Cracking of the concrete flange at the ends of composite beams can occur where there is continuity of the slab in the direction of the span (e.g. where secondary beams frame into both sides of a primary beam). Measures shall be taken to control cracking (e.g. for durability of the floor or satisfactory appearance of any applied floor finish).

NOTE: In New Zealand, additional guidance on cracking can be obtained from AS 3600.

6.4 VIBRATIONS

6.4.1 General

The response of a floor system incorporating composite beams to an applied source of vibration shall be controlled so that—

(a) no damage to the beam or the structure of which it is a part occurs;

(b) no unanticipated restrictions are imposed on the intended use of the structure; and

(c) there is a low probability of adverse comments from the occupants of the structure.

NOTE: Recommended limits for vibrations in a wide range of building environments are given in ISO 10137.

6.4.2 Serviceability limit state

6.4.2.1 *General*

For the prediction of vibrations of beams and floors, the modes of vibration and the associated frequencies and damping values shall be calculated. Examples of damping values (ζ) for some steel-framed floors are given in Table 6.4.2.1. For purposes of calculating the dynamic response and for assessment against serviceability criteria, floors commonly encountered in buildings shall be categorized as:

(a) low-frequency floors with a first mode natural frequency f_1 less than approximately 10 Hz; and

(b) high-frequency floors with a first mode natural frequency f_1 greater than approximately 10 Hz.

TABLE 6.4.2.1

CRITICAL DAMPING RATIOS FOR VARIOUS FLOOR TYPES

ζ	Floor finishes
0.5%	for fully welded steel structures (e.g. staircases)
1.1%	for completely bare floors, or floors where only a small amount of furnishings are present
2.0% to 3.0%	for normal floors
3.0% to 4.5%	for a floor where the partitions are located to interrupt the mode(s) of vibration (i.e. the partition lines are perpendicular to the main vibrating elements of the critical mode shape)

NOTE: The higher value of the damping ratio corresponds to floors with furniture, filing cabinets, etc.

6.4.2.2 *Low-frequency floors*

For floors of this type, all modes of vibration having natural frequency up to 12 Hz shall be taken into account. The weighted peak acceleration response at a position *r*, from an excitation at a point *e* should be taken to be:

$$a_{\mathrm{w,peak,e,r,n,h}} = a_{\mathrm{w,peak,e,r,n,h}} = \mu_{\mathrm{e,n}} \mu_{\mathrm{r,n}} \frac{F_{\mathrm{h}}}{M_{\mathrm{n}}} D_{\mathrm{n,h}} W_{\mathrm{h}} \qquad \text{. . . 6.4.2.2(1)}$$

where

$\mu_{e,n}$ = mode shape amplitude at the point on the floor where excitation force F_h is applied ($\mu_{e,n} \leq 1.0$)

$\mu_{r,n}$ = mode shape amplitude at the point where the response is to be calculated ($\mu_{r,n} \leq 1.0$)

F_h = excitation force for the h^{th} harmonic in Newtons from Equation 6.4.2.2(2)

M_n = modal mass of mode n, in kilograms

$D_{n,h}$ = dynamic magnification factor for acceleration from Equation 6.4.2.2(3)

W_h = frequency weighting parameter from ISO 2631.1 or AS ISO 2631.2 for the frequency of the harmonic under consideration hf_p (where h is the harmonic under consideration and f_p is the frequency of the activity)

For walking activities, the amplitude of the harmonic force for the h^{th} harmonic is given by:

$$F_h = \alpha_h Q \qquad \text{. . . 6.4.2.2(2)}$$

where

α_h = Fourier coefficient of the h^{th} harmonic (taken from Table 6.4.2.2)

Q = static force exerted by an ‘average person’, which shall be taken to be not less than 746 N

