Factors Influencing Footfall Vibration Analysis

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Background and Motivation

As one of the serviceability limit states of structural design, excessive vibration has attracted more attention in recent years, with the design trend moving toward lighter and more slender structures. The effects of floor vibration can be critical in a surgical operating room or a nuisance in an office building. Footfall vibration contains high uncertainties in nature, with significant variations in walker weight, walking speeds, and dynamic load factor. Since conservative designs can often lead to significant cost premiums, this study focuses on the stochastic assessment of footfall vibration of composite steel floors to better understand the variation in performance of various design factors. The results of this study will provide actionable guidance to stakeholders to weigh the benefits and costs between performance targets.

Proposed Solution

The steel composite model was developed and analyzed in Oasys GSA. Monte Carlo simulation was used to quantify the probability of exceeding certain common vibration criteria. Various iterations were then performed on the steel composite model in order to meet the desired response factor (RF). Response factors are used to quantify the vibration on a scale based on the maximum velocity level in micrometers per second. The models are developed in GSA, a structural analysis program, to provide a visual of the structure and to perform dynamic modal analysis and dynamic response footfall analysis. Compared to the current practice of analyzing structures for footfall vibration, this study includes a probabilistic approach by utilizing MC Walker, which accounts for the walker's weight and walking frequency.

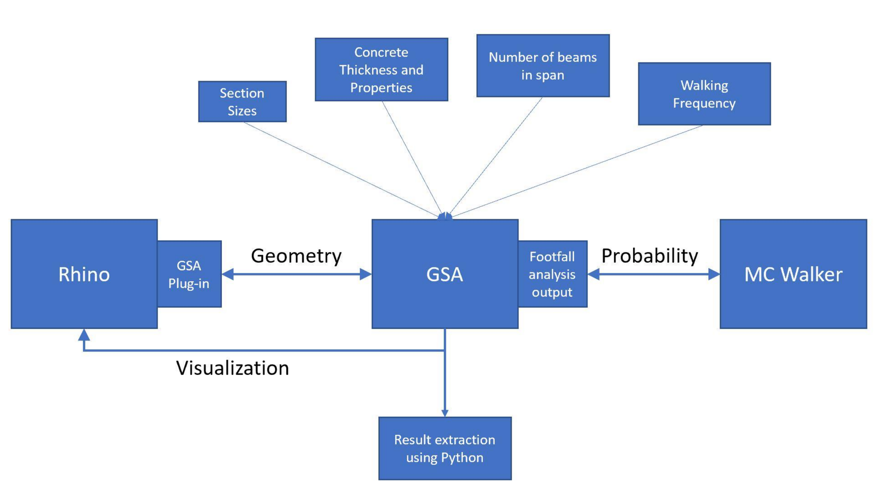

Figure 1: Framework for designing, constructing, and analyzing structural testbed models.

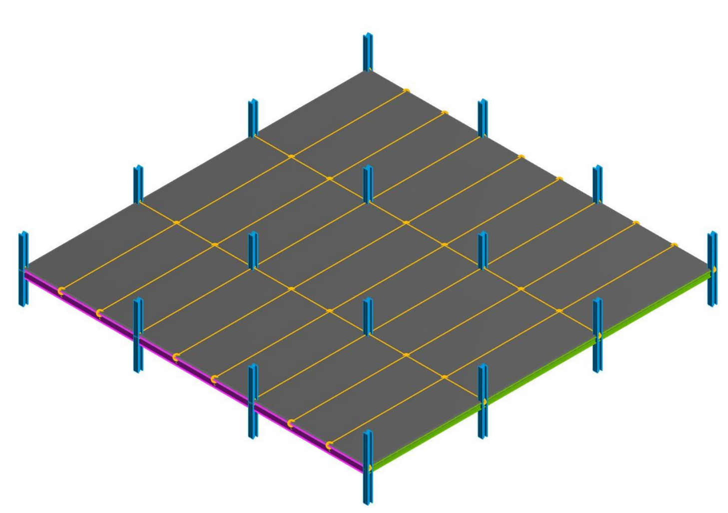

Figure 2: Steel composite model testbed in GSA structural analysis program.

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Methods

GSA, a structural analysis software, was used to test the various factors influencing footfall vibration. A footfall analysis was performed using the calculations set forth in the design guide CCIP-016. Multiple parameters were changed to meet different response factor (RF) criteria such as section sizes, concrete density, slab thickness, and increasing number of beams in span. After a given criteria was met by a model, a Monte Carlo simulation was performed to assess the probability of exceeding the criteria. The simulation combined the footfall analysis from GSA with normal distributions of two variables: the weight of the walker and the walker's walking frequency.

