Gym Acoustics Guidance Workshop

Launch of a new ProPG

29 March 2023

ANC | ACOUSTICS & NOISE CONSULTANTS

2.1 METHODOLOGY

Presented by

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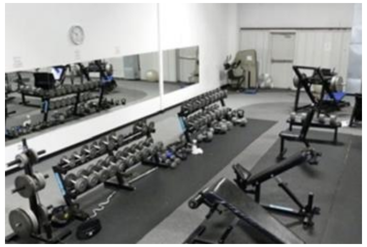
Senior Acoustic Consultant at RBA Acoustics Ltd, 9 years in industry

Methodology Considerations

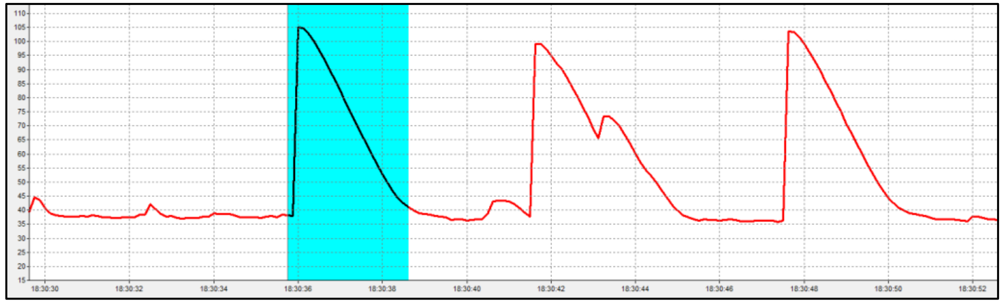
Types of Noise Issues from Gyms

	Noise Type	e.g.	Assessment
	Airborne Noise	Amplified Music	Standard Airborne Assessment (BS EN ISO 16283-1)
	High Impact Response (HIR)	Weight Drops, Fixed Pin Machines, Slamballs	Measurement of Gym Activity/ Weight Drop (Method 1 or 2, described in GAG document)
	Synchronised Repetitive Excitation (SRE)	Treadmills, Dance	Difficult to standardise – SQA experience Approaches to assist assessment could include: • Heel-drop test (SCI P354) • Flat-footed running (approx 11km/h or 160 BPM)

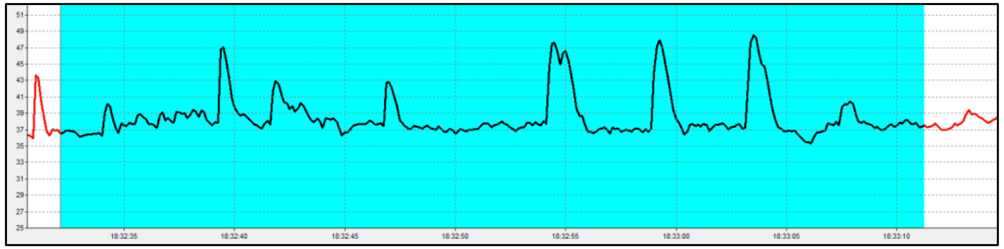
What is "Weight Drop" (HIR) Testing?

Examples of what we measure …

20kg Kettlebell on Lightweight Floor (L_{Afmax})



Jogging on Lightweight Floor (L_{Afmax})



Considerations for “Weight Drop” (HIR) Testing?

- Repeatability (Height, Mass, Location, Dropped Object, Number of Repeats)
- Health & Safety (HSE Manual Handling Masses, Equality, Lifting Barbells)
- Damage to structure (Mass, Object Shape & Material)
- Representative (Different Methods for different purposes)

Method 1 (Consistent, Generic Approach)

Aims to provide a minimum baseline methodology to provide initial indication of site suitability (for untreated, pre-fit-out sites) and to avoid damage to untreated structures.

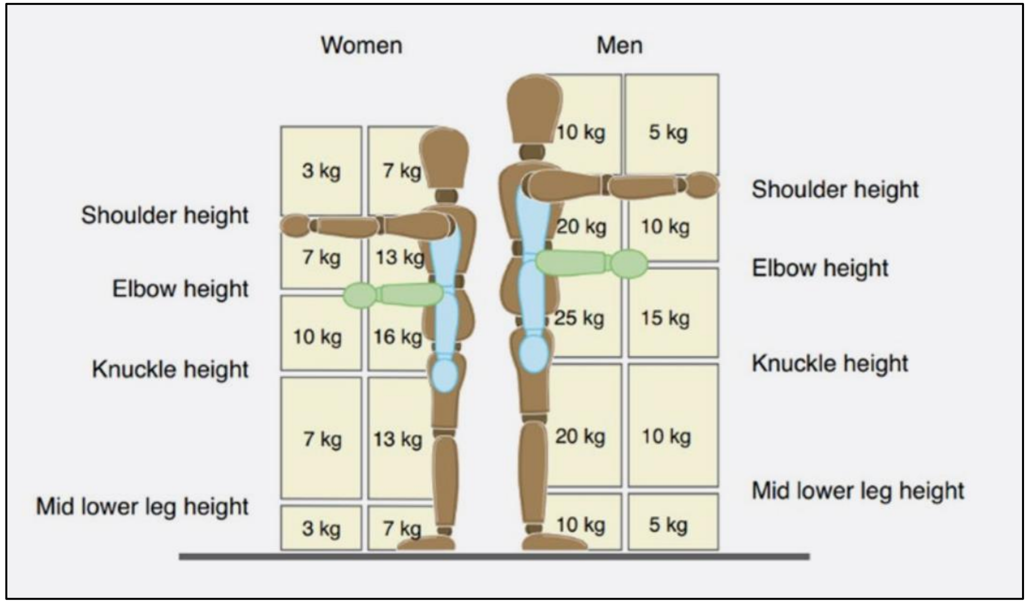
Method 2 (More Specific Approach)

Aims to measure the “real-life worst-case” proposed gym activity and would also typically be the default approach for investigative or diagnostic Acoustic testing, as site issues will typically be due to bespoke, site-specific activities.

Health & Safety

- Health & Safety Executive (HSE) states that there is no law on maximum weight carried, but places responsibility on employers to manage/control risk

- Lifting and lowering risk limits for manual handling in the UK, reproduced from guidance (below)



- A risk assessment is essential, taking into account the physical capability of each practitioner (including consideration of carrying tile/flooring samples)

- If necessary, a Gym Employee or Trained Weight-lifter should be used to drop heavier weights (recommended for Method 2 testing)

- RAMS should also include appropriate PPE which would typically require Steel-Toe-capped Boots to protect feet during weight-drop testing

Method 1 & Method 2 Testing

Method 1 Testing

Testing Method 1 aims to provide a minimum baseline methodology to provide initial indication of site suitability (for untreated, pre-fit-out sites) and to avoid damage to untreated structures	
Minimum no. of weight drops	3
Drop height from the finished floor level	0.5m
Weight Range	20-35kg (Standardised)

Anything above this height/weight would be classed as Method 2 testing

Method 1 Testing

Weight Shape	Repeatable impact surface area, so ideally kettlebell
Weight Finish	Rubberised finish

During ‘Method 1’ testing, complementary testing with other items (e.g.: slamball) could also be done, at discretion of SQA

Method 2 Testing

Aims to measure the "real-life worst-case" proposed gym activity and would also typically be the default approach for investigative or diagnostic Acoustic testing, as site issues will typically be due to bespoke, site-specific activities.	
Minimum no. of weight drops	3-6
Drop height from the finished floor level	Bespoke worst-case
Weight Range	Bespoke gym equipment/activity

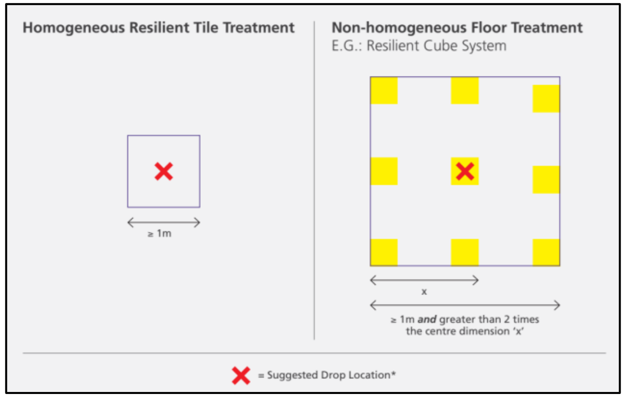
Method 2 Testing

Due to the variation in the way energy will be transferred into the structure for different activity types, **Method 2** testing should ideally include assessment of one of each of the following activities (where these items are proposed or are expected to occur in a gym)

*Note that the 'heaviest proposed unit' may not necessarily be the heaviest weight available, particularly for units with interchangeable weights, however, should be representative of the typical upper limit used by the strongest/most experienced Gym users. A view should be taken in consideration of guidance from the Gym users and operators

Slamball, Medicine ball, Weight bags	Slams using the heaviest proposed unit*, 'slammed' from **head height (approx 1.5 m)**. If slamballs are proposed to be slammed on walls, this should be measured. Generally, the worst-case weight would be around **10 kg** in that case
Dumbbells	Drops using the heaviest proposed unit*, in line with drop methodology given in Method 1. Generally, the typical worst-case weight would be around **35 kg**
Barbells	Drops using the heaviest proposed unit*, in line with drop methodology given in Method 1. Typically, the worst-case weight would be around **150 kg**
Treadmills	Running on the treadmill at a setting representative of a **fast run (around 10 km/h) with shoes** and with a flat-footed running style. This should ideally be measured continuously for a **minimum of 30 seconds**
Fixed-pin Machines	Given that the weight is fixed in the machine, it is recommended that the weight bars are released to drop from a height of around **0.2m**. Typically, the worst-case weight would be **50 kg** (depending on the type of machine)

