Floor Vibration Serviceability: Tips and Tools for Negotiating a Successful Design

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Floor vibrations in steel buildings increasingly are a condition of consideration for structural engineers, architects, owners and users. To assist the structural engineer in designing for this serviceability condition, AISC published *Design Guide 11, Floor Vibrations Due to Human Activity* (Murray, et al. 1997). In some cases, engineers find that the criteria are difficult to meet within budget, layout and other constraints.

Assessing floor vibration serviceability requires that three fundamental questions be answered.

1. Who or what will object to excessive vibration? This helps to define appropriate vibration limits within the occupied spaces.
2. Who or what is expected to cause the vibration? This helps to define the expected dynamic forces.
3. What is the expected response at the location of those objecting? This provides a means to establish whether vibration limits will possibly be exceeded.

The first two questions need to be answered by the building owner. The third question generally needs to be answered by the structural engineer, within the scope of understanding our industry has with respect to building floor vibrations. The negotiation begins when the answer to number three indicates unacceptable performance. When such an evaluation, like that recommended in *Design Guide 11*, requires an adjustment to the floor system design to meet vibration serviceability requirements, owners sometimes balk at the expense or alterations necessary. This paper is presented to increase the understanding of the vibration phenomenon, resolve some common questions and misconceptions, and provide additional design tools for the floor vibration serviceability condition.

VIBRATIONS DUE TO WALKING

When designing office floors, vibrations caused by walking should be considered. As design procedures and stronger steels yield smaller cross sections to satisfy strength requirements, the need to evaluate floors for excessive walking vibration becomes a more important design condition because it is more likely to control. When a strength design does not meet vibration requirements, the common solutions are to increase the member sizes, increase the slab thickness, or switch to normal weight concrete. An owner might question the necessity of a heavy floor system to meet vibration criteria.

Often, the difference between an acceptable floor and an unacceptable floor is in the architectural features. In office buildings, these features can vary over the life of the structure.

CASE STUDIES

An eight-story office building, built in 1974, recently developed a vibration problem on one floor. Each of the upper seven floors is framed similarly with composite steel (A36) beams, metal deck and concrete. The cause is a change in tenant layout. Prior tenants had a 1970s office layout: individual offices around the perimeter, framed with metal stud partition walls. The new tenants have a cubicle layout. Interior partitions have a positive effect on the vibration behavior of framed floor systems. They have been shown to provide additional support to the floor system and to provide some dissipative characteristics. Although careful consideration of the effect of non-structural walls might be included in a vibration assessment, this is not recommended because these elements might not endure. Methods of modeling the effect provided by lightweight partition walls are not well documented in the literature. There has been some suggestion that they can be considered as providing additional damping (Murray, et al. 1997), but this approach does not correlate well with measured results.

Problem vibrations after the tenant occupies the space can prove costly. An active control solution is currently being implemented. Another building with an open cubicle layout was repaired by extending partitions in the office space below to the underside of the problem floor. Because the floor below was slab-on-grade, there was no risk of transmitting the vibration problem to that floor. Another owner deemed his design-build project unacceptable in one area because of excessive vibration and refused to take ownership of the building until the problem was resolved. When a solution was proposed and the cost estimated, the owner decided not to fix the problem but rather to take a considerable discount on the building cost and live with it.

ON THE ISSUE OF DAMPING

Damping in office floor systems is provided mostly by non-structural elements, such as hung ceilings, ductwork, file cabinets, desk contents and people. The recommendation in Design Guide 11 for typical cubicle office layouts, where the floor supports a hung ceiling and ductwork below, is to assume a damping ratio of 0.03 of critical. Where the floor supports few non-structural elements, a damping ratio of 0.02 should be assumed for office areas. More specifically, if there is no hung ceiling supported by the floor system, a damping ratio of not more than 0.02 should be assumed. Additionally, when the office layout is very spacious and few paper files exist, a damping ratio of not more than 0.02 should be assumed (Murray 1998) even in the presence of a hung ceiling below. It is unlikely that values for damping will ever be conveyed more precisely than the descriptions above. Like partitions, elements that provide damping can vary over the life of a structure and recommended damping values are used to identify structures that might be "prone to excessive vibrations." Misinterpretation of the literature has resulted in assumed damping values that do not exist. Unless supplemental damping is provided, more than 0.03 should not be assumed for office floors.

ASSESSMENT PROCEDURE

When negotiating a successful design, it is usually best to consider vibration serviceability very early in design development, when changes to slab depth and weight or member depth are easier to make. The following preliminary assessment procedure applies to steel-framed office floors where the framing is the result of a strength design utilizing the most economical cross section. Additionally, framing members should meet a live load deflection limitation of L/360. The primary use of this evaluation is to determine whether a floor system, that has been designed to meet strength and live load deflection requirements, should be altered to meet walking vibration serviceability requirements.

Limitations and Assumptions

The limitations expressed below are the result of the strength design assumptions used in developing the database from which the preliminary assessment procedure is derived. More details on the formulation of the database can be found in Kim and Hanagan (2002). Additionally, a manuscript (Hanagan and Kim 2003) detailing the supporting research has been submitted to the AISC Engineering Journal and is currently under review. Acceptable deviations from the stated assumptions are noted below; however, it should be noted that the accuracy of the results are based on floors that satisfy the assumptions below.

1. Floor system must be defined by one of the six classes in Table 1.
2. Strength design is based on LRFD methods, except for K-series joist systems, which are based on ASD. Since LRFD design usually results in either the same, lighter, or shallower members, ASD designs can be evaluated conservatively with this procedure.
3. Grade 50 steel - Because this procedure will produce very conservative results for A36 steel, systems using A36 steel that are evaluated as being unacceptable should be re-evaluated by the Design Guide 11 procedure before any changes are considered.
4. Design loads are 15 psf superimposed dead load, 145 pcf for normal weight concrete, 110 pcf for light-weight concrete, 50 psf live load and 20 psf partition live loads with no live-load reduction applied. Systems designed for heavier loads can be evaluated conservatively. If heavier live loads were used, some live-load reduction can be considered conservatively.
5. Specified concrete strength is 3000 psi. Concrete strengths in the range of 2500-5000 psi can be considered with little loss in accuracy.
6. All members are assumed to be simply supported. The procedure will yield a conservative result for moment-connected members.
7. Composite steel framing is designed for un-shored construction.
8. For non-composite beam/steel joist and girder designs, the most economical cross section is used unless a live load deflection limit of L/360 controls member selection. When several beam depths exist for a particular beam weight, the deepest cross-section is selected.
9. Floors have at least three bays in each direction and the beam span is the same on each side of the girder. Systems where beam/joist spans differ on either side of the girder can be evaluated reasonably for each beam/joist span.
10. Common architectural elements are attached, thus assuming a damping value of 0.03. The evaluation assumes that a hung ceiling, ductwork, etc. are suspended below and that some paper files or books exist in the office cubicles. When office areas are very lightly loaded, as in electronic offices, or when few attachments are made below, the preliminary assessment procedure should not be used. Extensive full-height partitions enclosing offices are assumed not to exist.
11. Beam/joist spans range from 20'-40' and girder spans range from 15'- 40'. Shorter spans can be considered conservatively by assuming the minimum span noted. Longer spans should not be considered using this procedure.
12. Beam spacing is assumed to be equal within a bay and is determined to be the largest deck span allowed for the 20 GA, three-span, un-shored condition.

