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:

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

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 $e^{-0.35fn}$ part of the equation.

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

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

Where P_o = 0.29 kN
β = Dyamic 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 It_s = $(K_s D_s)^3 / (12n)$ 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 It_s 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 It_{SB} = I_{SB} / S_{SB} Beam stiffness per metre width between secondary beams spaced at S_{SB}

Then B_{SB} = $C_{SB} (It_S / It_{SB})^{0.25} L_{SB}$ (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} = $K_c w_{dyn} B_{SB} L_{SB}$

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)

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

Then B_{PB} = $C_{PB} (It_{SB} / It_{PB})^{0.25} L_{PB}$ (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 $g = 9800$ mm/s^{-2}
And $\delta_{static.SB} = 5/384\ (w_{dyn}$ x 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 $g = 9800$ mm/s^{-2}
And $\delta_{static.PB} = 5/384\ (w_{dyn}$ x 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 $g = 9800$ mm/s^{-2}
And $\delta'_{static.SB} = (L_{PB} / B_{SB})\ 5/384\ (w_{dyn}$ x 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:

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

And $a/g = (P_o\ e^{-0.35\ fn.PB}) / (\beta W_{PB})$ 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
  $W_{comb} = (\delta_{static.SB} / (\delta_{static.SB} + \delta_{static.PB}))$ x W_{SB} + $(\delta_{static.PB} / (\delta_{static.SB} + \delta_{static.PB}))$ x W_{PB}

- Assess the combined mode against the dynamic criteria as:

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

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