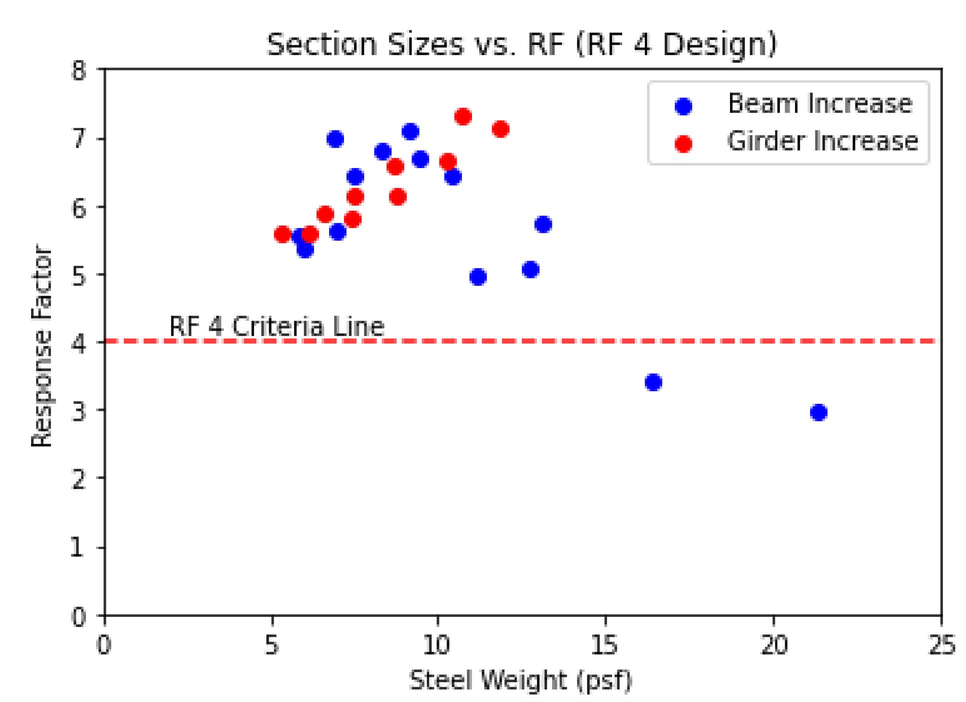

Figure 3: This figure depicts the multiple iterations made when changing section sizes in attempt to reach a response factor less than 4.

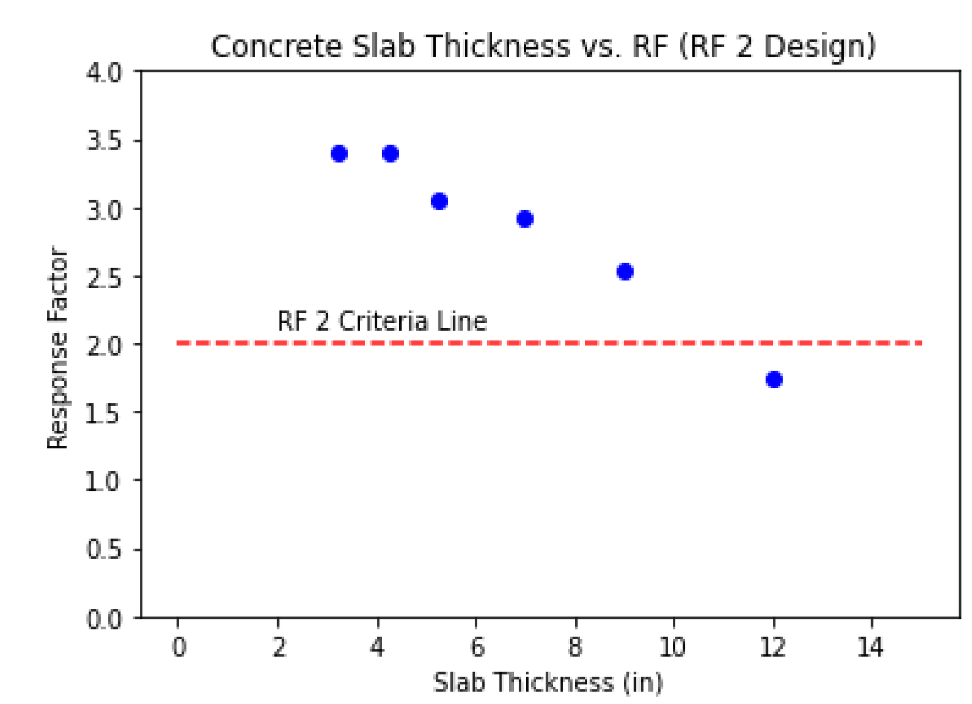

Figure 4: After meeting the RF 4 criteria by changing section sizes, that design was then modified by changing the slab thickness of normal weight concrete (150 pcf).

