CHAPTER II
EXPERIMENTAL WORK

2.1 Overview

Six full scale floor systems were constructed in the laboratory to determine if previous acceptability criteria can be applied to steel joist supported wood floor systems. Three floors were constructed with thirteen 14K1 steel joists spaced at 16 in. on center and the other three floors with nine 14K1 steel joists spaced at 24 in. on center. The sub-flooring for all floor systems was 23/32 in. tongue-in-groove oriented strand board (OSB). Each floor system was tested with three different cross bracing configurations.

Four tests were performed for each floor setup: heel drop impact, walking perpendicular and parallel to the floor joists, static concentrated load at the midspan, and a test to determine subjective evaluation. The heel drop impact gives an acceleration trace that can be transformed to find the fundamental frequency of the floor system. The walking tests help determine the amount of damping in the floor system. The static concentrated load tests at midspan were used to determine the accuracy of existing methods to predict floor deflection. The subjective evaluations were used to classify the floor system according to its acceptability.

Two two-joist test floors were constructed to measure the magnitude of composite action taking place between the sheathing and the joists. Frequency tests were also performed on these floor systems to determine the fundamental frequency of a single joist.

2.2 Multi-joist Line Floor Systems

This section describes the general layout, construction and testing of the multi-joist line floors. Appendix A provides a complete description of each floor system including layout, section properties and measured values.

2.2.1 Materials and Construction

All floors were constructed using 14K1 steel joists and 23/32 in. oriented strand board (OSB) tongue-in-groove decking fastened with self tapping screws (Figure 2.1). Each floor was assigned an identification according to its joist spacing (16 in. or 24 in.), a number identifying the live load deflection limitation used to determine the span length (L/360, L/480, or L/720) and a designation for the type of diagonal bracing (H, X, XH) used as will be discussed in Section 2.2.2. Floor designation and span lengths are listed in Table 2.1.

Table 2.1 Test Floor Span Lengths

Floor Designation	Spacing (in.)	Deflection Limitation	Span Length
16-360H	16	L/360, 30 psf LL	34'-0"
16-360XH	16	L/360, 30 psf LL	34'-0"
16-360X	16	L/360, 30 psf LL	34'-0"
16-480H	16	L/480, 30 psf LL	31'-0"
16-480XH	16	L/480, 30 psf LL	31'-0"
16-480X	16	L/480, 30 psf LL	31'-0"
16-720H	16	L/720, 30 psf LL	27'-3 _ "
16-720XH	16	L/720, 30 psf LL	27'-3 _ "
16-720X	16	L/720, 30 psf LL	27'-3 _ "
24-360H	24	L/360, 30 psf LL	30'-0"
24-360XH	24	L/360, 30 psf LL	30'-0"
24-360X	24	L/360, 30 psf LL	30'-0"
24-480H	24	L/480, 30 psf LL	27'-8"
24-480XH	24	L/480, 30 psf LL	27'-8"
24-480X	24	L/480, 30 psf LL	27'-8"
24-720H	24	L/720, 30 psf LL	24'-6"
24-720XH	24	L/720, 30 psf LL	24'-6"
24-720X	24	L/720, 30 psf LL	24'-6"

All floor systems were constructed at the Virginia Tech Structures and Materials Research Laboratory in Blacksburg, VA by laboratory personnel using typical building procedures and equipment. Concrete mortar unit (CMU) walls with 2 in. by 6 in. wood sill plates attached at the top were used to support the floor joists. These walls were constructed to simulate a typical basement wall or a continuous load bearing wall. The steel joists are bottom bearing as shown in Figure 2.2. The joists were connected by cross bracing at the ends and center for all floors. Three different diagonal bracing configurations were used. Bracing lines were placed perpendicular to the joists at the span quarter points. The diagonal bracing configurations are discussed in section 2.2.2. The sheathing was attached to the joists (Figure 2.3) with 2 in. No. 10 self-tapping screws. The screws were spaced 6 in. apart around the perimeter of the floor and 12 in. on center to the joists.

