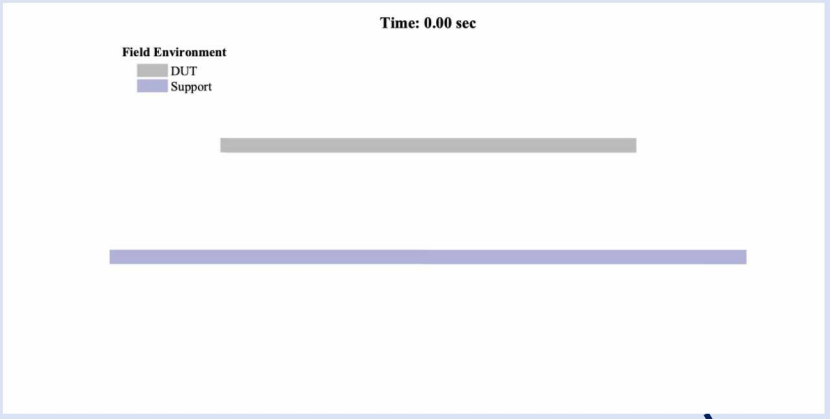

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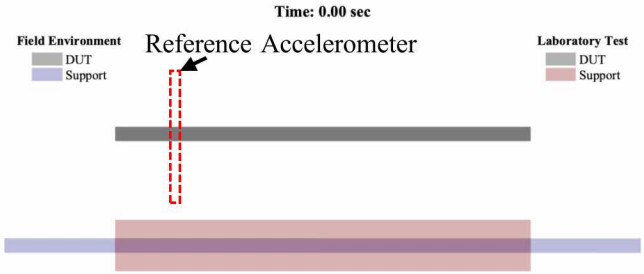

Field and Laboratory DUT Response Only Match at Reference DOF!

Motivation

- *We need to allow and account for boundary condition flexibility*

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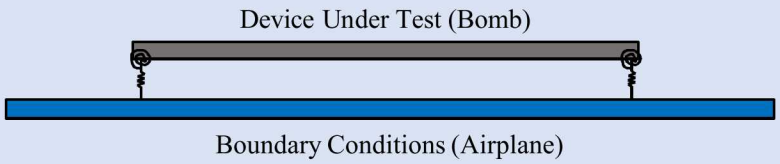

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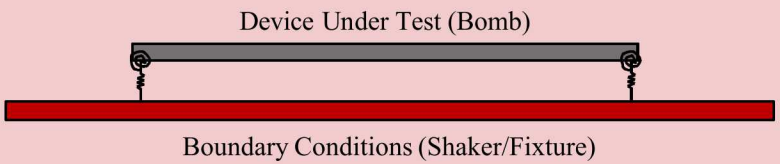
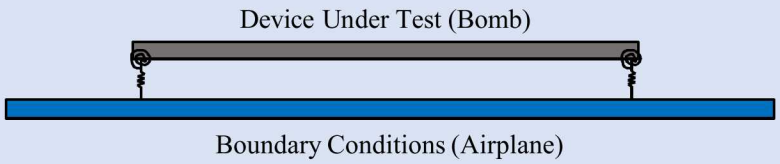


Motivation

- *We need to allow and account for boundary condition flexibility*
- *We need to allow and account for differences between field and laboratory boundary conditions*

Field Environment



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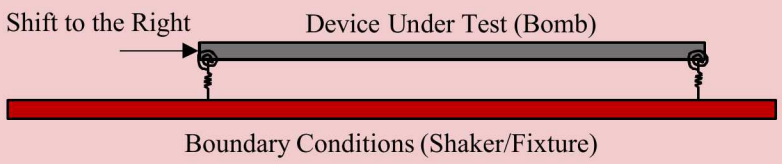

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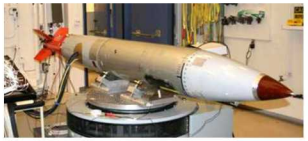

Analytical studies have shown that success is dependent on meeting a few conditions:

$$\mathrm{F}_{\mathrm{j}}^{(Lab)} = H_{ij}^{(Lab)^{g}} \ddot{X}_{\mathrm{j}}^{(Field)}$$

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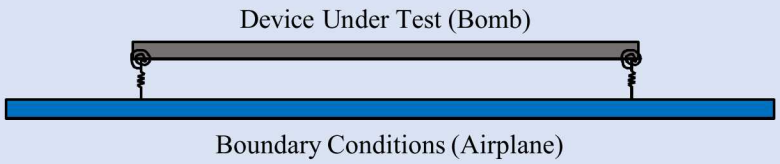

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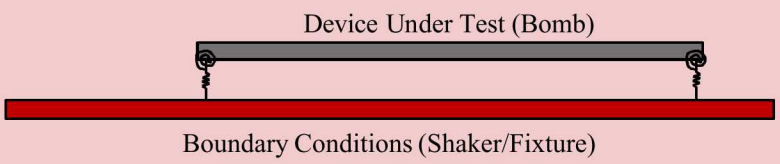

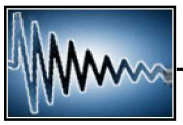

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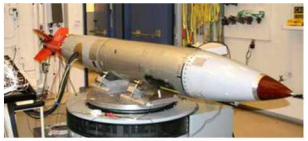

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 # Laboratory Excitation DOFs >= # Connection DOFs to DUT

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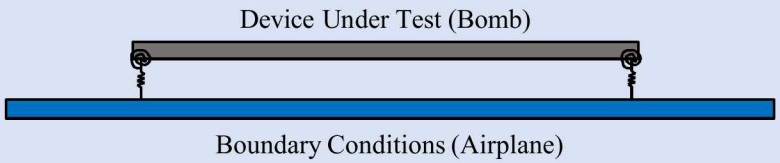

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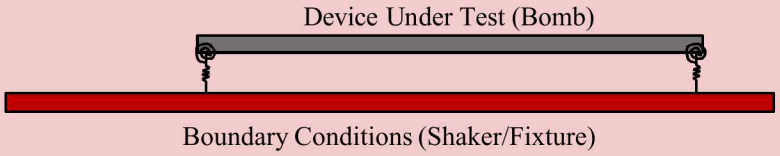
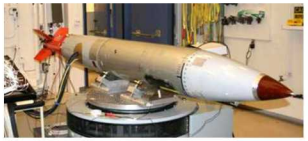


Motivation

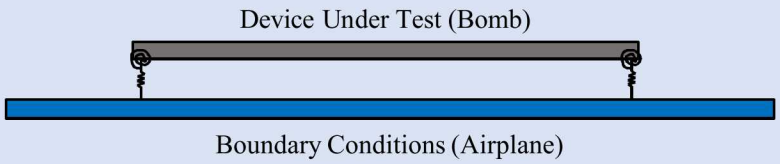


Analytical studies have shown that success is dependent on meeting a few conditions:

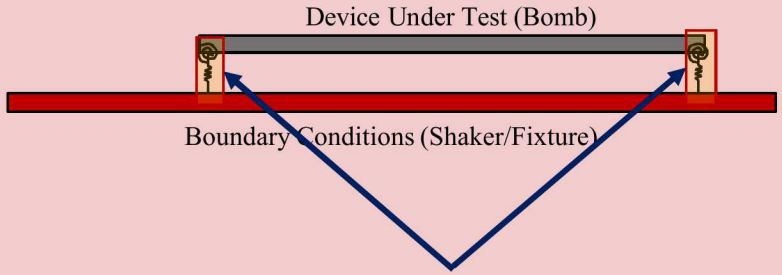
 # Laboratory Excitation DOFs >= # Connection DOFs to DUT

$$\mathrm{F}_{\mathrm{j}}^{(Lab)} = H_{ij}^{(Lab)^{g}} \ddot{X}_{\mathrm{j}}^{(Field)}$$

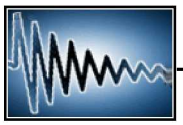
Field Environment



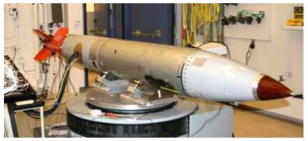
Laboratory Test



4 Connection DOFs to DUT



Motivation



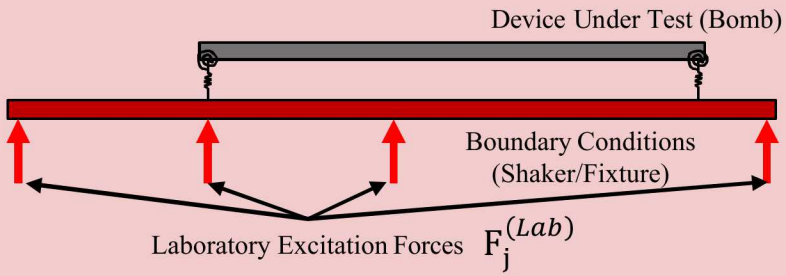
Analytical studies have shown that success is dependent on meeting a few conditions:

 # Laboratory Excitation DOFs >= # Connection DOFs to DUT

$$\mathrm{F}_{\mathrm{j}}^{(Lab)} = H_{ij}^{(Lab)^{g}} \ddot{X}_{\mathrm{j}}^{(Field)}$$

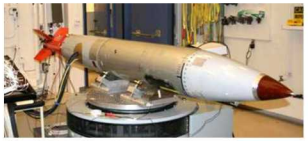
Field Environment

Laboratory Test



Excitation location

Motivation



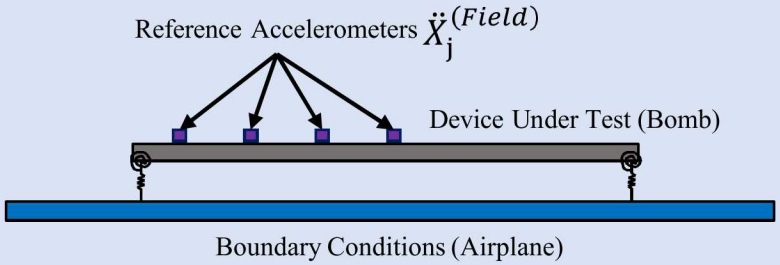
Analytical studies have shown that success is dependent on meeting a few conditions:

Laboratory Excitation DOFs >= # Connection DOFs to DUT

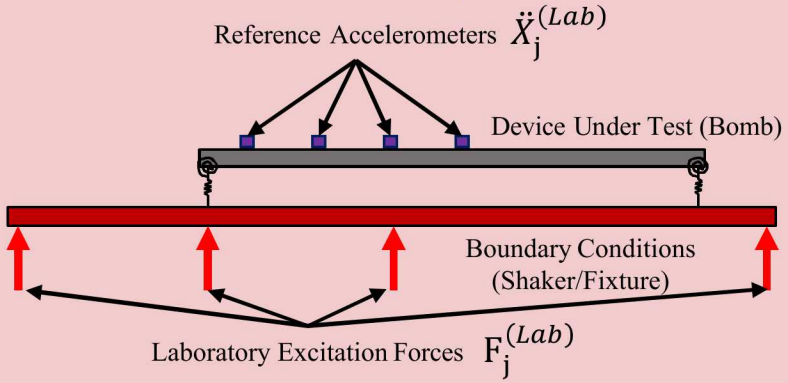
Reference Response DOFs >= # Connection DOFs to DUT

$$\mathrm{F}_{\mathrm{j}}^{(Lab)} = H_{ij}^{(Lab)^{g}} \ddot{X}_{\mathrm{j}}^{(Field)}$$

