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LOW FREQUENCY IMPACT SOUND TRANSMISSION THROUGH FLOOR SYSTEMS

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There has long been dissatisfaction with the standard tapping machine test [1,2]. It provides, at best, a mediocre prediction of user satisfaction when used to rate wood-joist and similar lightweight constructions. Walkers on such floors generate relatively high levels of sound at low frequencies not considered by the current rating systems. The work described here studied the properties of a tire impact machine that was being considered as a possible new standardized impactor for use in North America. Impact sound levels generated by a small automobile tire and wheel were compared with levels from other devices.

Transmission of impact sound was measured through 75 different floor structures: five wood joist or truss structures and one 15 cm thick concrete slab. Each basic structure was tested with three types of floating floor, a carpet and a carpet and underpad on top. Some other wood joist structures were included in the program although they were not tested with the floating floors on top.

Four different impact devices were used: 1) a modified version of a tire/wheel constructed to make measurements according to the JIS standard [3]; 2) the standard ASTM/ISO tapping machine; 3) a human walker; and 4) a device developed for research at NRC. Only two of these impactors can be seriously considered for an improved test: the ISO machine and the tire machine. There is too much variation between walkers and no practical hope of standardization of the footstep impact. Within a laboratory, however, tests using the same walker with the same shoes each time provide a reference to the most common source of impact sound in buildings. Although they correlate very well with the walker results, results from the NRC impact device are not presented here. In its present form it is too complex for widespread use.

Measurement of impact sound transmission with the ISO machine followed standard procedures [1,2], but the frequency range was extended to 50 Hz. The upper room at NRC is the source room and has a volume of 120 m^3. The lower room, the receiving room, has a volume of 65 m^3. The floor opening measures 2.44×2.44 m.

When measuring peak sound pressure levels generated by the Tire machine and the walker, sound absorbing material placed in the receiving room reduced the reverberant field there. A microphone 1 m from the underside of the ceiling was connected to a Nortronics 830 real-time analyzer set to have a 35 ms time constant. It recorded the maximum levels during a time of 1 second and sent them to a computer. Ten peak readings in the one-third octave bands from 25 to 6300 Hz were taken at five positions of the impactor on the floor.

The impact force of the tire machine specified in JIS 1418 was judged to be too great, and it was reduced to 2.9 kN for this work. Note also that the measurement procedures described in the previous paragraph are not the same as those specified in that standard.

The male walker weighed about 83 kg during these tests and walked in a random pattern on the floor. The same pair of medium-weight, leather-soled shoes was worn for each test; the heels had a hard rubber tip.

TYPICAL RESULTS FROM IMPACT DEVICES

To give some familiarity with the characteristics of the different impactors and the kinds of spectra measured on different floors, some typical results are now presented. Figure 1 shows the impact sound pressure levels generated on a bare concrete slab. Some points to note are:

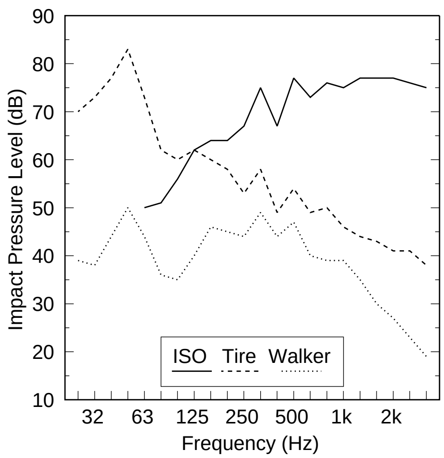

Figure 1: Impact sound pressure levels for a bare 150 mm concrete slab for the ISO machine, the tire machine and the walker.

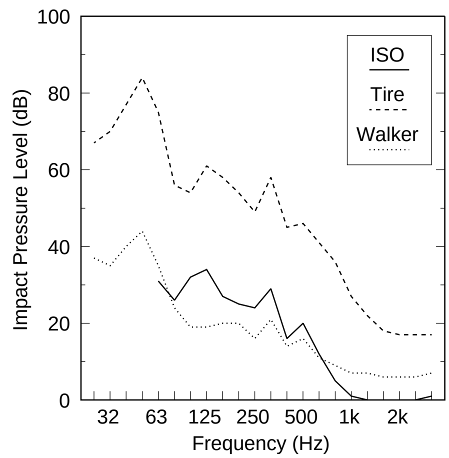

Figure 2. Impact sound pressure levels for a 150 mm concrete slab covered with a carpet and foam underpad.