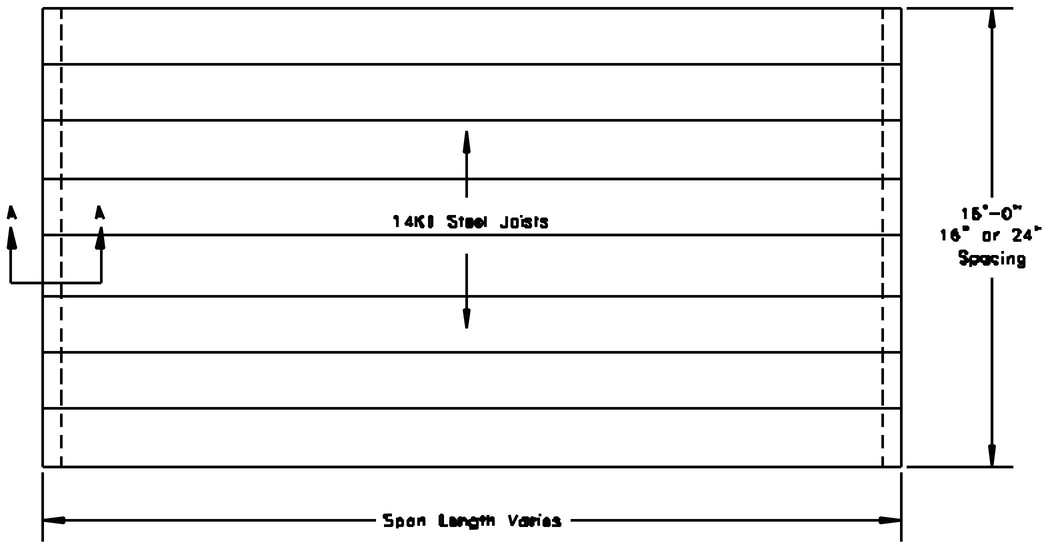


Figure 2.1 Typical Floor Setup

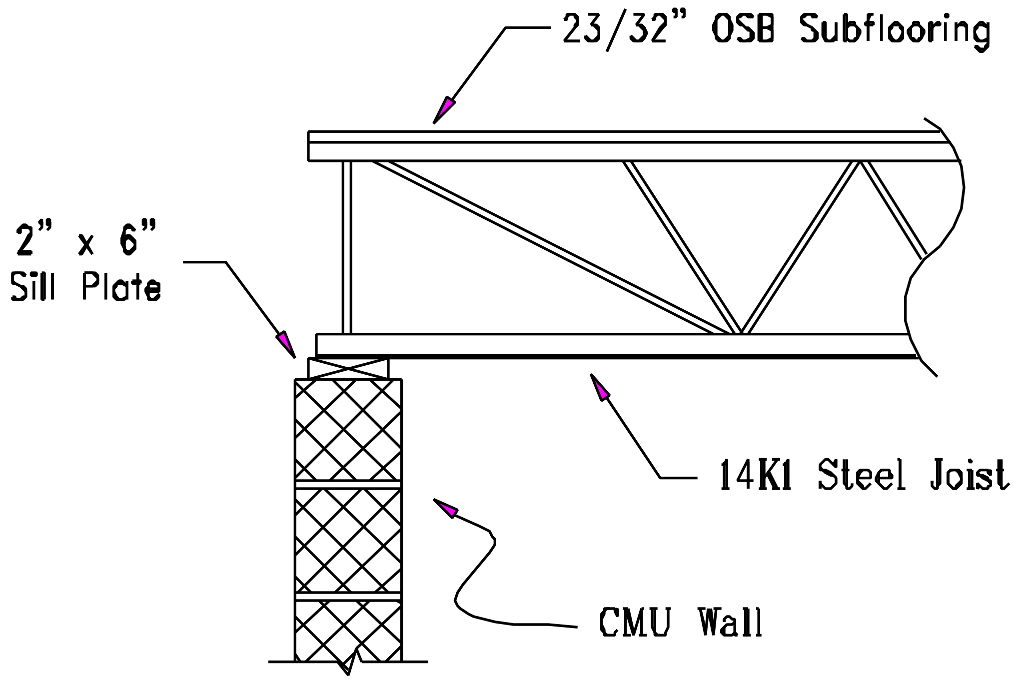


Figure 2.2 Section A-A from Figure 2.1

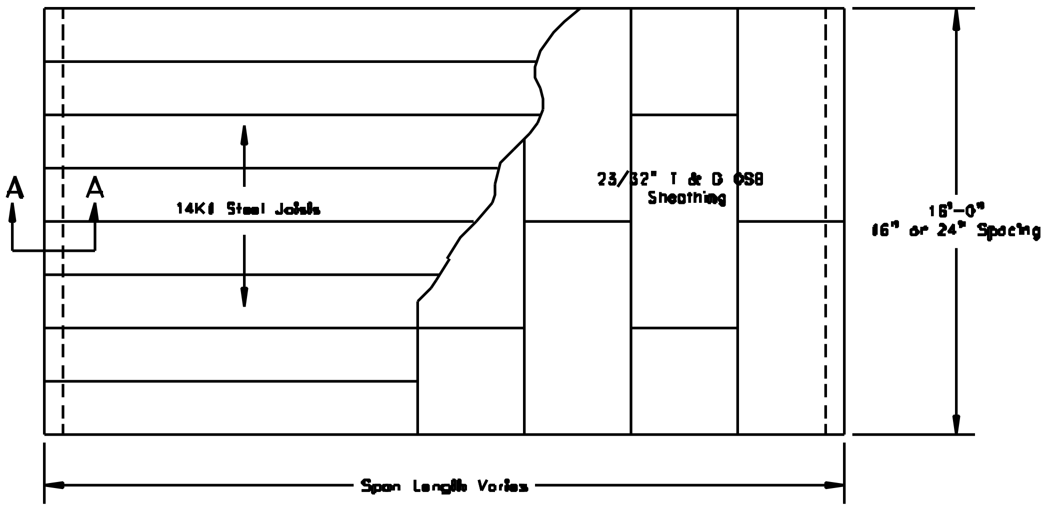
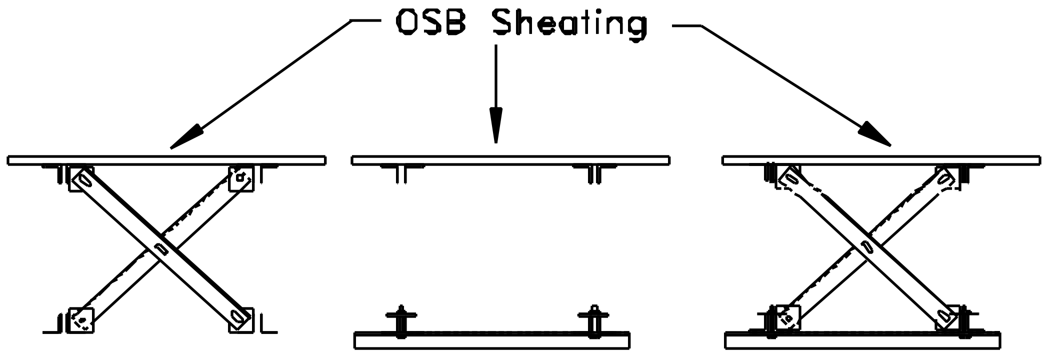


