HGC
NOISE | VIBRATION | ACOUSTICS

Detailing Strategies for Acoustic Performance in Mass Timber Structures

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Simon Edwards

NOISE VIBRATION ACOUSTICS

Disclaimer: This presentation was developed by a third party and is not funded by WoodWorks or the Softwood Lumber Board.

Presenter

Simon Edwards, MEng, PEng

- Specialty in Building Acoustics at HGC Noise Vibration Acoustics
- Mass Timber Team Lead
- Interior Building Acoustics (Design/Construction/Testing)
- Exterior Building Acoustics (Planning Studies/Balcony Noise)



Agenda



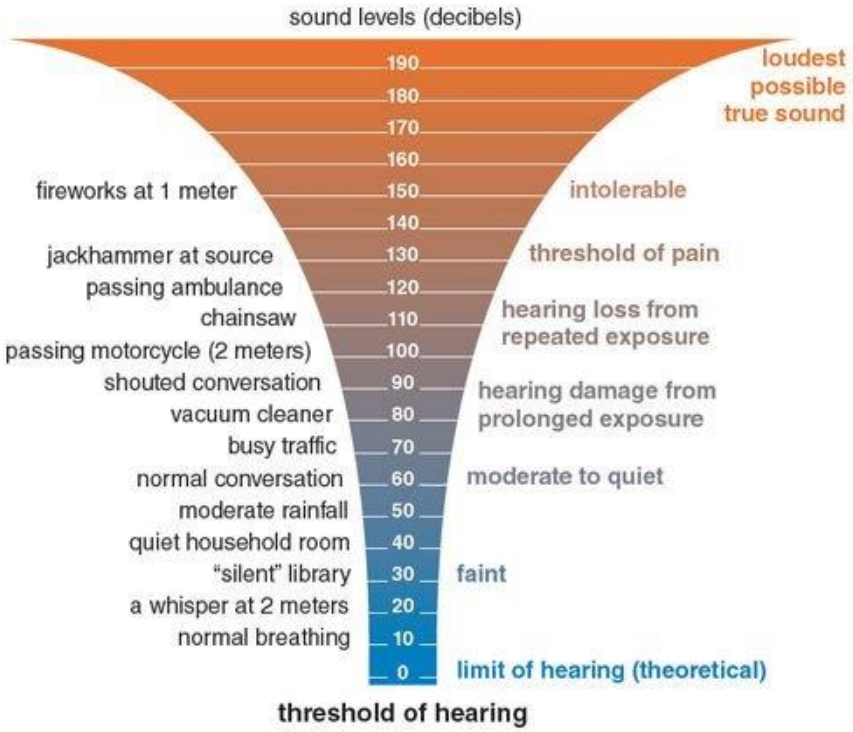
- Intro to Acoustics
- Measurements and Descriptors
- MT Direct Transmission
- MT Flanking Transmission
- Other MT Considerations

Intro to Acoustics

- Sound is measured in Decibels (dB)

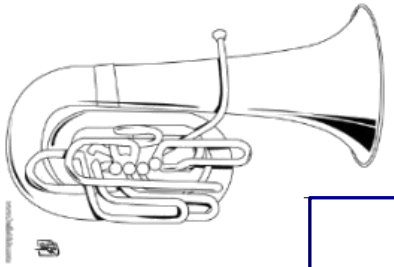
- Quiet House – 30 dB
- Normal conversation - 60 dB
- A lawnmower - 90 dB
- A rock concert or a jet engine - 120 dB
- A gunshot or firecracker - 140 dB

Gun shot is 100,000,000,000 times more powerful than a quiet house. This is why we use a log scale

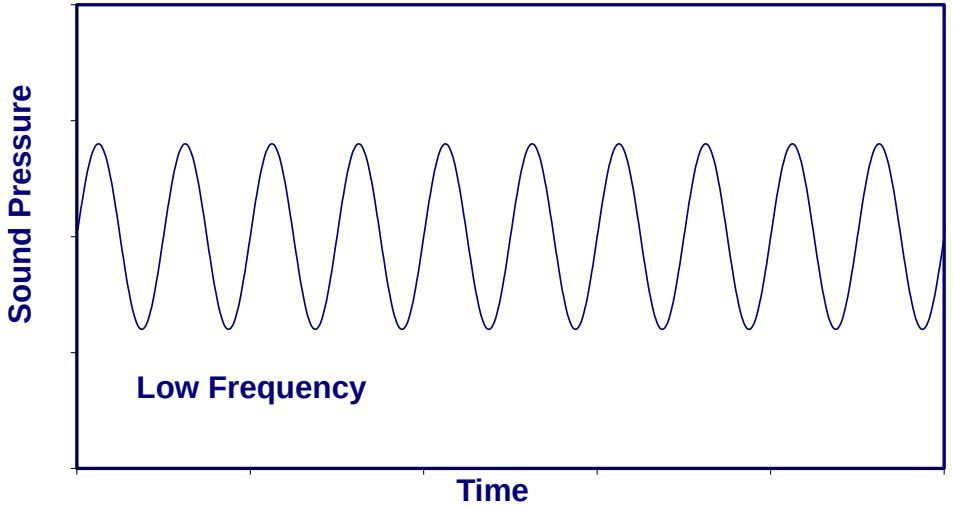


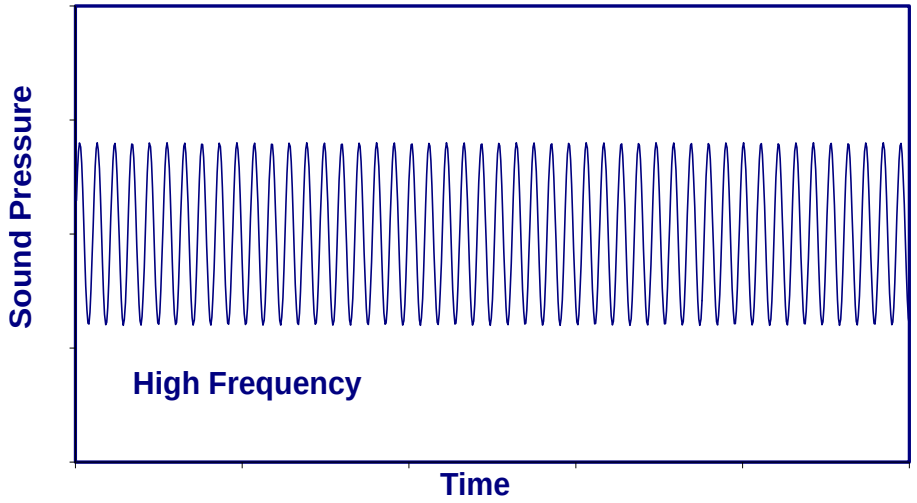
Intro to Acoustics

Sound Frequencies





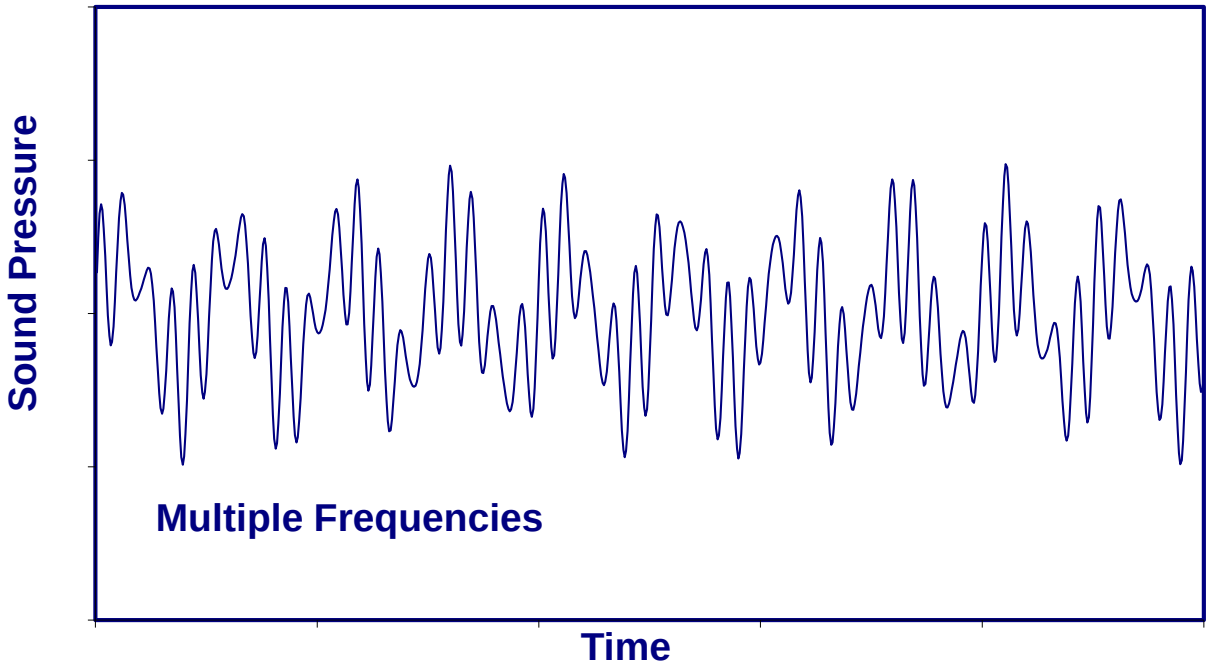




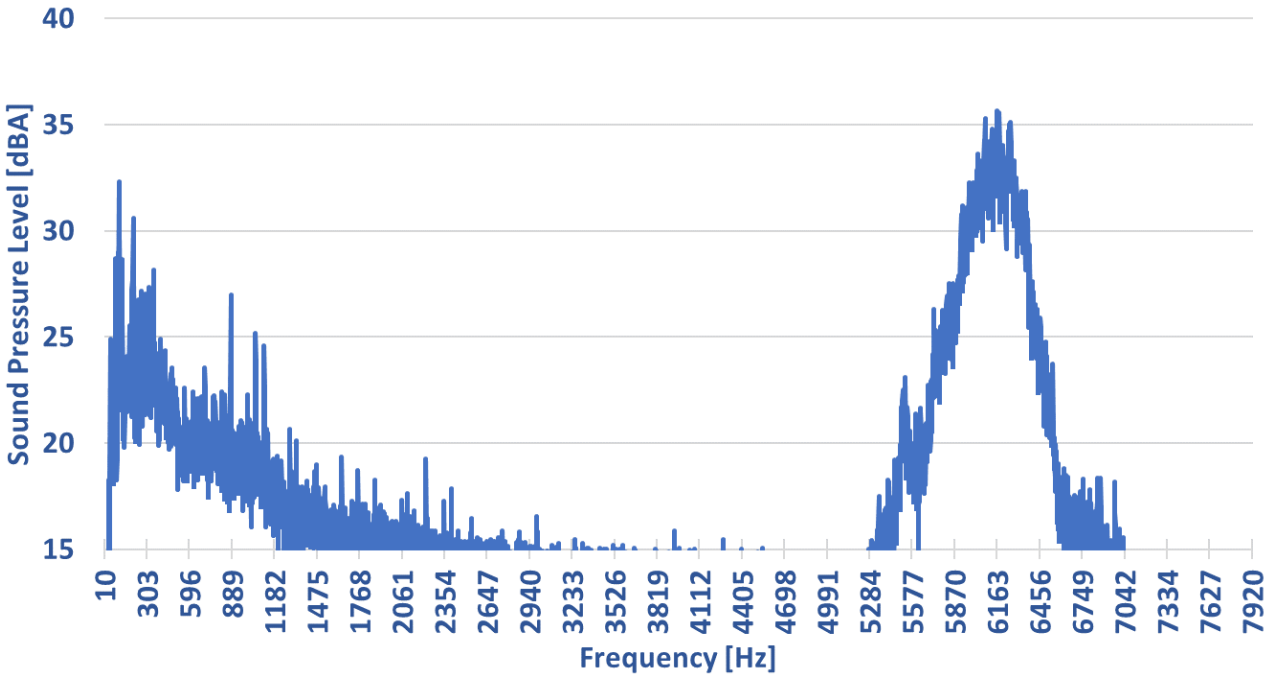
Intro to Acoustics

- Graphing Sound Level vs. Time
- Combining multiple frequencies creates more complex waveform over time