Preliminary Assessment Procedure

1. Define design class from Table 1.
2. Select C_1 from Table 2 according to class, deck thickness, and topping thickness. If a "U" is noted, all floors were found to be unacceptable for the spans studied. If an "A" is noted, all floors were found to be acceptable for the spans studied when damping is assumed to be 3% of critical. See assumption #10 above.
3. If step 2 did not result in a "U" or "A" rating, select C_2 according to class determined in step 1 from Tables 3 - 8.
4. Evaluate:

For $C_1 + C_2 \leq 0.5$, floor should be acceptable for normal office environments.

For $C_1 + C_2 > 0.5$, floor may be found unacceptable for office environments.

It should be reiterated that the assessment procedure above is to determine whether a floor system, that has been designed to meet strength and live load deflection requirements, should be altered to meet walking vibration serviceability requirements.

Table 1. Summary of Database Classes

Class	Concrete weight	Steel frame type	Construction type	Deck type
1	Normal weight	Rolled beams/ girders	Non-Composite	Form or Composite
2	Light weight	Rolled beams/ girders	Non-Composite	Form or Composite
3	Normal weight	Rolled beams/ girders	Composite	Composite
4	Light weight	Rolled beams/ girders	Composite	Composite
5	Normal weight	Steel joist/rolled girders	Non-Composite	Form deck
6	Light weight	Steel joist/rolled girders	Non-Composite	Form deck

Supplemental damping is not an economical choice in new structures where other alterations are possible to meet serviceability requirements.

VIBRATIONS DUE TO RHYTHMIC ACTIVITIES

Rhythmic activities, such as dancing, aerobics, foot stomping, and hand clapping, can create large synchronized forces at a steady beat. These forces result in a steady-state motion in the structure that can cause occupants' complaints and fear. The frequency of rhythmic activities is usually in the range of 1.5 to 3 Hz. Excessive vibrations due to rhythmic activities can occur at or below resonant frequencies of the structure. Because resonance can occur at multiples of the activity frequency, resonance is not just a problem in low frequency structures. The dynamic force that exists at multiples of the activity frequency are commonly referred to as harmonics of the force, and the dynamic force can be expressed as a sum of many sinusoidal forces. For jumping activities, like aerobics, the second harmonic of the dynamic force can actually be more problematic than the first, because it is more difficult to avoid resonance with the second harmonic.

CASE STUDY 1: LONG SPAN BALLROOM FLOOR

The operator of a facility with a long-span ballroom floor questioned the floor's safety and sought to reduce vibration levels caused by dancing. The floor, with a bay area of more than 10,000 sq. ft., is framed by truss-like members with span-to-depth ratios of 9.5 and 12.6 for the joists and girders, respectively. The floor slab is lightweight concrete on composite metal deck. The natural frequency of this system is around 3.25 Hz, and many popular dance tunes elicit movement acting in resonance, or close to resonance, with the floor.

When the excitation occurs at resonance, it doesn't take much to get the floor going. With a metronome set to 3.25 Hz, one person jumped in resonance at the floor mid-span. A steady-state acceleration level of 0.01g was measured. Repeating this test with three people produced almost 0.03g. To put this data into context, the vibration limit-state for this facility, as prescribed by *Design Guide 11* (Murray, et. al 1997), is 0.02g. A bay weighing more than 750,000 lb was driven by the rhythmic activities of three people to exceed the acceptable limit by almost 50 percent.

As far as the owner's concern for safety, the levels of vibration causing complaints are rarely near the strength-limit state. To use this floor as an example, assume the vibration levels reached 0.1g (five times the acceptable limit) at resonance, 3.25 Hz. Converted to displacement, the peak amplitude would be 2.35 mm (0.09 inches). Under this condition, people would perceive the vibration as so large that the activity causing it would probably be discontinued. An acceptable, affordable solution for this facility has been evasive.

CASE STUDY 2: WHOLE BUILDING VIBRATION

The building investigated in this case has an office suite on the 10th floor and a dance studio on the floor below. During certain activities in the dance studio, the vibration levels in the 10th floor office suite are large enough to be disturbing to the workers.

Measurements indicated that the disturbing vibrations on the 10th floor had a frequency of 4 Hz. Since most rhythmic activities have a fundamental frequency between 1.8 and 2.8 Hz, the motion was thought to be a resonance phenomenon occurring at the second harmonic of the activity frequency. To create the same phenomenon under a

