An in-depth analysis of the double bass to stage floor contact

by K Guettler, A Buen and A Askenfelt

Related documents:

Double Basses on the Stage Floor

On the interaction between double basses and the stage floor

AN IN-DEPTH ANALYSIS OF THE DOUBLE BASS-STAGE FLOOR CONTACT

K Guettler   Norwegian Academy of Music
A Buen   Brekke & Strand akustikk as
A Askenfelt   Dept. of Speech, Music and Hearing, Royal Institute of Technology (KTH)

1   ABSTRACT

While double bassists claim the importance of compliant floors for producing a warm and nuanced sound, the scarce research focusing on this topic has left few conclusions. In the mean time stage floors are constructed with great spread in design and conviction. In the present project floors of several halls were analysed, including the Oslo Concert Hall and Oslo's new Opera House. It was found that in the range where the double bass radiates poorly, i.e., below 100 Hz, and in particular below its Helmholtz resonance at ca 60 Hz, a favourable coupling can take place when the floor is compliant. In such cases the velocity transfer from the instrument's bridge to the floor (via the corpus and end pin) may often rise significantly above zero dB. The coupling, bass to floor, was also seen to affect the bridge mobility and thus the playing properties of the instrument. In the same frequency range the power transfer was observed to boost from about 3 to 40%. It remains to investigate how noticeable this effect is to the audience. Our measurements indicate, however, that a coupling to the stage floor can make an audible difference to the player.

2   INTRODUCTION

2.1   Method of Measurements

In this study floors of three concert halls, one orchestra-rehearsal hall, and one orchestra pit were analyzed with respect to their potential for being set in vibrations by a double bass through its endpin in the frequency range below 100 Hz. By use of force hammers and accelerometers their impedances were measured at the most and least mobile spots, normally between- and on joists, respectively.

The endpin impedances of three double basses, a small, a big, and an even larger one (the latter a 5-string bass) were measured in a similar way, utilizing a small adapter attached the endpin to ensure clean hits with the force hammer, while the instrument was laying down on foam rubber. For the two smaller basses, two different adapters were used in order to compare angled impacts (30° with respect to the endpin) to inline ones. Apart from small shifts in resonance frequencies, the impedance trends in magnitude and phase remained the same at both angles, implying that sitting vs. standing does not make much of a difference as far as transmission is concerned—at least when the end pin is stiff and not drawn out too far. In the 5-string bass the bridge impedance was also measured while the instrument was: (1) lying down on foam rubber, (2) standing on a small plywood plate resting on a thick foam-rubber cushion, (3) standing directly on the floor. In the lowest register it could be seen that the bridge impedance varied with the foundation.

Recordings were also done with a condenser studio microphone BK 4003 placed in the hall and on the podium of BwH (see below). Likewise, in order to acquire more information about radiation from the stage/pit-floors LiH and NOOP, measurements were done systematically over a number of seats in the audience with an impact machine drumming on the floors—on and between joists, respectively.

2.2 The Halls

The halls, although all reasonably new, differ quite significantly with respect to construction and acoustical properties.

The Berwald Hall (BwH) of Stockholm, opened 1979, with 1300 audience seats, was designed with the philosophy that the stage floor should be as rigid as possible: The entire wooden floor (Muninga) was glued onto bedrock with hot asphalt. This arrangement was perceived as unsatisfying by the musicians, however, not only for the bassists, but for the entire orchestra. The bassists complained about lack of response and nuances, which made it exhausting to play. After some years (in 1995) it was decided to rebuild parts of the stage floor. Sections, including those where the basses are positioned, were replaced by lifts constructed with wooden tops (Muninga) sealed to steel plates. No particular damping in the cavity below. This was unanimously perceived as a great improvement. Floor measurements were done at the old (bedrock) part and the on the lift.

