FLOOR VIBRATION

Floor vibration occurs, in varying degrees, in all types of building construction. Unlike steady state vibration, which can be isolated, vibration due to human impact is inconsistent in amplitude and frequency and therefore, more difficult to control.

The Steel Joist Institute and Nucor Research and Development have studied this phenomenon for many years. Laboratory research has been performed and numerous buildings, exhibiting both good and bad characteristics, were tested using seismic recording instruments. SJI Technical Digest #5 (1988) and AISC / CISC Steel Design Guide 11 (1997) discuss in detail methods for calculating vibrational properties for joist supported floors.

The vast majority of structures, including those utilizing steel joists, do not exhibit floor vibrations severe enough to be considered objectionable. However, human sensitivity to vibratory motion varies, and a satisfactory framing solution is dependent upon the sound judgment of qualified structural engineers.

DEFINITIONS

Floor vibration is measured in terms of acceleration amplitude, displacement amplitude, and frequency. These factors are not objectionable to all people at the same level since human sensitivity varies.

Acceleration amplitude is the maximum acceleration caused by a force excitation.

Displacement amplitude is defined as the magnitude or total distance traveled by each oscillation of the vibration.

Frequency is the term used to describe the speed of the oscillations and is expressed in cycles per second or Hz.

Acceleration is the only vibration factor which humans can sense.

Damping is defined as the rate of decay of amplitude.

The following observations, which were determined from research data to be beneficial in reducing vibration levels, are recommended only as a guide.

OPEN FLOOR AREAS are most subject to vibrational problems. Modern “electronic offices” tend to have lower live loading and damping, and hence can potentially be more prone to floor vibration. Partitions, file cabinets, book stacks, heavy furnishings and even crowds of people provide additional damping and minimize complaints.

THICKER FLOOR SLABS are an economical solution to floor vibration. Additional thickness increases floor system stiffness transverse to the joists, thus reducing the vibration. The additional mass of the system will reduce the objectionable vibration.

WIDER JOIST SPACINGS improve vibrational characteristics only when combined with thicker floor slabs. The resulting increase in joist size does not contribute significantly to the composite section. When used with a thicker slab, greater resistance to vibration can be achieved, and, since fewer pieces must be installed, may be more economical.

PARTITIONS introduce damping and usually eliminate vibration problems. They will be effective either above or below a floor as long as they are connected to the floor. Partitions below a joist supported floor ideally should be in direct contact with the steel deck. If partitions below a joist supported floor are in direct contact with the joists, the joist bottom chord and webs must be designed for such intermediate support conditions.

SUPPORT FRAMING BEAMS sometimes contribute to floor vibration. The natural frequency and amplitude for both the joist and supporting joist girders or hot-rolled girders need to be calculated. In this manner the resulting system acceleration or displacement and frequency can be determined from which the performance of the system can be predicted.

INCREASING JOIST STIFFNESS above that which is required by live load deflection may be beneficial. A higher frequency floor is generally a better floor for most applications. Increasing the stiffness of the steel joists themselves results in increasing the frequency and slightly decreasing the acceleration or displacement of the floor vibration.

BRIDGING of all standard types provide equal floor vibrational characteristics.

LONGER FLOOR SPANS have many advantages over shorter spans, both in construction cost and in vibrational response. Floor spans over 40 feet with a 2-1/2" thick concrete slab give a vibrational frequency in the 3 - 5 cycles per second range. There are many long spanning joist supported floors that perform satisfactorily.

PC-based software to evaluate vibration of joist supported floor systems is available from the

STEEL JOIST INSTITUTE
3127 Mr. Joe White Avenue
Myrtle Beach, SC 29577
phone (843) 626-1995

and

STRUCTURAL ENGINEERS, INC.
537 Wisteria Drive
Radford, VA 24141
phone (540) 731-3330

CONCLUSIONS:

Partitions eliminate vibration problems. When a floor area cannot have partitions, increasing the slab thickness and/or increasing the joist stiffness are the most economical and effective ways to reduce objectionable vibrations.

For more information refer to Steel Joist Institute Technical Digest No. 5 "Vibration of Steel Joist-Concrete Slab Floors", and the AISC / CISC Steel Design Guide 11 “Floor Vibrations Due to Human Activity”.