- The spectrum for the tire shows a peak at 50 Hz and falls steadily as the frequency increases. There is relatively less energy at the middle and high frequencies than there is in the walker spectrum.
- The ISO machine spectrum increases with frequency to reach a plateau about 500 Hz. This is quite different from the other impactors although the spectrum is roughly parallel to the walker spectrum up to 500 Hz.

Figure 2 shows results for the same slab with a carpet and underpad placed on top. Now all the curves are roughly parallel but the ISO machine is deficient at frequencies below about 100 Hz.

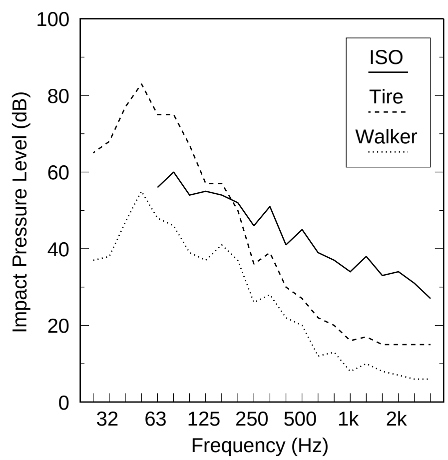

Figure 3: Impact sound pressure levels for a 150 mm concrete slab with a 40 mm slab of concrete floating on top.

These two figures alone give some insight into the problems with the ISO machine test and the impact insulation class (IIC)[4]. In Fig. 1, the IIC of 25 is determined by the levels around 3150 Hz. Even with fairly hard-heeled shoes, the walker does not generate significant sound energy there. When the carpet and underpad is added to the floor, the ISO machine spectrum changes drastically and the IIC increases to 86 — a 61 dB improvement. In comparison, the walker levels around 500 Hz drop by only about 25 dB; at 50 Hz, the level drops just 8 dB. It is not encouraging to see that the tire levels are almost exactly the same below 500 Hz; the tire machine underpredicts while the ISO machine overpredicts the effectiveness of carpet and underpad.

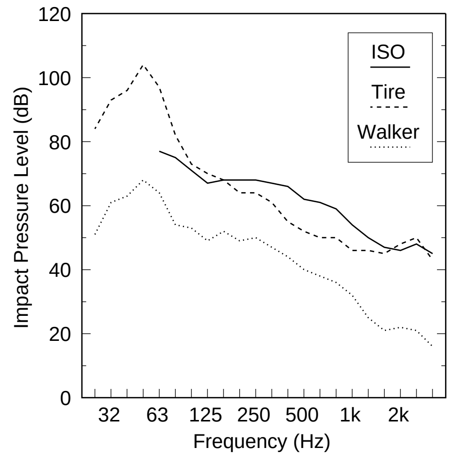

Figure 4: Impact sound pressure levels for a bare 300 mm wood truss floor.

Figure 3 shows results for the concrete slab with a floating floor on top. This comprised a 40 mm slab of concrete resting on 21 mm thick neoprene pads with a Fiberglas AF331 blanket beneath the slab. The tire machine spectrum has more low-frequency energy relative to the mid-frequencies than the walker spectrum. The ISO machine spectrum, although quite parallel to the walker over most of the plot, does not have as much low frequency sound relative to the mid-frequencies.

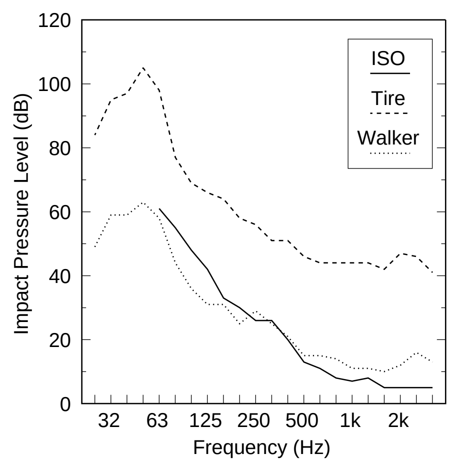

Figure 5: Impact sound pressure levels for a 300 mm wood truss floor covered with a carpet and foam underpad.

Figures 4 and 5 show results for a wood truss floor system. This floor had 16 mm plywood screwed to 300 mm wood trusses. 13 mm resilient channels were attached to the underside of the trusses and supported 16 mm gypsumboard. A layer of glass fiber 215 mm thick was placed in the cavity.