The Oslo Concert Hall (OCH), opened 1977, with 1404 audience seats in front of the stage and 212 behind, is designed with lifts in the centre and rear of the stage, but not where the basses normally are seated: on the right wing, as seen from the audience. This wing floor should have been build with a small cavity below, but the cavity was dropped for architectural, to our knowledge not acoustical, reasons. Instead the parquet flooring (Merbau) was fastened to plywood, which was glued with hot asphalt to the concrete floor. The paradoxical situation occurred that when the basses moved forward for repertory demanding smaller ensembles, they would enter one of the lifts, and the depth of the bass sound increased. Today, the bass group is normally placed on portable risers when seated on the wings, or on the rear lifts.

The Lindeman Hall (LiH), opened 1988, with 380 to 430 audience seats, part of the Norwegian Academy of Music, is quite successful with respect to supporting a warm double-bass sound, and, to our knowledge, has only been admired for its acoustical properties in the lower frequency range. The stage is smaller than the two mentioned above, but it accommodates well a fully-sized orchestra. The stage floor (22 mm Merbau parquet) is rather pliant, including the joists. Joists, 30 cm apart and resting on thin rubber blocks, hold the floor some 5-6 cm up from the concrete with the cavity in between well damped. Presently, the 20-years old, rather thin parquet needs replacement due to tongues and grooves wearing out. There are no lifts on this stage. The reverberation characteristics of LiH are adjustable by means of ceiling sections that can be opened.

The Norwegian Opera Rehearsal Hall (NORH), opened 2008, is a 6400 m^3 room with a floating floor for sound insulation. The floor is rather stiff, even between joists. Musicians are so far generally quite happy with the acoustics (which is adjustable within a reasonable range) although the bassists favour the acoustics of the orchestra pit due to its more pliant floor. Pitches with fundamental frequencies below 60 Hz do not seem well radiated from the basses, and the first author (who has practice as principal bass player both in the Oslo Philharmonic and the Norwegian Opera Orchestra) has experienced confusion in this hall about which octave is actually being played by the basses. The parquet is 22 mm Oregon pine on 25 mm birch plywood. Randomly separated joists (to avoid resonances) are resting on concrete and placed between 40 and 60 cm apart, with no damping in between.

The Norwegian Opera Orchestra Pit (NOOP), opened 2008. The hall has 1340 seats. The entire pit floor is mounted on a three-piece hydraulic lift. Bassists are quite happy with the playing conditions in the pit, where the floor appears "lively". In spite of this, for the audience pitches with fundamental frequencies below 60 Hz do not seem well radiated from the basses. In general, however, the overall acoustics appears balanced, and the balance between the stage and the orchestra seems exemplary. (These subjective statements are based on only one pit-floor position of several possible). Joists (200 $\times$ 95 mm, and resting on steel beams) are mounted quasi-randomly with as much as 160 mm separation in average (and extra non-touching joists in between to prepare for heavy loads). The floor is a 45 mm laminate. There is no particular damping.

3   IMPEDANCES AND TRANSFER FUNCTIONS

3.1   Impedances of the Double Basses at their End Pins

Figure 1 shows the end-pin impedances of the three double basses (small 4-string, large 4-string, and large 5-string). The end pins were impacted in line with their axes. However, angling the impacts 30° gave very similar results. The phase diagram shows that the basses were predominantly seen as mass (in the vicinity of +90°) up 80 Hz or higher.
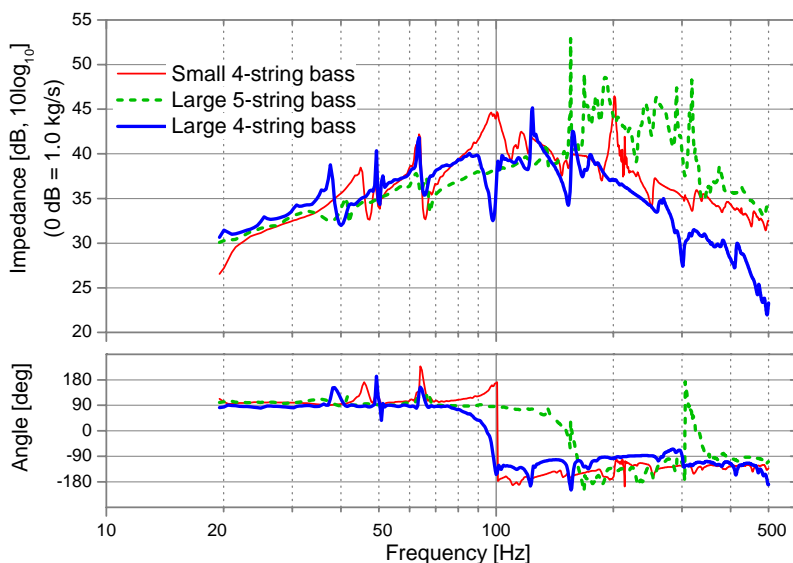

