Chapter 11
Analysis of Full-Field Response from a Multi-Shaker Test

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Abstract Multi-shaker testing is used to represent the response of a structure to a complex operational load in a laboratory setting. One promising method of multi-shaker testing is Impedance Matched Multi-Axis Testing (IMMAT). IMMAT targets responses at discrete measurement points to control the multiple shaker input excitations, resulting in a laboratory response representative of the expected operational response at the controlled measurement points. However, the relationship between full-field operational responses and the full-field IMMAT response has not been thoroughly explored. Poorly chosen excitation positions may match operational responses at the control points, but over or under excite uncontrolled regions of the structure. Additionally, the effectiveness of the IMMAT method on the whole test structure could depend on the type of operational excitation. Spatially distributed excitations, such as acoustic loading, may be difficult to reproduce over the whole test structure in a lab setting using the point force IMMAT excitations. This work will simulate operational and IMMAT responses of a lab-scale structure to analyze the accuracy of IMMAT at uncontrolled regions of the structure. Determination of the effect of control locations and operational locations on the IMMAT method will lead to better test design and improved predictive capabilities.

Keywords IMMAT · MIMO · Test methods · Model methods · Modal

11.1 Background

One major challenge in structural dynamics experimental methods is the ability to recreate a structure's response to a complex, real-world loading (the "environmental" response) in a laboratory setting (the "laboratory" response). One multi-shaker method that has shown significant promise in recreating environmental responses is the Impedance Matched Multi-Axis Testing (IMMAT) method, and is the focus of this work. IMMAT, first proposed by Daborn et al. [1], uses experimental measurements at reference points and the structure's frequency response function (FRF) matrix to calculate the required input force at chosen excitation locations to recreate the environmental response. This method has been shown to successfully recreate environmental responses in a laboratory setting at the reference points chosen [2]. This work has also been extended to show that additional points of the structure not included in the reference response set also respond similarly to the environmental response [3]. However, most previous research on IMMAT used experimental data for the environmental and laboratory responses, and therefore were limited to the analysis of a few discrete points.

Before IMMAT can become a substitute for more traditional laboratory measurement techniques, the robustness of the technique must be understood. A full-field analysis of the differences between the environmental and laboratory responses is needed to help identify sensitivities in the method to the chosen measurement locations, the chosen number of laboratory forces, and the environmental excitation characteristics, among other variables. To study the full-field response of a structure, a finite element (FE) model is needed. This work builds a FE model to simulate the full-field response of a structure to forces

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calculated using IMMAT. The visual full-field differences between the simulated environmental response and the simulated laboratory response can be used to better understand the extent to which IMMAT can simulate environmental responses.

11.2 Theory

In practice, IMMAT uses the measured environmental structural response cross power spectral density (CPSD), Sxx_0, at measurement points p to calculate the laboratory input force spectra, Sff_1, at chosen forcing locations, $q1$, to reproduce the response. When IMMAT is used with a FE model, the environmental response spectra must first be calculated. Let Sff_0 be the environmental force spectra due to forces at points $q0$, which in practice is unknown, but is selected for the simulation. The response to the environmental force is calculated using Eq. 11.1, where Hpq_0 is the frequency response function (FRF) matrix of the system, and the "H" superscript indicates the conjugate transpose. The required laboratory force to replicate the environmental response spectra is then calculated using Eq. 11.2, in which the "+" superscript indicates the matrix inverse. For this paper's calculation, the pseudoinverse was used. The success of the input force calculation can be analyzed by calculating the laboratory response to the new force, Sff_1 at points $q1$, using Eq. 11.3, and comparing with the original environmental response.