Table 2: Values for C_1

Deck Thickness	Total Slab Thickness	Class 1 NC/NW	Class2 NC/LW	Class 3 C/NW	Class 4 C/LW	Class 5 J/NW	Class 6 J/LW
0.5625	2	U	U	n/a	n/a	U	U
0.5625	2.5	0.476	U	n/a	n/a	U	U
0.5625	3	0.392	0.473	n/a	n/a	U	U
0.5625	3.5	A	0.400	n/a	n/a	U	U
0.5625	4	A	A	n/a	n/a	0.496	U
0.5625	4.5	A	A	n/a	n/a	0.434	U
0.5625	5	A	A	n/a	n/a	0.371	U
1	2.5	U	U	n/a	n/a	U	U
1	3	0.424	0.495	n/a	n/a	U	U
1	3.5	A	0.422	n/a	n/a	U	U
1	4	A	A	n/a	n/a	U	U
1	4.5	A	A	n/a	n/a	0.454	U
1	5	A	A	n/a	n/a	0.392	U
1	5.5	A	A	n/a	n/a	0.329	0.459
1.5	3.5	0.377	0.448	U	U	n/a	n/a
1.5	4	A	0.375	U	U	n/a	n/a
1.5	4.5	A	A	U	U	n/a	n/a
1.5	4.75	n/a	A	n/a	U	n/a	n/a
1.5	5	A	A	0.422	U	n/a	n/a
1.5	5.5	A	n/a	0.339	n/a	n/a	n/a
1.5	5.75	n/a	A	n/a	0.413	n/a	n/a
1.5	6	A	n/a	A	n/a	n/a	n/a
2	4	A	0.402	U	U	n/a	n/a
2	4.5	A	A	U	U	n/a	n/a
2	5	A	A	0.451	U	n/a	n/a
2	5.25	n/a	A	n/a	U	n/a	n/a
2	5.5	A	n/a	0.368	0.472	n/a	n/a
2	6	A	n/a	A	n/a	n/a	n/a
2	6.25	n/a	A	n/a	0.367	n/a	n/a
2	6.5	A	n/a	A	n/a	n/a	n/a
3	5	A	A	U	U	n/a	n/a
3	5.5	A	A	0.426	U	n/a	n/a
3	6	A	A	0.343	0.449	n/a	n/a
3	6.25	n/a	A	n/a	0.414	n/a	n/a
3	6.5	A	A	A	0.379	n/a	n/a
3	7	A	A	A	0.309	n/a	n/a
3	7.25	n/a	A	n/a	A	n/a	n/a
3	7.5	A	n/a	A	n/a	n/a	n/a

A: Acceptable for all spans studied when damping is assumed to be 3% of critical.
U: Unacceptable for all spans studied. Modification to meet vibration serviceability is suggested.
n/a: Configuration not studied
NC: Non-composite, rolled beams and girders
C: Composite, rolled beams and girders
J: K series joists with non-composite, rolled girders
NW: Normal weight concrete
LW: Light weight concrete

Table 3. Non-composite beam and non-composite girder framed floor systems, Normal weight concrete

	CLASS 1: C_2 Values																				
	L_j (ft)																				
L_g (ft)	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
15	0.043	0.044	0.046	0.047	0.048	0.049	0.050	0.050	0.051	0.051	0.051	0.050	0.050	0.049	0.047	0.046	0.044	0.042	0.039	0.036	0.03
16	0.066	0.067	0.069	0.070	0.071	0.071	0.072	0.072	0.072	0.072	0.071	0.070	0.069	0.068	0.066	0.063	0.060	0.057	0.053	0.049	0.04
17	0.085	0.086	0.088	0.089	0.089	0.090	0.090	0.090	0.090	0.089	0.088	0.087	0.085	0.083	0.081	0.078	0.074	0.070	0.066	0.061	0.05
18	0.101	0.102	0.103	0.104	0.104	0.105	0.105	0.105	0.104	0.103	0.102	0.101	0.099	0.096	0.093	0.090	0.086	0.081	0.076	0.071	0.06
19	0.113	0.114	0.115	0.115	0.116	0.116	0.116	0.116	0.115	0.114	0.113	0.111	0.109	0.106	0.103	0.100	0.095	0.090	0.085	0.079	0.07
20	0.122	0.122	0.123	0.124	0.124	0.124	0.124	0.124	0.123	0.122	0.121	0.119	0.117	0.114	0.111	0.107	0.103	0.098	0.092	0.085	0.07
21	0.128	0.128	0.129	0.129	0.129	0.130	0.129	0.129	0.128	0.128	0.126	0.124	0.122	0.120	0.116	0.113	0.108	0.103	0.097	0.091	0.08
22	0.131	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.131	0.130	0.129	0.128	0.125	0.123	0.120	0.116	0.112	0.107	0.101	0.094	0.08
23	0.133	0.133	0.133	0.133	0.133	0.133	0.133	0.132	0.132	0.131	0.130	0.129	0.127	0.124	0.121	0.118	0.114	0.109	0.103	0.097	0.08
24	0.133	0.132	0.132	0.131	0.131	0.131	0.131	0.131	0.130	0.130	0.129	0.128	0.126	0.124	0.121	0.118	0.114	0.110	0.104	0.098	0.09
25	0.131	0.130	0.129	0.128	0.128	0.128	0.128	0.127	0.127	0.127	0.126	0.125	0.124	0.122	0.120	0.117	0.113	0.109	0.104	0.098	0.09
26	0.127	0.126	0.125	0.124	0.123	0.123	0.123	0.123	0.122	0.122	0.122	0.121	0.120	0.119	0.117	0.114	0.111	0.107	0.102	0.097	0.09
27	0.123	0.121	0.119	0.118	0.117	0.117	0.117	0.116	0.116	0.116	0.116	0.116	0.115	0.114	0.113	0.110	0.108	0.104	0.100	0.095	0.08
28	0.119	0.116	0.113	0.112	0.110	0.110	0.109	0.109	0.109	0.110	0.110	0.110	0.109	0.109	0.107	0.106	0.103	0.100	0.096	0.091	0.08
29	0.114	0.110	0.107	0.105	0.103	0.102	0.102	0.102	0.102	0.102	0.102	0.102	0.102	0.102	0.101	0.100	0.098	0.095	0.092	0.087	0.08
30	0.109	0.104	0.100	0.097	0.095	0.094	0.093	0.093	0.093	0.094	0.094	0.095	0.095	0.095	0.095	0.094	0.092	0.090	0.087	0.083	0.07
31	0.104	0.098	0.093	0.090	0.087	0.086	0.085	0.085	0.085	0.085	0.086	0.086	0.087	0.087	0.087	0.087	0.086	0.084	0.081	0.077	0.07
32	0.100	0.093	0.087	0.083	0.080	0.078	0.077	0.076	0.076	0.077	0.077	0.078	0.079	0.080	0.080	0.080	0.079	0.077	0.075	0.071	0.06
33	0.096	0.088	0.082	0.077	0.073	0.070	0.069	0.068	0.068	0.068	0.069	0.070	0.071	0.072	0.072	0.072	0.072	0.070	0.068	0.065	0.06
34	0.094	0.085	0.077	0.071	0.067	0.063	0.061	0.060	0.060	0.060	0.061	0.062	0.063	0.064	0.065	0.065	0.064	0.063	0.061	0.057	0.05
35	0.094	0.083	0.074	0.067	0.062	0.058	0.055	0.053	0.053	0.053	0.053	0.054	0.055	0.056	0.057	0.057	0.057	0.056	0.053	0.050	0.04
36	0.096	0.083	0.072	0.064	0.058	0.053	0.050	0.048	0.046	0.046	0.047	0.047	0.048	0.049	0.050	0.050	0.049	0.048	0.046	0.042	0.03
37	0.099	0.085	0.073	0.063	0.056	0.050	0.046	0.043	0.041	0.041	0.041	0.041	0.042	0.043	0.043	0.043	0.042	0.041	0.038	0.034	0.02
38	0.105	0.089	0.075	0.064	0.055	0.049	0.044	0.040	0.038	0.037	0.036	0.036	0.036	0.037	0.037	0.037	0.035	0.033	0.030	0.025	0.01
39	0.114	0.096	0.080	0.068	0.058	0.049	0.043	0.039	0.036	0.034	0.033	0.032	0.032	0.032	0.032	0.031	0.029	0.027	0.023	0.017	0.01
40	0.126	0.106	0.088	0.074	0.062	0.053	0.045	0.040	0.036	0.033	0.031	0.030	0.029	0.028	0.027	0.026	0.023	0.020	0.015	0.008	0.00

*L_j = Beam span length, ft.
*L_g = Girder span length, ft.

