Acoustics'08 Paris
June 29-July 4, 2008
www.acoustics08-paris.org

Field airborne and impact sound insulation of wood truss floor systems

Chad Himmel and Daniel Kupersztoch

JEAcoustics, 1705 West Koenig Lane, Austin, TX 78756, USA
himmel@jeacoustics.com

A series of field measurements on wood truss floors of various types was recently completed at four residential apartment complexes. About 40 floors with different floor finishes, gypsum concrete underlayment, noise control underlayment systems, truss span lengths, ceiling types, and resilient metal channel types were constructed and measured. Trusses were all similar engineered prefabricated parallel chord wood trusses. Room volumes and room absorptive characteristics are varied and non-standard. Measurements are normalized according to ASTM E 1007 and proposed normalized impact sound rating (NISR) procedures to provide a reasonably consistent set for analysis. Low frequency measurements were conducted to 12.5 Hz one-third octave band. For both transmission loss and impact sound, many of the results compare well with predictions using simple regression analysis developed by others using variables such as the mass of the layers, truss depth and spacing, insulation thickness and density, and resilient metal channel spacing.

1 Introduction

Prefabricated parallel chord wood floor trusses, also known as metal plate connected flat wood trusses, are increasing in popularity as an alternative to conventional wood floor joist systems and open web steel joist systems in commercial and residential construction [1, 2]. Flat wood trusses are constructed from small dimensional lumber (minimum size 38 x 89 mm for horizontal chords, and 38 x 64 mm for vertical and diagonal webs) joined by toothed metal plate connectors.

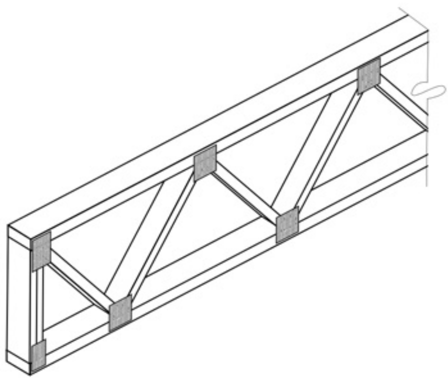

Fig.1 A parallel chord or flat wood truss.

While flat wood trusses are being used increasingly, acoustical data for impact and airborne sound insulation performance of floor-ceiling assemblies that use flat wood trusses is lacking and needs further investigation [3]. Some laboratory test data is available for wood trusses [3, 4] and for similar trusses or open web joists with metal webs and wood chords [5]. More reporting of lab and field test data is needed so that building designers can gauge the compliance of their designs with building code requirements. For example, the International Building Code (IBC) for multifamily dwellings, Sec. 1207 (sound transmission), sets forth minimum airborne and impact ratings when assemblies are laboratory or field tested [6].

The American Society for Testing and Materials (ASTM) standards include test methods for field measurements of the impact sound insulation provided by building elements. Tests involve measuring the sound pressure level in the receiving room below while an impact tapping machine is active on the floor of the source room above.

A number of field acoustical measurements on 457 mm deep flat wood truss floor systems was arranged and completed at newly constructed residential apartment complexes. A total of 43 tests were conducted on various floor-ceiling assemblies with different floor finishes, gypsum concrete underlayment, noise control underlayment systems, truss span lengths, ceiling types, and resilient metal channel types.

This paper presents normalized field test results in a reasonable consistent set that can hopefully fill a void in available data for use in analysis and design.

2 Field test standard procedures

2.1 Impact noise insulation field tests

Field transmission of impact sound through floors is measured in accordance with ASTM E 1007 [7]. A standardized tapping machine with five steel-faced hammers is placed in various specified positions on the sample floor-ceiling assembly. The hammers are driven by a motor to impact the floor surface at a rate of 10 impacts per second. Sound pressure levels and reverberation decay rates are measured in the receiving room below. The information collected is used to calculate the Impact Sound Pressure Level (L_p), Normalized Impact Sound Pressure Level (L_n), and the Field Impact Insulation Class (FIIC) according to ASTM E 989.