With this floor system, the tire machine and the walker give the same low-frequency results whether the floor is carpeted or not. The carpet and underpad do reduce walker levels at higher frequencies. In contrast, the ISO machine levels are reduced at all frequencies by the carpet and underpad, but more so at the higher frequencies. The tire machine in this case agrees better with the walker while the ISO machine overpredicts the effectiveness of carpet and underpad.

These figures are only isolated cases but they suggest that footstep noise is a primarily a low-frequency problem. The only case where high- frequency sound was significant was for the ISO machine with the bare concrete slab. Floating floors or carpets reduced high frequencies so they did not influence the impact insulation class. In most cases, the major transmission of sound energy was at low-frequencies, below 100 Hz. The current single-number ratings [4,5] which heavily penalize bare, hard-surfaced floors at frequencies around 2500 Hz and ignore frequencies below 100 Hz do not appear appropriate.

ANALYSIS OF DATA

Even if the spectrum shapes for two different impactors are different, the changes in level in each frequency band may be the same when different floors are tested. There are theoretical reasons why this should not be so, but, in practice, the variations may be acceptable. So, the correlations between the one-third octave band sound levels for the walker and those generated by the tire machine and the ISO machine were calculated.

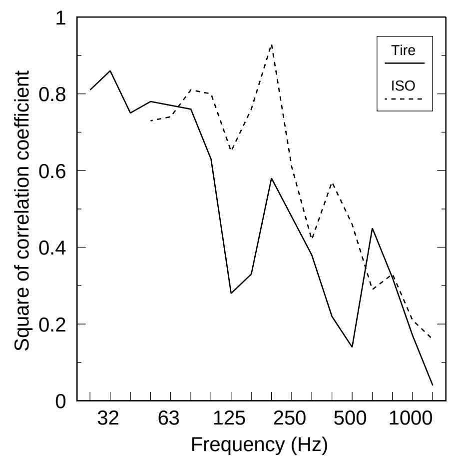

Figure 6: Square of correlation coefficient for each frequency for the Tire machine and the ISO machine. Carpeted and uncarpeted floors.

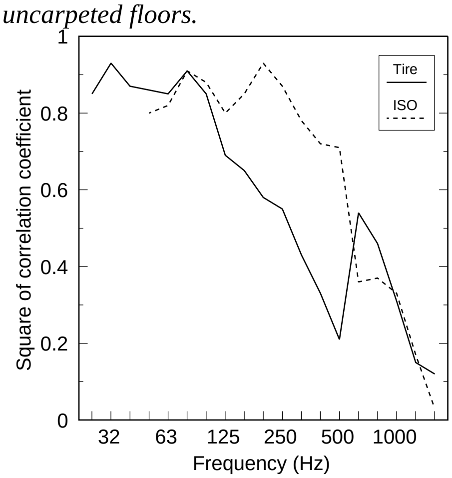

Figure 7: Square of correlation coefficient for each frequency for the Tire machine and the ISO machine. Uncarpeted floors

Figure 6 plots the square of the correlation coefficient for each frequency. Only data where the walker sound levels were at least 10 dB above background noise were used. Much of the data collected at high frequencies was contaminated by background noise, so the frequency range is limited to 1250 Hz.

The figure shows that the tire results correlate well with the walker from 25 to about 100 Hz but not so well above that frequency. The poor correlation around 500 Hz arises because the walker wore shoes; these cause a characteristic bump in the impact spectrum around 500 Hz.

It is perhaps surprising, but the ISO machine correlates quite well from 50 to about 250 Hz. This suggests that the ISO machine can be used to predict walker levels fairly accurately.

All correlations improved slightly when only uncarpeted floors were considered in the analysis (see Fig.7).

<u>Correlations Between Single Number Ratings.</u> Initially, the single number ratings used were based on established national and international standards: the impact insulation class (IIC), A-weighted levels and a slight modification of the single number rating used in the Japanese test. This was called tire impact class (TIC). The A-weighted level was calculated by the analyzer using all measured frequency bands.

The IIC ratings for the ISO machine, correlate poorly with IIC ratings for the walker (r^2 = 0.37). Neither do they correlate well with other walker ratings calculated.