Good Practice

Sound Level Meter	**Class 1 defined in IEC 60651 and IEC 60804**
Vibration Equipment	Compliant with the requirements of BS EN ISO 8041-1:2017 (certified laboratory calibration within the previous two-year period) Equipment should, ideally, be capable of simultaneous measurements in three orthogonal axes, as described within BS 6472:2008. Measurement in a single (z-) axis only may prove adequate when assessing the response of a floor
Gym Floor Test Samples	Size representative of a larger installation (Ideally min. 1m x 1m). For treatment types with 'centres' at larger dimensions (e.g.: Resilient Cube System at 1m centres) 

Good Practice

Number of Drop Positions	Enough to provide representative sample of area (Minimum 3 positions recommended)
Worst-case Positions	These should be identified by SQA and included. Typically adjacent to noise-sensitive areas and/or adjacent to transmitting structures (e.g.: walls, columns, facades)
Test Drop/Activity Location	• ≥ 0.5m from any transmitting structures, • but at least one position ≈0.7m from worst-case transmitting structure • Any test samples must not be in contact with transmitting structures • At least one position where floor deflection is maximal (i.e.: judgement of SQA)
Receive Position	• One receptor position may be suitable • Judgement of SQA to measure in worst-case location
Other flanking routes	As with Sound Insulation testing, it is critical that the effect of other flanking routes are mitigated, and considered in the analysis of data (e.g.: closing windows between test areas, excluding airborne component of impact drop on construction site)

Good Practice

Times of Weight Drops	Specific times of weight drops should ideally be recorded to avoid subsequent data analysis errors (most useful where resulting impact noise is quiet/barely audible). This is critical in live-use gyms, where other activity may also produce impact noise that should be excluded from analysis. Ideal scenario would of course, be empty gym & receptor, however site access limitations often prove non-idealised, in reality
Noise Measurements	1/3 Octave-band Measurements covering an appropriate range (recommended 20Hz minimum assessment frequency). Higher frequencies should also be considered to take account of re-radiated sources (e.g.: rattling lights/fixtures) (Recommended up to 10kHz assessment frequency). Measurements in ‘Full Storage’ mode with Integration time of 0.125s (to record an accurate time history for subsequent analysis) Microphone min. 0.7m from floor & min. 0.5m from walls in receive room Background noise measurement should be taken
Reverberation Time	If receive room will be different from test conditions, then RT could be calculated in like with ISO 354

Vibration Testing

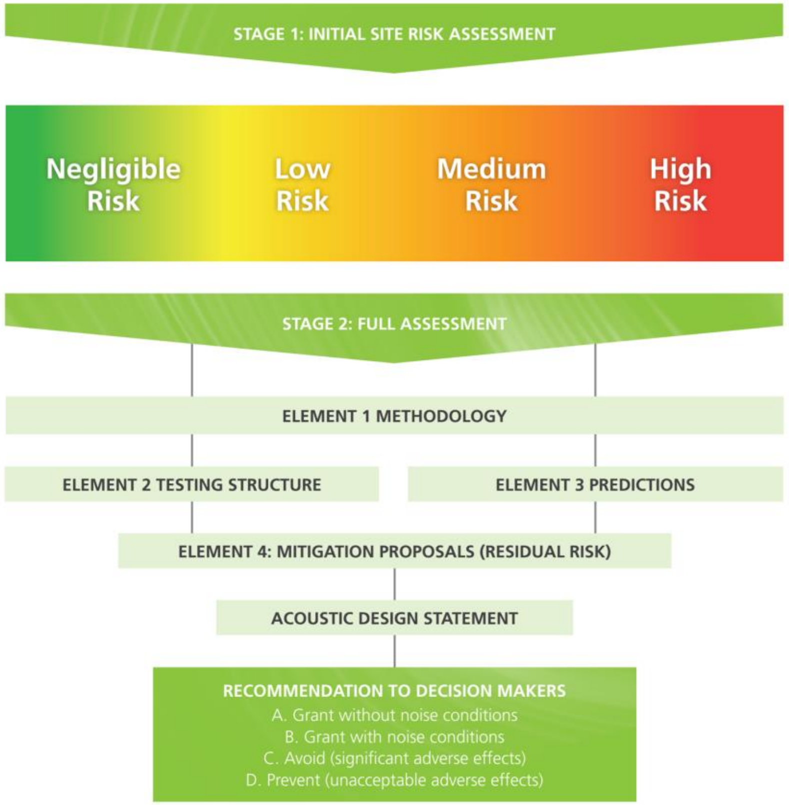
Vibration

- Tactile Vibration usually secondary concern to Sound Transfer
- Can be used to determine Natural Frequency of floor
- Useful to predict noise transfer where airborne flanking paths limit useful measurement pre-fit-out (e.g.: in large unit, that will later be subdivided into separate partitioned units).
- Measurements of the RMS and/or peak acceleration should be carried out in 1/3 octave bands. The frequency ranges covered by weighting networks designed to address human response (ref. BS 6472 and BS 6841) and those of the Vibration Criterion curves are encapsulated by the **minimum range 0.5Hz to 315Hz.**
- VDV measurements not recommended. In some cases, an eVDV could be established, although care should be taken in approximating regularity of events used.

Vibration

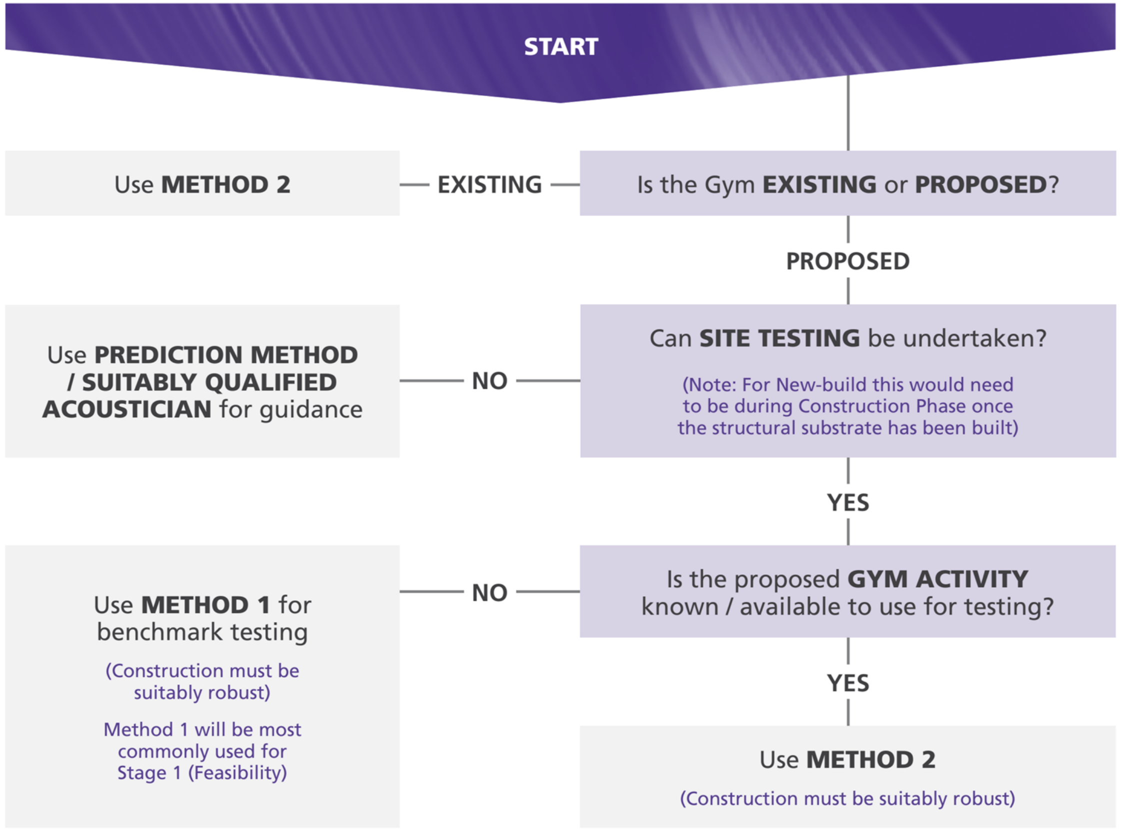
- Transducer mounted at levelled position corresponding to the most-affected occupant, this typically being taken as the centre of the room. A secure connection should be established with the structure, for example by using a proprietary tripod baseplate or by other appropriate means that neither amplifies nor attenuates the vibration to be measured. It should be recognised that, where floors in a building utilise constructions of differing stiffness or mobility, the worst-affected receptor may not necessarily be the closest to the Gym.
- Much of the instrumentation currently on the market comprises three channels, allowing concurrent triaxial measurement. Where only single axis measurements are possible, preference should be given to obtaining data in the vertical (z-) axis, unless it can be shown that one of the other axes dominates

Where does Testing fit in?



- Suitably Qualified Acoustician (SQA)
- Different types of testing may suit different stages of project
- Could be Baseline / Complaints / Commissioning Testing

When to use Method 1 or Method 2 Testing?