Table 4. Non-composite beam and non-composite girder framed floor systems, Light weight concrete

	CLASS 2: C_2 Values																				
	L_j (ft)																				
L_g (ft)	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
15	0.000	0.004	0.009	0.012	0.016	0.019	0.022	0.024	0.026	0.028	0.029	0.030	0.031	0.031	0.030	0.029	0.028	0.026	0.023	0.020	0.01
16	0.028	0.032	0.036	0.040	0.043	0.045	0.048	0.050	0.051	0.053	0.053	0.054	0.053	0.053	0.051	0.050	0.047	0.044	0.041	0.037	0.03
17	0.052	0.056	0.059	0.062	0.065	0.067	0.069	0.071	0.072	0.073	0.073	0.073	0.072	0.071	0.069	0.067	0.064	0.060	0.056	0.051	0.04
18	0.071	0.075	0.078	0.081	0.083	0.085	0.087	0.088	0.089	0.090	0.090	0.089	0.088	0.086	0.084	0.081	0.078	0.074	0.069	0.063	0.05
19	0.087	0.090	0.093	0.095	0.097	0.099	0.101	0.102	0.103	0.103	0.103	0.102	0.101	0.099	0.096	0.093	0.089	0.085	0.079	0.073	0.06
20	0.099	0.102	0.104	0.106	0.108	0.110	0.111	0.112	0.113	0.113	0.113	0.112	0.110	0.108	0.106	0.102	0.098	0.094	0.088	0.082	0.07
21	0.108	0.110	0.112	0.114	0.116	0.117	0.119	0.119	0.120	0.120	0.120	0.119	0.117	0.115	0.113	0.109	0.105	0.100	0.095	0.089	0.08
22	0.114	0.116	0.118	0.119	0.121	0.122	0.123	0.124	0.124	0.124	0.124	0.123	0.122	0.120	0.117	0.114	0.110	0.105	0.100	0.093	0.08
23	0.118	0.119	0.120	0.122	0.123	0.124	0.125	0.126	0.126	0.126	0.126	0.125	0.124	0.122	0.120	0.117	0.113	0.108	0.103	0.097	0.09
24	0.120	0.120	0.121	0.122	0.123	0.124	0.125	0.125	0.126	0.126	0.126	0.125	0.124	0.123	0.120	0.118	0.114	0.110	0.105	0.099	0.09
25	0.119	0.119	0.120	0.120	0.121	0.121	0.122	0.123	0.123	0.124	0.124	0.123	0.122	0.121	0.119	0.117	0.114	0.110	0.105	0.099	0.09
26	0.118	0.117	0.117	0.117	0.117	0.117	0.118	0.119	0.119	0.120	0.120	0.120	0.119	0.118	0.117	0.115	0.112	0.108	0.104	0.099	0.09
27	0.115	0.113	0.112	0.112	0.112	0.112	0.113	0.113	0.114	0.114	0.115	0.115	0.115	0.114	0.113	0.111	0.109	0.106	0.102	0.097	0.09
28	0.111	0.109	0.107	0.106	0.106	0.106	0.106	0.106	0.107	0.108	0.108	0.109	0.109	0.109	0.108	0.107	0.105	0.102	0.098	0.094	0.08
29	0.107	0.104	0.101	0.100	0.099	0.098	0.098	0.099	0.100	0.100	0.101	0.102	0.102	0.102	0.102	0.101	0.100	0.097	0.094	0.090	0.08
30	0.102	0.098	0.095	0.093	0.091	0.091	0.091	0.091	0.091	0.092	0.093	0.094	0.095	0.095	0.095	0.095	0.094	0.092	0.089	0.085	0.08
31	0.098	0.093	0.089	0.086	0.084	0.083	0.082	0.082	0.083	0.084	0.085	0.086	0.087	0.088	0.088	0.088	0.087	0.086	0.083	0.080	0.07
32	0.095	0.088	0.083	0.079	0.077	0.075	0.074	0.074	0.074	0.075	0.076	0.078	0.079	0.080	0.080	0.080	0.080	0.079	0.077	0.073	0.06
33	0.092	0.084	0.078	0.073	0.070	0.067	0.066	0.066	0.066	0.067	0.068	0.069	0.070	0.072	0.073	0.073	0.073	0.072	0.070	0.067	0.06
34	0.090	0.081	0.074	0.068	0.064	0.061	0.059	0.058	0.058	0.059	0.060	0.061	0.062	0.064	0.065	0.065	0.065	0.064	0.062	0.059	0.05
35	0.090	0.079	0.071	0.064	0.059	0.055	0.053	0.051	0.051	0.051	0.052	0.053	0.055	0.056	0.057	0.058	0.058	0.057	0.055	0.052	0.04
36	0.092	0.079	0.069	0.061	0.055	0.051	0.047	0.046	0.045	0.045	0.046	0.047	0.048	0.049	0.050	0.051	0.050	0.049	0.047	0.044	0.03
37	0.096	0.082	0.070	0.060	0.053	0.048	0.044	0.041	0.040	0.040	0.040	0.041	0.042	0.043	0.043	0.044	0.043	0.042	0.040	0.036	0.03
38	0.102	0.086	0.073	0.062	0.053	0.047	0.042	0.039	0.037	0.036	0.035	0.036	0.036	0.037	0.038	0.038	0.037	0.035	0.032	0.028	0.02
39	0.111	0.093	0.078	0.066	0.056	0.048	0.042	0.038	0.035	0.033	0.033	0.032	0.033	0.033	0.033	0.032	0.031	0.029	0.025	0.020	0.01
40	0.124	0.103	0.086	0.072	0.061	0.052	0.045	0.039	0.036	0.033	0.032	0.031	0.030	0.030	0.029	0.028	0.026	0.023	0.018	0.012	0.00

*L_j = Beam span length, ft.
*L_g = Girder span length, ft.

