ARCHIEF

A NEW SYSTEM FOR RATING IMPACT SOUND INSULATION

E. Gerretsen

Technisch Physische Dienst TNO-TH
(Institute of Applied Physics),
Delft (Netherlands)

SUMMARY

The rating of impact sound insulation on the basis of tapping machine measurements with the ISO-reference values has proven to be unsatisfactory in practice. This is mainly due to the differences in spectrum shape of tapping machine noise and real life impact noises, such as walking. The problem can be solved by changing the reference values in accordance with these differences in spectrum shape. The difference betwee tapping and walking noise spectra has been established by measurements on 49 different floors. In the most important frequency range (125 - 500 Hz) it turned out to be sufficiently constant for all floor constructions cosidered.
Thus a new set of reference values has been derived, based on the assumption that the NR-curves provide a correct subjective rating system for walking noise.

Furthermore, due account has been given to the different frequency content at higher frequencies of other impact noises than male walking, such as female walking, jumping children, moving of furniture etc..

INTRODUCTION

Impact sound insulation is an important problem in dwellings This is especially so since nowadays the desired sound insulation is often the determining factor for the floorconstructions to be applied; other criteria (e.g. strength) can easily be met with modern light-weight floors.
Practical experience shows however that the usual method of rating the impact sound insulation is not very satisfactory. This method, based on measurements with the ISO tapping machine and a comparison with reference values, results in a ranking of floorconstructions which is not in accordance with subjective judgements. This leads to an unneccessary application of expensive floorconstructions and materials on the one hand, and to the rejection of subjectively good constructions on the other hand. Furthermore, the subjective improvement in impact sound insulation caused by using thin, resilient floor coverings (such as felt) is far less than the improvement as suggested by the current rating method. An example of this effect is given in figure 1.
For a bare concrete floor and the same floor with linoleum on felt both the tapping machine sound spectra and the walking sound spectra are shown.

When one compares the tapping machine spectra with the (Dutch) reference curve (see Appendix A) it is seen that for the bare floor the resulting negative insulation-index is determined by the 2000 Hz octave band level. With the floor covering in place the spectrum is drastically changed; at 2000 Hz the level is much lower. The index is now determined by the 250 and 500 Hz octave band levels, in which bands however the floor covering has very little effect. The index-reduction is thus caused exclusively by the effect at 2000 Hz.

When one compares the walking sound spectra with a noise rating curve, one sees that the NR-numbers in both cases are determined by the 250 and 500 Hz octave band levels. Consequently only a small improvement by the floor covering is expected on the basis of these walking noise measurements.

Experiences of this kind have lead to a research programme, aimed at a better rating system for impact sound insulation. The research work has been carried out along the following lines of questioning:

- what kind of impact noise source represents adequately the common impact noises in dwellings?
- by which method is this, probably impulsive, sound to be measured?
- in which way can the sound levels of the representative impact source best be judged in order to yield the annoyance of impact noise?
- could the ISO tapping machine, either modified or via a revised rating of its spectra, be used as the standard measuring impact sound source?

A REPRESENTATIVE IMPACT SOUND SOURCE

Both from literature [1, 2] and own measurements the spectra of common impact noises have been gathered (figure 2). It is reasonable to assume that walking is the most frequent impact noise source. Moreover, the frequency characteristic for the combination of male and female walking (taking the maxima of the two in each frequency band) is a fairly good average of the other spectra.

It seems therefore justified to consider this combination of male and female walking as the representative impact sound source.

In this context male walking is taken to be walking on regular shoes with rubber heels and leather soles, whereas female walking is on high heeled shoes. It has been found from walking experiments that female walking gives higher levels only in the octave bands with center frequencies 1000 and 2000 Hz, the differences on the average being 5 and 10 dB respectively. Therefore it seems acceptable to consider only male walking in the further experiments and to take account of the females at a later stage.

THE MEASUREMENT OF WALKING SOUND

The sound of walking can be characterised as a short series of regular pulses with a repetition frequency of about 2 Hz. Therefore it cannot be considered as a continuous sound.

This means that the loudness of walking is not only determined by the strength of the pulses but also by the integration constant of the hearing system, the pulsetime, the repetition frequency and the rise and decay times of both the floor and the receiving room.
For the integration constant of the ear Neise [3] has reported a value of 23 ms, whereas Port [4] gives 70 ms.
By taking the average of the mentioned values we can regard the ear as a measuring system with an integration time of 50 ms. An equivalent of such a system is the Brüel & Kjaer level recorder at a writing speed of 800 dB/s.
Especially at low frequencies however it is impossible to use this writing speed because of overshoot problems. Therefore a correction method is needed for recording at lower writing speeds.
For the common materials and floordimensions the rise and decay time of the construction is negligible compared with the rise and decay time of the receiving room, so only the latter one need to be considered.