Field Environment

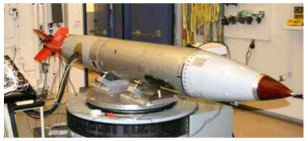


Laboratory Test

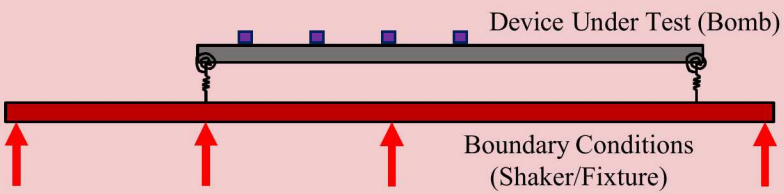


Excitation location Reference Response

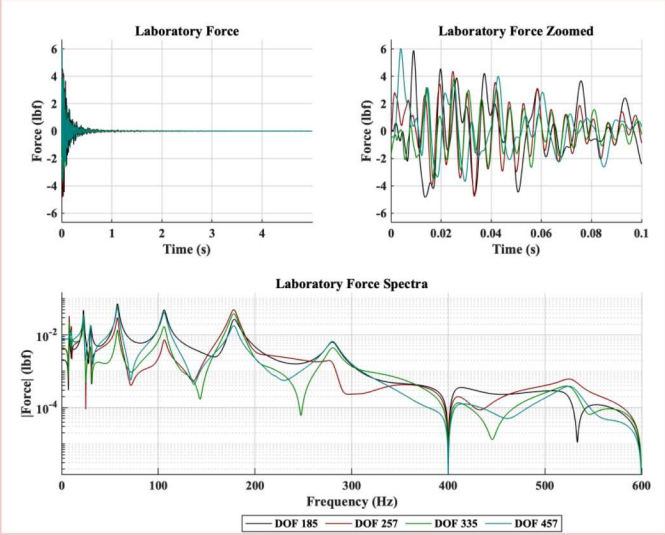
Motivation



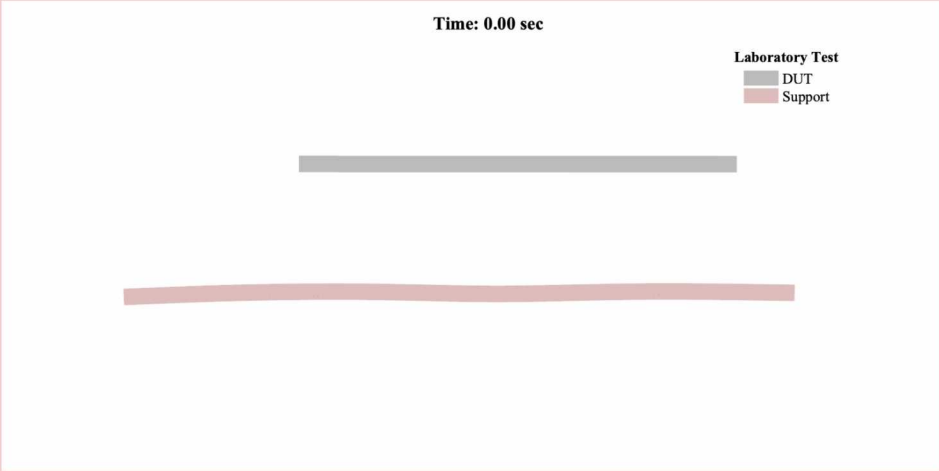
Reference Excitation Location



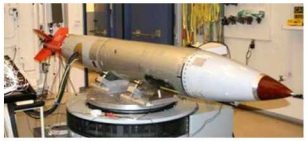
Excitation Force



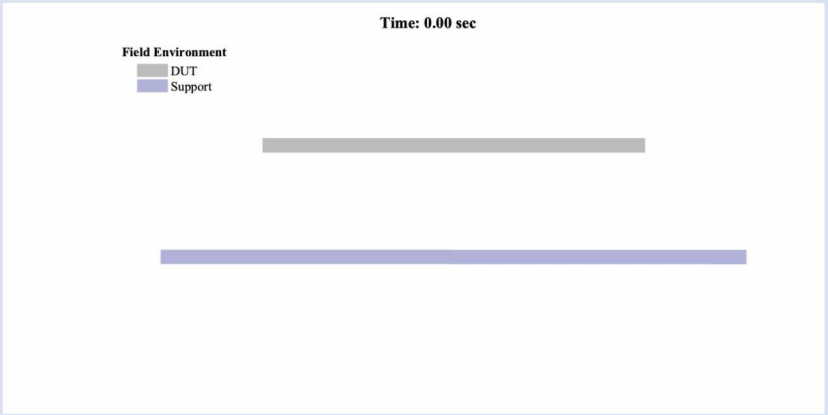
Reference Response



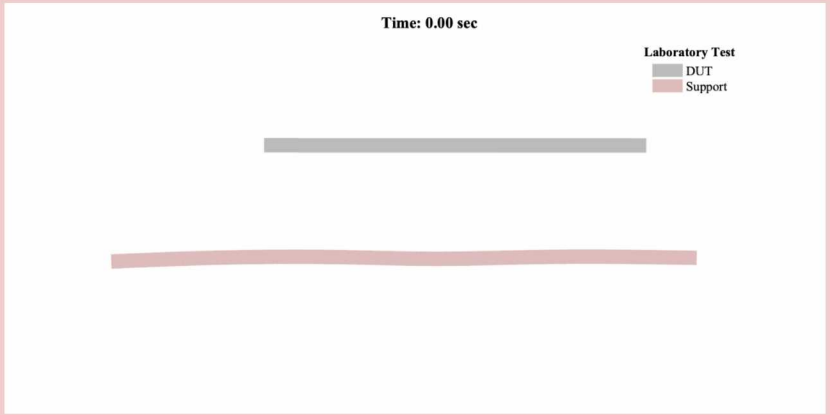
Motivation



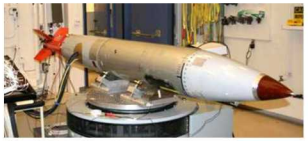
Field Environment Response



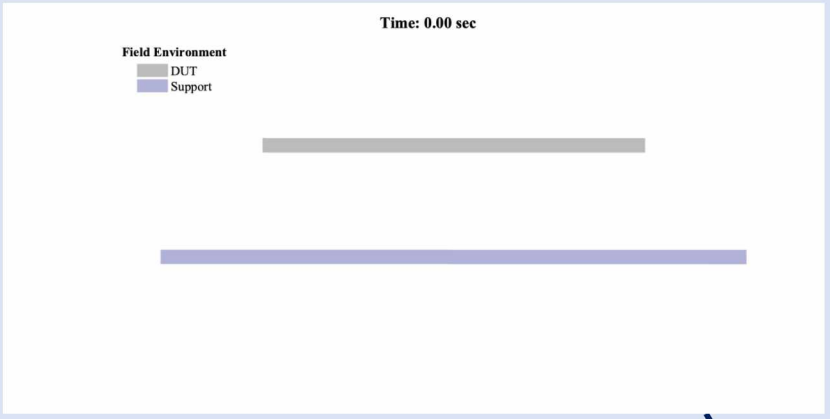
Matched Laboratory Test Response



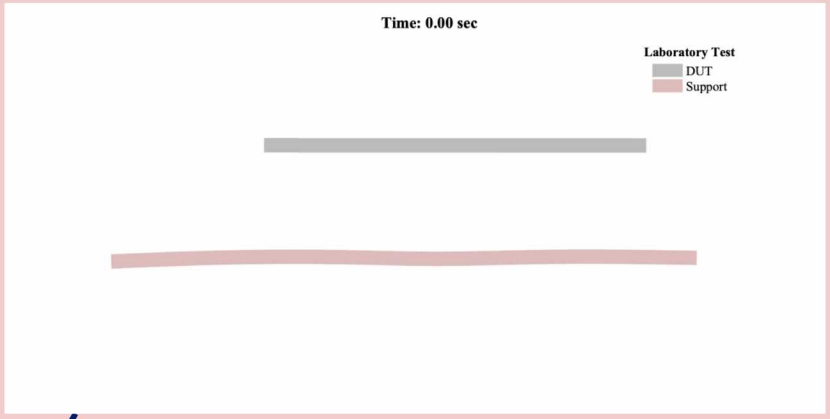
Motivation

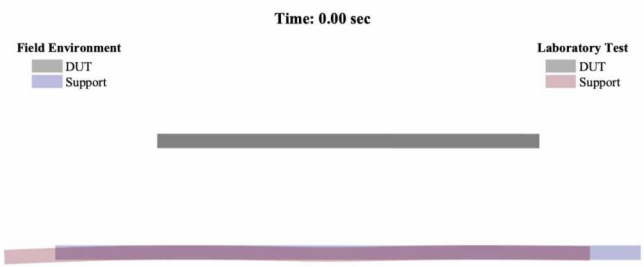


Field Environment Response

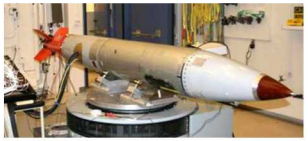


Matched Laboratory Test Response

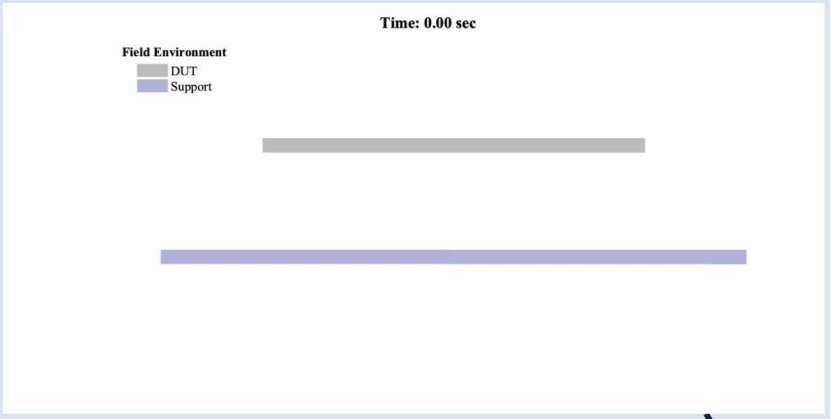




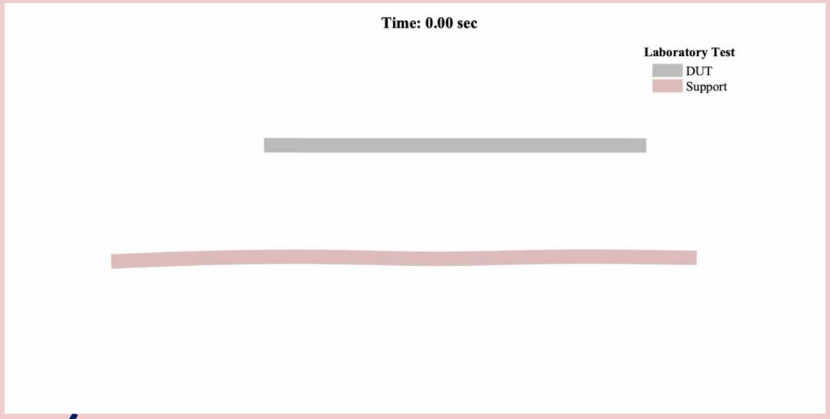
Motivation

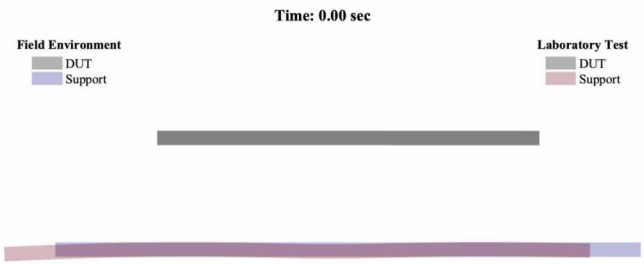


Field Environment Response



Matched Laboratory Test Response





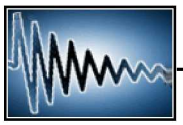
Field and Laboratory DUT Response Match Perfectly at all DUT DOFs!

Theory

How are the laboratory test system modes used to create the field environment motion?

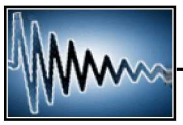
Modal Amplitude Contribution Map (MACM)

$$\left[M\ddot{A}CM\right] = \left[\overline{H}^{(Lab)}\right]\left[U_j^{(Lab)}\right]^T\left[\left[U_i^{(Lab)}\right]\left[\overline{H}^{(Lab)}\right]\left[U_j^{(Lab)}\right]^T\right]^g\left[U_i^{(Field)}\right]\cdot\left\{\ddot{P}^{(Field)}\right\}^T$$



Motivation

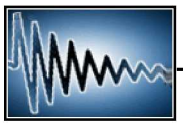
This approach replicates the field DUT response in the laboratory configuration analytically.



Motivation

This approach replicates the field DUT response in the laboratory configuration analytically.

Does it work experimentally?

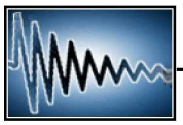


Motivation

This approach replicates the field DUT response in the laboratory configuration analytically.

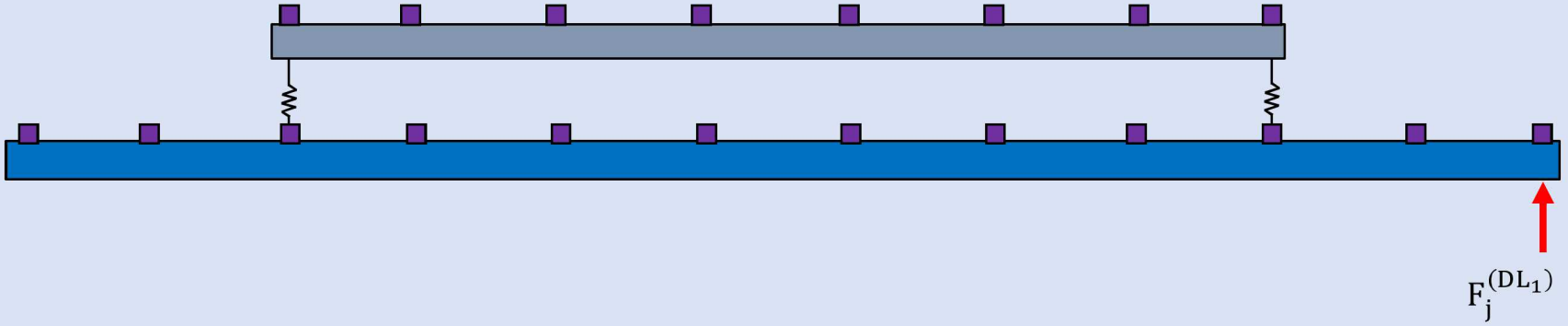
Does it work experimentally?

Can we calculate the MACM for an experimental response to help understand which modes are important and how they are utilized?



Test Setup

Field Environment Impulse



Excitation location Reference Response

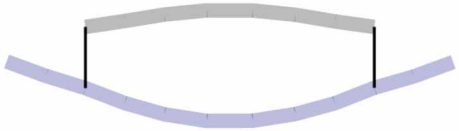
Results (Modal Characterization)

