A SunCam online continuing education course

Industrial Floor Framing for Vibrating Equipment

by

Ernest L. Klaber, P.E.

INTRODUCTION

Industrial buildings and structures frequently house vibrating equipment such as pumps, blowers/fans, centrifuges, vibrating screens, chain mills, etc. Floors that support these type of equipment must not only be sufficiently strong to carry the weight of the equipment but must also have elastic properties that result in a floor with a natural frequency that is different from the operating frequency of the equipment. If the natural frequency of the floor is too close to the operating frequency of the equipment, the floor will vibrate excessively, causing, at a minimum, discomfort to people that stand on the floor or, in more severe situations, resulting in faulty equipment operation or even in damaged equipment.

The purpose of this course is to introduce practical methods available for finding natural frequencies of beams, to describe guidelines used in the design of industrial floor framing and to illustrate the principles discussed with design examples.

The course starts by enumerating and describing some of the methods available for obtaining values for the natural frequencies of beams. Methods vary from simply matching the situation at hand with published values in the literature, to simplified hand calculations, to use of computer programs.
The hand calculation methods presented are useful in identifying the factors affecting the natural frequency of supports.
Computer programs are now commonly used to obtain beam natural frequencies; information in this course will provide a background that should result in a better understanding of modeling requirements of such programs and consequently lead to their proper application.
Parameters important to the design of supports for vibrating equipment are presented, and typical values commonly used in industrial practice are described. Finally, two floor framing design examples are given. The first is of a floor that supports a vibrating screen; it is an example of "high tuning." The example highlights the fact that the weight of equipment supported by springs should not be included when calculating the natural frequency of the support.
The second is of a floor that supports a blower/fan; it is an example of "low tuning." In this example the weight of the equipment is included in the calculations of the natural frequency of the support. The example represents a case where the weight of the support must be increased to attain the manufacturer's recommended ratio of support weight to equipment weight.

CALCULATION OF NATURAL FREQUENCY

A beam is a system where mass and elasticity are not physically isolated components, consequently it has an infinite number of natural frequencies. For many situations, such as in the design of floor framing for vibrating equipment, the lowest natural frequency is the most important.

Only the dead load that is firmly attached to the support, and the weight of the support should be used to calculate the natural frequency of the supports. Live loads, impact and dynamic loads are not included. When the equipment is supported by springs, the weight of the equipment is not included in the frequency calculations. This is because the springs will allow the support to vibrate independently of the equipment.

Beams also have internal damping but industrial practice for designing floors that support vibrating equipment typically disregards the effect of damping.

USE OF PUBLISHED NATURAL FREQUENCY VALUES

Exact solutions for beams with uniformly distributed mass can be found in the literature; see Figure 1 below.

Simple Support: Cn = 1.57

Cantilever: Cn = 0.56

Fixed Support: Cn = 3.56

Fixed Hinged: Cn = 2.45

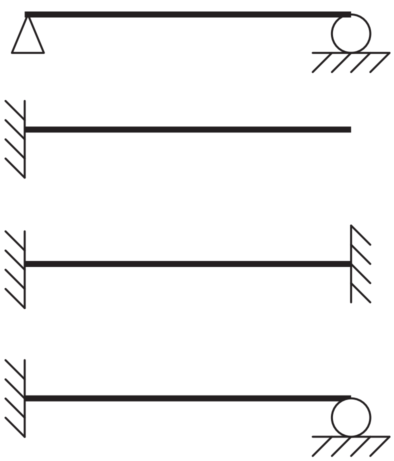


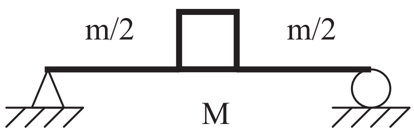
Figure 1
Natural Beam Frequencies for Beams with Uniformly Distributed Mass and Various End Supports
(adapted from Reference No. 1 page 57)

$$fn \ = Cn\sqrt{EI/ml^3} \qquad \textbf{(Equation 1)}$$

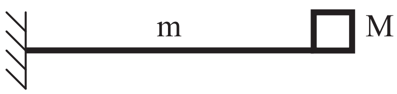
fn = natural frequency, cycles per second
Cn = coefficient
E = modulus of elasticity (lb/in^2)
I = moment of inertia (in^4)
m = mass of entire beam, $lb\text{-}sec^2/in$
l = length of beam (in)

Approximate solutions for slightly more complex systems can also be found in the literature; see Figure 2 below.

Simple support with mass in center:



Cantilever with mass on end:



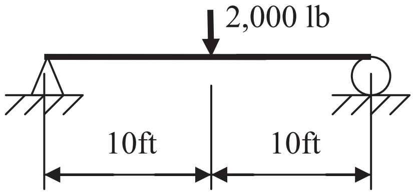
simple support: $fn = \frac{1}{2\pi}\sqrt{\frac{k}{M+m/2}}$ $k = (48EI)/l^3$ **(Equation 2)**

cantilever: $fn = \frac{1}{2\pi}\sqrt{\frac{k}{M+0.23m}}$ $k = (3EI)/l^3$ **(Equation 3)**

where:
fn = natural frequency, cycles per second
E = modulus of elasticity (lb/in^2)
I = moment of inertia (in^4)
m = mass of entire beam, lb-sec^2/ in
M = concentrated mass
l = length of beam (in)

Figure 2
Approximate Formulas for Natural Frequencies of Systems having both Concentrated and Distributed Mass
(adapted from Reference No. 2, page 7-4)

<u>Example 1:</u> **Calculate the natural frequency of a w10x22 beam loaded as shown:**



Using Equation 2:

$I = 118\ in^4$ $\quad l = 20x12 = 240$ in $\quad E = 29{,}000{,}000$ psi

$M = W/g = 2{,}000\ lb / (386\ in \times sec^{-2}) = 5.18\ lb\text{-}sec^2 / in$

$m = (22\ lb/ft \times 20\ ft) / (386\ in \times sec^{-2}) = 1.14\ lb\text{-}sec^2 / in$

$k = (48EI)/l^3 = (48 \times 29{,}000{,}000 \times 118) / (240)^3 = 11{,}882\ lb/in$

$$fn = \frac{1}{2\pi}\sqrt{\frac{k}{M+m/2}} = \frac{1}{2\pi}\sqrt{\frac{11{,}882}{5.18+1.14/2}}$$

= 7.23 cycles/sec

= 434 rpm (revolutions/minute)

USE OF DEFLECTIONS TO CALCULATE NATURAL FREQUENCIES

Most practical situations involve beam and equipment arrangements for which natural frequency values have not been published in the literature; consequently they must be computed. Engineers are familiar with the formula for natural frequency of a single degree of freedom system.

A single degree of freedom system is represented by a mass suspended from a spring as shown on Figure 3 at right. The equation for the un-damped natural frequency is listed in physics books as:

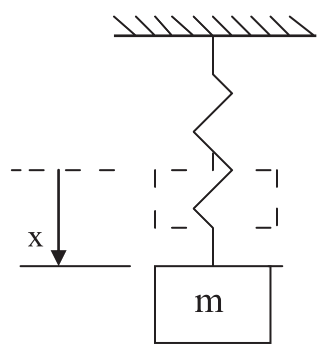
$$fn = \frac{1}{2\pi}\sqrt{k/m} \qquad \textbf{(Equation 4)}$$

where:

fn = natural frequency, cycles per second

k = spring stiffness, pounds per inch

m = mass, $lb\text{-}sec^2/in$



<u>Figure 3</u>

Refer to Figure 3 on previous page.
Force equation of spring: $F = k * x$
F = force mass "m" exerts on spring
x = displacement of mass "m" from original location

For the beam shown in Example 1, the equation for the deflection (Δ) under the 2000 lb weight (W) is:

$$\Delta = \frac{Wl^3}{48EI}$$

which can be written as: $$\frac{48EI}{l^3} = \frac{W}{\Delta}$$

note equivalency to spring equation: $$k = \frac{F}{x}$$

i.e. the beam can be thought of as a spring with a stiffness $k = \frac{48EI}{l^3}$
then its natural frequency will be given by:

$$fn = \frac{1}{2\pi}\sqrt{k/m} \qquad \text{(see Equation 4)}$$

Substituting W/g for m $$fn = \frac{1}{2\pi}\sqrt{kg/W}$$

Substituting Δ for W/k $$fn = \frac{1}{2\pi}\sqrt{g/\Delta} \quad \text{cycles/sec}$$

Substituting 386 in/sec^2 for g (standard value of gravitational acceleration) and multiplying the equation by: 60 sec/minute, we obtain:

$$fn = \frac{188}{\sqrt{\Delta}} \quad \text{(rpm)} \qquad \textbf{(Equation 5)}$$

Where: Δ = deflection, inches

$$\Delta = \frac{Wl^3}{48EI} = \frac{2{,}000(20\text{x}12)3}{48(29{,}000{,}000)118} = 0.168 \text{ in}$$

$$fn = \frac{188}{\sqrt{0.168}} = 459 \text{ rpm}$$

Note: the natural frequency calculated by assuming the beam to be a spring, and neglecting the mass of the beam, is only 5.8 % larger than the more exact value (434 rpm) obtained using Equation 2.