Normalization of impact sound pressure levels is calculated by

$$L_n = L_p - 10\log\left(A_0 / A_2\right) \qquad (1)$$

where L_p refers to the non-normalized receiving room impact sound pressure level, L_n is the receiving room sound pressure level normalized to a constant room absorption, A_0, and A_2 is the measured receiving room absorption. The value of A_0 is 10 m^2 or 108 sabins in ASTM E 1007 [8] and ISO 140.

2.2 Airborne noise insulation field tests

ASTM E 336 defines the field test metrics Noise Isolation Class (NIC) and Normalized Noise Isolation Class (NNIC) [9]. NNIC is similar to NIC, except that the measured noise reduction is normalized to a reverberation time of 0.5 s in the receiving room. The standard indicates that 0.5 s is the typical reverberation time when a space is “ordinarily furnished” for occupancy [10], so that NNIC presents what the NIC would be if the receiving room were normally furnished.

Normalization of receiving room sound pressure levels is calculated by

$$L'_n = L'_p - 10\log\left(T / T_0\right) \qquad (2)$$

where L'_n is the non-normalized receiving room sound pressure level, L'_p is the receiving room sound pressure level normalized to the reverberation time, T_0, and T is the reverberation time measured in the receiving room in seconds. The value of T_0 is 0.5 s in ASTM E 336 and ISO 140.

2.3 New metrics for impact test rating

New metrics have been introduced along with proposed modification of the ASTM standards as a solution to limitations in normalizing field impact sound insulation test results [11]. These new metrics are the Impact Sound Rating (ISR) and Normalized Impact Sound Rating (NISR). Instead of using Eq.(1) to normalize impact sound pressure levels, the NISR is calculated by normalization using Eq.(2), similar to NNIC.

3 Tested floor-ceiling samples

The basic floor-ceiling assembly for all samples tested in this effort consists of the following:

- Floor finish (various types, described below)
- 19–32 mm thick self-leveling gypsum concrete
- 2–5 mm resilient noise control floor underlayment system, where used (three types, described below)
- 19 mm thick tongue-and-groove structural plywood or oriented strand board
- 457 mm deep flat wood trusses spaced at 610 mm on center. Truss span lengths varied between 2.9 m and 7.6 m, and trusses were specified to be tied together with perpendicular bracing (or strongbacks) at a maximum spacing of 3 m along span.
- 89–152 mm thick glass fiber batt (GFB) insulation in cavities, tacked to underside of plywood decking under hard floor finishes (not used where floor finish consists of carpet above).
- Resilient metal channels (two types, described below)
- 16 mm type ‘C’ gypsum wallboard (GWB), with one or two layers

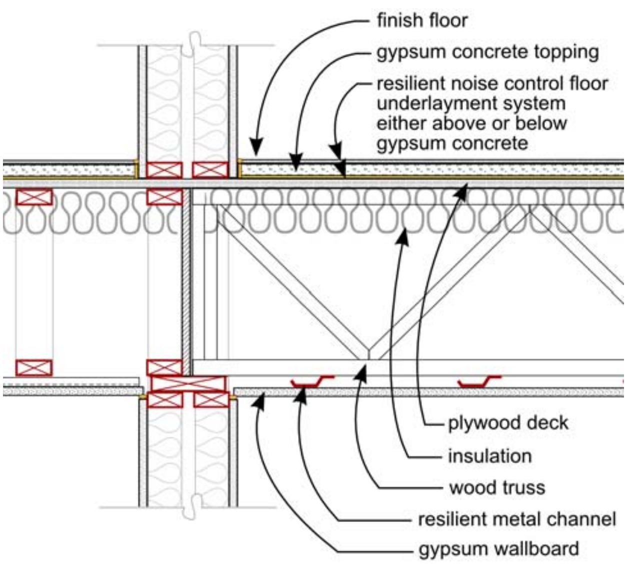

Fig.2 Basic wood truss floor-ceiling assembly with insulation and resilient metal channels.