Field Environment Modes

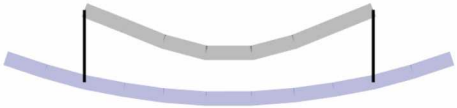
Mode 1 at 8.02 Hz

Mode 2 at 11.96 Hz

Mode 3 at 26.91 Hz

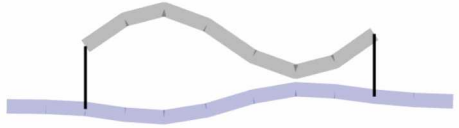


Mode 4 at 41.89 Hz

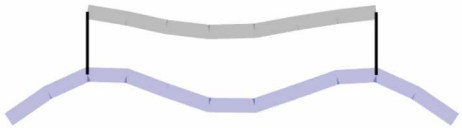


Mode 5 at 58.2 Hz

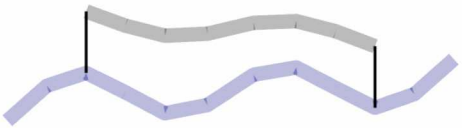
Mode 6 at 102.35 Hz



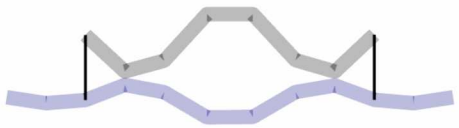
Mode 7 at 104.46 Hz

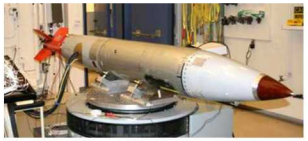


Mode 8 at 173.29 Hz



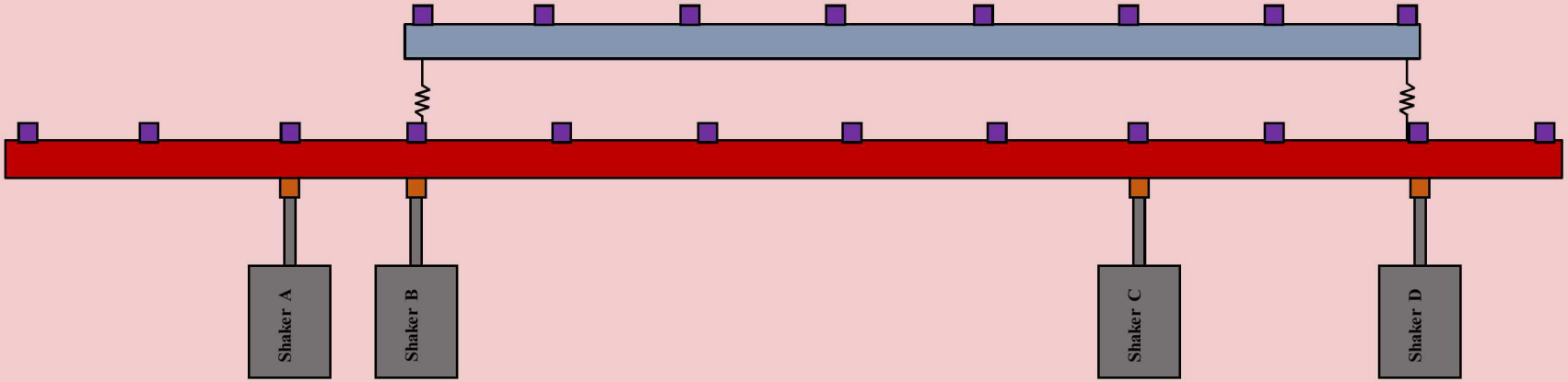
Mode 9 at 224.23 Hz

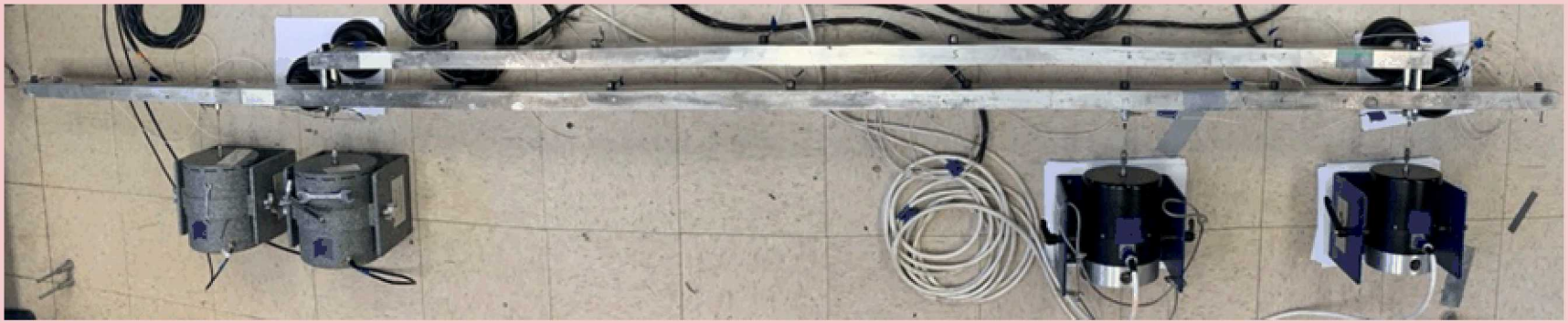




Test Setup

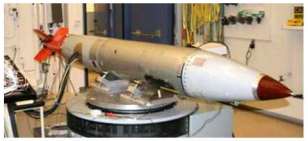
Laboratory Test Replication of Impulse



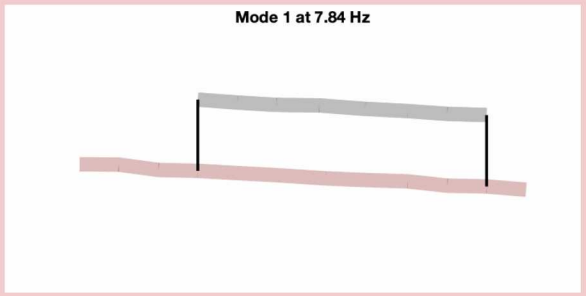


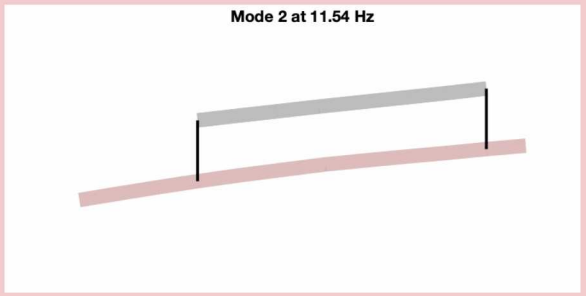
- Excitation location
- Reference Response

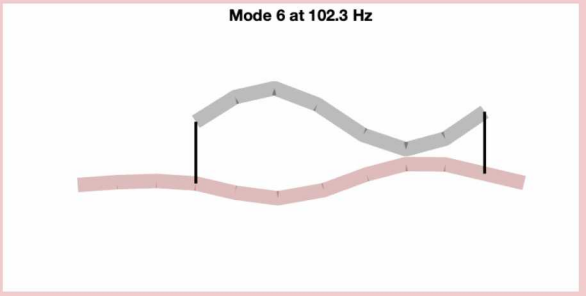
Results (Modal Characterization)

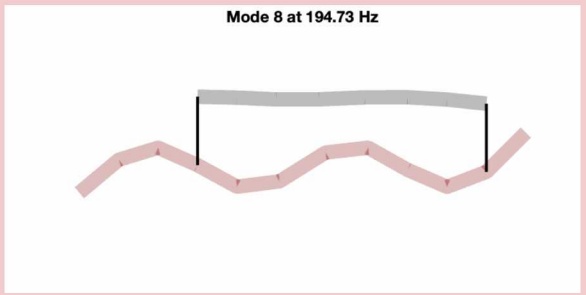


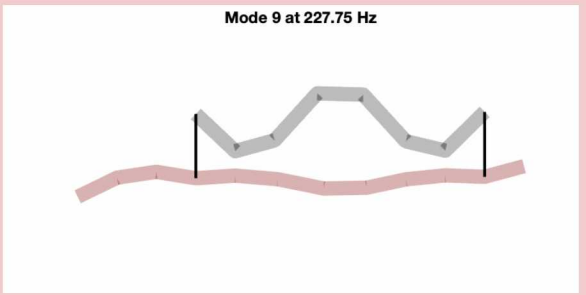
Laboratory Test Modes





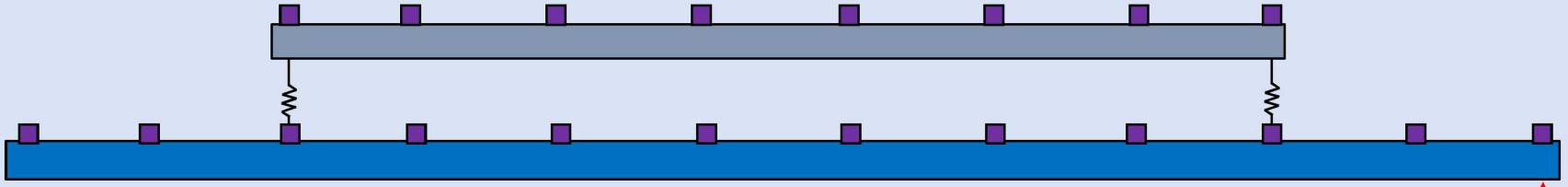




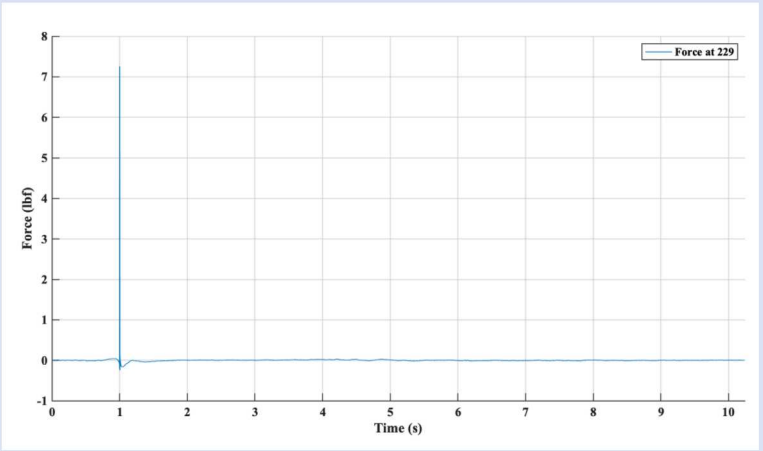


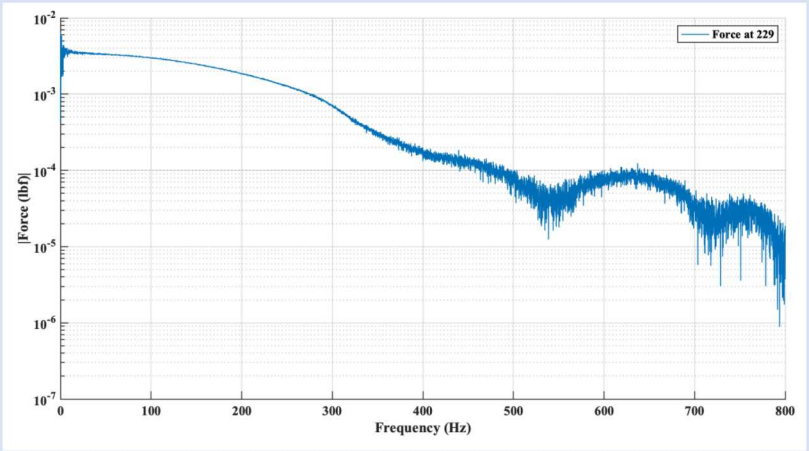
Test Setup

Field Environment Impulse



$F_j^{(DL_1)}$



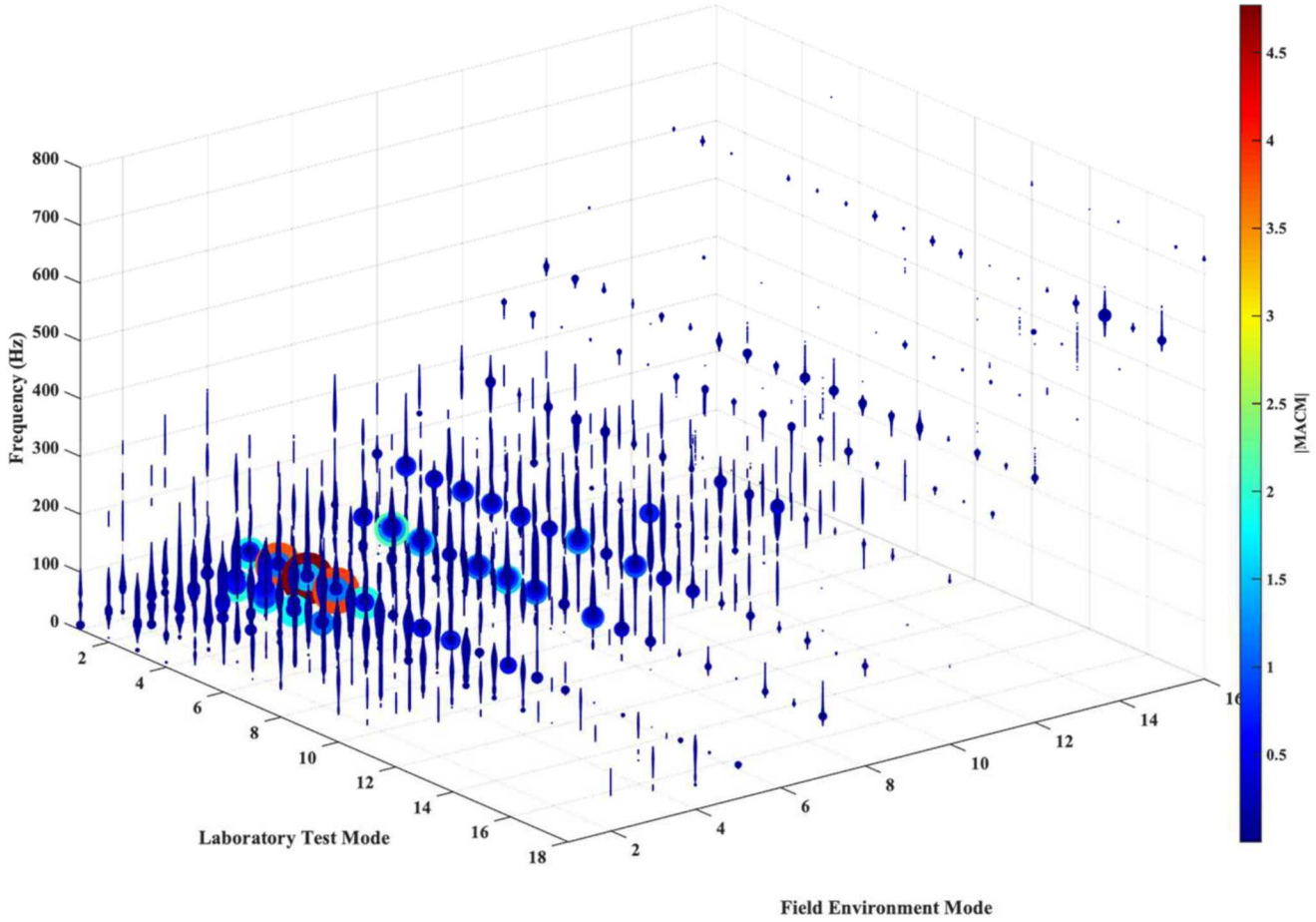


Excitation location

Reference Response

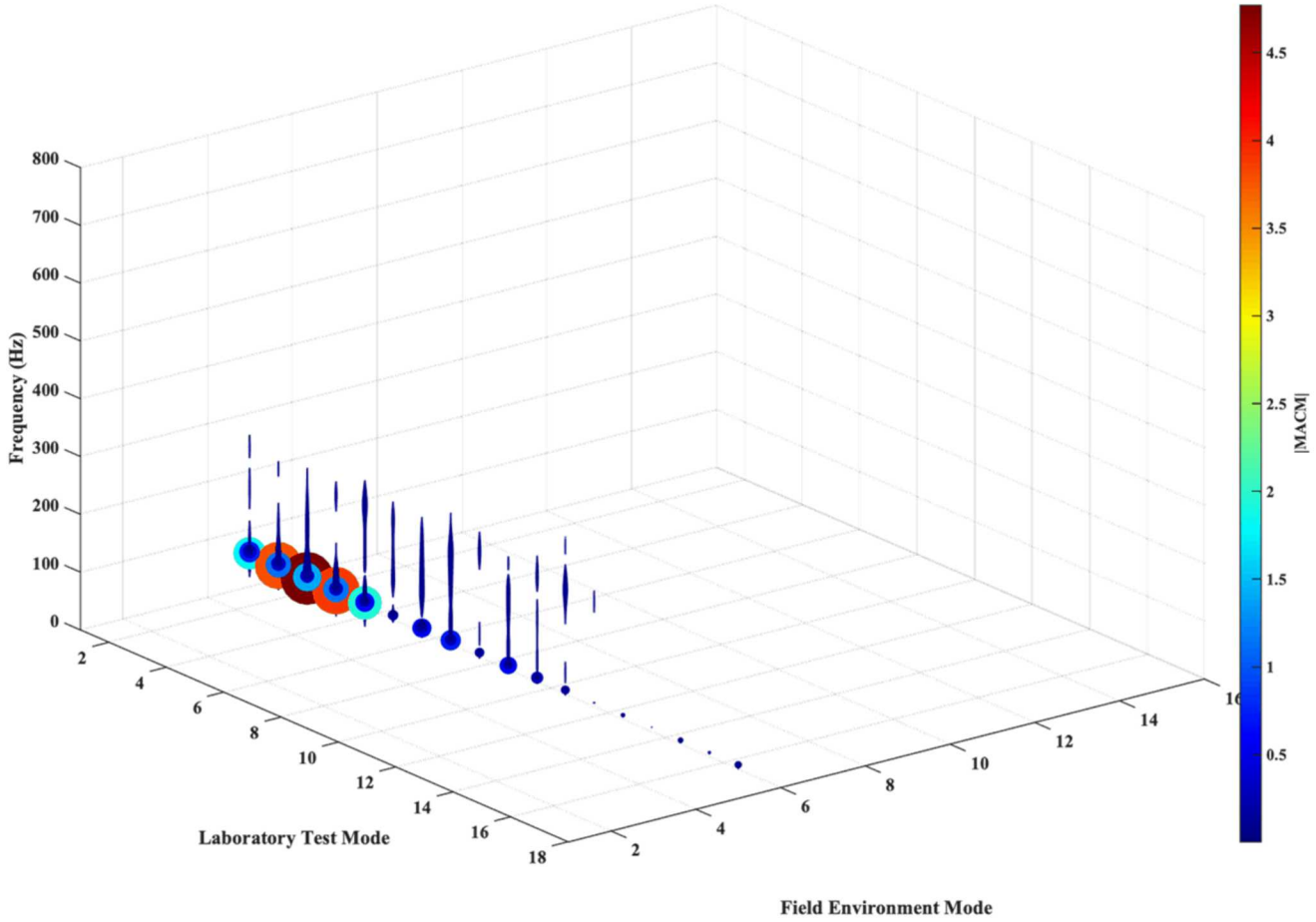
Results (Impulse)

