The aim of this feature is to share up-dates, design tips and answers to queries. The Steel Construction Institute provides items which, it is hoped, will prove useful to the industry.

AD 256

Design Considerations for the Vibration of Floors – Part 3

Introduction

AD 254 *Design Considerations for the Vibration of Floors - Part 2* gave a general over-view on the prediction of the acceleration and fundamental frequency of floors. This Advisory Desk article presents some design guidance, which is based on the results of a three-year study conducted by the SCI. The design recommendations presented here offer some enhancements over the existing guidance in SCI publication SCI 076 entitled *Design Guide on the Vibration of Floors**.

Fundamental Frequency

Minimum Fundamental Frequency

It is recommended that to avoid the possibility of continuous resonant excitation by the first harmonic component of the walking activity, the floor should have an absolute minimum fundamental frequency of **3.0Hz**. However, this should be raised to **3.55Hz** if the floor response is assessed using Equation (11), where only a single constant Fourier coefficient of 0.1 is used (which is appropriate for walking frequencies greater than the first harmonic component).

Natural Frequency of components

For cases when the adjacent spans are approximately equal, the natural frequency of each of the structural components can be estimated from Equation (7) given in AD 254. For cases where composite beams have dissimilar spans, and are continuous over supports (or beams whose second moment of area is significantly different in each span), the designer may wish to account for the beneficial stiffening effect provided by the shorter span(s) increasing the natural frequency of the structural element. In these circumstances, the natural frequency may be estimated from Equation (7), but replacing δ by $\bar{\delta}$.

For two continuous spans, this may be found from the following expression:

$$\bar{\delta} = \left[\frac{0.4 + \dfrac{k_m}{k_s}\left(1 + 0.6\dfrac{L_S^2}{L_M^2}\right)}{1 + \dfrac{k_m}{k_s}} \right] \delta_{ssM} \qquad (8)$$

where δ_{ssM} is the simply-supported deflexion due to the self weight and other permanent loads on the main (larger) span L_M, I_M and I_S are the second moment of area of the beam for the larger and smaller span respectively, L_M and L_S are the larger and smaller span respectively, $k_M = I_M / L_M$ and $k_S = I_S / L_S$.

For three continuous spans, the following equation may be used:

$$\bar{\delta} = \left[\frac{0.6 + 2\dfrac{k_m}{k_s}\left(1 + 1.2\dfrac{L_S^2}{L_M^2}\right)}{3 + 2\dfrac{k_m}{k_s}} \right] \delta_{ssM} \qquad (9)$$

where the variables are identified in the preceding equation, above.

Damping

From recent tests on real floors, it is suggested that the following damping ratios ζ should be used in design, for estimating the response of composite floor systems:

ζ = 1.1% for completely bare floors or floors where only a small amount of furnishings are present.
ζ = 3.0% for normal, open-plan, well-furnished floors.
ζ = 4.5% for a floor where the designer is confident that partitions will be appropriately located to interrupt the relevant mode(s) of vibration (i.e., the partition lines are perpendicular to the main vibrating elements of the critical mode shape)

The above values are, for all intents and purposes, identical to those given within the SCI guide, except that recent measurements indicate that the damping values for completely bare floors are slightly lower than those given previously. Although the damping values for completely bare floors are not used regularly (mainly because the floor would not be in this state when the building was occupied), it may be useful for the engineer to consider this condition, as adverse comments could be raised over the acceptability of a floor before the building is completely fitted-out.

Floor Response

Peak Acceleration

The peak acceleration should be calculated from the following expression, which assumes resonant response:

$$a_{peak} = \frac{\alpha_n P}{2M\zeta} R_1 = \frac{2\alpha_n P}{m L_{eff} S \zeta} R_1 \qquad (10)$$

where

f_0 is the fundamental frequency of the floor
α_n is the Fourier coefficient of the n^{th} harmonic component of the walking activity. For the first harmonic component, this may be taken as a constant of 0.4. For the higher harmonics, a value of 0.1 may be taken for all harmonics
P is the person's weight, taken as 745.6 N (76 kg)
M is the modal mass, calculated from Equation (2) in AD254 ($M = mL_{eff}S / 4$)
m is the floor distributed mass (kg/m^2) including other permanent loads
L_{eff} is the floor beam effective span (m), calculated from below
S is the floor effective width (m), calculated from below
ζ is the damping ratio, taken from the values recommended above
R_1 is the resonance build-up factor, calculated from below.