TABLE 6.4.2.2

FOURIER COEFFICIENTS FOR WALKING ACTIVITIES

Harmonic number, h	Excitation frequency range, hf_p (Hz)	Design value of coefficient for vertical direction, α_h	Phase angle, ϕ_h
1	1.8 to 2.2	$0.436(hf_p - +0.95)$	0
2	3.6 to 4.4	$0.006(hf_p - +12.3)$	$-\pi/2$
3	5.4 to 6.6	$0.007(hf_p - +5.2)$	π
4	7.2 to 8.8	$0.007(hf_p - +2.0)$	$\pi/2$

The dynamic magnification factor is given by the following:

$$D_{\mathrm{n,h}} = \frac{h^2 \beta_{\mathrm{n}}^2}{\sqrt{\left(1 - h^2 \beta_{\mathrm{n}}^2\right)^2 + \left(2h\zeta\beta_{\mathrm{n}}\right)^2}} \qquad \text{. . . 6.4.2.2(3)}$$

where

h = number of the h^{th} harmonic

β_n = frequency ratio (taken as f_p/f_n)

ζ = damping ratio

f_p = frequency corresponding to the first harmonic of the activity

f_n = frequency of the n^{th} mode under consideration

The total weighted acceleration response to each harmonic of the activity should be evaluated from the following equation:

$$a_{w,e,r}(t)=\sum_{n=1}^{N}\sum_{h=1}^{H}a_{w,e,r,n,h}(t)=\sum_{n=1}^{N}\sum_{h=1}^{H}\mu_{e,n}\mu_{r,n}\frac{F_h}{M_n}D_{n,h}\sin\left(2\pi hf_p t+\varphi_h+\varphi_{n,h}\right)W_h \quad \text{. . . 6.4.2.2(4)}$$

where

ϕ_h = phase angle

$\phi_{n,h}$ = phase of the response of the n^{th} mode relative to the h^{th} harmonic

where

$$tan\phi_{n,h}=\frac{-2h\beta_n\zeta}{1-(h\beta_n)^2} \text{ for } -\pi\leq\phi_{n,h}\leq 0$$

The total weighted root-mean-squared (rms) acceleration should be conservatively taken to be:

$$a_{w,rms,e,r}=\frac{1}{\sqrt{2}}\sqrt{\sum_{h=1}^{H}\left(\sum_{n=1}^{N}\left(\mu_{e,n}\mu_{r,n}\frac{F_h}{M_n}D_{n,h}W_h\right)\right)^2} \quad \text{. . . 6.4.2.2(5)}$$

6.4.2.3 *High-frequency floors*

For high-frequency floors, all modes with natural frequencies up to twice the first mode frequency shall be considered. The weighted peak acceleration response at a position *r*, from an excitation at a point *e* should be taken to be:

$$a_{w,peak,e,r,n}=2\pi f_n\sqrt{1-\zeta^2}\mu_{e,n}\mu_{r,n}\frac{F_I}{M_n}W_n \quad \text{. . . 6.4.2.3(1)}$$

where

F_I = excitation force in Newton-seconds (see Equation 6.4.2.3(2))

W_n = frequency weighting parameter from ISO 2631 or AS ISO 2631.2 for the frequency of the mode under consideration f_n

For walking activities, the equivalent design impulsive force F_I (representing a single footfall) should be taken to be:

$$F_I=60\frac{f_p^{1.43}}{f_n^{1.3}}\frac{Q}{700} \quad \text{. . . 6.4.2.3(2)}$$

where

f_p = pace frequency

f_n = frequency of the n^{th} mode under consideration

Q = static force exerted by an ‘average person’, which shall be taken to be not less than 746 N

