comparison of model-based GFRFs with the aforementioned, pre-selected parameters with recording-based ones, aiming to show the influences of some parameters in GFRF and GIRF. Fig. 7 and 8a,b show respectively the comparison of recording-based GFRF and GIRF at the 4th and 7th floors with respect to band-limited (ε=5%) impulsive motion at basement against model-based counterparts with respect to pure (ε=0%) impulsive motion at basement.

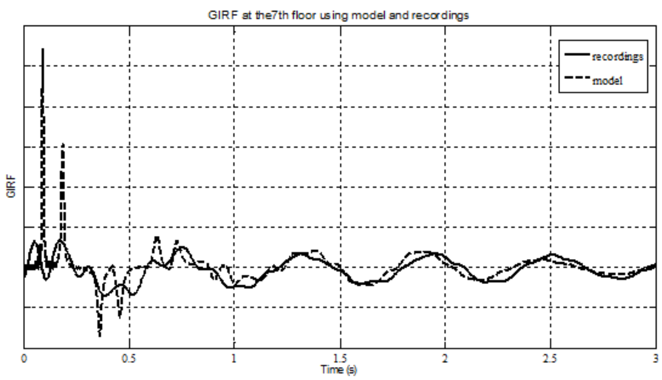

Fig 8a Comparison of GIRF at the 7th floors with respect to basement acceleration motion obtained from seismic recordings and model (Eqs. (9b) and (11a)).

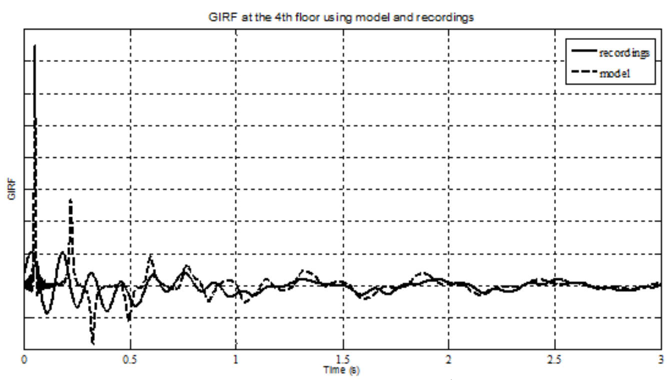

Fig. 8b Comparison of GIRF at the 4th floor with respect to basement acceleration motion obtained from seismic recordings and model (Eqs. (9b) and (11a)).

These three figures indicate that the two-layer model is able to capture the fundamental wave and vibration features shown in the recordings, exemplified as the first and second modal frequencies in Fig. 7, and proximity of first couples of wave arrival times and well-matched resonant vibration features in Figs. 8a,b. The major difference in spectral amplitudes at the first modal frequency in Fig. 7 and in wave amplitude and arrival time in the 0-0.5 *s* time window in Figs. 8a,b can be minimized with appropriate system-identification algorithm for identifying layer parameters and ε.

3.3 Influences of Multi-layer Model in Parametric Identification

While some fundamental characteristics of wave-based system identification are shown with the two-layer model, increased number of layers in the model would be in principle more appropriate in realistically capturing the physical multi-story structure of the building. To see the influence of multi-layer model in system identification, one can alternatively examine the difference of GFRF and GIRF with two-layer and 11-layer models. Based on the structural configuration in Fig. 1, the building can be modeled as 11 layers, with the top 11th layer being the same as the 2nd layer in the 2-layer model, and with the first ten layers having same flight time as the first layer in the 2-layer model. Due to the story-to-story proximity in structure in Fig. 1, the flight time for the first 10 layers is assumed to be equally shared with each of ten layers in 11-layer model. The minor difference in story height in Fig. 1 then leads to slightly-different velocity in each layer and $r_{lj}\approx 1$ for j=1-10. This yields

$T_{j\bar{j}} \approx T_{\bar{j}j} \approx 1,\quad R_{\bar{j}j} \approx R_{j\bar{j}} \approx 0,\quad for \quad j=1-10$ and $T_{ln} \approx T_{lm}T_{mn},\quad R_{ln} \approx R_{mn},\quad for \quad l,m=1-10$ with the aid of Eqs. (7) and (8), and subsequently leads to the *T*s and *R*s in the first ten layers in 11-layer model similar to those with first layer in 2-layer model. With those *Ts* and *R*s, GFRF with the 11-layer model obtained from Eq. (9a) with *N*=11 is essentially similar to Eqs. (11a,b) with two-layer model.

Figure 9 shows that both 2-layer and 11-layer models with Table 1 are consistent to each other in GFRF, in addition to capturing the two modal frequencies.