STATIC-DEFLECTION METHODS

These methods, based on the relationship between potential and kinetic energy of vibrating systems, provide the means for obtaining the lowest natural frequency value of multiple degree of freedom systems. These methods assume that the static deflection of the system is a reasonable approximation for the shape of the dynamic displacement, hence they are referred to as static deflection methods.

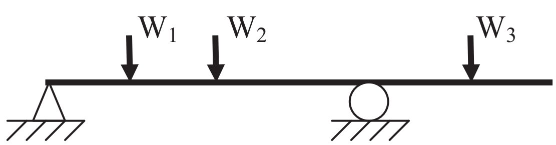
Southwell-Dunkerley Approximation.

If a system is broken into n parts, and each part is considered a single-degree-of-freedom system, then, the **lower bound** natural frequency for the coupled system is found by:

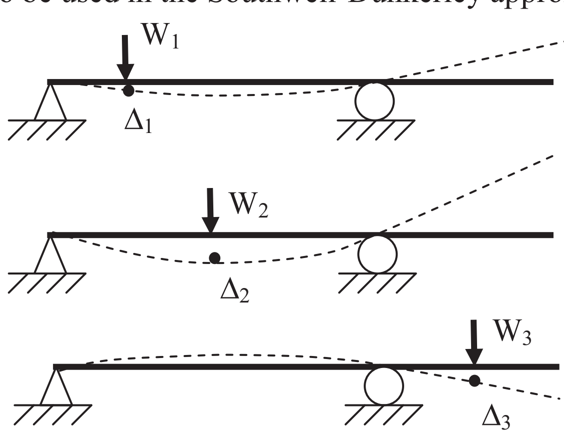
$$fn = \frac{188}{\sqrt{\Delta 1+\Delta 2+\ldots\Delta i+\ldots\Delta n}} \quad \text{(rpm)} \qquad \textbf{(Equation 6)}$$

where: Δi represents the deflection of the ith part in inches, due to the application of the ith load only. All loads are applied in the same direction.

For example, for a continuous beam supporting three large weights compared to the weight of the beam, thus:



The static deflections to be used in the Southwell-Dunkerley approximation would be:



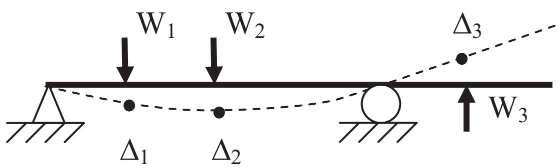
The value obtained with this method is always less than the "exact" answer.

The Southwell-Dunkerley method is used for hand calculation because the individual deflections can be calculated by using readily available formulas.

Rayleigh approximation.
The system is broken into nth parts, a deflected shape of the beam is assumed.
All the loads are applied simultaneously with the condition that the forces of gravity act in opposite directions on opposite side of the supports. The deflection in inches is calculated at each mass point, and all values are taken as positive regardless of the direction of the deflection. The values are then substituted into the following equation:

$$fn = 188\sqrt{\frac{W1\Delta1+\mathrm{W}2\Delta2+\mathrm{W}3\Delta3....+\mathrm{W}\Delta\mathrm{n}}{W1\Delta1^2+\mathrm{W}2\Delta^2+\mathrm{W}3\Delta3^2....+\mathrm{Wn}\Delta\mathrm{n}\hat{}2}} \quad \text{(rpm)} \qquad \textbf{(Equation 7)}$$

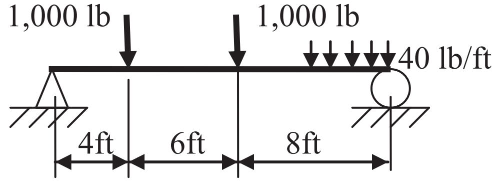
For the previous example, the deflections used in the Rayleigh approximation would be:



The frequency thus found will be an **upper bound** of the lowest natural frequency, i.e., the value calculated will be larger than the “exact” answer. This method lends itself to computer calculations, and is the method used by STAAD to calculate the natural frequency.
Note: current version of STAAD no longer labels the value as “natural frequency” but instead labels it as “Rayleigh frequency”

It is important to realize that the deflections used to calculate the natural frequencies are not actual deflections and are only a tool.
Note: the discussion of the static deflection methods has been adapted from Reference No. 1, Pages 58 and 59.

<u>Example 2</u>: Using the Southwell-Dunkerley method, calculate the natural frequency of an 18 y ft long w24x94 beam loaded as shown below. To account for the distributed loads, include the deflection at mid-span do to the distributed dead loads in the natural frequency equation.



Distributed dead load: w = 40lb/ft + 94lb/ft (weight of beam) = 134lb/ft

Using Equation 6:
$\Delta_1 =$ deflection under load 1 do to load 1 (1,000 lb load)
$\Delta_2 =$ deflection under load 2 do to load 2 (1,000 lb load)
$\Delta_3 =$ deflection at mid-span do to distributed dead load (134lb/ft)

$$\Delta_1 = \frac{Pa\text{^}2b\text{^}2}{3EI(l)} = \frac{1{,}000lb(4ft)\text{^}2(14ft)\text{^}2(\frac{1{,}728in^3}{ft^3})}{3\left(\frac{29{,}000{,}000lb}{in^2}\right)(2{,}700in^4)18ft} = 0.00128 \text{ in}$$

$$\Delta_2 = \frac{Pa\text{^}2b\text{^}2}{3EI(l)} = \frac{1{,}000lb(10ft)\text{^}2(8ft)\text{^}2(\frac{1{,}728in^3}{ft^3})}{3\left(\frac{29{,}000{,}000lb}{in^2}\right)(2{,}700in^4)18ft} = 0.00262 \text{ in}$$

$$\Delta_3 = \frac{5wl\text{^}4}{384EI} = \frac{5\left(\frac{134lb}{ft}\right)(18ft)(18x12)^3\ in^3}{(384)29{,}000{,}000lb/in^2(2{,}700in^4)} = 0.00404 \text{ in}$$

$$\Delta_1 + \Delta_2 + \Delta_3 = 0.00794 \text{ in}$$

$$fn = \frac{188}{\sqrt{0.00794}} = 2{,}110 \quad \text{rpm}$$

USE OF COMPUTER PROGRAMS TO CALCULATE NATURAL FREQUENCIES

There are many structural computer programs that can be used to find natural frequencies; this course uses STAAD, see Reference No. 3
The following paragraphs have been copied from STAAD's Technical Reference Manual. The manual's paragraphs are not copied in their entirety, only the parts applicable to this course. (Beginning of paragraphs copied from STAAD Technical Manual, Reference No. 3, pages 679 to 681.)

5.34 Frequency Calculation

There are two methods available in STAAD for calculating the frequencies of a structure: 1) an approximate method called the Rayleigh method and 2) a more exact method which involves the solution of an eigenvalue problem.

5.34.1 Rayleigh Frequency Calculation

This command may be used to calculate the Rayleigh Method approximate frequency of the structure for vibration corresponding to the general direction of deflection generated by the load case that precedes this command. Thus this command typically follows a load case.
General Format:

CALCULATE RAYLEIGH (FREQUENCY)

(Note: in previous versions of STAAD, the command was: calculate natural frequency.)
Description
This command is specified after all other load specifications of any primary load case for which the Rayleigh frequency is calculated.
The frequency calculated estimates the frequency as if the structure were constrained to vibrate in the static deflected shape generated by the loads in the load case.
In many instances, the forces should be in one global direction to get the mode and frequency associated with that direction.

5.34.2 Modal Calculation Command

This command may be used to obtain a full scale eigensolution to calculate relevant frequencies and mode shapes.
General Format:

MODAL (CALCULATION REQUESTED)

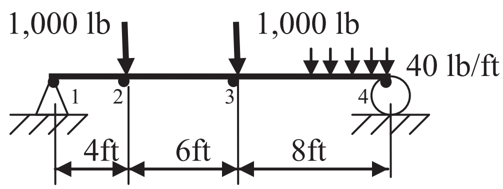
(End of paragraphs copied from STAAD Technical Manual)
The "Calculate Rayleigh Frequency" command calculates only the frequency of the system vibrating in the shape produced by the input loads. The advantage of the Modal Calculation, is that it calculates the frequency of each possible mode of vibration for the system. The Modal

Calculation results are not the "theoretically exact" answers for a system consisting of elements with distributed mass; the answers are accurate for a system represented by masses concentrated at the joints. The Modal Calculation takes all distributed self weights and member loads, and distributes them proportionally to the adjacent joints, then it calculates the modes of vibration for the masses concentrated at the joints. The answers are sufficiently accurate for all practical purposes. The Modal Calculation command will be illustrated in Example 3.

STAAD will now be used to calculate the natural frequency of Example 2, for computer input and output see STAAD COMPUTER RUNS section, Example 2-1. The beam is modeled so that a joint is located at each of the concentrated loads:

Example 2-1:

$\bullet_1$ Indicates joint number 1



From STAAD run, example 2-1, the Rayleigh frequency calculated is:

$$fn = 35.6 \text{ cycles/sec} = 2{,}136 \text{ rpm} \quad \text{(upper bound)}$$

the value calculated using Southwell-Dunkerley (example 2) method was:

$$fn = 2{,}110 \text{ rpm} \quad \text{(lower bound)}$$

the closeness between the two values indicates that, for this example, the methods supply a relatively accurate answer.

