Site Investigation of the Dynamic Behaviour of the iSPAN Floor System

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1. Introduction

A site investigation was conducted on October 13, 2005 to determine the dynamic characteristics of the iSPAN Floor System. The tested house was located in Clarington, Ontario. A photograph of the house is shown in Figure 1.1.

The house is a single storey house with a basement. The floor area of the house is approximately 2,100 ft^2. The floor plan is shown in Figure 1.2. The house is mostly completed and furnished except that ceilings in basement were not installed. The tests were conducted on the longest joist spans which are located in the living room. The location of the living room is marked by line 2 and 3 and line A and B as shown in Figure 1.2. All furniture in the living room was removed prior to the tests. The floor joist depth is 12 inch and the designation of the joist is iSPAN 18-16-18 joist with a span length of 17'-10-1/2" center to center to the supports. One end of the joists is bearing on a wooden stud stub wall while the other end of the joists is bearing on a hot-rolled W-shape steel beam. The subfloor material is 3/4" tongue-in-grove OSB and the floor of the living room is finished with hardwood floors.

2. Objective

The objective of the testing is to establish the dynamic characteristics of the iSPAN cold formed steel floor system by performing on-site tests in a finished housing unit (as related to OBC Clause 4.1.1.6).

3. Test Set Up

The site tests comprised of two types of dynamic tests (a heel drop test and a sandbag drop test with a person on the floor) and a static deflection test.

The heel drop test was performed by a male individual weighing 175 lbs. A photo of the heel drop test is shown in Figure 3.1. The sandbag drop was performed by the male individual dropping a 10-kg sandbag from a height of 300 mm as shown in Figure 3.2.

Three accelerometers were placed on the floor to collect the floor dynamic responses as shown in Figure 3.3, in which accelerometer 1 is located at the floor centre of the living room while accelerometers 2 and 4 are located 36" and 49-1/2" away from accelerometer 1, respectively.

In both of the sandbag and heel drop tests, the acceleration response of the floor at the location of each accelerometer was measured by three accelerometers and recorded by the data acquisition system. The recorded acceleration response, as a function of time, was later processed by applying Fast Fourier Transforms (FFT) to obtain frequency spectra of the floor response. The FFT analysis was performed using MATLAB. A graphic plot of the frequency spectra of the floor response (power spectral density vs. natural frequency) obtained from Accelerometer 1 in heel drop test No. 6 is shown in Figure 3.4, from which the natural frequencies of the floor can be identified. Power spectral density is defined as the power per unit frequency interval. A plot of this quantity indicates the frequency distribution of power.

The static test was performed by placing a 1-kN weight at the centre of the floor system as shown Figure 3.5. A digital dial gauge located at the mid-span of each of the two centre joists was placed underneath the bottom flange of the joists as shown Figure 3.6. The mid-span deflection of a neighbouring joist was also measured. The mid-span deflections of the iSPAN joists were measured at the loaded and unloaded state. This process of loading and unloading was repeated three times and the average deflection was reported.

4. Test Results

The natural frequency obtained from the frequency spectrum is independent of the location of the measured point on the floor. However, the different spectrum densities are influenced by different locations of measurements as is demonstrated in Figures 3.4, 4.1, and 4.2, which are illustrations of the frequency spectra of the floor responses obtained from Accelerometer 1, 2 and 4 in heel drop test No. 1 and No. 6.

The bandwidth method (Xu, 2000) was applied to obtain the damping ratio of the floor. The response obtained by each the three accelerometers was recorded and processed, average values of the floor frequencies and damping ratios of the floor were then reported.

Six dynamic heel drop tests were carried out and the results of each test consistently show that the floor frequencies associated with the first three vibration modes were about 20, 23 and 33 Hz, respectively. The test results of the six heel drop tests are shown in Table A.1 of the Appendix. The average values of the floor frequencies obtained from the six tests are adopted as the floor frequencies and are presented in Table 1.

Five sand bag drop tests were conducted. Similar to that of the heel drop tests, the results of each test consistently show that the floor frequencies associated with the first three vibration modes are about 20, 23 and 33 Hz, respectively. The test results of the five sandbag drop tests are shown in Table A.2 of the Appendix. The average values of the floor frequencies obtained from the six tests are adopted as the floor frequencies and are presented in Table 1.

Four static tests were carried out. As previously described, the joist displacements of loading and unloading states were measured and the floor mid-span deflection was obtained from the average value of the two centre joists' deflection under the action of a 1-kN load. The maximum floor deflection, 0.36 mm, was then obtained based on the average value of the floor mid-span deflections from the four tests. Table A.3 presents the deflections obtained from the four tests, in which the displacements associated with dial gauge 1 and 2 were measured from the two centre joists while the displacement of dial gauge 3 was the one obtained from the joist on the east side of the centre joists.