In order to solve these problems - the correction for different writing speeds and the normalization to a standard reverberation time - comparison tests have been done with artificial walking sounds under different reverberation conditions. At the same time the levels have been registered with different writing speeds.

It followed that the reverberation time T should be taken into account by adding to the measured maximum levels a term:

$$6.8 \log T/0.5 \qquad (1)$$

when recordings are made at a writing speed of 800 dB/s. From the same analyses correction terms were deduced (to be added to the recorded level) for recording at other writing speeds than 800 dB/s, as a function of the reverberation time (figure 3).

Thus for impulsive sound with a repetition frequency of 2 Hz the loudness at standard conditions (here T = 0.5 s) can be derived by measuring the level with a recorder at a appropriate writing speed and applying corrections according to (1) and figure 3.

A check of this procedure showed that the octave levels derived by this method, are equal to the levels of random noise by which the walking sounds are just masked.

THE ANNOYANCE OF WALKING SOUNDS

A common and well-tried system for rating the annoyance of continuous noise is the Noise Rating system. If the annoyance of walking noise is a function of loudness, this NR-system can also be used for discontinuous sound, since according to Neise and Port [3,4] the frequency response of the ear is the same for impulsive as it is for continuous noise.

According to a Dutch inquiry [5] the percentage of people hearing their neighbours walking is much greater than the percentage who say to be annoyed by it. This implies that the loudness of walking is indeed important.
Watters [6] concludes from his research however, that walking is judged to be annoying whenever it can be heard, regardless of its relative loudness.
Thus there is no direct answer to the question whether the annoyance of walking is based on pure detectability or on the loudness (NR); it may very well be that the more critical a person's attitude towards (walking) noise the more his judgement shifts from one based on loudness to one based on detectability.

In order to be able to rate walking noise on detectability Watters measured background levels in dwellings during the evening period. These were ranked on the basis of their Speech Interference Level in order to take due account of the negative effect of background noise, i.e. the disturbing of (speech) communication. These curves are given in figure 4, together with two NR-curves, showing that the background curves do not flatten towards the high frequencies like the NR-curves, but do flatten at the low frequencies, in contrast with the NR-curves.

The difference at the higher frequencies is not very important since these frequencies are not dominant in walking noise; the low frequency difference can be very important however.

In order to check on this low frequency behaviour we made a subjective comparison test between two different floors.
One of these was a heavy concrete floor with a rather flat walking noise spectrum, the other a light weight construction with a floating floor where the low frequencies are dominant.
The background noise spectrum was similar to that found by Watters, so on the basis of his conclusion the heavy concrete floor should be judged better since the noise of walking on this floor will be more often masked by the background noise.
The results of our tests show quite the opposite; thus the conclusion must be that the rating at low frequencies should not be more severe than with the NR-system. We have therefore decided to use the NR-curves as basis for the rating of walking noise.

DO WE NEED AN ISO-WALKING MACHINE?

In the foregoing a representative impact sound source was derived and a way of measuring and rating the sound from this source in such a way that the subjective judgement of the impact sound insulation of floorconstructions can be estimated. This does not mean however that we have to follow this procedure for rating dwellings on their impact sound insulation.

It would even be desirable not to do it this way for two reasons. First the measuring method for actual walking noise is quite complicated. Furthermore measuring walking noise means always measuring in the vicinity of the background noise level, so that in a fairly noisy situation a good floor could not even be investigated at all. It would be desirable to use an impact sound source which creates higher noise levels of a more continuous character in order to facilitate measurements, like for instance the ISO tapping machine. For such a source reference values should than be deduced on the basis of the foregoing, which give the same rating of floor constructions as does the walking-noise-NR-system. Such a procedure would be much the same as is common for airborne sound where random noise at a high level is used in order to rate the insulation of a construction for softer sounds produced by the radio, TV or the human voice.

In case of impact sound however such a procedure gives rise to some problems which have to be discussed

Some kinds of floor coverings are known to behave non-linearly. This will obviously lead to varying results, depending on the characteristics of the source used.

But especially in these cases using a realistic source like walking is a fictitious solution since then one will encounter almost certainly measuring problems with respect to the background noise. A real solution seems unattainable. These cases are, however, of minor importance here: we are aiming at a rating system for dwellings, whose floors must meet the requirements without the help of soft floor coverings.

A floorconstruction that meets the requirements for impact sound only with a soft floor covering (carpet etc.) is not acceptable. As, moreover, these floor coverings will never worsen the situation, it is permissible to leave them out of consideration.