Table 5. Composite beam and Composite girder framed floor systems, Normal weight concrete

	CLASS 3: C_2 Values																				
	L_j (ft)																				
L_g (ft)	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
15	0.018	0.023	0.027	0.031	0.035	0.038	0.041	0.044	0.047	0.050	0.052	0.054	0.056	0.057	0.059	0.060	0.061	0.061	0.062	0.062	0.06
16	0.037	0.040	0.042	0.044	0.046	0.047	0.049	0.050	0.051	0.052	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.052	0.051	0.050	0.04
17	0.056	0.056	0.057	0.057	0.057	0.057	0.057	0.056	0.056	0.055	0.054	0.053	0.052	0.051	0.049	0.047	0.046	0.044	0.042	0.039	0.03
18	0.074	0.073	0.071	0.070	0.068	0.067	0.065	0.063	0.061	0.059	0.056	0.054	0.051	0.049	0.046	0.043	0.040	0.037	0.034	0.031	0.02
19	0.091	0.088	0.085	0.082	0.079	0.076	0.073	0.070	0.066	0.063	0.059	0.056	0.052	0.048	0.044	0.040	0.036	0.032	0.028	0.024	0.01
20	0.107	0.103	0.099	0.095	0.090	0.086	0.081	0.077	0.072	0.068	0.063	0.058	0.053	0.049	0.044	0.039	0.034	0.029	0.023	0.018	0.01
21	0.123	0.117	0.112	0.106	0.101	0.095	0.089	0.084	0.078	0.073	0.067	0.061	0.055	0.049	0.044	0.038	0.032	0.026	0.020	0.014	0.00
22	0.137	0.130	0.124	0.117	0.111	0.104	0.097	0.091	0.084	0.078	0.071	0.064	0.058	0.051	0.045	0.038	0.031	0.024	0.018	0.011	0.00
23	0.150	0.143	0.135	0.128	0.120	0.113	0.105	0.098	0.090	0.083	0.076	0.068	0.061	0.053	0.046	0.039	0.031	0.024	0.016	0.009	0.00
24	0.162	0.154	0.145	0.137	0.129	0.121	0.113	0.104	0.096	0.088	0.080	0.072	0.064	0.056	0.048	0.040	0.032	0.024	0.016	0.008	0.00
25	0.172	0.163	0.155	0.146	0.137	0.128	0.119	0.111	0.102	0.093	0.085	0.076	0.067	0.059	0.050	0.042	0.033	0.025	0.017	0.008	0.00
26	0.181	0.172	0.162	0.153	0.144	0.135	0.125	0.116	0.107	0.098	0.089	0.080	0.071	0.062	0.053	0.044	0.035	0.027	0.018	0.009	0.00
27	0.188	0.179	0.169	0.159	0.150	0.140	0.131	0.121	0.112	0.102	0.093	0.084	0.075	0.065	0.056	0.047	0.038	0.029	0.020	0.011	0.00
28	0.194	0.184	0.174	0.164	0.155	0.145	0.135	0.126	0.116	0.106	0.097	0.087	0.078	0.068	0.059	0.050	0.040	0.031	0.022	0.013	0.00
29	0.197	0.187	0.178	0.168	0.158	0.148	0.139	0.129	0.119	0.110	0.100	0.090	0.081	0.071	0.062	0.053	0.043	0.034	0.025	0.015	0.00
30	0.199	0.189	0.179	0.170	0.160	0.150	0.141	0.131	0.122	0.112	0.103	0.093	0.084	0.074	0.065	0.055	0.046	0.037	0.027	0.018	0.00
31	0.198	0.189	0.179	0.170	0.161	0.151	0.142	0.132	0.123	0.114	0.104	0.095	0.086	0.077	0.067	0.058	0.049	0.039	0.030	0.021	0.01
32	0.195	0.186	0.177	0.168	0.159	0.150	0.141	0.132	0.123	0.114	0.105	0.096	0.087	0.078	0.069	0.060	0.051	0.042	0.033	0.024	0.01
33	0.190	0.182	0.173	0.165	0.157	0.148	0.140	0.131	0.123	0.114	0.105	0.097	0.088	0.079	0.071	0.062	0.053	0.045	0.036	0.027	0.01
34	0.183	0.175	0.167	0.160	0.152	0.144	0.136	0.128	0.120	0.112	0.104	0.096	0.088	0.080	0.072	0.063	0.055	0.047	0.039	0.030	0.02
35	0.172	0.166	0.159	0.152	0.145	0.138	0.131	0.124	0.117	0.109	0.102	0.095	0.087	0.079	0.072	0.064	0.057	0.049	0.041	0.033	0.02
36	0.159	0.154	0.148	0.142	0.136	0.130	0.124	0.118	0.111	0.105	0.098	0.092	0.085	0.078	0.071	0.064	0.057	0.050	0.043	0.035	0.02
37	0.144	0.139	0.135	0.130	0.125	0.120	0.115	0.110	0.104	0.099	0.093	0.087	0.082	0.076	0.069	0.063	0.057	0.050	0.044	0.037	0.03
38	0.125	0.122	0.119	0.115	0.112	0.108	0.104	0.100	0.096	0.091	0.087	0.082	0.077	0.072	0.067	0.061	0.056	0.050	0.044	0.038	0.03
39	0.103	0.102	0.100	0.098	0.096	0.093	0.091	0.088	0.085	0.082	0.078	0.075	0.071	0.067	0.063	0.058	0.053	0.049	0.044	0.038	0.03
40	0.078	0.078	0.078	0.078	0.077	0.076	0.075	0.074	0.072	0.070	0.068	0.066	0.063	0.060	0.057	0.054	0.050	0.046	0.042	0.038	0.03

*L_j = Beam span length, ft.
*L_g = Girder span length, ft.