Table 1: Summary of test results

Floor Test	**1st frequency (Hz)**	**2nd frequency (Hz)**	**3rd frequency (Hz)**	**Damping ratio**	**Maximum floor deflection (mm)**
Heel drop	20.22	23.75	33.69	7.0%	
Sand bag drop	20.35	23.82	33.64	4.8%	
Static					0.36

Joist span length = 17’-10-1/2”
Joist designation = iSPAN 18-16-18
Joist spacing = 24”
Subfloor = 3/4" OSB

5. Conclusions

- *Ontario Building Code* (1997), Sections 4.1.1.6 requires that floor systems susceptible to vibrations shall be designed so that there will be no significant adverse effects on the occupancy of the building from vibration and that the design should comply with *National Building Code of Canada* (1995) on floor vibration. In the *National Building Code of Canada* (1995), Sections 4.1.10.5(1) and 4.1.10.6, as well as the *National Building Code of Canada* (2005), Sections 4.1.3.6(1) and 4.1.3.6(2), require an investigation by means of a dynamic analysis for floor structures supporting assembly occupancies when the fundamental vibration frequency is less than 6 Hz. Since the fundamental frequency (the lowest natural frequencies, i.e the 1^{st} frequency) of the floor tested is substantially greater than 6 Hz, dynamic analysis for the floor structure is not required.

- Floors susceptible to annoying floor vibration generally have a fundamental frequency between 5 and 8 Hz. If the natural frequency of a floor is greater than 9-10 Hz, significant resonance with walking harmonics does not occur. Therefore, resonance due to human walking is not likely to occur for the tested floor.

- Rhythmic activities, such as dancing, foot stamping, jumping exercises, and marching, create periodic forces with rhythmic frequencies in the range of 1 to 4 Hz. Since the frequencies of the floor in all the tests are over 20 Hz, no resonance due to rhythmic activities is expected.

- Where the natural frequency of the floor exceeds 9-10 Hz or where the floors are light such as the floor investigated herein, resonance becomes less important in human induced vibration. For light weight floor, floor response should also include time variation of static deflection due to a moving repeated load (human working). In such a case, the point load stiffness criterion is appropriate for the static deflection components. For the tested floor span, the corresponding deflection limit based on the criteria proposed by the Canadian Wood Council (CWC *et al.*, 1996) and Advanced Technology Council (ATC, 1999) is $\Delta \leq 0.88$ mm and $\Delta \leq 0.93$ mm, respectively. Considering that the maximum floor deflection is only 0.35mm as found from the static tests and the fact that the natural frequency of the floor is over 20 Hz, it is thus concluded that the vibration performance of the tested floor exceeds current code requirement.

- The owner's satisfaction (based on the interview of the owner) and the subjective evaluation conducted by this investigator also support the foregoing conclusion with regards to the vibration performance of the tested iSPAN floor system.

References

ATC, 1999, *Design Guide 1: Minimizing Floor Vibrations*, Applied Technology Council, Redwood, California, USA.

CWC 1996, *Development of Design Procedures for Vibrations Controlled Spans using Engineered Wood Members*, Canadian Wood Council *et al.*, Final Report Prepared for Canadian Construction Material Centre and Industry Partnership Consortium.

NBCC, 1995, *National Building Code of Canada*, National Research Council of Canada, Ottawa, Ontario, Canada.

Ontario Building Code of Canada, 1997.

Xu, L, 2000, *Dynamic Behaviour of Residential Floor Systems Using Cold-Formed Steel Joists* (Phase I), Final Report Prepared for the Canadian Sheet Steel Building Institute, Cambridge, Ontario, Canada.

Appendix

Table A.1 Floor response of heel tests (Hz)

Heel Drop Test No. 1				
Floor frequency	Accelerometer 1	Accelerometer 2	Accelerometer 4	Average Values
1	19.32	19.52	20.72	19.85
2	22.87	23.38	24.15	23.47
3	33.36	34.59	28.44	32.13
Damping Ratio	0.155	0.063	0.059	0.093
Heel Drop Test No. 2				
Floor frequency	Accelerometer 1	Accelerometer 2	Accelerometer 4	Average Values
1	20.10	19.58	20.66	20.11
2	23.15	24.20	24.60	23.98
3	33.72	35.16	33.69	34.19
Damping Ratio	0.103	0.004	0.049	0.052
Heel Drop Test No. 3				
Floor frequency	Accelerometer 1	Accelerometer 2	Accelerometer 4	Average Values
1	19.90	20.89	20.95	20.58
2	22.93	23.50	24.54	23.66
3	34.24	35.26	33.77	34.42
Damping Ratio	0.121	0.032	0.046	0.066
Heel Drop Test No. 4				
Floor frequency	Accelerometer 1	Accelerometer 2	Accelerometer 4	Average Values
1	19.47	20.48	20.95	20.30
2	23.12	23.44	24.60	23.72
3	33.74	34.74	33.57	34.02
Damping Ratio	0.123	0.026	0.046	0.065
Heel Drop Test No. 5				
Floor frequency	Accelerometer 1	Accelerometer 2	Accelerometer 4	Average Values
1	19.41	19.56	20.89	19.95
2	23.10	23.32	24.61	23.68
3	33.33	34.88	33.16	33.79
Damping Ratio	0.158	0.010	0.051	0.073
Heel Drop Test No. 6				
Floor frequency	Accelerometer 1	Accelerometer 2	Accelerometer 4	Average Values
1	19.39	21.38	20.81	20.53
2	22.90	24.60	24.58	24.03
3	33.86	33.23	33.68	33.59
Damping Ratio	0.160	0.021	0.060	0.081

Table A.2 Floor response of sandbag tests (Hz)

