VIBRATION EVALUATION OF FLOOR SYSTEMS FOR FOOTFALL[1]

The six steps for evaluating the perception and acceptability of vibration caused by footfall in a conventionally reinforced or post-tensioned floor system are:

1 – **Natural Frequency**
Determine the natural frequency of the floor system (Hz). For specific areas of interest, such as a lab or operating room of a hospital, determine the "dominant" frequencies of the location of interest.

2 – **Exiting Force of Vibration**
Select a probable weight of the person (P) likely to be the source of vibration (assume 150 lb; 667 N) kg). Assume a number of steps that the person is likely to take. Assume 2 steps per second. Referring to Fig. 1, the fraction of the weight of the person that excites the vibration is 0.53. In summary:

Assume weight of person P = 150 lb (667 N)
Constant force representing the walking force P_O = 0.53 * 150 = 79.5 lb (354 N)

3 – **Floor Type**
Select the appropriate damping factor (β) of the floor system from Table 1. Use 0.03 if not sure.

4 – **Weight of Vibrating Floor Panel**
Calculate the effective weight (W) of the panel under consideration and the superimposed load that follows its vibration

5 – **Acceleration Caused by Walking Person**
Use the relationship (1) below to determine the peak acceleration ratio caused by the footfall on the floor (a_p /g).

6 – **Evaluation**
With the natural frequency (Hz) from step 1 and the peak acceleration ratio ((a_p /g) from step 5 refer to the ATC chart (Fig. 1) to determine the acceptability of the vibration.

For more details and additional information refer to ADAPT Technical Note TN290

TABLE 1 RECOMMENDED DAMPING FACTORS FOR VARIOUS OCCUPANCIES

Occupancy	Damping factor β
Bare concrete floor	0.02
Furnished, low partition	0.03
Furnished, full height partition	0.05
Shopping malls	0.02

Formula to determine the peak ground acceleration as a result of footfall on a floor panel. The formula gives the value as ratio of ground acceleration “g”

$$\left(\frac{a_p}{g}\right) = \frac{P_0 e^{-0.35 f_n}}{\beta W} \qquad \textbf{(1)}$$

where

a_p = peak acceleration;
g = gravitational acceleration [32.2 ft/sec^2; 9.81 m/sec^2];
P_o = constant force representing the walking force (from Fig. 1 and weight of walking person);
β = modal damping ratio, recommended in Table 1;
W = effective weight of the panel and the superimposed dead load; and
f_n = first natural frequency (Hz).

Figure 1 is chart from Applied Technology Center (ATC) used to determine the perception and acceptability of vibration in a floor system. Note that the ordinate of the chart is in percentage of ground acceleration. Values obtained from formula 1 must be multiplied by 100, before using them in the chart below.

