# VIBRATION EVALUATION OF A PARKING STRUCTURE[1]

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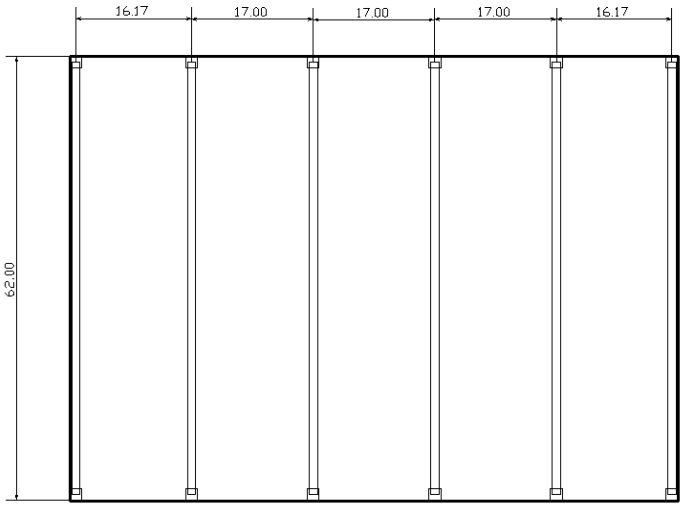
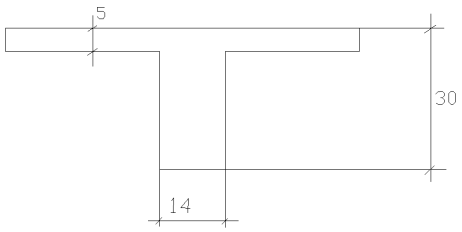
This Technical Note reports the vibration analysis of a typical section of a parking structure, and the evaluation of the outcome with respect to the perception of the vibration by individuals, and its acceptability or objection. The analysis and evaluation are based on the procedure outlined in ADAPT TN290.

The parking structure (Fig. 1) is a beam and one-way slab construction, typical of layout in the US for two-way traffic and two stalls for normal parking between adjacent columns. The columns are 17 ft apart; beams are 14 in. wide and 30 in. deep. The slab is 5 in. thick. Both beams and slabs are assumed post-tensioned. Hence, the stiffness assumed in the analysis is that of the gross cross-sectional area, with no allowance for reduction due to cracking.

Three dimensional views of the parking structure region are shown in Fig. 2.




(a) Plan of the structure (ft)




(b) Section of the beams (in.)

FIGURE 1 Geometry of a Typical Section of the Parking Structure

The columns are 20” square; floor to floor height is 10’; concrete (28 day cylinder) is 4000 psi. The structure is assumed to have 10 psf added weight due to installations and possible covering.

There are six steps to follow in the vibration analysis and evaluation of a concrete structure. These are detailed in ADAPT TN338 and used in the following.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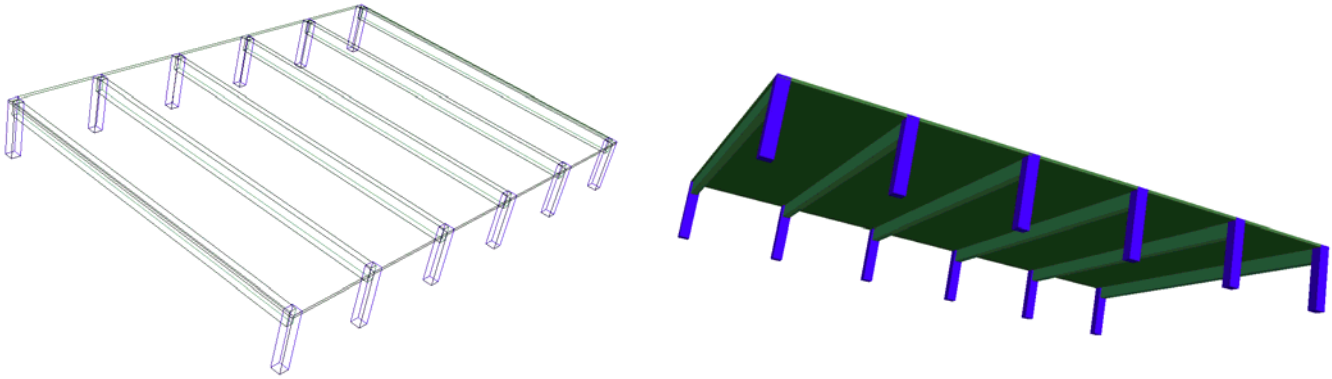
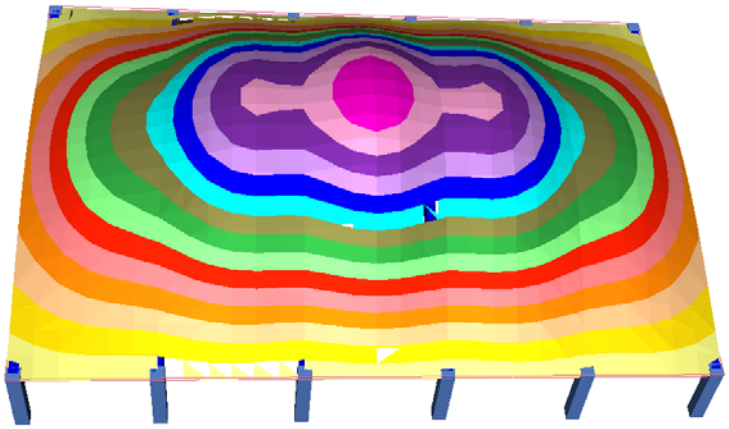