Sandbag Test No. 1				
Floor frequency	Accelerometer 1	Accelerometer 2	Accelerometer 4	Average Values
1	20.28	20.32	20.94	20.51
2	23.30	23.38	24.49	23.72
3	33.57	34.50	33.20	33.76
Damping Ratio	0.074	0.039	0.059	0.057
Sandbag Test No. 2				
Floor frequency	Accelerometer 1	Accelerometer 2	Accelerometer 4	Average Values
1	20.29	19.55	20.95	20.26
2	23.09	23.42	24.52	23.68
3	33.78	33.66	32.85	33.43
Damping Ratio	0.083	0.008	0.048	0.046
Sandbag Test No. 3				
Floor frequency	Accelerometer 1	Accelerometer 2	Accelerometer 4	Average Values
1	20.16	19.50	20.95	20.20
2	22.84	23.39	24.63	23.62
3	33.48	34.53	33.42	33.81
Damping Ratio	0.066	0.009	0.049	0.041
Sandbag Test No. 4				
Floor frequency	Accelerometer 1	Accelerometer 2	Accelerometer 4	Average Values
1	20.16	20.80	20.75	20.57
2	23.21	24.23	24.40	23.95
3	33.55	34.13	33.46	33.72
Damping Ratio	0.059	0.031	0.051	0.047

Table A.3 Floor deflection of static tests (mm)

Static Test No. 1				
	Dial gauge 1	Dial gauge 2	Dial gauge 3	Span Deflection
Loading	0.375	0.369	0.13	0.372
Unloading	0.083	0.024	-0.01	
Difference	0.292	0.345	0.14	
Sandbag Test No. 2				
	Dial gauge 1	Dial gauge 2	Dial gauge 3	Span Deflection
Loading	0.374	0.383	0.16	0.379
Unloading	0.076	0.014	0.01	
Difference	0.298	0.369	0.15	
Sandbag Test No. 3				
	Dial gauge 1	Dial gauge 2	Dial gauge 3	Span Deflection
Loading	0.342	0.383	0.15	0.363
Unloading	0.041	0.016	-0.005	
Difference	0.301	0.367	0.155	
Sandbag Test No. 4				
	Dial gauge 1	Dial gauge 2	Dial gauge 3	Span Deflection
Loading	0.284	0.368	0.14	0.326
Unloading	0	0.028	0.01	
Difference	0.284	0.34	0.13	