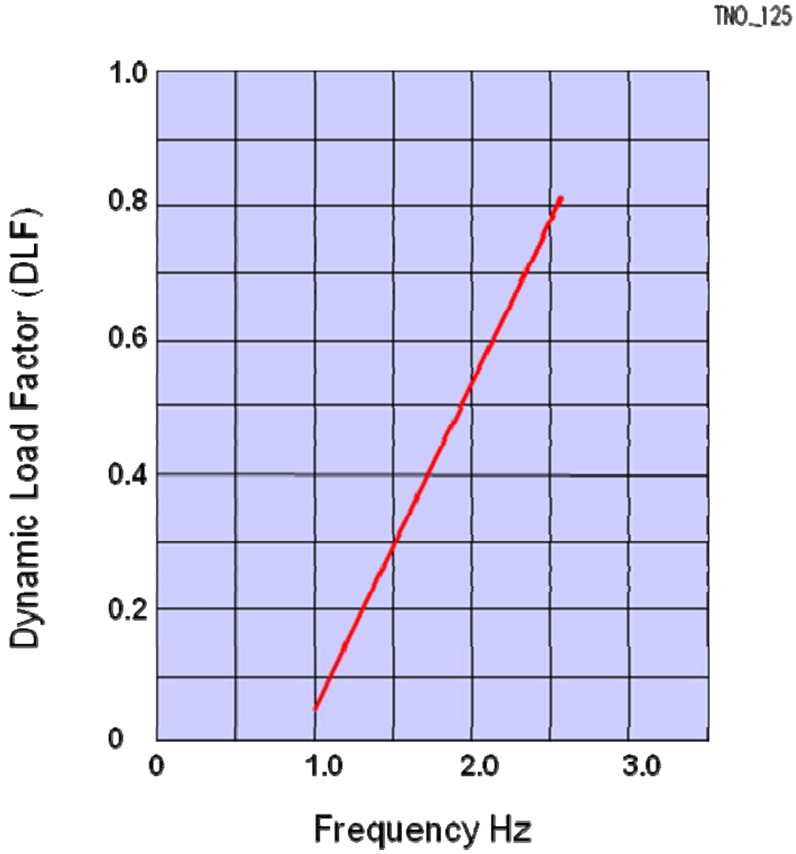


FIGURE 1 DYNAMIC LOAD FACTOR
FOR WALKING FORCE

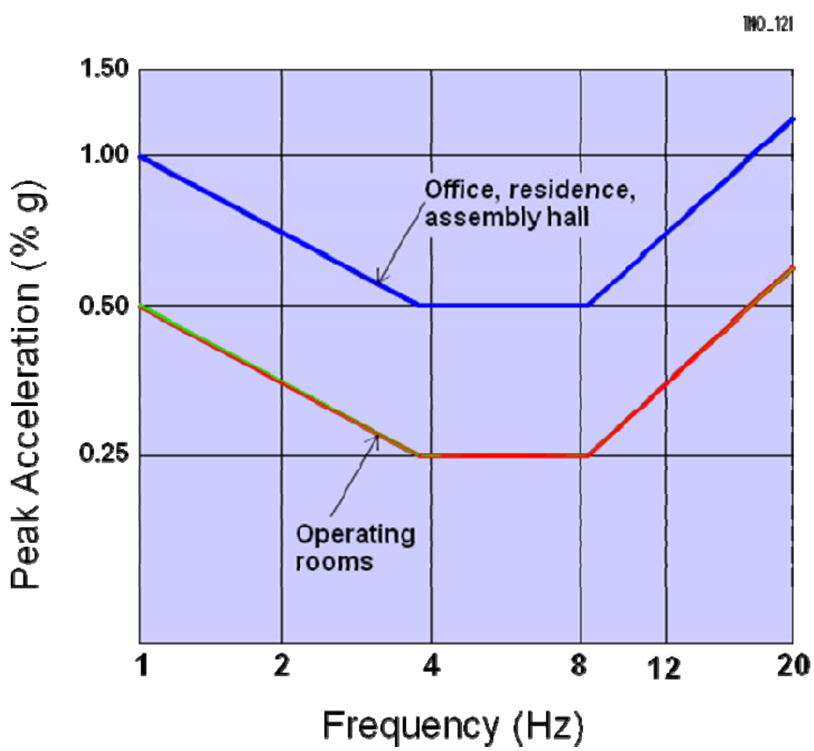


FIGURE 2 CHART FOR PERCEPTION AND ACCEPTABILITY
OF FLOOR VIBRATION

EXAMPLE 1

Figure EX-1 shows the view of a concrete floor resting on columns. Evaluate the perception and acceptability of vibration of the panel of the floor system shown in Fig. EX-2. The floor is furnished with low partitions.