Method 2 testing would be the default for diagnostic/complaint investigation testing

2.2 PREDICTION

Presented by

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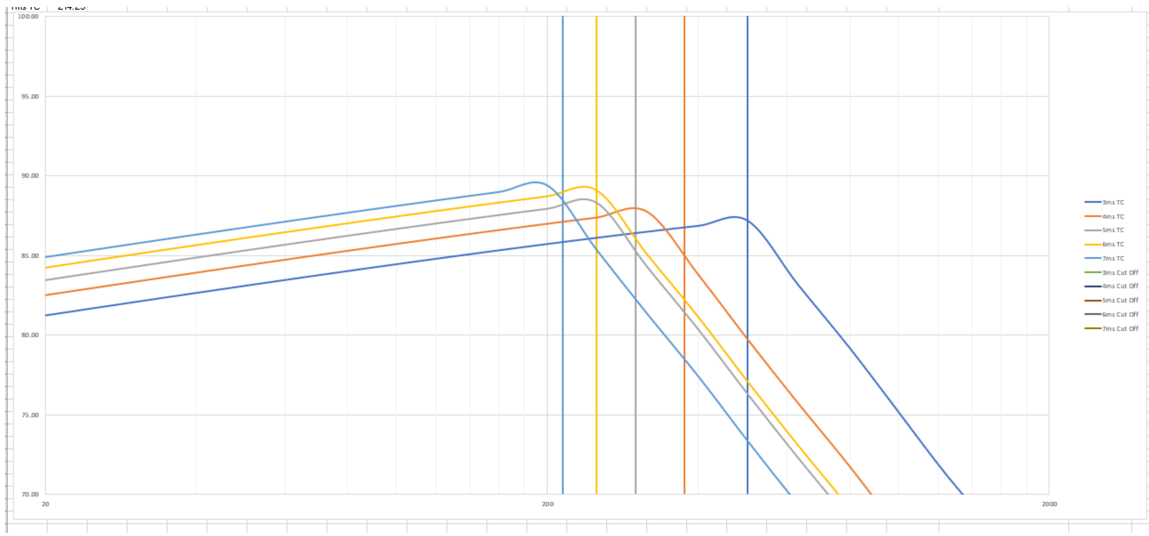
Associate Director and Vibration Group Leader at Hoare Lea. 18 years in industry

Thank you, consultees!

- The feedback received during the consultation period was extremely useful. Thanks to all who got in touch.
- Input from BAG and Professor Carl Hopkins was gratefully received.
- My colleagues Ollie Buxton, Nikhilesh Patil and Matthew Naylor.
- Special mention to those who sent me their own version of the calculation process, along with typo spots!

50	63	80	100	125	160	200	250	315	400	500	630	800
56578	587888.3	746524.8	933156	1166445	1493049.6	1866312	2332890	2939441	3732624	4665780	5878883	7465248
50	63	80	100	125	160	200	250	315	400	500	630	800
4.7779	11875.220	15079.644	18849.555	23561.944	30159.289474	37699.111	47123.889	59376.101	75398.223	94247.779	118752.20	150796.44
47069	0.593033	0.752992	0.941118	1.176158	1.504939377	1.880196	2.348337	2.954988	3.744166	4.665111	5.847253	7.36128
50	63	80	100	125	160	200	250	315	400	500	630	800
00057	0.000456	0.000359	0.000287	0.00023	0.000179495	0.000144	0.000115	9.12E-05	7.18E-05	5.74E-05	4.56E-05	3.59E-05
15142	0.135988	0.121803	0.11	0.099443	0.089056942	0.080711	0.073246	0.066344	0.06	0.054721	0.049841	0.045355
07333	0.058201	0.045833	0.036667	0.029333	0.022916667	0.018333	0.014667	0.01164	0.009167	0.007333	0.00582	0.004583
7E-05	8.63E-05	9.63E-05	0.000107	0.000118	0.000131659	0.000145	0.00016	0.000176	0.000194	0.000213	0.000232	0.000253
8.893	79.35958	79.83761	80.27972	80.71703	81.19451734	81.61963	82.0376	82.46167	82.88864	83.27456	83.65745	84.02955
2.532	92.99867	93.4767	93.9188	94.35612	94.83360475	95.25871	95.67668	96.10075	96.52773	96.91364	97.29654	97.66864
.3033	77.76988	78.24791	78.69002	79.12733	79.6048173	80.02993	80.4479	80.87197	81.29894	81.68486	82.06775	82.43985
-30.2	-26.2	-22.5	-19.1	-16.1	-13.4	-10.9	-8.6	-6.6	-4.8	-3.2	-1.9	-0.8
.1033	51.56988	55.74791	59.59002	63.02733	66.2048173	69.12993	71.8479	74.27197	76.49894	78.48486	80.16775	81.63985
74	74	76	78	79	75	80	84	81	84	82	79	78

1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000
9331560	11664450	14930496	18663120	23328900	29394414	37326240	46657800	58788828	74652480	93315600
1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000
188495.55	235619.44	301592.89	376991.11	471238.89	593761.01	753982.23	942477.79	1187522.0	1507964.4	1884955.592
9.08598	11.13879	13.78688	16.44953	19.19721	21.82423	23.85477	24.72134	24.35392	22.72271	20.39307
1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000
2.87E-05	2.3E-05	1.79E-05	1.44E-05	1.15E-05	9.12E-06	7.18E-06	5.74E-06	4.56E-06	3.59E-06	2.87E-06
0.041623	0.038284	0.035	0.032361	0.03	0.027817	0.025811	0.024142	0.022599	0.02118	0.02
0.003667	0.002933	0.002292	0.001833	0.001467	0.001164	0.000917	0.000733	0.000582	0.000458	0.000367
0.000272	0.00029	0.000307	0.000317	0.000319	0.00031	0.000288	0.000255	0.000213	0.000167	0.000127
84.34761	84.62628	84.86999	85.00826	85.03897	84.92032	84.59424	84.07047	83.28863	82.23158	81.04173
97.9867	98.26537	98.50907	98.64735	98.67806	98.55941	98.23333	97.70956	96.92772	95.87066	94.68082
82.75791	83.03658	83.28029	83.41856	83.44927	83.33062	83.00454	82.48077	81.69893	80.64188	79.45203
0	0.6	1	1.2	1.3	1.2	1	0.5	-0.1	-1.1	-2.5
82.75791	83.63658	84.28029	84.61856	84.74927	84.53062	84.00454	82.98077	81.59893	79.54188	76.95203
72	67	65	63	58	56	53	50	47	44	41

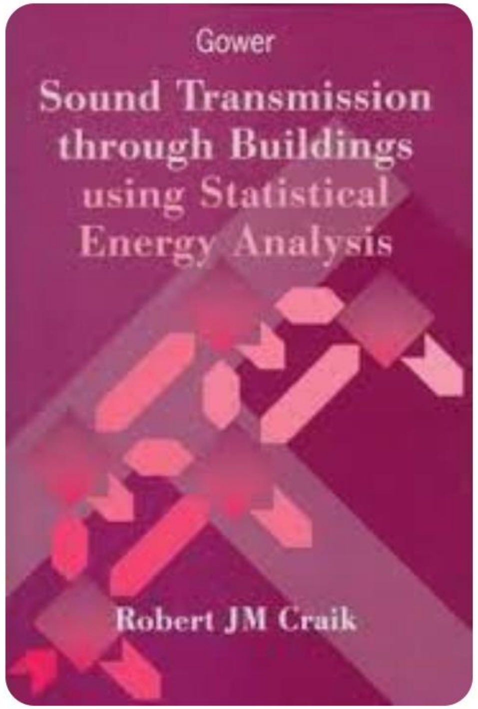


Background and Motivation

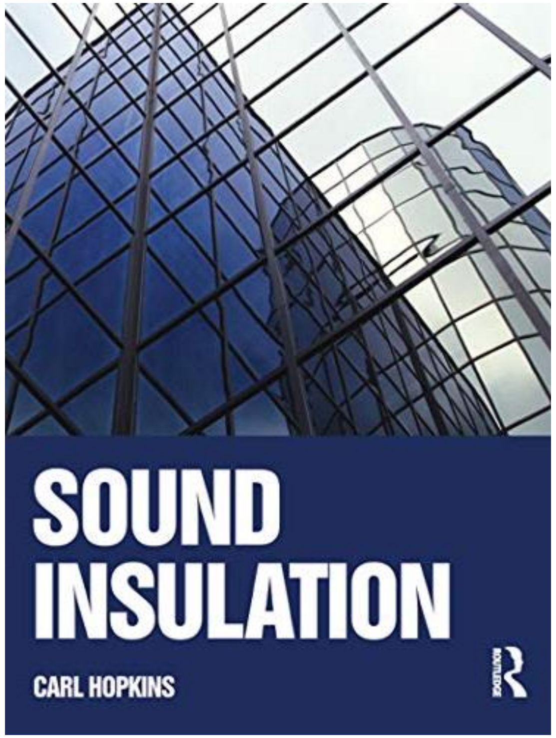
- To provide an engineering-grade means of prediction so as to provide early flags during design or feasibility stages.
- Something that does not require specialist software or is computationally expensive. Can be executed in a spreadsheet package.
- Allows mitigation to be built in – based on empirical values rather than complex methods.
- Focussed on gyms above a sensitive receiver however the model can be extended if needed.
- Does not negate the need for testing – which shall always be considered to be the most reliable means of assessment. *The prediction can however be used as a complementary tool alongside testing to extrapolate to heavier values.*