Another construction that may give rise to varying results is the floating floor. This is not primarily due to the noise source one uses, but depends on the accuracy with which the floating floor has been constructed. If the floor is not constructed faultlessly the measuring results will vary greatly, both with time as with excitation position, but they will do so for any impact noise source. In this case measurements should be used first of all to check on the accuracy of the construction. If this is shown to be insufficient it is useless to rate the floor at all; if not there is no reason to expect different results for different impact sound sources.
Thus, the tapping machine as standardized by ISO, can serve the purpose of rating dwellings with respect to impact sound insulation in a practical way. A new tapping machine which really imitates walking noise is not needed and is even undesirable, due to its low power level.

COMPARISON BETWEEN WALKING AND TAPPING MACHINE NOISE

As a next step 66 floors have been investigated in order to derive a rating system for tapping machine noise based upon the walking-noise-NR-system. The aim was of course to obtain a same subjective rank ordening of the floors with both systems. These floors were different in construction and/or covering; they have partly been tested in practice, partly in the laboratory.

For each floor both the tapping machine spectrum and the walking sound spectrum were measured. The walking tests were done with two testwalkers, whose spectra under the same floor are practically equal. In some cases also female walkers were used in order to establish accurately the difference between male and female walking.

For the walking tests as well as for the tapping tests the sound levels were normalized to a reverberation time of 0.5 s.

The floors are divided in three different groups:

- homogeneous floors, with or without covering.
- floors with a concrete floating floor
- floors with a wooden floating floor

A short description of the floors is given in Appendix B.

In two cases a floor was covered with a thick soft carpet; in fifteen cases it was found that floating floors were not properly constructed*. These seventeen floors have been left out of consideration in this chapter.

The difference in spectrum between walking and tapping, indicated as D, is given in figure 5, for the 49 floors combined and, for the three groups of floors, seperately.

This difference D can be used to derive a spectrum from the tapping machine spectrum which is equivalent to the walking spectrum. For this equivalent walking spectrum the NR-number can be determined (NRW_e) which is the counterpart of the NR-number directly obtained from the walking sound spectrum (NRW).

* as a criteria the slope of the tapping spectrum at high frequencies was chosen; if the level difference between 1000 and 2000 Hz is less than 5 dB the construction was considered to be inaccurate.

Obviously, one would get the best possible results when one would use the values for D appropriate for the construction of the floor in question. This is hardly practicable, however; it would mean different sets of rating curves for different floor construction types. On the other hand, using the mean value of D might give a rather large possible error. We derived a single set of D-values for the frequency bands concerned through the following reasoning.

1. For male walking, the NR-numbers of the walking spectra are nearly always determined by the 250 Hz and 500 Hz octave levels; in a few exceptions the 63 or 125 Hz octave levels were dominating (see figure 6).

   In these low frequency bands the values of D are nearly the same for all types of floor contruction: the spread around the average value is ± 5 dB (90% confidence range), only in the 63 Hz octave band greater deviations occur, but they are mainly caused by the smaller measuring accuracy in this band. Therefore, we took the average values for 63, 125, 250 and 500 Hz as the final values for D.

2. The octave bands 1000 Hz and 2000 Hz are not determinant for the NR-numbers of male walking spectra; they might be of some importance for other impact noises, especially in the case of homogeneous floors, which have the poorest impact sound insulating properties at high frequencies. For the 2000 Hz octave band, indeed, there are hardly any data for the other floor types: either the walking levels or the tapping levels or both were obscured by background noise. Therefore we retained the 2000 Hz value of D, found for the homogeneous floors as final value of D for that octave band.

3. For the 1000 Hz octave band, no clear arguments for a choice between either the average value or the value for the homogeneous floors can be given on the basis of the data presented here.
   The latter one might be too lenient, i.e. giving for some floors a too low indication about the expected impact noise levels; the former one was therefore chosen, resulting in a 6,5 dB more stringent value.

Thus one gets the weighted difference D_w for all floors as shown in table 1.
The values for D_w apply only to male walking as stated in paragraph 2. Corrections are to be introduced for high frequencies in view of female walking. The resulting values of (D_c) are found in table 1 also.

Table 1

Weighted difference and corrected values for walking compared with tapping

freq.	63	125	250	500	1000	2000	Hz
D_w	-0.7	+9.7	+12.8	+17.1	+26.3	+39.9	dB
D_c	-0.7	+9.7	+12.8	+17.1	+21.3	+28.9	dB

A regression analysis was carried out to check if, using the average or corrected difference gives as good an estimation of walking noise for all floors as does the use of the difference per group of floors. Compared are the NR-number for the walking spectrum (NRW) and the NR-numbers for the equivalent walking spectra (NRW_e) constructed from the tapping spectrum by subtracting resp. the differences D_{group}, D_w and D_c.
The results are presented in table 2.