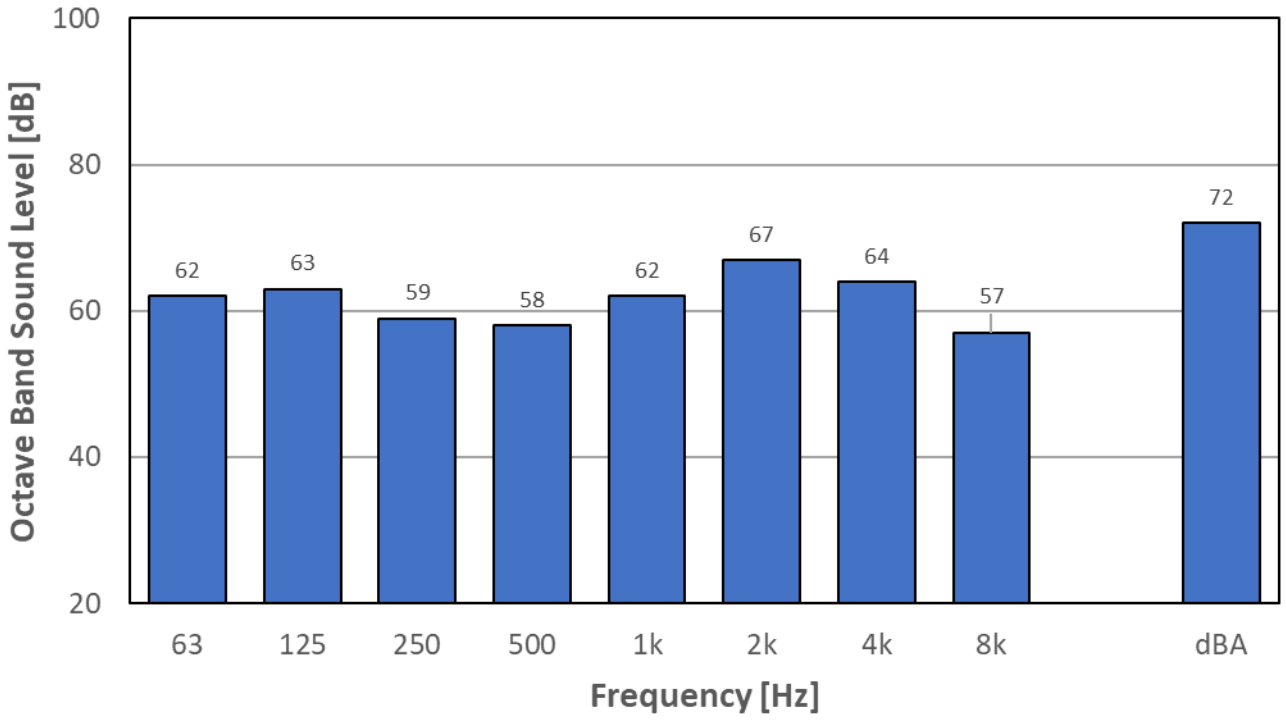


Intro to Acoustics



- Graphing Sound Level vs. Frequency
- Narrowband = Thousands of frequencies, each with a sound level
- All narrowband levels combine to overall level

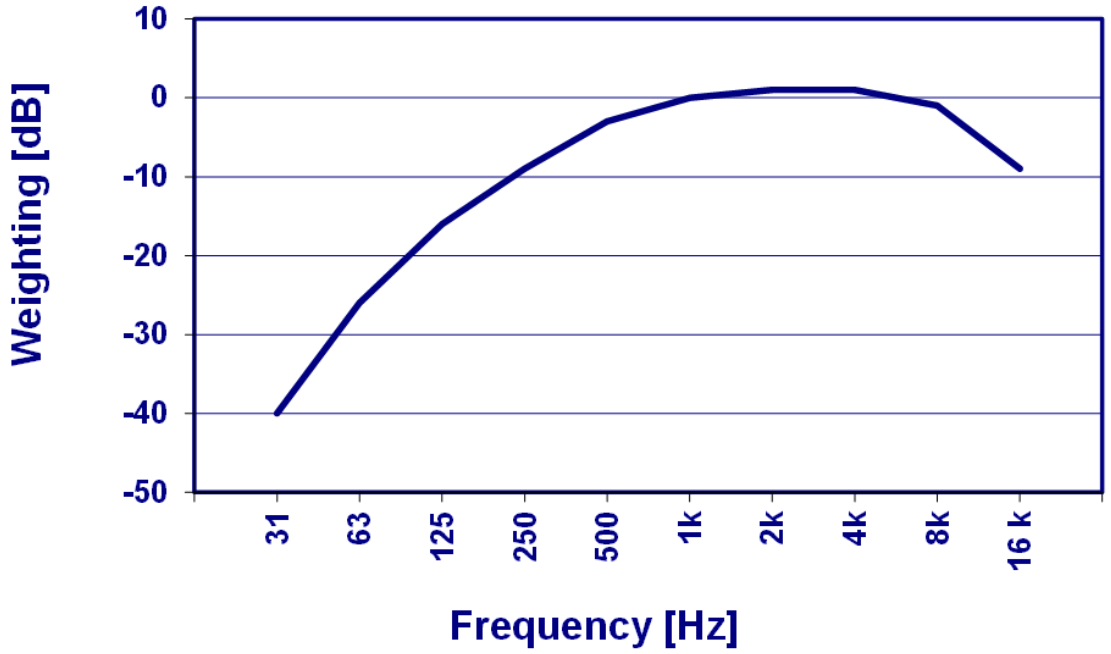
Intro to Acoustics



- Graphing Sound Level vs. Frequency
- Octave Bands = Typically 8 frequencies, each with a sound level
- Similarly, all octave band levels combine to overall level

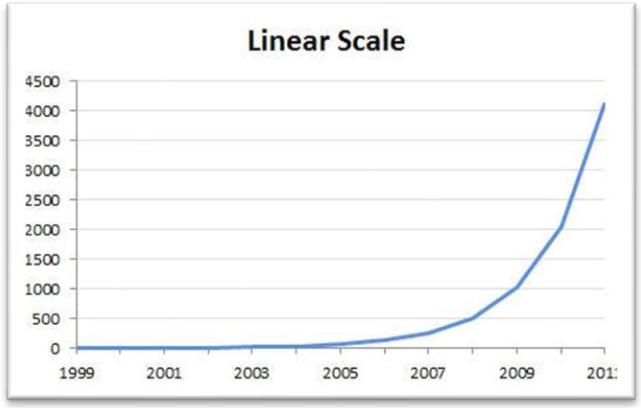
Intro to Acoustics

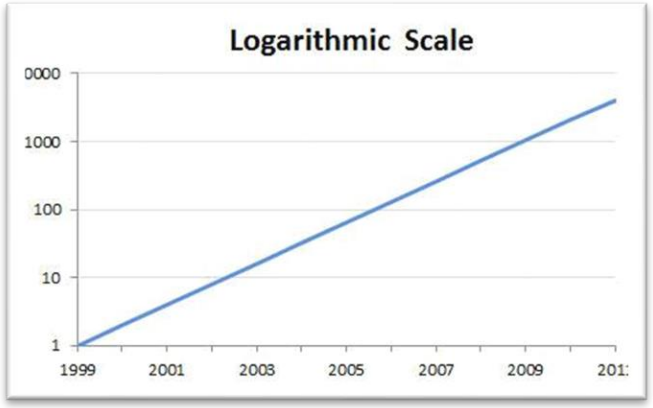
- A-weighted Sound (dBA):
  - Applies a filter based on how human ear hears frequencies
  - Used as an ‘overall’ sound level



Intro to Acoustics

- Logarithmic scale (Log_{10}) to reflect human perception of hearing





- I.e., 50 dBA + 50 dBA = 53 Dba; 53 dBA + 50 dBA = 55 dBA

Intro to Acoustics

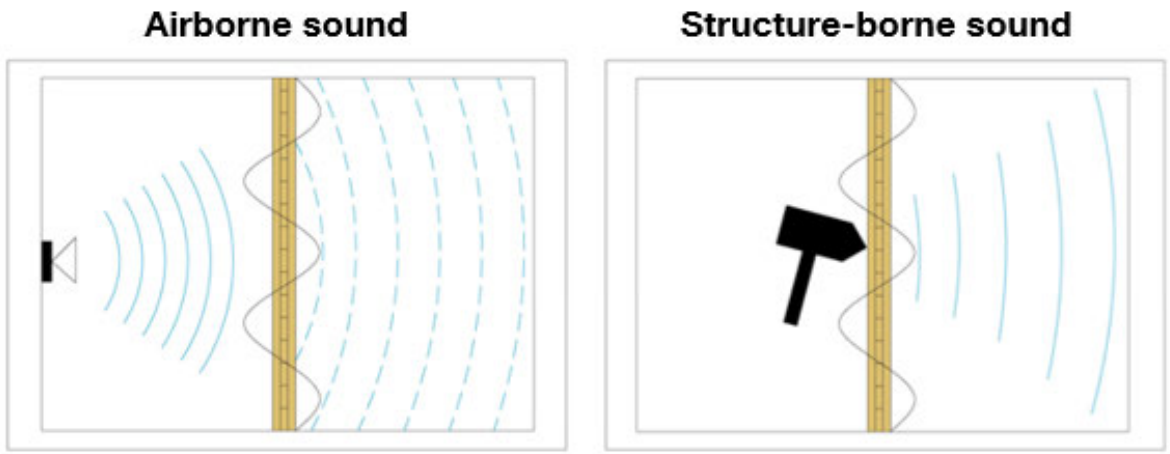
- Sound Power vs. Sound Pressure

- Lamp Analogy:
  - Sound Power ≈ power of lightbulb
  - Sound Pressure ≈ how bright where you're standing
  - **Sound pressure requires corresponding distance**



Intro to Acoustics

- How does sound travel?

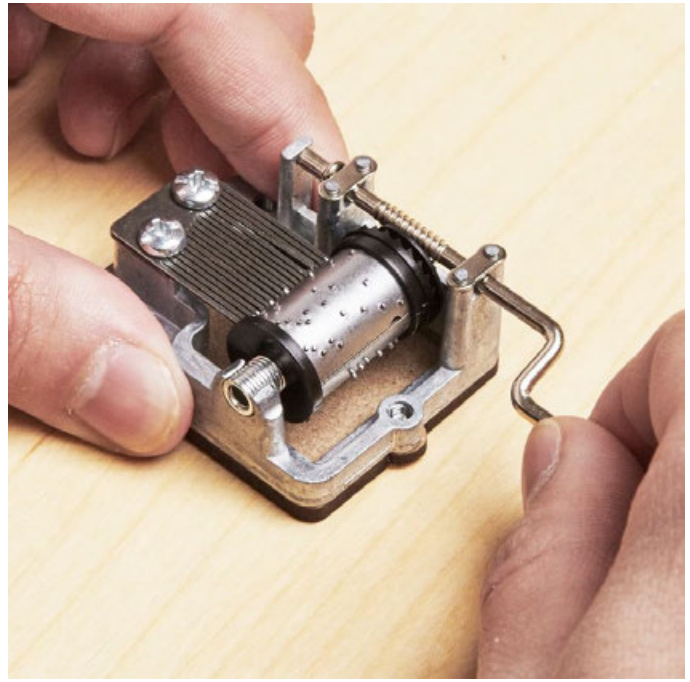


- Airborne sound: sound from source through air
  - Talking or music, machine noise
- Structure-borne sound: sound from vibrational energy through structure
  - Footsteps or weight drops, machine vibration

Intro to Acoustics

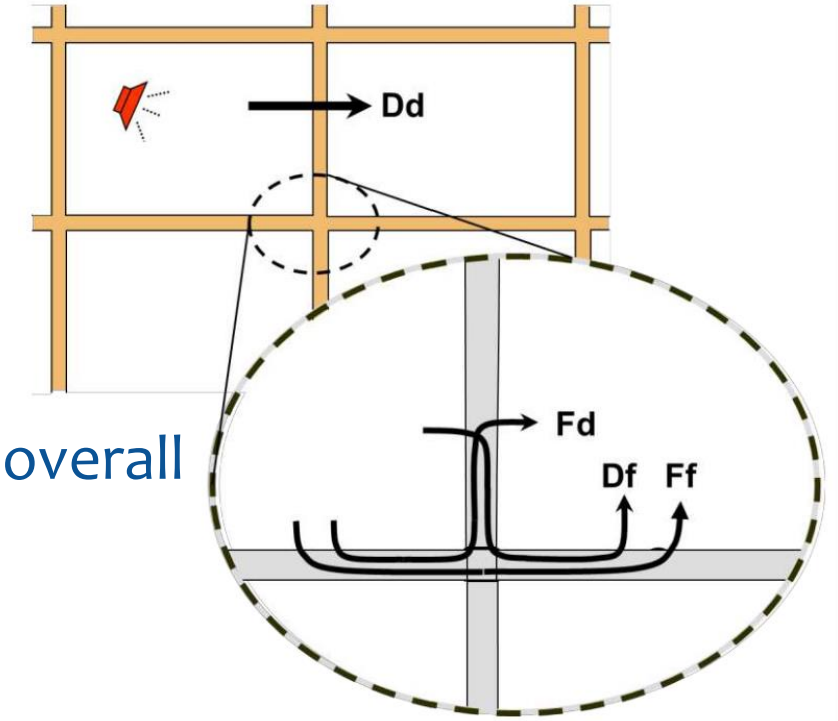
Music Box Demonstration

a. Airborne sound only
b. Airborne and Structure-Borne sound
c. Structure-Borne only (enclosed unit)
d. Airborne only (isolated unit)
e. Neither (isolated and enclosed)