IMPORTANCE OF PROPER MODELING

When creating a structural model for vibrating frequency determination, it is very important to create a joint at each significant concentrated weight location. The frequency calculation method involves only weights at joints and their displacements, as was seen in Equation 7.

In the computer program, weights between joints, such as distributed loads and self weights, are distributed proportionally between the joints of the member. The weights of the joints are then used in the weight-deflection calculations.

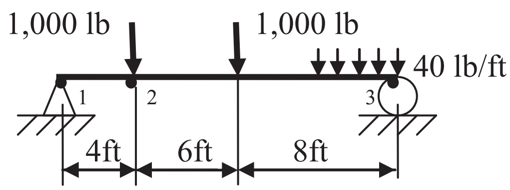
If a concentrated weight is input as a member load instead of as a joint load, then the deflection under that weight will not be calculated and the frequency calculated for the system will be in error.

The importance of proper modeling is illustrated in Example 2-2:

Example 2-2: incorrect modeling

●1 Indicates joint number 1

The joint under the second 1,000 lb load has been omitted



From STAAD run, sample 2-2, the Rayleigh frequency calculated is:

$$fn \;=\; 49.2 \text{ cycles/sec} \;=\; 2{,}952 \text{ rpm}$$

i.e. <u>the frequency calculated with incorrect modeling,</u>
<u>2,952 rpm is 38% larger than correct upper bound value = 2,136 rpm</u>

DESIGN PARAMETERS FOR FLOOR SYSTEMS SUPPORTING VIBRATING EQUIPMENT

Equipment manufacturers should always be consulted regarding their recommendations for these parameters. Sometimes equipment manufacturers' drawings do not list information such as dynamic loads, operating frequencies and equipment weights. It is the responsibility of the design engineer to contact the manufacturer to obtain all necessary information.
The important design parameters are:

1. Ratio of support natural frequency to forcing frequency: fn/ff

fn: is the natural frequency of the support

ff: forcing frequency (equipment operating frequency)

When the operating frequency of the equipment approaches the natural frequency of the support system, resonance ensues; this means the amplitude of the floor vibration increases significantly. The magnification factor is given by the following equation:

$$\text{Magnification Factor:} \quad Mf = \left| \frac{1}{\left(1 - \frac{ff^2}{fn^2}\right)} \right| \qquad \textbf{(Equation 8)}$$

In Table 1, several magnification factors have been calculated for various ratios fn/ff

fn/ff	0.5	0.7	0.75	0.8	0.9	1.1	1.5	2.0	2.5
Mf	0.33	0.96	1.28	1.78	4.26	5.76	1.8	1.33	1.19

Table 1
Magnification Factor - vs – fn/ff

It can be seen that amplitudes become excessive for ratios of $fn/ff > 0.8$ and ratios of $fn/ff < 1.5.$ When these limits are exceeded, the Mf is larger than $\approx$ 1.8.
The limits placed on the ratio fn/ff provide a **safety factor** against excessive vibrations.
The most common cause of floors vibrating excessively is that the natural frequency of the floor is too close to the operating frequency of the equipment. Recommended fn/ff factors have been developed to prevent such occurrences. See Table 2 below.

Type of end support (framed to)	Span	fn/ff
Column	Less than 20 feet	Greater than 1.5 or less than 0.8
Column	Greater than 20 feet	Greater than 2.0 or less than 0.75
Beam	Less than 20 feet	Greater than 2.0 or less than 0.75
Beam	Greater than 20feet	Greater than 2.5 or less than 0.75

Table 2.- Recommended fn/ff ratios.
(Adapted from Reference No. 4, page 100)

It is more desirable that the natural frequency of the support be greater than the equipment operating frequency (high tuning), that way the natural frequency of the support is never approached.
If the natural frequency of the support is lower than that of the equipment (low tuning), the frequencies will be close when the equipment starts and when it stops and resonance will occur. If the equipment starts and stops quickly, then the situation may be acceptable. If the equipment starts and stops slowly, then resonance will occur over a longer time period and support vibrations may become intolerable.

Sometimes however, economic considerations will dictate the use of low tuning.
When low tuning, the support's frequency for the other modes of vibration should be investigated to insure that they are not close to the equipment frequency. This can be done with the modal calculation command mentioned previously. See Example 4.
The most cost effective way to increase a support natural frequency is to keep spans as short as possible, this can be done in the planning stage. The next most effective way to increase the natural frequency of a support is to increase the depth of the beams.

2. Mass ratio.
Many equipment manufacturers, not all, have recommendations regarding the ratio of weight of support to weight of equipment. For example, a ratio of 4 to 1 is commonly recommended by manufacturers of large fans.

3. Equipment balancing.
Improperly balanced equipment is the second most common cause of problems for floors that support vibrating equipment. If the equipment is not balanced correctly, it will cause the floor to vibrate excessively, even if the floor has been designed properly. Although balancing the equipment is not the responsibility of the floor designer, he should be aware of the possibility of it being the cause of excessive vibrations.

4. Impact.
An impact factor of 50% for live loads is common for vibrating equipment.

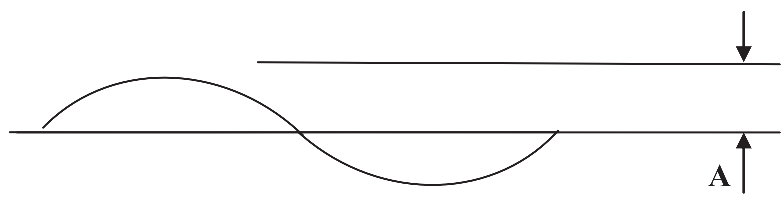
5. Damping.
Industrial practice for designing floors that support vibrating equipment typically disregards the effect of damping. For steel and concrete floors, the resonant damped frequency is very close to the un-damped natural frequency, also, the damped amplitude of vibration is not significantly different from the value calculated neglecting damping.

6. Displacement amplitude.
Support vibrations, may become uncomfortable to operators and, when severe, may cause faulty equipment operation and even equipment failure. Table 3 can be used as a guide for design; it shows general limits of displacement amplitude for different frequencies of vibration. Equipment manufacturers should be consulted regarding their recommendations for allowable support vibration oscillation amplitudes. Note: Table 3 describes displacement amplitude "A" as one half of the total oscillation.

RPM	Amplitude troublesome to persons	Amplitude limit for machines
300	0.035-0.017	0.03
400	0.0025-0.01	0.025
500	0.002-0.007	0.02
800	0.0015-0.0035	0.013
1,000	0.001-0.0025	0.01
2,000	0.0005-0.007	0.005

Table 3.- Limits of Displacement Amplitude for various RPM
(Adapted from Diagram on page 902, Reference No. 5)

A = Displacement Amplitude:



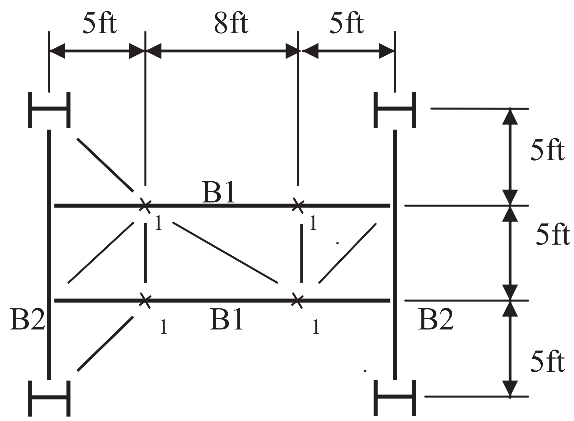
DESIGN EXAMPLE OF FLOOR SUPPORTING A VIBRATING SCREEN

Example 3 (See Figure 4)

Equipment Information:
Equipment: Vibrating screen
Screen weight: 10,000 lb
Live Load: 700 lb
Operating frequency: 800 rpm
Type of supports: spring mounts, 4 locations (for support locations see "x_1" in Figure 4)
Dynamic load transmitted by springs: 665 lb each mount
Impact load factor recommended by vendor: 50% of screen weight
Allowed support displacement: 0.03 inches, total oscillation
Vendor does not have any mass ratio requirements.
Note: since the screen is supported by springs, the screen dead load **should not** be added to support dead load for natural frequency calculations.

Support information:
Support plan is shown in Figure 4
Access platforms for the screen, not shown, are supported independently from the screen support.
Screen spring mounts sit on elevated, rigid posts above support floor. Weight of each post and attached vertical bracing is 300 lb.
A chute attached to bottom of beams B1 adds 200 lb at each post.
Diagonal floor bracing shown are WT4x9's, 5 ft beams that connect B1 beams are W8x18.

The natural frequency of a floor like the one shown in Figure 4 can be obtained by means of hand calculations. The natural frequency of beam B1 would be calculated as shown in Example 2, and then similarly for B2 (the reactions from B1 are added to B2 as concentrated loads and B2 is treated independently). The results are acceptable if the natural frequencies of interconnecting beams differ by a factor of 2 or more. For Example 3, it was found that the natural frequencies of B1 and B2 differ by less than 5%, consequently a computer run of the entire floor must be carried out. The natural frequency of the supports is found by means of the MODAL (CALCULATION REQUESTED) command.