(a) 3D view of the structure (b) Solid model of the structure

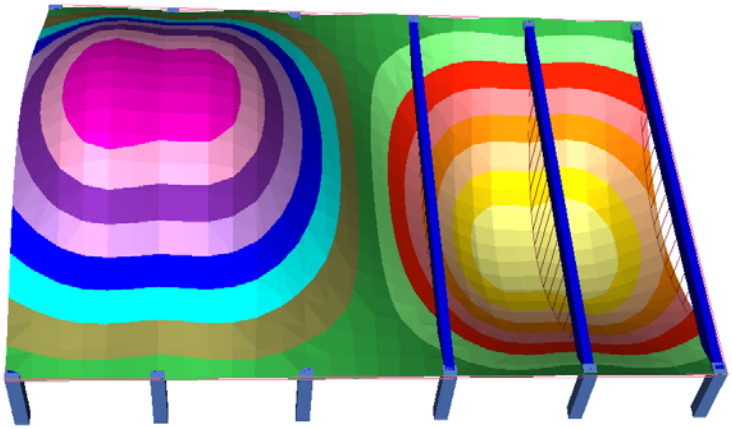
FIGURE 2 Three-dimensional Views of the Parking Structure Region

**1 – Natural Frequency**

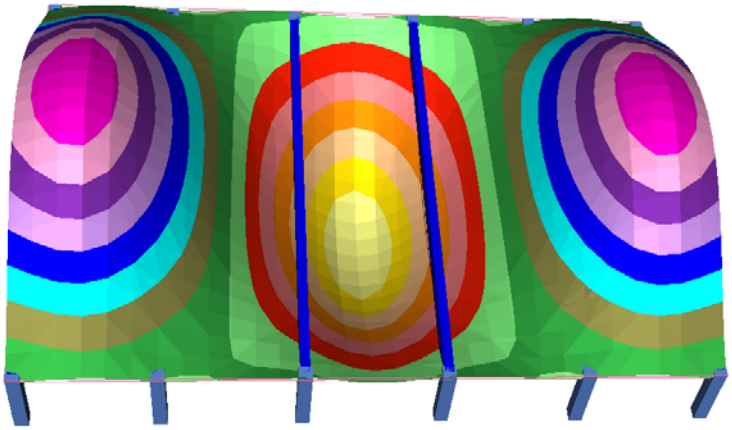
Using the computer program FLOOR-Pro, the structure was discretized into a fine finite element mesh, with beams represented below the slab as they occur in the actual structure. The impact of the added weight due to installations and topping (superimposed load) was included as added mass following the vibration, but with no stiffness. The modulus of elasticity assumed was 1.2 times the static value to account for the larger stiffness of concrete under dynamic action. The first three natural frequencies and modes of vibration of the structure were extracted (Fig. 1-1).



(a) First mode – frequency 3.73 Hz



(b) Second mode – frequency 3.93 Hz



(c) Third mode – frequency 4.33 Hz

FIGURE EX1-2 THE FIRST THREE MODES AND FREQUENCIES

**2 - Exiting Force of Vibration** ($P_O$)

The exciting force of vibration is the force of impact from rolling cars. The impact factor assumed in vehicular traffic on roadways is about 10%. The speed of travel on a parking structure deck is much less than roadways. The speed is likely to be between 5 to 10 miles per hour. Hence, the impact factor is less than cars on roadways driving over uneven surface. For parking decks, an impact factor between 4% to 6% is more appropriate.