Intro to Acoustics

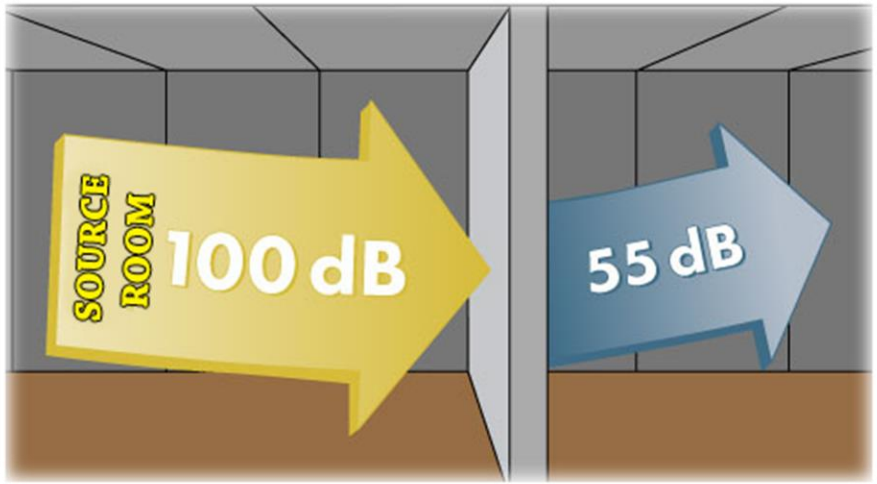
- For every demising assembly (with four junctions), there are 12 different flanking paths:
- E.g. for a demising wall assembly at the floor:
  - $Floor_{SRC}$ to $Floor_{RCVR}$
  - $Floor_{SRC}$ to $Wall_{RCVR}$
  - $Wall_{SRC}$ to $Floor_{RCVR}$
- Each path as the ability to single-handedly increase the overall sound transmission!



Measurements and Descriptors

Measurements and Descriptors

- (Apparent) Sound Transmission Class (STC/ASTC):
  - Single-integer rating
  - Standardized test method (per ASTM E336 - ASTC)
  - Airborne acoustical performance of a partition
- Noise Isolation Class (NIC):
  - No corrections for reverberation and ambient
  - Does not require minimum room dimensions
  - NNIC corrects for a normalized reverberation (0.5s)



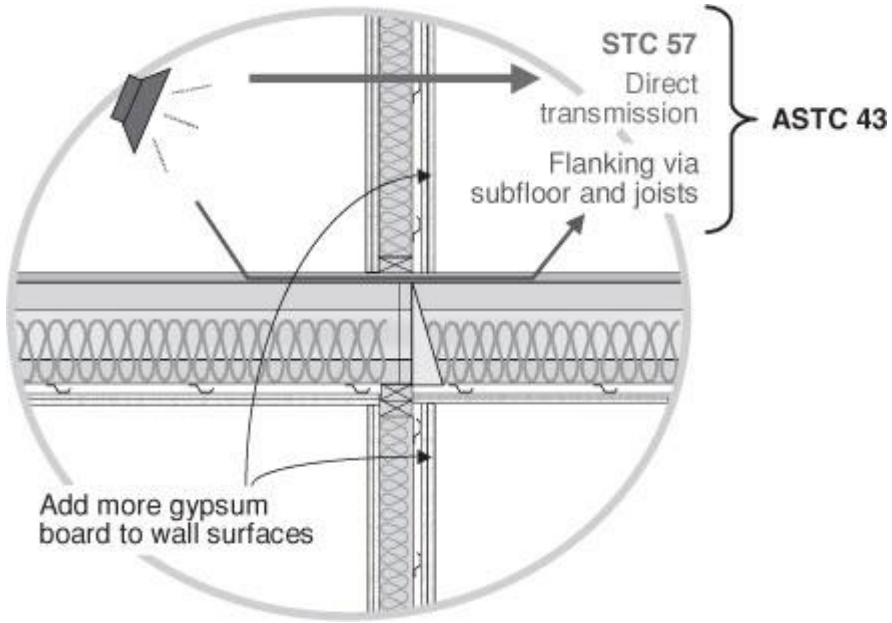
Measurements and Descriptors

Typical IBC STC Minimum Requirements

- *Either a design STC rating of 50*
  - As tested in the lab (no flanking)

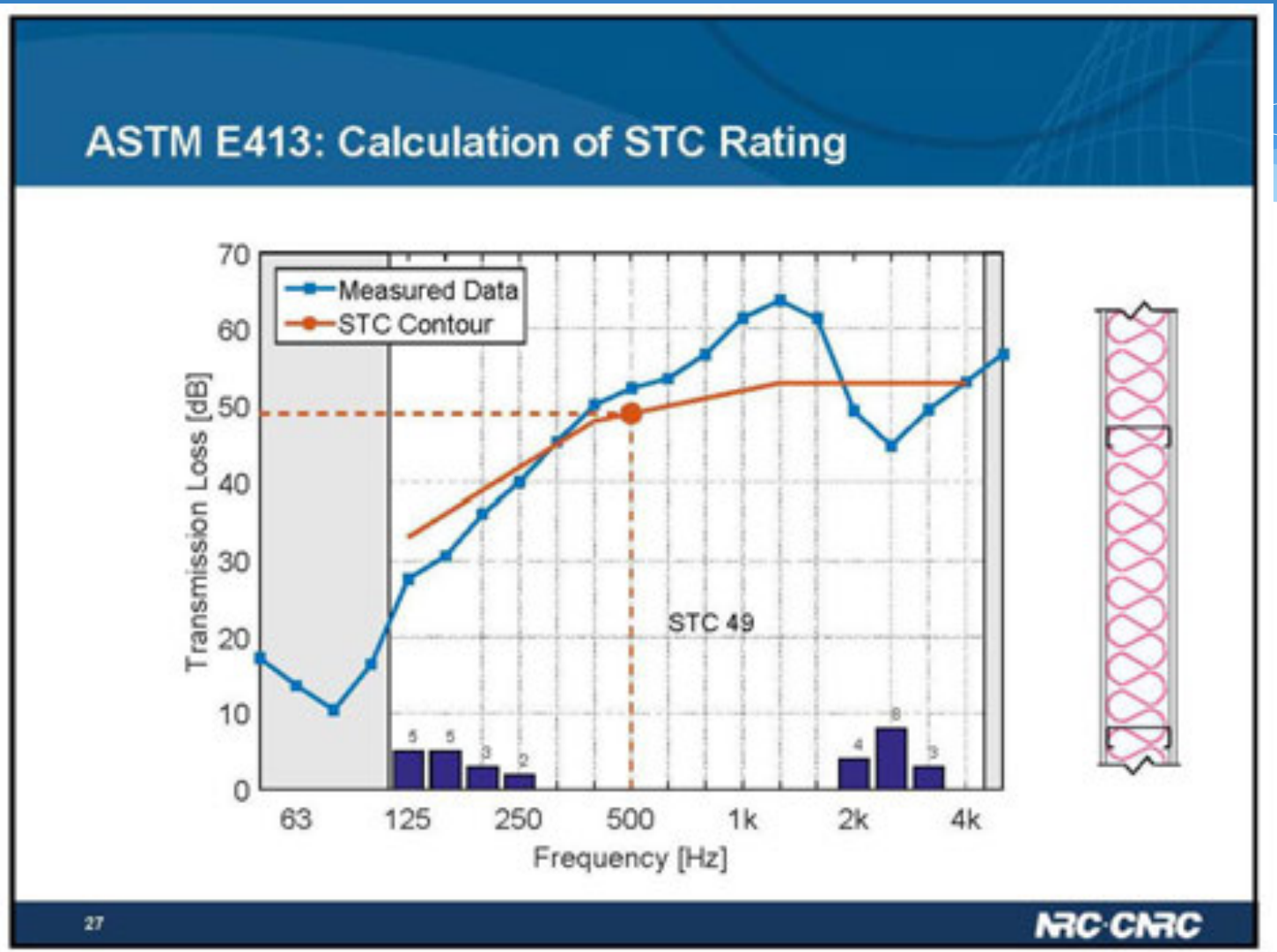
OR

- An NNIC rating of 45 if field-tested for the "*separating assembly and adjoining constructions*"
  - As tested in the field (includes flanking)



Measurements and Descriptors

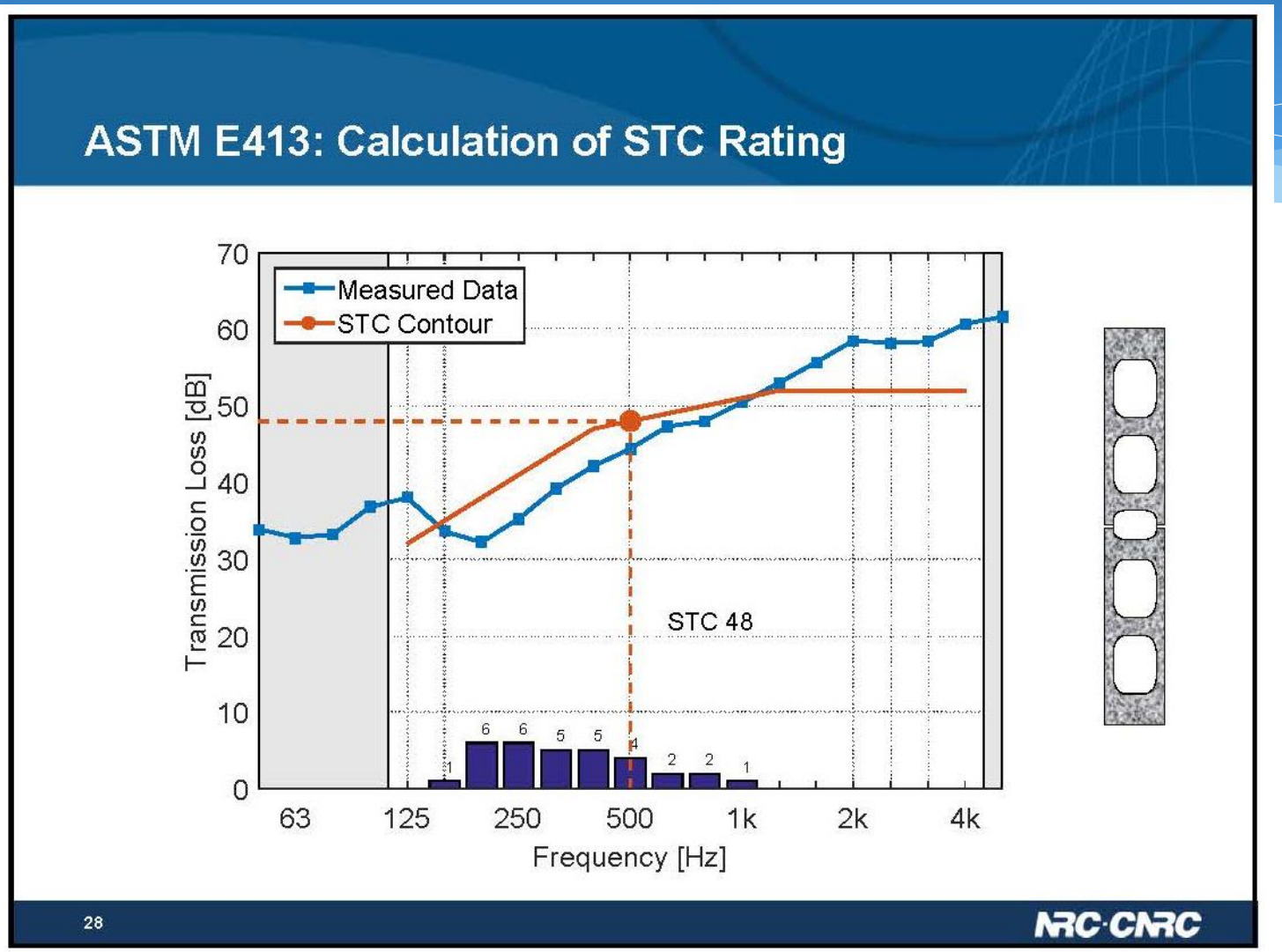
Example:



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Measurements and Descriptors

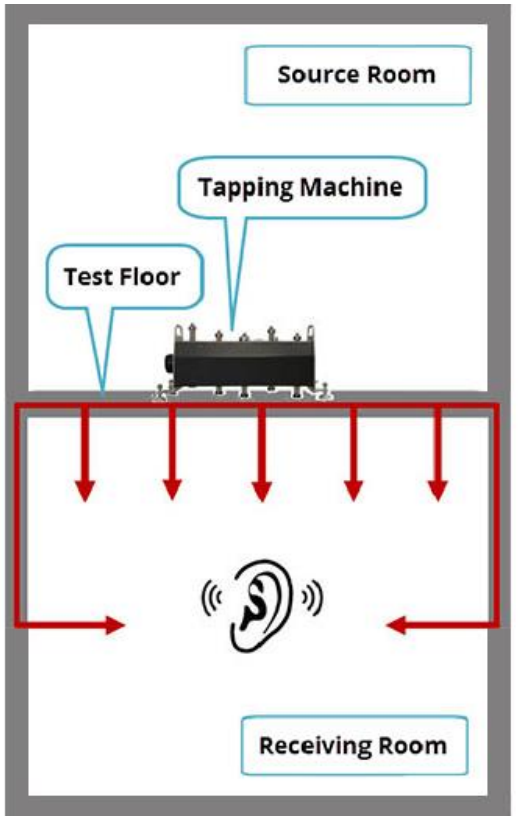
Example:



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Measurements and Descriptors

- Impact Insulation Class (IIC):
  - Single-integer rating
  - Standardized test method (per ASTM E1007)
  - Structure-borne acoustical performance of a partition
- Impact Sound Rating (ISR):
  - No corrections for reverberation and ambient
  - Does not require minimum room dimensions
  - NISR corrects for a normalized reverberation (0.5s)



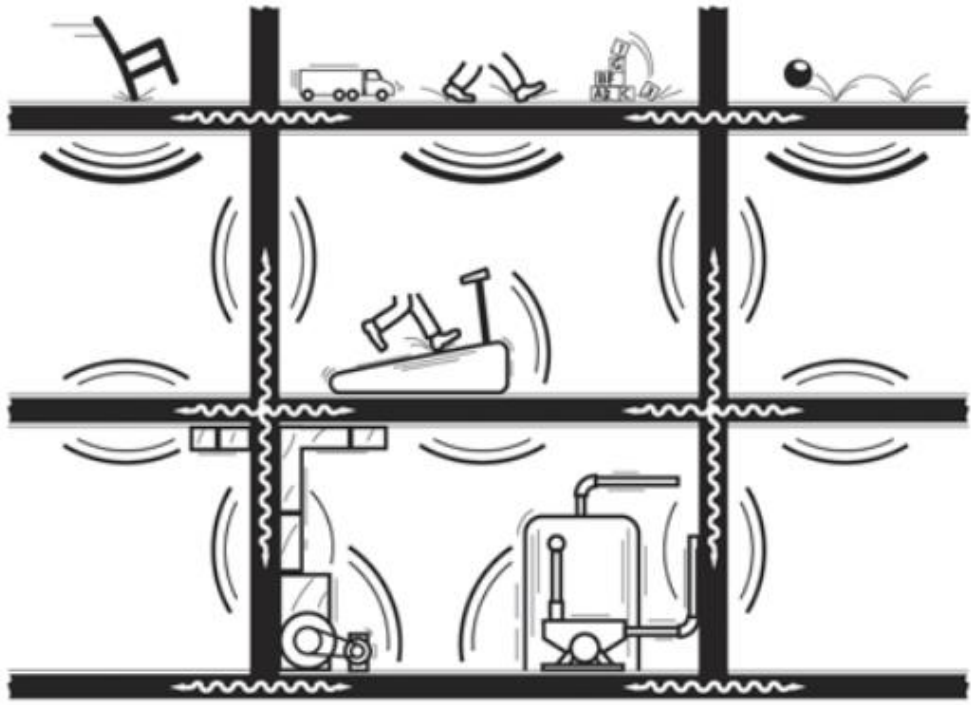
Measurements and Descriptors

Typical IBC IIC Minimum Requirements

- *Either a design IIC rating of 50*
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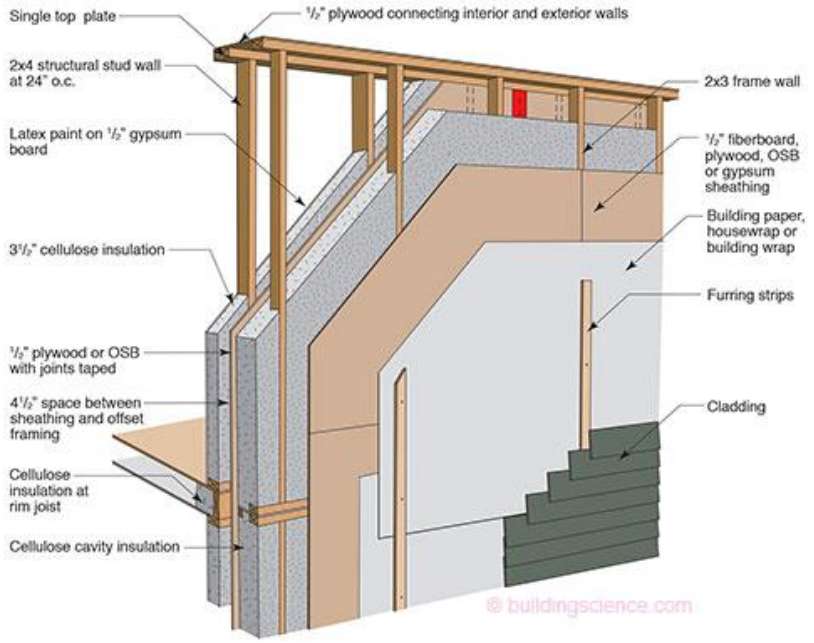
OR

- An NISR rating of 45 if field-tested for the "*separating assembly and adjoining constructions*"
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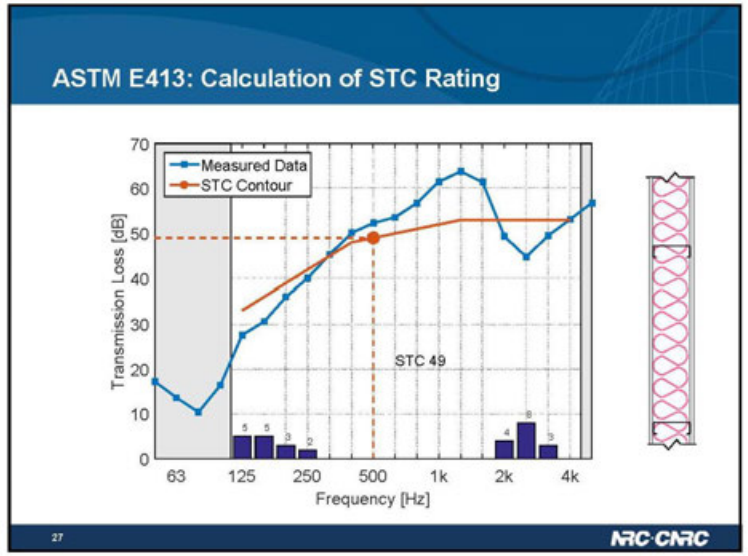
Measurements and Descriptors

- Limitations:
  - Assumes flawless construction of assembly (unless field-tested)



Measurements and Descriptors

- Limitations:
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  - Limited range of frequencies (e.g., STC does not include below 125 Hz)



Measurements and Descriptors

- Limitations:
  - Assumes flawless construction of assembly (unless field-tested)
  - Limited range of frequencies (e.g., STC does not include below 125 Hz)
  - Location-dependent descriptors (e.g., STC vs R_w)

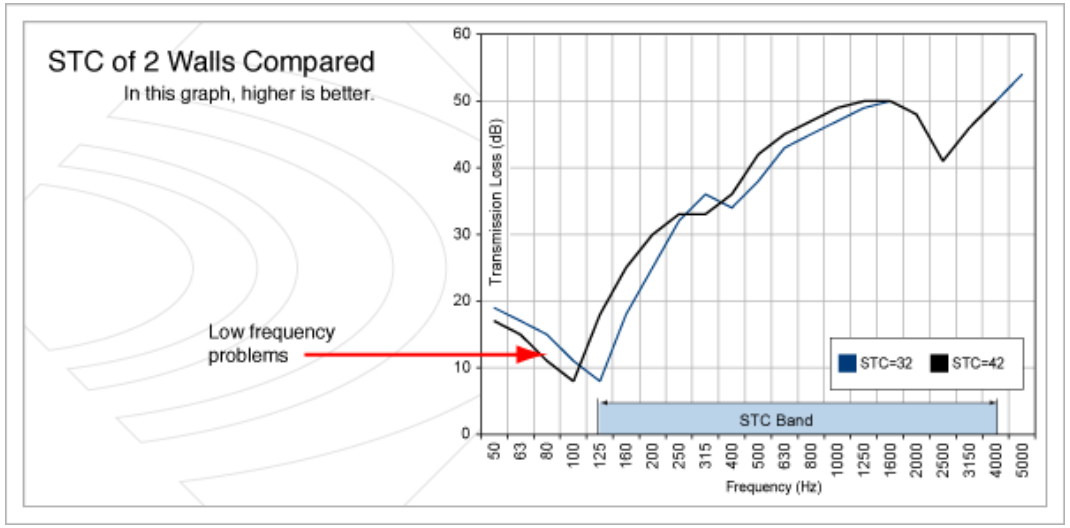


vs



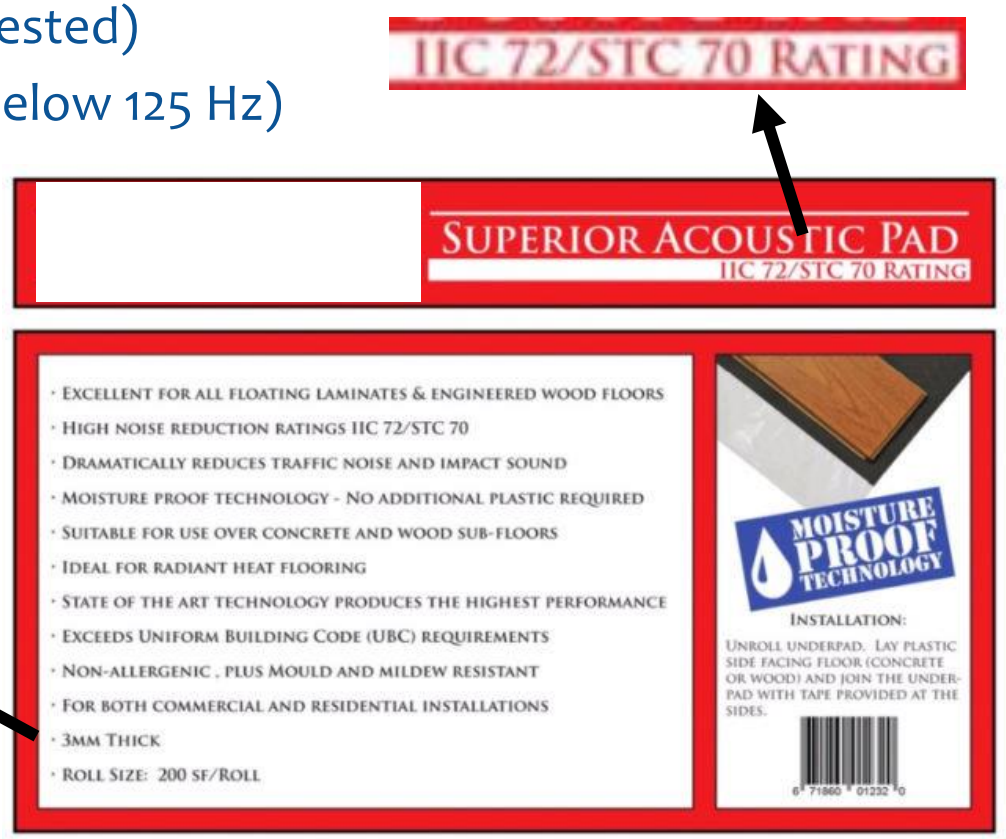
Measurements and Descriptors

- Limitations:
  - Assumes flawless construction of assembly (unless field-tested)
  - Limited range of frequencies (e.g., STC does not include below 125 Hz)
  - Location-dependent descriptors (e.g., STC vs R_w)
  - Leaves out frequency details that vary from wall to wall