Legend:

× 1 Denotes concentrated load:

Dead load: 300 lb posts + 200 lb chute = 500 lb

Screen weight: 10,000 lb/4 = 2,500 lb

Live load: 700 lb/4 material + 665 lb dynamic spring load = 840 lb

Live load with impact: 840lb x 1.5 = 1,260lb (governs)

Vendor impact load: 0.5(10,000/4) = 1,250 lb

PLAN – SCREEN SUPPORT
T/S EL. 100' - 0"
Figure 4

STAAD RUN:
See Example 3 in STAAD COMPUTER RUNS Section.
Joint numbers, member numbers and member shapes are shown in Figure 5.
The following command is required in order to request a modal calculation:
CUT OFF MODE SHAPE 3

LOAD COMANDS
To calculate the natural frequency of the floor, only the 500 lb concentrated dead loads at each support point, plus self weight of the beams is used. The weight of the screen is NOT used.
LOAD 1 LOAD TYPE DEAD TITLE LOAD CASE 1
SELFWEIGHT Y -1
JOINT LOAD
2 3 6 7 FY -0.5

For calculation of vibration amplitude, only the 665 lb spring load is used.

LOAD 2 LOAD TYPE LIVE
JOINT LOAD
2 3 6 7 FY -0.665

To check the floor's strength adequacy, the screen weight (2,500 lb), the attached dead loads (500 lb), and the live loads with impact (1,260 lb) are used: 2.5k + 0.5k + 1.26k = 4.26k

LOAD 3 TYPE NONE
SELFWEIGHT Y -1
JOINT LOAD
2 3 6 7 FY -4.26

The vendor impact load (1,250 lb) is intended as a value added to the dead loads for design of supports to make them sufficiently rigid so as to avoid objectionable vibrations. This value is not intended as an additional load when material loads and dynamic spring loads are considered.

STAAD RUN RESULTS

Natural Frequency:
It is not immediately clear how Table 2 values apply to Example 3. Some engineers would say a ratio of 2 is required, others would say a ratio of 1.5 is acceptable. We will use the more conservative value of 2 for this example.

Natural frequency (mode 1) = 27.998 cycle/seconds x 60 seconds/minute = 1,680 rpm
Therefore fn/ff = 1,680/800 = 2.1 > 2 therefore OK

The maximum joint displacement for the 665 lb dynamic loads = 0.00798 inches
From Table 1, we can see Mf will be around 1.3
Using Equation 8: $Mf = \left|\frac{1}{\left(1-\frac{ff^2}{fn^2}\right)}\right| = \left|\frac{1}{(1-\frac{800^2}{1680^2})}\right| = 1.29$

Magnified displacement amplitude = 0.00798*1.29 = 0.0103 inches < 0.013 (limit for 800 rpm listed in Table 3)
Maximum oscillation = 0.0103 x 2 = 0.0206 < 0.03 recommended by Vendor
Therefore beam sizes are acceptable.

Note: if the access platforms had been part of the screen support, then the allowed support displacement would be limited to less than 0.0035 inches, and the beam sizes would have to be increased.

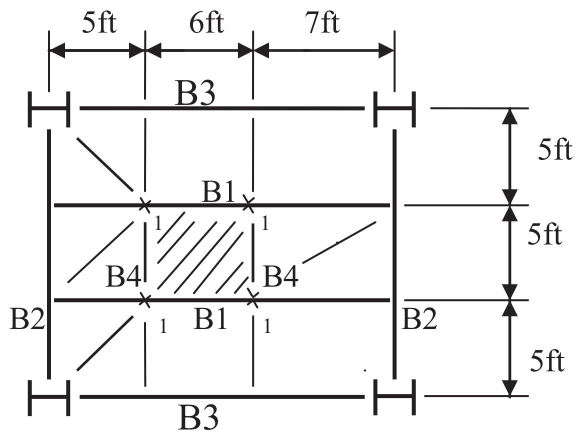
Support strength:
Code check results indicate that the beams are stressed only to within 15% of their capacity; the beams are therefore acceptable. Low level beam capacity usage is common with high tuning when dealing with spans and frequencies similar to Example 3.
Support reactions: all support reactions consist of vertical forces; this confirms that floor has been modeled properly.

DESIGN EXAMPLE OF FLOOR SUPPORTING AN INDUSTRIAL FAN

Example 4 (See Figure 6)

Equipment Information:
Equipment: Industrial Fan
Fan weight: 2,400 lb (shaft plus wheel = 426 lb, casing = 1,974 lb)
Dynamic load listed in vendor drawing: 50% of shaft plus wheel weight = 0.5 x 426 lb = 213 lb
Impact load factor recommended by vendor: 25% of fan weight = 0.25 x 2,400 lb = 600 lb
Operating frequency: fan = 1,411 rpm, motor = 1,800 rpm
Vendor recommended mass ratio: weight of support/weight fan = 4

Support information:
Support plan is shown in Figure 6
Grating DL = 9 psf
Floor LL = 100 psf
Fan duct = 800 lb
Weight of support: in order to obtain 4/1 mass ratio, beams B1 and B4 are selected 18 inches deep and the space is filled with 150 pcf concrete.
Diagonal floor bracing shown are WT4x9's, 5 ft beams that connect B1 beams to B3 beams are W8x18.
Concrete fill weight: 1.58 ft (beam depth+grating thickness) x 5ft x 6 ft x 150pcf = 7,110 lb
Support weight: 7,100 lb conc. fill + 800 lb duct + 2,000 lb steel beams + grating = 9,900 lb
Support weight/fan ratio = 9,900 lb/2,400 lb = 4.12 (≈ value recommended by manufacturer)



Legend:

$\times_1$ Denotes concentrated load:

Dead load: (2,400 lb fan + 800 lb duct + 7,100 lb conc. fill = 10,300 lb)

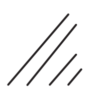
Each x_1: 10,300 lb/4 = 2,575 lb

Vendor impact load: 600/4 = 150 lb

Dynamic load: 213/4 = 53.25 lb

Distributed dead load: 22.5 lb/ft (grating dl) on beams B1 (9 psf x 2.5 ft = 22.5 lb/ft)
22.5 lb/ft (additional grating dl on beams B1 along 5 ft and 7 ft sections)
22.5 lb/ft (grating dl) on beams B3

Distributed live load: 500 lb/ft on beams B1 (100 psf x 5 ft = 500 lb/ft)
250 lb/ft on beams B3 (100 psf x 2.5 ft = 250 lb/ft)

 Denotes area filled with concrete.

PLAN – FAN ACCESS FLOOR

T/S EL. 150' - 0"

Figure 6

STAAD RUN:
See Example 4 in STAAD COMPUTER RUNS Section.
Joint numbers, member numbers and member shapes are shown in Figure 7.

LOAD COMANDS
To calculate the natural frequency of the floor, all the dead loads including the weight of the fan are input.
The following command is required in order to request a modal calculation:
CUT OFF MODE SHAPE 6

LOAD 1 LOAD TYPE DEAD TITLE LOAD CASE 1
SELFWEIGHT Y -1
JOINT LOAD
2 3 6 7 FY -2.575
MEMBER LOAD
1 to 6 20 TO 25 UNI GY -0.0225
1 3 4 6 UNI GY -0.0225
MODAL CALCULATION REQUESTED

For calculation of displacement amplitude, only the 213 lb FAN dynamic load is used.
LOAD 2 LOAD TYPE LIVE
JOINT LOAD
2 3 6 7 FY -0.05325

To check the floor's strength adequacy, all dead and live loads are input. Dead loads were input in load case 1, live loads plus fan impact load are input in load case 3. Load case 4 combines case 1 plus case 3.
LOAD 3 TYPE LIVE
JOINT LOAD
2 3 6 7 FY -0.15
MEMBER LOAD
1 TO 6 UNI GY -0.5
20 TO 25 UNI GY -0.25
LOAD COMB 4 COMBINATION LOAD CASE 4
1 1.0 3 1.0

The vendor recommended impact load (600 lb) is larger than the fan dynamic load of 213 lb, so it is used. (660 lb/4 = 150 lb at each of 4 support joints). It is not intended that both the impact load and the dynamic load values be used together, only the larger of the two.

STAAD RUN RESULTS

Natural Frequency:
Since the fan operating frequency is 1,410 rpm, and since a 4/1 support to fan weight mass ratio is recommended by fan vendor, it is more economical to "low tune" the frequency of the supports. Table 2 recommends a fn/ff ratio = < 0.75.

Natural frequency (mode 1) = 9.268 cycle/seconds x 60 seconds/minute = 556 rpm
Therefore fn/ff = 556/1,411 = 0.394 < 0.75 therefore OK
Note: the floor's fifth mode of vibration has a frequency (27.06 x 60 = 1,636 rpm) that is close to the operating frequency of the fan, however the mass participation for that case is "0.09"
A mass participation factor of "0.09" means very little energy will be transmitted to the floor at that frequency and therefore there will be no resonance.

The maximum joint displacement for the 213 lb dynamic loads = 0.0019 inches
From Table 1, we can see Mf will be less than 0.33
Using Equation 8: $Mf = \left|\frac{1}{\left(1 - \frac{ff^2}{fn^2}\right)}\right| = \left|\frac{1}{\left(1 - \frac{1{,}411^2}{556^2}\right)}\right| = 0.184$

Magnified displacement amplitude = 0.00194*0.184 = 0.000357 inches < 0.00075 (beginning of amplitude value "troublesome to persons" interpolated from Table 3 for 1,411 rpm)
Therefore beam sizes are acceptable.