Background and Motivation

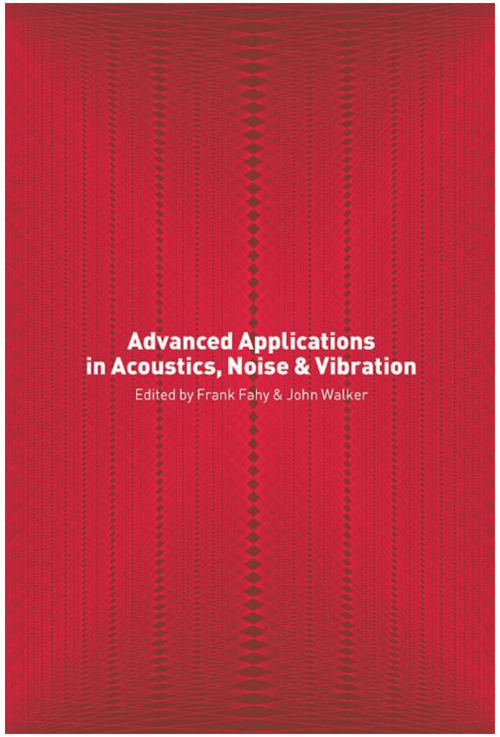
Lyon, R.H., 1975. *Statistical energy analysis of dynamical systems. Theory and Applications.*



Craik, R.J.M , 1996. Sound Transmission Through Buildings: Using Statistical Energy Analysis}



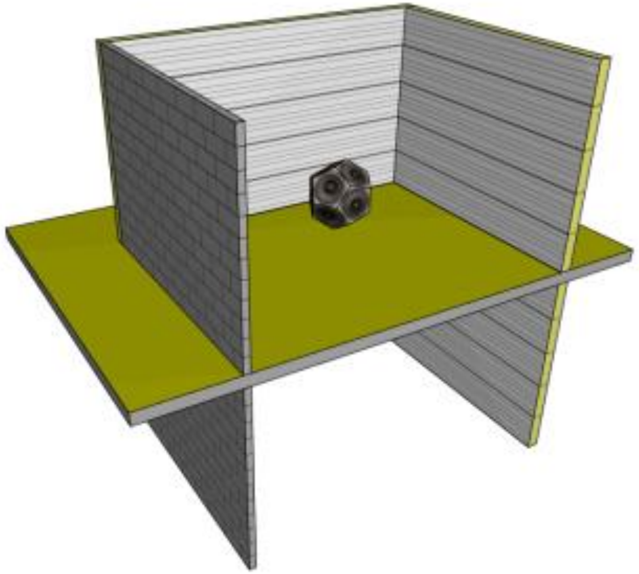
Hopkins, C., 2012. Sound insulation. Routledge..



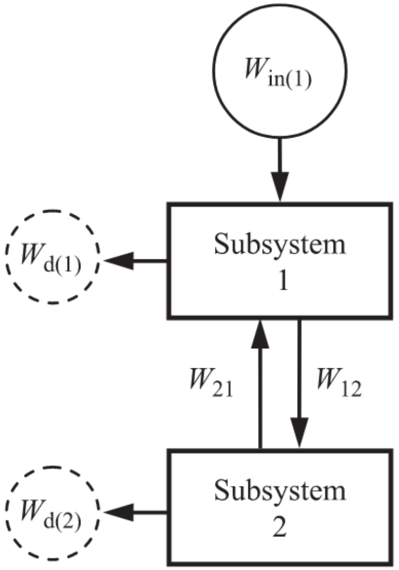
Fahy, F. and Walker, J. eds., 2018. Advanced applications in acoustics, noise and vibration. CRC Press.

Prediction framework

- The prediction methodology is based on Statistical Energy Analysis (SEA).
- You might already be familiar with the concepts. A simplified SEA approach is utilised in Standard EN 12354 and implemented in software which predicts to this standard.
- Like K_{ij} terms within EN 12354, we concern ourselves with the passing of energy once between subsystems.



Source: BASTIAN (DataKustik GmbH) product literature.

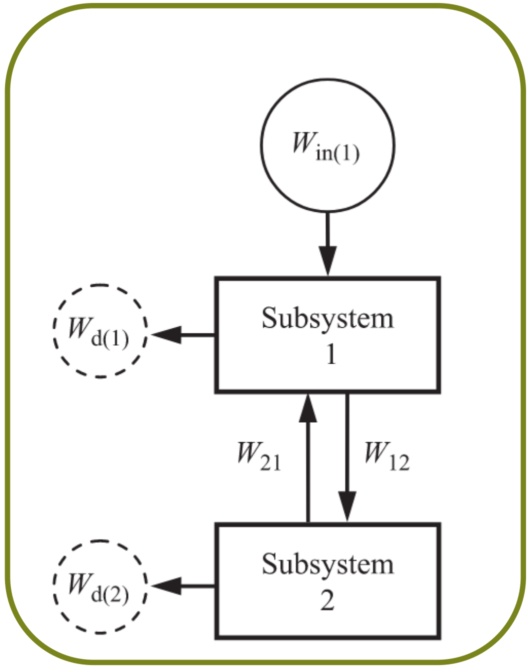


Source: Hopkins, C., 2012. Sound insulation. Routledge..

Prediction framework

- The SEA-based prediction in GAG is a 2 subsystem model, comprising floor under impact and receiving room below.
- Procedure is similar to that which can be used to predict tapping machine vibration (See Hopkins).
- Because of the limited number of subsystems, and the fact that we are considering the 1-way path from floor to receiver, this permits a relatively light calculation.

$$\begin{bmatrix} \sum_{n=1}^{N} \eta_{1n} & -\eta_{21} & -\eta_{31} & \cdots & -\eta_{N1} \\ -\eta_{12} & \sum_{n=1}^{N} \eta_{2n} & -\eta_{32} & & \\ -\eta_{13} & -\eta_{23} & \sum_{n=1}^{N} \eta_{3n} & & \\ \vdots & & & \ddots & \\ -\eta_{1N} & & & & \sum_{n=1}^{N} \eta_{Nn} \end{bmatrix} \begin{bmatrix} E_1 \\ E_2 \\ E_3 \\ \vdots \\ E_N \end{bmatrix} = \begin{bmatrix} \frac{W_{\mathrm{in}(1)}}{\omega} \\ \frac{W_{\mathrm{in}(2)}}{\omega} \\ \frac{W_{\mathrm{in}(3)}}{\omega} \\ \vdots \\ \frac{W_{\mathrm{in}(N)}}{\omega} \end{bmatrix}$$



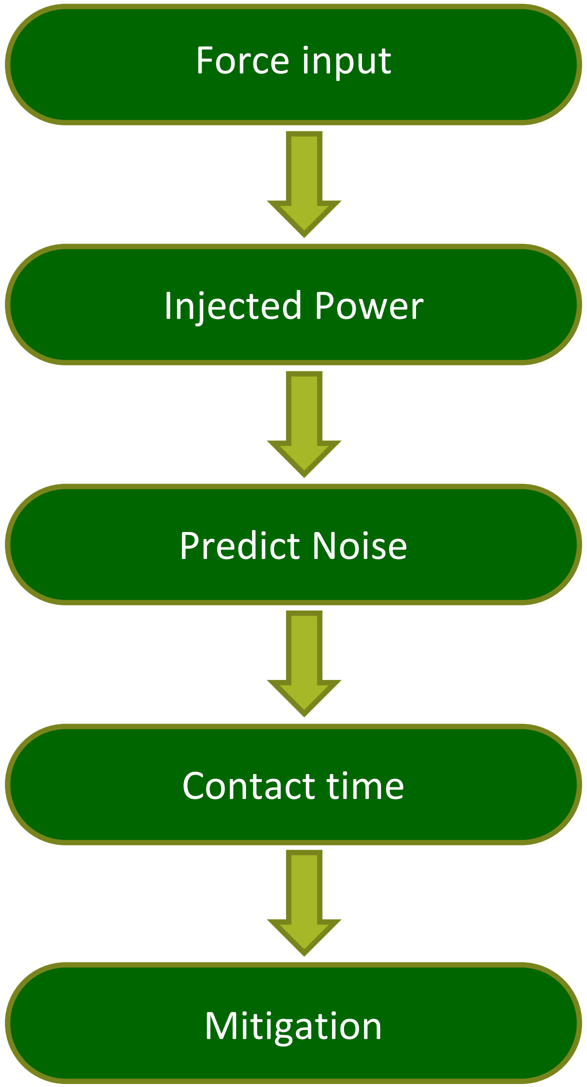
Source: Hopkins, C., 2012. Sound insulation. Routledge..

Factors affecting transmission

- Mass of impactor (free-weight/dumbbell/barbell).
- Radius of weight impacting upon the surface (contact area).
- Weight drop height.
- Contact stiffness of the floor covering.
- Mass and dimensions of the floating and structural floor.
- Damping.
- Room acoustics.
- Properties of any floating floor system for mitigation purposes.
- Flanking structural (or airborne) transmission paths.

Prediction in 5 steps

- You can actually obtain a noise level output in Step 3, however, we need to make some corrections to better align predictions with real-world observation.
- By Step 4, the hard work is done, leaving only Step 5 to consider the reduction in noise level you would be expected to achieve via floating floor mitigation.
- The guidance is all you need and the document is presented in a way such that all variables are defined. No guesswork, just follow the steps!