Figure 1: Impedances of the three double basses. The magnitude is in average increasing from approx. 1000 kg/s (30 dB) at 20 Hz to 10000 kg/s (40 dB) at 100 Hz. The average phase is near +100° in the same region, i.e., predominantly mass.

3.2   Impedances of the Floors

In order to compare floor impedances of the five different floors it is convenient to separate the most pliant sections of each floor from the most rigid ones. The most pliant sections were all found between joists (on the stage-/pit lifts of BwH, OCH, and NOOP), while the most rigid sections were found on the parquet glued to bedrock (the old floor of BwH), on the parquet fastened to plywood and glued onto concrete (the stage wings of OCH), or simply on the joists (LiH, NORH, and NOOP).

As we shall see, the velocity transfer between the bass and the floor is particularly good where their respective impedance magnitudes match. Below this frequency, the transfer function is rapidly falling, while above it more or less stays constant up to approx. 200 Hz. Notice the frequencies, at which the bass impedance matches the floor impedance, and see the corresponding peaks in the transfer functions of next section (Figures 4 and 5). The heights of these peaks are related to the phase properties of the two impedances. That is, the closer the floor's impedance phase is to the bass impedance phase minus 180°, the higher the peaks become. Hence, to the extend that the floor's phase is a controllable parameter in this frequency region, it is probably a good idea to keep it slightly lower than the pure-spring phase at –90°. (The pliant floor section of LiH, which shows the smoothest transfer function in our investigation, has a phase angle of approx. –115° near the impedance magnitude match point at 46 Hz.)
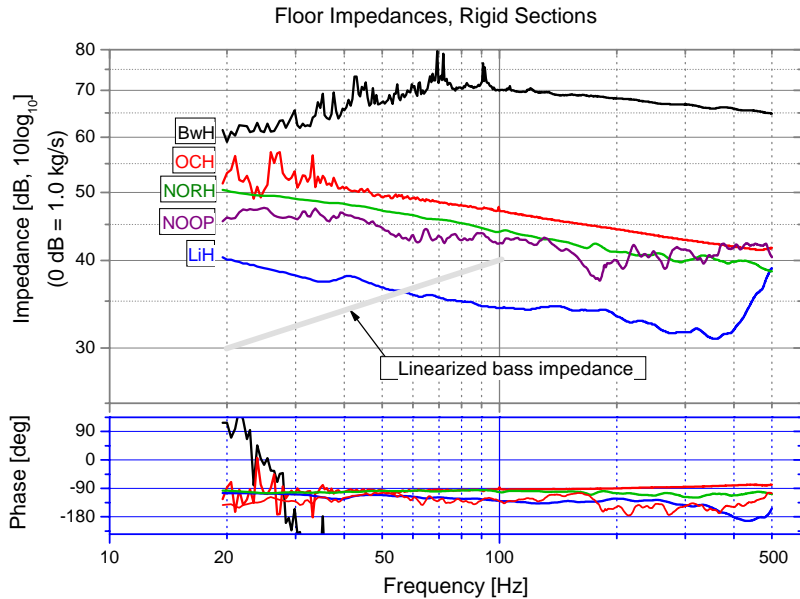
Floor Impedances, Rigid Sections