Support strength:
Code check results indicate that the beams are stressed only to less than 50% of their capacity, the beams are therefore acceptable.
Beam deflections:
The maximum beam deflection for load case no 4 is around 0.4 inches, this means a span to deflection ratio = 18x12/0.4 = 540. 540 > 360, 360 is typical minimum span to deflection ratio required by many Building Codes. Beams are therefore acceptable.
Support reactions: all support reactions consist of vertical forces; this confirms that floor has been modeled properly.

STAAD COMPUTER RUNS

Example 2-1 , Example 2-2, Example 3, Example 4

STAAD.Pro V8i SELECTseries3 * * Version 20.07.08.20 *

*** Proprietary Program of * * Bentley Systems, Inc. * ***

EXAMPLE 2-1

INPUT FILE: EXAMPLE 2-1.STD

```
STAAD PLANE
START JOB INFORMATION
ENGINEER DATE 2012
JOB NAME SC_IND_FLOOR_FRAMING
JOB CLIENT NONE
JOB NO EXAMPLE 2-1
END JOB INFORMATION
INPUT WIDTH 79
UNIT FEET KIP
JOINT COORDINATES
1 0 0 0; 2 4 0 0; 3 10 0 0; 4 18 0 0
MEMBER INCIDENCES
1 1 2; 2 2 3; 3 3 4
DEFINE MATERIAL START
ISOTROPIC STEEL
E 4.176E+006
POISSON 0.3
DENSITY 0.489024
ALPHA 6E-006
DAMP 0.03
TYPE STEEL
STRENGTH FY 5184 FU 8352 RY 1.5 RT 1.2
END DEFINE MATERIAL
MEMBER PROPERTY AMERICAN
1 TO 3 TABLE ST W24X94
CONSTANTS
MATERIAL STEEL ALL
SUPPORTS
1 PINNED
4 FIXED BUT FX MZ
```

```
31. LOAD 1 LOADTYPE DEAD TITLE LOAD CASE 1
32. JOINT LOAD
33. 2 3 FY -1.
34. SELFWEIGHT Y -1 LIST ALL
35. MEMBER LOAD
36. 1 TO 3 UNI GY -0.04
37. CALCULATE RAYLEIGH FREQUENCY
38. PERFORM ANALYSIS
```

PROBLEM STATISTICS

```
NUMBER OF JOINTS/MEMBER+ELEMENTS/SUPPORTS = 4/ 3/ 2
SOLVER USED IS THE OUT-OF-CORE BASIC SOLVER
  ORIGINAL/FINAL BAND-WIDTH= 1/ 1/ 6 DOF
  TOTAL PRIMARY LOAD CASES = 1, TOTAL DEGREES OF FREEDOM = 9
  SIZE OF STIFFNESS MATRIX = 1 DOUBLE KILO-WORDS
  REQRD/AVAIL. DISK SPACE = 12.0/ 170096.3 MB



************************************************************ **



RAYLEIGH FREQUENCY FOR LOADING 1 = 35.60952 CPS * *



MAX   DEFLECTION   =   0.00919   INCH   GLO   Y,   AT   JOINT   3   *   **
************************************************************



39. FINISH


          *********** END OF THE STAAD.Pro RUN ***********

                      **** DATE= 2012 ****
```


STAAD.Pro V8i SELECTseries3 * * Version 20.07.08.20 * *

Proprietary Program of * * Bentley Systems, Inc. * *

EXAMPLE 2-2

INPUT FILE: EXAMPLE 2-2.STD

```
STAAD PLANE
START JOB INFORMATION
ENGINEER DATE 2012
JOB NAME SC_IND_FLOOR_FRAMING
JOB CLIENT NONE
JOB NO EXAMPLE 2-2
END JOB INFORMATION
INPUT WIDTH 79
UNIT FEET KIP
JOINT COORDINATES
1 0 0 0; 2 4 0 0; 3 18 0 0
MEMBER INCIDENCES
1 1 2; 2 2 3
DEFINE MATERIAL START
ISOTROPIC STEEL
E 4.176E+006
POISSON 0.3
DENSITY 0.489024
ALPHA 6E-006
DAMP 0.03
TYPE STEEL
STRENGTH FY 5184 FU 8352 RY 1.5 RT 1.2
END DEFINE MATERIAL
MEMBER PROPERTY AMERICAN
1 2 TABLE ST W24X94
CONSTANTS
MATERIAL STEEL ALL
SUPPORTS
1 PINNED
3 FIXED BUT FX MZ
LOAD 1 LOADTYPE DEAD TITLE LOAD CASE 1
SELFWEIGHT Y -1
MEMBER LOAD
2 CON GY -1.0 6
MEMBER LOAD
```



```
36. 1 2 UNI GY -0.04
37. JOINT LOAD
38. 2 FY -1.0
39. CALCULATE RAYLEIGH FREQUENCY
40. PERFORM ANALYSIS
```

PROBLEM STATISTICS

NUMBER OF JOINTS/MEMBER+ELEMENTS/SUPPORTS = 3/ 2/ 2

SOLVER USED IS THE OUT-OF-CORE BASIC SOLVER

ORIGINAL/FINAL BAND-WIDTH= 1/ 1/ 5 DOF
TOTAL PRIMARY LOAD CASES = 1, TOTAL DEGREES OF FREEDOM = 6
SIZE OF STIFFNESS MATRIX = 1 DOUBLE KILO-WORDS
REQRD/AVAIL. DISK SPACE = 12.0/ 170100.5 MB

```
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
   RAYLEIGH FREQUENCY FOR LOADING 1 = 49.21853 CPS * *

   MAX DEFLECTION = 0.00625 INCH GLO Y, AT JOINT 2 * **

  41. FINISH

          *********** END OF THE STAAD.Pro RUN ***********

            **** DATE= 2012 ****
```

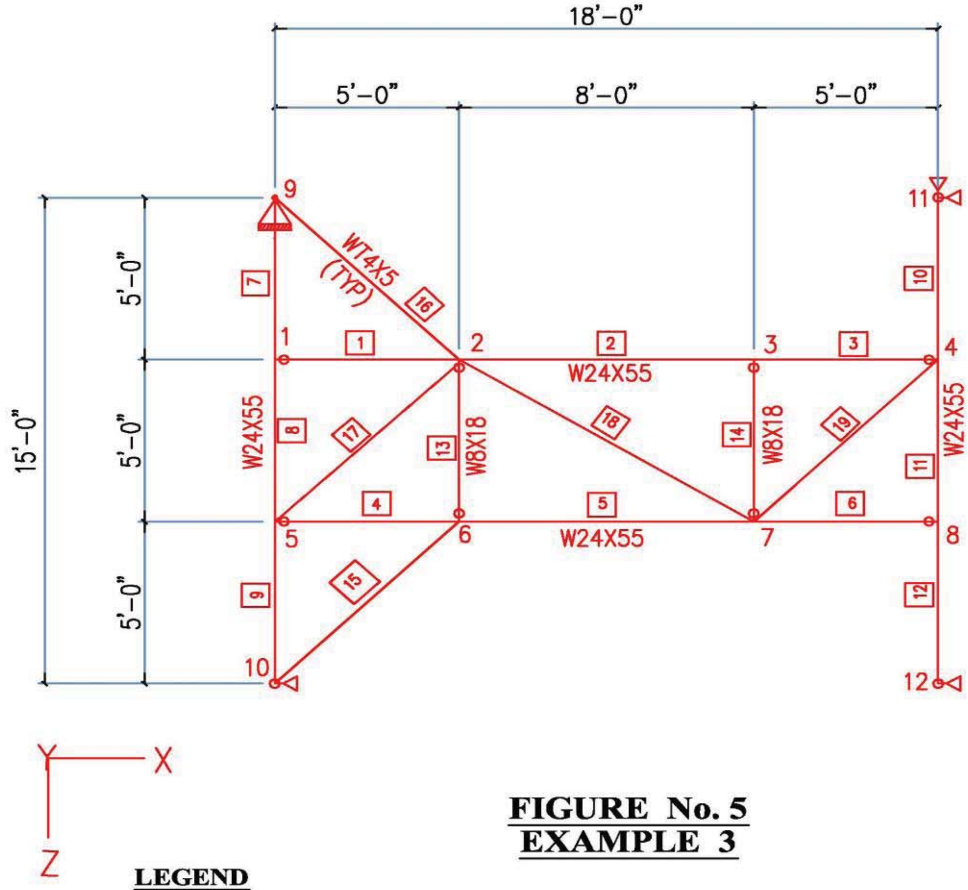



FIGURE No. 5
EXAMPLE 3

LEGEND

PINNED SUPPORT

SUPPORT FIXED GLOBAL X DIRECTION

SUPPORT FIXED GLOBAL Z DIRECTION

SUPPORT RELEASE GLOBAL MX

END OR START MEMBER RELEASE MY MZ

1 JOINT NUMBER

1 MEMBER NUMBER


```
*      STAAD.Pro V8i SELECTseries3      *
*     Version     20.07.08.20           *
*        Proprietary Program of         *
*         Bentley Systems, Inc.         *
*      Date=       2012                 *
*      Time=                            *
*                                       *
```

