

C8. Assessment of Dynamic Performance of Floor System

C8.1 Definition of the dynamic assessment process

Refer to Section A4 for references to the papers and codes that form the basis for the method of dynamic assessment adopted for this design example. The paper by Ng and Yum is the primary reference. The notation used in this text is consistent with the Ng and Yum notation.

Refer to Appendix III for discussion of general issues relating to dynamic performance and analysis. The intention is that this section will provide step by step guidance in application of the “Murray Allen” assessment process for a very standard floor panel – essentially as a “black box” method. If you wish to gain understanding of the method that will allow you to apply it to non standard situations, then you will need to study Appendix III and the referenced papers related to dynamic assessment of floors. The Murray Allen method for assessment of the dynamic performance of flooring system as defined in the paper by Ng and Yum is as follows:

- At the overall level, assessment is similar to that for static deflections. Firstly, the dynamic behaviour of a secondary beam and of a primary beam are considered in isolation. Secondly the results from these analyses are combined to determine the dynamic response that will result from the combined dynamic response of the primary and secondary beams. This is similar to the process of finding the static deflections of individual beams (assuming their supports are fixed) and then adding the resulting deflections to determine the combined total deflection (on the diagonal as illustrated in the previous calculations).
- The dynamic assessment shall be carried out assuming the “lowest credible” amount of load w_{dyn} is supported by the individual beams in the flooring system corresponding to self weight plus a live load of 0.5 kPa and a superimposed dead load of 0.2 kPa.
- The dynamic stiffness of the composite beams $I_{trans,eff,dyn}$ shall be assessed on the basis of the following assumptions. Refer to Appendix III that provides detailed calculations for calculation of $I_{trans,dyn,eff}$ that are consistent with these assumptions.
 - The dynamic modulus of elasticity of the concrete = $1.35 E_c$ (1)
 - At the small stress ranges associated with floor vibrations it shall be assumed that there is 100% shear connectivity between the concrete and the steel (even though for strength the connectivity may be assessed as only 50%)
 - The effective width of the concrete flange for both secondary and primary beams shall be taken as the minimum of the supported width and 0.4L for internal beams and 0.2L for edge beams. L is the span of the beam under consideration. The “supported width” shall be assessed in the normal fashion. For an internal beam it shall be the beam spacing while for an edge beam it shall be half the beam spacing plus any cantilever slab on the outside edge of the beam. Note that particularly for the primary beams the dynamic flange width is considerably larger than the flange width b_{cf} used in the assessment of the strength of the composite beams.
 - For assessment of $I_{trans,eff,dyn}$ for secondary beams (with ribs perpendicular to span) only the concrete above the ribs will be considered. For assessment of $I_{trans,eff,dyn}$ where the ribs are parallel to the span, the full depth of the slab shall be used with a small ribbed profile such as Bondek (or an average depth if using a “trapezoidal” deck).



- The effect of a pedestrian walking on the flooring system will be taken as causing a repetitive load of the form:

$$P = P_o e^{-0.35f_n} \sin(2\pi f_n t) \quad (2)$$

Where P_o = A reference value of the pedestrian stepping force taken as 0.29 kN
 And f_n = The natural frequency of the beam under consideration

This is an empirical equation that matches the measured effects of a person walking. While the basic stepping frequency is around 1.6 to 2.2 Hz, higher frequency loading is induced by the upper harmonics of the stepping frequency but the magnitude of the dynamic force reduces sharply for these higher harmonics. This reduction in dynamic force with frequency is represented by the $e^{-0.35f_n}$ part of the equation.

- The criteria for acceptable dynamic performance for an office floor may be defined as:

$$a/g = (P_o e^{-0.35f_n}) / (\beta W) \text{ must be } < 0.5\% \text{ for } f_n \text{ between } 4 \text{ and } 8 \text{ Hz.} \quad (3)$$

Where P_o = 0.29 kN
 β = Dynamic damping ratio generally taken as 0.025 for an office floor
 And W = The total weight of that portion of the floor that is involved in a particular natural frequency mode of vibration

(Higher accelerations are acceptable at natural frequency outside this range but most floors will have their critical natural frequency between 4 and 8 Hz.)