$$Sxx_0 = Hpq_0\ Sff_0\ Hpq_0^H \tag{11.1}$$

$$Sff_1 = Hpq_1^+\ Sxx_0\ Hpq_1^{+H} \tag{11.2}$$

$$Sxx_1 = Hpq_1\ Sff_1\ Hpq_1^H \tag{11.3}$$

11.3 Method and Results

A FE model of a three-tiered structure dubbed the "wedding cake" was used for this paper's analysis, as shown in Fig. 11.1. Also shown as blue points are a sub-set of measurement points that match previous experimental testing. The environmental input force was chosen to be three points (17, 51, and 91), with each point excited in the X, Y, and Z directions (respectively),

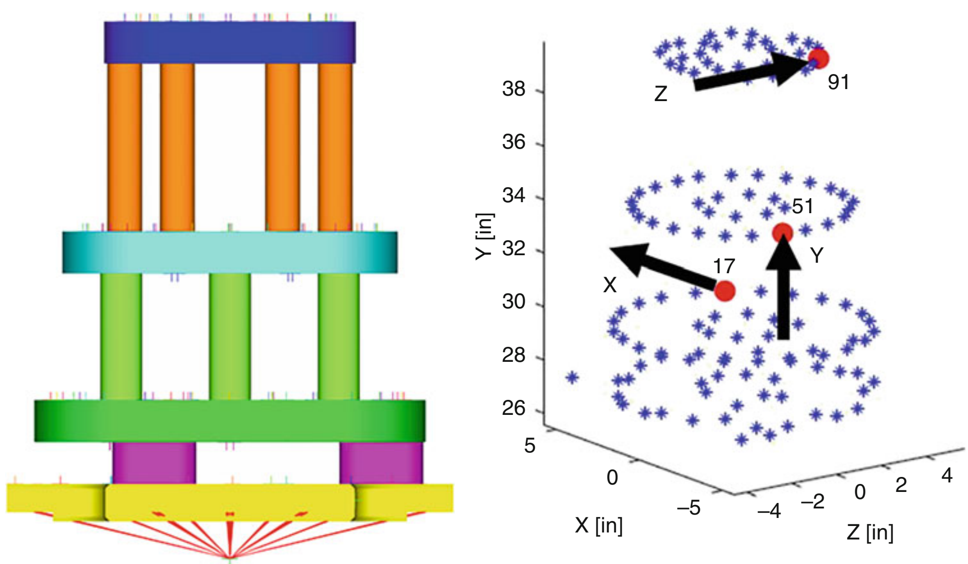

Fig. 11.1 Simulation wedding cake structure (left) and the sample response points (shown in blue) with the forcing points and direction shown as red dots (right)

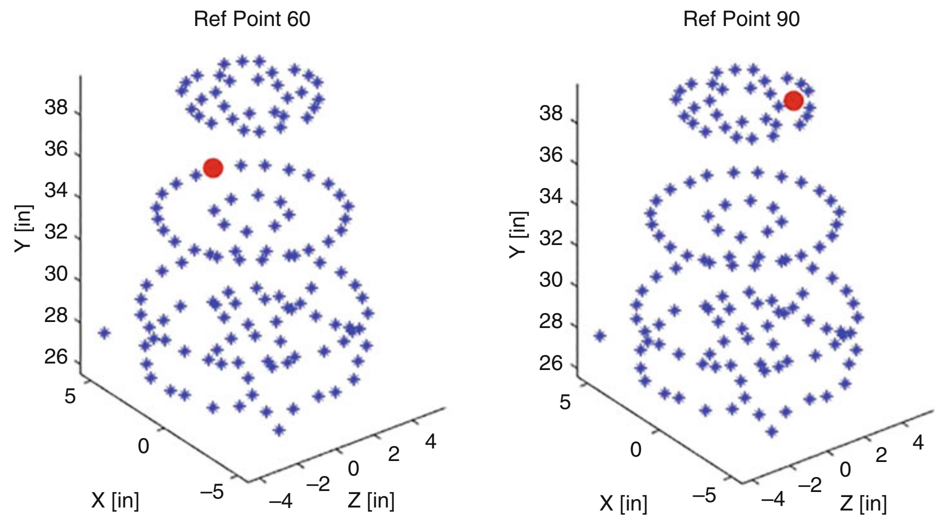

Fig. 11.2 Example point 60 (left) and example point 90 (right)