EXAMPLE 3

STAAD SPACE INPUT FILE: Example-3.STD

```
START JOB INFORMATION

1.  STAAD SPACE
2.  START JOB INFORMATION
3.  ENGINEER DATE 2012
4.  JOB NAME SC_IND_FLOOR_FRAMING
5.  JOB NO EXAMPLE 3
6.  END JOB INFORMATION
7.  INPUT WIDTH 79
8.  UNIT FEET KIP
9.  JOINT COORDINATES
10. 1 0 0 5; 2 5 0 5; 3 13 0 5; 4 18 0 5; 5 0 0 10; 6 5 0 10; 7 13 0 10; 8 18 0 10
11. 9 0 0 0; 10 0 0 15; 11 18 0 0; 12 18 0 15
12. MEMBER INCIDENCES
13. 1 1 2; 2 2 3; 3 3 4; 4 5 6; 5 6 7; 6 7 8; 7 9 1; 8 1 5; 9 5 10; 10 11 4
14. 11 4 8; 12 8 12; 13 2 6; 14 3 7; 15 10 6; 16 9 2; 17 5 2; 18 2 7; 19 7 4
15. DEFINE MATERIAL START
16. ISOTROPIC STEEL
17. E 4.176E+006
18. POISSON 0.3
19. DENSITY 0.489024
20. ALPHA 6E-006
21. DAMP 0.03
22. TYPE STEEL
23. STRENGTH FY 5184 FU 8352 RY 1.5 RT 1.2
24. END DEFINE MATERIAL
25. MEMBER PROPERTY AMERICAN
26. 13 14 TABLE ST W8X18
27. 15 TO 19 TABLE T W8X10
28. 7 TO 12 TABLE ST W24X55
29. 1 TO 6 TABLE ST W24X55
30. CONSTANTS
31. MATERIAL STEEL ALL
32. MEMBER TRUSS
33. 15 TO 19
34. MEMBER RELEASE
```



```
35. 1 4 13 14 START MY MZ
36. 3 6 13 14 END MY MZ
37. SUPPORTS
38. 9 PINNED
39. 11 FIXED BUT MX
40. 12 FIXED BUT FZ MX
1.  10 FIXED BUT FZ MX
2.  CUT OFF MODE SHAPE 3
3.  **** LOAD FOR NATURAL FREQUENCY CALCULATION
4.  LOAD 1 LOADTYPE DEAD TITLE LOAD CASE 1
5.  SELFWEIGHT Y -1
6.  JOINT LOAD
7.  2 3 6 7 FY -0.5
8.  MODAL CALCULATION REQUESTED
9.  **** LOAD FOR DISPLACEMENT AMPLITUDE CALCULATION
10. LOAD 2 LOAD TYPE LIVE
11. JOINT LOAD

52. 2 3 6 7 FY -0.665
53. **** LOAD FOR STRENGHT OF BEAMS CHECK
54. **** DEAD LOAD PLUS LIVE WITH IMPACT
55. LOAD 3 LOAD TYPE NONE
56. SELFWEIGHT Y -1
57. JOINT LOAD
58. 2 3 6 7 FY -4.26
59. PERFORM ANALYSIS

           PROBLEM STATISTICS

           NUMBER OF JOINTS/MEMBER+ELEMENTS/SUPPORTS =    12/    19/    4

          SOLVER USED IS THE OUT-OF-CORE BASIC SOLVER

     ORIGINAL/FINAL BAND-WIDTH=    8/    4/    27 DOF
     TOTAL PRIMARY LOAD CASES = 3, TOTAL DEGREES OF FREEDOM =     56
     SIZE OF STIFFNESS MATRIX = 2 DOUBLE KILO-WORDS
     REQRD/AVAIL. DISK SPACE = 12.1/ 170650.7 MB

     NUMBER OF MODES REQUESTED = 3
     NUMBER OF EXISTING MASSES IN THE MODEL = 8
     NUMBER OF MODES THAT WILL BE USED = 3


  STAAD SPACE                                          --PAGE NO.        3
           CALCULATED FREQUENCIES FOR LOAD CASE         1

  MODE              FREQUENCY(CYCLES/SEC)          PERIOD(SEC)      ACCURACY
  1                        27.998                   0.03572       9.404E-16
  2                        37.279                   0.02682       3.145E-11
  3                        53.899                   0.01855       2.270E-07
```

```
 The following Frequencies are estimates that were calculated. These are for
 information only and will not be used. Remaining values are either above
 the cut off mode/freq values or are of low accuracy. To use these
 frequencies, rerun with a higher cutoff mode (or mode + freq) value.
           CALCULATED FREQUENCIES FOR LOAD CASE 1

MODE                FREQUENCY(CYCLES/SEC)         PERIOD(SEC)          ACCURACY


4                       95.398                      0.01048             1.173E-09
5                       99.456                      0.01005             2.448E-11



      MODAL   WEIGHT (MODAL MASS TIMES g) IN KIP GENERALIZED

 MODE              X               Y                 Z            WEIGHT

   1          0.000000E+00     5.015405E+00     0.000000E+00     4.159832E+00
   2          0.000000E+00     1.337197E-07     0.000000E+00     3.759044E+00
   3          0.000000E+00     4.513065E-05     0.000000E+00     2.916189E+00


          MASS PARTICIPATION FACTORS IN PERCENT


     MODE      X         Y        Z        SUMM-X      SUMM-Y      SUMM-Z

.       1     0.00     92.65     0.00      0.000       92.646      0.000
.       2     0.00      0.00     0.00      0.000       92.646      0.000
.       3     0.00      0.00     0.00      0.000       92.647      0.000

60.     LOAD LIST 2
61.     PRINT JOINT DISPLACEMENTS LIST 2 3 6 7
```

JOINT DISPLACEMENT (INCH RADIANS) STRUCTURE TYPE = SPACE

JOINT	LOAD	X-TRANS	Y-TRANS	Z-TRANS	X-ROTAN	Y-ROTAN	Z-ROTAN
2	2	0.00000	-0.00798	0.00000	0.00003	0.00000	-0.00005
3	2	0.00000	-0.00798	0.00000	0.00003	0.00000	0.00005
6	2	0.00000	-0.00798	0.00000	-0.00003	0.00000	-0.00005
7	2	0.00000	-0.00798	0.00000	-0.00003	0.00000	0.00005

```
  ************** END OF LATEST ANALYSIS RESULT **************
  62.   LOAD LIST 3
  63.   PARAMETER
  64.   CODE AISC
  65.   BEAM 1 ALL
  66.   CHECK CODE MEMBER 1 TO 12
```



```
ALL UNITS ARE -KIP FEET (UNLESS OTHERWISE NOTED)

  MEMBER     TABLE      RESULT/         CRITICAL COND/    RATIO/    LOADING/
_                         FX                  MY              MZ      LOCATION
=======================================================================

     1  ST   W24X55                              (AISC SECTIONS)
                          PASS            AISC-H1-3        0.104         3
                         0.00 T             0.00          -23.53      5.00
     2  ST   W24X55                          (AISC SECTIONS)
                          PASS            AISC-H1-3        0.118         3
                         0.00 T             0.00          -23.90      3.33
     3  ST   W24X55                          (AISC SECTIONS)
                          PASS            AISC-H1-3        0.103         3
                         0.00 T             0.00          -23.39      0.00
     4  ST   W24X55                          (AISC SECTIONS)
                          PASS            AISC-H1-3        0.103         3
                         0.00 T             0.00          -23.43      5.00
     5  ST   W24X55                          (AISC SECTIONS)
                          PASS            AISC-H1-3        0.118         3
                         0.00 T             0.00          -23.90      4.00
     6  ST   W24X55                          (AISC SECTIONS)
                          PASS            AISC-H1-3        0.104         3
                         0.00 T             0.00          -23.49      0.00
     7  ST   W24X55                          (AISC SECTIONS)
                          PASS            AISC-H1-3        0.113         3
                         0.00 T             0.00          -25.59      5.00
     8  ST   W24X55                          (AISC SECTIONS)
                          PASS            AISC-H1-3        0.114         3
                         0.00 T             0.00          -25.76      2.50
     9  ST   W24X55                          (AISC SECTIONS)
                          PASS            AISC-H1-3        0.113         3
                         0.00 T             0.00          -25.59      0.00
    10  ST   W24X55                          (AISC SECTIONS)
                          PASS            AISC-H1-3        0.113         3
                         0.00 T             0.00          -25.55      5.00
    11  ST   W24X55                          (AISC SECTIONS)
                          PASS            AISC-H1-3        0.113         3
                         0.00 T             0.00          -25.72      2.50
    12  ST   W24X55                          (AISC SECTIONS)
                          PASS            AISC-H1-3        0.113         3
                         0.00 T             0.00          -25.55      0.00


67. PRINT SUPPORT REACTIONS ALL
```


SUPPORT REACTIONS -UNIT KIP FEET STRUCTURE TYPE = SPACE

JOINT	LOAD	FORCE-X	FORCE-Y	FORCE-Z	MOM-X	MOM-Y	MOM Z
9	3	0.00	5.27	0.00	0.00	0.00	0.00
11	3	0.00	5.25	0.00	0.00	0.00	0.00
12	3	0.00	5.25	0.00	0.00	0.00	0.00
10	3	0.00	5.27	0.00	0.00	0.00	0.00