DEFLECTION OF STEEL JOISTS

The deflection of a steel joist when loaded with a uniformly-distributed load depends upon the following factors:

w= uniformly-distributed load carried by the joist (plf)
L= (span of the joist -.33)(ft.)
E= modulus of elasticity of steel (29,000,000 psi)
I= 26.767 W_{LL} (L3) (10^{-6}) where W_{LL}=red figure in load table

Tests have shown that deflection at mid-span may be determined with reasonable accuracy using the following formula:

Deflection (inches)=

$$\frac{1.15 \times 5wL^4 (12^3)}{384EI} = \frac{25.88wL^4}{EI}$$

Example: Determine the approximate total load deflection of a 24K8 for the following conditions:

W=280 plf L=40.0 ft
W_{LL}= 161 plf E=29,000,000 psi
I=26.767(161) $(40-.33)^3$ (10^{-6})= 269.0 in.^{4}

Deflection=

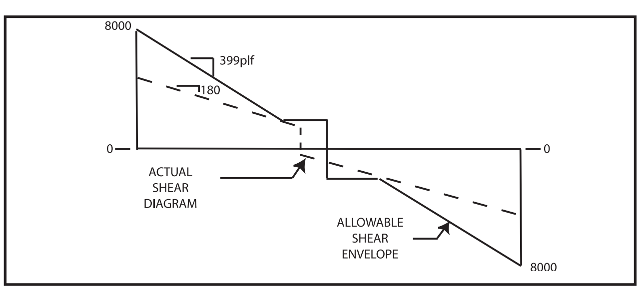
$$\frac{25.88(280)(40-.33)^4}{29{,}000{,}000(269)} = 2.30 \text{ in.}$$

HOW TO SPECIFY JOISTS FOR CONCENTRATED LOADS ON STEEL JOISTS

When specifying joists for concentrated loads, the specifying professional should first attempt to specify a larger standard joist or a KCS series joist. The joist specified must have adequate moment and shear resistance throughout the length of the joist.

The shear resistance of K or LH series joists varies throughout the length of the joist. The shear capacity of the joist must be checked at every location by use of a shear diagram showing the allowable shear envelope created by the uniform design load of the joist (given in the table), versus the actual shear diagram. This diagram can be easily drawn with free software (Vulcraft Assistant Program) available at our web site www.vulcraft.com. The following diagram is an example of a 40' joist with a 180 plf uniform load plus a concentrated load of 1900 lbs. at 17' from the left end.

In this case, using the developed 399 plf load, either a 30K10 with an 11% stress reversal, or a standard 26KCS3 could be specified.



Web members have a 5% stress reversal reserve capacity. If a stress reversal is larger than 5%, clearly specify the stress reversal with the joists. An "SP" is not required as long as the stress reversal requirement is clearly specified.

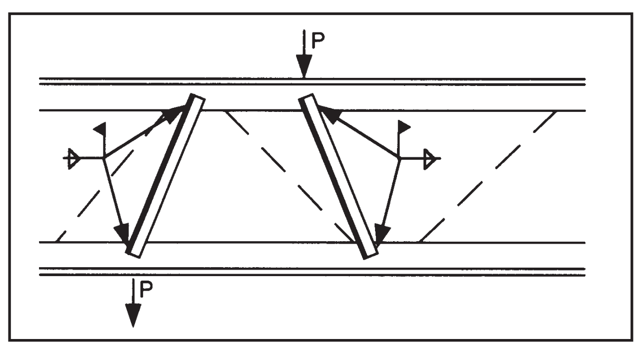
When a suitable K or LH series joist cannot be specified, use the required moment and shear to select a KCS series joist or use double joists to attain the required capacity. Note that LH series have deeper standard bearing depths than K or KCS series joists.

In some cases, a standard joist cannot be reasonably specified. In this case, all uniform, non-uniform (such as drift loads or varying uniform loads) and concentrated loads must be given on the drawing or load diagram with all dimensions given. The drawback of this method is that the exact dimensions and locations must be given. Often this information is not available at the time of joist fabrication.

Regardless of whether K-series, KCS-series or LH-series joists are specified, it is important to note that even though sufficient shear and moment capacity are provided within the special joist, the localized bending of the chord members due to concentrated loading between panel points is not considered. The joist design generally presumes that all concentrated loads are to be applied at panel points. When this is not the case, the specifying professional must specify on the structural drawings of the contract documents that a field installed member be located at all concentrated loads not occurring at panel points (see detail C1).

If the magnitude and locations of all loads are provided on the structural drawings, Vulcraft can design for the localized chord bending due to the load at the locations given.

The second alternative is the most economical.



DETAIL C1

VARYING UNIFORM LOADS ON STEEL JOISTS

The selection process of a joist for varying uniform loads such as drift loads or stepped uniform loads is essentially the same as that for concentrated loads. For K-series joists where the uniform load exceeds 550 pounds per lineal foot, the only options are: double joists or the use of special (SP) joists. Again a load diagram should be shown on the structural drawings.