3.1 Floor finishes

Six types of floor finishes were evaluated: carpet and pad (CPT), vinyl sheet (VSHT), vinyl plank (VPLK), engineered wood laminate (WD), ceramic tile (CER), and slate tile (SLT). In two cases, no floor finishes were installed, and testing was conducted on bare gypsum concrete surfaces.

3.2 Resilient noise control underlayments

Three different resilient noise control floor underlayment systems were evaluated:

Two were different thicknesses of the same type—a recycled rubber mat underlayment (RMU), either 2 mm or 5mm thick, placed above the gypsum concrete topping.

The other type was a resilient composite sheet underlayment (CSU), 5 mm thick, with polyester core of fused entangled filaments attached to a non-woven fabric, placed below the gypsum concrete topping.

3.3 Resilient metal channels

Two types of resilient metal channels were evaluated:

“Standard” resilient metal channels (STD), described to the authors by building contractors as having round holes spaced approximately 50 to 100 mm on center.

“Deluxe” resilient metal channels (DLX), consisting of 25-gauge channel, flange slotted with holes 76 mm by 10 mm wide, spaced 100 mm on center.

Resilient channels are spaced at 406 mm on center, except in two tests, where channels were spaced at 203 mm.

Where resilient metal channels were used, the interface joints of drywall at ceiling and walls were intended to include 6 mm gaps to maintain separation of resiliently mounted ceiling drywall. However, the authors did not observe construction of the tested assemblies, and all drywall joints were taped and floated when testing was conducted. Therefore, it is quite possible that there are rigid connections between drywall panels at walls and ceiling, rather than the intended resilient gaps. It is also possible, but not likely, that 6 mm gaps exist beneath the taped joints.

4 Test procedures

Tests were conducted in general accordance (not strict conformance) with ASTM E 1007 and ASTM E 336. Other exceptions included: no identification and elimination (closure) of flanking paths, no determination of confidence limits, fewer than five samples for linear regression analyses to determine reverberation decay rates, and fewer than four tapping machine positions per test location.

For expediency of field testing, the tapping machine was typically placed in two perpendicular positions, and the other two (diagonal) positions specified by ASTM were not tested. In one of the tests, one position was used, oriented perpendicular to the floor truss, and in five of the tests, all four positions were used.

Measurements were made from 12.5 Hz to 10 kHz.