Figure 2: Impedances of the rigid floor sections (NORH, NOOP, and LiH on the joists, while BwH/OCH on bedrock/concrete). The linearized double-bass impedance is superimposed in gray for comparison. Notice that LiH is the only floor, which impedance magnitude crosses the bass impedance within the range 20 to 100 Hz. With the exception of BwH, the phases are mostly in the range −90 to −120° below 100 Hz.
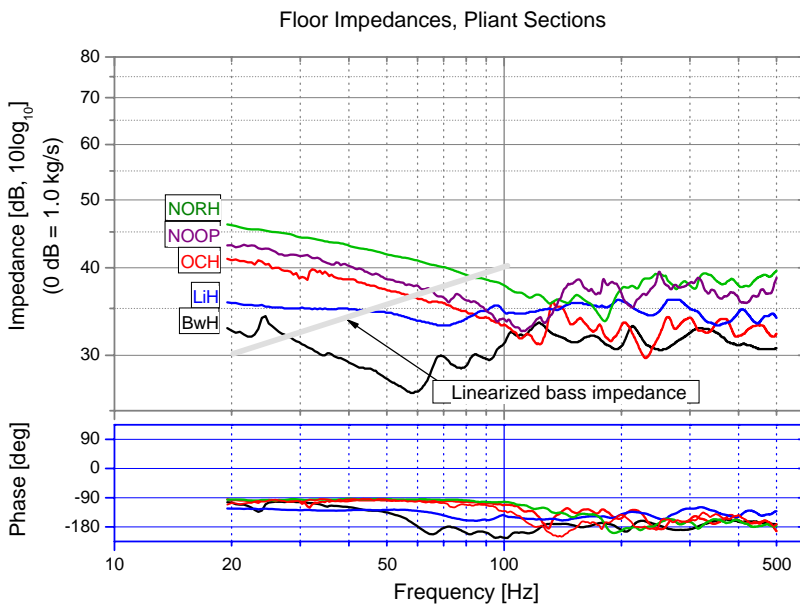
Floor Impedances, Pliant Sections

Figure 3: Impedances of the pliant floor sections (between joists). NOOP, OCH, and BwH have these sections placed on lifts. The superimposed double-bass impedance crosses all floor impedances within the 20 to 100 Hz range.

3.3   The Bass End-Pin to Floor Transfer Functions

The velocity transfer function, bass end pin to floor, is simply calculated as function of their respective complex impedances:

$$H = \frac{v_{FLOOR}}{v_{BASS\_CORPUS}} = \frac{z_{END\_PIN}}{z_{END\_PIN} + z_{FLOOR}} \tag{1}$$

This builds on the presumption that the end pin stays in contact with the floor as if it were glued onto it within the frequency range of interest. Our measurements indicate that this is a fair simplification, at least when the floor is compliant.

The plots of Figures 4 and 5 show transfer functions calculated from the measured end-pin impedance of the big bass and the respective floor impedances. With the exception of LiH, there is only limited transmission to the rigid floor sections. Transmissions to the pliant floor sections are

significantly better, but, as is seen in Figure 5, the different halls produce different roll-off frequencies at the transmission's low end, dependent on where the end-pin impedance curve crosses the floor's impedance curve.
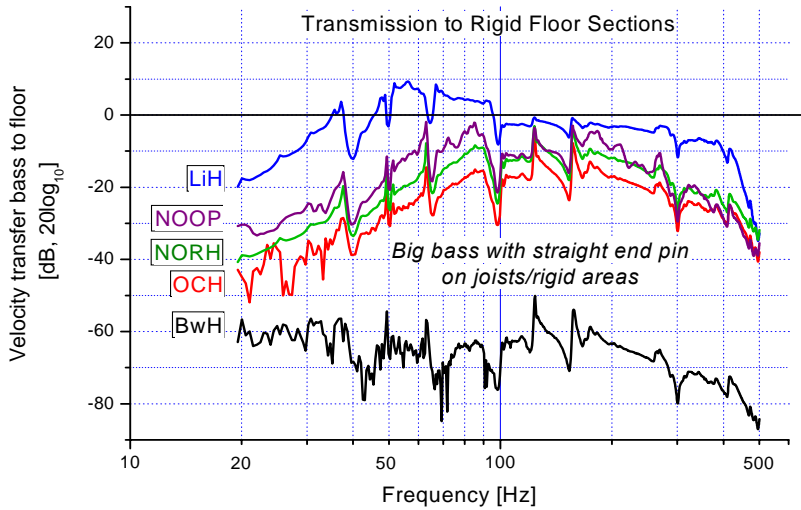