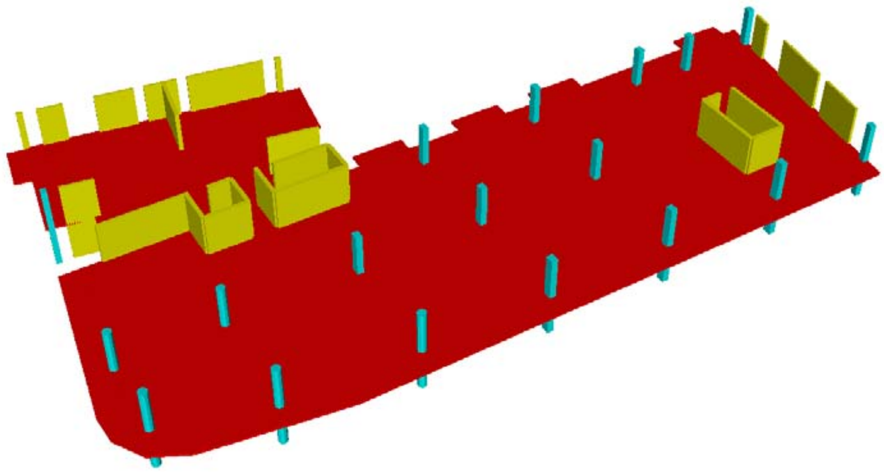


FIGURE EX-1 3D VIEW OF THE FLOOR SYSTEM

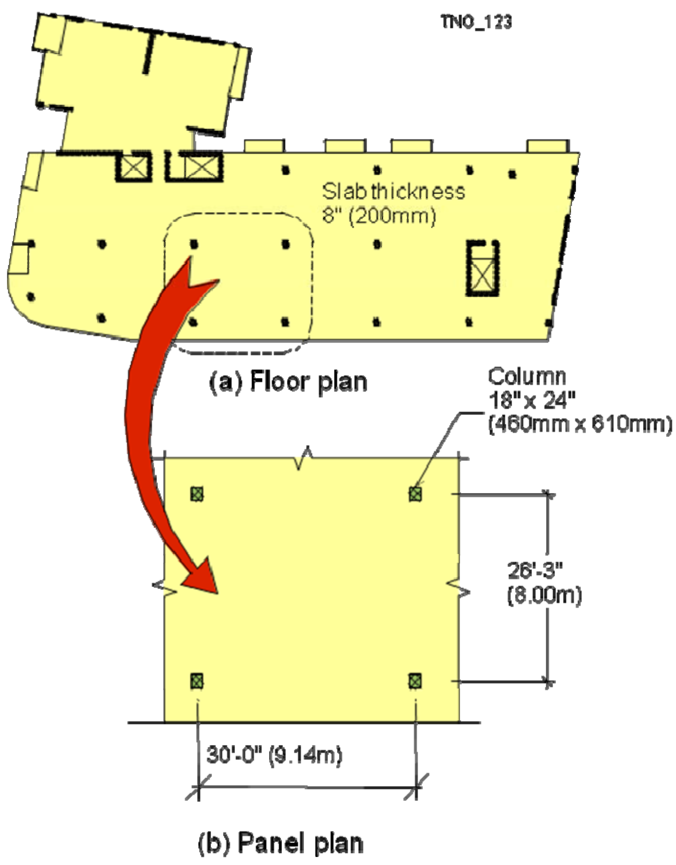


FIGURE EX-2 IDENTIFICATION OF PANEL FOR EVALUATION

Step 1 – Natural Frequency
Generate a model in the program ADAPT-Floor Pro and determine the first three frequencies of the floor system. The lowest first frequency generally governs the evaluation. Since concrete floors exhibit a somewhat greater stiffness in their dynamic response than under static loads, it is recommended to use a modulus of elasticity in your model equal to 1.2 times the modulus of elasticity given in the codes [ADAPT TN 290].

Figures EX1-1 through EX1-4 show the discretization of the floor using ADAPT-Floor Pro and the results of the first three frequencies. The first three frequencies determined are: 5.79, 6.33 and 6.44.