Figure 2.3 Sheathing Attachment

2.2.2 Diagonal Bracing Configurations

Three different diagonal bracing configurations (X, H, AND XH) were studied for each floor system (Figure 2.4). The purpose was to determine the degree of stiffness attributed to each type of diagonal bracing used. The floor systems were first constructed using "X" diagonal bracing and then the sheathing was attached. After each floor was tested with X-bracing, the appropriate bracing pieces were added or removed depending on the next configuration. Since the sub-flooring was in place, it was impossible to attach the top piece of the H-bracing member to the floor. It was found that the floor system would act in the same manner without this member attached since the sheathing provided stiffness in the direction perpendicular to the joists.

The bracing was made of 1.0 in. by 1.0 in. by 0.109 in. steel angle. The steel joists had clip angles welded to the chords where the diagonal cross bracing was attached. The cross bracing had short slotted holes for minor adjustments and was attached to the clip angles by 3/8 in. machine bolts 1.0 in. long The cross bracing was also bolted where the two angles met. The horizontal bracing was attached through the bottom chord by 3/8 in. machine bolts 3 in. long with an oversized washer.



A) H-Bracing B) X-Bracing C) XH-Bracing

Figure 2.4 Bracing Configurations

2.2.3 Description of Tests

Four tests were used to access the behavior of each floor system. The procedure and instrumentation used in each test is described below.

2.2.3.1 Heel Drop Impact Test

The heel drop impact is considered a standard method of obtaining the frequency modes of a floor system. The heel drop is approximated by a linear decreasing ramp function from 600 lb. to 0 lb. within 50 milliseconds (Figure 1.3). Since a heel drop will vary depending on the person performing the test, a heel drop simulator (HDS) was used instead. An HDS (Figure 2.5) is a machine developed by Murray that is used to approximate a heel drop performed by a human. The results from the HDS are easily repeated and are consistent.

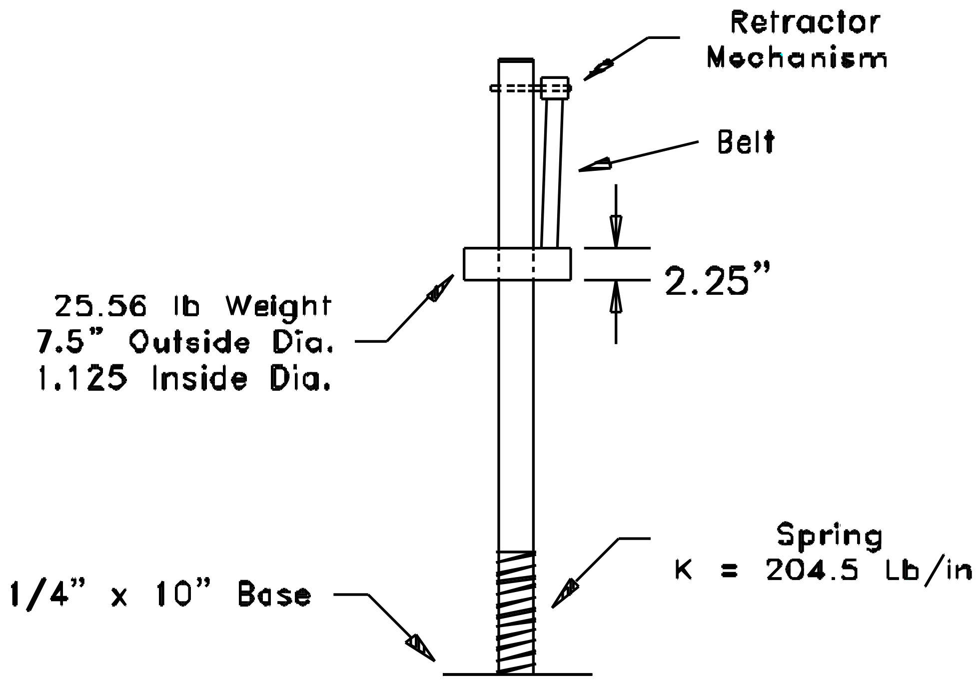


Figure 2.5 Heel Drop Simulator (HDS) Machine

A force plate was used to measure the excitation force introduced into the floor system during a heel drop impact. The force plate used was made of four Nikkei cantilever beam type load cells, model NSB-500, with a capacity of 500 pounds each. The load cells produced a voltage that was summed together by a junction box that was connected to channel 1 of a HP 35660A dynamic signal analyzer. Calibration of the force plate was achieved by a static load test which yielded a calibration factor of 65,202 lb/volt.