For the special case when the fundamental frequency is greater or equal to 3.55 Hz, only a single value for the Fourier coefficient need be considered ($\alpha_n = 0.1$). In these circumstances, the above equation may be simplified to give the following design expression for the peak acceleration:

$$a_{peak} = \frac{2 \times 0.1 P}{m L_{eff} S \zeta} R_1 = \frac{0.2P}{m L_{eff} S \zeta} R_1 \qquad (11)$$

Resonance Build-up Factor

The resonance build-up factor R_1 is given by:

$$R_1 = 1 - e^{-2\pi f_0 \zeta T_w} \leq 1.0 \qquad (12)$$

where T_w is the walking time ($T_w = D/V$) in seconds, D is the characteristic dimension in metres taken as the longer of the floor's plan dimensions or, when known, the longest corridor length and V is the walking velocity in m/s given by:

$$V = 1.67 f_p^2 - 4.83 f_p + 4.50 \text{ for } 1.7 \text{ Hz} \leq f_p \leq 2.4 \text{ Hz} \qquad (13)$$

where f_p is the walking frequency in Hz, which is taken as the lowest whole number fraction n, or *harmonic*, of the fundamental frequency of the floor (e.g., if f_0 = 8.6 Hz, n = 4 and f_p = 2.15 Hz).

For an open plan building, or where the designer is unsure of the corridor dimensions, R_1 may conservatively be taken as 1.0.

Modal mass

The effective vibrating mass M may be calculated from Equation (2) in AD 254. In this equation, the dimensions S and L_{eff} account for the effective plan area of the floor participating in the motion. Their values should be taken from Table 1 (reproduced from the SCI guide 076), where:

$RF_{main\ beam}$ is the relative flexibility of the primary beam (i.e., the deflexion of the primary beam compared to the total deflexion used in the calculation of the fundamental frequency)

S^* is the effective width of the floor participating in the vibration, calculated from the effective slab stiffness, given by:

$$S^* = 4.5\left(\frac{EI_1}{mf_0^{\,2}}\right)^{1/4} \quad (m)$$

where EI_1 is the dynamic flexural rigidity of the slab (Nm^2 per metre width)

L^* is the effective span of the secondary beam participating in the vibration, calculated from effective composite beam stiffness, given by:

$$L^* = 3.8\left(\frac{EI_b}{mbf_0^{\,2}}\right)^{1/4} \quad (m)$$

where EI_b is the dynamic flexural rigidity of the composite secondary beam (Nm^2) and b is the secondary beam spacing (m)

W is the width of the floor plate under consideration (m)

L_m is the span of the primary beam (m)

L_{max} is the total length of the secondary beam when considered to act continuously (m)

From recent tests on real floors, when the ratio of the slab stiffness to the beam stiffness I_1L / I_b < 0.133 the predictions using Equation (2) in AD254 may become conservative. In these circumstances, advanced analytical modelling, such as Finite Element analyses, is more suitable in estimating the likely level of floor response.

Acceptability Criteria

As was shown in AD254, the limits to vibrations in BS 6472 are given in terms of the root-mean-square (rms) acceleration a_{rms}. For a purely sinusoidal response, the rms acceleration may be calculated by simply dividing the peak acceleration, calculated from either Equation (10) or (11), by √2 (i.e., $a_{rms} = a_{peak} / \sqrt{2}$). Although the structural response to walking loads will not be a simple sine wave, this approach will produce

