

VIBRATION EVALUATION OF FLOOR SYSTEMS FOR FOOTFALL USING ADAPT-FLOOR PRO

This technical note provides the six steps for evaluating the perception and acceptability of vibration caused by footfall in a conventionally reinforced or post-tensioned floor system. The general steps are followed by a step-by-step example of how to use the new modal vibration analysis capabilities in ADAPT-Floor Pro 2010 to carry out a footfall analysis and check. The example first uses the vibration response of the entire modeled floor system and then uses the Exclude Mesh function to isolate a specific sub-region. The information outlined in this technical note is intended to help structural engineers address their vibration compliance requirements, in particular footfall analysis, with greater ease, speed, and accuracy using ADAPT software.

Vibration of concrete floor systems is distinctly different from that of steel floors. The skeletal construction of a steel structure, made up of discrete beams and girders responds differently from the continuum of a concrete floor.

In every concrete floor system, a large fraction of the floor area is covered by slabs. Slabs being the predominant load carrying member govern the vibration response of the floor. When excited, flat slabs vibrate in form of homogeneous plates. This is particularly true in modern floor systems, where larger spans and fewer beams accentuate the contribution of slabs.

Subdivision of a floor into girders of higher stiffness, and primary/secondary beams leads to vibration characteristics of each panel becoming specific to its member layout. For this reason, as is reflected in AISC recommendations, the evaluation of a steel floor calls upon empirical relationships developed specifically for steel structures. In the contrast, concrete slabs with or without beams lend themselves to be analyzed fairly accurately using the Finite Element Method, where a combination of interconnected shell and beam elements govern the response of a panel.

This technology, as employed in ADAPT-Builder can represent large spans, irregular geometry and support layout that have become the norm of modern structures, where advances in structural engineering can meet the advances in construction materials and daring architectural aspirations.

SIX STEP PROCESS FOR CARRYING OUT FOOTFALL VIBRATION ANALYSIS

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 that specific location.

2 – Excting Force of Vibration

Select a probable weight of the person (P) likely to be the source of vibration (assume 150 lb; 70 kg). Assume a number of steps that the person is likely to take. For example, someone who takes 2 steps per second walks at a frequency of 2 Hz. 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

Constant force representing the walking force $P_o = 0.53 * 150 = 79.5$ lb

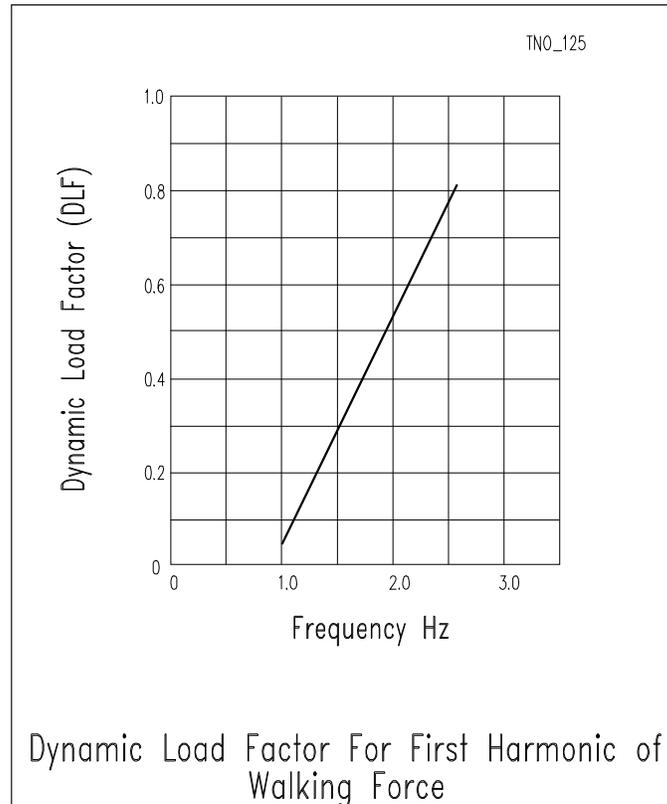


FIGURE 1 DYNAMIC LOAD FACTOR FOR WALKING FORCE

3 – Floor Type

Select the appropriate damping factor (β) of the floor system from Table 1. Use 0.03 if unsure.