- The weight W involved in a particular natural frequency shall be calculated on the basis of the relative stiffness of the beam under consideration and the stiffness of the slab (or slab and beam system) at right angles to the beam under consideration – with both stiffnesses expressed per unit width. The slightly different methods of determining W for secondary and primary beams are shown below:

The nomenclature used in the following calculations is the same as that of Ng and Yum. Note that the letter “t” indicates that the quantity has been averaged over the supported width of the beam while the suffixes SB, PB1 and PB2 refer to the secondary beam and the two primary beams considered.

For a secondary beam W_{SB} shall be calculated as follows:

Firstly I_t = $(K_s D_s)^3 / (12n)$ The slab stiffness per unit width transformed to steel

With D_s = The actual slab depth
 K_s = A modifier for the small areas of slab “missing” from the deck ribs = 0.96 for Bondek
 n = $E_{steel} / E_{c,dyn}$ The modular ratio so that I_t is referred to the stiffness of steel

Now I_{SB} = $I_{trans,eff,dyn}$ (On basis of previously declared assumptions and as implemented in spreadsheet output for a secondary beam)

And I_{tSB} = I_{SB} / S_{SB} Beam stiffness per metre width between secondary beams spaced at S_{SB}

Then B_{SB} = $C_{SB} (I_t / I_{tSB})^{0.25} L_{SB}$ (But not greater than 2/3 x floor width perpendicular to secondary Beams)

With C_{SB} = 2 for internal secondary beams
 = 1.0 for a secondary beam parallel with and adjacent to an edge

Then W_{SB} = $K_{c,dyn} B_{SB} L_{SB}$



With K_c = A continuity factor
 = 1.5 if there is an adjoining secondary beam on the same line with a span not less than 0.7L
 = 1.0 otherwise

W_{dyn} = Self weight of flooring (slab + beams) plus 0.2 kPa superimposed g and 0.5 kPa q as previously discussed

L_{SB} = The span of the secondary beam

B_{SB} = The effective width as calculated

For an internal primary beam W_{PB} shall be calculated as follows:

I_{PB} = $I_{trans,eff,dyn}$ (On basis of previously declared assumptions and as implemented in spreadsheet output for a primary beam)

I_{tPB} = I_{PB} / L_{SB} For an internal primary beam

Then B_{PB} = $C_{PB} (I_{tSB} / I_{tPB})^{0.25} L_{PB}$ (But not greater than 2/3 x floor width perpendicular to primary beams nor less than the supported width of the beam.)

With C_{PB} = 1.8 For internal primary beams, web side plate connected to secondary beams

Then W_{PB} = $K_c W_{dyn} B_{PB} L_{PB}$

With K_c = A continuity factor
 = 1.0 Because it is assumed that any continuity will be lost across the column

L_{PB} = The span of the primary beam

B_{PB} = The effective width as calculated

For an external or edge primary beam

It becomes difficult to interpret the detailed intent of both Murray and Allen and Ng and Yum for primary beams at the edge of a slab. The following matters appear to be generally agreed:

- Caution and conservatism is appropriate in dynamic assessment of edge beams at an internal slab edge such as around the perimeter of an internal atrium as often found in supermarkets and the like. Such slab systems often form cantilevers off the main floor and their static and dynamic serviceability may both be problematic. People leaning against the railing to the edge of the slab may be very aware of the dynamic effect of people walking around them and exciting the cantilever floor to vibrate. Depending on the magnitude of the dynamic response, not all people may be concerned but some may be alarmed.
- External edge beams that support the external wall of a high rise building may generally be regarded as being infinitely stiff for the purposes of dynamic assessment. The reason for this is that if for example the wall cladding is of reinforced concrete then it will almost inevitably stiffen up the edge beam. If the wall cladding is relatively light (say a glass curtain wall) then there is still likely to be some stiffening of the edge beam but more importantly the detailing of such light walls will almost inevitably introduce a high level of damping associated with the edge beam.

As a consequence of these matters, for the purposes of this design example, no consideration will be given to the external edge beams.