Figure 1.1: Outside View of Tested House

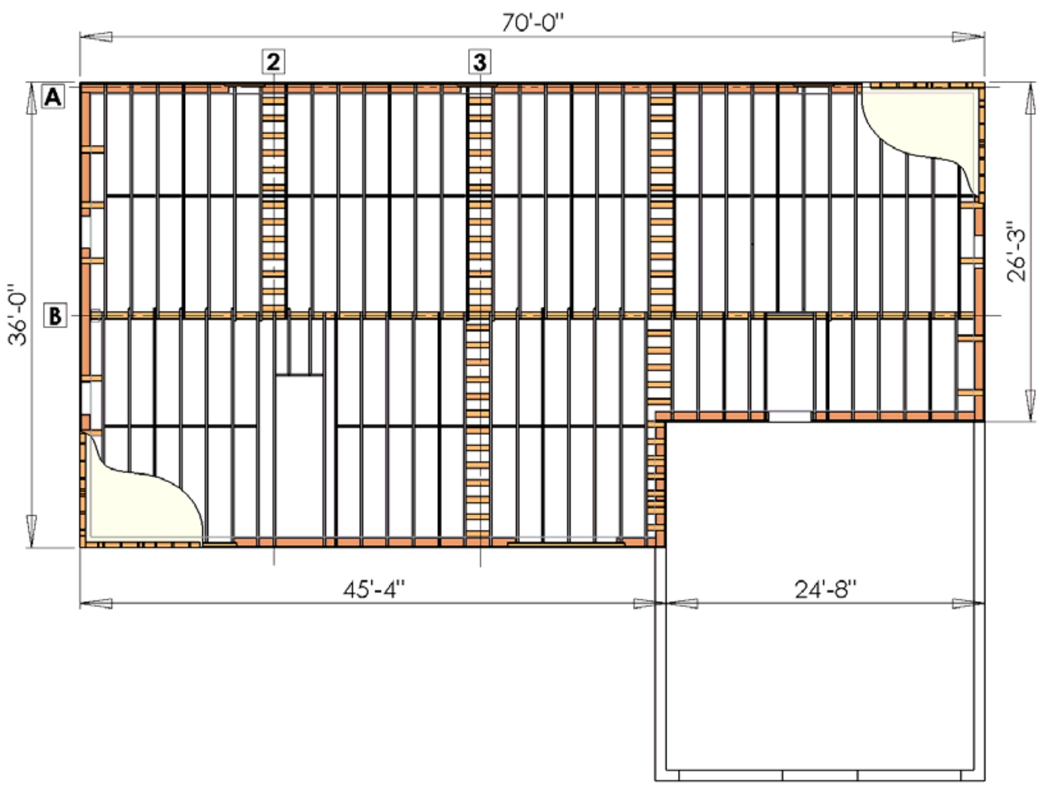

Figure 1.2: Floor Plan

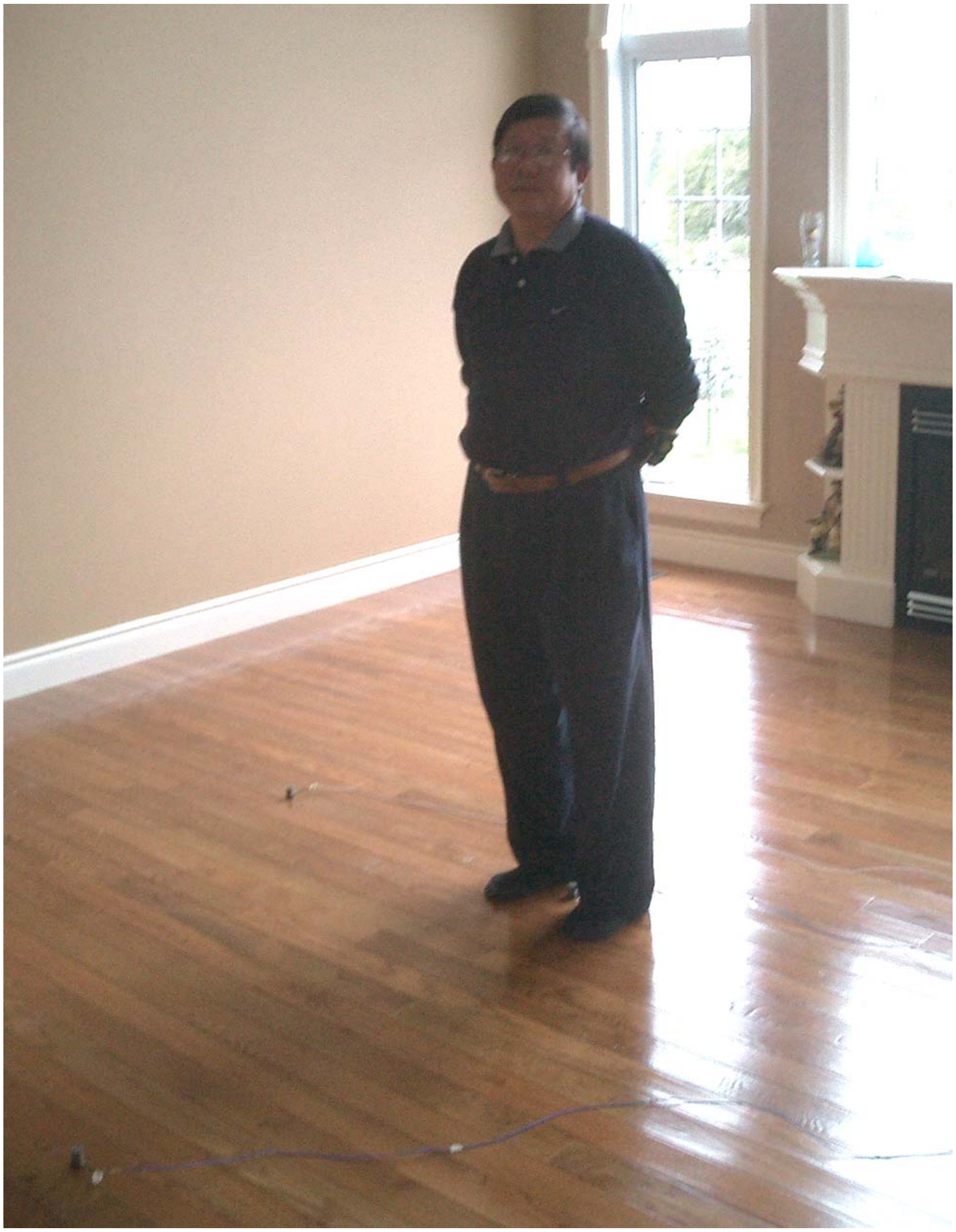

Figure 3.1: Heel drop test

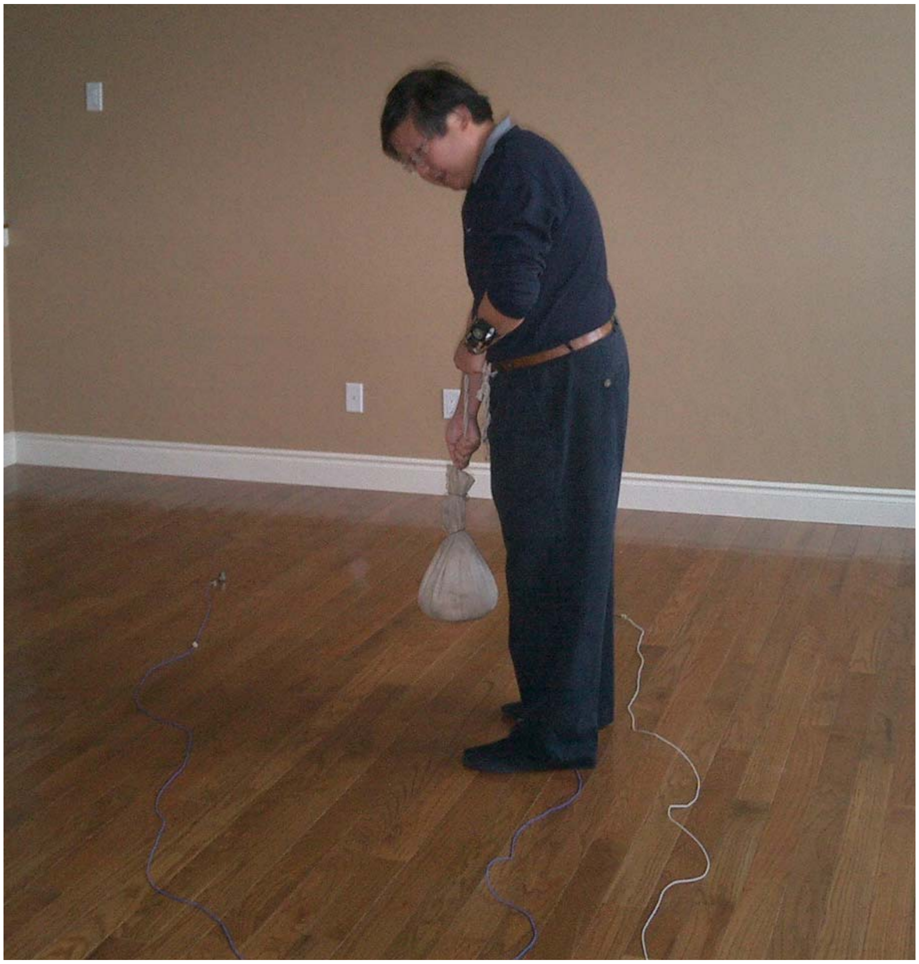