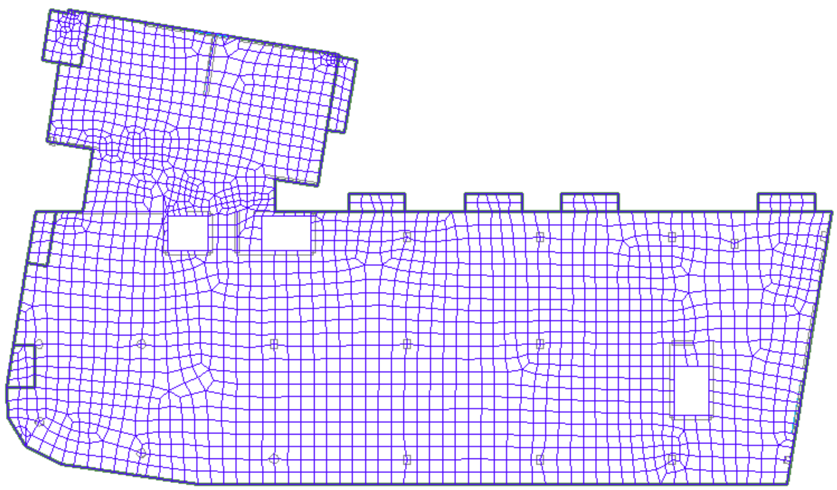
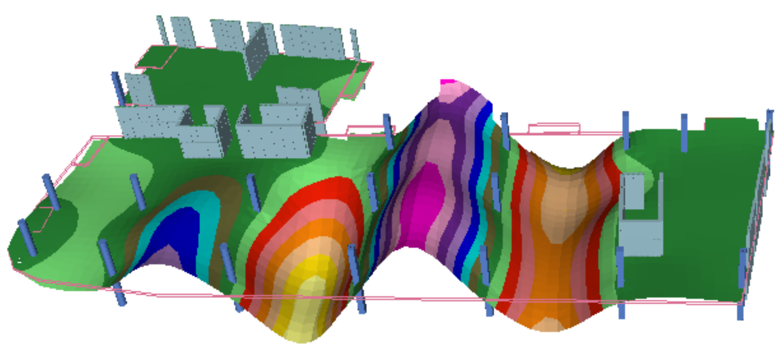
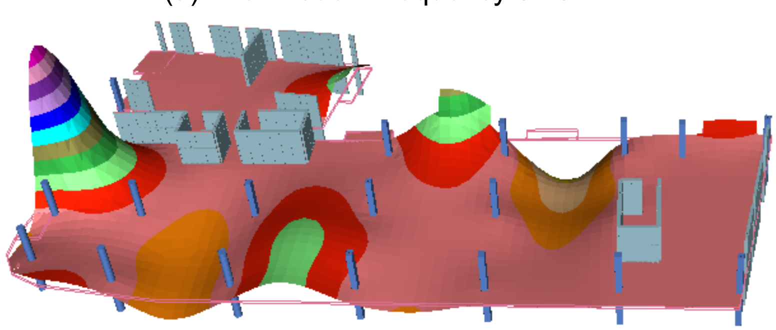


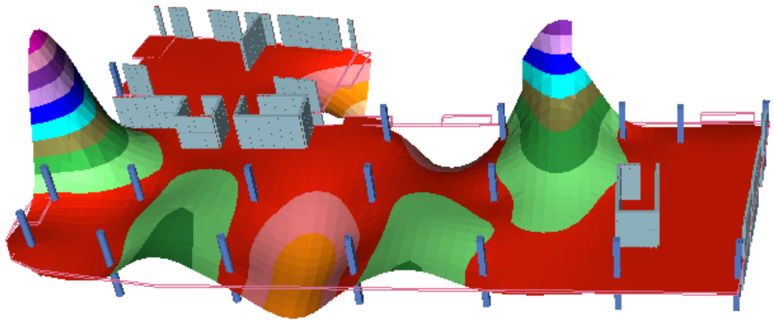
FIGURE EX1-1 – DISCRETIZATION OF THE ENTIRE FLOOR MODEL



(a) First mode – frequency 5.79 Hz



(b) Second mode – frequency 6.33 Hz



(c) Third mode – frequency 6.44 Hz
FIGURE EX1-2 THE FIRST THREE MODES AND FREQUENCIES

STEP 2 – Exiting Force of Vibration (P_O)
Assume most persons likely to use the space are 170 lb (667 N); walking with 2 steps per second. From Fig. 1:

Constant force representing the walking force P_O = 0.53 * 150 = 79.50 lb (354 N)

STEP 3 – Floor Type
Since the floor is furnished with low partitions, from Table 1, select a damping ratio $\beta = 0.03$.

STEP 4 – Weight of Vibrating Floor Panel
Calculate the effective weight (W) of the panel under consideration and the superimposed load that follows its vibration

The dimensions of the panel are (30 x 26.5 ft; 9.14 x 8.00m) ; slab is 8 in. (200 mm) thick and subjected to 20 lb (1 kN/m2) of partitions that are tied to the slab and are going to follow the motion of the slab in harmony. Hence their mass is additive to that of the panel. Unit weight of concrete is 0.15 k/cu ft.

The total weight of the panel W is :

$$W = (30 \times 26.25) \times \left(\frac{8}{12} \times 0.15 + 0.02\right) = 94.5 \text{ k} \ \ (421 \text{ kN})$$

STEP 5 – Acceleration Caused by Walking Person
Use the relationship (1) to determine the peak acceleration ratio (a_p /g) caused by the footfall on the floor

$$\left(\frac{a_p}{g}\right) = \frac{P_0 e^{-0.35 fn}}{\beta W} \qquad \textbf{(1)}$$