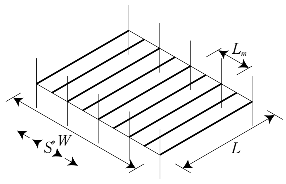
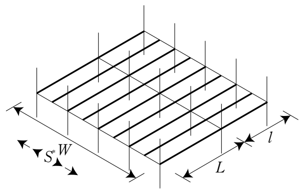
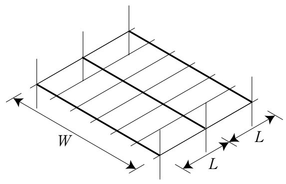
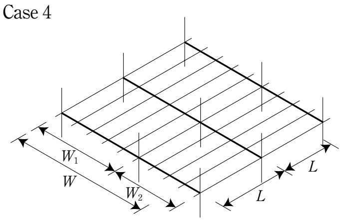
Indicative floor layout		Qualifying conditions	L_{eff} (m)	S (m)
Mode shape governed by motion of secondary beams	Case 1 	$RF_{main\ beam} < 0.2$	L	S^* but $\leq W$
		$RF_{main\ beam} > 0.2$	L	Greater of S^* or L_m but $\leq W$
	Case 2 	$l = L$	$2L$	As for Case (1) above
		$0.8L < l < L$	$1.7L$	
		$l < 0.8L$	L	
Mode shape governed by motion ofprimary beams	Case 3 	$RF_{main\ beam} < 0.6$	$2L$	W
		$RF_{main\ beam} > 0.6$	L^* but $\leq L_{max}$	
	Case 4 	$W_2 = W_1$	As for Case (3) above	$2W_1$
		$W_2 > 0.8W_1$		$1.7W_1$
		$W_2 < 0.8W_1$		W_1

Table 1. Values for dimensions L_{eff} and S used in determining the effective mass of the floor.

results that are on the conservative side. For engineers who wish to predict more accurately the acceptability of a floor, the vibration dose level (VDV) may be calculated in accordance with BS 6472.

As was discussed in AD254, the limiting rms acceleration is given by the base curve acceleration a_{base} multiplied by the response factor R, appropriate to the use of the floor (i.e., $a_{\rm rms} \leq a_{base} \times R$). From Fig. 1 in AD 254, the limiting acceleration is a function of the fundamental frequency of the floor, and may be calculated from:

$$a_{\rm rms} \leq 0.005R \qquad \text{for } 3.0 \text{ Hz} < f_0 < 8.0 \text{ Hz}$$

or (14)

$$a_{\rm rms} \leq 0.005R\left(\frac{f_0}{8}\right) \qquad \text{for } f_0 > 8.0 \text{ Hz}$$

For office accommodation, it is recommended that the following response factors should be adopted (reproduced from the SCI guide):

Type of Office	Response factor, R
General office	8
Special office	4
Busy office	12

Table 2. Response factors for offices

According to the SCI guide, the 'special office' is suitable for technical tasks requiring prolonged special concentration, including precision operations on computer screens. The 'general office' classification provides a suitable environment for normal office activities, including the use of computers and normal text operations on computer screens. The 'busy' office is one accessible to a large number of persons, with both visual and audible distractions concurrent with any vibration.

For areas subject to repeated walking traffic, with people walking briskly and purposefully, such as may be associated with large public circulation areas (e.g. pedestrian malls, extensive lobbies, trading floors, etc.), the response factor should not exceed $R = 4$.

Where the highest environmental quality is required (precision manual operations) lower values may be specified. Much lower values of R may be appropriate for certain critical processes, notably in the semi-conductor manufacturing industry. In these cases guidance on acceptable criteria must be sought from the Client.

In all cases, an open-minded approach should be made to selecting the value of R and a realistic balance struck between the risk and potential consequences of reaction at the 'some adverse comment' level and the cost of the floor. In many cases, adverse comment would not be associated with tangible loss. Changing R by a factor of 2 is equivalent only to the most marginal change of human perception.

The above gives some design recommendations for the vibration of floors. Although these recommendations are based on the present SCI guide, in some areas, this Advisory Desk article offers further enhancements over the existing design guidance. Details of the background to these recommendations may be found in the SCI technical report RT852 entitled *Design Guide for Vibrations of Long Span Composite Floors**. It should be noted that this article is not intended as a replacement to SCI publication SCI 076; for floors that are not covered directly here, guidance may be found in this publication.

Contact: Dr Stephen Hicks: e-mail: s.hicks@steel-sci.com

** Design Guide on the Vibration of Floors (P-076) photocopies only available at £12.50.*
Design Guide for Vibration of Long Span Composite Floors (RT-852) non-members £50, members £25.
Prices subject to p&p.
Tel: 01344 872775 E-mail: publications@steel-sci.com