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

4 – Weight of Vibrating Floor Panel

Calculate the effective weight (W) of the panel under consideration and the superimposed load that is attached to the floor and 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).

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”

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

where

a_p = peak acceleration;

g = gravitational acceleration [32.2 ft/sec²; 9.81 m/sec²];

P_0 = 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).

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. 2) to determine the acceptability of the vibration.

Figure 2 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 Relationship 1 must be multiplied by 100, before using them in the chart below.

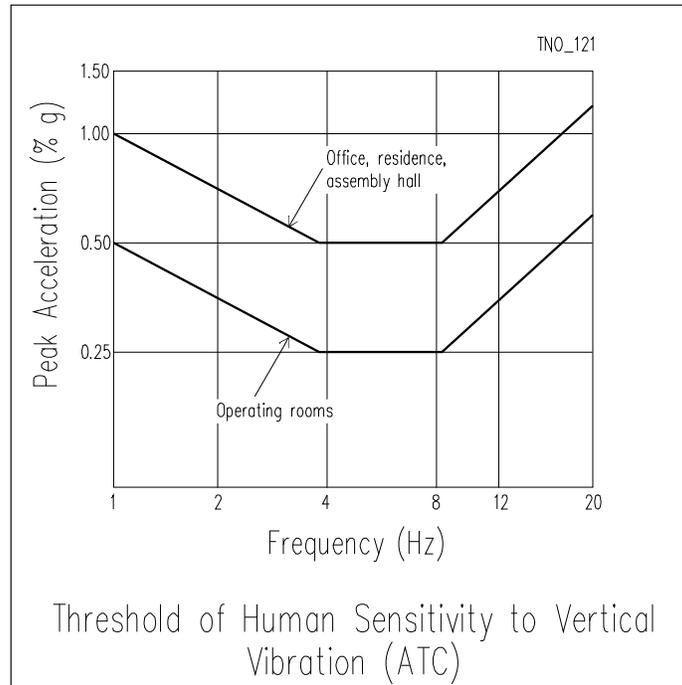


FIGURE 2 CHART FOR PERCEPTION AND ACCEPTABILITY OF FLOOR VIBRATION

For more details and additional information refer to ADAPT Technical Note TN290 that is available for download at www.adaptsoft.com.

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.