Table 6. Composite beam and Composite girder framed floor systems, Light weight concrete

	CLASS 4: C_2 Values																				
	L_j (ft)																				
L_g (ft)	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
15	0.000	0.008	0.016	0.023	0.030	0.036	0.041	0.046	0.051	0.054	0.057	0.060	0.062	0.063	0.064	0.064	0.064	0.063	0.061	0.059	0.05
16	0.022	0.028	0.033	0.038	0.043	0.046	0.050	0.053	0.055	0.057	0.058	0.059	0.060	0.059	0.059	0.058	0.056	0.054	0.051	0.048	0.04
17	0.043	0.047	0.050	0.053	0.055	0.057	0.059	0.060	0.061	0.061	0.060	0.060	0.059	0.057	0.055	0.053	0.050	0.046	0.043	0.038	0.03
18	0.063	0.065	0.066	0.067	0.068	0.068	0.068	0.067	0.066	0.065	0.063	0.061	0.059	0.056	0.053	0.049	0.045	0.041	0.036	0.031	0.02
19	0.083	0.083	0.082	0.082	0.081	0.079	0.077	0.075	0.073	0.070	0.067	0.064	0.060	0.056	0.051	0.047	0.042	0.036	0.031	0.025	0.01
20	0.102	0.100	0.098	0.095	0.093	0.090	0.087	0.083	0.080	0.076	0.071	0.067	0.062	0.057	0.051	0.046	0.040	0.033	0.027	0.020	0.01
21	0.119	0.116	0.113	0.109	0.105	0.101	0.096	0.092	0.087	0.081	0.076	0.071	0.065	0.059	0.052	0.046	0.039	0.032	0.024	0.017	0.00
22	0.136	0.131	0.127	0.122	0.117	0.111	0.106	0.100	0.094	0.088	0.081	0.075	0.068	0.061	0.054	0.047	0.039	0.031	0.023	0.015	0.00
23	0.151	0.146	0.140	0.134	0.128	0.121	0.115	0.108	0.101	0.094	0.087	0.079	0.072	0.064	0.056	0.048	0.040	0.031	0.023	0.014	0.00
24	0.165	0.158	0.152	0.145	0.138	0.130	0.123	0.116	0.108	0.100	0.092	0.084	0.076	0.068	0.059	0.051	0.042	0.033	0.024	0.015	0.00
25	0.177	0.170	0.162	0.155	0.147	0.139	0.131	0.123	0.115	0.106	0.098	0.089	0.080	0.071	0.062	0.053	0.044	0.035	0.025	0.016	0.00
26	0.188	0.180	0.172	0.164	0.155	0.147	0.138	0.130	0.121	0.112	0.103	0.094	0.085	0.075	0.066	0.057	0.047	0.037	0.027	0.018	0.00
27	0.197	0.188	0.180	0.171	0.162	0.153	0.145	0.136	0.126	0.117	0.108	0.099	0.089	0.079	0.070	0.060	0.050	0.040	0.030	0.020	0.01
28	0.203	0.195	0.186	0.177	0.168	0.159	0.150	0.141	0.131	0.122	0.112	0.103	0.093	0.083	0.073	0.063	0.053	0.043	0.033	0.023	0.01
29	0.208	0.199	0.190	0.181	0.172	0.163	0.154	0.145	0.135	0.126	0.116	0.107	0.097	0.087	0.077	0.067	0.057	0.047	0.037	0.026	0.01
30	0.210	0.201	0.193	0.184	0.175	0.166	0.157	0.148	0.138	0.129	0.119	0.110	0.100	0.090	0.080	0.070	0.060	0.050	0.040	0.029	0.01
31	0.210	0.202	0.193	0.185	0.176	0.167	0.158	0.149	0.140	0.131	0.122	0.112	0.103	0.093	0.083	0.073	0.063	0.053	0.043	0.033	0.02
32	0.207	0.199	0.192	0.183	0.175	0.167	0.158	0.150	0.141	0.132	0.123	0.114	0.105	0.095	0.086	0.076	0.066	0.056	0.046	0.036	0.02
33	0.202	0.195	0.187	0.180	0.172	0.164	0.157	0.148	0.140	0.132	0.123	0.114	0.106	0.097	0.087	0.078	0.069	0.059	0.049	0.039	0.02
34	0.194	0.188	0.181	0.174	0.167	0.160	0.153	0.145	0.138	0.130	0.122	0.114	0.106	0.097	0.088	0.079	0.070	0.061	0.052	0.042	0.03
35	0.183	0.177	0.172	0.166	0.160	0.154	0.147	0.141	0.134	0.127	0.120	0.112	0.104	0.096	0.088	0.080	0.071	0.063	0.053	0.044	0.03
36	0.169	0.164	0.160	0.155	0.150	0.145	0.140	0.134	0.128	0.122	0.115	0.109	0.102	0.095	0.087	0.079	0.071	0.063	0.055	0.046	0.03
37	0.151	0.148	0.145	0.142	0.138	0.134	0.130	0.125	0.120	0.115	0.110	0.104	0.098	0.091	0.085	0.078	0.070	0.063	0.055	0.047	0.03
38	0.130	0.129	0.128	0.126	0.123	0.121	0.118	0.114	0.111	0.106	0.102	0.097	0.092	0.087	0.081	0.075	0.068	0.061	0.054	0.047	0.03
39	0.106	0.107	0.107	0.106	0.106	0.104	0.103	0.101	0.098	0.096	0.092	0.089	0.085	0.080	0.076	0.070	0.065	0.059	0.052	0.045	0.03
40	0.078	0.081	0.083	0.084	0.085	0.085	0.085	0.085	0.084	0.083	0.081	0.079	0.076	0.072	0.069	0.065	0.060	0.055	0.049	0.043	0.03

*L_j = Beam span length, ft.
*L_g = Girder span length, ft.

Table 7. Non-composite open web steel joist and non-composite rolled girder framed floor systems,