5 Results

Room Vol. (m^3)	Floor Finish	RMU (mm)	Gyp. Conc. (mm)	CSU (mm)	Floor Deck (mm)	Span (m)	GFB (mm)	RC Type	RC o.c. (mm)	GWB (mm)	ISR	FIIC	NISR	NNIC
109.6	---	---	19	---	19		89	STD	203	16	31	33	32	51
281.7	---	---	19	---	19		89	STD	203	(2) 16	40	---	---	---
65.9	CER	---	19	---	19	2.9	152	STD	406	16	40	44	41	57
166.5	CPT	---	19	---	19	3.7	152	STD	406	16	70	70	71	55
131.7	WD	---	19	---	19	4.8	152	STD	406	16	44	43	44	56
109.8	CPT	---	19	---	19	4.0	152	STD	406	16	73	74	74	53
65.9	CER	---	32	---	19	4.9	89	STD	406	16	36	40	38	53
59.5	CER	---	25	5	19	4.3	89	STD	406	16	49	54	51	58
59.5	CER	---	25	5	19	4.3	89	DLX	406	16	43	48	45	55
65.9	CER	---	25	5	19	4.9	89	STD	406	(2) 16	44	49	47	57
65.9	CER	---	32	---	19	2.9	89	DLX	406	16	37	41	38	55
65.9	CER	---	32	---	19	2.9	89	DLX	406	16	38	41	38	50
73.2	CER	---	25	5	19	5.5	89	DLX	406	(2) 16	47	50	49	58
130.8	CPT	---	32	---	19	3.7	---	STD	406	16	70	71	72	---
130.8	CPT	---	32	---	19	4.1	---	STD	406	16	76	76	77	---
130.8	CPT	---	32	---	19	4.1	---	DLX	406	16	70	69	71	---
130.8	CPT	---	32	---	19	3.7	---	STD	406	(2) 16	73	73	74	---
210.4	VSHT	---	32	---	19	5.8	89	STD	406	16	43	43	45	55
210.4	VSHT	---	25	5	19	4.3	89	STD	406	16	51	50	53	59
210.4	VSHT	---	25	5	19	4.3	89	DLX	406	16	50	49	51	57
210.4	VSHT	---	25	5	19	5.8	89	STD	406	(2) 16	49	48	51	55
263.4	VPLK	---	32	---	19	6.6	89	DLX	406	16	46	44	48	57
263.4	VPLK	---	32	---	19	6.6	89	DLX	406	16	46	45	49	56
201.2	VSHT	---	25	5	19	5.2	89	DLX	406	(2) 16	52	51	53	56
336.6	CPT	---	32	---	19	5.5	---	STD	406	16	73	69	73	55
345.7	CPT	---	32	---	19	6.9	---	STD	406	16	73	70	75	59
345.7	CPT	---	32	---	19	6.9	---	DLX	406	16	72	68	73	55
336.6	CPT	---	32	---	19	5.5	---	STD	406	(2) 16	76	74	79	54
221.3	CPT	---	32	---	19	7.0	---	DLX	406	(2) 16	71	70	73	59
70.0	CER	---	19	---	19	3.0	89	STD	406	16	33	37	35	53
51.2	CER	2	19	---	19	7.6	89	DLX	406	16	40	45	42	57
43.9	CER	2	19	---	19	2.9	89	DLX	406	16	39	44	40	59
57.6	CER	5	19	---	19	2.9	89	DLX	406	16	41	46	43	58
36.6	SLT	---	19	---	19	5.6	89	STD	406	16	40	47	42	---
54.9	SLT	2	19	---	19	7.6	89	DLX	406	16	46	51	48	---
29.3	SLT	5	19	---	19	6.3	89	STD	406	16	49	57	51	---
164.6	VSHT	---	19	---	19	5.5	89	STD	406	16	42	42	44	55
137.2	VPLK	2	19	---	19	7.6	89	DLX	406	16	49	50	51	55
249.7	SLT	2	19	---	19	5.5	89	DLX	406	16	48	46	50	58
137.2	VPLK	2	19	---	19	6.1	89	STD	406	16	44	45	46	50
249.7	SLT	5	19	---	19	5.5	89	DLX	406	16	49	48	51	62
329.3	CPT	---	19	---	19	6.4	---	STD	406	16	68	65	70	55
190.2	CPT	---	19	---	19	4.3	---	DLX	406	16	74	74	76	58

Table 1 Impact and airborne sound insulation results for various floor-ceiling assemblies with 457 mm deep wood trusses

6 Predictive analyses

Results were compared with predictions using simple regression analyses developed by others [12]. The predictive analyses used were developed from laboratory tests and are intended for prediction of ratings of STC and IIC, rather than field performance ratings of NNIC and FIIC. Predictive analyses do not include resilient floor underlayment systems, so no impact insulation comparisons were conducted for floors with resilient underlayment systems. Comparisons were made to investigate differences between field performance results and predicted lab performance estimates.

6.1 With sound absorbing material

IIC and STC performance may be estimated for wood I-joist floor-ceiling assemblies with resilient metal channels and sound absorbing material by

$$STC = 5.6 + 30 \log(M) + .014\, d + .016\, t_i \quad (3)$$

$$IIC = 29.7 + 7 \log(M) + .01\, d + .012\, t_i + .094\, \rho_i \quad (4)$$

where M is the mass of layers, d is I-joist depth (we use truss depth), t_i is thickness of insulation in the cavity, and ρ_i is density of insulation.

The range in values tested with sound absorbing material is shown in Table 2.