Modal check

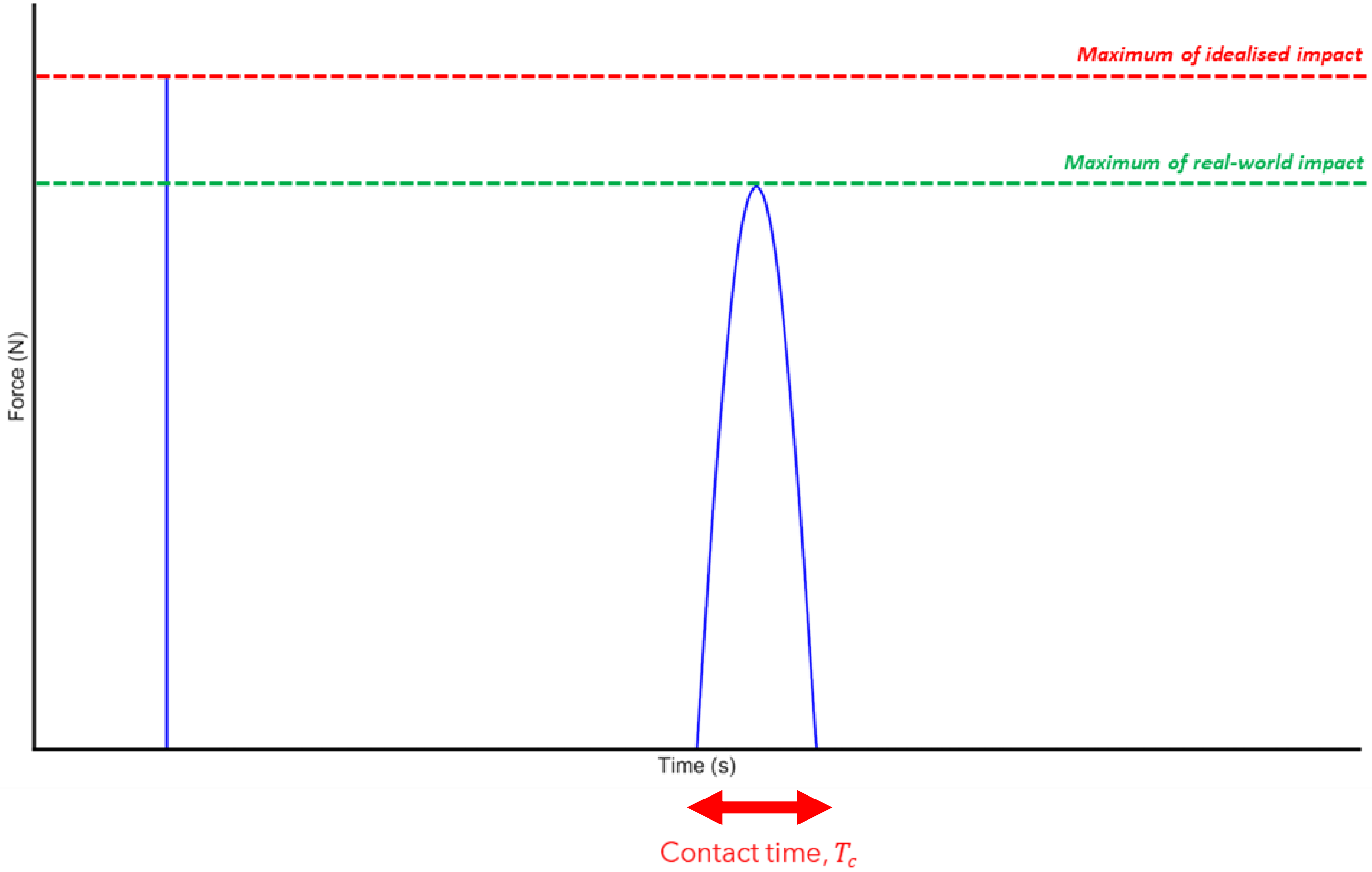
- SEA relies on modes in the system. No modes, implies no energy to flow between subsystems.
- Often referred to as a mid-high frequency method of calculation. What does that mean for floors and thuds from weight drops?
- Typically speaking, the fundamental mode of vibration in floors is lower than that which is in a room. This means sufficient modes in the floor usually exist in the lower regions of the audible spectrum. If the room has a modal overlap greater than 1, this is a good sign the model will provide reasonable results.
- The document sign posts other methods should the user wish to investigate further, as it is the case that other means of calculating modal overlap between connected subsystems is more reliable. For most purposes the method in the document should suffice.

$$M = f\eta n(f)$$

Modal overlap

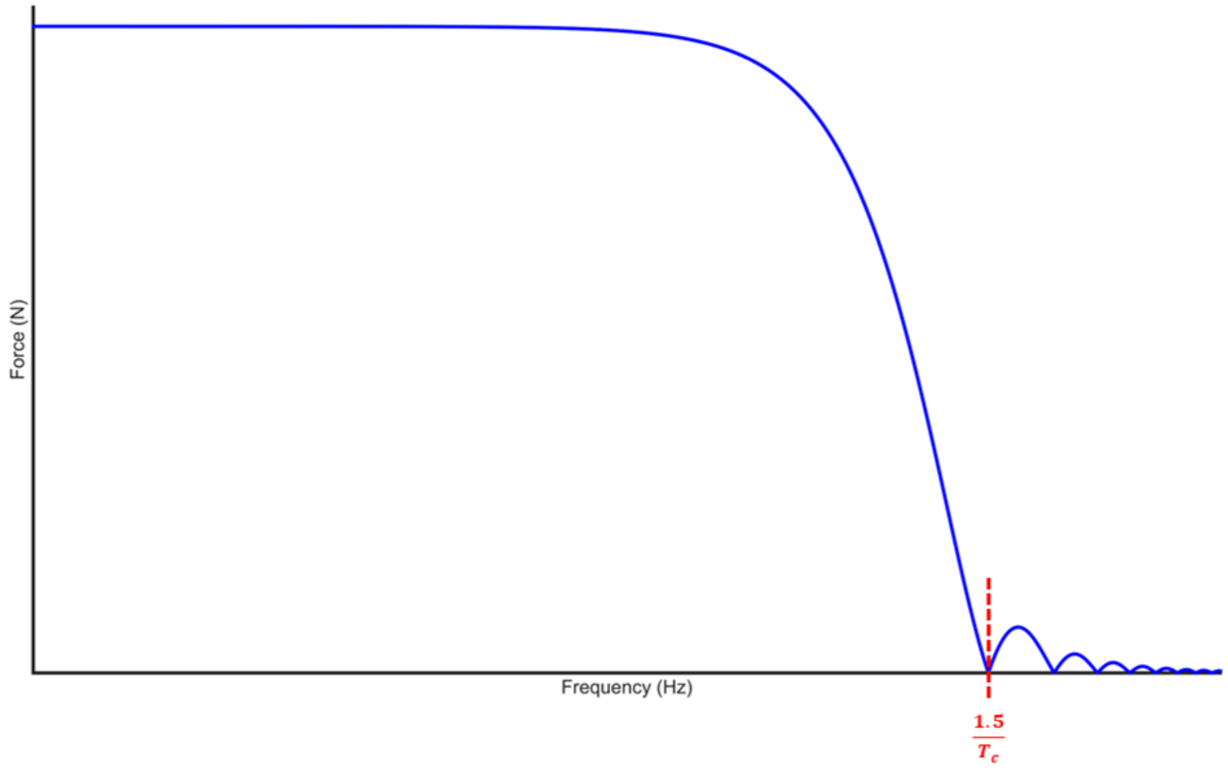
It all starts with a bang

- We initially impact assuming infinitesimally small contact time.
- In reality, the impact will occur over a contact time period, which we refer to as T_c.
- Making some assumptions as to how energy is conserved, by increasing the contact period, we increase the area under the Force vs Time curve.
- Peak response reduces. Impulse remains the same.



Frequency content

- The contact time no affects the force pulse in the time domain, but also the spectral content in the frequency domain.
- Shorter duration impacts have a broader frequency range (think tapping machine on concrete vs timber floors).The point at which high frequency content rolls off is related to the contact time.
- The frequency at which a significant degree of attenuation occurs can be estimated by the relationship $\frac{1.5}{T_c}$.

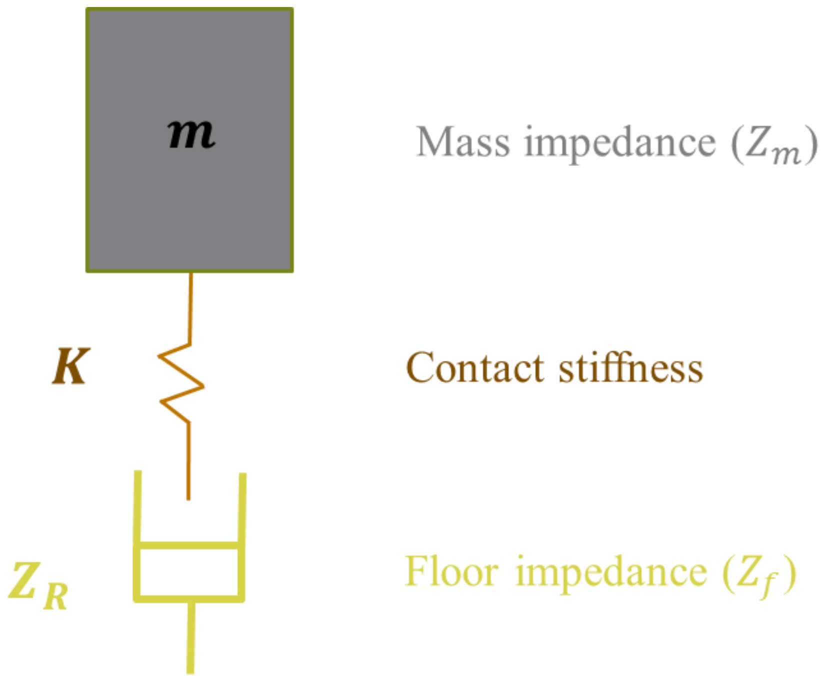


Impedance

- In step 2, we are required to determine the injected power into power injection into slab.
- The impedance of the falling object and the receiving floor influence the transmitted power. We can think of these impedances acting in series ($Z_{tot} = Z_f + Z_m$).
- From this, and terms defined for force, we derive the injected power by taking the real part of $\frac{1}{Z_{tot}}$.

$$W_{in} = F_{rms}^2 \, Re\left\{\frac{1}{(Z_f + Z_m)}\right\}$$

TIP: Excel has commands for complex values!