Figure 3.2: Sandbag Drop Test

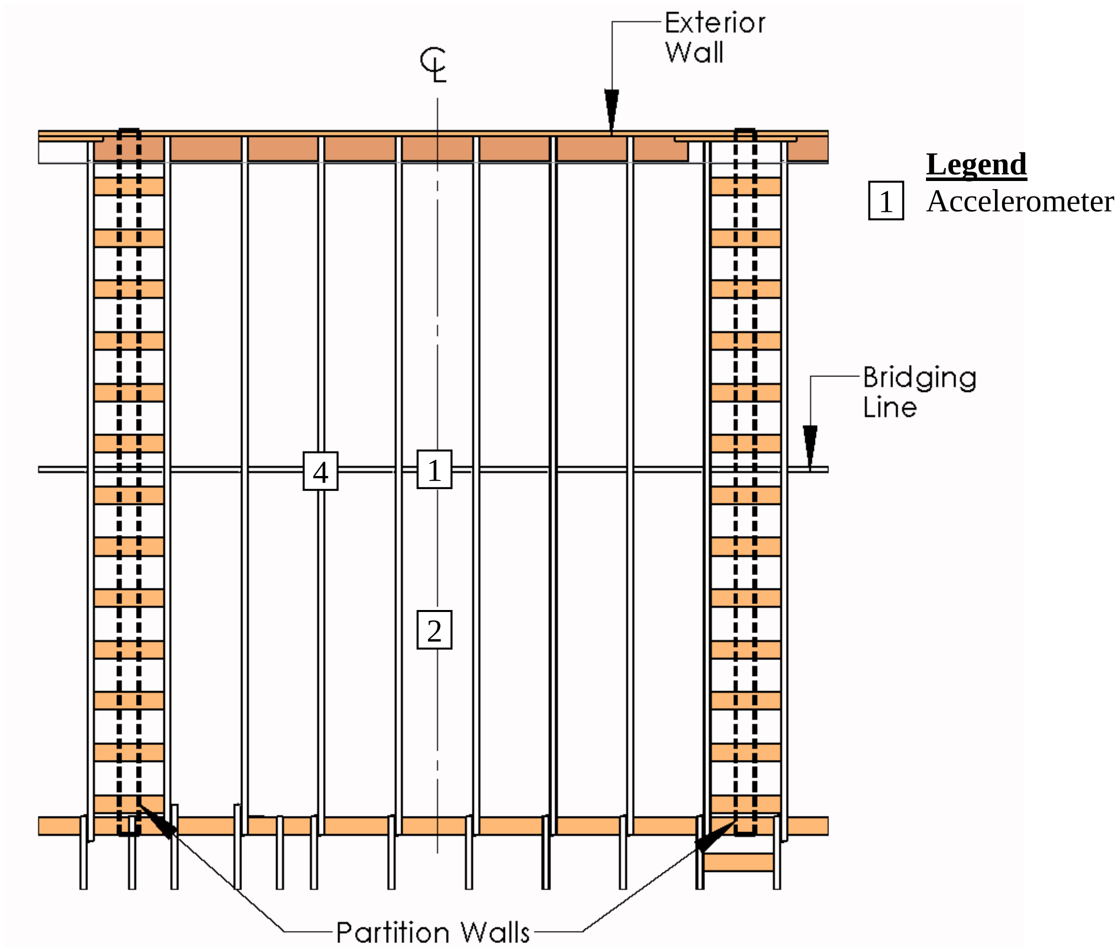

Figure 3.3: Locations of accelerometers

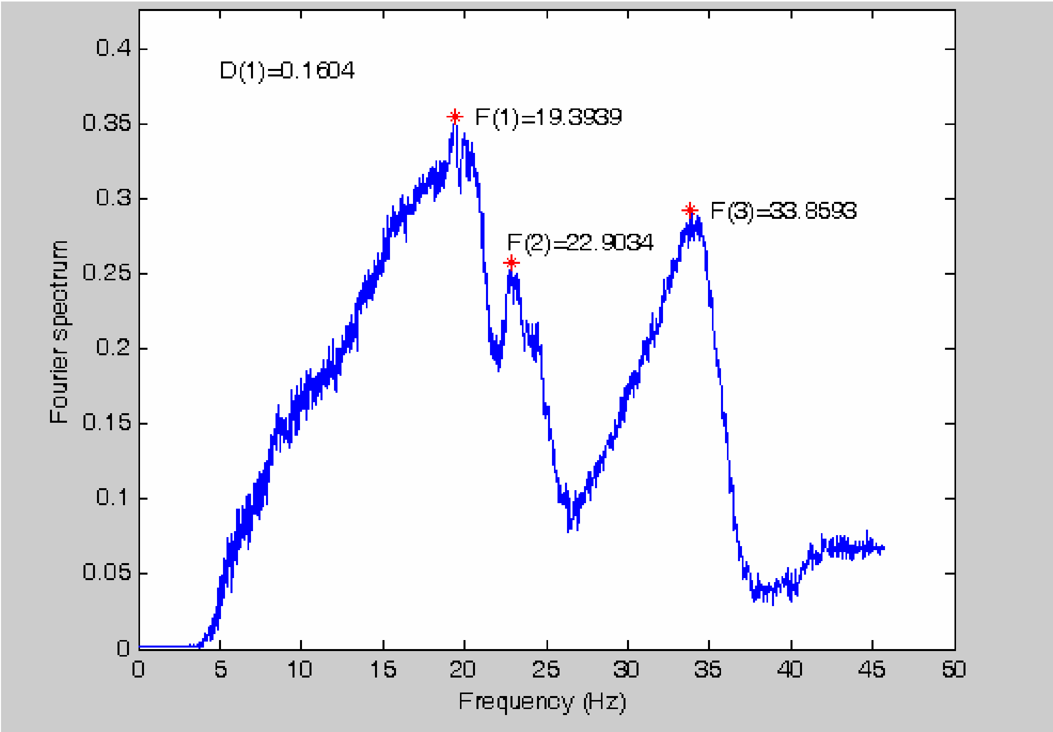

Figure 3.4: Floor dynamic response of heel drop test No. 1 (Accelerometer 1)