The acceleration of the floor was measured by a Wilcoxon Model 731, liquid damped, piezoelectric accelerometer connected to a Wilcoxon Model P-31 Power unit/amplifier that was connected to channel 2 of the analyzer. Two different heel drop tests were performed for each floor configuration. The first used an accelerometer and the HDS, resting on a force plate, both located at the midspan of the floor system (Figure 2.6). This test was used to determine the fundamental frequency of the floor system. A second test was performed where the HDS and force plate were located at the 1/4 point of the floor (in both directions) while the accelerometer was located at the opposite 1/4 point (Figure 2.7).

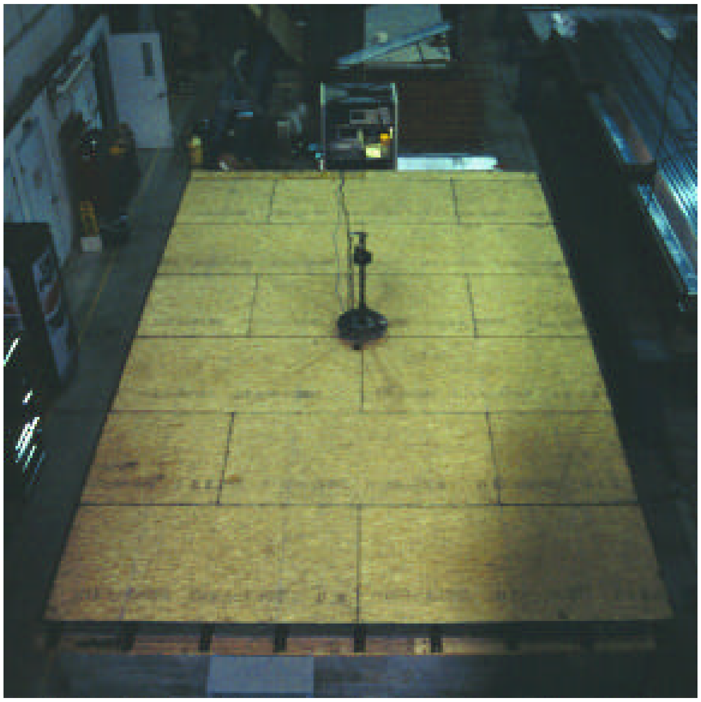


Figure 2.6 HDS, Force Plate and Accelerometer Located at midspan of Floor

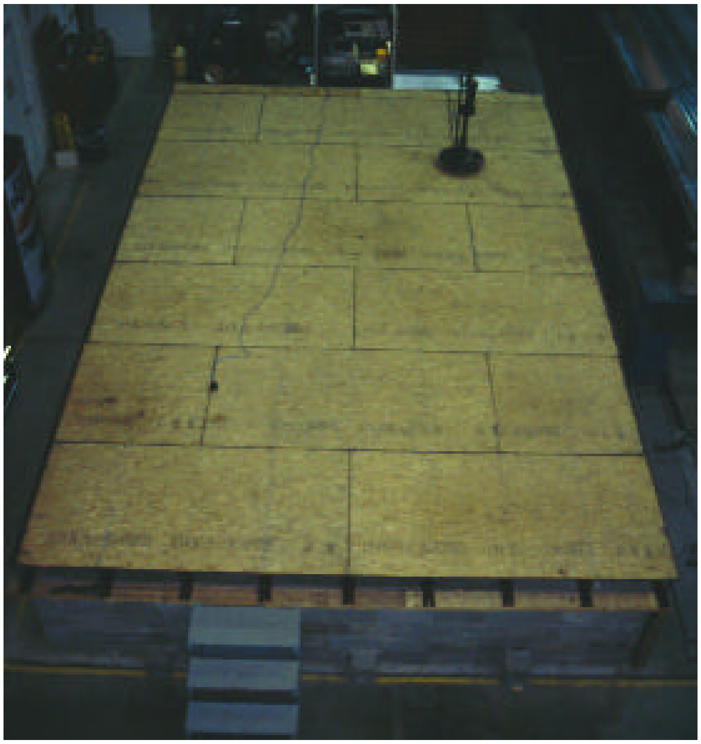
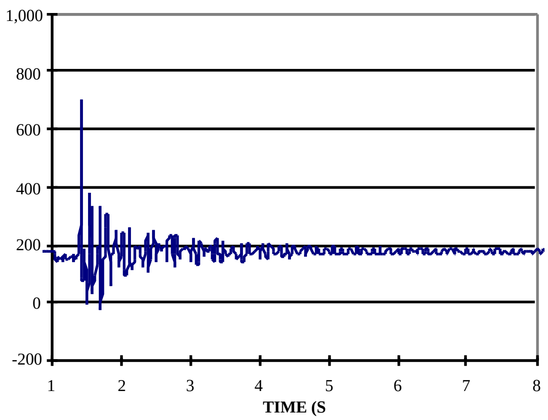
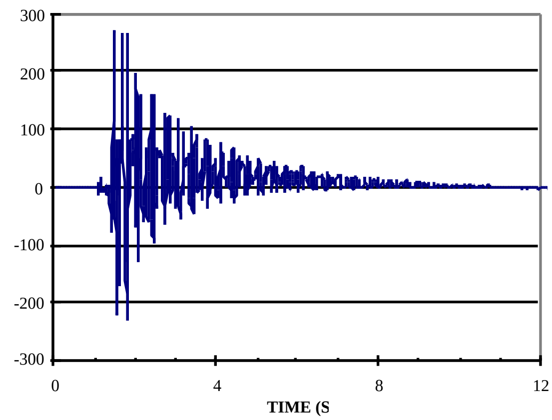


