Appendix A
Basic Data Input

A.1 Longspan Composite Slab Specimen

Dimensions
- 30 ft square bay, 3.88 ft long columns

Shell Properties (Slab is 8.75 in. thick, total, on 4.63 in. deck, 4 in.± ribs @ 12 in.)
- Weight per unit volume = 145 pcf
- Mass per unit volume = 4.50 pcf-sec.²/ft
- Thickness = 4.13 in. (Orthotropic stiffness provided by modifying the elastic modulus.)
- Modulus of elasticity parallel to ribs = 35000 ksi (Determined to result in $EI = 2,460,000$ kip-in.²/ft with 4.13 in. thick shell.)
- Modulus of elasticity perpendicular to ribs = 7220 ksi (Equals 5080 ksi increased 42% to account for non-prismatic section—slab is thicker at ribs than in between them.)
- Poisson’s ratio = 0.2
Girder Properties
- Area $= 13.0 \text{ in.}^2$, $I_3 = 3860 \text{ in.}^4$ ($E=29000$ ksi, transformed section) (W21x44 with 72 in. of 4.13 in. solid slab on one side, top of slab 8.75 in. above top of steel beam, $n = 5.71$).

Beam Properties
- Area $= 6.49 \text{ in.}^2$, $I_3 = 1730 \text{ in.}^4$ ($E=29000$, transformed section) (W14x22 with 72 in. of 4.13 in. solid slab and 24 in. of slab in ribs on one side, top of slab 8.75 in. above top of steel beam, $n = 5.71$).

Column Properties

Additional Mass
- Deck $= 6.53$ psf; Concrete in ribs $= 19.3$ psf. Therefore $25.8/32.2 = 0.801$ psf-sec.$^2$/ft is added as a superimposed mass over the entire model.

A.2 Longspan Composite Slab Mockup

![Figure A.2: Longspan Composite Slab Mockup Model](image)
Shell Properties

- Weight per unit volume = 145 pcf
- Mass per unit volume = 4.51 pcf-sec.²/ft
- Modulus of elasticity = 4710 ksi
- Poisson’s ratio = 0.2
- Long-span slab thickness = 6.63 in. (9.63 in. total thickness slab on 4.5 in. composite deck, 4 in.± ribs at 12 in.)
- Long-span slab flexural stiffness modifiers = 2.07 , 0.463
- Superimposed mass to account for long-span deck = 0.130 psf-sec.²/ft
- Corridor slab thickness = 4.92 in. (5.25 in. total thickness slab on 2 in. inverted composite deck, approximately 1 in. wide rib voids at 6 in.; Shell thickness and property modifiers set to result in correct mass and EI.)
- Corridor slab flexural stiffness modifiers = 1.11, 1.00
- Superimposed mass to account for corridor deck = 0.0621 psf-sec.²/ft

Girder 1 Properties
- Area = 17.1 in.², I₃ = 4190 in.⁴

Girder 2 Properties
- Area = 17.1 in.², I₃ = 2490 in.⁴

Girder 3 Properties
- Area = 17.1 in.², I₃ = 2330 in.⁴

Girder 4 Properties
- Area = 17.1 in.², I₃ = 1482 in.⁴

Beam 1 Properties
- Area = 7.69 in.², I₃ = 1955 in.⁴

Beam 2 Properties
- Area = 7.65 in.², I₃ = 204 in.⁴

Column Properties
A.3 Square-End Joist Footbridge

Figure A.3: Square-End Joist Footbridge Model (3D View)

Figure A.4: Square-End Joist Footbridge Model (Joist Elevation)

Dimensions

- 30 ft overall length, 4 ft c/c between joists, slab overhangs 18 in. at both sides.
- Distances from left end to web member intersections at bottom chord: 4.08 ft, 4.08 ft, 4.23 ft, 7.04 ft, 7.08 ft, 10.9 ft, 11.1 ft, 14.9 ft, 15.0 ft, 15.2 ft, 19.0 ft, 19.1 ft, 19.2 ft, 23.0 ft, 23.0 ft, 23.0 ft, 25.8 ft, 26.0 ft.
- Distances from left end to web member intersections at top chord: 0.42 ft, 3.01 ft, 5.20 ft, 5.22 ft, 7.0 ft, 8.85 ft, 8.98 ft, 11.0 ft, 12.9 ft, 13.0 ft, 15.0 ft, 17.1 ft, 17.2 ft, 19.0 ft, 21.0 ft, 21.1 ft, 23.0 ft, 24.7 ft, 24.82 ft, 27.0 ft, 29.6 ft, 29.9 ft
Slab Properties