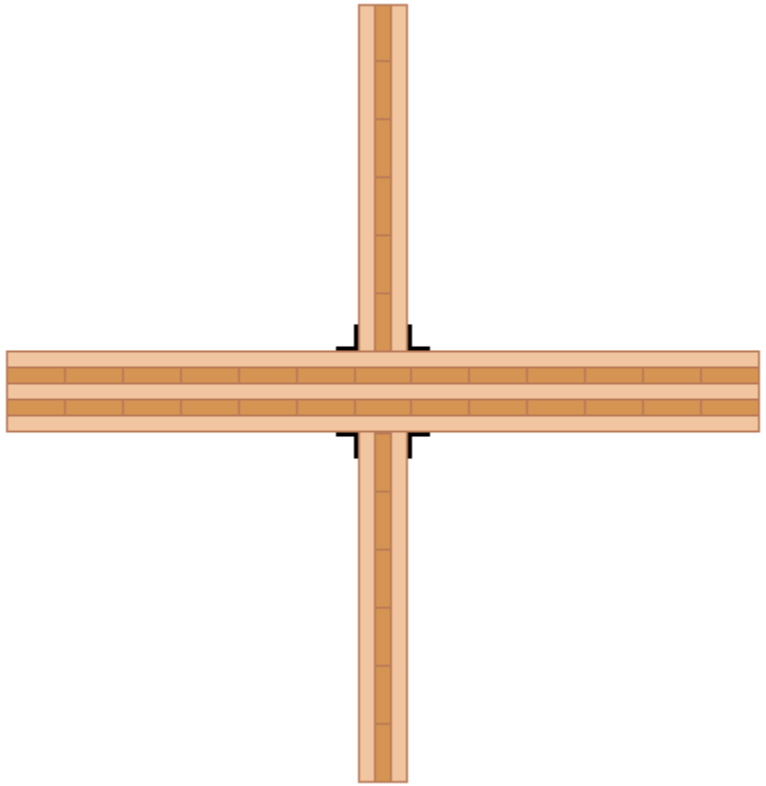
Measurements and Descriptors

- Limitations:
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  - Limited range of frequencies (e.g., STC does not include below 125 Hz)
  - Location-dependent descriptors (e.g., STC vs R_w)
  - Leaves out frequency details that vary from wall to wall
  - Leaves out details from individual components



MT Direct Transmission

MT Direct Transmission



- Non-MT Buildings typically have:
  - High Direct STC
  - Dropping ceilings and/or wall protection
  - Less vibration transmission through junctions (from very thick concrete or interrupted GWB)
- MT Buildings typically have:
  - As much exposed wood as possible
  - High vibration transmission through continuous CLT panels
  - Low IIC (like other lightweight structures)

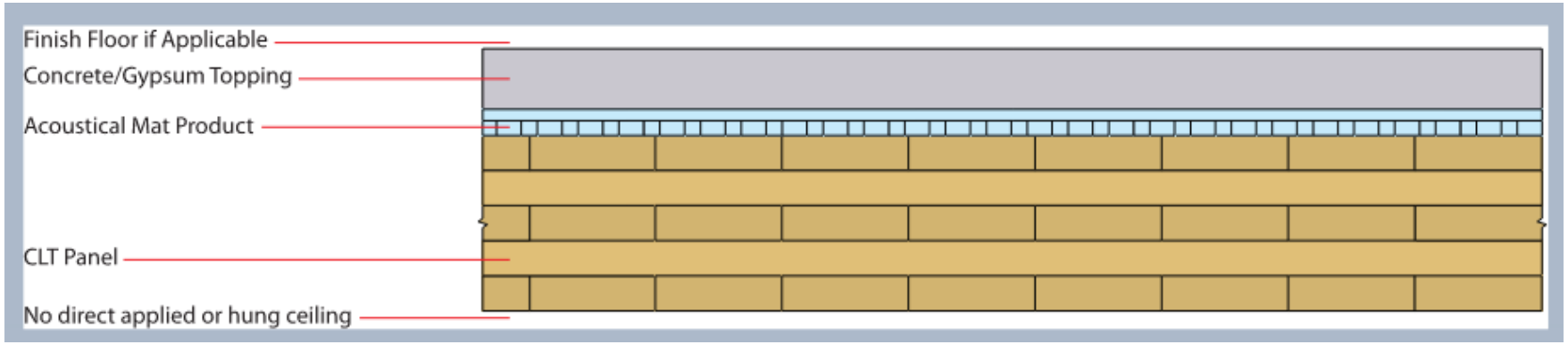
MT Direct Transmission

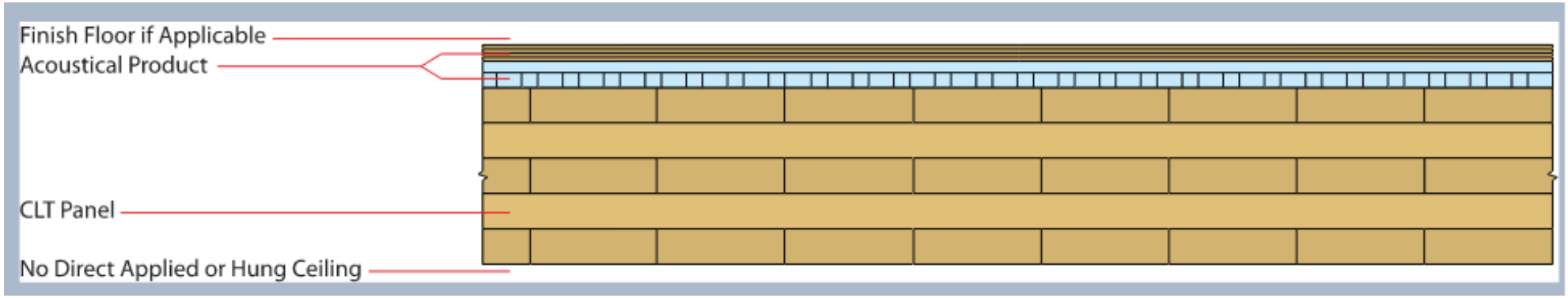
- Start with direct sound transmission
- Available test data from (among others):
  - Pliteq
  - AcoustiTECH
  - Maxxon

- Woodworks Guide is an *excellent* resource for direct sound transmission

MT Direct Transmission

- Wet vs. Dry Build-ups





MT Direct Transmission

- Wet vs. Dry Build-ups

Can meet STC-50+/IIC-50+ (direct) with either option!

However, further relevant discussion on lateral flanking…

From AcousiTECH:





MASS TIMBER | ENGINEERED WOOD | ACOUSTITECH SOFIX, 5/8" PLYWOOD, 1/2" PLYWOOD, ACOUSTITECH LEAD 6 | NAILED DOWN

Acoustic performance
AIIC: 53 à 56
ASTC: 53 à 56

MASS TIMBER | ENGINEERED WOOD | INSONOFLOOR (SOPREMA), 1"1/2 CONCRETE TOPPING, INSONOMAT (SOPREMA) | FLOATING

Acoustic performance
AIIC: 47 à 51
ASTC: 53 à 55

More details

MT Direct Transmission

- Wet vs. Dry Build-ups

Can meet STC-50+/IIC-50+ (direct) with either option!

However, further relevant discussion on lateral flanking…

From Pliteq:

STC 51 IIC 50 HIIC 57 — VIEW REPORT — SELECT

Base Structure
5-Ply Cross Laminated Timber (5-Ply CLT) - 175 mm (6 7/8 in)

Date Tested
02/05/2020

Cross-Section Detail



Laboratory
Intertek/ATI York

Standards
ASTM E90
ASTM E492

Test Number
k5952.02-113-11-r0

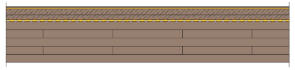
Components	Measurements
Luxury Vinyl Tile/Plank	5 mm (3/16 in)
Pliteq GenieMat® RST02	2 mm (1/16 in)
Concrete Topping	51 mm (2 in)
Pliteq GenieMat® FF10	10 mm (3/8 in)
Cross Laminated Timber (5-Ply)	175 mm (6 7/8 in)

STC 52 IIC 52 HIIC 67 LIIC 55 — VIEW REPORT — SELECT

Base Structure
5-Ply Cross Laminated Timber (5-Ply CLT) - 175 mm (6 7/8 in)

Date Tested
06/30/2021

Cross-Section Detail



Laboratory
Intertek/ATI York

Standards
ASTM E90
ASTM E492

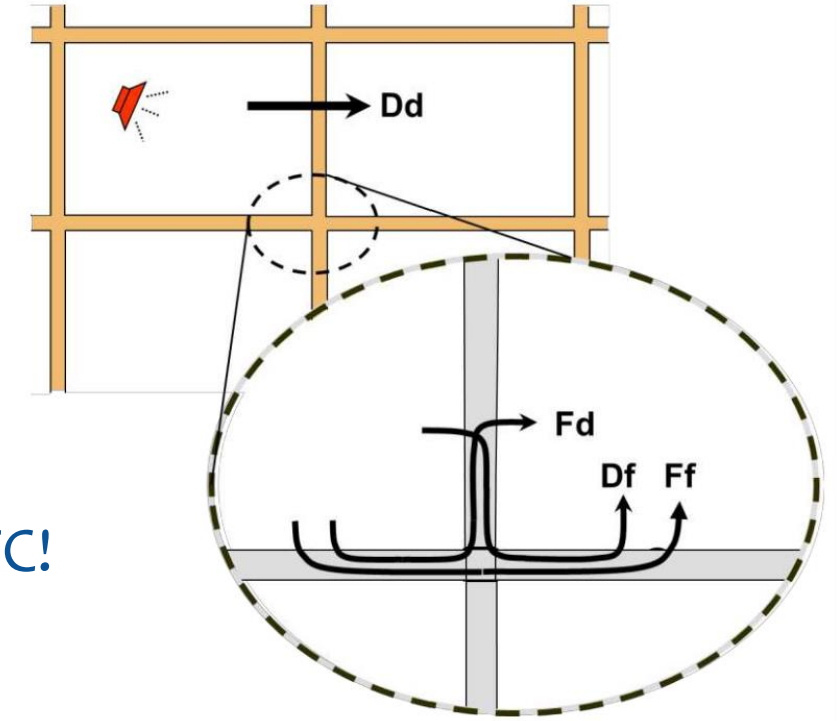
Test Number
m5094.04-113-11-r0

Components	Measurements
Luxury Vinyl Tile/Plank	5 mm (3/16 in)
Pliteq GenieMat® RST05	5 mm (3/16 in)
GenieBoard 302	25 mm (1 in)
GenieBoard 301	20 mm (13/16 in)
Pliteq GenieMat® FF10	10 mm (3/8 in)
Cross Laminated Timber (5-Ply)	175 mm (6 7/8 in)

MT Flanking Transmission

MT Flanking Transmission

- For every demising assembly (with four junctions), there are 12 different flanking paths:
- E.g. for a demising wall assembly at the floor:
  - $Floor_{SRC}$ to $Floor_{RCVR}$
  - $Floor_{SRC}$ to $Wall_{RCVR}$
  - $Wall_{SRC}$ to $Floor_{RCVR}$



- Each path as the ability to single-handedly tank the ASTC!