Figure 2.7 HDS and Accelerometer Located at Opposite _ Points of Floor System



a) Force Trace



b) Acceleration Trace

Figure 2.8 Example of Force and Acceleration Traces

For all tests, the analyzer was set to record 1024 data points over a 16 second period. These recordings are called a time trace since the variation of the floor was measured over time. Figure 2.8a is an example of an input force trace while Figure 2.8b is an example of an acceleration trace.

The analyzer can be used to perform a fast fourier transform (FFT) of the data so the user can view the frequency power spectrum of the acceleration trace almost instantly. A frequency power spectrum is a graph that plots the relative power for each frequency. The relative height of each peak represents the relative amount of energy used by each frequency. Figure 2.9 is an example of a typical power spectrum for a given acceleration trace. Traces for each floor system are found in Appendix A.

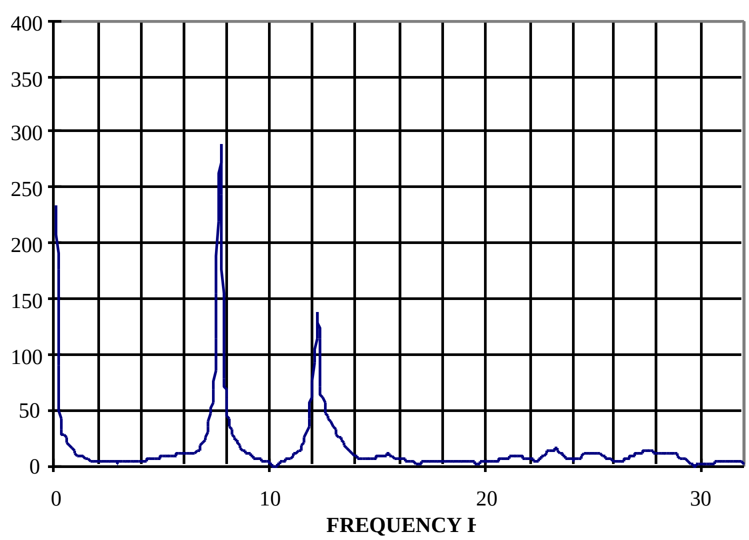


Figure 2.9 Example Power Spectrum

2.2.3.2 Walking Parallel and Perpendicular to Floor Joists Test

Acceleration measurements were taken for a 150 lb man walking perpendicular and parallel to the joist span of each floor. The maximum root mean square (RMS) acceleration for such excitation is sometimes used to asses floor acceptability, but not in this study. Acceleration records for these tests are found in Appendix A.

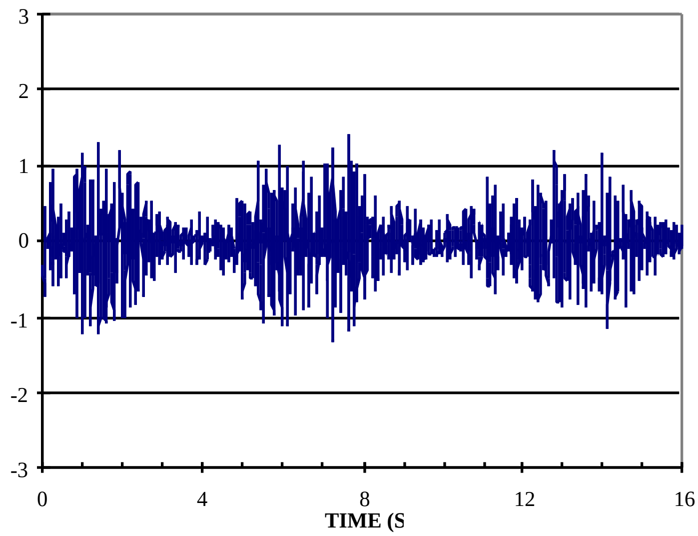


Figure 2.10 Example of a Walking Acceleration Trace

2.2.3.3 Concentrated Load Tests

Four of the five criteria examined in this study use midspan deflection as a part of the acceptability requirements. A 225 lb. concentrated load was placed at midspan of each floor system and deflection readings for each joist were recorded. A midspan deflection profile was plotted for each floor system. Figure 2.11 is a typical midspan deflection profile of a floor system.