- 6 in. thick, total, on 1.5 VL Vulcraft deck
- 3.5 ksi, normal weight concrete

Members (steel angle dimensions in inches)

- Top Chord: 2L2x2x0.148 with 1 in. separation
- Bottom Chord: 2L1.5x1.5x0.155 with 1 in. separation.
- Web Members (Left half, joist is symmetrical): L2x2x0.148, L2x2x0.176, L1.25x1.25x0.109, L2x2x0.148, L1.5x1.5x0.113, L1x1x0.109, L2x2x0.148, L1x1x0.109, L1x1x0.109, L1.5x1.5x0.113, L1x1x0.109, L1x1x0.109 (vertical web at midspan)

A.4 Shear-Connected Joist Footbridge

![Shear-Connected Joist Footbridge Model (3D View)](image1)

**Figure A. 5: Shear-Connected Joist Footbridge Model (3D View)**

![Shear-Connected Footbridge Model (Joist Elevation)](image2)

**Figure A. 6: Shear-Connected Footbridge Model (Joist Elevation)**

Dimensions

- 90 ft overall length, 3x30 ft spans, 4 ft c/c between joists, slab overhangs 18 in. at both sides.
- Distances from left end to web member intersections at bottom chord: 4.08 ft, 4.08 ft, 4.20 ft, 7.04 ft, 7.08 ft, 10.9 ft, 11.1 ft, 14.9 ft, 15.0 ft, 15.2 ft, 19.0 ft, 19.1 ft, 19.2 ft, 23.0 ft, 23.0 ft, 23.0 ft, 25.8 ft, 26.0 ft.
Distances from left end to web member intersections at top chord: 0.42 ft, 3.01 ft, 5.20 ft, 5.22 ft, 7.0 ft, 8.85 ft, 8.98 ft, 11.0 ft, 12.9 ft, 13.0 ft, 15.0 ft, 17.1 ft, 17.2 ft, 19.0 ft, 21.0 ft, 21.1 ft, 23.0 ft, 24.7 ft, 24.82 ft, 27.0 ft, 29.6 ft, 29.9 ft

Slab Properties
- 6 in. thick, total, on 1.5 VL Vulcraft deck
- 3.5 ksi, normal weight concrete

Members (steel angle dimensions in inches, joists are identical)
- Top Chord: 2L2x2x0.148 with 1 in. separation
- Bottom Chord: 2L1.5x1.5x0.155 with 1 in. separation.
- Web Members (Left half, joist is symmetrical): L2x2x0.176, L1.25x1.25x0.109, L2x2x0.148, L1.5x1.5x0.113, L1x1x0.109, L2x2x0.148, L1x1x0.109, L1x1x0.109, L1.5x1.5x0.113, L1x1x0.109, L1x1x0.109 (vertical web at midspan)

A.5 Riverside MOB

Figure A.7: Riverside MOB Model (3D View)
Figure A.8: Riverside MOB Member Key Plan

Dimensions
- Typical bay 30 ft. Beams 10 ft apart. Columns extend to 6.34 ft below and above the slab (halfway to the floors below and above)

Slab Properties
- 5.5 in., total, on 2 VLI Vulcraft composite deck
- 4 ksi, normal weight concrete

Members (See Key Plan, above)
- B1: W16x36 (1700 in.$^4$ transformed)
- B2: W21x73 (4970 in.$^4$ transformed)
- B3: W16x26 (2930 in.$^4$ transformed)
- B4: W12x14 (447 in.$^4$ transformed)
- G1: W21x55 (3860 in.$^4$ transformed)
• G2: W21x62 (4380 in.\(^4\) transformed)
• G3: W18x40 (5350 in.\(^4\) transformed)
• G4: W16x36 (4250 in.\(^4\) transformed)

A.6 First Bank and Trust

![Slab Properties](image)

Slab Properties
- 3 in., total, on 0.6C Vulcraft non-composite deck
- 4 ksi, normal weight concrete