Impedance

Mobility

$$Y_s = \frac{v(j\omega)}{F(j\omega)}$$

Impedance

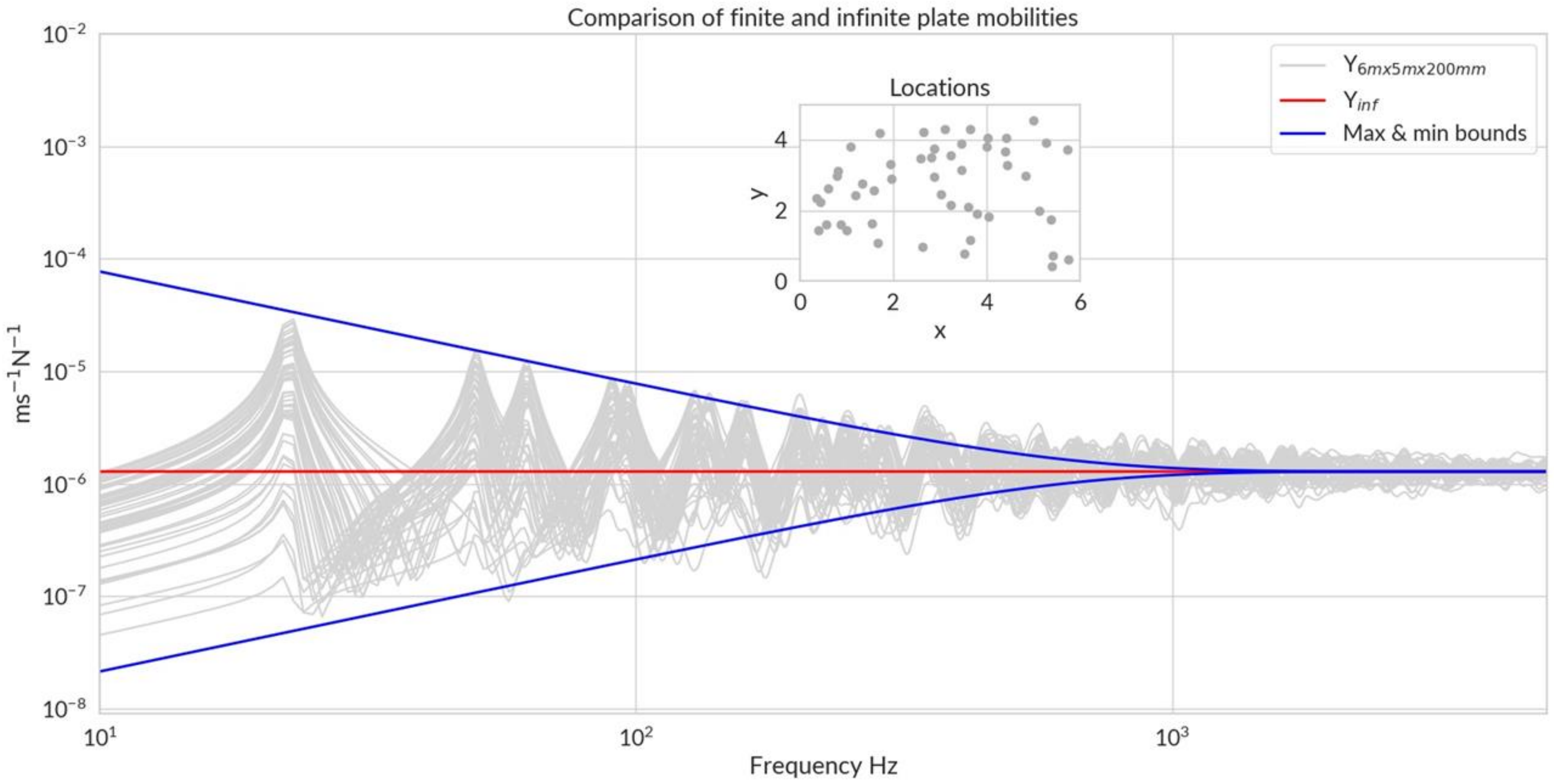
$$Z_s = \frac{F(j\omega)}{v(j\omega)}$$

Note:

Source & Receiver the same = ‘driving point mobility’

Source & Receiver different = ‘transfer mobility’

Impedance


Comparison of finite and infinite plate mobilities
$Y_{6mx5mx200mm}$
Y_{inf}
Max & min bounds
Locations
y
x
0
2
4
6
10^{-2}
10^{-3}
10^{-4}
10^{-5}
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$ms^{-1}N^{-1}$
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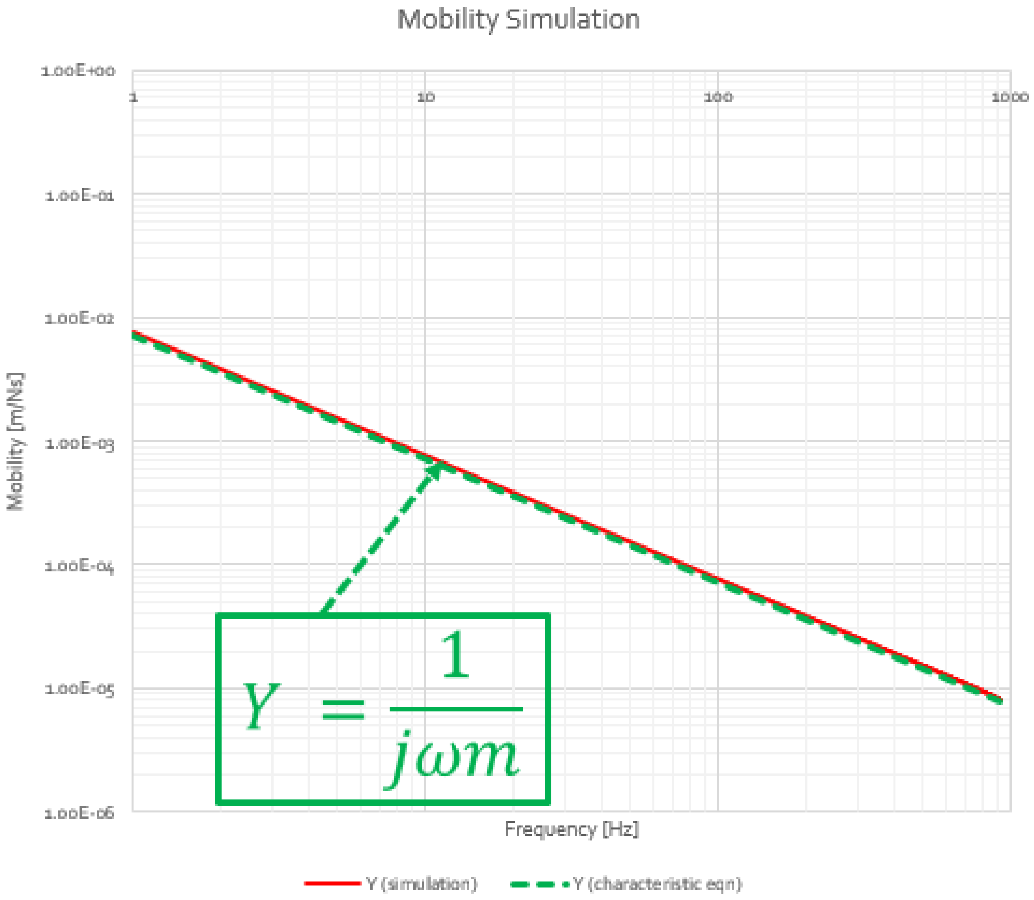
10^{3}
Frequency Hz

Impedance


Mobility Simulation
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1
10
100
1000
Mobility [m/Ns]
Frequency [Hz]
$Y = \frac{1}{j\omega m}$
Y (simulation)
Y (characteristic eqn)

Radiation

- In Step 3, we predict the noise in the room below the impact source. We do this using a 2 subsystem model with one-way coupling and some other rudimentary assumptions on flow. The energy in the room can be expressed as

$$E_2 = \frac{\eta_{12}}{\eta_1\,\eta_2}\frac{W_{in\{1\}}}{\omega}$$

- η_1 = total loss factor for the plate/floor, estimated as 0.01 + 1/√f for bending wave motion within concrete structures
- η_2 = total loss factor for the room
- η_{12} = is the plate-to-room coupling loss factor. → $\eta_{12} = \frac{\rho_0 c_0 \sigma}{\omega \rho_s}$
- The value σ is the value chosen for radiation efficiency.