A-weighted levels for the tire and the ISO machine correlated poorly with those for the walker (r^2 = 0.17, 0.07, respectively); this is due to the de-emphasis of the low-frequencies by the A-weighting filter and to spectral differences at the higher frequencies; these were automatically included in calculations by the analyzer.

The TIC ratings for the tire machine do not correlate well with those for the walker because of spectral differences around 500 Hz (r^2 = 0.41). These arise because of the pulses from the shoe heel. In many cases, TIC for the tire was determined by the levels around 50 Hz while TIC for the walker was determined by the levels around 500 Hz.

Thus, despite the fairly good correlation in individual frequency bands, none of these single number ratings correlate well with the walker ratings. They will therefore not predict walker levels or user satisfaction very well.

Possible New Single Number Ratings. Other researchers have considered alternative single number rating systems for use with the ISO machine. This work considered among others, loudness, C-weighted levels, the unweighted, or flat level, a rating similar to one proposed by Bodlund [6] and here called BIC (Bodlund impact class), and a straight-line rating as proposed by Fasold [7]. Calculations were restricted to the frequency range from 50 to 500 Hz. Above that frequency much of the walker data was lost in background noise, and as pointed out above, the high-frequencies were not important relative to the low frequencies.

The good correlations between the ISO machine and the walker one-third octave levels suggest that if the spectra from the ISO machine were treated differently, the single number ratings calculated would correlate better with walker ratings. To derive a weighting spectrum, the difference between the mean spectra for walker and ISO machine tests was calculated. Differences were rounded to the nearest 5 dB. This weighting was needed only at the lower frequencies. In the bands from 50 to 100 Hz, the weighting factors were 15, 15, 10, and 5. Once these values were added to the measured ISO machine spectra, new single number ratings were calculated for them. Other weightings were investigated but gave no significant improvement.

The correlations are shown in Table 1for all floors tested and for floors without carpets. Ratings calculated for the weighted ISO spectra are in the columns headed ISO_W.

Table 1: Correlations, r^2, with walker single number ratings. A linear fit was assumed.

	All 75 floors, including carpet			51 Floors, without carpets		
	ISO	Tire	ISO_w	ISO	Tire	ISO_w
Loudness	0.54	0.61	0.82	0.69	0.78	0.84
Flat	0.62	0.76	0.81	0.59	0.87	0.78
C	0.61	0.76	0.82	0.60	0.87	0.79
BIC	0.69	0.76	0.81	0.65	0.87	0.74
Fasold	0.65	0.73	0.84	0.66	0.81	0.78

Examination of this table shows that the ratings calculated from the unweighted spectra from the ISO machine do not correlate as well with those from the walker data as do the tire ratings. This is true for the complete set of data and for the set restricted to floors without carpets. For the tire machine, the ratings correlate well with the walker ratings; the correlation improves when only uncarpeted floors are considered. The weighted ISO machine spectra give ratings that correlate quite well with the walker ratings for carpeted and uncarpeted floors.

Possible New Test Procedure. On the basis of correlations alone, one might choose the tire machine for evaluating floor systems, especially if ratings are only applied to uncarpeted floors. There are, however, other considerations.

- The tire machine is expensive. Tires could be dropped manually but this decreases the precision of the test and makes field measurement more difficult.
- The blows from the tire are rather violent even with the reduced impact force used in this work. This makes the tire machine less attractive for use in furnished homes.
- Many laboratories and consultants already have ISO machines. A new test procedure based on the present machine would present little technical hardship.

The differences between the correlation coefficients for the alternative ISO machine ratings and those for the tire machine are not very significant unless only bare floors are considered. If the ISO machine spectra are weighted as was done here, then the ISO machine performs well.

Considering these factors, it appears that there is no need to introduce a new standardized test based on a tire drop. The ISO machine can be used to make measurements to lower frequencies and a more appropriate single number rating can be developed.

Bodlund came to a similar conclusion. He did not find, however, that it was necessary to increase the weighting of the ISO machine levels below 100 Hz. This set of data was obtained in one laboratory only and with one floor size. Almost all of the floors tested had peak transmission around 50 Hz. Floors in homes may not show the same peak around 50 Hz. This might explain the difference between Bodlund's findings and the results here. Further research work is needed to address this issue.

REFERENCES

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2. ISO 140/VI — Measurement of Sound Insulation in Buildings and of Building Elements — Part VI: Laboratory Measurements of Impact Sound Insulation of Floors.
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