Variable	Values
NISR*	35–53
Predicted IIC*	48–50
NNIC	50–62
Predicted STC	65–72
Trusses	
Depth, mm	457
Spacing, mm	610
Sound absorbing material	
Thickness, mm	89–152
Density, kg/m^3	11.2
Resilient metal channels	
Spacing, mm	203–406
Flooring layers	
Flooring + deck, kg/m^2	53–90
Ceiling, kg/m^2	11–23

Table 2 Estimated maximum and minimum values of parameters used in regression analysis for wood truss floors with resilient metal channels and sound absorbing material, *excluding floors with resilient noise control underlayment systems installed (20 floors)

6.2 Without sound absorbing material

All samples that were tested without sound absorbing material had carpet and pad floor finish. The predictive analysis, however, is intended for floor-ceilings that have hard floor finishes, not carpet. Therefore, it is not possible to compare predicted and measured impact insulation for the assemblies tested without sound absorbing material. On the other hand, with respect to airborne noise insulation it is possible to compare predicted and measured airborne noise insulation for those assemblies without sound absorbing material. STC performance may be estimated for wood structure floors with hard or carpet finishes, resilient metal channels, and no sound absorbing material by

$$STC = 8.8 + 26.7 \log(M) \quad (5)$$

where M is the mass of layers.

The range in values tested without sound absorbing material is shown in Table 3.

Variable	Values
NNIC	54–59
Predicted STC	55–61
Trusses	
Depth, mm	457
Spacing, mm	610
Resilient metal channels	
Spacing, mm	406
Flooring layers	
Flooring + deck, kg/m^2	56–88
Ceiling, kg/m^2	11–23

Table 3 Estimated maximum and minimum values of parameters used in regression analysis for wood structure floors with resilient metal channels and no sound absorbing material (11 floors)

We should expect predictive analyses for lab performance estimates to exceed measured performance in the field. Bearing this in mind, Table 2 shows good correlation between measured NISR and predicted IIC. Table 3 shows good correlation between measured NNIC and predicted STC. However, in Table 2, there is a pronounced difference between measured NNIC and predicted STC—between 7 and 21 points.

7 Low frequency impact sound levels

Results for low frequency performance could not easily be normalized, because results of reverberation decay measurements appeared to be inconsistent. Therefore, results for non-normalized impact sound levels (L_p) were compared separately for floor-ceiling assemblies with carpet finish, with hard (non-carpet) finish with resilient underlayment systems, and with hard (non-carpet) finish and no resilient underlayment system.

Fig.3 shows that floors with carpet and having relatively shorter span lengths, less than 4.5 m, may tend to allow relatively more low frequency impact noise to emanate at multiple peak frequencies than do spans longer than 4.5 m.

All carpeted floors without absorbing material show a prominent peak at 20 Hz one-third octave band.

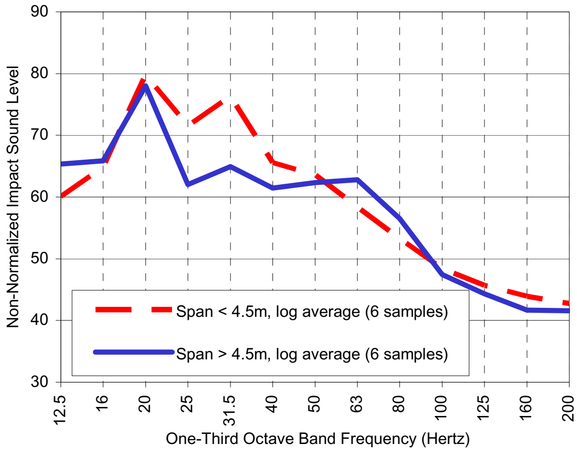

Fig.3 Non-normalized low-frequency impact sound level (L_p) for carpeted wood truss floors without sound absorbing material, for various span lengths.

Fig.4 and Fig.5 show non-normalized low frequency results for floors with hard finishes, sound absorbing material, with and without resilient underlayment systems, and for various spans. Little can be concluded from these comparisons, but it is interesting to note that these results do not share the peaks at 20 Hz (and 31.5 Hz) seen in Fig.3.