MT Flanking Transmission

Frequency	Separating floor					Ext. wall 1		Ext. wall 2		Int. wall 1		Int. wall 2		Total
	R_{Dd}	R_{1d}	R_{2d}	R_{3d}	R_{4d}	R_{D1}	R_{11}	R_{D2}	R_{22}	R_{D3}	R_{33}	R_{D4}	R_{44}	R'
Hz	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB
50	31,8	41,2	39,5	45,0	43,9	41,2	44,8	39,5	42,4	45,0	47,2	43,9	46,1	**28,8**
63	33,8	41,5	39,9	45,0	44,0	43,8	45,7	42,2	43,4	47,3	47,5	46,3	46,4	**30,4**
80	41,4	42,8	41,3	46,6	45,6	48,2	43,8	46,8	41,8	52,1	46,4	51,0	45,3	**33,4**
100	45,9	47,0	45,2	45,7	44,7	55,3	50,5	53,6	47,9	54,0	42,8	53,0	41,7	**35,3**
125	50,3	48,7	47,0	47,8	46,5	60,0	52,4	58,2	49,8	59,0	45,3	57,7	43,7	**37,6**
160	55,2	50,5	48,7	49,9	48,6	64,9	54,2	63,2	51,6	64,4	48,0	63,1	46,4	**40,0**
200	60,7	52,6	50,8	53,2	51,9	69,9	55,8	68,2	53,3	70,6	52,0	69,3	50,4	**43,1**
250	66,5	55,3	53,9	56,6	55,3	75,6	58,3	74,1	56,3	76,9	55,8	75,6	54,2	**46,4**
315	72,5	58,4	56,9	59,9	58,6	81,6	61,4	80,2	59,5	83,2	59,3	81,9	57,7	**49,7**
400	78,5	61,4	60,0	63,1	61,8	87,8	64,5	86,4	62,6	89,5	62,8	88,2	61,2	**52,9**
500	84,1	64,3	62,8	66,0	64,7	93,6	67,4	92,1	65,5	95,3	65,8	94,0	64,3	**55,9**
630	89,9	67,2	65,7	69,0	67,7	99,5	70,4	98,0	68,5	101,3	68,9	100,0	67,4	**58,9**
800	95,8	70,1	68,7	72,0	70,8	105,5	73,4	104,1	71,6	107,4	72,1	106,2	70,6	**61,9**
1 000	101,3	72,9	71,5	74,8	73,6	111,2	76,2	109,8	74,4	113,2	75,1	111,9	73,6	**64,8**
1 250	106,9	75,3	73,9	77,7	76,4	116,5	78,3	115,1	76,5	118,9	78,0	117,7	76,5	**67,3**
1 600	112,9	76,7	75,3	80,8	79,6	121,1	78,1	119,8	76,4	125,2	81,2	124,0	79,8	**69,0**
2 000	118,5	78,0	76,7	83,6	82,4	125,4	78,0	124,0	76,3	131,0	84,2	129,8	82,8	**70,2**
2 500	123,6	79,1	77,8	85,8	84,7	129,4	77,9	128,1	76,3	136,1	86,3	134,9	84,9	**71,0**
3 150	126,2	79,0	77,7	85,8	84,6	132,3	77,9	131,0	76,2	139,0	86,3	137,9	84,9	**70,9**
4 000	129,0	78,9	77,7	85,7	84,6	135,3	77,9	134,0	76,3	142,1	86,4	141,0	85,0	**70,9**
5 000	131,6	78,9	77,6	85,7	84,6	138,2	77,9	136,9	76,3	145,0	86,4	143,9	85,1	**70,9**
R_w (dB)	**75,1**	**67,3**	**65,7**	**68,0**	**66,7**	**84,5**	**70,6**	**82,8**	**68,4**	**84,3**	**66,7**	**83,1**	**65,1**	**57,8**

12 Flanking ASTCs

Direct (Lab) STC

*Note: R_w is like ASTC (ISO vs ASTM Metrics)

Overall ASTC

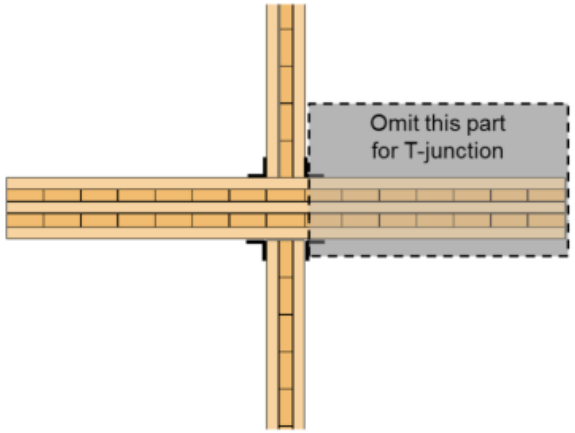
MT Flanking Transmission

- Generally, calculating a Flanking ASTC Depends on:
  a. Geometrical dimensions of the room
  b. Direct Lab STC of the Flanking Element
  c. Any lining of flanking elements (e.g., dropped ceilings, wall partitions, floor toppings)
  d. Vibration Reduction Index (K_{ij})

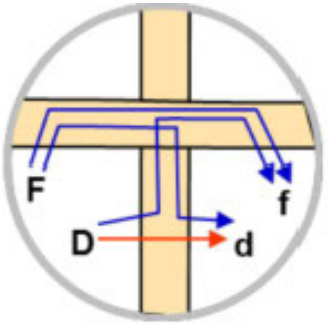
$$STC_{ij} = \frac{STC_i}{2} + \frac{STC_j}{2} + K_{ij} + \max(\Delta STC_i, \Delta STC_j) + \frac{\min(\Delta STC_i, \Delta STC_j)}{2} + 10 \cdot \log_{10} \frac{S_s}{l_0 \cdot l_{ij}}$$

MT Flanking Transmission

- Low K_{ij} rating = lots of sound through that specific path
- High K_{ij} rating = minimal sound transmission through that path

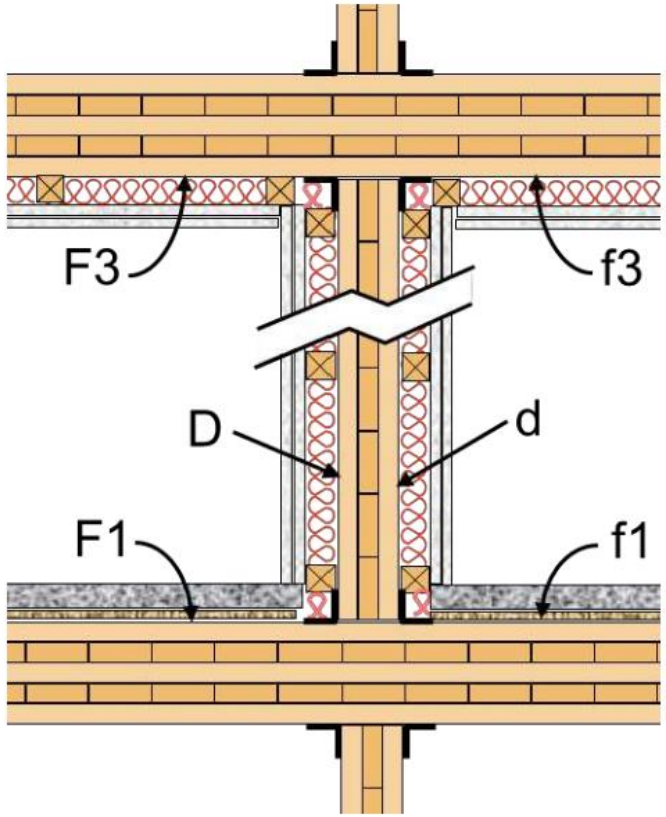


CLT-WC-Xa-01
Wall-Ceiling
X-junction



Path	Vibration Reduction Index, K_{ij}
Ff	1.1
Fd	10.5
Df	10.5

MT Flanking Transmission



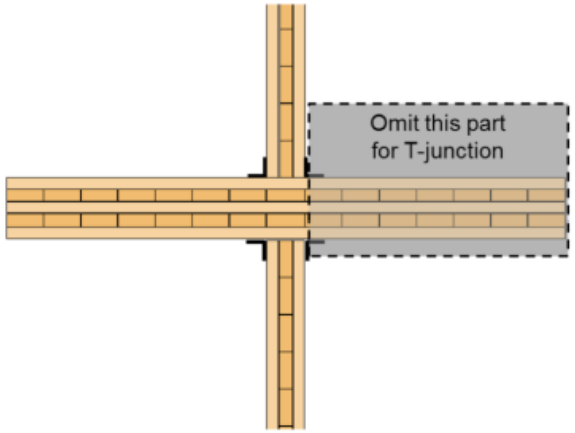
In the context of Mass Timber

- This means you can avoid calculating flanking if:
  - Wall have drywall finish interrupted by floor/ceiling
  - Ceiling have drywall finish interrupted by walls
  - Floor have plywood/concrete floor interrupted by walls

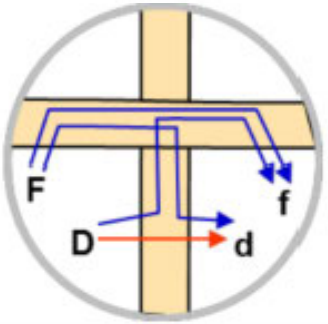
This is the simple way…

MT Flanking Transmission

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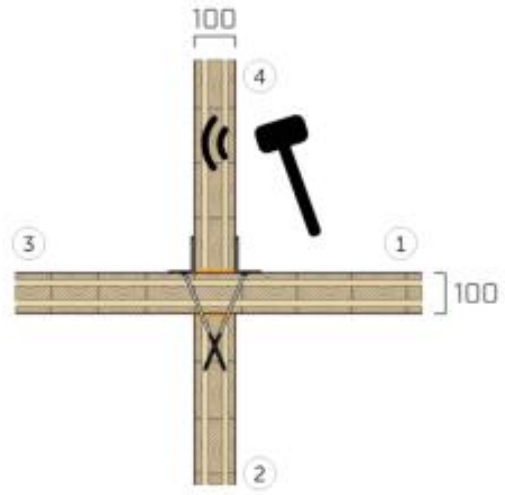


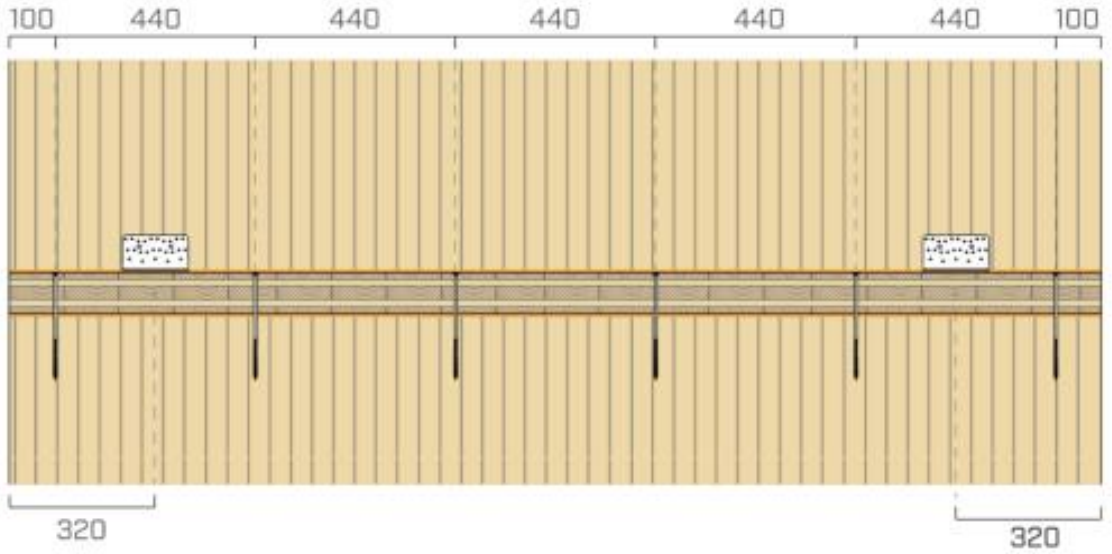
CLT-WC-Xa-01
Wall-Ceiling
X-junction



Path	Vibration Reduction Index, K_{ij}
Ff	1.1
Fd	10.5
Df	10.5

MT Flanking Transmission





f [Hz]	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150
K_{14} [dB]	19,5	21,5	19,6	17,0	17,5	14,7	19,1	21,0	20,8	19,3	22,2	23,2	22,6	20,4	19,8	19,9

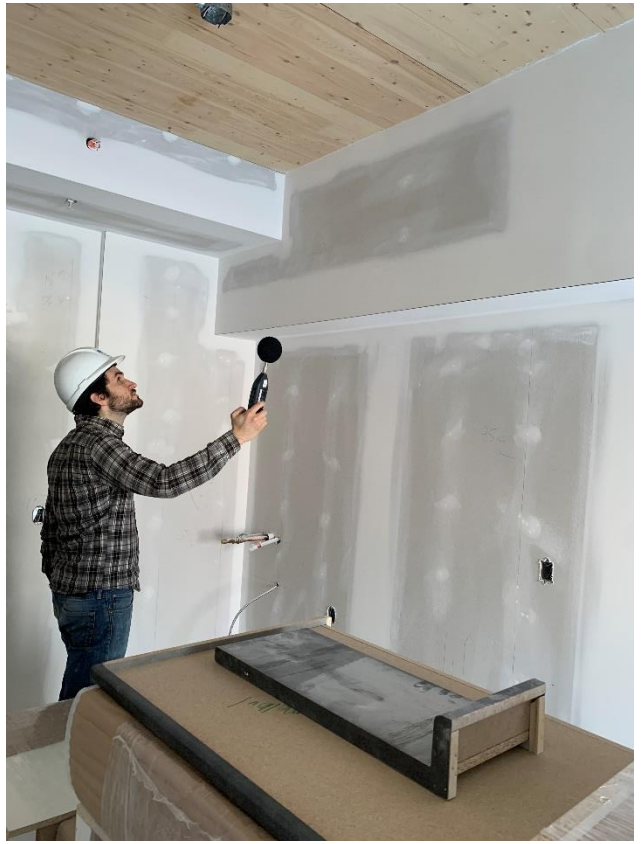
$\overline{K_{14}} = \mathbf{19,9\ dB}$ $\overline{K_{14,0}} = \mathbf{17,0\ dB}$ $\Delta_{l,14} = \mathbf{2,9\ dB}$