The total weighted acceleration from the activity shall be evaluated from the following equation:

$$a_{\mathrm{w,e,r}}(t)=\sum_{n=1}^{N} a_{\mathrm{w,e,r,n}}(t) \qquad \ldots\ 6.4.2.3(3)$$

$$= \sum_{n=1}^{N} 2\pi f_{\mathrm{n}}\sqrt{1-\zeta^{2}}\,\mu_{\mathrm{e,n}}\mu_{\mathrm{r,n}}\frac{F_{\mathrm{I}}}{M_{\mathrm{n}}}\sin\left(2\pi f_{\mathrm{n}}\sqrt{1-\zeta^{2}t}\right)e^{-\zeta 2\pi f_{n}^{t}}W_{\mathrm{n}}$$

The total weighted rms acceleration shall be calculated using the following equation:

$$a_{\mathrm{w,rms,e,r}}=\sqrt{\frac{1}{T}\int_{0}^{T} a_{\mathrm{w,e,r}}(t)^{2}\,dt} \qquad \ldots\ 6.4.2.3(4)$$

where

T = integration time in seconds (which may be taken as $1/f_{\mathrm{p}}$)

6.4.3 Synchronised crowd movement

6.4.3.1 *Ultimate limit state*

6.4.3.1.1 *General*

Dynamic loads are significant when any crowd movement (dancing, jumping, rhythmic stamping, aerobics, etc.) is synchronized. In practice, this only occurs in conjunction with a strong musical beat such as occurs at lively pop concerts or aerobics. The dynamic loading is thus related to the dance frequency or the beat frequency of the music and is periodical. Such crowd movement can generate both horizontal and vertical loads. If the synchronized movement excites a natural frequency of the affected part of the structure, resonance occurs which can greatly amplify its response.

Where floors are likely to be subject to dancing and jumping activities characterized by synchronized crowd movement, the floor shall be designed for ultimate limit state considerations. In these situations the structure should be designed either—

(a) by avoiding significant resonance effects (Clause 6.4.3.1.2); or

(b) to withstand the anticipated dynamic loads (Clause 6.4.3.1.3).

6.4.3.1.2 *Design to avoid resonance*

To avoid resonance effects the vertical frequency should be greater than 8.4 Hz and the horizontal frequencies should be greater than 4.0 Hz (with the frequencies being evaluated for the mode of vibration in the empty structure).

6.4.3.1.3 *Design to withstand the anticipated dynamic loads*

For the calculation of dynamic response, a range of load frequencies and loading types should be considered. As the chances of obtaining a resonant situation in combination with the imposed loads given in AS/NZS 1170.0 are small, actual static loads for the activity should be used in the determination of dynamic loads. For these conditions a load factor of 1.0 shall be applied to the dynamic loads.

Synchronized dynamic loading caused by activities such as jumping and dancing are periodic and mainly depend upon—

(a) the static weight of the dancer(s), G;

(b) the period of the dancing load(s), T_{p}; and

(c) the contact ratio α_{c}, which is the ratio of the duration within each cycle when the load is in contact with the floor and the period of the dancing.

The force per unit area shall be calculated using the following equation, assuming a crowd density for the floor use:

$$F(t) = q\left\{1.0 + \sum_{h=1}^{H} \alpha_{\mathrm{h}} D_{\delta,\mathrm{h}} \sin\left(2\pi h f_{\mathrm{p}} t + \phi_{\mathrm{h}} + \phi_{1,\mathrm{h}}\right)\right\} \qquad \text{. . . 6.4.3.1.3(1)}$$

where

q = the weight of the jumpers per unit area (to enable the crowd to participate in synchronized activities, some suggested crowd densities are: 0.25 persons/m^2 for aerobic and gymnasium activities; and 2.0 persons/m^2 for social dancing activities)

H = total number of Fourier terms to be considered

α_{h} = Fourier coefficient of the h^{th} term from Table 6.4.3.1.3 or Equation 6.4.3.1.3(2)

f_{p} = frequency of the jumping load

ϕ_{h} = phase lag of the h^{th} term from Table 6.4.3.1.3

$\phi_{1,\mathrm{h}}$ = phase of the response of the first mode relative to the h^{th} harmonic from Equation 6.4.2.2(4)