Conclusion

Regarding the factors influencing the analysis, the relationship between girder sizing and response factor was an unpredictable phenomenon, as an increase in mass usually assists in lowering floor vibration. However, the increase in slab thickness did result in a lower response factor. Another key takeaway is the rapid increase exceeding the various RF criteria for a specific design as shown in *Figure 7.* It is important to note that there is no single design used for reducing footfall vibration and many methods can be used to meet a specific constraint set by the client. Hence, the stochastic approach to footfall will provide a better lens for the issue. The results gathered from this research can be useful for engineering firms to design for footfall vibration and will become more applicable as the focus on vibration increases. Future research will continue to test the different building materials such as timber and concrete and to obtain better results through more iterations of the current parameters.

Results

After multiple iterations were made to bring the response factors below their respective criteria, three designs were created for the composite steel bay. For each design, the probability of exceeding different response factors was determined by the Monte Carlo simulation.

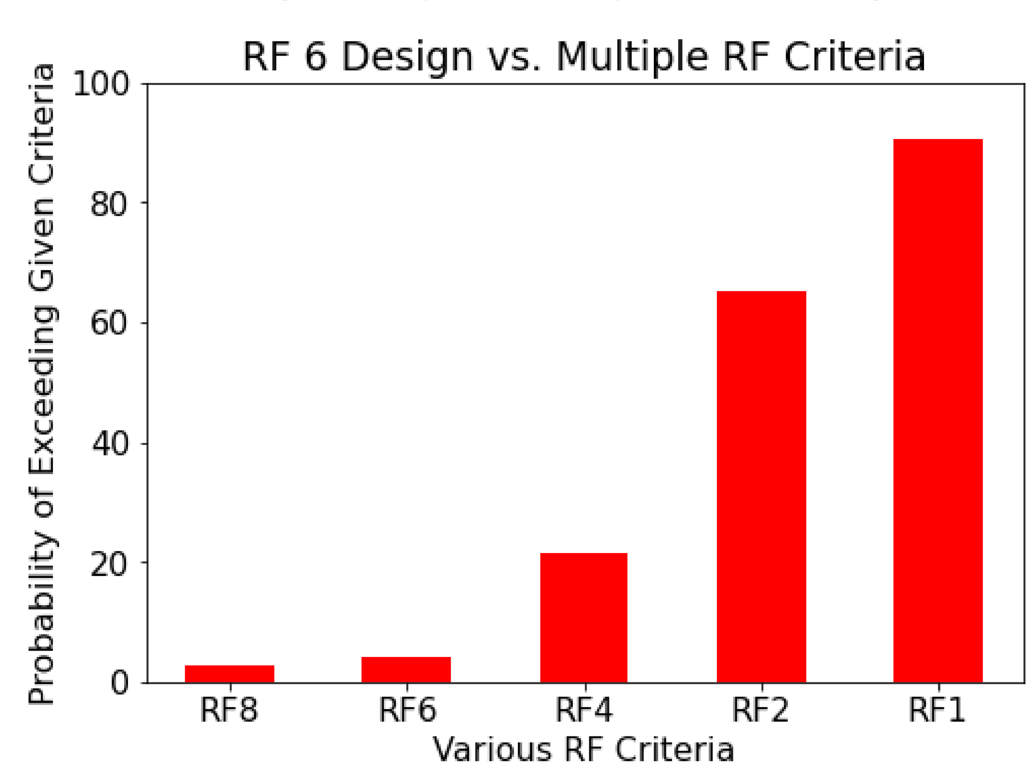

Figure 5: This figure shows how an office bay designed for a response factor of 6 reacts to other response factors.