Figure 4: Velocity transmission from the big 4-string bass to the rigid floor sections (NORH, NOOP, and LiH on the joists, while for BwH/OCH the most rigid sections are found on bedrock/concrete). Only LiH, with joists on rubber blocks, show significant transfer in the region below 60 Hz.
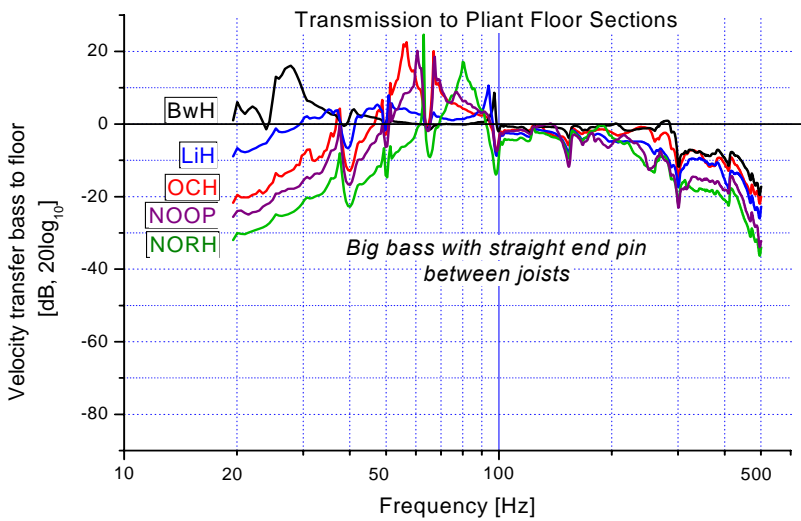

Figure 5: Velocity transmission of the big 4-string bass to the pliant floor sections (between joists). NOOP, OCH, and BwH have these sections placed on undamped lifts. Both BwH and LiH show excellent transmission down to 30 Hz. OCH, NOOP, and NORH, roll off at 35, 48, and 60, respectively Major peaks are found at 56, 60, and 80 Hz for the same floors. In the region 100 to above 200 Hz the transmission is relatively good for all pliant floors.

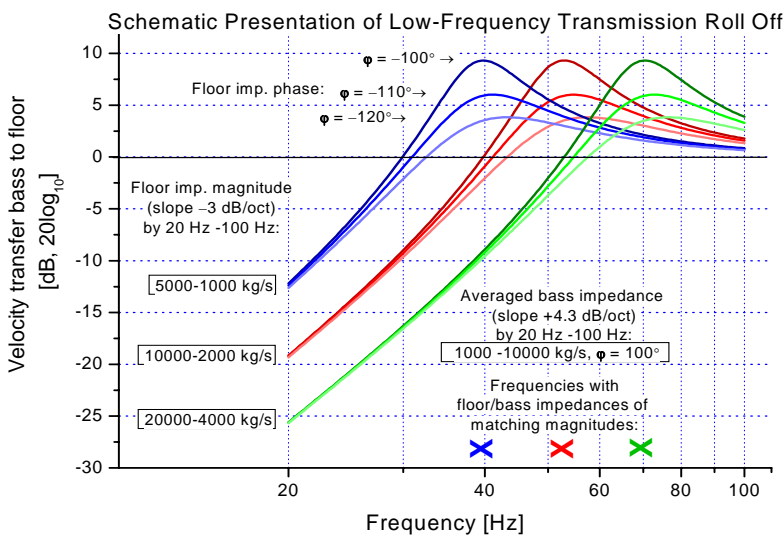Figure 6: Schematic calculations of transmission roll offs at low frequencies. In this plot three arbitrarily chosen floor impedances are linear within the log-log plane. These are falling −3 dB per octave and cross the above-mentioned linearized end-pin imp. at 39, 52, and 69 Hz, respectively (indicated by x-es in the plot). Peaks of different heights result from floor-impedance phases of −100, to −110 and −120°, respectively.