MACM (Impulse Excitation)



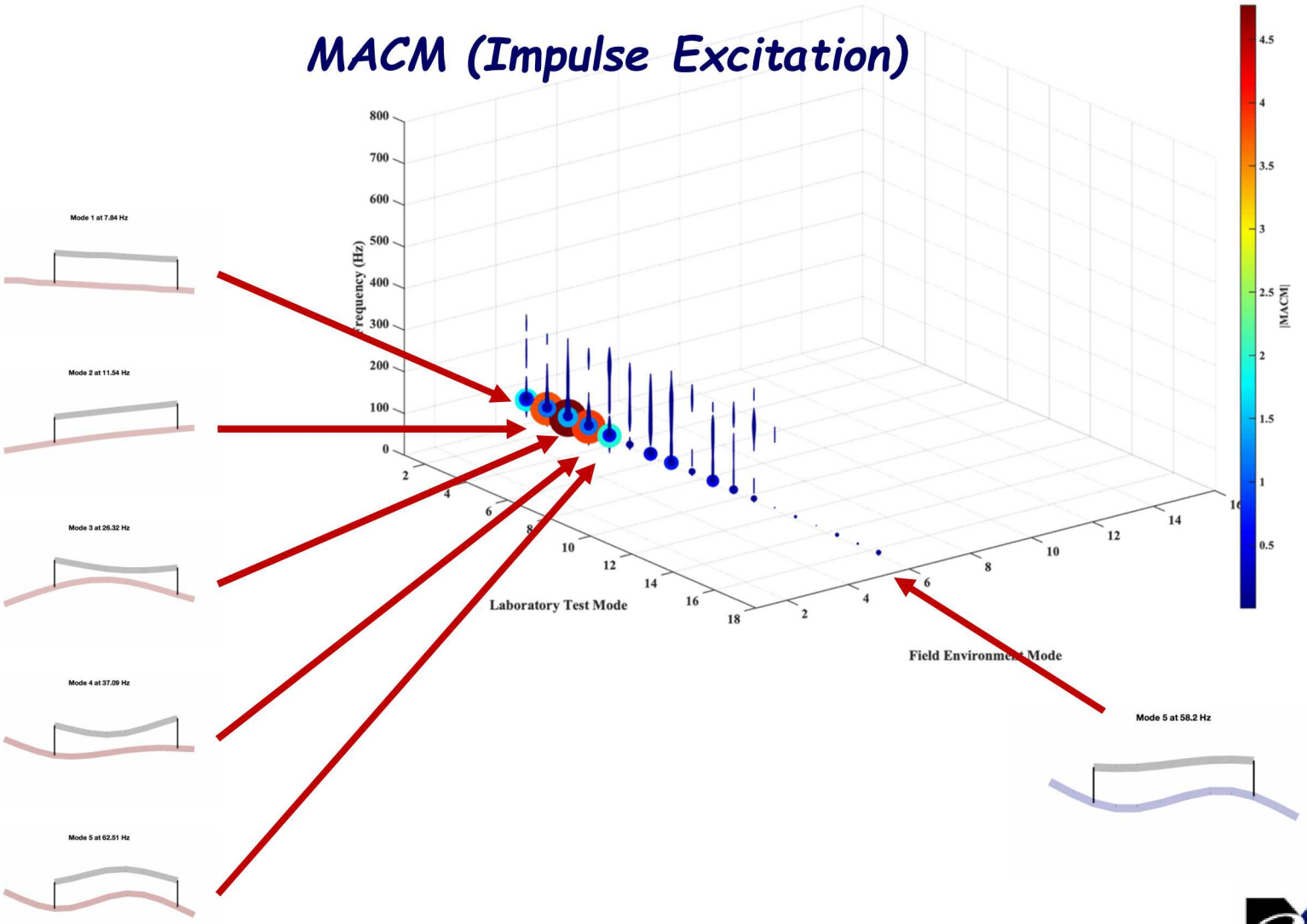
Results (Impulse)

MACM (Impulse Excitation)

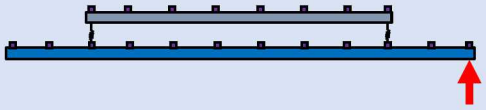


Results (Impulse)

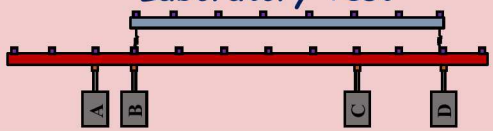
MACM (Impulse Excitation)



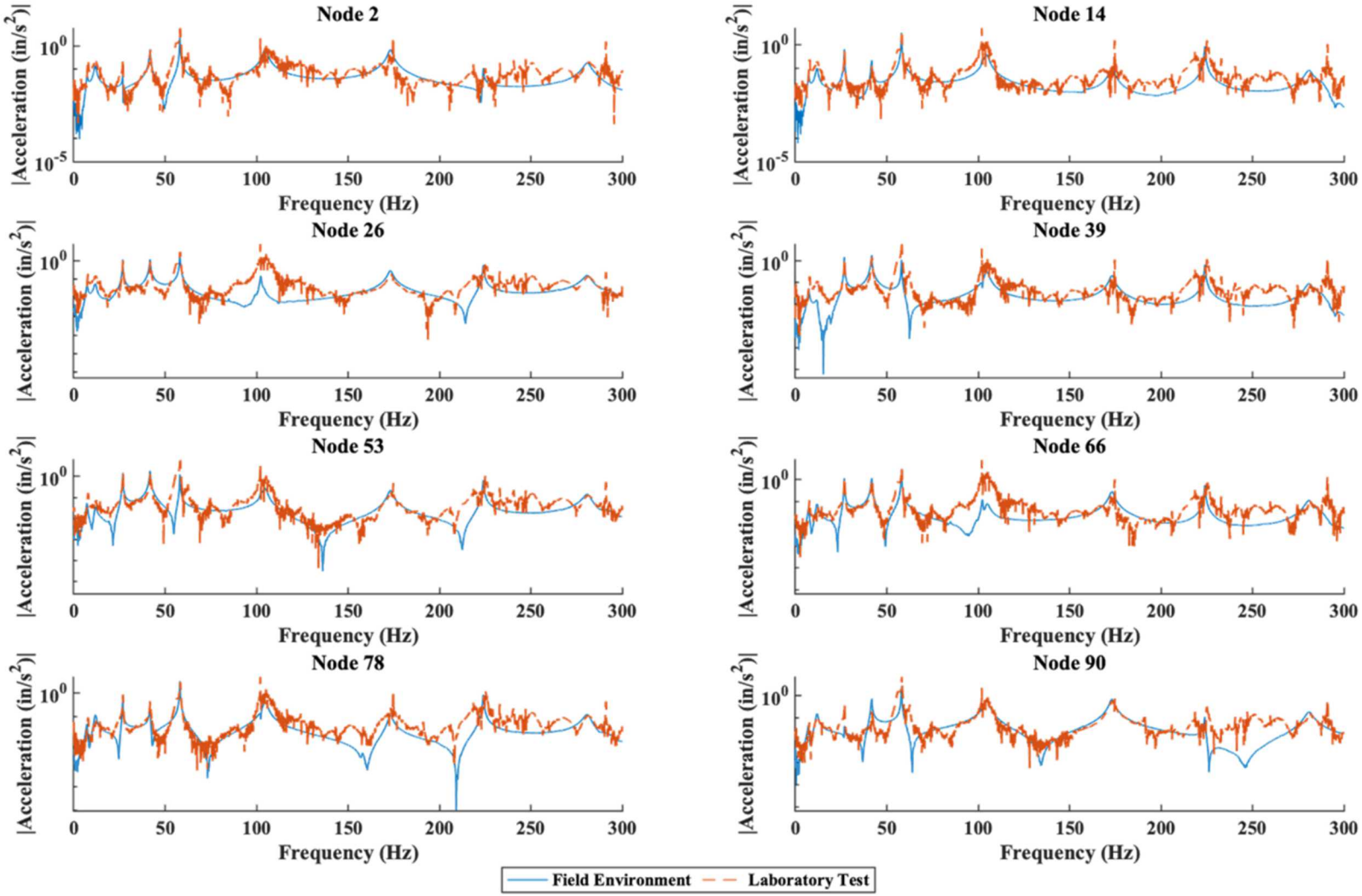
Field Environment



Laboratory Test



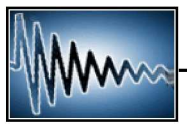
Results (Impulse)



Results (Impulse)

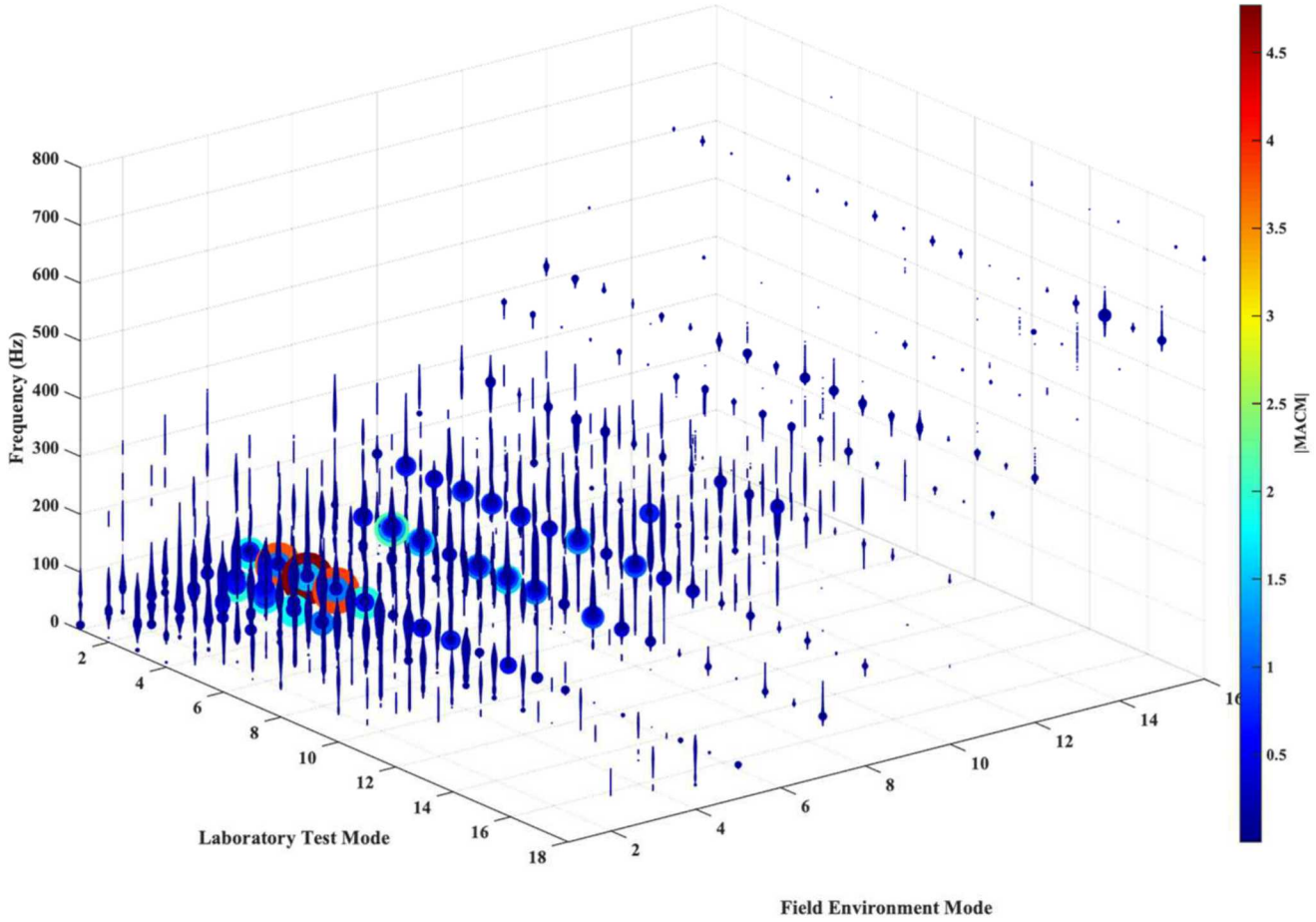
Using the MACM matrix, the excitation was re-calculated based on a truncated model.