Radiation

- In the GAG, a value $\sigma = 1$ is generally ok for practical purposes. Though some care is required.
- Those familiar with groundborne vibration may well be using similar assumptions without realising. The ANC redbook equation $L_p = L_v - 27$, assumes $\sigma = 1$ used when predicting groundborne noise from spatial average velocity.
- Other expressions and methods for predicting radiated noise and radiation efficiency can be sought if deemed necessary.

$$L_p = L_v - 27 + \xcancel{10log_{10}(\sigma)}$$

$$L_p = 10log(\sigma) + 6 + L_v - 10log\left(\frac{A}{S}\right)$$

For $f < f_c$:

$$\sigma = \frac{U}{2\pi\mu kS\sqrt{\mu^2 - 1}}\left[\ln\left(\frac{\mu + 1}{\mu - 1}\right) + \frac{2\mu}{\mu^2 - 1}\right]\left[C_{BC}C_{OB} - \mu^{-8}(C_{BC}C_{OB} - 1)\right]$$

For $f = f_c$:

$$\sigma \approx \left(0.5 - \frac{}{L_2}\right)\sqrt{k}\sqrt{L_1}$$

For $f > f_c$:

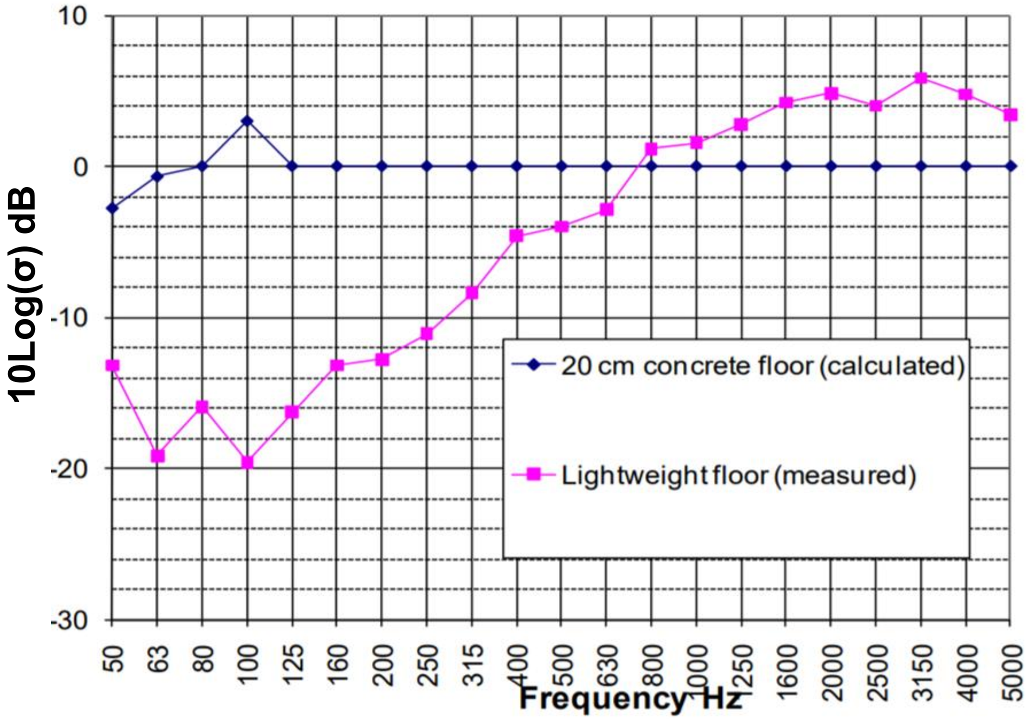
$$\sigma = \frac{}{\sqrt{1 - \mu^2}}$$

Radiation

“Procedures to predict exposure in buildings and estimate annoyance” (2012)

M. Villot, C. Guigou, P. Jean, N. Picard

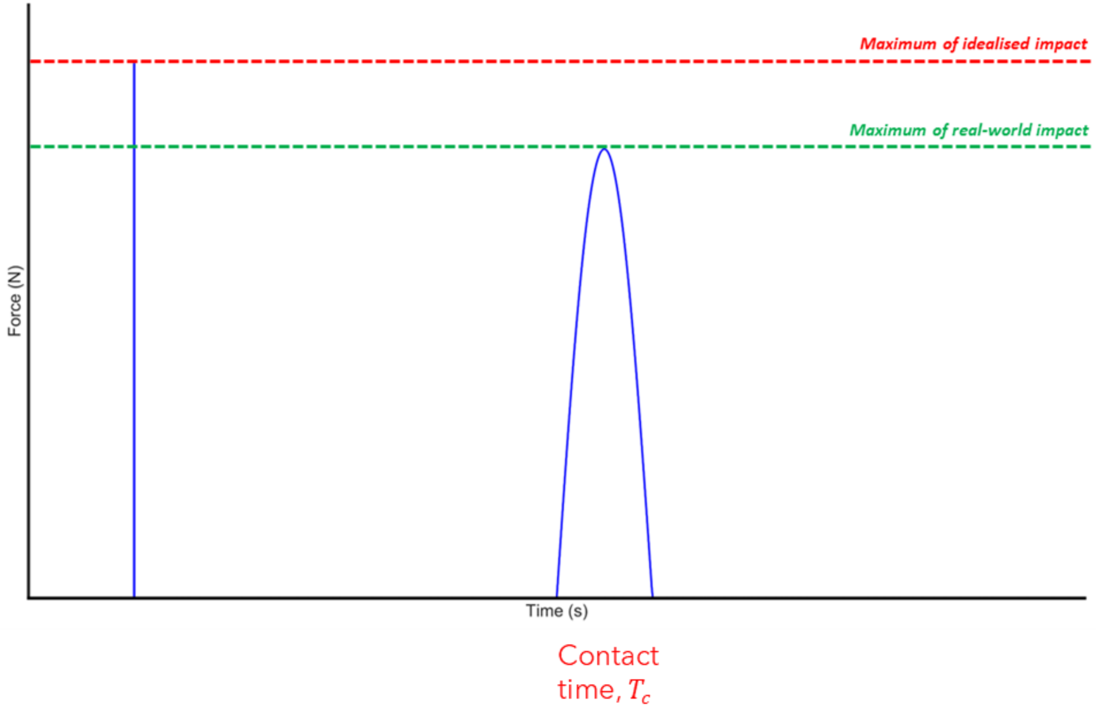
- In general terms, the radiation efficiency is equal to one **above its critical frequency** (f_c). As such, the value for σ is not the same for all materials. Below it, not much happens.
- Heavier materials/constructions tend to have a low f_c. This is partially why it has been accepted to assume radiation efficiency as 1 for groundborne noise assessments.
- The same cannot be assumed for lightweight constructions.



Corrections for contact time

- As we saw earlier, the contact time T_c will influence both the maximum observed force level in time and the spectral content in the frequency domain.
- If the force spectrum is not modified to account for the contact time, it will overestimate the sound pressure level significantly. We are also usually interested in a fast-weighted noise level L_{fmax} so we need to stretch the energy in the contact time period to 100ms, which serves as a reasonable estimator.

$$L_{Fmax(est)} = L_p + 10\log\left(\frac{Tc}{0.1}\right)$$



Corrections for transmission above/elsewhere

- Transmission to floors above is more difficult in an SEA framework owing to the growth of coupled subsystems.
- Spreadsheet packages likely to become cumbersome/impractical.
- Empirical corrections for floor to floor vibration may be used, though results can be highly variable depending on the size of floor/structural conditions.

$$\begin{bmatrix} \sum_{n=1}^{N}\eta_{1n} & -\eta_{21} & -\eta_{31} & \cdots & -\eta_{N1} \\ -\eta_{12} & \sum_{n=1}^{N}\eta_{2n} & -\eta_{32} & & \\ -\eta_{13} & -\eta_{23} & \sum_{n=1}^{N}\eta_{3n} & & \\ \vdots & & & \ddots & \\ -\eta_{1N} & & & & \sum_{n=1}^{N}\eta_{Nn} \end{bmatrix} \begin{bmatrix} E_1 \\ E_2 \\ E_3 \\ \vdots \\ E_N \end{bmatrix} = \begin{bmatrix} \frac{W_{\mathrm{in}(1)}}{\omega} \\ \frac{W_{\mathrm{in}(2)}}{\omega} \\ \frac{W_{\mathrm{in}(3)}}{\omega} \\ \vdots \\ \frac{W_{\mathrm{in}(N)}}{\omega} \end{bmatrix}$$

Mitigation

- Prediction is actually quite complex in reality due to dynamic effects, cavity resonances etc.
- Rarely achieve idealised mitigation scenarios (SDOF transmissibility for example).
- A general consensus through supplier discussions in the group.
- Leaves scope for suppliers to undertake R&D or provide evidence of betterment. Values are not set in stone.