$D_{\delta,\mathrm{h}}$ = the dynamic amplification factor for displacements for the h^{th} harmonic of the activity frequency, taken as

$$= \frac{1}{\sqrt{\left(1 - h^2\beta^2\right)^2 + \left(2h\zeta\beta\right)^2}}$$

where

h = number of the h^{th} harmonic

β = frequency ratio (taken as f_{p}/f_1)

ζ = damping ratio

f_1 = first mode frequency of the floor based on an empty structure

For large groups, the lack of coordination between participants can lead to lower Fourier coefficients. To reflect this lack of coordination the first three Fourier coefficients in Table 6.4.3.1.3 may be replaced by the following, used in conjunction with the phase angles presented in Table 6.4.3.1.3 for ‘normal jumping’:

$$\left.\begin{aligned} \alpha_1 &= 1.61 p^{-0.082} \\ \alpha_2 &= 0.94 p^{-0.24} \\ \alpha_3 &= 0.44 p^{-0.31} \end{aligned}\right\} \qquad \text{. . . 6.4.3.1.3(2)}$$

where

p = Number of participants in rhythmic activity, with $2 < p \leq 64$

As an alternative to Equation 6.4.3.1.3(1), the dynamic force may be conservatively calculated from:

$$F(t) = q\left\{1.0 + \sum_{h=1}^{H} \alpha_{\mathrm{h}} D_{\delta,\mathrm{h}}\right\} \qquad \text{. . . 6.4.3.1.3(3)}$$

TABLE 6.4.3.1.3

FOURIER COEFFICIENTS AND PHASE LAGS FOR DIFFERENT CONTACT RATIOS FOR SMALL GROUPS

Contact ratio α_c	Activity	Fourier coefficient and phase lag for h^{th} harmonic						
			h = 1	h = 2	h = 3	h = 4	h = 5	h = 6
2/3	Low impact aerobics	α_h	9/7	9/55	2/15	9/247	9/391	2/36
		ϕ_h	$-\pi/6$	$-5\pi/6$	$-\pi/2$	$-\pi/2$	$-5\pi/6$	$-\pi/2$
1/2	High impact aerobics	α_h	$\pi/2$	2/3	0	2/15	0	2/35
		ϕ_h	0	$-\pi/2$	0	$-\pi/2$	0	$-\pi/2$
1/3	Normal jumping	α_h	9/5	9/7	2/3	9/55	9/91	2/15
		ϕ_h	$\pi/6$	$-\pi/6$	$-\pi/2$	$-5\pi/6$	$-\pi/6$	$-\pi/2$

6.4.3.2 *Serviceability limit state*

There is no generally agreed acceptance criterion for floors subjected to synchronised crowd movement of this type. However, the multiplying factor values in Table 6.4.3.2, which have been developed from grandstands, may be used as a guide.

TABLE 6.4.3.2

HUMAN REACTION TO VARIOUS ACCELERATION LEVELS

ISO 10137 multiplying factor	Human reaction
<70	Reasonable limit for passive persons
<250	Disturbing
<340	Unacceptable
>340	Probably causing panic

SECTION 7 DESIGN FOR FIRE RESISTANCE

7.1 SCOPE

7.1.1 General

This section deals with the design of composite steel and concrete structures for fire resistance. Typical members include composite slabs, composite beams, composite columns A1 and structural systems incorporating composite members. The effect of openings and penetrations shall be considered in the analysis of fire resistance.

This section also deals with the provision of passive protection for fire resistance of members. Active protection measures are not covered. The use of this section is to design structural members for load bearing in fire conditions and to provide fire separation.

The design methods specified in this section apply to structural steel types as specified in AS 4100 or NZS 3404.

For profiled steel sheeting, reference should be made to Section 2.2.1. Reinforcing bars shall be in accordance with AS/NZS 4671. With the exception of composite slabs, for which the use of lightweight concrete is acceptable, this section assumes the use of normal weight concrete.