Field modes 1:10 were replicated using laboratory test modes 1:12

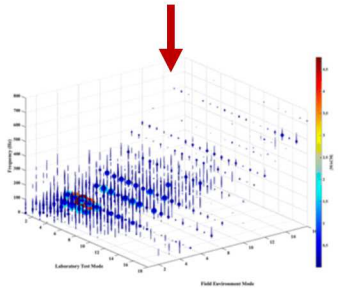


Results (Impulse)

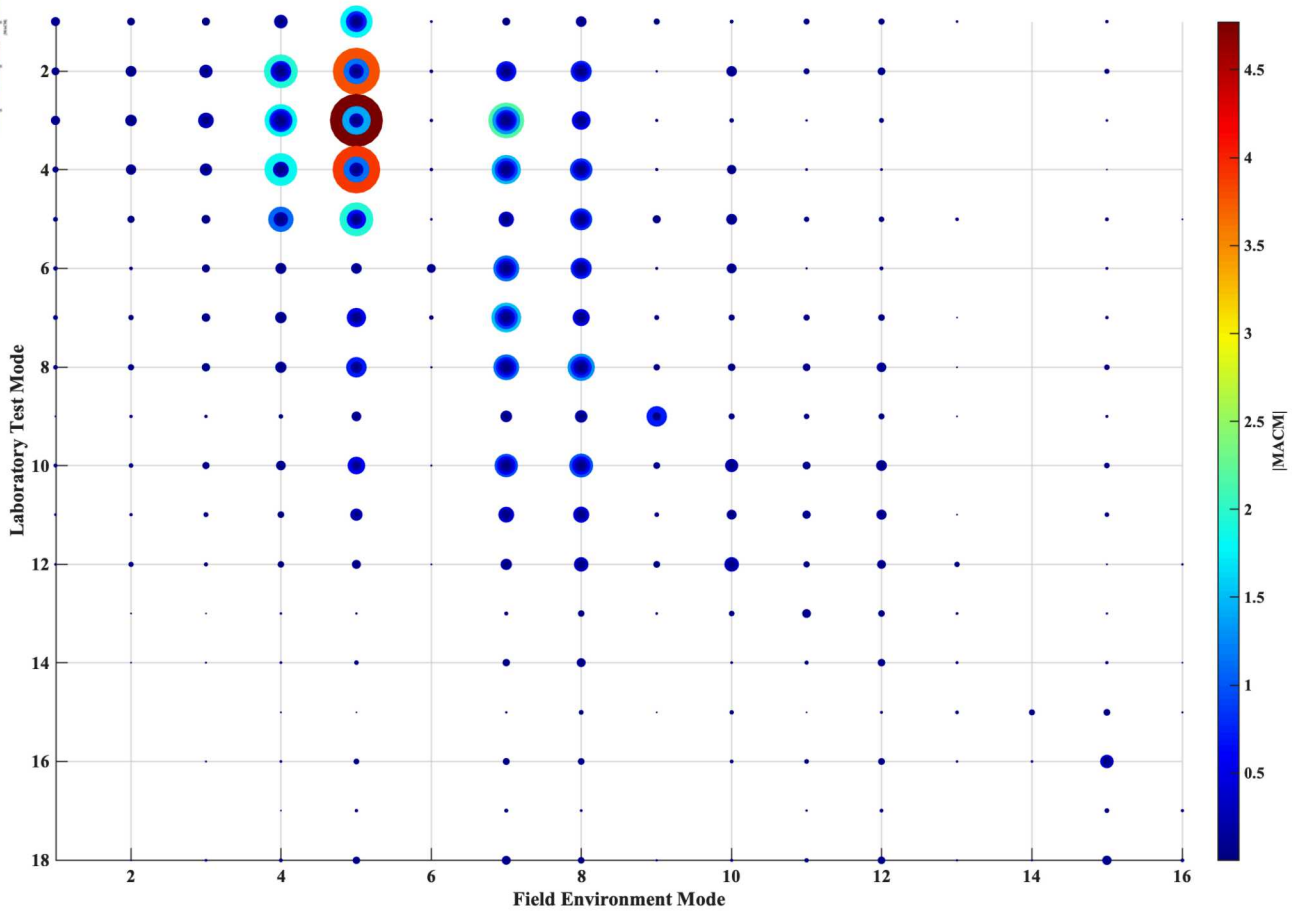
MACM (Impulse Excitation)



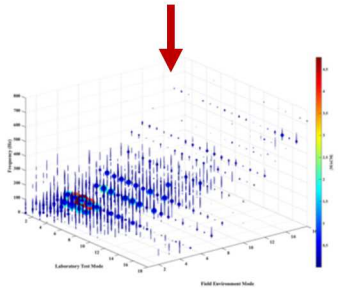
Results (Impulse)



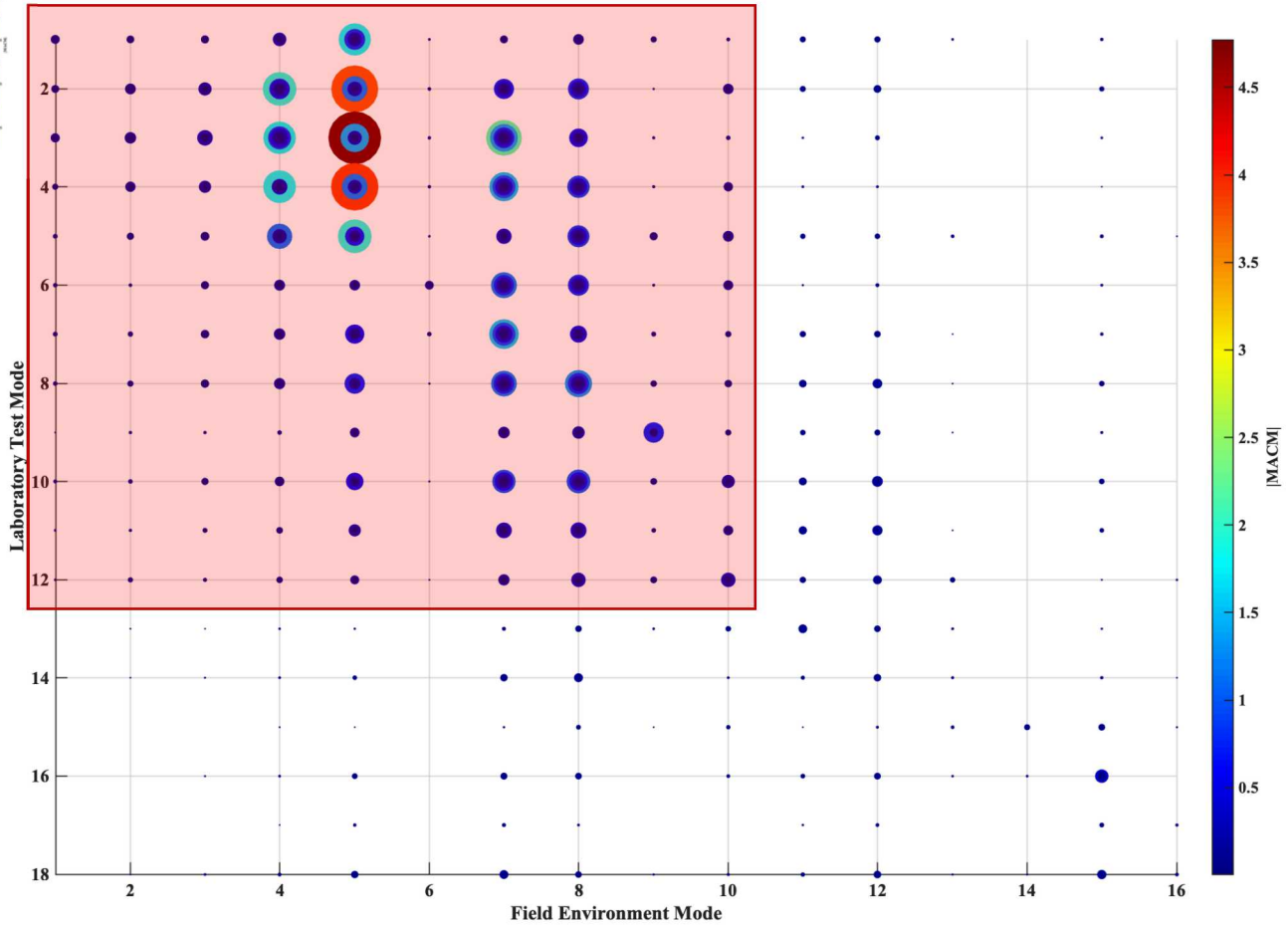
MACM (Impulse Excitation)



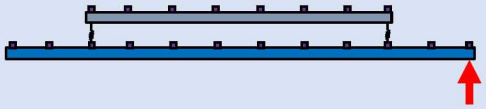
Results (Impulse)



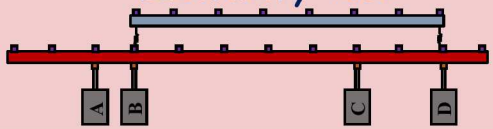
MACM (Impulse Excitation)



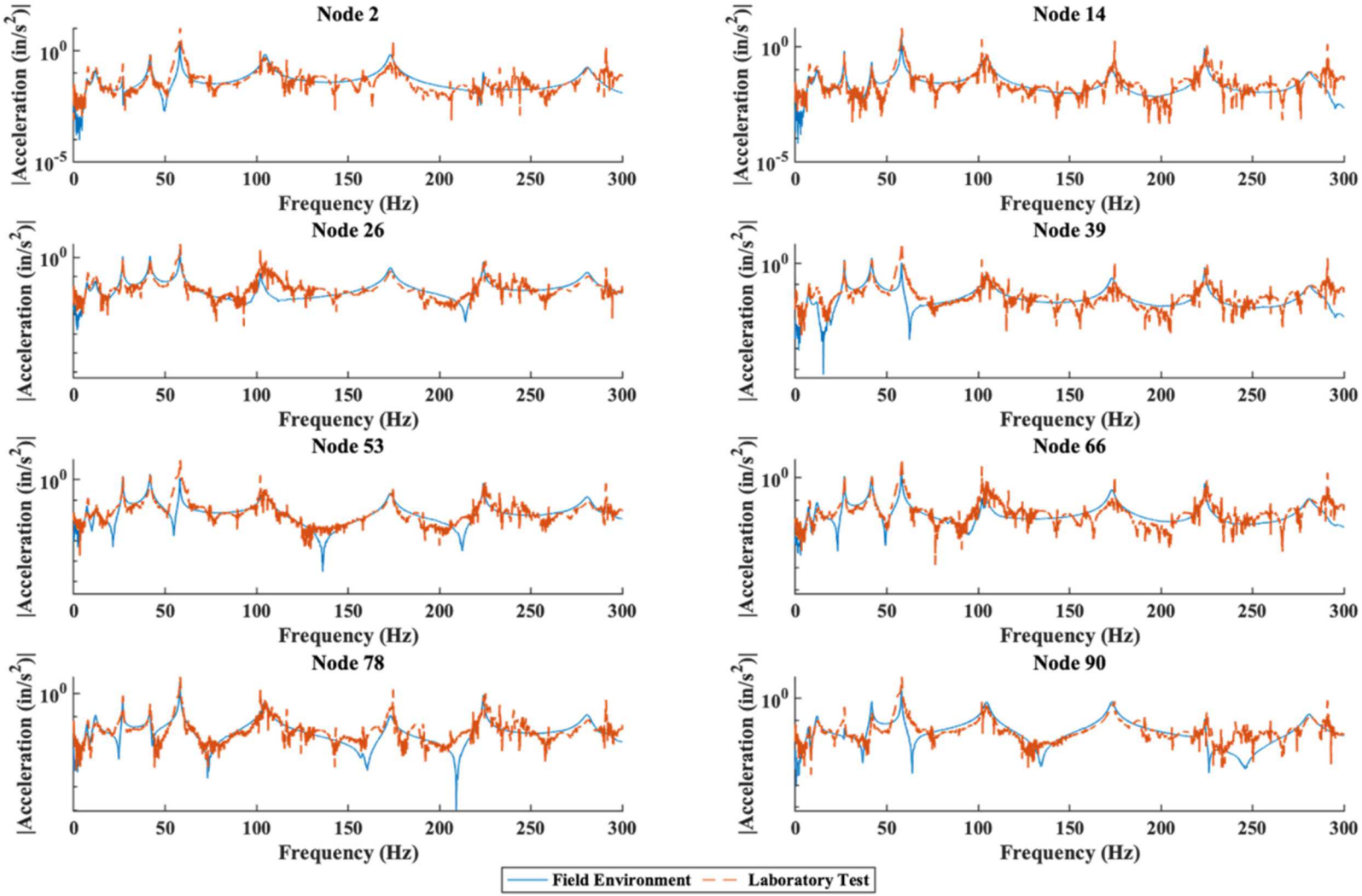
Field Environment

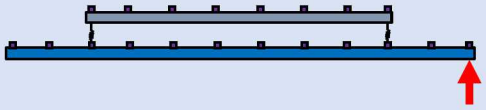


Laboratory Test

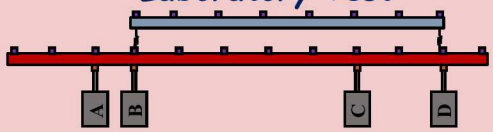


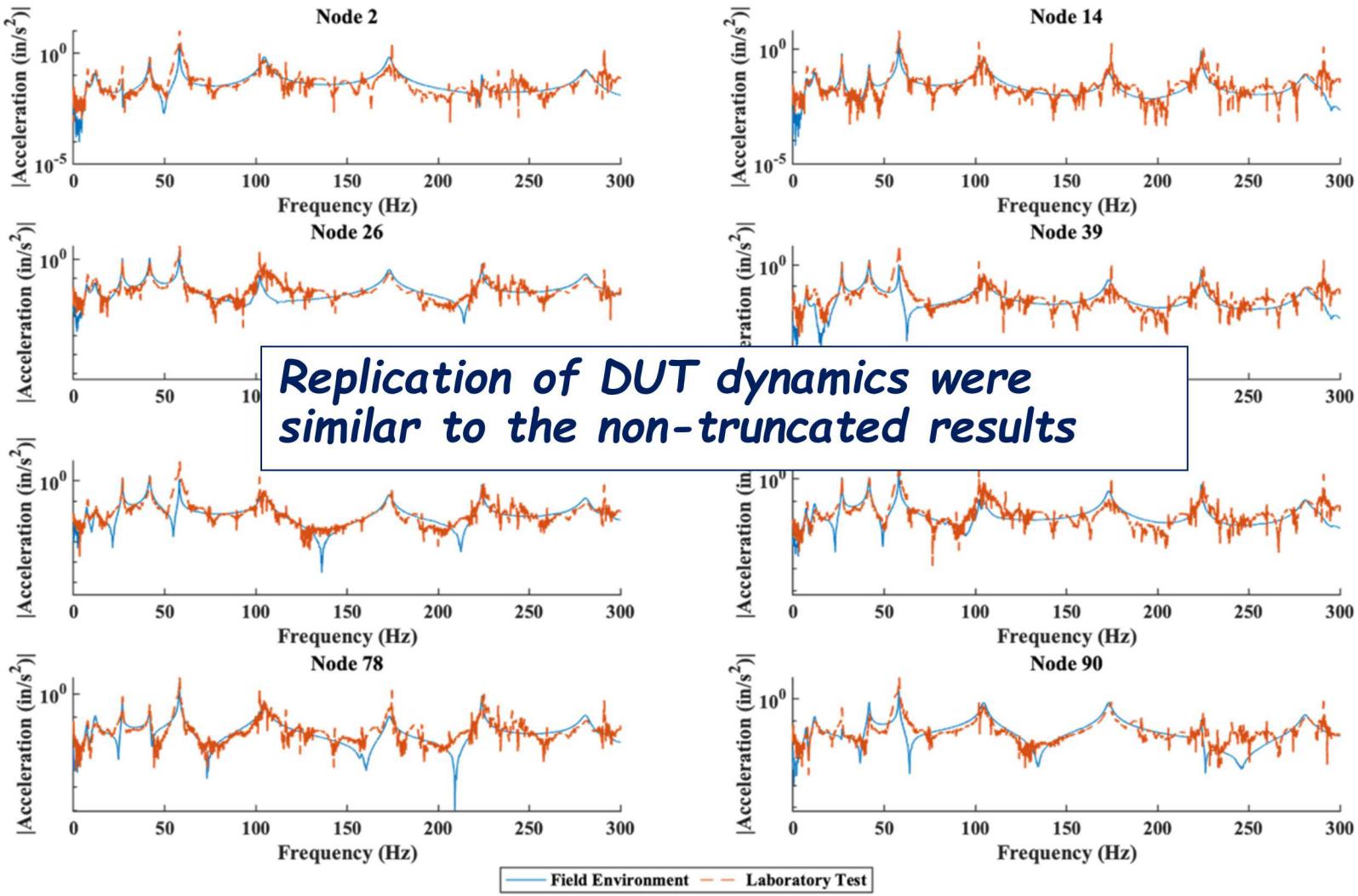
Results (Impulse)





Results (Impulse)