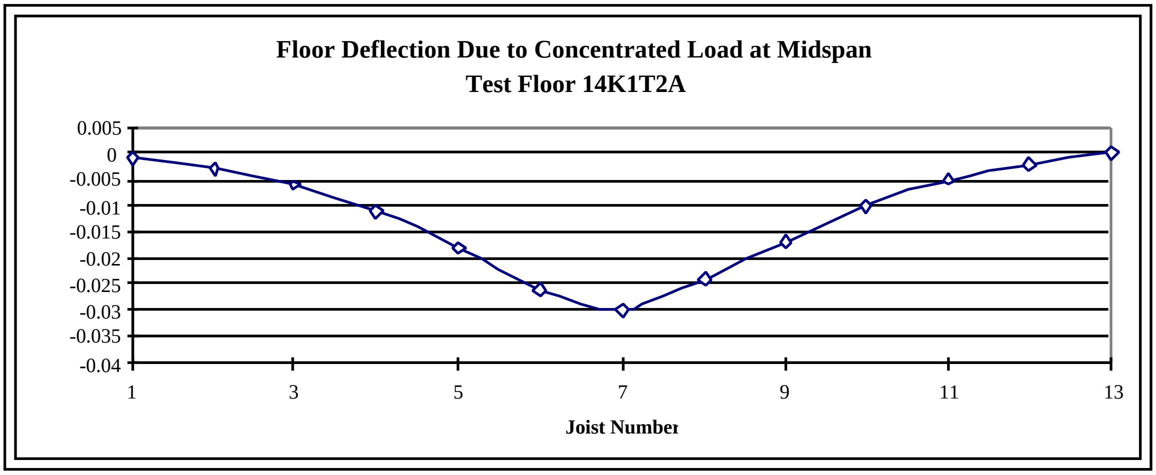


Figure 2.11 Typical Midspan Deflection Profile

2.2.3.4 Test to Determine Subjective Evaluation

Subjective evaluation is the only way to determine the acceptability of a floor system. Three people were asked to rate each floor system based on the vibration level. Each subject was placed in a chair at the midspan of the floor and allowed to sit for a few seconds to adjust to the surroundings. After the subject adjusted to the environment, a 245 lb. man walked around the floor at a normal walking pace. The subjects were asked if the floor was acceptable, marginal or unacceptable if it was in their home. They were also asked to rate the vibrational characteristics of the floor as: Imperceptible; Barely Perceptible; Distinctly Perceptible; Strongly Perceptible; or Severe. The responses were then averaged to obtain the rating of the floor.

2.3 Two-Joist Floor Systems

To determine the magnitude of composite action between the OSB sub-flooring and the steel joists, two-joist floor systems were constructed. This section describes the general layout, construction and testing of the two-joist line floors. Appendix B provides a complete description of each floor system including layout, section properties and measured values.

2.3.1 Materials and Construction

Two two-joist floor systems were constructed one at 24 in. joist spacing and the other at 16 in. spacing. Each floor was constructed in a similar manner as was used for the multi-joist floors, except that there were no subflooring joints parallel to the joists. The width of the OSB sub-flooring was twice the joist spacing and oriented in the same direction as in the multi-joist floor systems. Diagonal cross bracing (X-bracing Figure 2.4) was used at the ends, quarter points, and at the midspan.

2.3.2 Description of Tests

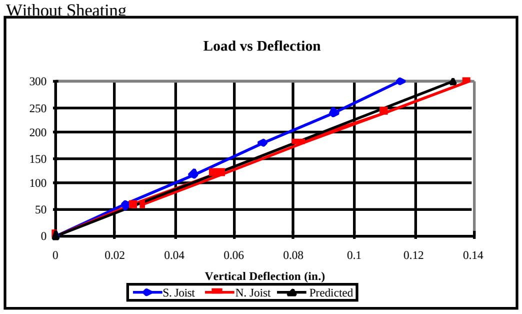
2.3.2.1 Concentrated Load Tests

To determine the effect OSB has on the stiffness of the floor system, the moments of inertia must be known with and without the OSB sheathing present. The moment of inertia was determined by placing static load on the floor system and measuring midspan deflection. The simple beam equation was then used to back calculate the moment of inertia. Figure 2.12 shows the load versus deflection plots for each test.

Dial gages were placed to measure midspan deflection and support deflection. The overall deflection was found by subtracting the average of the support deflections from the midspan deflection. Load versus deflection plots for each configuration is located in Appendix B. By rearranging Equation 1.2 the moment of inertia was calculated for each configuration. Table 2.2 shows the results. Clearly there is insignificant increase in the moment of inertia after adding the OSB sub-flooring.