Normal weight concrete

	CLASS 5: C_2 Values																				
	L_j (ft)																				
L_g (ft)	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
15	0.099	0.096	0.093	0.090	0.088	0.086	0.084	0.083	0.082	0.081	0.080	0.079	0.079	0.078	0.078	0.078	0.078	0.078	0.078	0.079	0.07
16	0.120	0.116	0.112	0.109	0.105	0.102	0.100	0.097	0.095	0.092	0.090	0.088	0.086	0.084	0.082	0.080	0.079	0.077	0.075	0.073	0.07
17	0.139	0.134	0.129	0.125	0.121	0.117	0.113	0.110	0.106	0.103	0.099	0.096	0.093	0.090	0.086	0.083	0.080	0.076	0.073	0.069	0.06
18	0.155	0.150	0.144	0.139	0.134	0.130	0.125	0.121	0.116	0.112	0.108	0.103	0.099	0.095	0.090	0.086	0.081	0.076	0.071	0.066	0.06
19	0.170	0.163	0.157	0.152	0.146	0.141	0.135	0.130	0.125	0.120	0.115	0.110	0.105	0.100	0.094	0.089	0.083	0.077	0.071	0.065	0.05
20	0.182	0.175	0.168	0.162	0.156	0.150	0.144	0.138	0.133	0.127	0.121	0.116	0.110	0.104	0.098	0.092	0.085	0.079	0.071	0.064	0.05
21	0.192	0.185	0.177	0.171	0.164	0.157	0.151	0.145	0.139	0.133	0.127	0.121	0.114	0.108	0.102	0.095	0.088	0.080	0.072	0.064	0.05
22	0.201	0.193	0.185	0.177	0.170	0.163	0.157	0.150	0.144	0.138	0.131	0.125	0.118	0.112	0.105	0.097	0.090	0.082	0.074	0.065	0.05
23	0.207	0.199	0.190	0.183	0.175	0.168	0.161	0.154	0.148	0.141	0.135	0.128	0.121	0.115	0.107	0.100	0.092	0.084	0.076	0.066	0.05
24	0.212	0.203	0.194	0.186	0.178	0.171	0.164	0.157	0.150	0.144	0.137	0.131	0.124	0.117	0.110	0.102	0.095	0.086	0.077	0.068	0.05
25	0.216	0.206	0.197	0.188	0.180	0.173	0.166	0.159	0.152	0.145	0.139	0.132	0.126	0.119	0.112	0.104	0.096	0.088	0.079	0.070	0.06
26	0.218	0.207	0.198	0.189	0.181	0.173	0.166	0.159	0.152	0.146	0.139	0.133	0.126	0.120	0.113	0.106	0.098	0.090	0.081	0.072	0.06
27	0.218	0.207	0.197	0.188	0.180	0.172	0.165	0.158	0.151	0.145	0.139	0.133	0.127	0.120	0.114	0.107	0.099	0.091	0.083	0.074	0.06
28	0.217	0.206	0.196	0.186	0.178	0.170	0.163	0.156	0.149	0.143	0.137	0.132	0.126	0.120	0.114	0.107	0.100	0.092	0.084	0.075	0.06
29	0.215	0.203	0.193	0.183	0.174	0.166	0.159	0.153	0.146	0.141	0.135	0.130	0.124	0.119	0.113	0.107	0.100	0.093	0.085	0.076	0.06
30	0.212	0.200	0.188	0.179	0.170	0.162	0.155	0.148	0.142	0.137	0.132	0.127	0.122	0.117	0.111	0.106	0.099	0.093	0.085	0.076	0.06
31	0.208	0.195	0.183	0.173	0.164	0.156	0.149	0.143	0.137	0.132	0.127	0.123	0.118	0.114	0.109	0.104	0.098	0.092	0.084	0.076	0.06
32	0.203	0.189	0.177	0.166	0.157	0.149	0.142	0.136	0.131	0.126	0.122	0.118	0.114	0.110	0.106	0.101	0.096	0.090	0.083	0.075	0.06
33	0.197	0.182	0.170	0.159	0.150	0.142	0.135	0.129	0.124	0.120	0.116	0.112	0.109	0.105	0.101	0.097	0.092	0.087	0.080	0.072	0.06
34	0.190	0.175	0.162	0.151	0.141	0.133	0.126	0.121	0.116	0.112	0.109	0.105	0.102	0.099	0.096	0.092	0.088	0.082	0.076	0.069	0.06
35	0.183	0.167	0.153	0.142	0.132	0.124	0.117	0.112	0.107	0.103	0.100	0.098	0.095	0.092	0.089	0.086	0.082	0.077	0.071	0.063	0.05
36	0.175	0.158	0.144	0.132	0.122	0.113	0.107	0.101	0.097	0.094	0.091	0.089	0.087	0.084	0.082	0.079	0.075	0.070	0.064	0.057	0.04
37	0.166	0.149	0.134	0.121	0.111	0.102	0.096	0.091	0.086	0.083	0.081	0.079	0.077	0.075	0.073	0.070	0.066	0.062	0.056	0.048	0.03
38	0.157	0.139	0.123	0.110	0.099	0.091	0.084	0.079	0.075	0.072	0.070	0.068	0.066	0.065	0.063	0.060	0.057	0.052	0.046	0.038	0.02
39	0.148	0.129	0.112	0.098	0.087	0.078	0.072	0.066	0.062	0.059	0.057	0.056	0.054	0.053	0.051	0.049	0.045	0.040	0.034	0.026	0.01
40	0.139	0.118	0.101	0.086	0.075	0.066	0.058	0.053	0.049	0.046	0.044	0.043	0.041	0.040	0.038	0.035	0.032	0.027	0.020	0.011	0.00

*L_j = Joist span length, ft.
*L_g = Girder span length, ft.

Table 8. Non-composite open web steel joist and non-composite rolled girder framed floor systems,