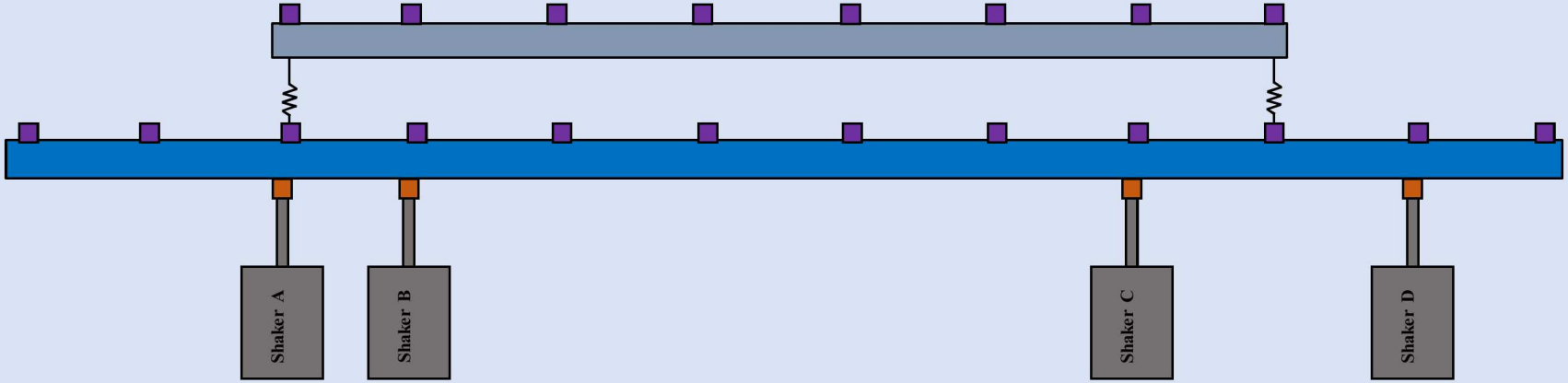




Replication of DUT dynamics were similar to the non-truncated results

Test Setup

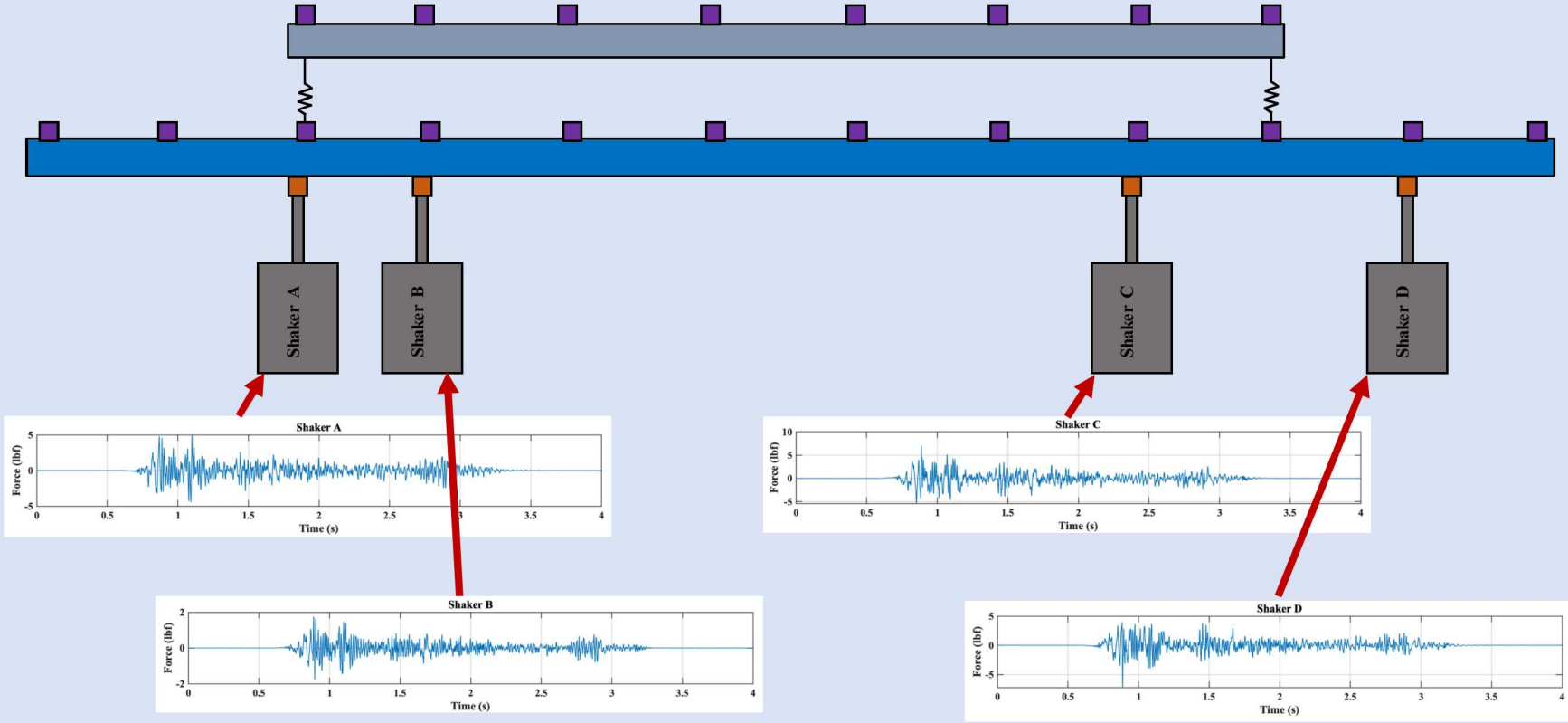
Field Environment Earthquake Excitation



■ Excitation location ▪ Reference Response

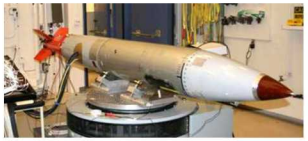
Test Setup

Field Environment Earthquake Excitation



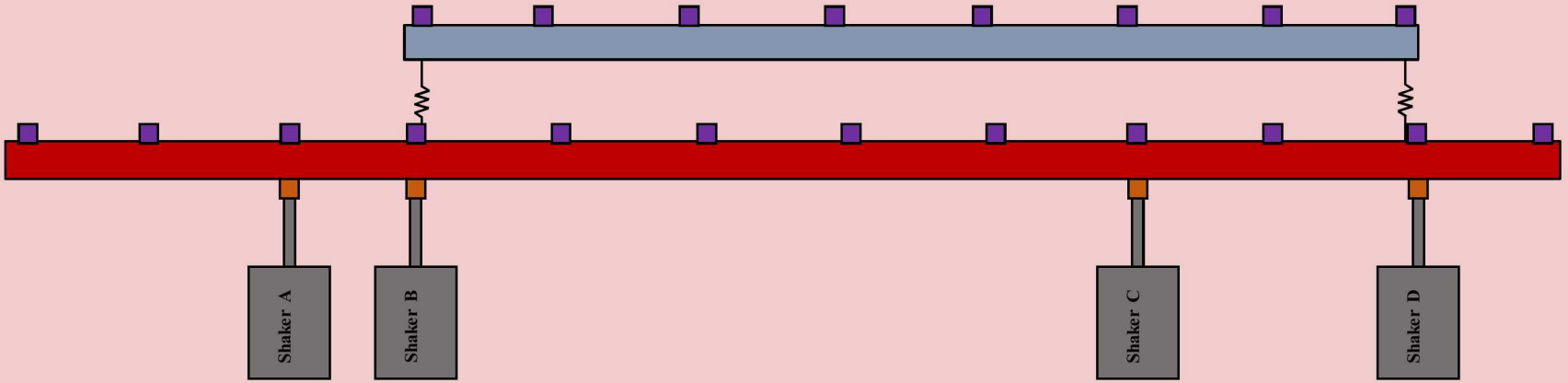
Excitation location

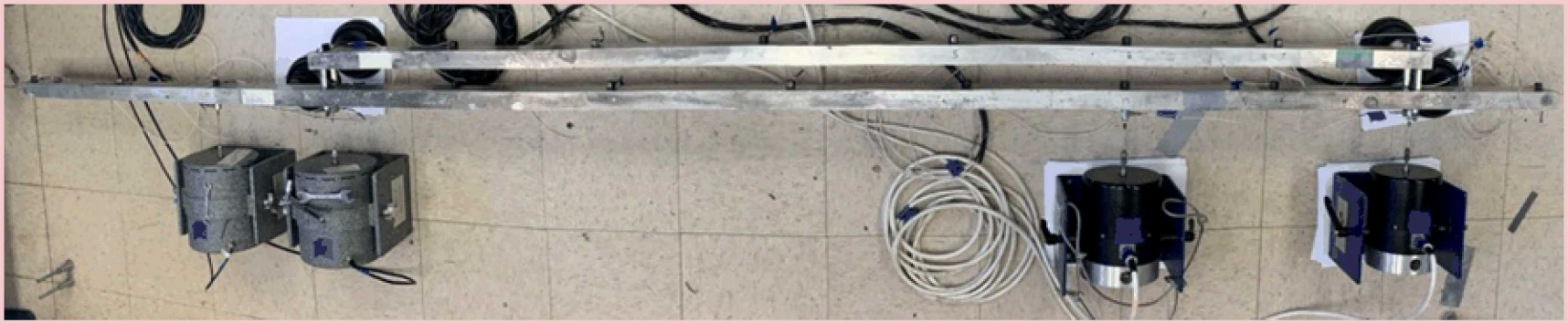
Reference Response



Test Setup

Laboratory Test Replication of Earthquake Excitation

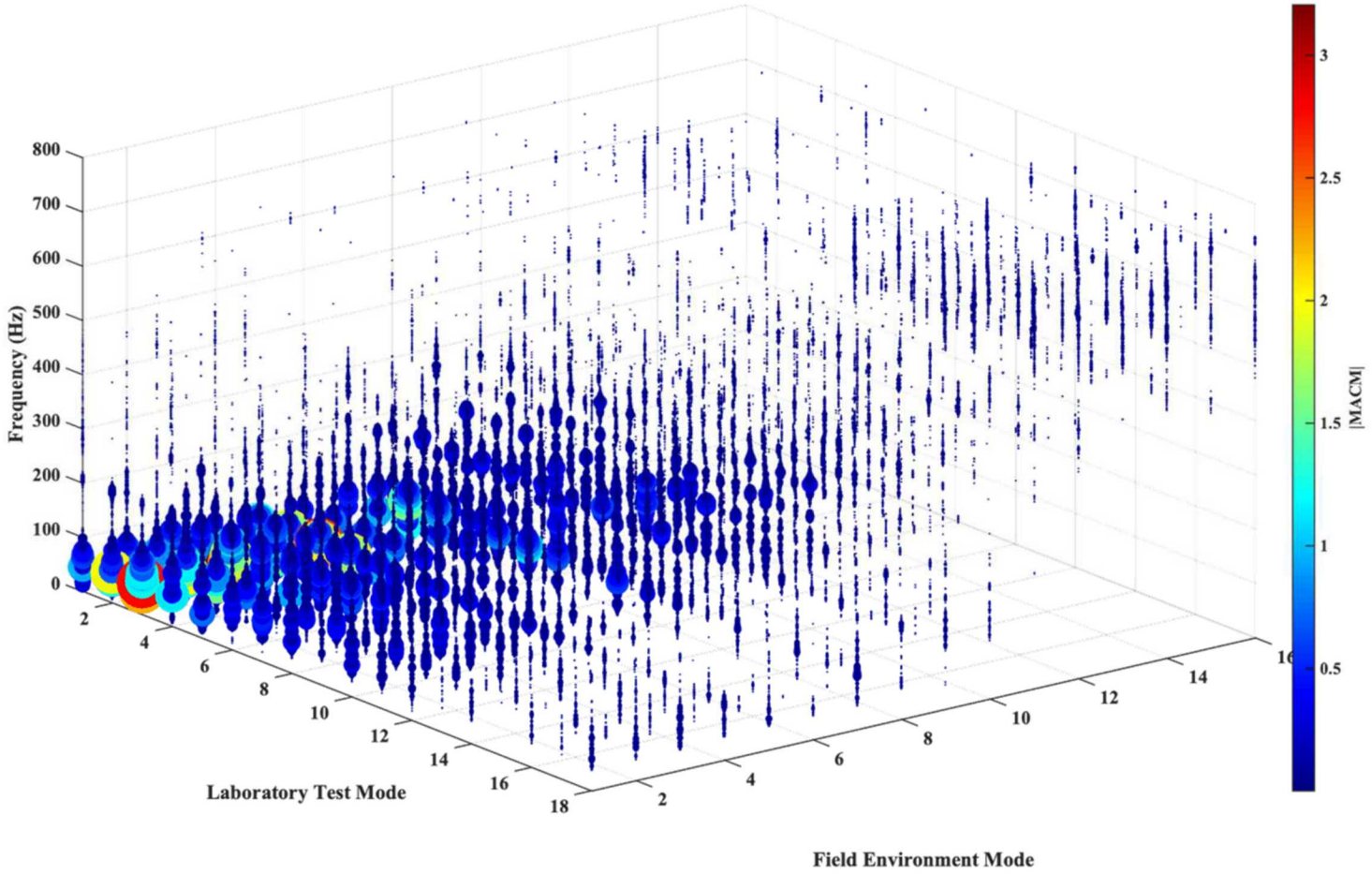


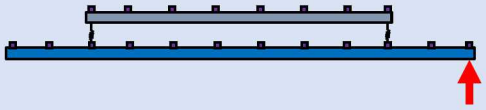


- Excitation location
- Reference Response

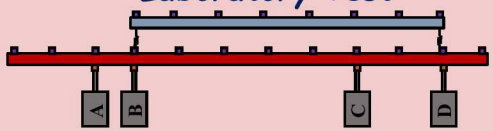
Results (Earthquake)