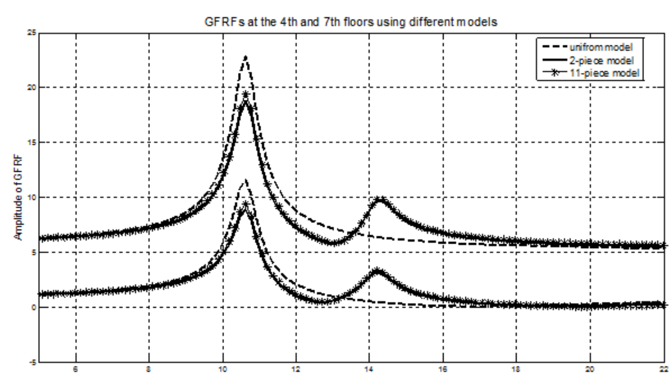

Fig. 9 Comparison of GFRF amplitudes at the 4th and 7th floors with respect to impulsive basement acceleration obtained with uniform (one-layer), two-layer and eleven-layer models from seismic recordings and models.

Table 1 Identified shear wave speeds and damping and their comparison with results from others, which are associated with uniform, one-layer model with a pair of Yorb Linda earthquake recordings at basement and the 8th floor [9] and with 11-set recordings of the same earthquake shown in Fig. 2 [1], and Table 11.1.1 in Chopra [11] with Lytle and San Fan Fernando earthquake recordings respectively.

Table 1: Yorb Linda Earthquake recordings

	ω_1 and ω_2 (rad/s)	Wave Speed, height	Damping
w/ Lytle EQ (w/ San Fan Fernando EQ)	12.08 (10.13) 52.36 (48.33)		0.029 0.064
One-layer model from Zhang et al. 2011 (identified data from Snider and Safak 2006)	10.77	v=330 *m/s*, h=48.2 *m* (322 *m/s*)	0.0187 (0.0244)
2-layer model	10.77 14.21	v_1=345 *m/s*, h_1=47 *m* v_2=10 *m/s*, h_2=1.2 *m*	γ_1=0.03 γ_2=0.03
11-layer model	10.77 14.21	$v_j=h_j/\tau_j$, τ_j=0.0136 s, h_j is obtained with Fig. 1 as j=1-9, h_{10}=7.98 m, v_{11}=10 m/s, h_{11}=1.2 m	γ_j=0.03 j=1-11

On the other hand, wave and vibration features in GFRF and GIRF with uniform one-layer model is qualitatively different from those in 2- or 11-layer model, for the former cannot capture the motions with the second modal frequency, as shown in Fig. 9. The difference can also be seen in Fig. 10, although it is not as qualitatively clear as in Fig. 9.

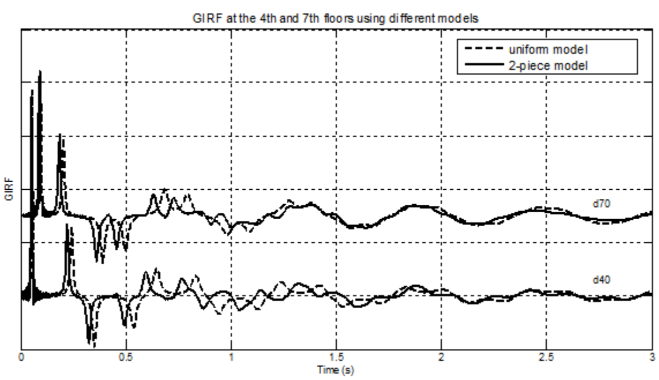

Fig. 10 Comparison of GIRFs at the 4th and 7th floor with respect to impulsive basement acceleration obtained with one- and two-layer models.

In summary, the presented analysis suggests that two-layer model is effective in system identification for buildings structures like Millikan Library in general, and in improved accuracy in capturing higher-order wave motions in particular. The increased number of layers in the modeling is not essentially helpful in capturing fundamental wave features. It could nevertheless be useful in system identification with non-uniform structure in height.

3 Conclusion

This study proposes piecewise continuous modeling for seismic wave motion in high-rise structures. It first derives the generalized impulse and frequency response functions (GIRF and GFRF) which are fundamentally important in constructing response to the motion input to a system, not the traditional force input. The features of GIRF and GFRF as well as seismic responses are also examined in detail, revealing not only well-observed vibration features of building structures, but also some perspective of seismic wave behaviors of structures which traditional vibration-based approach does not show clearly. The proposed model can then be used for system identification of building structures, exemplified with Millikan Library with two-layer model. Results show the proposed approach is efficient.

While this study focuses on system identification, it can be easily extended for damage diagnosis in post-earthquake conditional assessment for a pair of available recordings of an earthquake, which is the subject of future study.

5 Acknowledgment

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