Light weight concrete

	CLASS 6: C_2 Values																				
	Lj (ft)																				
Lg (ft)	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
15	0.048	0.049	0.050	0.051	0.051	0.052	0.051	0.051	0.050	0.049	0.047	0.045	0.043	0.041	0.038	0.035	0.031	0.028	0.023	0.019	0.01
16	0.068	0.069	0.069	0.068	0.068	0.067	0.066	0.065	0.063	0.061	0.059	0.056	0.053	0.050	0.047	0.043	0.039	0.035	0.030	0.025	0.02
17	0.087	0.086	0.085	0.084	0.083	0.081	0.079	0.077	0.075	0.072	0.069	0.066	0.063	0.059	0.055	0.051	0.046	0.041	0.036	0.031	0.02
18	0.104	0.102	0.101	0.099	0.097	0.094	0.091	0.089	0.085	0.082	0.079	0.075	0.071	0.066	0.062	0.057	0.052	0.047	0.041	0.036	0.03
19	0.119	0.117	0.115	0.112	0.109	0.106	0.102	0.099	0.095	0.091	0.087	0.082	0.078	0.073	0.068	0.063	0.058	0.052	0.046	0.040	0.03
20	0.133	0.130	0.127	0.123	0.120	0.116	0.112	0.108	0.103	0.099	0.094	0.089	0.084	0.079	0.073	0.068	0.062	0.056	0.050	0.044	0.03
21	0.146	0.142	0.138	0.133	0.129	0.125	0.120	0.115	0.110	0.105	0.100	0.095	0.089	0.084	0.078	0.072	0.066	0.060	0.054	0.047	0.04
22	0.156	0.152	0.147	0.142	0.137	0.132	0.127	0.122	0.116	0.111	0.105	0.099	0.094	0.088	0.082	0.076	0.069	0.063	0.057	0.050	0.04
23	0.165	0.160	0.155	0.149	0.144	0.138	0.133	0.127	0.121	0.115	0.109	0.103	0.097	0.091	0.085	0.078	0.072	0.065	0.059	0.052	0.04
24	0.173	0.167	0.161	0.155	0.149	0.143	0.137	0.131	0.125	0.118	0.112	0.106	0.099	0.093	0.087	0.080	0.074	0.067	0.060	0.054	0.04
25	0.178	0.172	0.166	0.159	0.153	0.146	0.140	0.134	0.127	0.121	0.114	0.108	0.101	0.094	0.088	0.081	0.075	0.068	0.061	0.055	0.04
26	0.183	0.176	0.169	0.162	0.155	0.149	0.142	0.135	0.128	0.122	0.115	0.108	0.101	0.095	0.088	0.081	0.075	0.068	0.062	0.055	0.04
27	0.185	0.178	0.171	0.164	0.156	0.149	0.142	0.135	0.128	0.121	0.115	0.108	0.101	0.094	0.088	0.081	0.074	0.068	0.061	0.055	0.04
28	0.186	0.178	0.171	0.163	0.156	0.149	0.141	0.134	0.127	0.120	0.113	0.106	0.100	0.093	0.086	0.080	0.073	0.067	0.060	0.054	0.04
29	0.185	0.178	0.170	0.162	0.154	0.147	0.139	0.132	0.125	0.118	0.111	0.104	0.097	0.091	0.084	0.077	0.071	0.065	0.059	0.053	0.04
30	0.183	0.175	0.167	0.159	0.151	0.144	0.136	0.129	0.121	0.114	0.107	0.101	0.094	0.087	0.081	0.075	0.069	0.063	0.057	0.051	0.04
31	0.179	0.171	0.163	0.155	0.147	0.139	0.131	0.124	0.117	0.110	0.103	0.096	0.089	0.083	0.077	0.071	0.065	0.059	0.054	0.048	0.04
32	0.174	0.165	0.157	0.149	0.141	0.133	0.125	0.118	0.111	0.104	0.097	0.091	0.084	0.078	0.072	0.066	0.061	0.055	0.050	0.045	0.04
33	0.167	0.158	0.150	0.141	0.133	0.126	0.118	0.111	0.104	0.097	0.091	0.084	0.078	0.072	0.067	0.061	0.056	0.051	0.046	0.042	0.03
34	0.158	0.149	0.141	0.133	0.125	0.117	0.110	0.103	0.096	0.089	0.083	0.077	0.071	0.065	0.060	0.055	0.050	0.046	0.041	0.037	0.03
35	0.148	0.139	0.130	0.122	0.115	0.107	0.100	0.093	0.086	0.080	0.074	0.068	0.063	0.058	0.053	0.048	0.044	0.040	0.036	0.033	0.03
36	0.136	0.127	0.119	0.111	0.103	0.096	0.089	0.082	0.076	0.070	0.064	0.059	0.054	0.049	0.045	0.041	0.037	0.033	0.030	0.027	0.02
37	0.122	0.113	0.105	0.098	0.090	0.083	0.076	0.070	0.064	0.058	0.053	0.048	0.044	0.039	0.035	0.032	0.029	0.026	0.024	0.021	0.02
38	0.107	0.098	0.091	0.083	0.076	0.069	0.063	0.057	0.051	0.046	0.041	0.037	0.033	0.029	0.026	0.023	0.020	0.018	0.016	0.015	0.01
39	0.090	0.082	0.074	0.067	0.060	0.054	0.048	0.042	0.037	0.032	0.028	0.024	0.021	0.018	0.015	0.013	0.011	0.009	0.008	0.008	0.00
40	0.071	0.064	0.056	0.049	0.043	0.037	0.032	0.027	0.022	0.018	0.014	0.011	0.008	0.005	0.003	0.002	0.001	0.000	0.000	0.000	0.00

*L_j = Joist span length, ft.
*L_g = Girder span length, ft.

more controlled environment, simultaneous acceleration measurements were taken at several locations on the dance studio floors and the 10th floor while between four and six people jumped to the beat of a metronome in the studio. A jumping frequency of 2 Hz caused the largest response at the 10th floor. A significant portion of the motion at the 10th floor was found to be the result of column shortening.

From the experimental results, it was estimated that an equivalent weight of 3.3 million lb was experiencing peak acceleration levels of up to 0.01g, twice the level considered acceptable in an office environment, with only six people jumping. That is approximately 1000 lb of people moving 3.3 million lb!

DYNAMIC AMPLITUDE PREDICTION FOR PARTIALLY LOADED BAYS

The maximum size of the dance floor is something that can be established by the owner / operator and possibly negotiated to provide an acceptable design. A method of determining the effective dynamic load for partially loaded bays is given in a recent paper by the author (Hanagan 2002). When using this strategy, it is important to remember that avoiding resonance is still crucial. Again for the purpose of perspective, the ballroom floor in Case Study 1 could only support a 100-sq.-ft dance floor without exceeding the 0.02g limit prescribed in Design Guide 11. Considering that this is a 20,000-sq.-ft ballroom, this would certainly not be an option.

CONCLUSIONS

Vibration serviceability is best considered in the early stages of design development. Owners and architects must be made aware of the implications of their decisions. Engineers should not take responsibility for conditions they cannot control. For office floors, use of thin and / or light-weight concrete slabs can yield vibration complaints either immediately or at some point in the future. Owners and developers must understand that unless architectural layouts can be controlled, floors not meeting the walking vibration criterion in *Design Guide 11* can ultimately lead to serious problems and unhappy tenants.

In the case of vibration due to rhythmic activities, resonance with first, second and sometimes even the third harmonic of the activity frequency should be avoided. Because only very small displacements are tolerated, it is important that extremely stiff structures are provided. For mid- and high-rise buildings, occupancies combining rhythmic activities with sensitive uses like offices or residences should be considered with care. Long-span floors are particularly susceptible to excessive vibrations caused by rhythmic activities. This condition should generally be approached with the understanding that it is going to take a massive structure, including a huge steel weight on a pound-per-sq.-ft basis and very deep members, to meet the criteria of *Design Guide 11*. Convention center facilities are known to have ballrooms located over exhibition halls with 100'+ column spacing. Although architecturally, placing one column-free space over another is logical, from a vibration serviceability perspective, this condition is problematic and should be avoided. In most cases, these floors cannot be repaired without adding columns below.

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