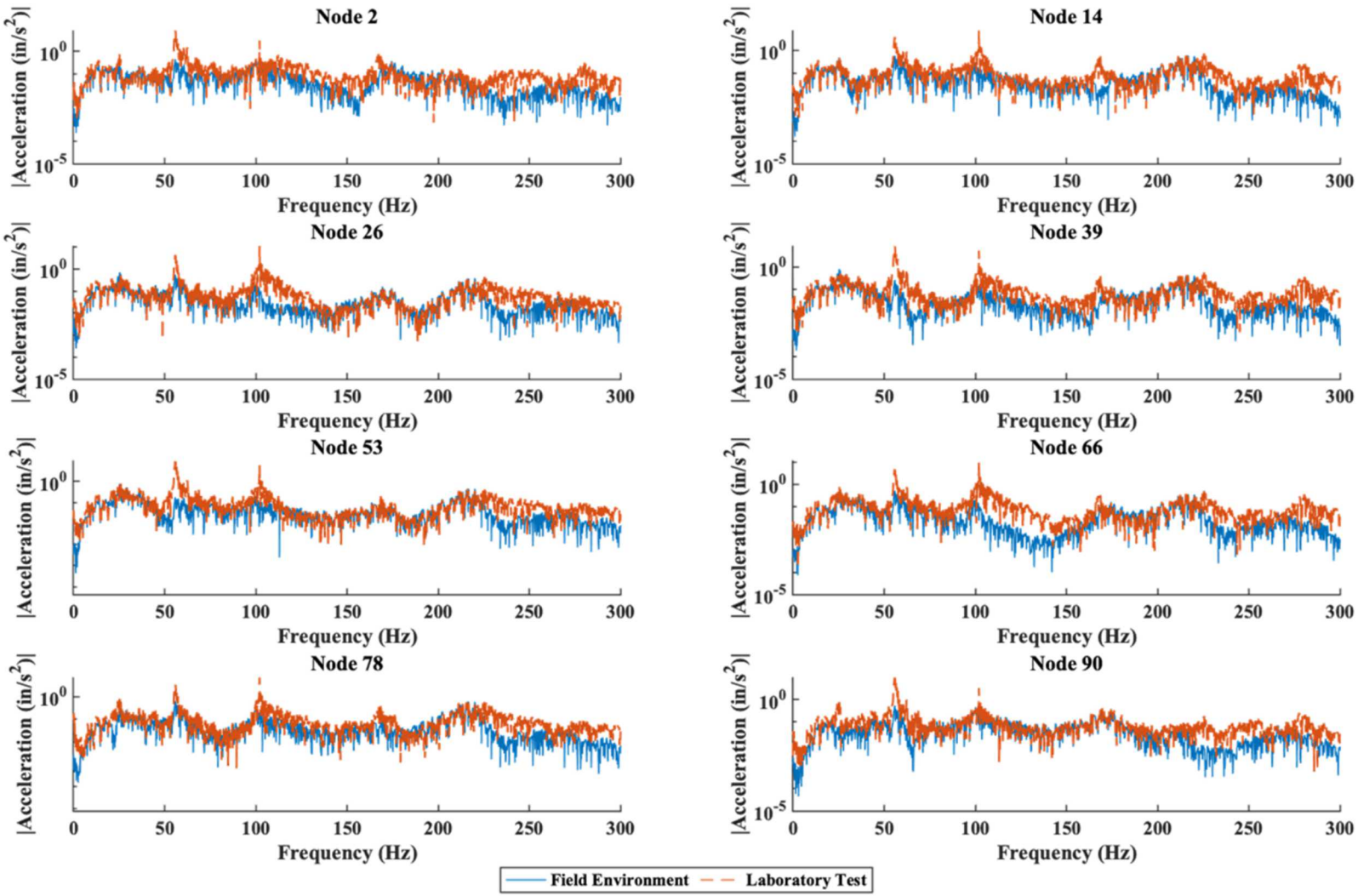
MACM (Earthquake Excitation)

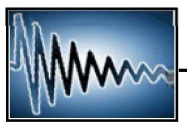




Results (Earthquake)



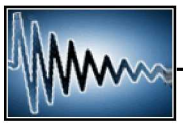




Results (Earthquake)

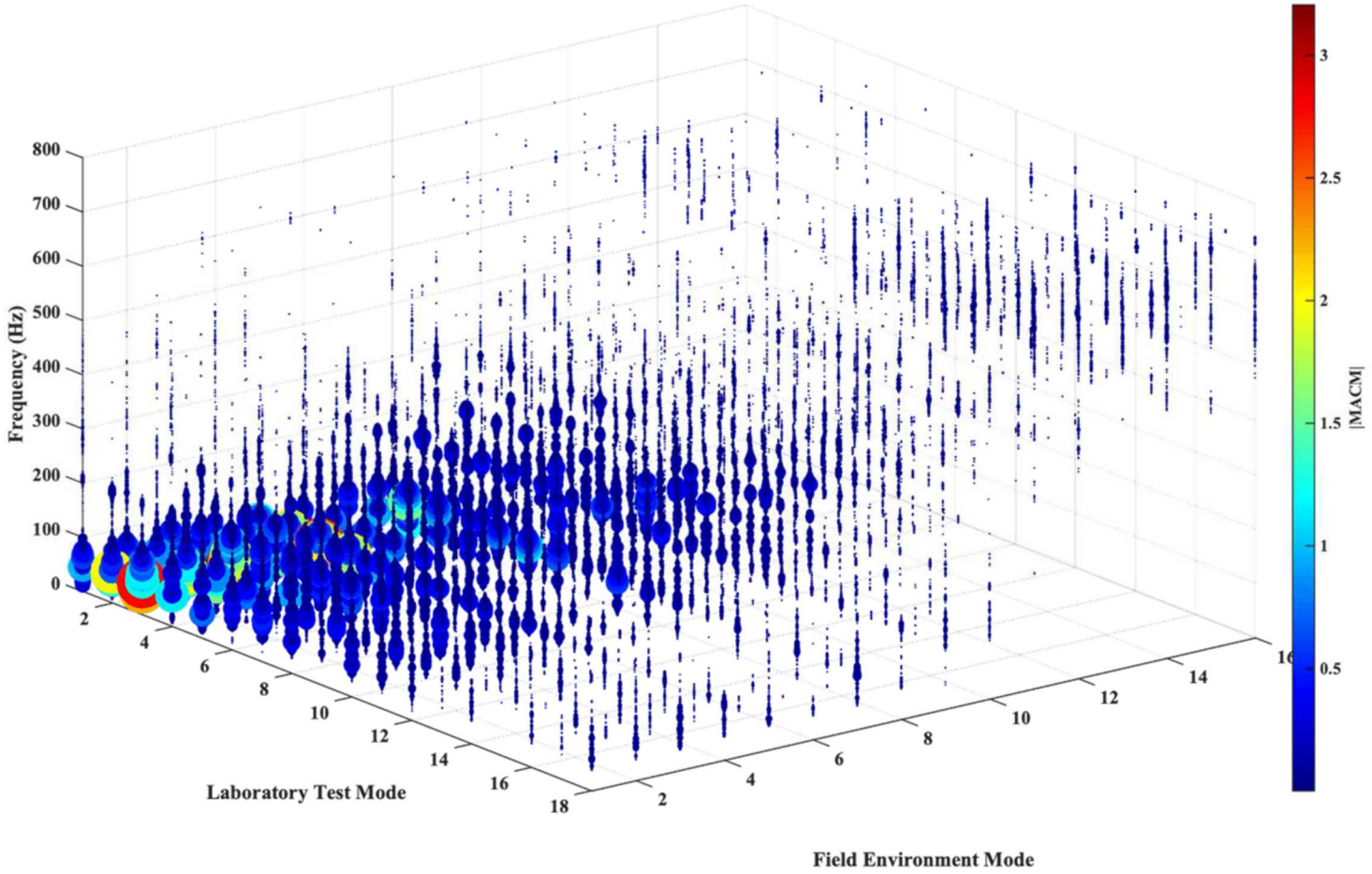
Using the MACM matrix, the excitation was re-calculated based on a truncated model.

Field modes 1:10 were replicated using laboratory test modes 1:12

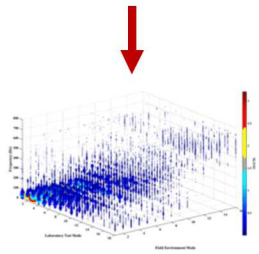


Results (Earthquake)

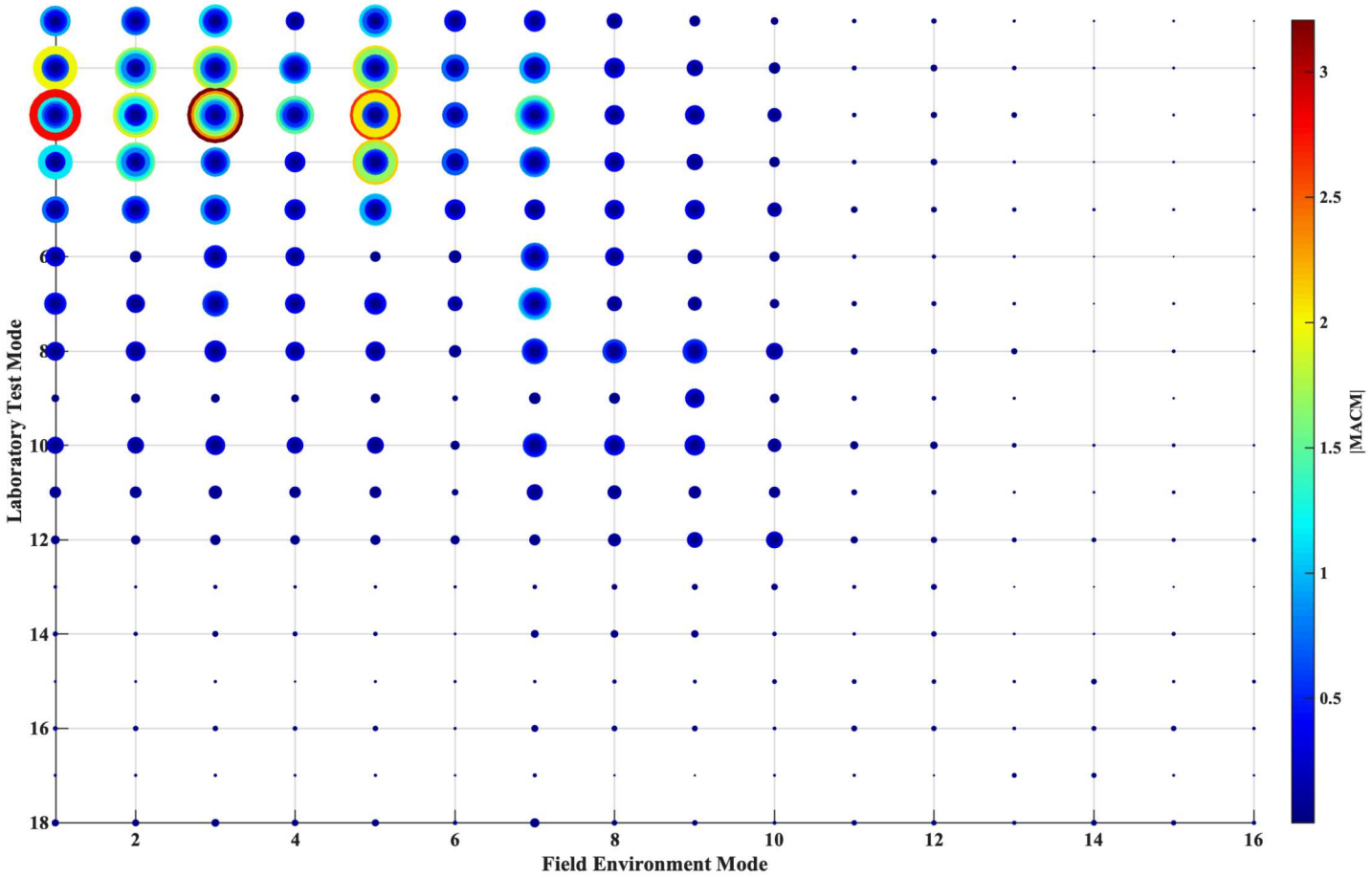
MACM (Earthquake Excitation)



Results (Earthquake)

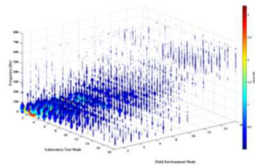


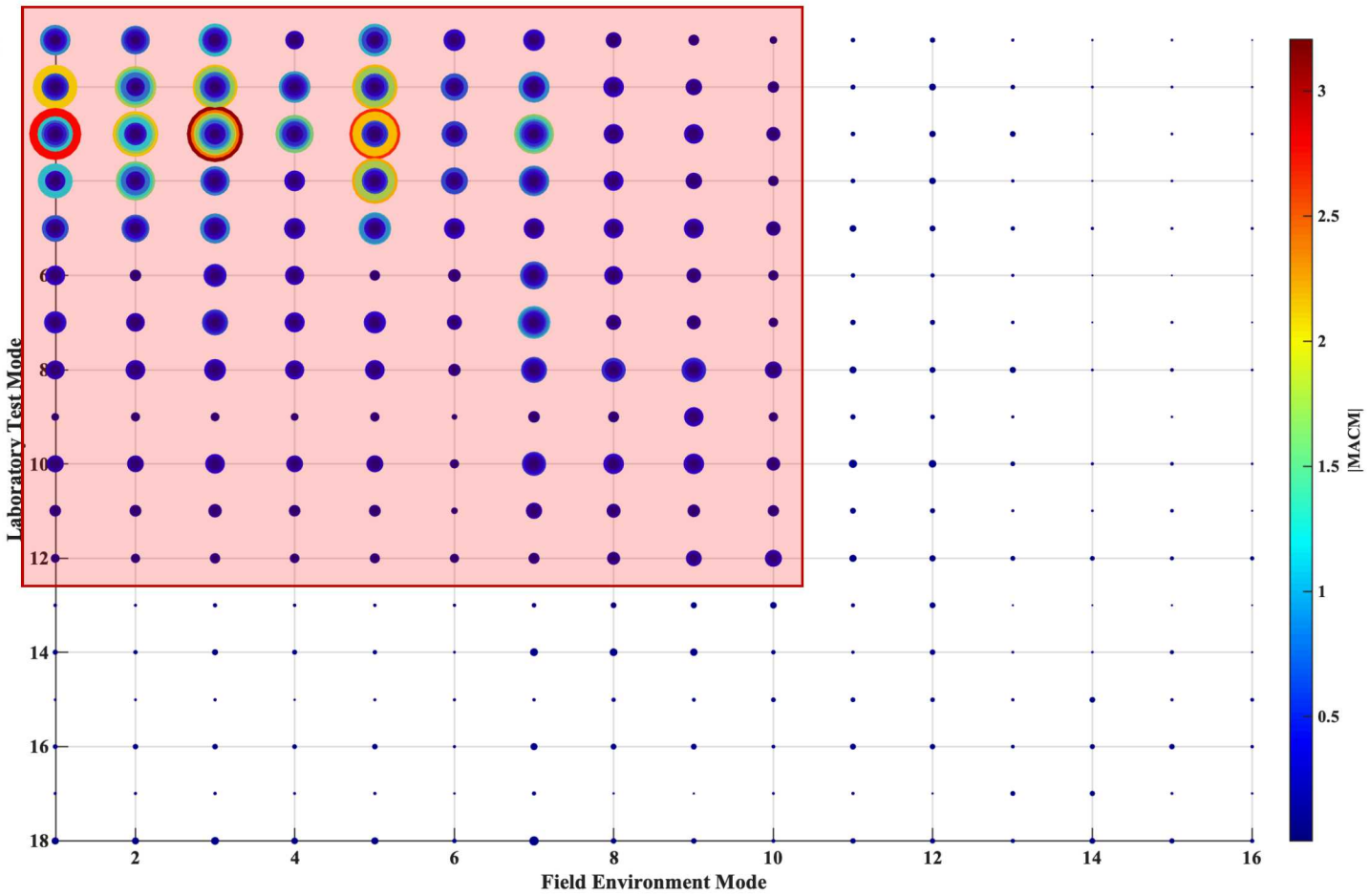
MACM (Earthquake Excitation)

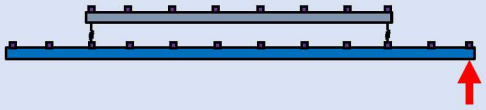


Results (Earthquake)