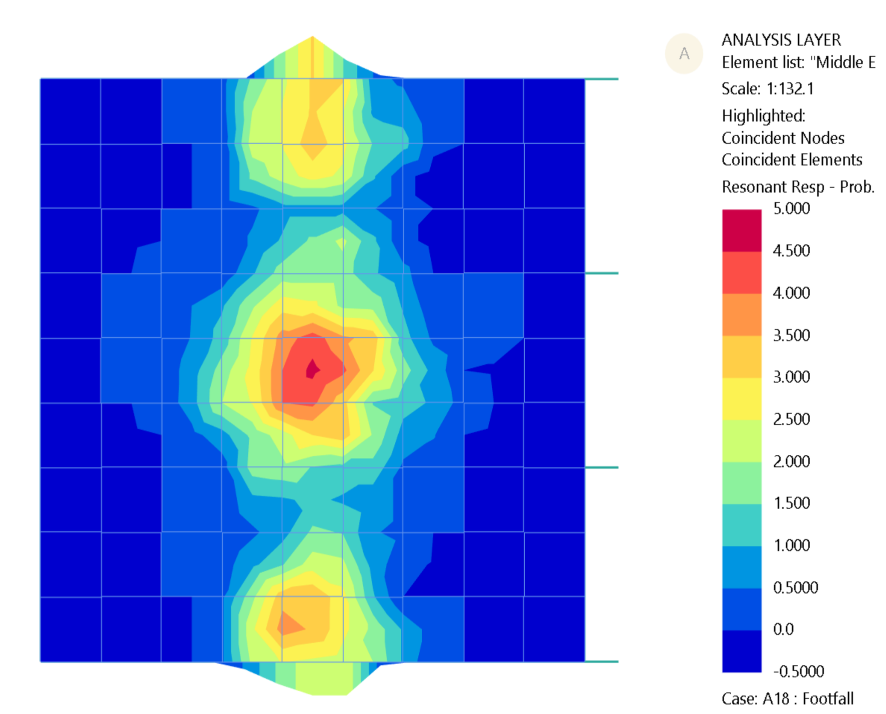

Figure 6: This image is a contour from the Monte Carlo simulation depicting the probability of exceeding a response factor of 6 at all locations in the bay.

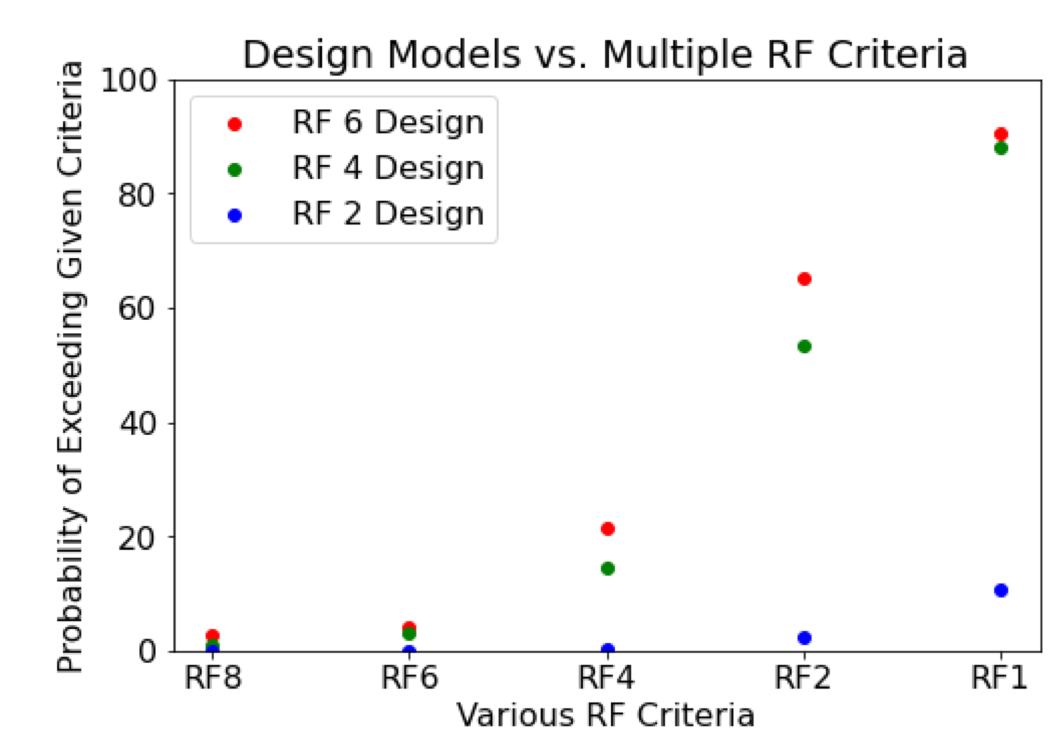

Figure 7: This figure shows the probability of exceeding the different RF criteria for each designed model: RF6, RF4, and RF2

Steel Model with 2 Beams Per Span								
				Probability of Exceeding Resonant RF Criteria (%)				
Designed RF Criteria	**Beam Profile**	**Girder Profile**	**Concrete**	**RF 8**	**RF 6**	**RF 4**	**RF 2**	**RF 1**
RF6	W16x26	W21x44	LWC 3.25"	2.8	4.267	21.33	65.2	90.4
RF4	W18x130	W21x44	LWC 3.25"	0.933	3.067	14.4	53.33	88
RF2	W18x130	W21x44	NWC 12"	0	0	0.2667	2.4	10.67

Table 1: The table above lists the different designs and their properties when trying to meet the vibration criteria.