Similarly, the floor's damping influences the height of the peak just above roll-off frequency. Of the three halls LiH has the greatest damping (as well as a low impedance), and hence the smoothest transfer below 100 Hz.

We found it interesting to calculate the transfer in terms of power. The measurements and calculations were performed in the following way: The big-5-string bass was used in the BwH at the pliant section. First, the instrument's bridge impedance was found by use of a force hammer and accelerometer on the low-string side of the bridge. Then a chromatic scale was played loudly (f – 2.2 seconds each note) from B_0 through A_2, during which time accelerometers were fastened to the bass bridge and to the floor near the end pin, respectively. These signals were integrated and split into to phase-correct octave/3-bands by use of forward and backwards 4th-order Butterworth filtering. Utilizing the bridge signal, maximum RMS over a time window of 0.5 second was located for each band, and the corresponding power values calculated using the equations below.

$$P_{\text{BRIDGE}} = \text{RMS}\left(v_{\text{BRIDGE}}\right)^2 \text{Re}\left(z_{\text{BRIDGE}}\right), \quad \text{and } P_{\text{FLOOR}} = \text{RMS}\left(v_{\text{FLOOR}}\right)^2 \text{Re}\left(z_{\text{FLOOR}}\right), \tag{2}$$

where v is the frequency - filtered, time - dependent velocity, and

z is the averaged impedance of the frequency band in question.

The results are shown in Table 1:

Table 1: Bass-to-floor transmission			
Mid frequency [Hz]	Power (input) at bridge [mW]	Power transmitted to floor [mW]	Percent of power transmitted [%]
20	1.07	.38	35.8
25	7.43	1.58	21.3
31	12.31	4.88	39.7
40	49.33	4.86	9.8
50	111.49	2.89	2.6
63	218.86	5.59	2.6
80	298.79	2.99	1.0
100	328.78	4.14	1.3

As we remember from Figure 5, the velocity transfer of in BwH is remarkably good in the range 20 to 40 Hz. This is reflected in the relative power transmission shown in the rightmost column of Table 1, which displays values between 20 and 40 % in this range. On the other side, in terms of absolute power transmitted to the floor the values are no more than 5-6 mW within the instrument's lowest octave (31 to 62 Hz).

3.4   Effect of Floor Properties on Bridge Impedance

The foundation, on which the bass is resting, plays a role in determining the instrument's playing properties, which is shown in Figure 7. Here the bridge mobility of the 5-string bass was measured in BwH under four different conditions[*]: (1) with the bass standing on the pliant floor section, (2) standing on the old bedrock floor section (3), standing on a small plywood plate cushioned by thick foam rubber, (4) lying sideways down on thick foam rubber with the endpin free. As opposed to the frequency region 100 to 500 Hz, the foundation clearly affects the bridge impedance in the region below. (Earlier measurements have also shown effects in some regions above 500 Hz). As should be well known, the damping of the string, and thus the playing properties are closely related to the bridge impedance.