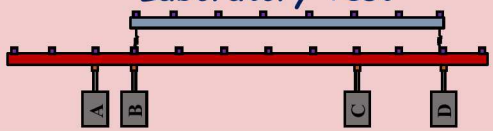
MACM (Earthquake Excitation)

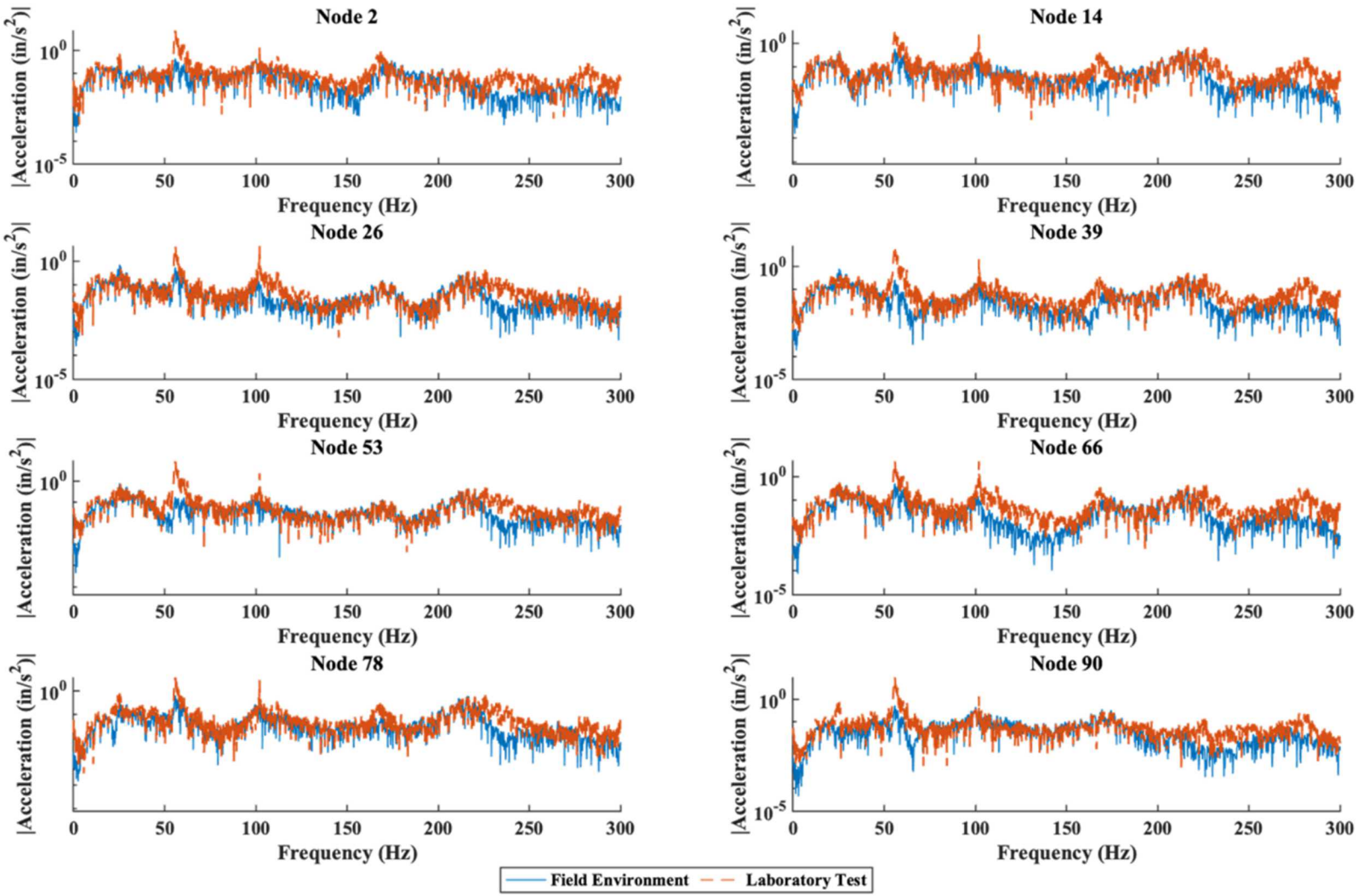


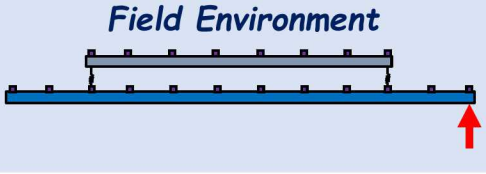




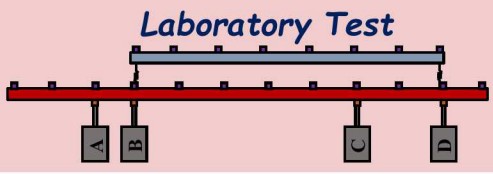
Results (Earthquake)

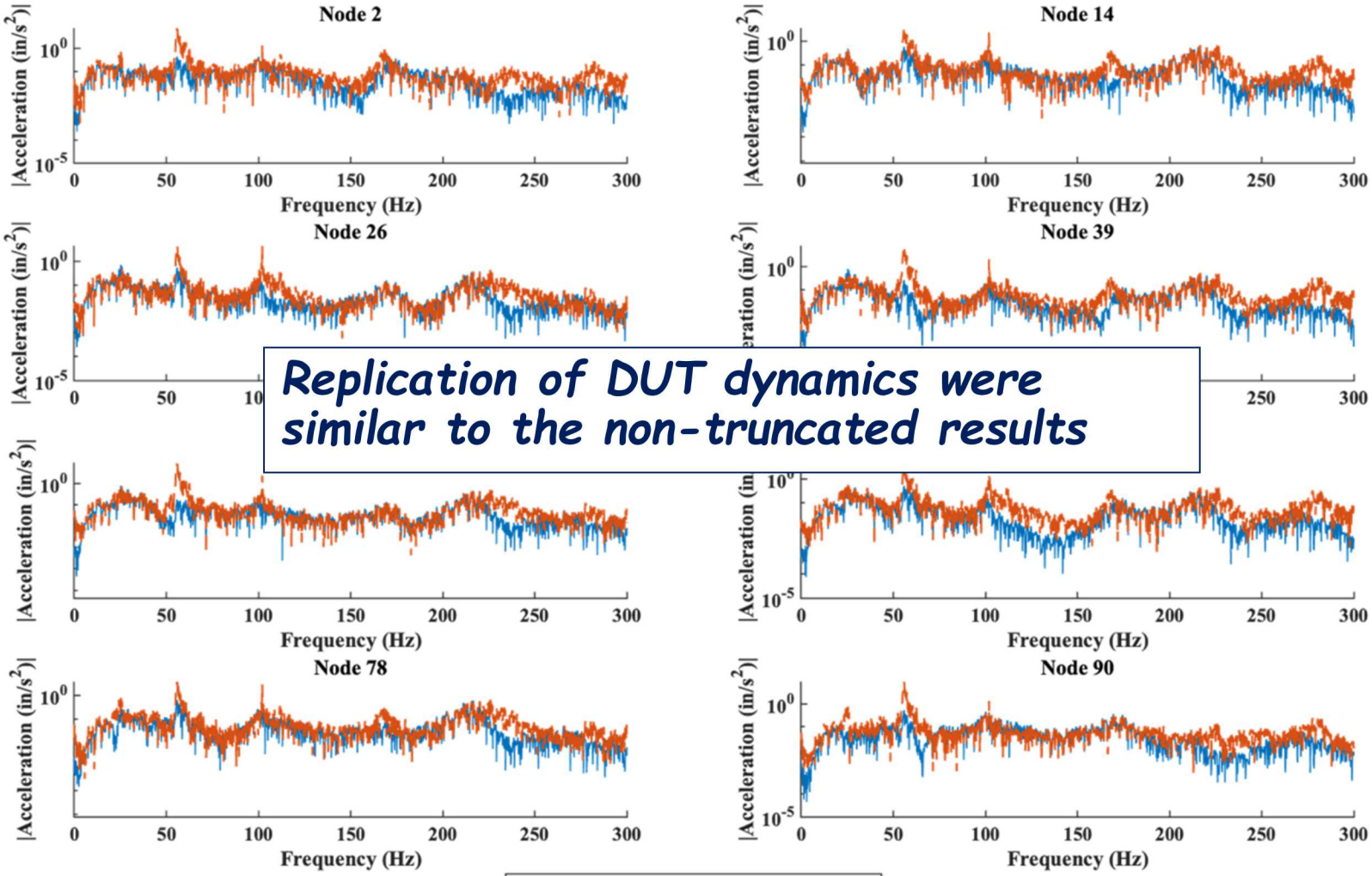






Results (Earthquake)

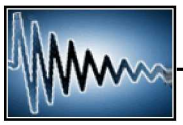




Replication of DUT dynamics were similar to the non-truncated results

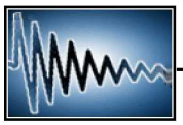
Conclusions

- The modal transformation matrix between field and laboratory modal response was calculated from experimental data.



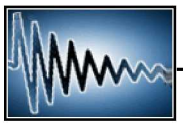
Conclusions

- The modal transformation matrix between field and laboratory modal response was calculated from experimental data.
- Impulse and earthquake excitations were replicated reasonably well in the DUT beam under different boundary conditions.



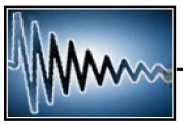
Conclusions

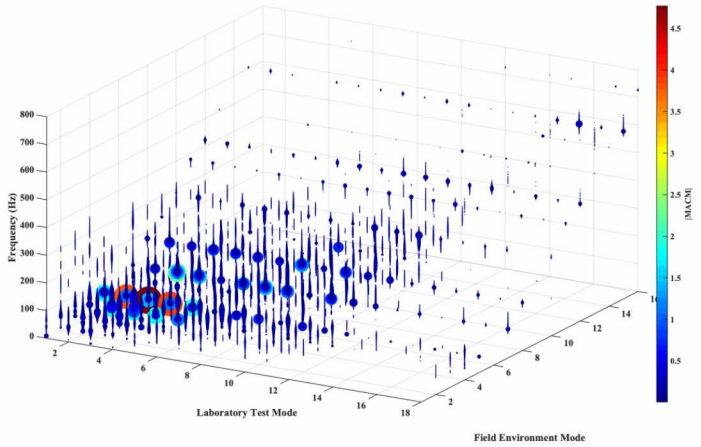
- The modal transformation matrix between field and laboratory modal response was calculated from experimental data.
- Impulse and earthquake excitations were replicated reasonably well in the DUT beam under different boundary conditions.
- Insight from the MACM matrix was utilized to truncate the model utilized for calculating the excitations. Similar replication of field environment dynamics were achieved with the truncated model.



Acknowledgements

Sandia National Laboratories provided funding for this research. I am extremely grateful for their support.





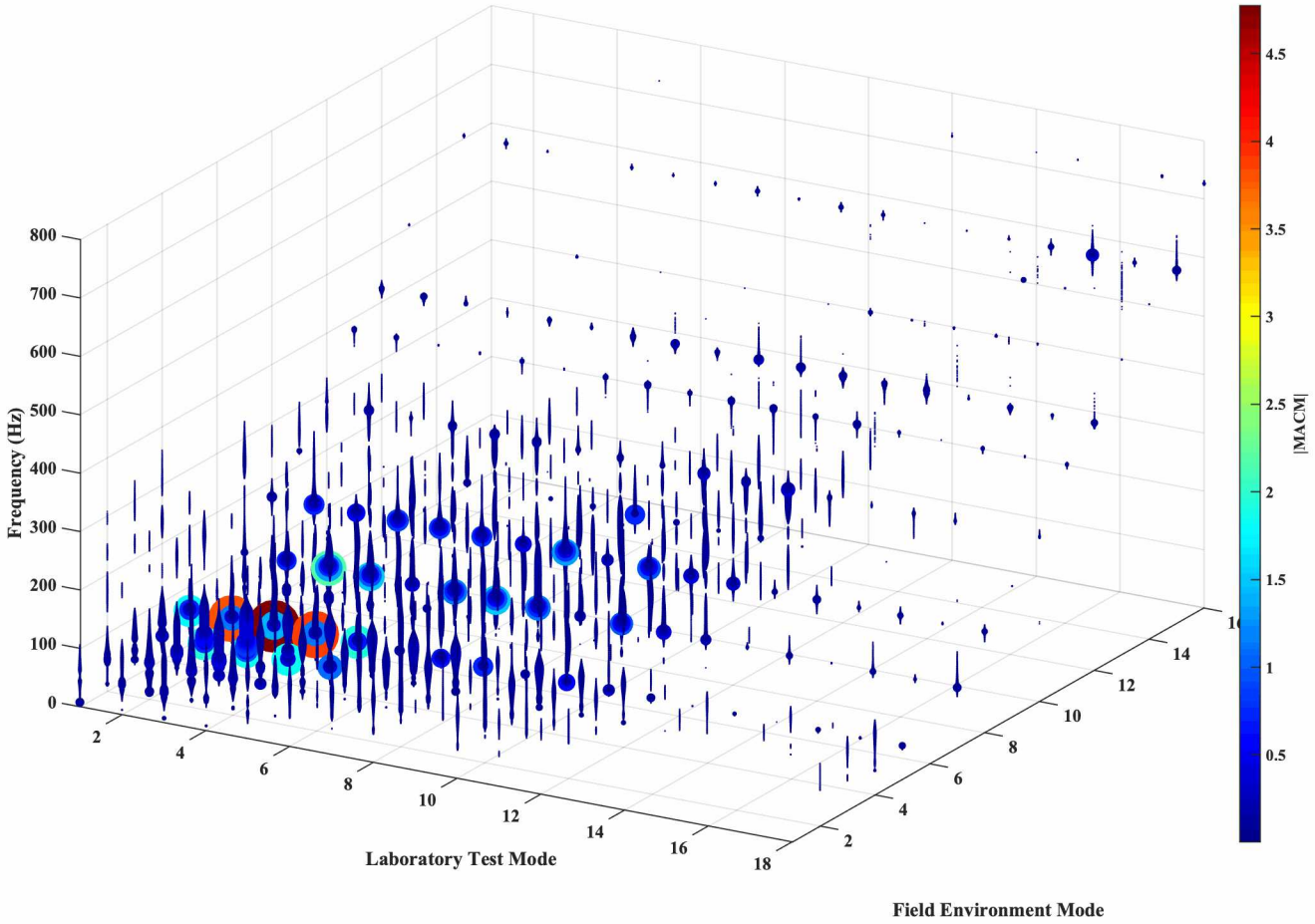
Experimental Application of Boundary Condition Compensation Map (From Field to Laboratory Response)

Brandon Zwink, Brett Daniels, Peter Avitabile
Structural Dynamics and Acoustic Systems Laboratory
University of Massachusetts Lowell

D. Gregory Tipton
Structural Dynamics Group
Sandia National Laboratories

Results (Impulse)

MACM (Impulse Excitation)



Results (Earthquake)

MACM (Earthquake Excitation)