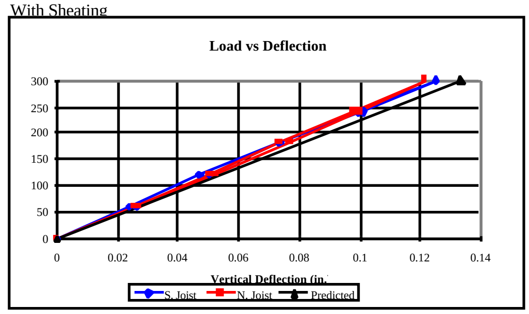
2J16-720 Span Length = 27.29 (ft)

Without Sheating



Moment of Inertia From Deflection Test is59.05 in^4

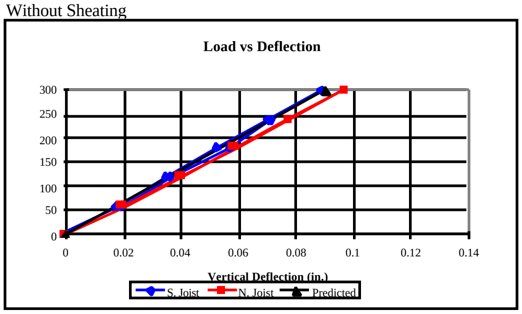
With Sheating



Moment of Inertia From Deflection Test is60.91 in^4

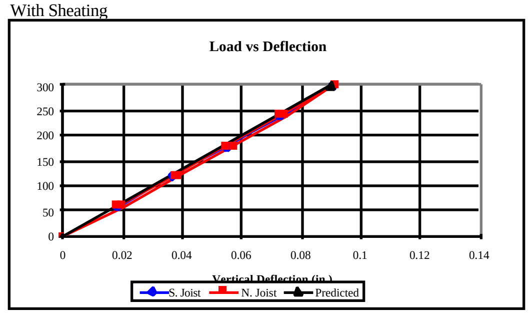
2J24-720 Span Length = 24.50 (ft)

Without Sheating



Moment of Inertia From Deflection Test is57.60 in^4

With Sheating



Moment of Inertia From Deflection Test is58.16 in^4

Figure 2.12 Load versus Deflection Tests for Two-Joist Floor Systems

Table 2.2 Measured Moment of Inertia For Two-Joist Floor Systems

Floor	I_x Without Sub-flooring (in^4)	I_x With Sub-flooring (in^4)
2J16-720	59.05	60.91
2J24-720	57.60	58.16

2.3.2.2 Heel Drop Impact and Walking Tests

The heel drop impacts and walking tests were performed only after the OSB decking was in place. As required, the HDS, force plate, and accelerometer were located at the midspan of the floor system. Data was acquired with the same equipment as used in the multi-joist tests. The results from both sets of tests are summarized in Table 2.3 and are compared to the predicted frequency found using Equation 1.24 with the measured transformed moment of inertia of the system, with only the selfweight of the floor system. The next chapter will discuss the results of these tests in detail.

Table 2.3 Frequency Results of Two-Joist Floor Systems

Floor	$f_{measured}$ (Hz)	$f_{predicted}^{*}$ (Hz)
2J16-720	10.19	12.99
2J24-720	10.06	14.76

*Calculated using the measured (Table 2.2) transformed moment of inertia of each floor system

2.4 Multiple and Torsional Modes of Vibration

Multiple modes of vibration other than the fundamental mode can contribute to the response of a wood floor system (Johnson 1994). It is usually difficult to excite a lightweight floor system without having these additional modes of vibration in the power spectrum. The amount of force in the dynamic impact may also affect the multiple modes of vibration that are in the power spectrum. Johnson (1994) also pointed out that higher frequencies may be excited if the joists are not moving in unison. Figure 2.13 is a power spectrum of a multi-joist line floor with the fundamental frequency near 10 Hz and the second frequency of vibration near 13 Hz.

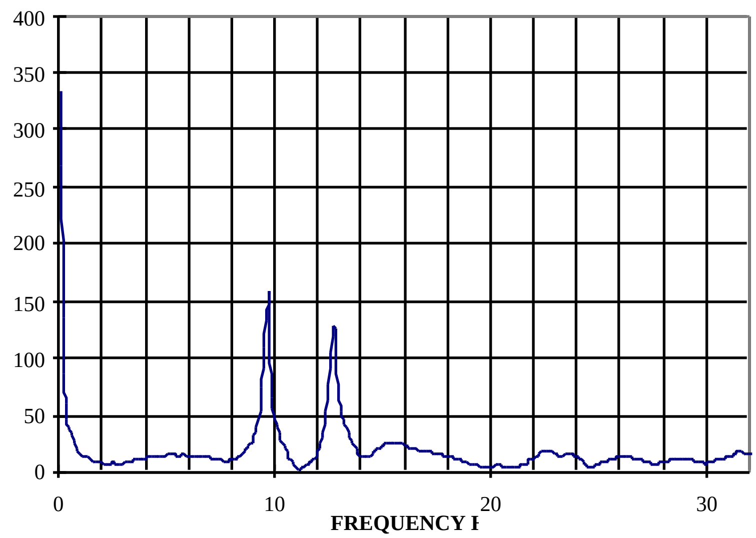


Figure 2.13 Power Spectrum Showing Two Frequencies of Vibration

Heel drop tests were performed at a quarter point with the accelerometer located at the opposite quarter point of each floor system as discussed in Section 2.2.3.1. These tests were performed to determine if there were multiple modes of vibration. It is believed that a dynamic impact at a quarter point will show the second mode of vibration at the opposing quarter point. The fundamental frequencies from these tests were within ten percent of the fundamental frequency when measured from the midspan of all multi-joist floor systems in this study, as shown in Figure 2.14. This indicates that the fundamental frequency is the dominant frequency. All pertinent data from these tests for each floor system is found in Appendix A.