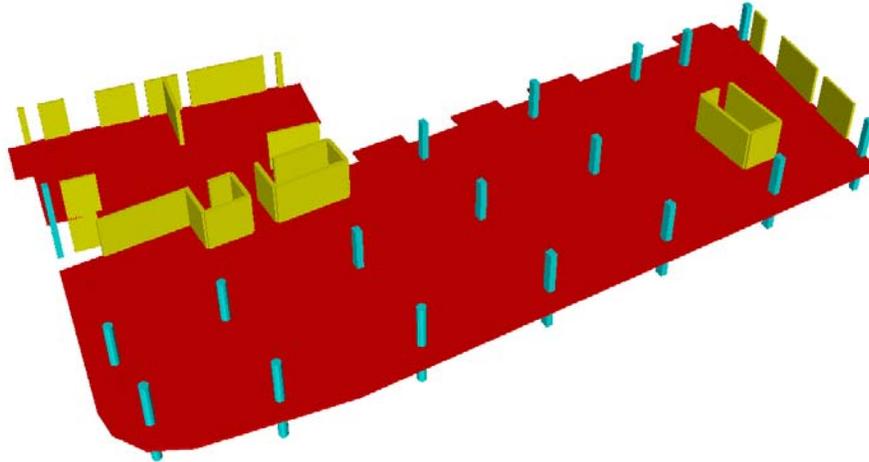


FIGURE EX-1 3D VIEW OF THE FLOOR SYSTEM

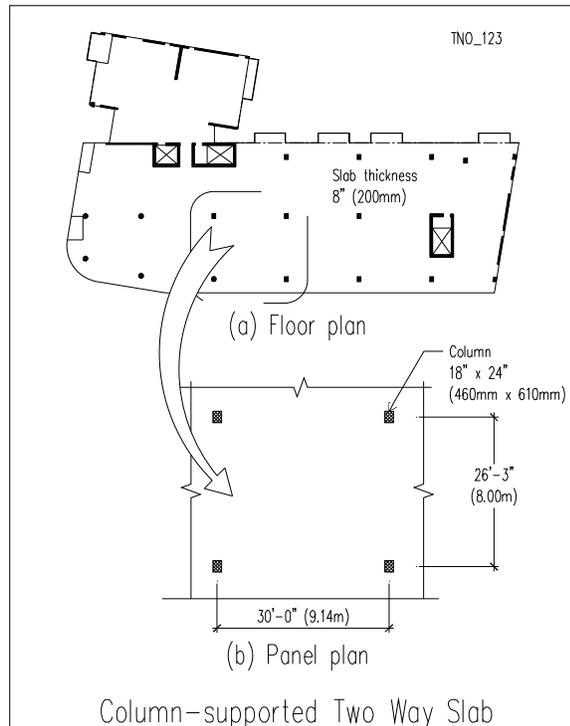


FIGURE EX-2 IDENTIFICATION OF PANEL FOR EVALUATION

Step 1 – Natural Frequency

Generate a model in the program ADAPT-Floor Pro and analyze to 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].

By default, ADAPT-Floor Pro only considers the vertical contribution of selfweight for its modal vibration analysis. However, the user has the option to include other mass in the calculation by defining project specific Vibration Combinations. Figure EX-3 shows the interface used to customize the mass combinations used during vibration analysis.

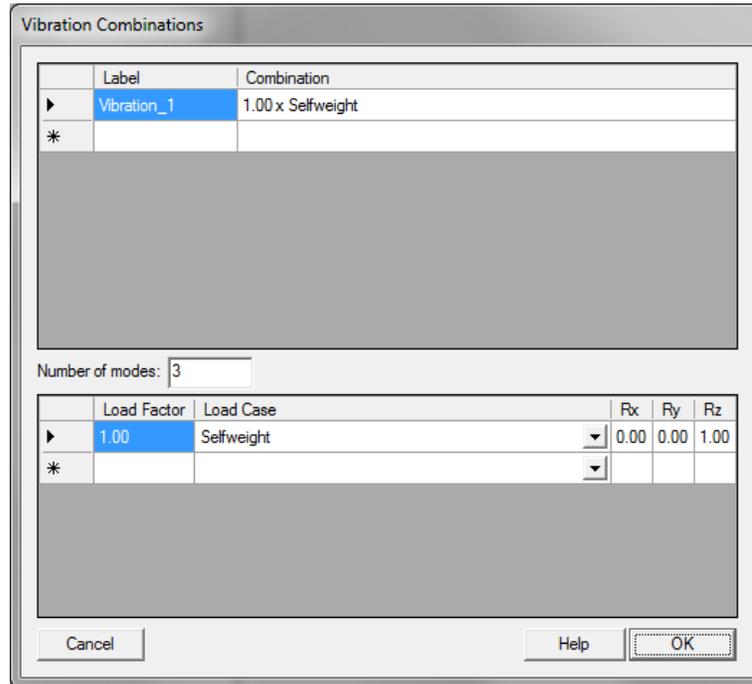


FIGURE EX-3 IDENTIFICATION OF PANEL FOR EVALUATION

Figures EX1-4 through EX1-5 show the discretization of the floor using ADAPT-Floor Pro and the results of the first three frequencies. The first three frequencies determined are: 5.97 Hz, 6.33 Hz and 6.44 Hz.