MT Flanking Transmission

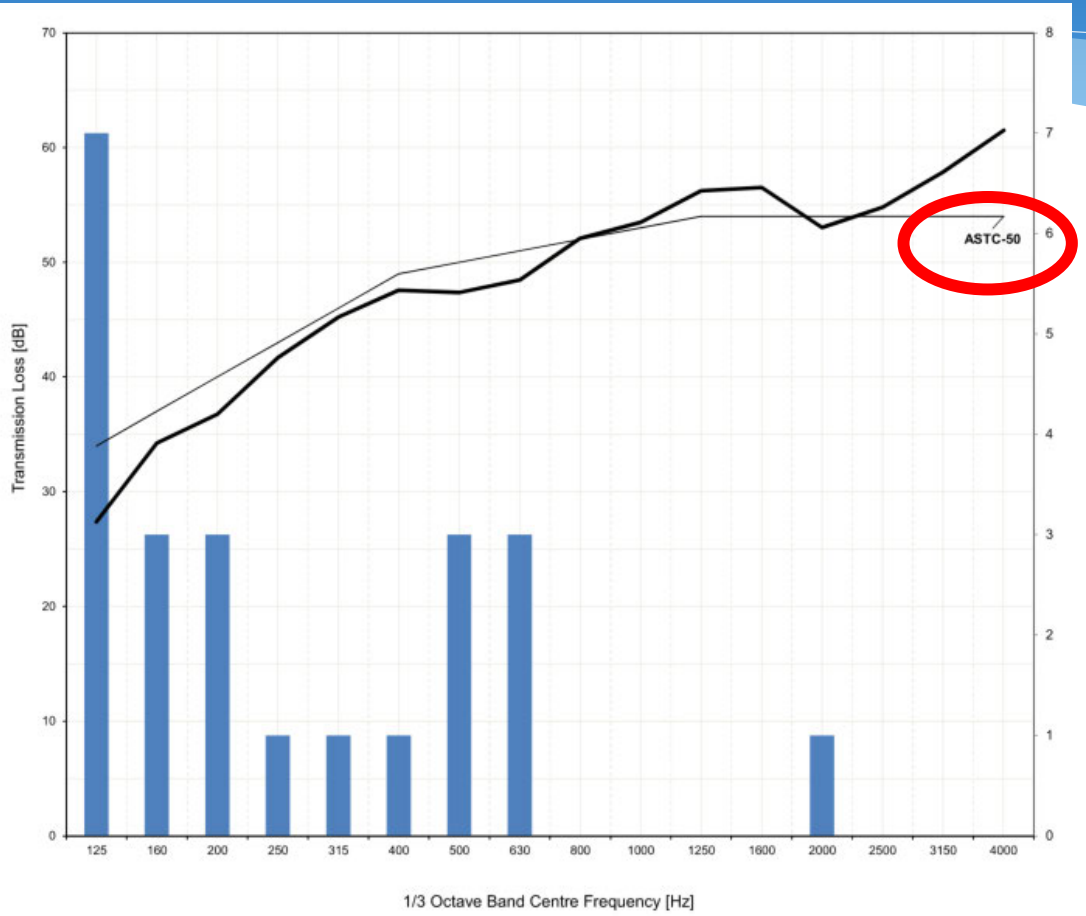
- We tested continuous 175 mm 5-ply CLT with an isolated concrete topping above and got…

  ASTC-52! Huh?