Table 4: Typical performance estimates for various isolation systems

Isolation type	Typical system thickness mm	Typical capped-maximum[1] reduction in impact noise/vibration per octave/third-octave band dB[2]
Pad/Matting (multiple layers)	100-150	10-20
Pad/Matting with solid elements	150-190	30-35
Floating timber floors/sport floors	80-100	10-15
Floating concrete floors with matting to upper surface	200-350	30-40

Table 4 Notes:

1. *Values correspond to stated thickness ranges.*
2. *Values assume a concrete structural floor. Very thin or lightweight structures would be expected to have lower values than presented.*

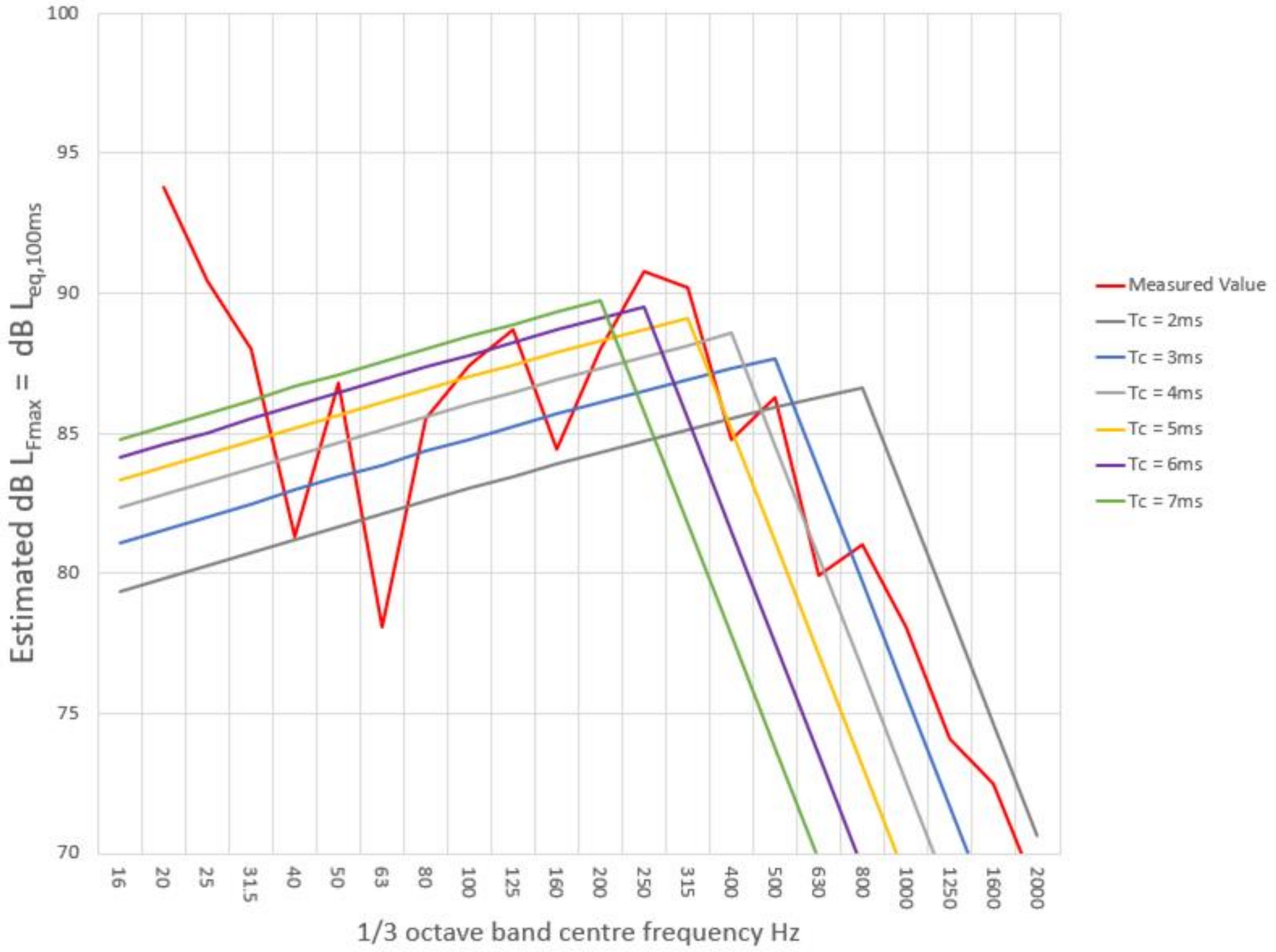
Case Studies

- Provided to give you confidence in the approach, and also something to benchmark against to check your working!
- Case studies were predicted blind before comparing to measurement data.
- Reiterate that the main purpose is investigate order of magnitude impact. Useful for feasibility studies and deciding what level of intervention may be required.

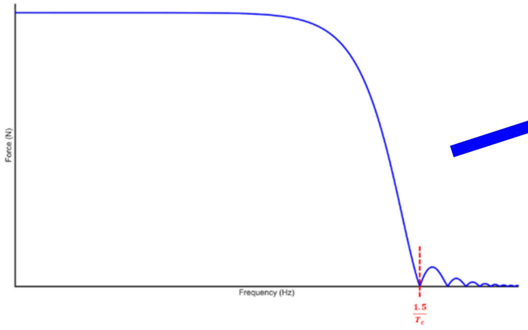
Table H5: Input parameters for prediction model

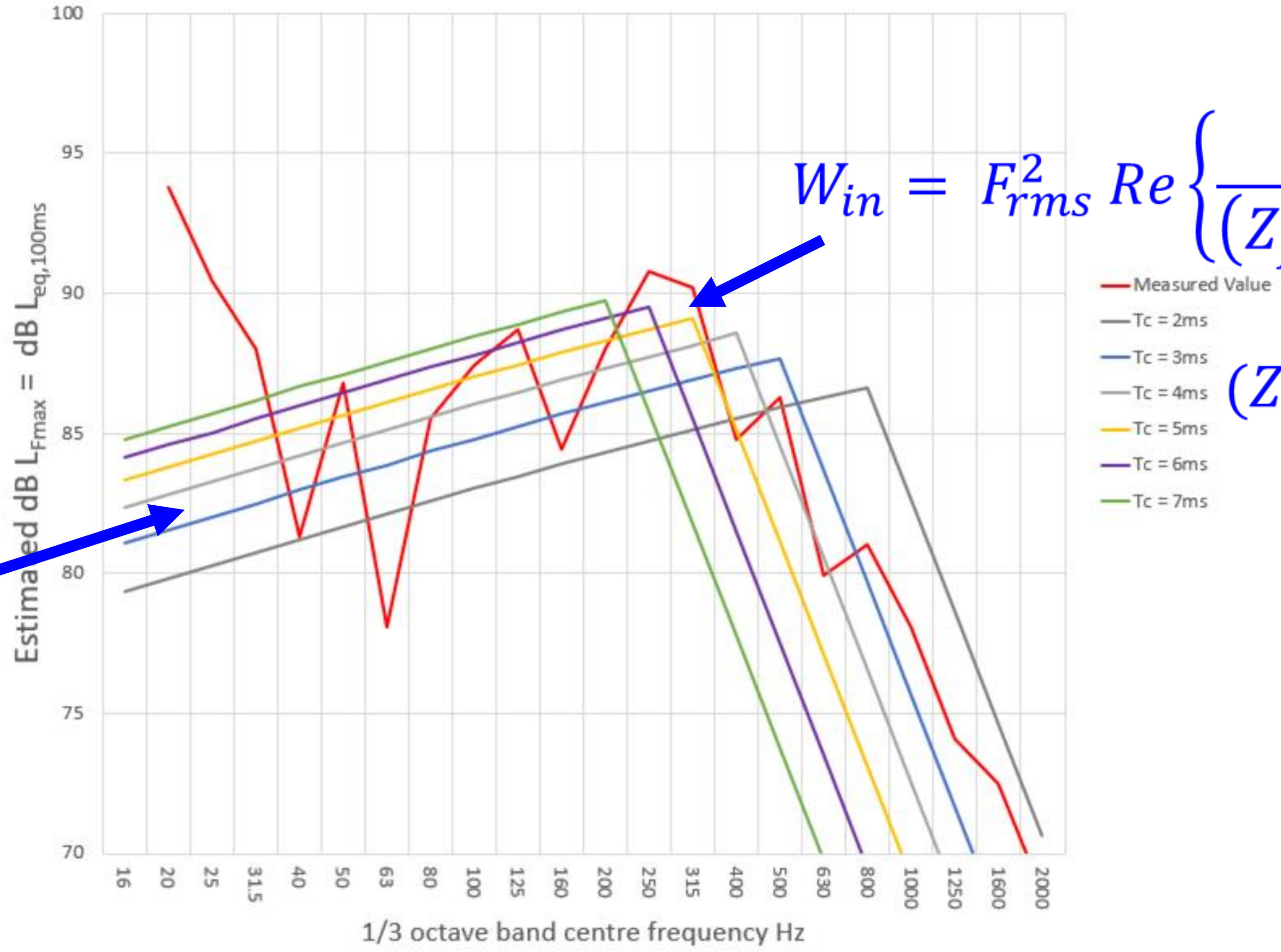
Step	Parameter Required	Value
1	Mass	35 kg/m³
	Drop height	1m
2	Floor density	2300kg
	Floor thickness	250mm
	Young's modulus	30x109N/mm
	Poisson ratio	0.2
3	Reverberation Time	0.6s (at each band)
	Speed of sound in air	343m/s
	Density of air	1.21kg/m³
	Radiation efficiency	1 (for all bands)
	Room volume	15
4	Contact time	2-7ms

Case Studies



Case Studies





$$W_{in} = F_{rms}^2 \, Re\left\{\frac{1}{(Z_f + Z_m)}\right\}$$

$$(Z_m = j\omega m)$$

Conclusion

- Prediction methodology is there to avoid costly issues or problematic designer/client/user issues down the line.
- When used correctly with knowledge of limitations, the user should have a good feel for the degree for the problem at hand.
- That said, measurements would still be preferable!