P = 150 lb (667 N)
Walking speed = 2.0 Hz
DLF = 0.53 (from Fig. 1)
P_0 = 0.53 *150 = 79.5 lb (0.354 kN)

f_n = natural frequency equal to 5.97 Hz (from Fig. EX1- 2a)
β = 0.03
W = 94.5 k (421 kN)

$$\frac{a_p}{g} = \frac{79.5 \times e^{-0.35 \times 5.79}}{0.03 \times 94.5 \times 1000} = 0.00367 \ ; \ \mathbf{0.37\ \%}$$

STEP 6 – Evaluation

With the natural frequency (Hz) from step 1 equal to 5.79 Hz and the peak acceleration ratio ((a_p /g) from step 5 equal to 0.37% refer to the ATC chart (Fig. 2) to determine the perception and acceptability of the vibration.

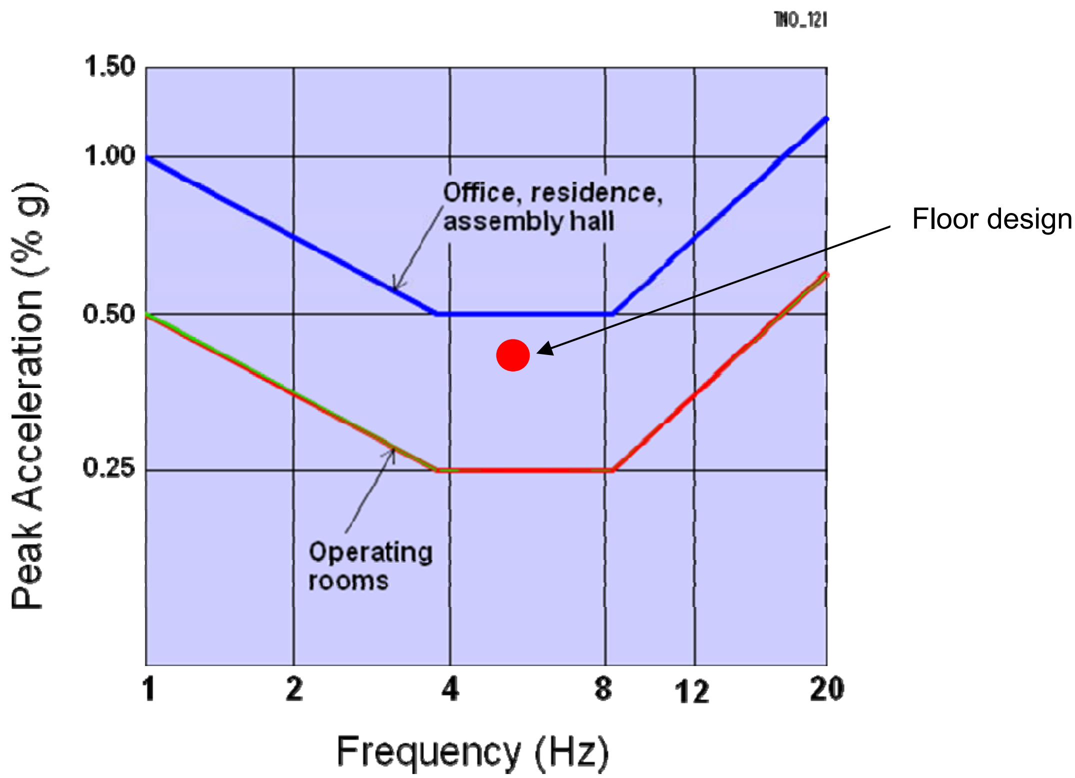


FIGURE EX1-3 EVALUATION OF FLOOR VIBRATION

From Fig. EX1-3 the evaluation parameters indicate that the floor panel is acceptable for office and residential occupancy, but not for operating rooms in hospitals.

