# Appendix III Dynamic assessment of the floor system

The dynamics of floor systems has been the subject of considerable academic research over the last 50 years. Despite this, no solid consensus has been reached regarding a design method for dynamic assessment. A number of methods have been proposed most of which represent different algebraic rearrangements of the same basic mathematics of a single degree of freedom dynamic system. While the methods look different they are generally identical except for the semi empirical methods used to model the floor as a single degree of freedom system. Most academic papers focus on an "internal panel" of a floor system despite the fact that most floor systems will not have any truly internal panels. This appendix is intended to provide background that will allow you to make reasonable judgements in relation to the application of the method of dynamic assessment generally referred to as the Murray Criterion. You should refer to the main calculations for the detailed application of the principles discussed in this appendix.

A primary focus in design for serviceability is the assessment of maximum static deflections. Excessive deflections can give rise to complaints regarding "droopy looking" slabs and a variety of alignment problems such as doors that jam and furniture that does not sit properly. Excessive deflections may also give rise to cracking and distortion of supported walls.

Another serviceability issue relates, not to deflections or displacements but rather to the second derivative of displacement with respect to time – ie acceleration. Accelerations will develop in a structure in response to regularly varying dynamic loads. The primary source of such dynamic loads has been identified as being a single pedestrian walking at a regular pace across the floor. The magnitude of the dynamic loads is low and the static deflections associated with them small, but there can be significant dynamic amplification of the static deflections if resonance develops, when the stepping frequency matches a natural frequency of the floor system.

People's sensitivity to vibrations varies with the frequency of the vibration. In the range of around 4 to 8 Hz accelerations as low as 0.5% of gravity may cause some people to complain while at both higher and lower frequencies they will tolerate higher accelerations. Figure 1 is consistent with AS2670.2 and illustrates the limits of the acceleration considered acceptable in three different situations. Note that for an office, the acceptable accelerations are considerably lower than in "busier" environments where vibrations tend not to be noticed.

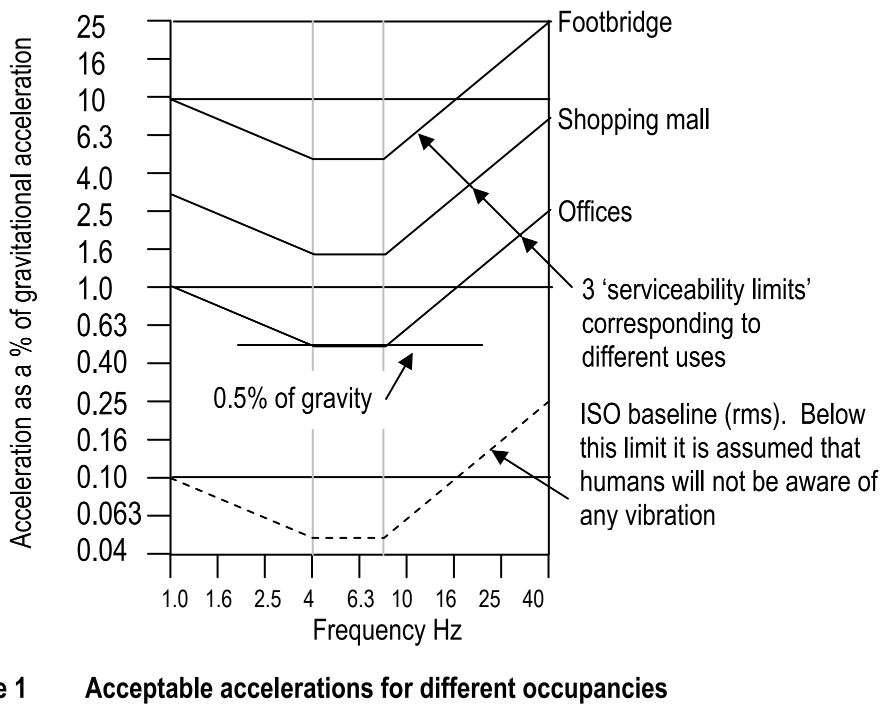



**Figure 1 Acceptable accelerations for different occupancies**

Dynamic accelerations in excess of 0.5% of gravity will generally only occur when a regularly varying load is applied for a reasonable length of time, at a frequency close to the natural frequency of the structure such that “resonance” develops. The natural frequency of a beam may be determined as:

$$f = 0.18\sqrt{\frac{g}{\delta_{static}}} \quad \text{Hertz} \qquad \text{or} \qquad \omega = 2 \times \pi \times 0.18\sqrt{\frac{g}{\delta_{static}}} \quad \text{rad/sec} \qquad (1)$$