Members (See Figure A.9)
- 22K4 (243 in.\(^4\) transformed, effective)
- 24K5 (325 in.\(^4\) transformed, effective)
- 12K1 (51.4 in.\(^4\) transformed, effective)
- G1: W24x68 (2690 in.\(^4\) transformed, effective)
- G2: W24x84 (3420 in.\(^4\) transformed, effective)
- G3: W27x94 (10800 in.\(^4\) transformed, effective)
- G4: W27x94 (10800 in.\(^4\) transformed, effective)
- G5: W12x26 (815 in.\(^4\) transformed, effective)
- G6: W27x94 (10800 in.$^4$ transformed, effective)
- G7: W21x44 (3140 in.$^4$ transformed, effective)
- G8: W24x62 (5850 in.$^4$ transformed, effective)
Appendix B

Examples

Figure B.1: Example Floor Bay

Given:

- Bay is 30 ft square.
- Bare slab, so damping is 0.5% of critical (viscous).

Objective:

- Illustrate steps preceding response history analysis for prediction of acceleration due to walking using individual footstep loading.
- Illustrate steps preceding response history analysis for prediction of acceleration due to walking using Fourier series loading.
- Illustrate the simplified frequency domain method prediction of acceleration due to walking.

B.1 Response History Analysis With Individual Footstep Loading

The first step is to determine which natural frequency will cause the maximum response if excited. Standard eigenvalue analysis predicts the modes shown in Figure B.2 which are all modes up to 15 Hz.

Several modes are predicted, so steady-state analysis is used to determine which will cause the maximum response. In SAP2000, this is accomplished by first creating a 1
lbic unit load case at the location of the walking force. In this case, it is assumed that the walker crosses the entire bay, so the point load is applied at mid-bay as shown in Figure B.3. The steady-state analysis case is created using the forms shown in Figure B.4. In this case, SAP2000 is set to use in. and kip units, so the acceleration will be output in in./sec.². However, %g is the more intuitive unit, so the output is scaled using the scale factor of 0.2591 which is equal to 100%g / 386 in./sec.². Because a 1 lbic force is the load, the resulting FRF magnitude is in %g / lbic. Hysteretic damping is set to 1% of critical which corresponds to 0.5% of critical viscous damping. The acceleration is monitored at the location of interest, in this case mid-bay and the resulting predicted FRF magnitude is shown in Figure B.5. Of the seven predicted modes, it is obvious that the second mode, at 5.21 Hz provides the maximum response if excited.

Figure B.2: Predicted Mode Shapes. (a) 4.44 Hz Lateral Mode, (b) 5.21 Hz Bending Mode, (c) 10.1 Hz Bending Mode, (d) 10.3 Hz Lateral Mode, (e) 12.6 Hz Bending Mode, (f) 13.3 Hz Torsional Mode, (g) 14.5 Hz Bending Mode
The step frequency is chosen so that one of the first four harmonics of the walking force will match the dominant natural frequency, 5.21 Hz. The reasonable step frequency range is 1.6 Hz to 2.2 Hz. The first harmonic is the step frequency, so it is far below 5.21 Hz. For the second harmonic to match the natural frequency, the step frequency would have to be $5.21 \text{ Hz} / 2 = 2.61 \text{ Hz}$ which is outside the reasonable step frequency range. For the third harmonic to match the natural frequency, the step frequency would have to be $5.21 \text{ Hz} / 3 = 1.74 \text{ Hz}$, which is within the reasonable step frequency range. Therefore, the analysis case is developed using a 1.74 Hz step frequency. To cause resonance, the footsteps must be applied at $1 / 1.74 \text{ Hz} = 0.578 \text{ sec.}$ measured from the beginning of one footstep to the beginning of the next. The next step is to select the design footstep waveform to be applied. The step frequency 1.74 Hz equals 104 bpm, so the 105 bpm footstep is used. (The next design footstep in Chapter 2 below 105 bpm is at 100 bpm.) In SAP2000, the footsteps are applied using the “Arrival Time” shown in Figure B.6. Note also that the Scale Factor is set to $100/386 = 0.2591$ so that the waveform will be reported in $\% g$ rather than in./sec.$^2$ The floor is 30 ft across, so it will take approximately $30 \text{ ft} / 2.5 \text{ ft} = 12$ steps to cross the floor. At 0.578 sec. / step, this will take 6.9 sec. At a time step of 0.005 sec., the required number of Output Time Steps is approximately 1400.
Figure B.4: Steady-State Analysis Case
Figure B.5: Example Predicted Accelerance FRF ($f_n = 5.21$ Hz, $A_{\text{Peak}} = 0.382$ %g/lbf)