This section applies to structures that are within the scope of this Standard and designed according to this Standard.

7.1.2 Performance requirements

Structural members designed and constructed shall achieve the following:

(a) To maintain their structural resistance for the designated fire resistance level/fire resistance rating.

(b) To maintain their separating function if they form the boundaries of the fire cell/fire compartment, for the designated fire resistance level/fire resistance rating.

7.1.3 Definitions

For the purpose of this section the following definitions apply.

7.1.3.1 *Burnout*

Burnout exposure to fire for a time that includes fire growth, full development, and decay in the absence of intervention or automatic suppression.

7.1.3.2 *Enclosure*

A closed space in which a fire occurs.

7.1.3.3 *Equivalent time of exposure*

The equivalent time of standard fire exposure generated by burnout of the actual fire in a firecell/fire compartment.

7.1.3.4 *Fire cell/Fire compartment*

Any space, including groups of contiguous spaces, on the same or different levels within a building which is enclosed by any combination of fire separations, internal walls, roofs or floors.

7.1.3.5 *Fire resistance (R)*

The length of time for which the member or other component will withstand exposure to the fire without the load capacity falling below the fire limit state factored load, measured in minutes.

7.1.3.6 *Fire resistance level (FRL)*

The term used in Australia to describe the fire resistance of structural elements as determined in the standard test for fire resistance. It comprises three numbers giving the time for which each of the criteria of *R*, Structural Resistance, *E*, Integrity and I, Insulation are satisfied, and is presented always in that order, measured in minutes.

7.1.3.7 *Fire resistance rating (FRR)*

The New Zealand equivalent term for the 'Fire resistance level' (see Clause 7.1.3.6).

7.1.3.8 *Fire separation*

Any building element which separates firecells/fire compartments and provides a specific fire resistance rating.

7.1.3.9 *Flashover*

Stage of fire transition to a state of total room involvement in a fire of combustible materials within an enclosure or fire cell/fire compartment.

7.1.3.10 *Fully developed fire*

A fire, at its maximum rate of burning that involves all combustible materials in a given room within an enclosure or fire cell/fire compartment.

7.1.3.11 *Insulation (Fire)*

The ability of a fire separating member such as a wall or floor to limit the surface temperature on one side of the member when exposed to fire on the other side, measured in minutes.

7.1.3.12 *Integrity (Fire)*

The ability of a fire separating element such as a wall or floor to resist the passage of flame or hot gases through the member when exposed to fire on one side, measured in minutes.

7.1.3.13 *Load level*

The ratio of the effect of an action at the fire limit state to the design ambient temperature capacity of the structural member.

7.1.3.14 *Load ratio*

The ratio of the effect of an action at the fire limit state to the capacity of the structural member at time, $t = 0$ min in the fire.

7.1.3.15 *Localised fire*

A natural fire involving only a limited area of the fire load in the compartment.

7.1.3.16 *Natural fire*

A fire which can involve a localized fire or a realistic compartment fire with a growth and decay phase.

7.1.3.17 *Parametric fire (time temperature exposure)*

A representation of a natural fully developed fire determined on the basis of fire models and specific physical parameters defining the conditions in the fire compartment.

7.1.3.18 *Period of structural adequacy (PSA)*

As used in AS 4100 or NZS 3404 and referred to herein as Structural Resistance, *R* (see Clause 7.1.3.25), measured in minutes.

7.1.3.19 *Protected member*

A member which is protected from direct exposure to the fire by thermally insulating material applied to the member.

7.1.3.20 *Separating element*

Barrier that exhibits fire integrity, structural adequacy, thermal insulation, or a combination of these for a period of time under standard fire conditions.

7.1.3.21 *Simple joints*

Joints which are simple joints for ambient temperature design and which are also not considered to develop negative moment resistance for fire conditions.