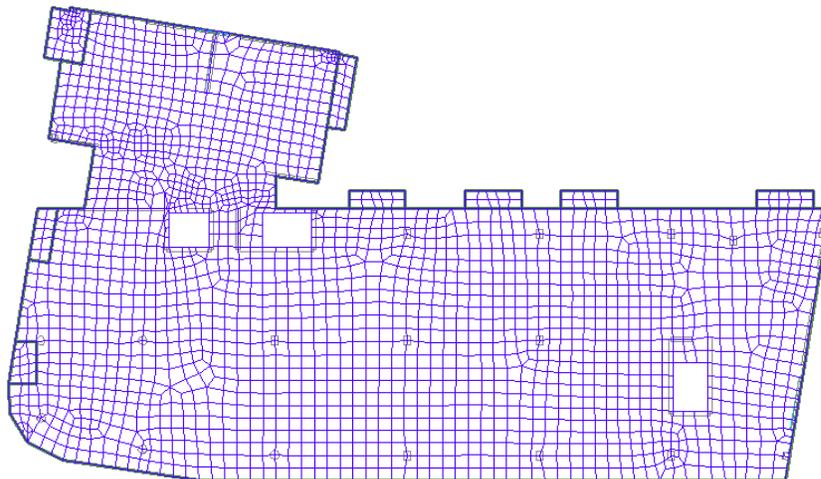
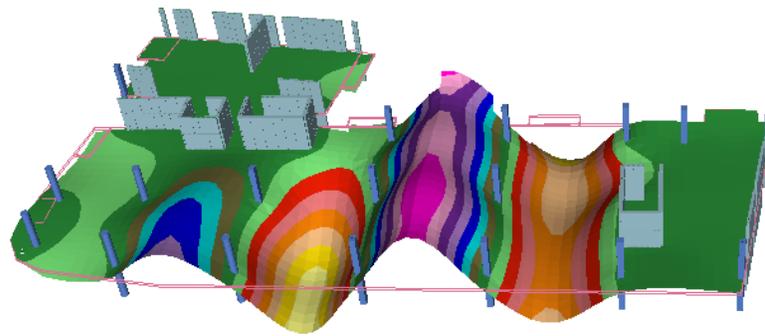
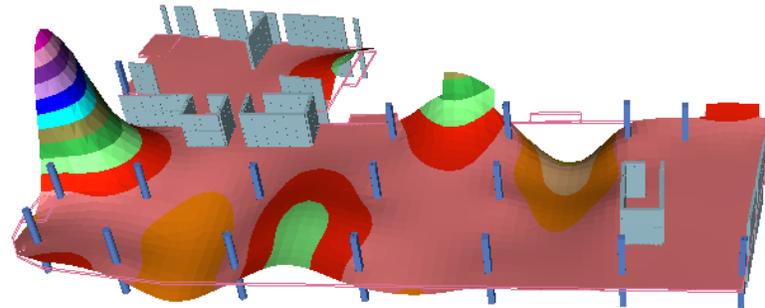


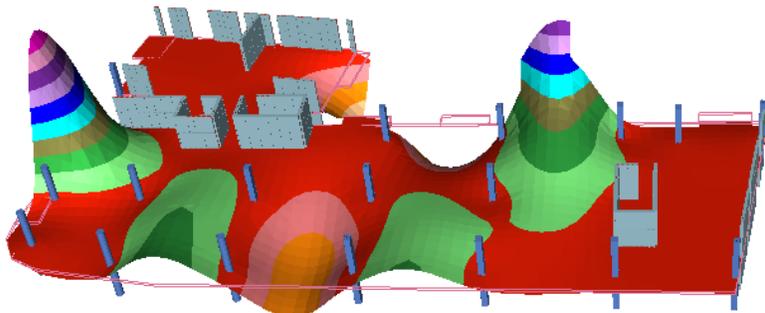
FIGURE EX1-4 – DISCRETIZATION OF THE ENTIRE FLOOR MODEL



(a) First mode – frequency 5.97 Hz



(b) Second mode – frequency 6.33 Hz



(c) Third mode – frequency 6.44 Hz

FIGURE EX1-5 THE FIRST THREE MODES AND FREQUENCIES

STEP 2 – Excting Force of Vibration (P_o)

Assume most persons likely to use the space are 170 lb (70 kg); walking with 2 steps per second. From Fig. 1:

Constant force representing the walking force $P_o = 0.53 * 170 = 90.1$ lb

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, slab is 8 in. thick and subjected to 20 psf 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 :

$$W = (30 \times 26.25) \times \left(\frac{8}{12} \times 0.15 + 0.02 \right) = 94.5 \text{ k (420 kN)}$$

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

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

- P = 150 lb
- Walking speed = 2.0 Hz
- DLF = 0.53 (from Fig. 1)
- $P_0 = 0.53 * 150 = 79.5 \text{ lb}$

- f_n = natural frequency equal to 5.97 Hz (from Fig. EX1- 5a)
- $\beta = 0.03$
- W = 94.5 k

$$\frac{a_p}{g} = \frac{79.5 \times e^{-0.35 \times 5.97}}{0.03 \times 94.5 \times 1000} = 0.00347 ; \text{ 0.35 \%}$$

STEP 6 – Evaluation

With the natural frequency (Hz) from step 1 equal to 5.97 Hz and the peak acceleration ratio (a_p / g) from step 5 equal to 0.35% refer to the ATC chart (Fig. 2) to determine the perception and acceptability of the vibration.

