$$a_{max} = \frac{1}{2\beta} x \frac{580e^{-0.35fn}}{M_e} \qquad (16)$$

Equation 16 is a powerful one. It allows direct assessment of the maximum acceleration of a single degree of freedom system being driven at resonance by a pedestrian dynamic load – provided the natural frequency f_n, the damping ratio β and the equivalent mass M_e are known. Once the acceleration a_{max} at a particular natural frequency is determined this can be compared to the "acceptable accelerations" defined in figure 1.

It is important to recognise that there are no approximations in equation (15). It is an "exact" mathematically derived prediction for a single degree of freedom system. Equation 16 contains an approximation to the variation of the dynamic stepping force with frequency that is substantiated by experimental data. The more significant approximation is that involved in modelling the "real" structure to the single degree of freedom system – and this in turn is concerned with the estimation of the natural frequency f_n, the equivalent mass M_e and the system damping β.

The two referenced papers by Allen and Murray and by Ng and Yum both replace the equivalent mass M_e by half the total mass ½ M, because for beam and slab type systems the equivalent mass is generally close to half the total mass involved in the vibration as previously discussed. Next they replace the experimentally determined magnitude of the stepping load ($580\ e^{-0.35fn}$) by half of this value on the basis that a person does not continue walking indefinitely in the same spot and thus the full potential acceleration will not be reached. In addition they divide by g to obtain the acceleration as a fraction of the acceleration due to gravity to match the limits of acceptability defined in figure 1.

$$a_{max} / g = \frac{1}{2\beta} x \frac{0.5x580e^{-0.35fn}}{0.5Mg}$$

$$= \frac{290e^{-0.35fn}}{\beta W} \qquad \text{With W in Newtons} \qquad (17)$$

With W being the total (not equivalent) weight of the mass of the system (in Newtons) that is involved in the mode corresponding to the natural frequency f_n (Hz).

In different variants of the Murray method proposed at different times by different authors, equation 17 has been algebraically rearranged to the following forms with the limit of $a_{max.limit}$ / g taken as 0.5% or 0.005:

βW	must be >	$290\ e^{-0.35fn} / (a_{max.limit} / g)$	=	$58\ 000 \times e^{-0.35fn}$	Newtons	(17a)
f_n	must be >	2.86 ln(58 000 / βW)			With W in Newtons	(17b)

The damping ratio β for assessment of equation 17

The magnitude of the damping ratio can only be assessed on the basis of published recommendations based on testing. Allen and Murray recommend the following values;

Offices, residences, churches	0.03
Shopping malls	0.02
Pedestrian bridges	0.01

They also provide more detail suggesting the value of β as "0.05 for offices with full – height partitions and 0.02 for floors with few non structural components (ceilings, ducts, partitions etc) as can be found in churches".

Ng and Yum provide photos of typical office fitouts with recommendations for values of β as follows;

- Electronic office with work stations carpet and no services below $\beta = 0.02$
- Electronic office with work stations carpet and with services below $\beta = 0.025$
- Paper office with half height partitions, carpet, filing cabinets and furniture with suspended ceiling, air conditioning ducts and services below, $\beta = 0.03$
- Paper office with full height partitions perpendicular to floor beams, carpet, numerous filing cabinets, with suspended ceiling, air conditioning ducts and services below $\beta = 0.05$

In equation 17 the maximum acceleration is inversely proportional to β. A choice of β = 0.04 compared to 0.02 will cause a 100% change in the predicted acceleration. Consequently the designer must give careful consideration to the value of β adopted for design. For a typical office β = 0.025 should represent a conservative choice while anything above 0.03 would only be appropriate in very specific circumstances.

The natural frequency f_n for assessment of equation 17

Equation 1 may be used to determine the natural frequency of the secondary and primary beams considered in isolation using $\delta_{static.SB}$ and $\delta_{static.PB}$. The "combined" natural frequency of a panel of floor consisting of both primary and secondary beams may be calculated using equation 1, but using the sum of the separate deflections ie $\delta_{static.SB+PB}$. Thus

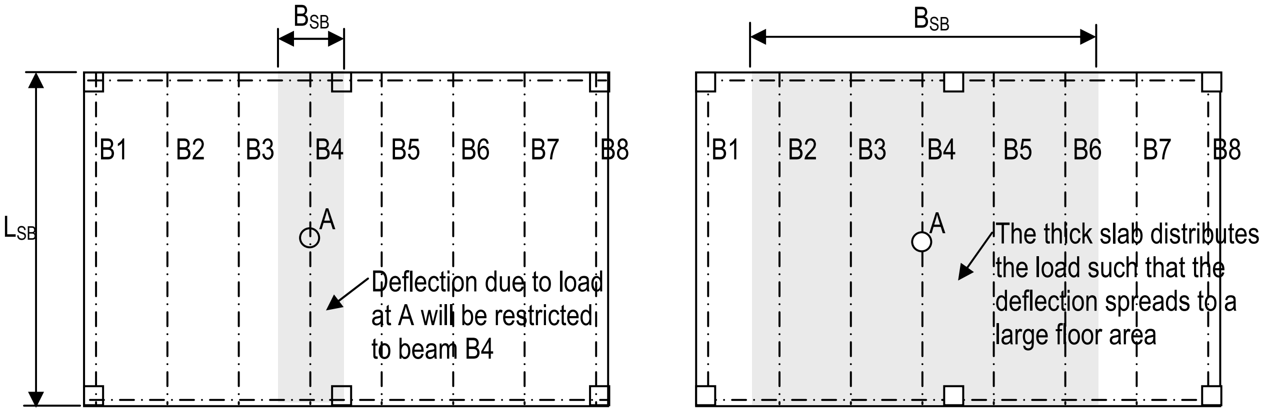
$$f_{combined} = 0.18\sqrt{\frac{g}{\delta_{static.SB} + \delta_{static.PB}}} \quad \text{Hertz} \qquad (18)$$

Note that from equation 17, the maximum acceleration is strongly dependent on the natural frequency of the system. A 25% increase in natural frequency from 4 to 5 Hz causes a 32% decrease in maximum acceleration. Consequently an accurate estimate of the natural frequency is critical to the dynamic assessment.

The value of W for use in assessment of equation 17

There are two fundamentally different masses used in assessing dynamic performance of a floor system. The first is the "traditional" supported mass (or weight) for an individual beam that is used for assessment of δ_{static} and thus the natural frequency using equation 1. The second is the mass (or weight) "W" that is "involved in a particular natural frequency mode". This mass may be several times the traditional supported mass. In equation 17 an increase in W causes a reduction in maximum acceleration because, if the single pedestrian has to "excite" a large mass then it will be more difficult than to excite a relatively small mass – firstly because more mass means more inertia to mobilise and secondly because more moving mass means more damping.

Assessment of W, represents the most "mysterious" approximation required in order to evaluate equation 17. The weight "W" represents the mass of the floor system that is "involved" in a particular natural frequency mode. That is it represents the mass of the floor that moves significantly for a particular natural frequency mode. The nature of the problem may be illustrated by analogy to static analysis of a beam and slab system as illustrated in figure 5.



Very thin slab - or no slab at all

Relatively thick slab

Figure 5 A "static" analogy to the problem of assessing W

For the floor system illustrated in figure 5, firstly imagine that there is no slab (or that the slab is very thin and flexible). For this situation, when a point load is applied to beam B4 then the load will be fully supported by this single beam. The only part of the floor that will deflect in response to the load at A will be directly in the vicinity of

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