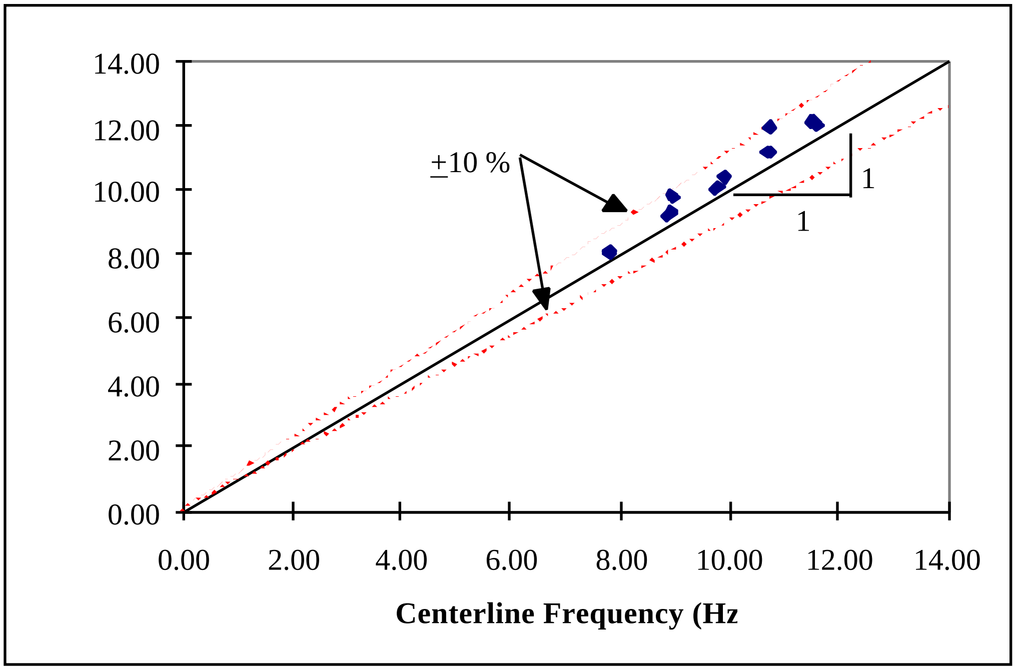


Figure 2.14 Fundamental Frequency from Heel Drop Impact Tests at Different Locations: Quarter Point versus Midspan

Torsional modes of vibration may also appear in the power spectrum. They usually show up as a range of frequencies that have a relatively large influence in the power spectrum. The two-joist floor systems were the only floors in this study that exhibited any torsional modes of vibration. Figure 2.15 shows a range of torsional and multiple frequencies between 10 and 15 Hz with the fundamental frequency being near 10 Hz.

In summary, the fundamental frequency can be predicted reliably with Equation 1.24 for the floor systems tested and there is little contribution from multiple or torsional modes of vibration. Vibration acceptability can be based on the fundamental frequency of vibration without taking into account multiple and torsional frequencies for steel joist wood supported floor systems.

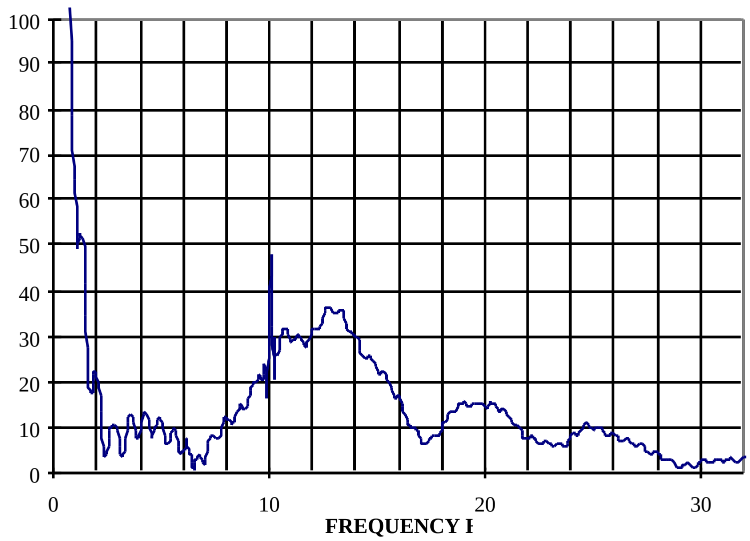


Figure 2.15 Power Spectrum Showing Multiple and Torsional Modes of Vibration