With g = 9.8ms$^{-2}$ and $\delta_{static}$ = the static deflection due to the (static) mass assumed to be supported by the beam for the purposes of dynamic analysis. If it is assumed that $\delta_{static}$ is limited to say Span/500 then equation 1 becomes:

$$f = \frac{12.6}{\sqrt{Span}} \quad \text{Hertz} \qquad \text{(with the Span in metres)} \qquad (2)$$

Evaluating equation 2 for spans of 5 and 10 metre gives natural frequencies of 5.6 Hz and 3.98 Hz. That is longer spanning systems inevitably tend to have lower natural frequencies. As will be demonstrated below, such long span, low frequency systems will experience higher accelerations in response to pedestrian loading. Prior to the advent of longer spanning systems, resonance effects associated with pedestrian loading were seen as being unlikely, provided the normal static deflection criteria were applied. The increasing use of longer span flooring systems associated with both prestressed concrete and composite construction means that it is no longer sufficient to consider only the static deflections of a structure and a separate dynamic investigation is required.

**The dynamic load characteristics of a single pedestrian**

The pedestrian ‘stepping’ frequency is generally taken as varying between 1.6 and 2.2 Hz. As the maximum stepping frequency is less than the typical natural frequency of a beam or floor system at around 4 to 6 Hz, it might seem that resonance should not develop – but it turns out that while the stepping frequency may be limited to 2.2 Hz, the pedestrian loading contains significant harmonics at integer multiples of this frequency.

Walking is a complex process and it gives rise to a complex load that varies both with time and with position as a person walks across a structure as illustrated in figure 2.

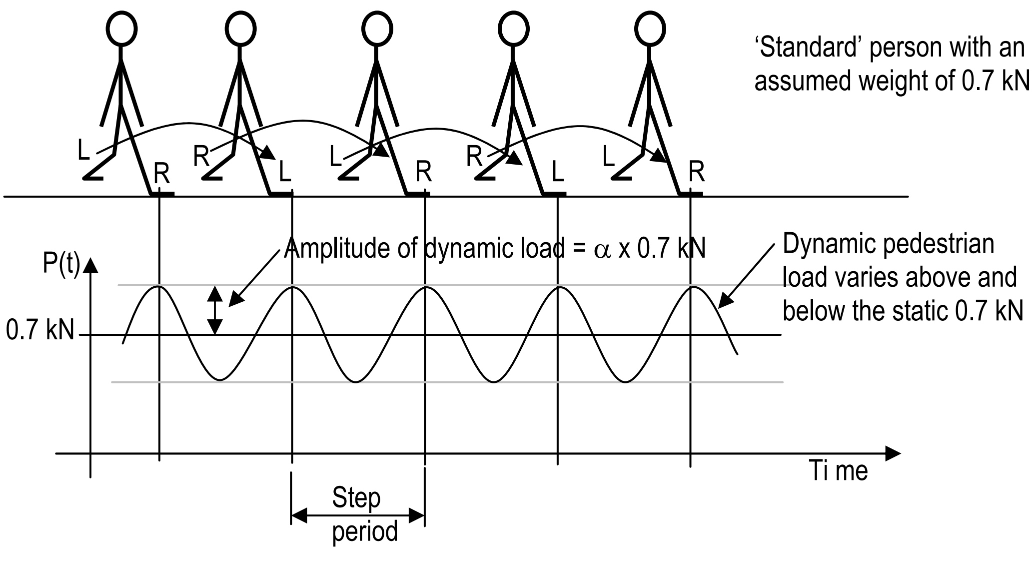



**Figure 2 The vertical load induced by a single pedestrian**

Figure 2 implies a perfectly smooth sinusoidal variation to the dynamic pedestrian load P(t) that could be expressed as:

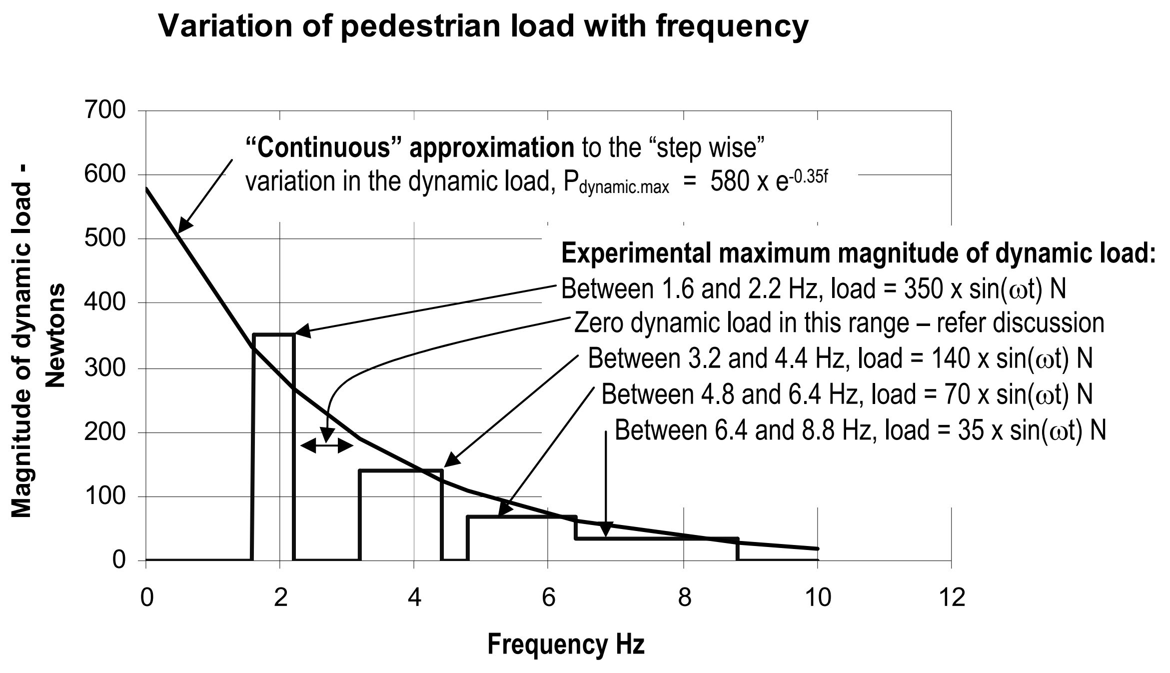
$$P(t) = 0.7kN \times (1 + \alpha\cos \omega t) \text{ with } \omega = 2\pi f = \text{the stepping frequency in radians per second.} \quad (3)$$

The 'real' stepping load is more complex. The experimentally measured pedestrian loading curve has been found to vary as a "square wave" rather than being simply sinusoidal. Allen and Murray (on the basis of a Fourier transform of the measured loading) give the following expression for the single person vertical pedestrian load as follows with the basic stepping frequency $\omega = 2\pi f$ and with frequency f taken to vary between 1.6 and 2.2 Hz:

$$P(t) = 0.7 \text{ kN} \times (1 + 0.5\cos \omega t + 0.2 \cos 2\omega t + 0.1 \cos 3\omega t + 0.05 \cos 4\omega t) \quad (4)$$

Graph 1 shows the experimentally determined "step wise" variation in the magnitude of the pedestrian load at frequencies corresponding to the basic stepping frequency and the higher frequency harmonics with significant dynamic loads up to frequencies of 10 Hz. The step wise variation implies that if the natural frequency of a floor was say 2.5 Hz, then the magnitude of the dynamic pedestrian load at this frequency would be zero, because 2.5 Hz is above the upper limit of the basic stepping frequency (2.2 Hz) but below the lower limit of the $2^{nd}$ harmonic frequency of 3.2 Hz. It would be very unwise to conclude that if a floor has a predicted natural frequency of 2.5 Hz then it could not be subject to possible resonance induced problems. On the one hand, any estimate of natural frequency has considerable uncertainty while on the other hand there could be a pedestrian with a higher or lower natural stepping pace.

For this reason and because the step wise "discontinuities" make mathematics awkward, it is convenient and appropriate to replace the step wise variation of the dynamic load with a continuous approximation for $P_{dynamic.max}$ as a function of the natural frequency as also illustrated in graph 1.




**Graph 1 Measured and approximated variation of dynamic load with frequency**

**Dynamic load characteristics for organised rhythymic events**

The"Murray Allen" method concentrates on the dynamic response of a structure to the loading originating from a single pedestrian. The question may well be asked 'why focus on a single individual when there may be hundreds of individuals walking on the structure?' The answer is that the dynamic effect of a single individual is

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