Figure 3.5: 1-kN weight setup of static test

Figure 3.6: Deflection measurement setup of static test

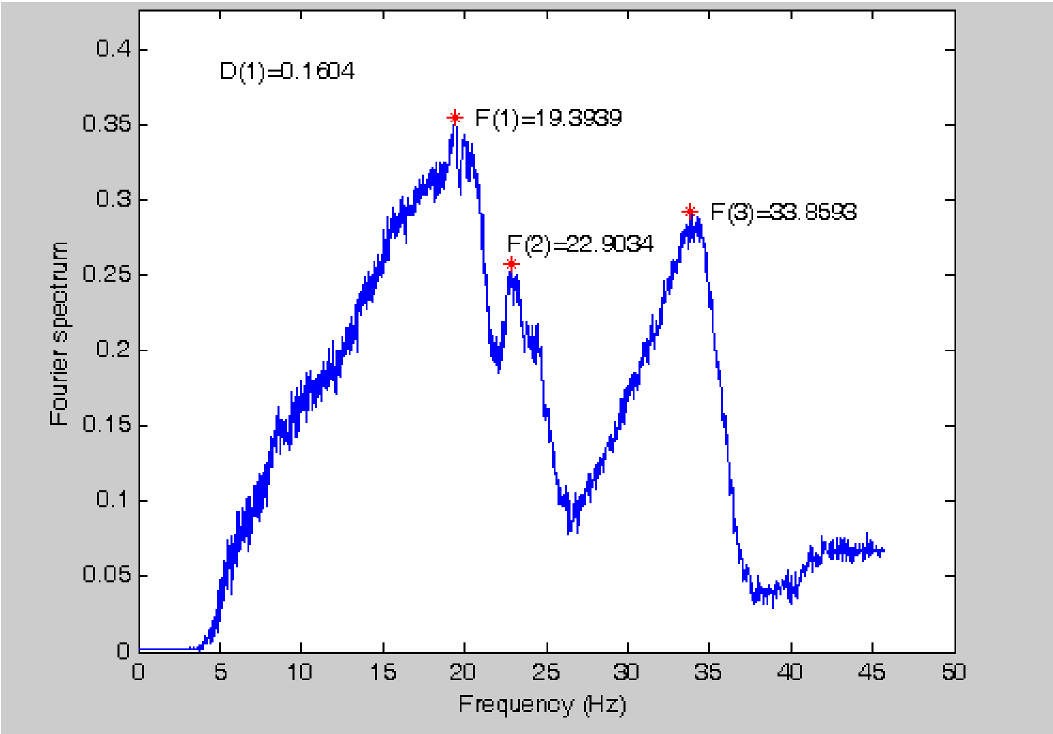

Figure 4.1: Floor dynamic response of heel drop test No. 6 (Accelerometer 2)