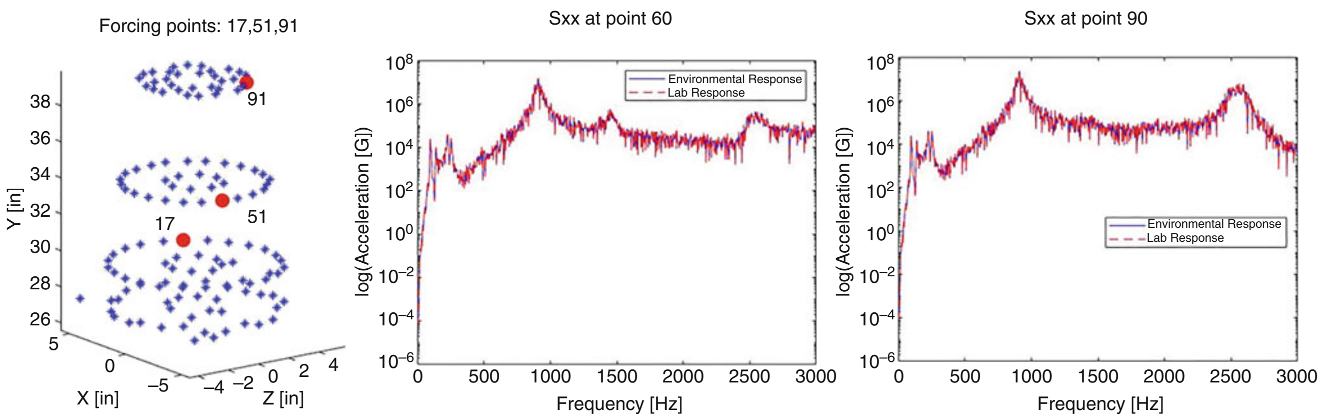

Fig. 11.3 Environmental and laboratory response PSD for the same forcing points (points 17, 51, and 91)

as indicated in the figure. The excitation points were chosen to be distributed around the radius of the structure and among the tiers to better excite the modes.

To verify the force calculation method, the laboratory force locations, $q1$, were chosen to be the same as the environmental force locations, q0. The chosen excitation points were points 17, 51, and 91, as shown in Fig. 11.1. The response power spectral densities (PSDs) were calculated at example points 60 and 90 (given in Fig. 11.2) for a simple comparison. The example points were chosen because their response was representative of the overall response comparisons. The response PSD comparison given in Fig. 11.3 shows that the environmental response and the laboratory response are the same.

Next, three different laboratory force locations were chosen to only excite the bottom two tiers. Not including a response on the top tier helps demonstrate how neglecting to excite a sub-component makes the response recreation in the laboratory case more difficult. The laboratory response PSD at example points 60 and 90 are no longer exactly the same as the experimental response PSD, although the two responses are very similar (Fig. 11.4).

Finally, only two of the previous laboratory force locations were chosen, and no forcing points were included on the top two tiers of the wedding cake. This represents the most challenging case for response recreation in the laboratory case. The laboratory response PSD at example points 60 and 90 now significantly differ from the environmental response, especially at lower frequencies (Fig. 11.5).

The simulations of the wedding cake show that forcing location and number is important to the success of laboratory recreation of an environmental response. However, comparing the responses at each point is difficult to analyze. Now that a FE model has been built, the full field differences between the environmental response and the laboratory response can be studied more efficiently by animating the FE responses at all points to both the environmental and the laboratory forces. Images and discussion of the full field responses and comparisons will be included in the presentation.