---

[*] Impedances 1, 3, and 4 were measured in one recording session, while impedance 2 was *calculated* from the ratios between bridge impedances measured on the old floor and the pliant floor half a year later. This procedure was required since the bass bridge in the meantime had experienced a minor impedance shift.
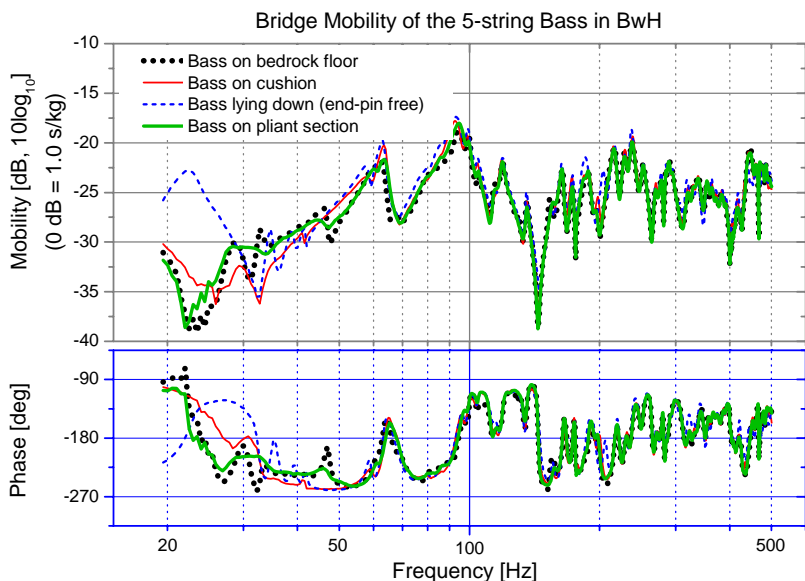
Figure 7: Bridge mobility of the 5-string bass when resting on different types of foundation. Noticeable differences occur in the range 20 to 100 Hz. The string's damping is a function of these values, and the loss at bridge varies nearly proportionally with the bridge mobility. The string's damping is directly related to the playing properties of the instrument.

3.5   Sound Levels in the Hall

The big remaining question is, of course, how much of the bass' low-frequency energy is transmitted to the audience in the hall. The plots of Figure 8 are kind of disappointing in that respect. By use of a force hammer and microphone the ratios between sound pressure and excitation force were measured in BwH with the bass (a) standing on the pliant floor section, and (b) insulated from it by use of the pad arrangement described above. Two microphone positions were utilized: (1) in the hall's first row, some seven meters away from the bass, (2) on the podium, at a point comparable to the position of the player's head.
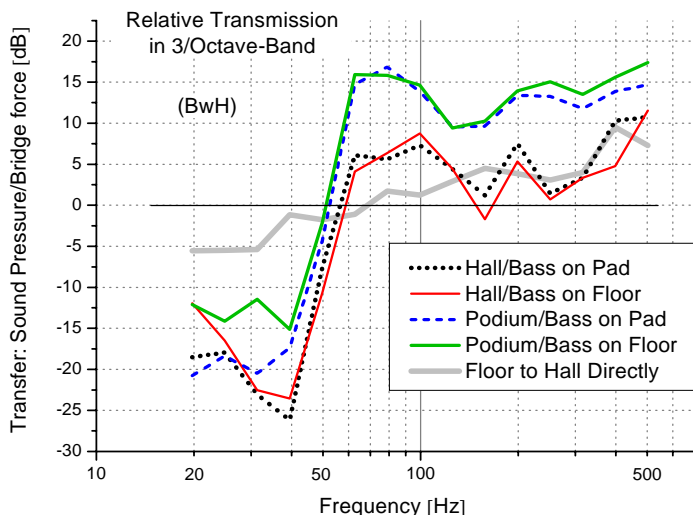

Figure 8: Relative transmission in BwH from bridge force to sound pressure in oct/3-bands. A certain boost in the range 20 to 40 Hz is seen on the podium when the bass is in contact with the floor. The boost is less apparent in the hall. In all cases the transmission is rather week below 50 Hz. (For reference, the gray curve indicates direct transmission from the pliant floor to the hall.)

Figure 9 shows radiation from the floor of NOOP and LiH as excited by an impact machine drumming *on* and *between* joists, respectively. Levels are averaged over the entire audience areas. LiH, which might be the preferable radiator or lower frequencies in this study, shows somewhat higher relative radiation in the frequency range 50 to 90 Hz.