The natural frequency f_n of the primary and secondary beams may be calculated as:

For a secondary beam:

$$f_{n,SB} = 0.18(g / \delta_{static,SB})^{0.5}$$

Where $g = 9800 \text{ mm/s}^2$

And $\delta_{static,SB} = 5/384 (w_{dyn} \times \text{supported width}) L_{SB}^4/EI_{SB}$ (in mm)

(Note that the “supported width” used in this equation is the conventional supported width and is quite different to the B_{SB} and B_{PB} effective widths.)

For a primary beam:

If $L_{PB} > B_{SB}$
Then $f_{n,PB} = 0.18(g / \delta_{static,PB})^{0.5}$

Where $g = 9800 \text{ mm/s}^2$

And $\delta_{static,PB} = 5/384 (w_{dyn} \times \text{supported width}) L_{PB}^4/EI_{PB}$ (in mm)

If $L_{PB} < B_{SB}$
Then $f_{n,PB} = 0.18(g / \delta'_{static})^{0.5}$

Where $g = 9800 \text{ mm/s}^2$

And $\delta'_{static} = (L_{PB} / B_{SB}) 5/384 (w_{dyn} \times \text{supported width}) L_{PB}^4/EI$ (in mm)
(Provided L_{PB} / B_{SB} greater than 0.5)

Assessment of primary and secondary beams separately against the dynamic criteria as:

$$a/g = (P_o e^{-0.35 f_n,SB}) / (\beta W_{SB}) \quad \text{For an office must be } < 0.5\% \text{ for } f_n \text{ between 4 and 8 Hz.}$$

And $a/g = (P_o e^{-0.35 f_n,PB}) / (\beta W_{PB})$ Ditto

Assess against dynamic criteria for the combined dynamic mode involving both primary and secondary beams:

In the following equations, use $\delta_{static,PB}$ if $L_{PB} > B_{SB}$. If $L_{PB} < B_{SB}$ then replace $\delta_{static,PB}$ with $\delta'_{static,PB}$ as set out in previous section.

- Determine the combined frequency f_{comb} as:

$$f_{comb} = 0.18 (g / (\delta_{static,SB} + \delta_{static,PB}))^{0.5}$$

- Determine the weight W_{comb} involved in the combined dynamic response as

$$W_{comb} = (\delta_{static,SB} / (\delta_{static,SB} + \delta_{static,PB})) \times W_{SB} + (\delta_{static,PB} / (\delta_{static,SB} + \delta_{static,PB})) \times W_{PB}$$

- Assess the combined mode against the dynamic criteria as:

$$a/g = (P_o e^{-0.35 f_{comb}}) / (\beta W_{comb}) \quad \text{For an office must be } < 0.5\% \text{ for } f_n \text{ between 4 and 8 Hz.}$$