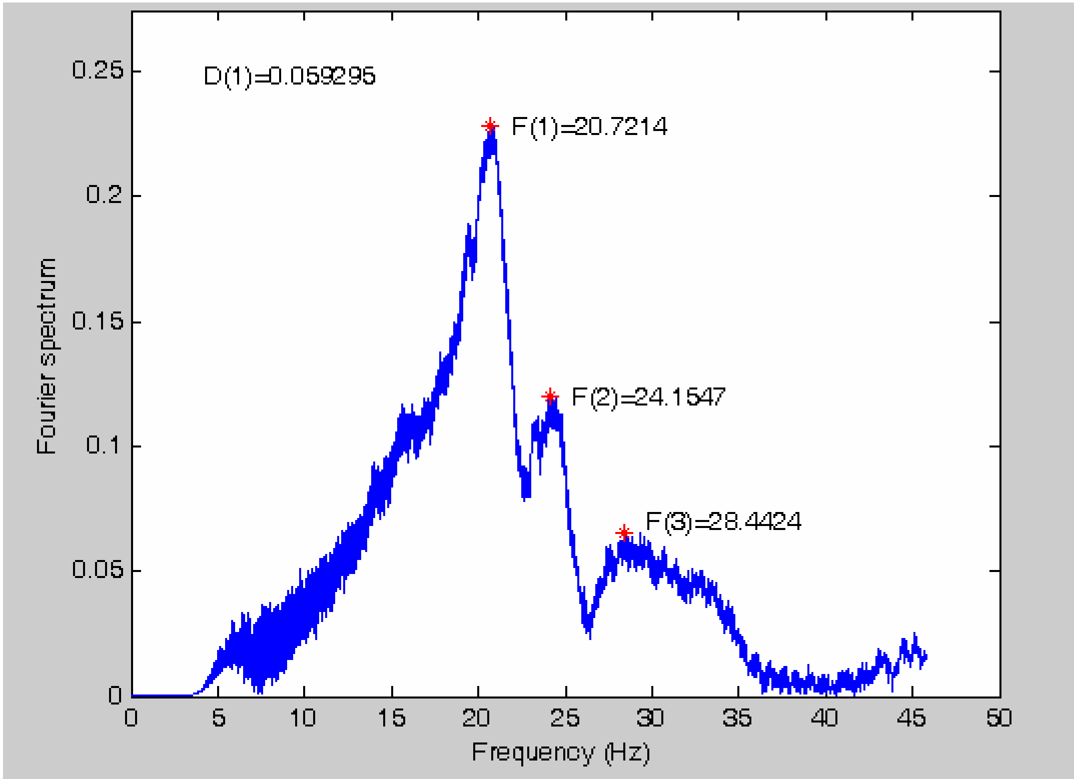

Figure 4.2: Floor dynamic response of heel drop test No. 1 (Accelerometer 4)

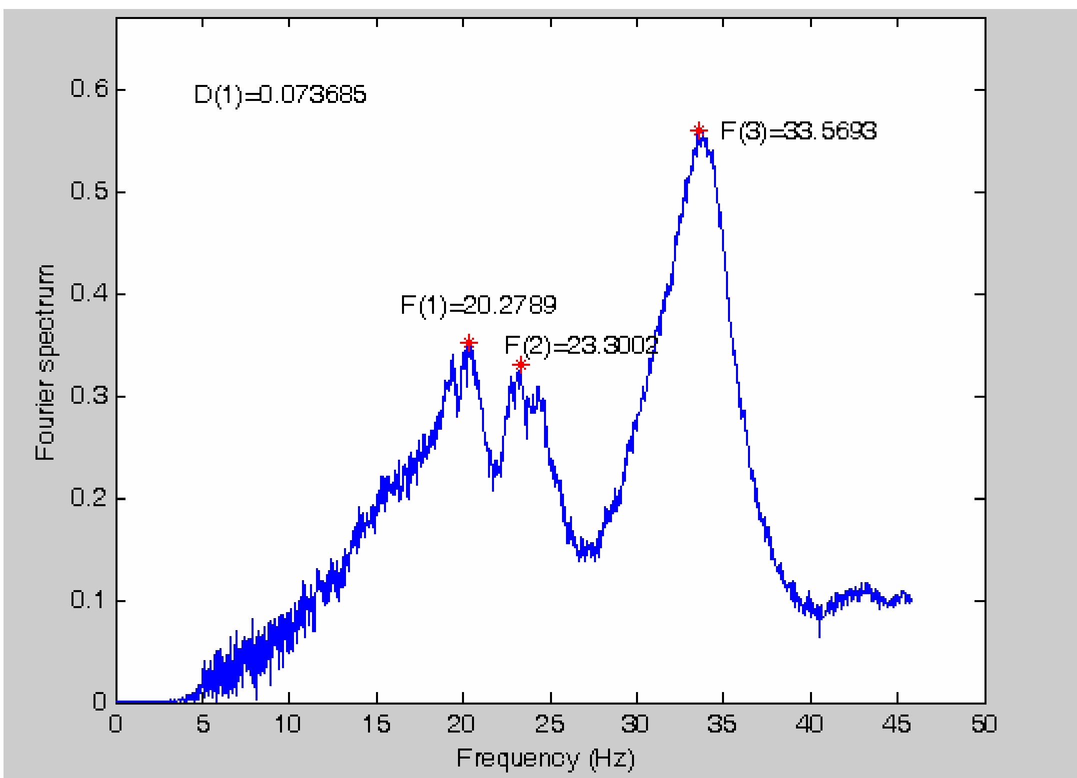

Figure 4.3: Floor dynamic response of sandbag drop test No. 1 (Accelerometer 1)