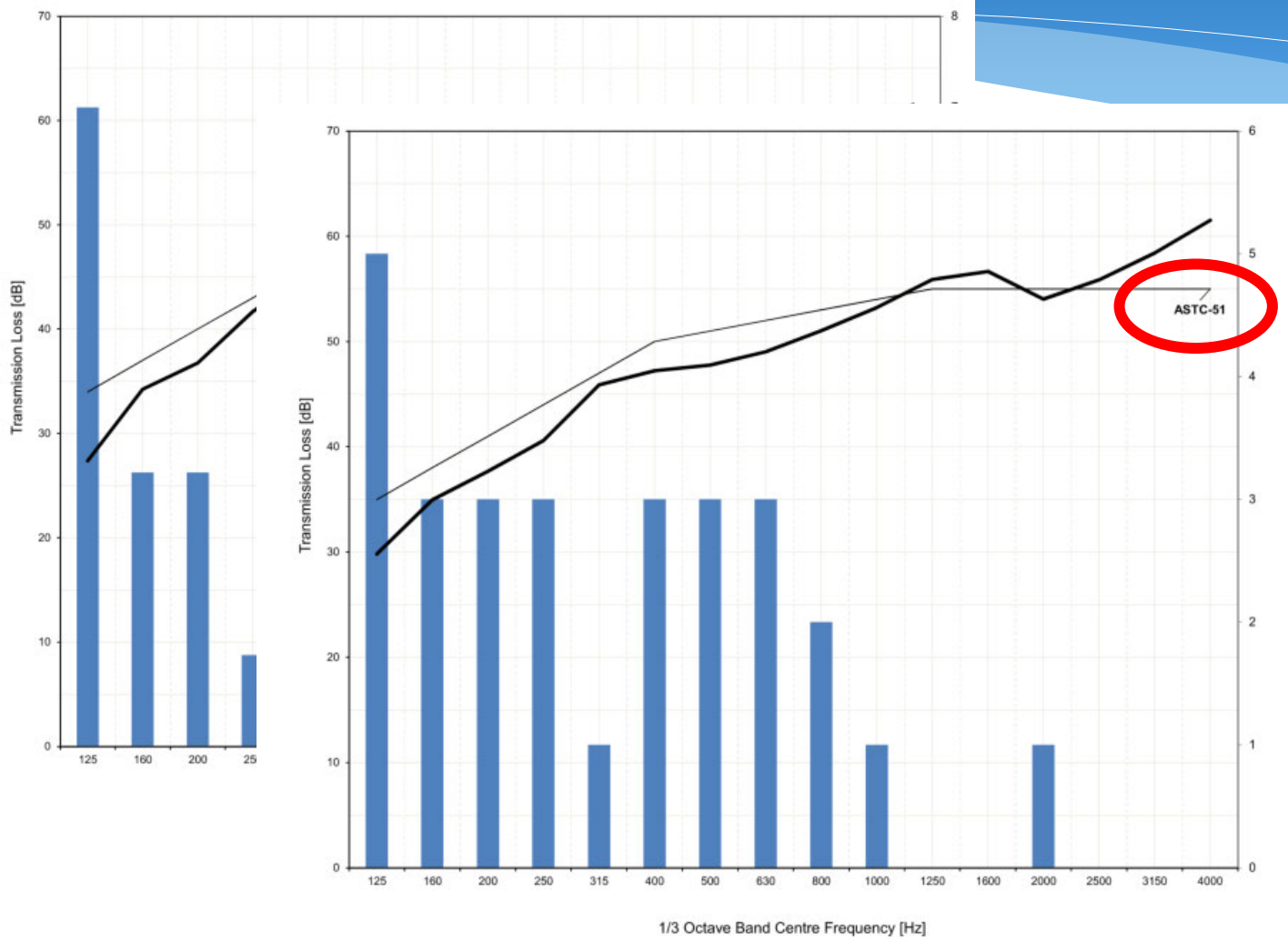
  So, we went to more buildings…



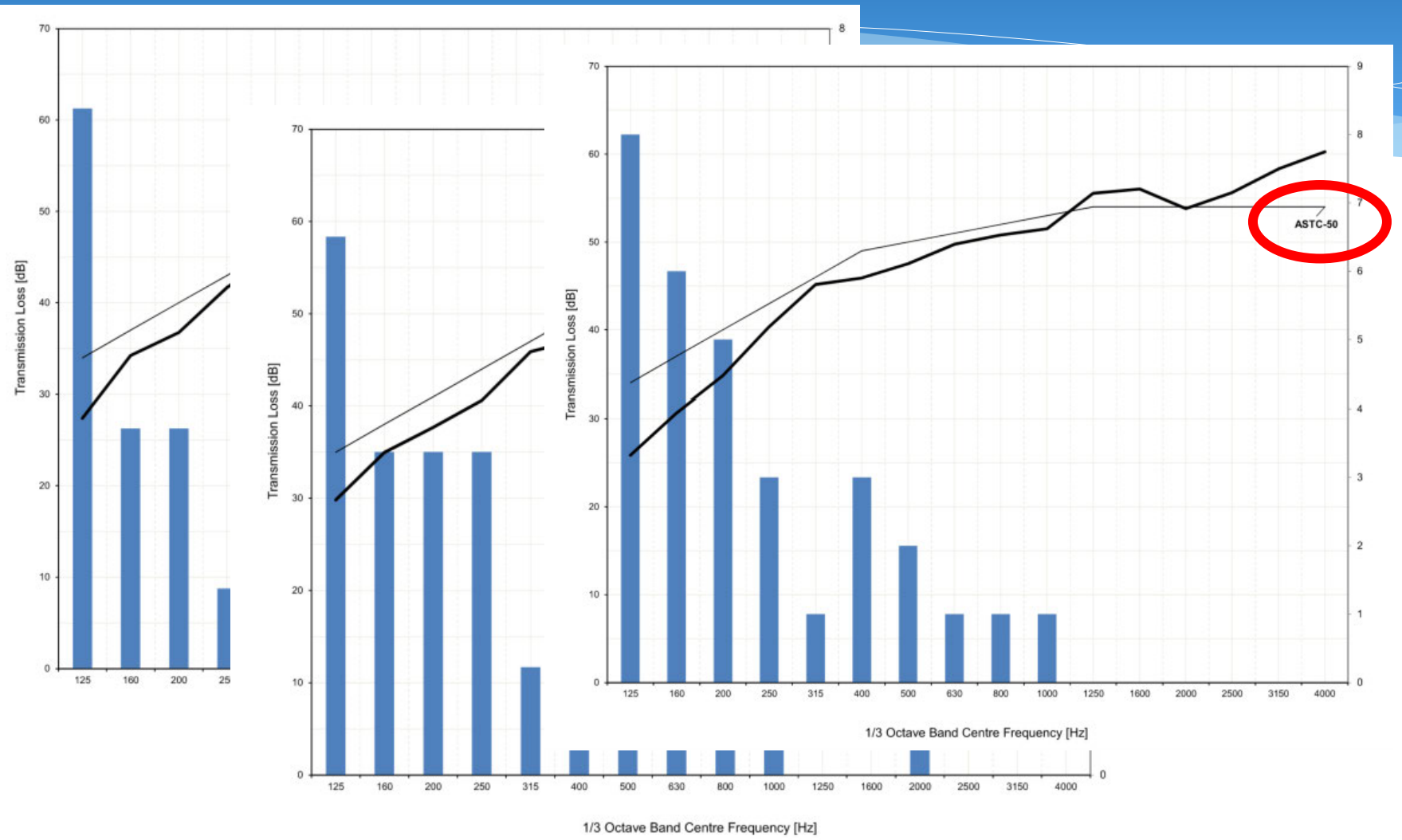
MT Flanking Transmission



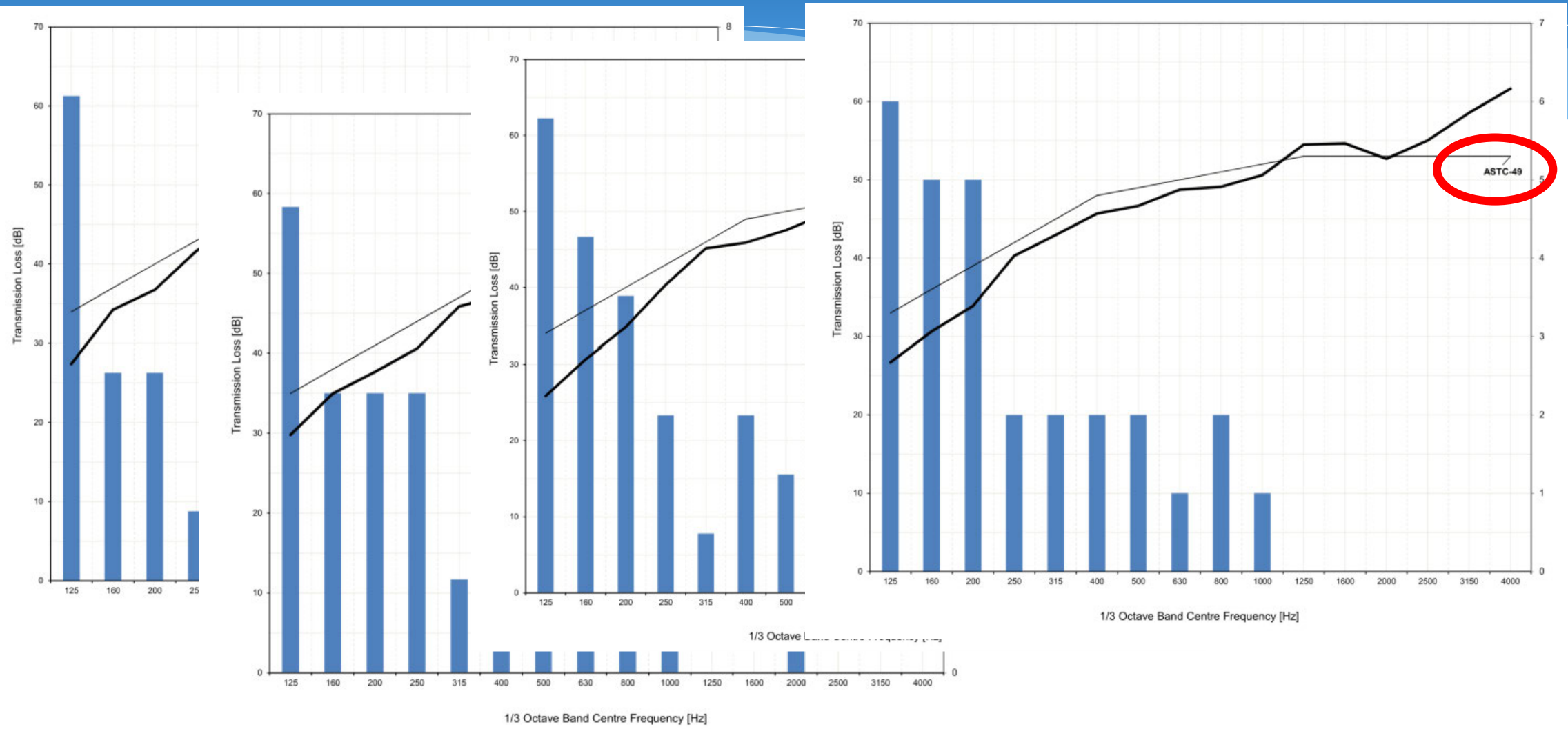
MT Flanking Transmission



MT Flanking Transmission

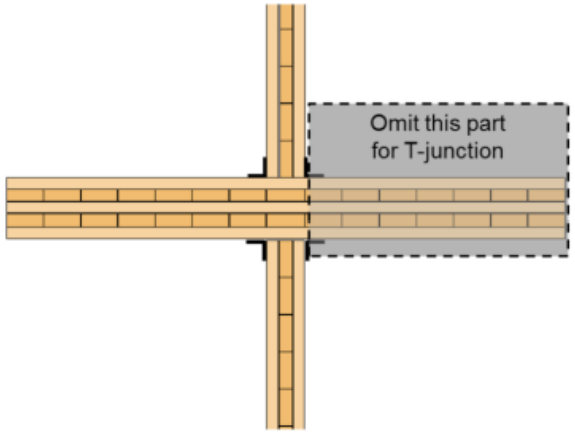


MT Flanking Transmission

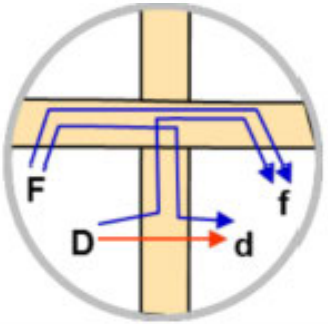


MT Flanking Transmission

- Low K_{ij} rating = lots of sound through that specific path
- High K_{ij} rating = minimal sound transmission through that path



CLT-WC-Xa-01
Wall-Ceiling
X-junction



Path	Vibration Reduction Index, K_{ij}
Ff	1.1
Fd	10.5
Df	10.5

MT Flanking Transmission

- Outstanding questions:
  - How does the Kij of continuous CLT change with the isolated concrete topping?
  - Does a dry build-up provide a similar Kij difference?
  - Does a roof build-up provide a similar Kij difference?
  - How does 3-ply CLT affect the delta Kijs?

Future testing is planned shortly!



MT Flanking Transmission

- Upcoming Testing:
  - Ceiling-to-ceiling Kij Lab (NRC) and Field (HGC) testing* of continuous 5-ply CLT with:
    - Isolated wet concrete topping above
    - Isolated dry topping above
    - No topping above
  - ASTC testing with continuous 5-ply CLT with roof assembly above
  - ASTC testing with continuous 3-ply CLT and NLT with wet concrete topping above

In partnership with McCallumSather, R-hauz (Assembly Corp), Pliteq

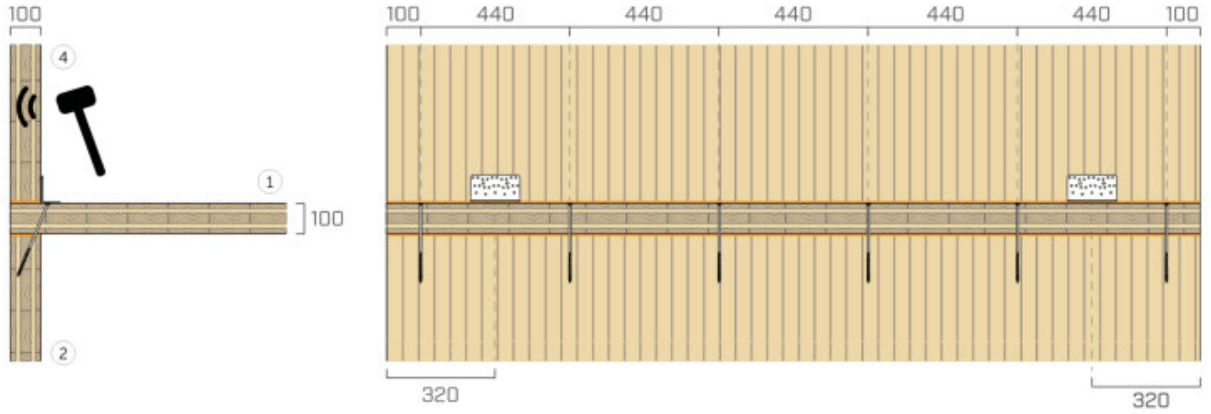
*Published paper to follow Kij testing



Other MT Considerations

Other MT Considerations

- Exposed demising wall or exterior wall CLT panels



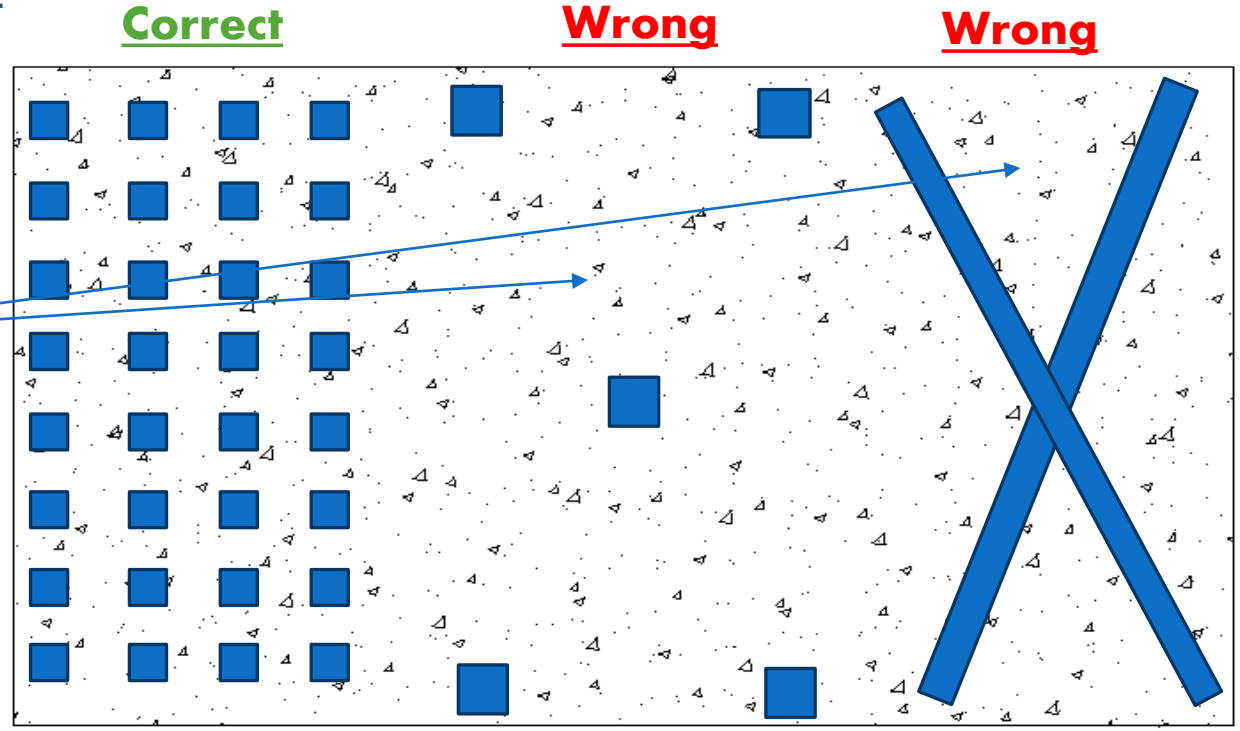
f [Hz]	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150
K_{14} [dB]	15,5	16,0	16,1	17,7	16,9	19,1	18,0	16,6	17,6	18,8	17,1	19,1	19,8	16,1	17,8	21,1

$\overline{K_{14}}$ = **17,6 dB** $\overline{K_{14,0}}$ = **13,3 dB** $\Delta_{l,14}$ = **4,3 dB**

Other MT Considerations

- Exposed demising wall or exterior wall CLT panels
- Laminating drywall to underside of CLT

Large air gaps amplify sound, lower STC rating



Other MT Considerations

- Exposed demising wall or exterior wall CLT panels
- Laminating drywall to underside of CLT
- M&E vibration isolation of small piping/conduits



Other MT Considerations

- Absorption benefits of Mass Timber:

Material	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
Mass Timber	0.13	0.09	0.08	0.06	0.06	0.07
Concrete	0.01	0.01	0.02	0.02	0.02	0.05
Gypsum Board on solid backing	0.03	0.03	0.02	0.03	0.04	0.05
Plasterboard on studs, 100 mm airspace with insulation	0.08	0.11	0.05	0.03	0.02	0.03

- CLT slightly better than concrete or laminated GWB
- May still need some secondary absorption for large spaces with low reverberation targets

Wrap-up

What did we discuss?

- Intro to Acoustics
- Measurements and Descriptors
- MT Direct Transmission
- MT Flanking Transmission
- Other MT Considerations



Who is HGC Noise Vibration Acoustics?

- One of North America's largest acoustical engineering firms
- Founded in 1994
- Headquartered in Toronto, Ontario
  - One of the most tightly regulated jurisdictions in North America with regards to noise.
- Additional offices in Dallas, Texas; Calgary, Alberta; and Montreal, Quebec.



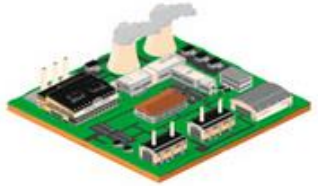


Who is HGC Noise Vibration Acoustics?



Built Environment

We actively support developers, planners, architects and engineers in addressing all issues pertaining to noise, vibration and acoustics within a structure and in its relationship to environmental zones of influence nearby.



Industrial

We assist industries in every business sector to complete requirements for their Environmental Compliance Approvals. We conduct accurate surveys to identify all significant noise and vibration sources associated with large industrial facilities, plants and operational complexes.



Transportation

Whether rail, road or air, transportation represents a major potential source of environmental noise and vibration for neighboring communities. We work with all relevant stakeholders conducting impact studies and developing mitigation solutions that facilitate the approval process and alleviate community concerns.



Defence & Security

Defence and Security related technologies and support systems represent potential occupational noise and vibration hazards for their operators and the public at large. We work with officials to research and develop noise abatement strategies and solutions that alleviate exposure concerns.



Product R&D

We have partnered with manufacturers across multiple industries to investigate and incorporate effective acoustic best practices into their product design for greater consumer preference and comfort.

HGC
NOISE | VIBRATION | ACOUSTICS

Questions?

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www.acoustical-consultants.com

NOISE VIBRATION ACOUSTICS

This concludes The American Institute of Architects Continuing Education Systems Course.