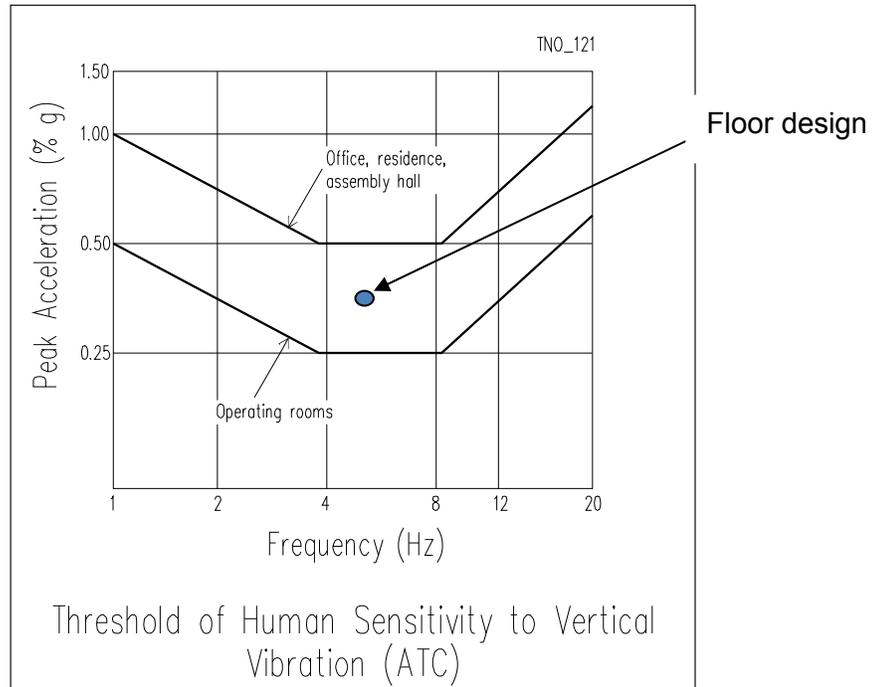


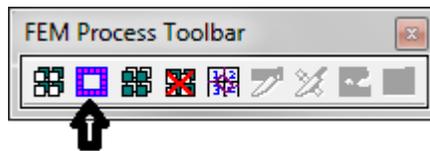
FIGURE EX1-6 EVALUATION OF FLOOR VIBRATION

From Fig. EX1-6 the evaluation parameters indicate that the floor panel is acceptable for office and residential occupancy, but not for operating rooms in hospitals.

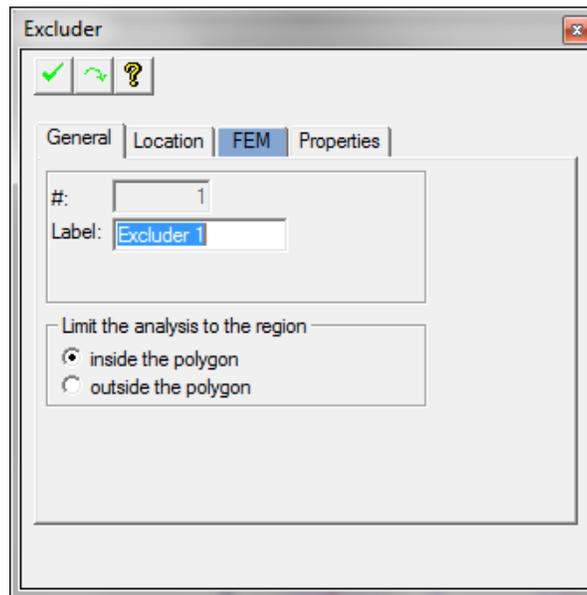
USING EXCLUDER FUNCTION FOR LOCATION SPECIFIC EVALUATION

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 of 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 the unique Exclude/Include Meshing function in ADAPT-Floor Pro, you can identify and isolate any subregion of your full 3D building model to determine its vibration characteristic in isolation. This saves the design engineer considerable time by not requiring the creation and maintenance of separate simplified floor models for the sole purpose of vibration analysis. The area of interest is simply delineated by an Exclude Mesh boundary drawn around it and selecting whether the software should only mesh and analyze inside or outside the polygon region defined. The Exclude Mesh function can be found on the FEM Process Toolbar, shown in Figure EX1-7.