The weight of vehicles commonly used in parking structures falls within the following groups

| | |
|---|---|
| Cars | up to 4000 lbs (1800 kgs) |
| Pick-ups | 2500 – 5000 lbs (1100 - 2300 kgs) |
| SUVs | 2500 - 5000+ lbs (1100 - 2300 kgs) |

For this example, we assume a vehicle with 4000 lb weight. This represents most pick-ups and SUVs.

With the assumption of an impact factor of 5% and a vehicle weight of 4000 lb, the exciting force will be:

Exciting force $P_O$ = 0.05 * 4000 = 200 lb

### 3 – Damping Factor

Damping factors for vibration vary between 2% to 5% for parking floor systems. For an empty multi-span parking structure the damping factor is likely to be 2%. For a full parking structure it is closer to 5%. A damping factor of 3% is suitable for a parking floor in moderate use. Hence, $\beta$ = 0.03 .

TABLE 3-1 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

The effective weight (W) of the panel under consideration, and the superimposed load that follows its vibration is subject to interpretation. A conservative estimate for a first analysis is to assume a region consisting of one panel only and excluding the weight of the supporting beams. An upper bound estimate is a region that extends at least one half the panel on each side of the center panel that represents the position of the vehicle, and includes the weight of the beams that support the considered region. For a long rectangular panel, such as the parking structure under consideration, a distance equal to 1.5 times the short direction is assumed in the beam direction.

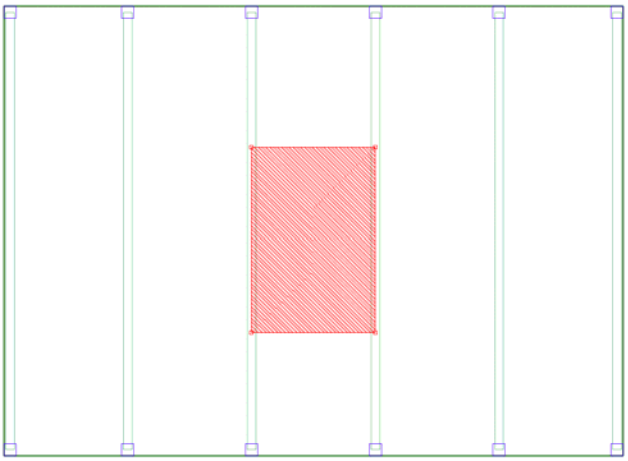


FIGURE 4-1 Identification of the Slab Region for Weight Calculation

Dimensions of the panel = 17 * 17*1.5 = 433.5 $ft^2$
Unit weight of the panel, consisting of 5” thick slab with 10 lb superimposed load

Weight of slab = (5/12)*150 + 10 = 72.5 psf

The total weight of the panel W is :

W = 433.5*72.5 = 31,429 lb

**5 – Acceleration Caused by the exciting force**

The following relationship yields an estimate of the peak acceleration ratio ($a_p$ /g) caused by the force applied to the floor

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

$P_0$ = 200 lb

$f_n$ = natural frequency equal to 3.73 Hz
β = 0.03
W = 20,952.5 lb

$$\frac{a_p}{g} = \frac{200 \times e^{-0.35 \times 3.73}}{0.03 \times 31{,}429} = 0.058 \ ; \ \textbf{5.8 \%}$$

**6 – Evaluation**

With the first natural frequency (Hz) from step 1 equal to 3.73 Hz and the peak acceleration ratio ($a_p$ /g) from step 5 equal to 5.8% refererence is made to the ATC chart below to determine the perception and acceptability of the vibration for a parking structure, dance halls, or gyms.