(To the discussion on to what extent a pliant podium would absorb energy in the low-frequency range, Sabine calculations show that in two halls with volumes 8000 and 24000 m^3, a pliant stage floor of 150 m^2 with absorption coefficient, $\alpha = 0.25$ would shorten the reverberation times with some 92 and 32 ms, respectively, which is practically inaudible, as compared to stage floors with an absorption coefficient, $\alpha = 0.04$.)
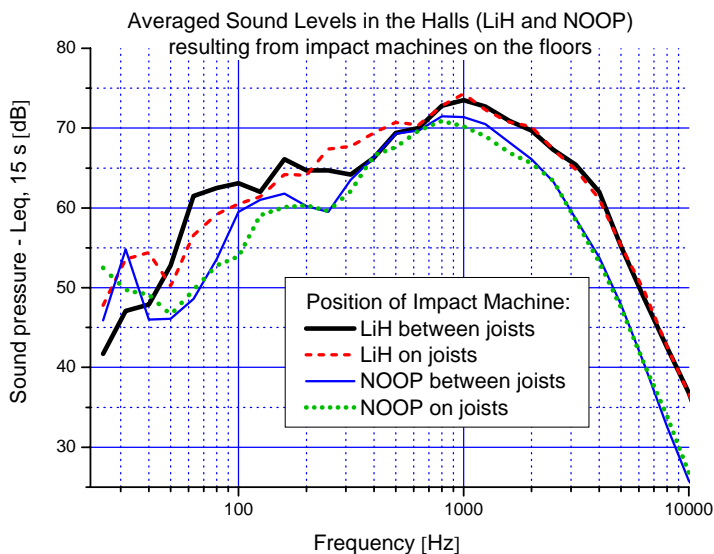
Figure 9: Averaged sound levels in the Norwegian Opera and the Lindeman Hall. Compared to the opera hall LiH shows somewhat stronger relative radiation below 100 Hz, particularly between joists.

Tables 2 and 3 below show some properties of floors of NORH and NOOP. The calculation methods as well as tables for the other halls are found in: K. Guettler, Askenfelt, A.., and Buen, A.. "Double basses on the stage floor" Proc. ISMA'07 (2007), Barcelona

Table 2: Norwegian Opera Rehearsal Hall (NORH) On/Between Joists							
Freq. band [Hz]	Decay$_{-60dB}$ [ms]		Loss factor		Impedance magn. [kg/s]		phase [degrees]	
20	243	257	.458	.433	102509	37832	−98	−96
25	179	220	.494	.402	89079	32297	−104	−98
31	133	170	.527	.411	76217	25522	−103	−96
40	115	131	.484	.426	65049	20220	−102	−95
50	95	100	.464	.443	52371	15383	−98	−95
63	74	87	.474	.405	41095	11596	−98	−96
80	61	86	.455	.324	33427	8307	−97	−99
100	48	70	.458	.317	25562	5883	−98	−105
125	39	128	.446	.137	20508	4145	−100	−126
160	33	133	.419	.105	16418	3695	−103	−144

Table 3: Norwegian Opera Orchestra Pit (NOOP) On/Between Joists							
Freq. band [Hz]	Decay$_{-60dB}$ [ms]		Loss factor		Impedance magn. [kg/s]		phase [degrees]	
20	714	417	.156	.267	42714	19866	−144	−108
25	1390	383	.064	.231	49419	17128	−129	−101
31	1365	181	.051	.388	44485	13783	−130	−99
40	361	144	.154	.387	41431	10465	−121	−96
50	1069	187	.041	.236	28413	7360	−108	−97
63	925	140	.038	.251	20913	5231	−125	−102
80	356	130	.078	.214	20403	3932	−132	−113
100	257	147	.086	.150	19493	2325	−128	−129
125	134	155	.131	.113	17927	2588	−121	+169
160	167	152	.083	.092	10447	5663	−111	−178

4   CONCLUSION

Our work with this study has convinced us that the matter of low-frequency radiation—as well as perception—is a very complex problem with no easily-found answers. The fundamental frequencies of pitches around B_0 to D_1 (31 to 37 Hz) may never be heard by the audience in any of the halls investigated here. Yet there are great differences in how these pitches are perceived and experienced at the different venues. At the present stage in our ongoing study we feel need of some supplementary perceptional tests to establish what exactly could provide this difference, if not the fundamental frequencies. From the players' point of view, however, the vibrating floor makes such a difference in practical playing that it would seem arrogant to ignore their preference in lack of an acoustical explanation.