(a) FEM Process Toolbar with arrow pointing to Exclude Mesh function



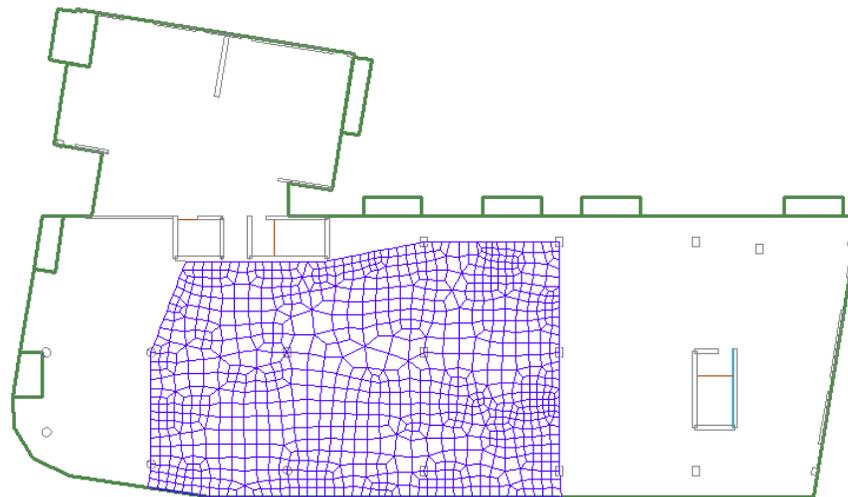
(a) FEM Process Toolbar with arrow pointing to Exclude Mesh function

FIGURE EX1-7 EXCLUDE MESH FUNCTION ALLOWS USER TO DEFINE ANY POLYGON REGION AND ONLY MESH INSIDE OR OUTSIDE OF THE REGION

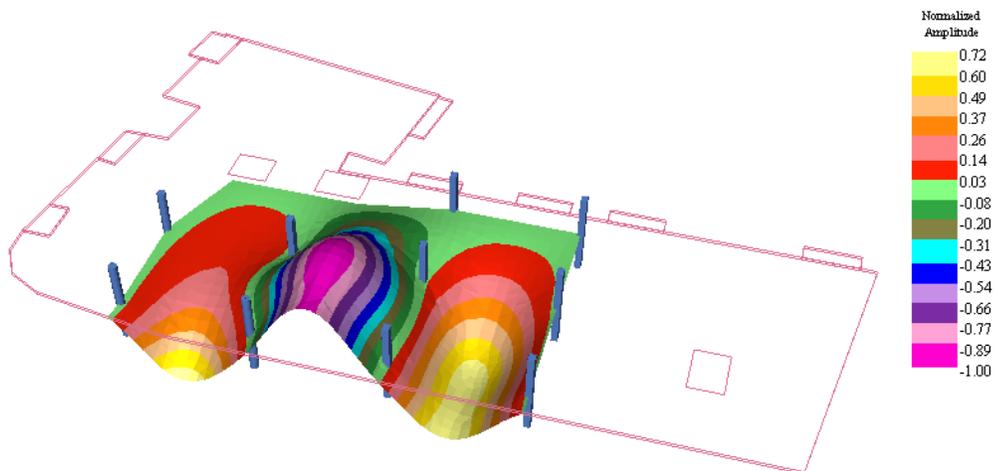
The support conditions along this isolated boundary (polygon defining Excluder) are user defined. In most cases, simple support, or no support is applicable. For better results, the boundary is drawn somewhat larger than the slab region of interest, in order to minimize the impact of the user imposed conditions on the vibrations of the interest region. The following example illustrates the point.

Figure EX1-8 (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 the user has the option to modify it.

The first mode of vibration and frequency of the region selected is shown in part (b) of Fig. EX1-8. Note that it is somewhat different from the values obtained from the overall analysis shown in Fig. EX-5.



(a) Selection of an extended region



(b) First mode of vibration – Frequency 6.07 Hz

FIGURE EX1-8 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.