************** END OF LATEST ANALYSIS RESULT **************

68. FINISH

*********** END OF THE STAAD.Pro RUN ***********

**** DATE= 2012 ****

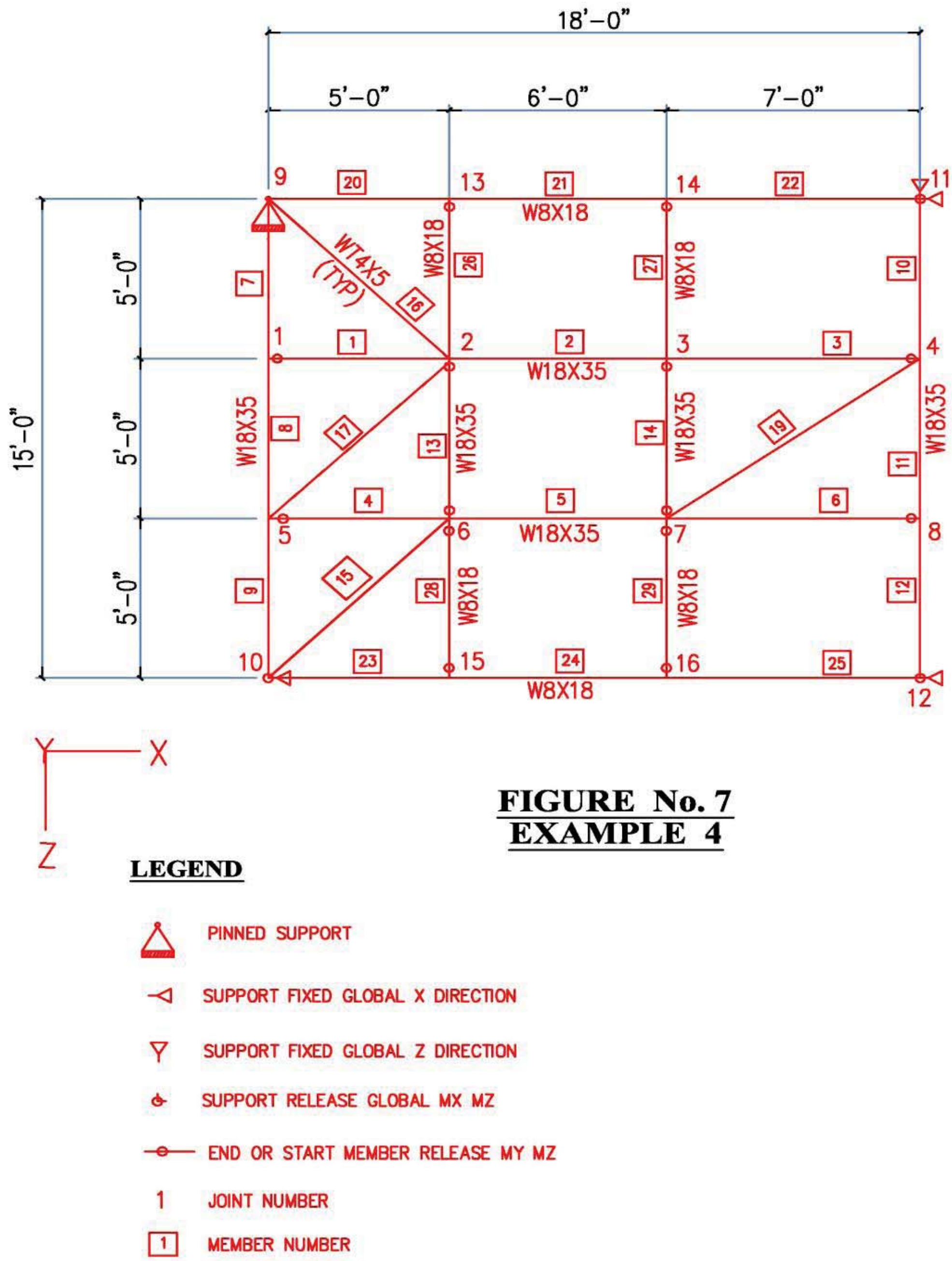


FIGURE No. 7
EXAMPLE 4

```
*      STAAD.Pro V8i SELECTseries3      *
*     Version    20.07.08.20            *
*        Proprietary Program of         *
*         Bentley Systems, Inc.         *
*      Date=      2012                  *
*                                       *
```

EXAMPLE 4

```
   1.  STAAD SPACE
 INPUT FILE: Example-4.STD
2.      START JOB INFORMATION
3.      ENGINEER DATE 2012
4.      JOB NAME SC_IND_FLOOR_FRAMING
5.      JOB NO EXAMPLE 4
6.      END JOB INFORMATION
7.      INPUT WIDTH 79
8.      UNIT FEET KIP
9.      JOINT COORDINATES
10. 1 0 0 5; 2 5 0 5; 3 11 0 5; 4 18 0 5; 5 0 0 10; 6 5 0 10; 7 11 0 10; 8 18 0 10
11. 9 0 0 0; 10 0 0 15; 11 18 0 0; 12 18 0 15; 13 5 0 0; 14 11 0 0; 15 5 0 15
12. 16 11 0 15
13. MEMBER INCIDENCES
14. 1 1 2; 2 2 3; 3 3 4; 4 5 6; 5 6 7; 6 7 8; 7 9 1; 8 1 5; 9 5 10; 10 11 4
15. 11 4 8; 12 8 12; 13 2 6; 14 3 7; 15 10 6; 16 9 2; 17 5 2; 19 7 4; 20 9 13
16. 21 13 14; 22 14 11; 23 10 15; 24 15 16; 25 16 12; 26 13 2; 27 14 3; 28 6 15
17. 29 7 16
18. DEFINE MATERIAL START
19. ISOTROPIC STEEL
20. E 4.176E+006
21. POISSON 0.3
22. DENSITY 0.489024
23. ALPHA 6E-006
24. DAMP 0.03
25. TYPE STEEL
26. STRENGTH FY 5184 FU 8352 RY 1.5 RT 1.2
27. END DEFINE MATERIAL
28. MEMBER PROPERTY AMERICAN
29. 26 TO 29 TABLE ST W8X18
30. 15 TO 17 19 TABLE T W8X10
31. 7 TO 12 TABLE ST W18X35
32. 1 TO 6 13 14 TABLE ST W18X35
33. 20 TO 25 TABLE ST W8X18
34. CONSTANTS
35. MATERIAL STEEL ALL
36. MEMBER TRUSS
```

```
15 TO 17 19
MEMBER RELEASE
1 4 13 14 26 TO 29 START MY MZ
3 6 13 14 26 TO 29 END MY MZ
    SUPPORTS
    9 PINNED
    11 FIXED BUT MX MZ
    12 FIXED BUT FZ MX MZ
    10 FIXED BUT FZ MX MZ
    CUT OFF MODE SHAPE 6
    **** LOAD FOR NATURAL FREQUENCY CALCULATION
    LOAD 1 LOADTYPE DEAD TITLE LOAD CASE 1
    SELFWEIGHT Y -1
    JOINT LOAD
    2 3 6 7 FY -2.575
    MEMBER LOAD
    1 TO 6 20 TO 25 UNI GY -0.0225
    1 3 4 6 UNI GY -0.0225
    MODAL CALCULATION REQUESTED
    **** LOAD FOR DISPLACEMENT AMPLITUDE CALCULATION
    LOAD 2 LOAD TYPE LIVE
    JOINT LOAD
    2 3 6 7 FY -0.05325
    **** LIVE LOAD PLUS FAN IMPACT LOAD
    LOAD 3 LOAD TYPE LIVE
    JOINT LOAD
    2 3 6 7 FY -0.15
    MEMBER LOAD
    1 TO 6 UNI GY -0.5
    20 TO 25 UNI GY -0.25
    **** LOAD FOR STRENGHT OF BEAMS CHECK
    **** DEAD LOAD PLUS LIVE LOAD PLUS FAN IMPACT LOAD
    LOAD COMB 4 COMBINATION LOAD CASE 4
    1 1.0 3 1.0
    PERFORM ANALYSIS

          PROBLEM STATISTICS

  NUMBER OF JOINTS/MEMBER+ELEMENTS/SUPPORTS =    16/   28/     4

        SOLVER USED IS THE OUT-OF-CORE BASIC SOLVER

  ORIGINAL/FINAL BAND-WIDTH=    11/     5/    33    DOF
  TOTAL PRIMARY LOAD CASES =    3,  TOTAL DEGREES OF FREEDOM =     83
  SIZE OF STIFFNESS MATRIX =    3 DOUBLE KILO-WORDS
  REQRD/AVAIL. DISK SPACE =     12.1/ 170415.9 MB
```

```
NUMBER OF MODES REQUESTED = 6
NUMBER OF EXISTING MASSES IN THE MODEL = 12
NUMBER OF MODES THAT WILL BE USED = 6

CALCULATED FREQUENCIES FOR LOAD CASE 1
```