Composite Design Example for Multistorey Steel Framed Buildings

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Table of contents

Table of contents	iii
Preface	v
Section A: INPUT INFORMATION	1
A1. Client and Architectural Requirements	2
A2. Site Characteristics	4
A3. Statutory Requirements	5
A4. Serviceability	8
A5. Design Loads	9
A6. Materials and Systems	10
A7. Design Aids and Codes	11
Section B: CONCEPTUAL AND PRELIMINARY DESIGN	12
B1. Conceptual and Preliminary Design	13
B1.1 Consideration of alternative floor framing systems– Scheme A	14
B1.2 Consideration of alternative floor framing systems– Scheme B	15
B1.3 Framing system for horizontal loading – initial distribution of load	16
B1.4 Alternatives for overall distribution of horizontal load to ground	17
B2. Preliminary Slab Design	21
B3. From Alternatives to Adopted Systems	22
B3.1 Adopted floor framing arrangement	22
B3.2 Adopted framing arrangement for horizontal loading	23
B4. Indicative Construction Sequence and Stages	24
B4.1 The importance of construction stages in composite design	24
B4.1 Indicative construction sequence and construction stages	25
B4.2 Adopted construction sequence for design of erection columns	27
B4.3 Core construction alternatives	27
B4.4 Adopted construction method for the core	27
B5. Preliminary Sizing of Primary and Secondary Beams	28
B6. Plenum Requirements and Floor to Floor Height	30
B7. Preliminary Column Sizes and Core Wall Thickness	33
Section C: DETAILED DESIGN	35
C1. Detailed Design - Introduction	36
C2. Design Stages and Construction Loading	37
C3. Detailed Load Estimation After Completion of Construction	38
C3.1 Vertical loading	38
C3.2 Wind loading	39
C3.3 Seismic loading Not considered	40
C4. Erection Column Design	41
C4.1 Load distribution for erection column design	42
C4.2 Side Column C5 (typical of C5 to C10)	43
C4.3 End column C2 (typical of C2, C3, C12 and C13)	44
C4.4 Corner column C1 (typical of columns C1, C4, C11 and C14)	44
C5. Floor Beams – Construction Stage 1	45
C5.1 Secondary beams Group S1(11 050, 2800) (Beams B22 – B41, B43 – 48)	45
C5.2 Primary beams Group P1(9800, 5725) (Beams B1, B7 to B12, B18,	46
B19 – 21, B49 – 51 and B42)	46
C5.3 Primary beams Group P2(9250, 6600) (B2, B6, B13 and B17)	47
C6. Floor Beams – Construction Stage 3	48
C6.1 Secondary beams Group S1(11 050, 2800) (Beams B22 – 41, B43 – 48)	48
C6.2 Primary beams Group P1(9800, 5725) (Beams B1, B7 - B12, B18 – 21,	49
B49 – 51 and B42)	49
C6.3 Primary beams Group P2(9250, 6600) (Beams B2, B6, B13, B17)	49
C7 Floor Beam Design for Occupancy Loading	50
C7.1 Secondary beams Group S1(11 050, 2800) (Beams B19, B21, B22 - B41,	51
B43 – B49 and B51)	51



C7.2	Primary beams Group P1(9800,5725) (Beams B1, B7 to B12, B18)	58
C7.3	Primary beams group P2(9050, 6600) (Beams B2, B6, B13, B17)	63
C8.	Assessment of Dynamic Performance of Floor System	69
C8.1	Definition of the dynamic assessment process	69
C8.2	Application of the dynamic assessment process	73
C9	Final Slab Design	79
C9.1	Slab design for the office areas	79
C9.2	Slab design for the compactus areas	80
C10.	Longitudinal Shear Reinforcement Design	81
C10.1	Introduction	81
C10.2	Proprietary longitudinal shear reinforcement products	83
C10.3	Secondary beams group S1, B22 typical – longitudinal shear design	84
C10.4	Internal primary beams group P2, (B2 typical) longitudinal shear design	85
C10.5	Primary beams P1, (B1 typical) – longitudinal shear design	87
C10.6	Perimeter beams B19 to 21 and B49 to 51	88
C11.	Floor System Design Review and Final Decisions	89
C11.1	Floor design review	89
C11.2	Final floor framing plan and deck reinforcement	90
C12.	Final Design of RC Columns	91
C13.	Detailed Design of the Core	91
C13.1	Preliminary discussion and statement of limitations of this section	91
C13.2	Basic modelling of the core using beam elements	92
C13.3	The Space Gass Analysis Model	96
C13.4	Model verification and static deflections for W_s	97
C13.5	Dynamic analysis for natural frequency of building	98
C13.6	Interpretation and application of stress resultants from Space Gass	100
C13.7	Further investigation of the core using a Strand7 finite element model	102
C13.8	Review of core investigations	105
C14.	Steel Connection Design	106
C14.1	Can it be built?	106
C14.2	Representative connections	108
C14.3	Web side plate connection design for $V^* = 142$ kN	108
C14.4	Flexible end plate connection for $V^* = 279$ kN	112
C14.5	B2 to core web side plate connection for $V^* = 308$ kN	113
C14.6	Column splice for a load of $N^* = 1770$ kN	114
C14.7	Column base plate for a load of $N^* = 1770$ kN	115
C15.	Web Penetrations	116
C16.	Some Final Thoughts and Disclaimers	117
Appendix I	Theory and discussion – composite slabs	119
Appendix II	Theory and discussion - composite beams	133
Appendix III	Dynamic assessment of the floor system	149
Appendix IV	Theory and discussion steel connections	163
Appendix V	Corrosion and fire protection	175