<table>
<thead>
<tr>
<th>Initial Conditions</th>
<th>Analysis Case Name</th>
<th>Notes</th>
<th>Analysis Case Type</th>
<th>Time History Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero Initial Conditions</td>
<td>Walking For Design</td>
<td>Set Def Name</td>
<td>Modify/Show...</td>
<td>Linear</td>
</tr>
<tr>
<td>Continue from State at End of Modal History</td>
<td></td>
<td>IMPORTANT NOTE: Loads from this previous case are included in the current case</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Modal Analysis Case**
- Use Modes from Case: MCDAL

**Loads Applied**
- Modal Damping: Constant at 5.000E-03

**Time Step Data**
- Number of Output Time Steps: 1400
- Output Time Step Size: 5.0000E-03

**Figure B.6: Response History Analysis Case**
B.2 Response History Analysis With Fourier Series Loading

This example shows how to develop the Fourier series loading for use in a response history analysis. The Fourier series is of the following form:

\[ F(t) = \sum_{h=1}^{4} DLF_h Q \sin(2\pi f_h t - \phi_h) \]  

Eq. B.1

where

- \( h \) = Harmonic number
- \( DLF_h \) = “Design” DLF of the \( h \)th harmonic from Section 3.4.1.
- \( Q \) = Average bodyweight, 168 lbf
- \( f_h \) = Frequency of the \( h \)th harmonic
- \( \phi_h \) = Phase lag of the \( h \)th harmonic from Section 3.4.1.

The following steps are identical to those shown in the previous section:

- Eigenvalue analysis to determine natural frequencies and mode shapes.
- Steady-state analysis to determine which natural mode causes the maximum response.

As in the previous example, the step frequency is 1.74 Hz which is the frequency of the first harmonic of the Fourier series. Therefore, the frequencies for all four harmonics of the Fourier series, \( f_h \), are: 1.74 Hz, 3.47 Hz, 5.21 Hz, 6.95 Hz. Note that the third harmonic sinusoidal frequency matches the dominant natural frequency, so will cause resonance.

The dynamic load factors are determined using Figures 3.9 through 3.12, in this case using the equations. They are:

\[ DLF_1 = 0.50(1.74) - 0.53 = 0.340 \]
\[ DLF_2 = 0.0054(3.47) + 0.066 = 0.0847 \]
\[ DLF_3 = 0.006(5.21) + 0.03 = 0.0613 \]
\[ DLF_4 = 0.0066(6.95) + 0.01 = 0.0559 \]  

Eq. B.2

Therefore, the sinusoidal amplitudes for the four Fourier series terms are: 57.1 lbf, 14.2 lbf, 10.3 lbf, and 9.39 lbf. The four phase lags are 0, -\( \pi/2 \), \( \pi \), and \( \pi/2 \) which are from Section 3.4.1. The Fourier series is completely defined using amplitudes, frequencies, and phase lags.
The Fourier series is applied at midspan rather than “walking” it across the bay. The number of time steps in the response history is 6.94 sec. / 0.005 sec./step = 1387 steps.

B.3 Simplified Frequency Domain Method

This example shows the complete process of using the SFDM to predict the acceleration due to walking. The bay and damping are the same as shown in the previous two examples. Recall that the dominant natural frequency is 5.21 Hz and the accelerance FRF peak magnitude is 0.382 %g/lbf (Figure B.5).

As in the previous two methods, the step frequency is determined to be 1.74 Hz. The third harmonic of the walking force, at 5.21 Hz, will cause resonance. From Section 5.5, the third harmonic amplitude is 12 lbf.

The steady-state response to walking is

$$ a_{\text{Steady State}} = A_{\text{Peak}} F = (0.382)(12) = 4.58\%g $$  \hspace{1cm} \text{Eq. B.3} $$

The steady-state response to walking is the response to a complete resonant build-up, so must be reduced based on the actual duration of walking (6.94 sec. as determined in the previous section).

$$ \rho = 1 - e^{-2\pi \zeta_3} = 1 - e^{-2\pi(5.21)(0.005)(6.94)} = 0.679 $$ \hspace{1cm} \text{Eq. B.4} $$

Therefore, using the reduction factor proposed in Section 5.5, the acceleration due to walking is predicted to be

$$ a_{\text{Peak}} = 0.65 \cdot a_{\text{Steady State}} \cdot \rho = 0.69(4.58)(0.679) = 2.14\%g $$ \hspace{1cm} \text{Eq. B.5} $$