7.1.3.22 *Solid webs*

Webs of an I section with either no web openings or with only a few, discrete web openings.

7.1.3.23 *Standard fire (time temperature exposure)*

Fire represented by a time–temperature relationship as given in AS 1530.4.

7.1.3.24 *Standard (fire) test*

A fire test performed in accordance with AS 1530.4.

7.1.3.25 *Structural fire resistance*

The ability of a member to maintain its load-bearing function for the duration of the fire exposure. It is more commonly defined in terms of time of exposure to fire, in which case it is expressed as the 'Fire resistance' (see Clause 7.1.3.5), but can also be expressed in terms of a limiting temperature or load-bearing capacity.

7.1.3.26 *Structural fire severity*

The combination of thermal exposure and duration imposed on a structure by a fire which imposes deformations and internal actions on the structural system.

7.1.3.27 *Time equivalence*

See 'Equivalent time of exposure' (Clause 7.1.3.3).

7.1.3.28 *Unprotected member*

A member which is directly exposed to the gas temperatures generated by the fire.

7.1.4 Notation

For the purpose of this section, the following notations apply:

$A_{\mathrm{i,T}}$ = area of material *i*, at any given temperature *T* (*i* is steel, reinforcement or concrete)

A_{m} = directly heated surface area of member per unit length

A_{m}/V = section factor of structural member

$[A_{\mathrm{m}}/V]_{\mathrm{b}}$ = box value of A_{m}/V

A_{p} = area of the inner surface of the fire protection material per unit length of the part of the steel member

A_{p}/V = section factor of the part of the steel cross-section (with contour protection)

D_{s} = depth of the steel section

E = integrity criterion

$E_{fi,d}$ = design effect of actions under fire conditions

$(EI)_{fi}$ = effective flexural stiffness under fire conditions

$E_{s,T}$ = temperature dependent modulus of elasticity of steel

$E_{r,T}$ = temperature dependent modulus of elasticity of reinforcement

$E_{c,sec,T}$ = temperature dependent secant modulus of elasticity of concrete

FRL or FRR = specified Fire Resistance Level (Australia) or Fire Resistance Rating (New Zealand).

$I_{s,T}$ = temperature dependent second moment of area of steel

$I_{r,T}$ = temperature dependent second moment of area of reinforcement

$I_{c,T}$ = temperature dependent second moment of area of concrete

I = thermal insulation criterion

L = length of primary beam

$L_{e,T}$ = buckling length of the column in the fire limit state condition

$M_{fi,d}$ = design value of the bending moment under fire conditions

$M_{fi,Rd,t}$ = design value of the bending moment capacity under fire conditions

M_{pp} = plastic sagging moment capacity of protected primary beam at time t

M_{ps} = plastic sagging moment capacity of protected secondary beam at time t

M_u = plastic sagging moment capacity of unprotected intermediate beam at time t

$N_{c,omb}$ = elastic critical load (Euler buckling load) under fire conditions

$N_{fi,d}$ = design value of the axial load under fire conditions

$N_{b,fi,Rd,t}$ = design value of the buckling capacity at any time t under fire conditions

$N_{c,fi,Rd}$ = design section compression capacity at the fire limit state

R = load bearing criterion

R_d = design resistance for ambient temperature design

$R_{fi,d,t}$ = design fire resistance, at time t

$R_{fi,d,20°C}$ = design fire resistance, at time t = 0 min

T = temperature

$T_{bottom\ flange}$ = beam bottom flange temperature

T_c = temperature of concrete around welded stud connector

= temperature of concrete part of the cross section

T_{fire} = fire temperature

$T_{fi,d,t}$ = temperature of the member at a given time t in the fire

T_g = ambient gas temperature at the end of the time interval Δt

T_r = temperature of rebar

T_s = temperature of steel

= steel temperature at time t, taken as uniform in each part of the steel cross-section