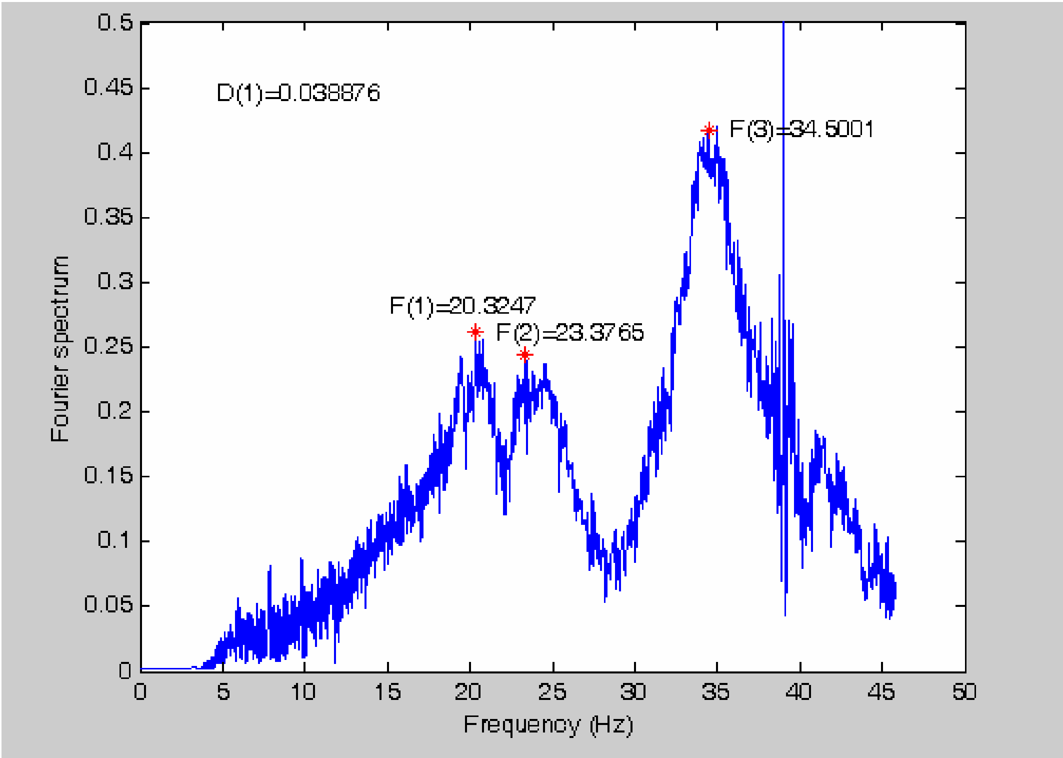

Figure 4.4: Floor dynamic response of sandbag drop test No. 1 (Accelerometer 2)

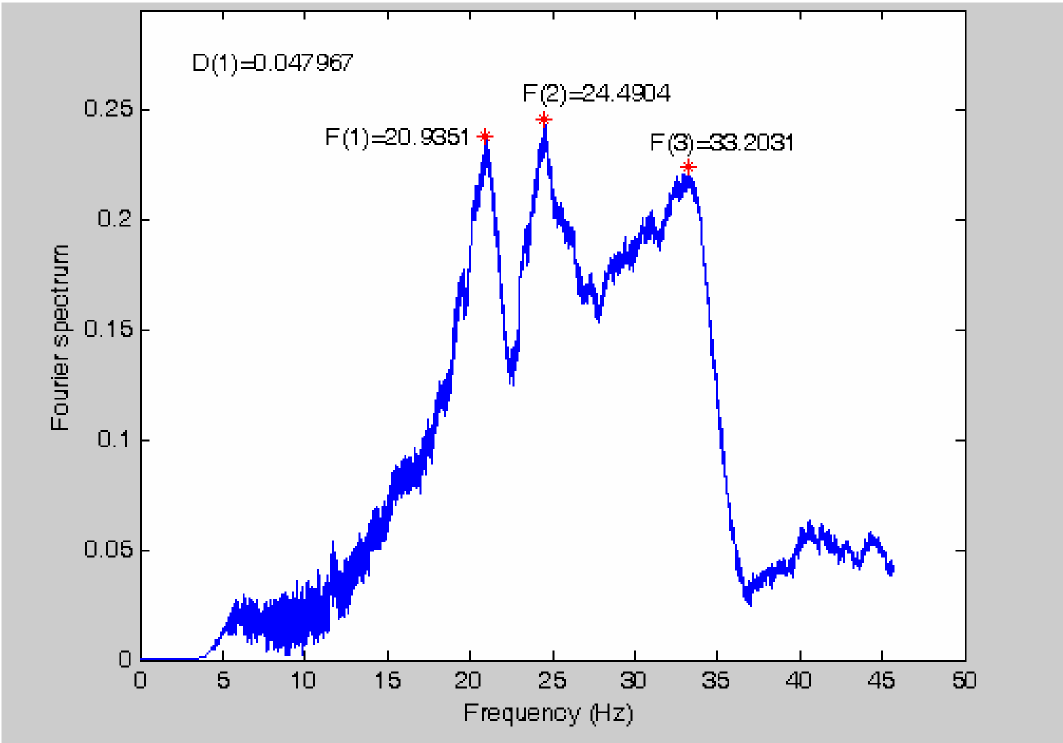

Figure 4.5: Floor dynamic response of sandbag drop test No. 1 (Accelerometer 4)