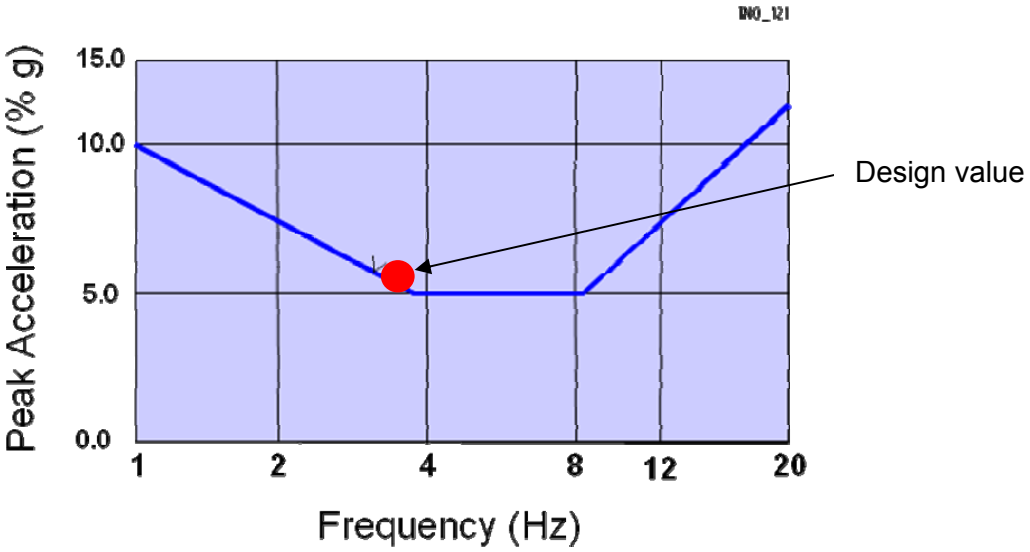



FIGURE 6-1 Threshold of Human Sensitivity to Vertical Vibration
From Rhythmic/Dynamic Activities (ATC)

The review of the chart, and the value calculated for the structure indicate that the level of vibration arising from the rolling of the larger vehicles assumed is likely to be on the borderline of being objectionable, when the parking structure is not nearly full. The larger damping factor associated with full occupancy will reduce the undesirable impact of vibration.

## 7 – Comments

The evaluation used in this example is primarily based on whether persons in the structure will consider the vibration annoying. The level of perception of vibration, as shown in Fig. 7-1 is much lower that the values shown in Fig. 6-1 and used in the evaluation. For parking structures, it is assumed that the structure will be subject to vibrations that are perceived by the persons using the structure

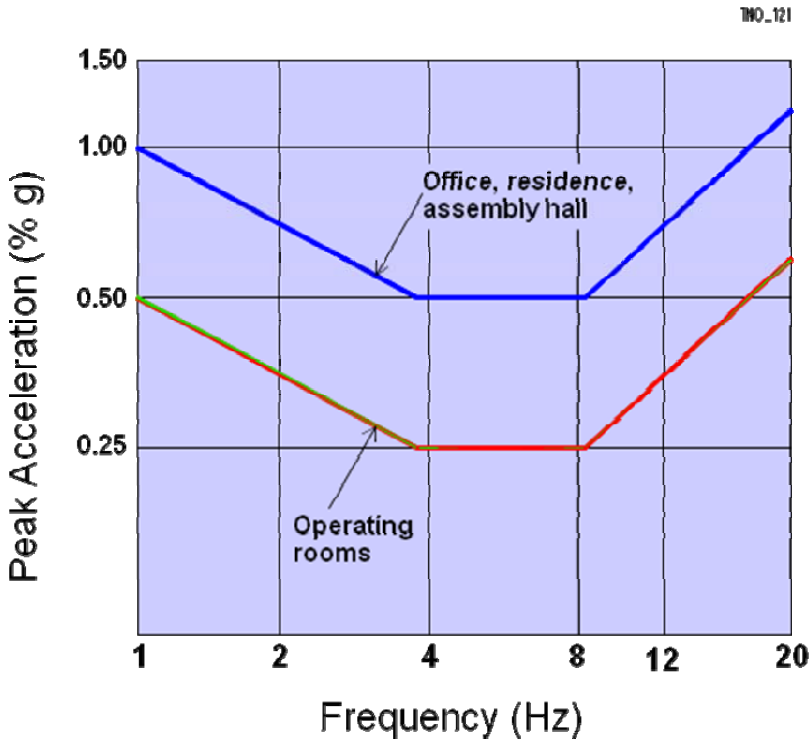



FIGURE 7-1 CHART FOR PERCEPTION AND ACCEPTABILITY OF FLOOR VIBRATION

## REFERENCES

ADAPT TN338 (2011), "*Vibration Evaluation of Floor Systems for Footfall,"* ADAPT Corporation, Redwood City, CA, www,Adaptsoft.com, 2011, pp 10

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