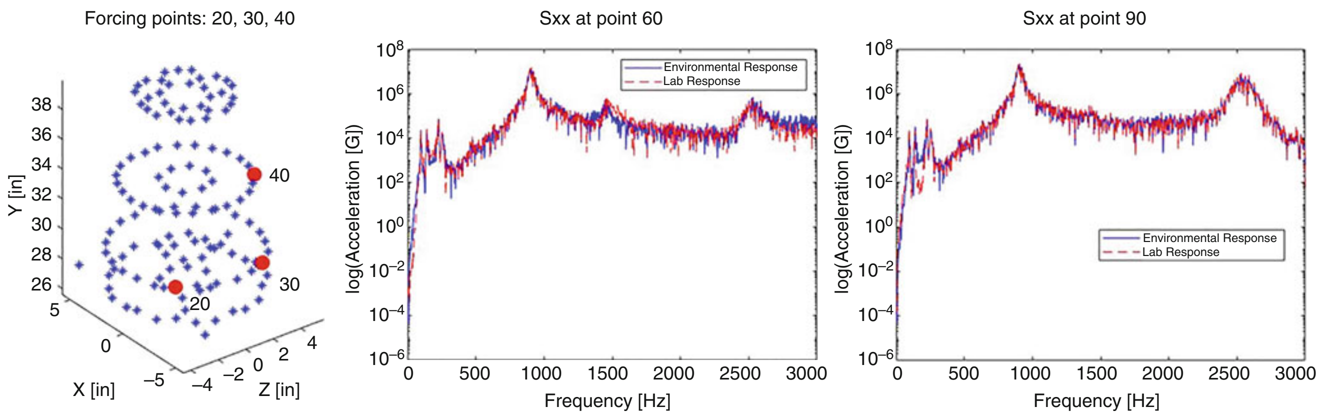

Fig. 11.4 Environmental and laboratory response PSD for laboratory forcing points 20, 30, and 40

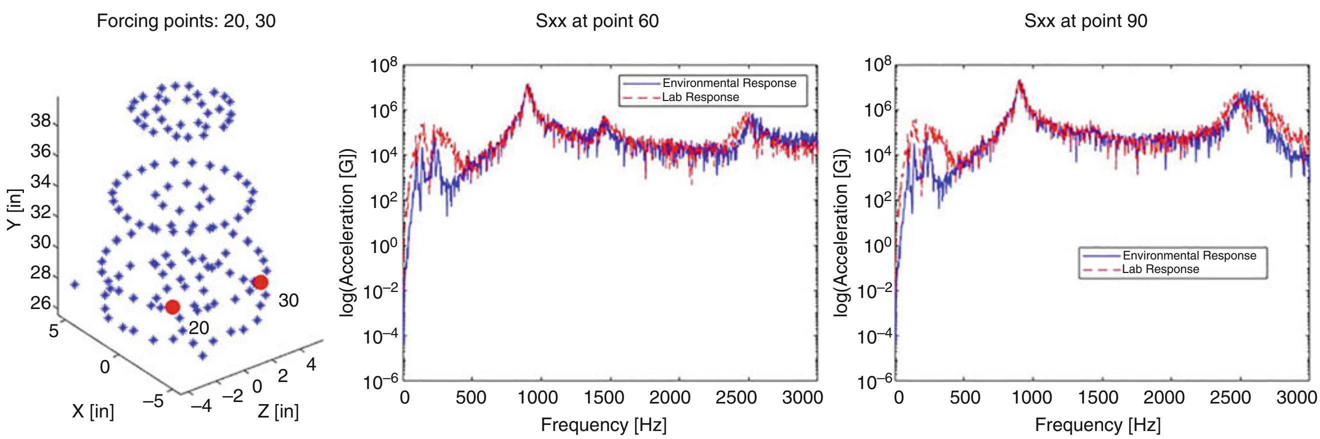

Fig. 11.5 Environmental and laboratory response PSD for laboratory forcing points 20, 30, and 40

References

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