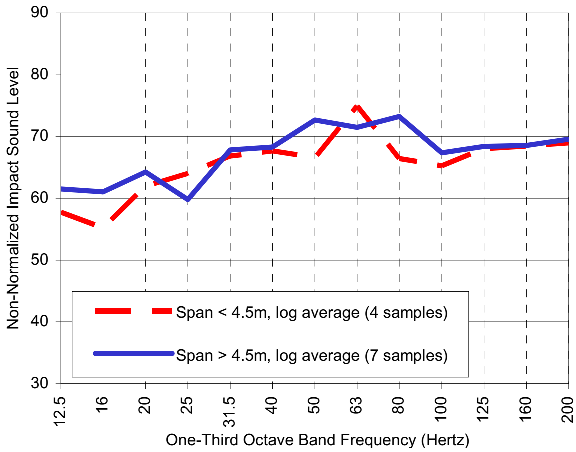

Fig.4 Non-normalized low-frequency impact sound level (L_p) for hard finish floors with sound absorbing material and no resilient floor underlayment systems for various span lengths.

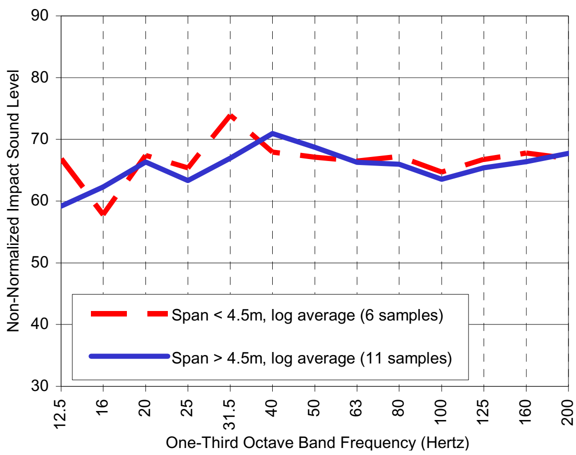

Fig.5 Non-normalized low-frequency impact sound level (L_p) for hard finish floors with sound absorbing material and resilient floor underlayment systems for various spans.

8 Conclusion

This paper presents normalized and non-normalized field test results in a reasonably consistent set that can hopefully fill a void in available data for use in acoustical analysis and design for buildings using wood truss floor systems.

Impact insulation ratings normalized according to proposed NISR methods match reasonably well with predictive analyses.

While the authors expected to find less impact sound insulation associated with longer spans, results did not support that theory. Results do show some surprising evidence that shorter spans with carpet finish or resilient underlayment systems may tend to exhibit less low frequency impact sound insulation. Further investigation is warranted to explore the relationships between span length and impact insulation. Further investigation is also warranted to analyze effects of resilient and rigid connections of ceiling wallboard to walls where resilient metal channels are used.

References

[1] *Metal Plate Connected Wood Truss Handbook*, Third Edition, Wood Truss Council of Am. (2004).

[2] K.A. Harman, J.R. Lawson, "A study of metal truss plate connectors when exposed to fire," U.S. Dept of Commerce (2007).

[3] A.C.C. Warnock, "Sound transmission and impact insulation data," IRC RR-169, National Research Council Canada (2005).

[4] J.S. Bradley, J.A. Birta, "Laboratory measurements of the sound insulation of building façade elements," IRC IR-818, National Research Council Canada (2000).

[5] R.B. DuPree, "Catalog of STC and IIC ratings for wall and floor/ceiling assemblies," Office of Noise Control, California Department of Health Services (1981).

[6] International Building Code 2003, Sec. 1207, Sound Transmission.

[7] ASTM E 1007-04e1, "Standard test method for field measurement of tapping machine impact sound transmission through floor-ceiling assemblies and associated support structures," ASTM International.

[8] Reference 6, Sec. 12.1.

[9] ASTM E 336-05, "Standard test method for measurement of airborne sound attenuation between rooms in buildings," ASTM International.

[10] Reference 9, Sec. 3.2.6.1 and Sec. 5.4.2.

[11] J.J. LoVerde, D. W. Dong, "Field impact insulation testing: Inadequacy of existing normalization methods and proposal for new ratings analogous to those for airborne noise reduction," *J. Acoust. Soc. Am.* 118, 638–646 (2005).

[12] A.C.C. Warnock, J.A. Birta, "Sound transmission class and impact insulation class results," IRC IR-766, National Research Council Canada, (1998).