MODE	FREQUENCY(CYCLES/SEC)	PERIOD(SEC)	ACCURACY
1	9.268	0.10790	5.364E-16
2	11.537	0.08668	2.446E-13
3	13.931	0.07178	1.603E-14
4	13.952	0.07168	4.024E-15
5	27.066	0.03695	5.208E-10
6	40.268	0.02483	1.904E-08


```
The following Frequencies are estimates that were calculated. These are for
information only and will not be used. Remaining values are either above
the cut off mode/freq values or are of low accuracy. To use these
frequencies, rerun with a higher cutoff mode (or mode + freq) value.
          CALCULATED FREQUENCIES FOR LOAD CASE 1

MODE                 FREQUENCY(CYCLES/SEC)       PERIOD(SEC)            ACCURACY


  7                        53.401                 0.01873                 1.333E-08
  8                        53.415                 0.01872                 2.077E-07
  9                        53.797                 0.01859                 5.055E-07

      MODAL WEIGHT (MODAL MASS TIMES g) IN KIP                      GENERALIZED
 MODE            X                 Y                  Z                 WEIGHT

   1       0.000000E+00      1.366596E+01       0.000000E+00      1.188153E+01
   2       0.000000E+00      3.010401E-05       0.000000E+00      1.081749E+01
   3       0.000000E+00      1.134849E+00       0.000000E+00      9.688837E-01
   4       0.000000E+00      9.170433E-13       0.000000E+00      9.688013E-01
   5       0.000000E+00      1.362813E-02       0.000000E+00      5.251514E+00
   6       0.000000E+00      1.683358E-05       0.000000E+00      1.057684E+01


    MASS PARTICIPATION FACTORS IN PERCENT

MODE         X      Y        Z        SUMM-X     SUMM-Y     SUMM-Z
 1         0.00   88.75     0.00      0.000      88.746     0.000
 2         0.00    0.00     0.00      0.000      88.747     0.000
 3         0.00    7.37     0.00      0.000      96.116     0.000
 4         0.00    0.00     0.00      0.000      96.116     0.000
 5         0.00    0.09     0.00      0.000      96.205     0.000
 6         0.00    0.00     0.00      0.000      96.205     0.000

72.     LOAD LIST 2
73.     PRINT JOINT DISPLACEMENTS LIST 2 3 6 7
```

```
  JOINT DISPLACEMENT (INCH RADIANS) STRUCTURE TYPE = SPACE


JOINT     LOAD     XTRANS      YTRANS        ZTRANS     X-ROTAN    Y-ROTAN      Z-ROTAN
   2        2     0.00000    -0.00179       0.00000     0.00001    0.00000     -0.00001
   3        2     0.00000    -0.00194       0.00000     0.00001    0.00000      0.00001
   6        2     0.00000    -0.00179       0.00000    -0.00001    0.00000     -0.00001
   7        2     0.00000    -0.00194       0.00000    -0.00001    0.00000      0.00001

  ************** END OF LATEST ANALYSIS RESULT **************

74.      LOAD LIST 4
75.      PARAMETER 1
76.      CODE AISC
77.      BEAM 1 MEMB 1 TO 12 20-25
78.      CHECK CODE MEMB 1 TO 12 20 TO 25
```



```
ALL UNITS ARE -KIP FEET (UNLESS OTHERWISE NOTED)

MEMBER     TABLE       RESULT/          CRITICAL COND/    RATIO/                    LOADING/
                         FX                 MY              MZ                      LOCATION
=======================================================================================


 1    ST   W18X35                     (AISC SECTIONS)
                        PASS          AISC-H1-3       0.302                           4
                      0.00 T            0.00       -34.47                          5.00
 2    ST   W18X35                     (AISC SECTIONS)
                        PASS          AISC-H1-3       0.353                           4
                      0.00 T            0.00       -40.32                          4.50
 3    ST   W18X35                     (AISC SECTIONS)
                        PASS          AISC-H1-3       0.389                           4
                      0.00 T            0.00       -39.76                          0.00
 4    ST   W18X35                     (AISC SECTIONS)
                        PASS          AISC-H1-3       0.302                           4
                      0.00 T            0.00       -34.45                          5.00
 5    ST   W18X35                     (AISC SECTIONS)
                        PASS          AISC-H1-3       0.354                           4
                      0.00 T            0.00       -40.36                          4.50
 6    ST   W18X35                     (AISC SECTIONS)
                        PASS          AISC-H1-3       0.389                           4
                      0.00 T            0.00       -39.81                          0.00
 7    ST   W18X35                     (AISC SECTIONS)
                        PASS          AISC-H1-3       0.374                           4
                      0.00 T            0.00       -42.62                          5.00
 8    ST   W18X35                     (AISC SECTIONS)
                        PASS          AISC-H1-3       0.375                           4
                      0.00 T            0.00       -42.74                          2.50
 9    ST   W18X35                     (AISC SECTIONS)
                        PASS          AISC-H1-3       0.374                           4
                      0.00 T            0.00       -42.64                          0.00
10    ST   W18X35                     (AISC SECTIONS)
                        PASS          AISC-H1-3       0.346                           4
                      0.00 T            0.00       -39.51                          5.00
11    ST   W18X35                     (AISC SECTIONS)
                        PASS          AISC-H1-3       0.347                           4
                      0.00 T            0.00       -39.61                          2.50
12    ST   W18X35                     (AISC SECTIONS)
                        PASS          AISC-H1-3       0.346                           4
                      0.00 T            0.00       -39.49                          0.00
```

```
MEMBER     TABLE       RESULT/          CRITICAL COND/    RATIO/              LOADING/
                          FX                 MY              MZ                LOCATION
=======================================================================================


 20   ST   W8X18                         (AISC SECTIONS)
                        PASS             AISC-H1-3        0.322                    4
                       0.00 T                0.00       -9.69                   5.00
 21   ST   W8X18                         (AISC SECTIONS)
                        PASS             AISC-H1-3        0.439                    4
                       0.00 T               0.00       -12.02                   4.00
 22   ST   W8X18                         (AISC SECTIONS)
                        PASS             AISC-H1-3        0.418                    4
                       0.00 T               0.00       -11.46                   0.00
 23   ST   W8X18                         (AISC SECTIONS)
                        PASS             AISC-H1-3        0.322                    4
                       0.00 T                0.00       -9.69                   5.00
 24   ST   W8X18                         (AISC SECTIONS)
                        PASS             AISC-H1-3        0.439                    4
                       0.00 T               0.00       -12.02                   4.00
 25   ST   W8X18                         (AISC SECTIONS)
                        PASS             AISC-H1-3        0.418                    4
                       0.00 T               0.00       -11.46                   0.00
```



```
   79.  PRINT JOINT DISPLACEMENTS LIST 2 3 6 7 1 5 13 14 15 16


     JOINT DISPLACEMENT                                         STRUCTURE TYPE = SPACE
         (INCH RADIANS)
  -----------------

JOINT         X-TRANS   Y-TRANS      Z-TRANS   X-ROTAN    Y-ROTAN      Z-ROTAN
       LOAD
    2     4   0.00000  -0.24080      0.00000   0.00102    0.00000     -0.00143
    3     4   0.00000  -0.26520      0.00000   0.00099    0.00000      0.00083
    6     4   0.00000  -0.24085      0.00000  -0.00102    0.00000     -0.00143
    7     4   0.00000  -0.26531      0.00000  -0.00099    0.00000      0.00084

    1     4   0.00000  -0.11261      0.00000   0.00104    0.00000     -0.00579

    5     4   0.00000  -0.11263      0.00000  -0.00104    0.00000     -0.00579
   13     4   0.00000  -0.30681      0.00000   0.00204    0.00000     -0.00360
   14     4   0.00000  -0.37430      0.00000   0.00199    0.00000      0.00190
   15     4   0.00000  -0.30681      0.00000  -0.00204    0.00000     -0.00360
   16     4   0.00000  -0.37430      0.00000  -0.00199    0.00000      0.00190
         ************** END OF LATEST ANALYSIS RESULT **************

80. PRINT SUPPORT REACTIONS ALL
```


SUPPORT REACTIONS -UNIT KIP FEET STRUCTURE TYPE = SPACE

JOINT	LOAD	FORCE-X	FORCE-Y	FORCE-Z	MOM-X	MOM-Y	MOM Z
9	4	0.00	11.29	0.00	0.00	0.00	0.00
11	4	0.00	10.64	0.00	0.00	0.00	0.00
12	4	0.00	10.64	0.00	0.00	0.00	0.00
10	4	0.00	11.30	0.00	0.00	0.00	0.00

```
************** END OF LATEST ANALYSIS RESULT **************

  81. FINISH

                   *********** END OF THE STAAD.Pro RUN ***********

                             **** DATE= 2012   ****
```

REFERENCES

1. F. E. Richart, Jr., R. D. Woods, J. R. Hall, Jr. (1970). "Vibrations of Soils and Foundations." Prentice-Hall, Inc., Englewood Cliffs, New Jersey.
2. Cyril M. Harris, Charles E. Crede. (1976). "Shock and Vibration Handbook." Second Edition. McGraw-Hill Book Company. New York.
3. STAAD .Pro V8i (Select Series 3) Technical Reference Manual. Bentley. Last Updated 10 October 2011.
4. Lawrence R. Burkhardt, M. ASCE. (October, 1961). "Vibration Analysis For Structural Floor Systems" Journal of the Structural Division. Proceedings of the American Society of Civil Engineers.
5. Richart, F.E. Jr. (1962). "Foundation Vibrations." Transactions, ASCE, Paper 3351, Vol. 127.