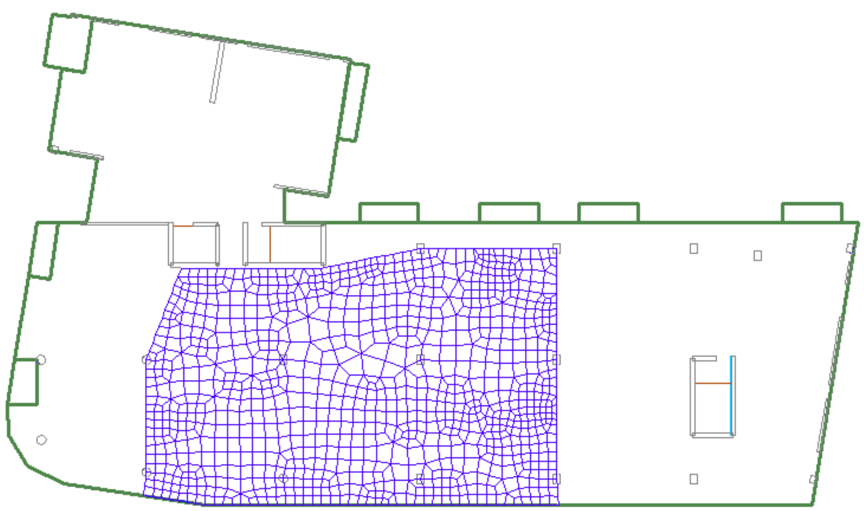
LOCATION SPECIFIC EVALUATION

It can be argued that the response evaluation of a specific panel as performed in the above example is greatly influenced by the vibration values based on the entire floor system. Figure EX1-2 implies that the frequencies determined are largely influenced by excitations other than the panel under consideration. In a large floor area, the sensitive laboratory or operating room may cover a fraction of the entire floor area. For a more credible evaluation, It is critical to focus on the response of the location of interest, and undertake mitigation measures that are directed to that area.

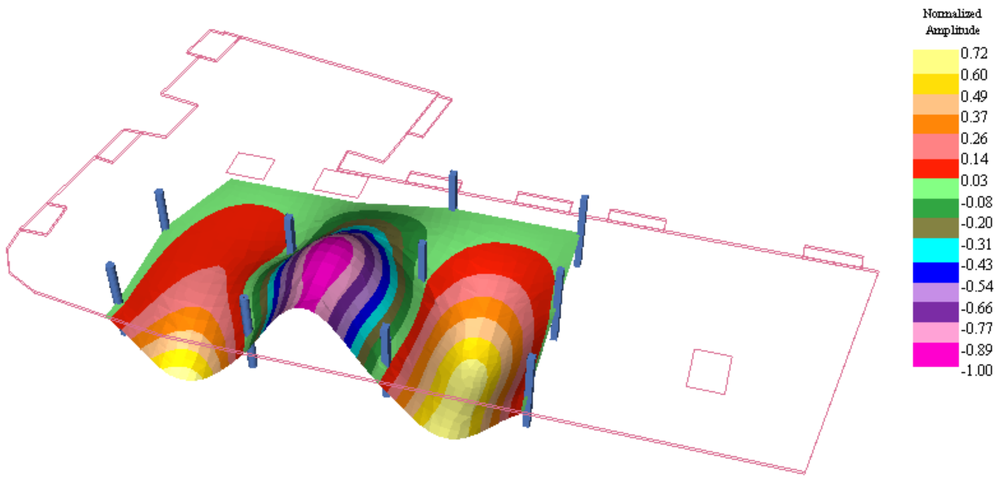
Using ADAPT-Floor Pro, you can identify the floor area of interest in the full 3D model of a building generated for the overall design, and determine its vibration characteristic in isolation. The area of interest is simply delineated by a boundary drawn around it. The support conditions along this isolated boundary are user defined. In most cases, simple support, or no support is applicable. For better results, the boundary is drawn somewhat larger than the slab region of interest, in order to minimize the impact of the user imposed conditions on the vibrations of the interest region. The following example illustrates the point.

Figure EX1-4 (a) shows the floor region selected for analysis. Note that the region selected extends one or more panels beyond the area of interest, in order to minimize the impact of the boundary conditions selected at the far ends. ADAPT-Floor Pro assumes a simply supported boundary condition at the far ends of the selected region, but you as user have the option to modify it.

The first mode of vibration and frequency of the region selected is shown in part (b) of the figure. Note that it is somewhat different from the values obtained from the overall analysis above.



(a) Selection of an extended region



(b) First mode of vibration – Frequency 6.07 Hz

FIGURE EX1-4 SELECTION AND VIBRATION OF AN EXTENDED REGION

REFERENCES

ADAPT TN290 (2010), "*Vibration Design of Concrete Floors for Serviceability,"* ADAPT Corporation, Redwood City, CA, www,Adaptsoft.com, 2010, pp 20

ATC, (1999) "ATC Design Guide 1," *Minimizing Floor Vibration*," Applied Technology Council, Redwood City, CA, 1999, 49 pp.