Table 2

Results of the regression analysis

regression parameters	regression coefficient	spread (dB) (90% - confidence limits)
$NRW-NRW_e(D_{group})$	+0.86	±3.4
$NRW-NRW_e(D_w)$	+0.87	±3.8
$NRW-NRW_e(D_c)$	+0.87	±3.9

Compared with the best possible fit ($NRW_e(D_{group})$) the two other results can not be considered significantly worse. The regression coefficient is even better, while the spread is only enlarged by about 0.5 dB.

Thus the desired reference values for tapping machine spectra can be deduced by adding the corrected difference D_c to the appropriate NR-curve.

ABSOLUTE VALUES FOR RATING PURPOSES

The choice of a specific NR-curve as an acceptable limit to walking noise can be based on the inquiry in dwellings [5] about the annoyance by impact noise. This cannot be done directly, however, since no walking sound measurements were made in these particular dwellings.

The inquiries werd held in dwellings, devided into three groups according to the weight per surface unit of the applied homogeneous floors: approx. 300, 400 and 500 kg/m^2.

In these dwellings also tapping machine measurements were made.

Some of the results of the inquiry are given in table 3.

Table 3

Some results of the inquiry in dwellings [5]

weight of floor (kg/m^2)	percentage of people		typical impact insulation index *)	
	hear walking	annoyed by walking	I_{co}	proposed I_{co}
490	14	3	-5	ca. + 2
410	33	8	-8	0
300	50	9	-14	-5

*) See Appendix A

From this it can be concluded that a homogeneous floor of at least 500 kg/m^2 would be desirable, while as a minimum the weight of the floor should not be less than about 400 kg/m^2.
On the basis of the 66 measured floorconstructions it can be deduced that this minimum requirement corresponds to the NR-45 curve as a limit for walking noise.
Thus the reference values for tapping machine noise result, by adding the values D_c to the NR-45 curve. By streamlining the curve a bit the reference values become (figure 7):

Table 4

Proposed reference values for impact sound insulation

frequency	63	125	250	500	1000	2000	Hz
reference values	70	70	66	66	66	70	dB

THE NEW (DUTCH) RATING SYSTEM FOR IMPACT SOUND INSULATION

In accordance with practice both in the Netherlands and elsewhere, the impact sound insulation index is not based on a peak-method (NR-method) but on a comparison between the impact sound spectrum and reference values over the complete frequency range of interest.
The Dutch method of "weighting" the measured levels against the reference curve is somewhat different from the method used in other countries and from that described in ISO-Recommendation R 717. The Dutch method, described in Appendix A, however is comparable in its effective "weighting" but it is simpler and more straightforward.

Since the 63 Hz octave band is not very important for impact sounds, this band has been deleted in view of the measuring difficulties met at these low frequencies, notably in small rooms. Besides, in almost all cases the level in the 125 octave band is as good an indication of the low frequency behaviour as the 63 Hz band, even if in fact this lower band is dominating the spectrum.

For all 66 measured floors, i.e. the 49 used to derive the new reference values and the 17 floors that were not incorporated for the reasons given, the impact sound insulation index has been calculated, according to the reference values being in force (comparable with ISO R 717) and the proposed reference values.

Both these indices are compared with the NR-number for male walking noise under the same floors. Here we have to pay attention to two points. First of all the indices are meant as an indication for impact noises in general and not just for male walking. Furthermore the measured sound levels are not normalized in the same way: both the walking sound and the impact levels for the new method (I_{co}-proposed) are normalized to a reverberation time of 0.5 s, but the impact levels for the old method (I_{co}) are normalized to an absorption of 10 m^2.

For the laboratory facilities these two normalizations give differences of about 5 dB.

Figure 8 give the results of the comparison. The filled circles are for the 49 floors, the asterisks for the inaccurately constructed 15 floating floors and the stars for the two homogeneous floors with a thick, soft carpet.
In the figures the regression coefficient for the 49 floors is indicated, together with the spread (90% - confidence limits).
There is a distinct improvement in regression coefficient with the proposed reference values, together with a smaller spread of results. The regression coefficient and the spread are only slightly worse for the proposed index compared with male walking, than for the comparison between the NR-number for male walking and the equivalent NR-number from tapping machine measurements with seperate corrections for the three different groups of floors (table 2). Another indication of the improvement is the slope of the regressionline, which is much closer to 45^{o}. This indicates that one index-dB now is compatable with one NR-number i.e. a certain numerical difference in the subjective rating (NR-number) now is comparable to the same numerical difference in index.

CONCLUSION

The proposed reference values, together with measurements with the ISO-tapping machine, represent a rating system for impact sound insulation that solves, to a certain extent, the difficulties encountered with the existing rating system.

We consider the results to be sufficient for rating dwellings as such, leaving open the problem of rating improvements by soft floor coverings which react non-linearly. This however is not felt as a serious shortcoming of the system.

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APPENDIX A

Dutch standard "Sound insulation in dwellings" NEN 1070

The Dutch standard NEN 1070 dates from 1962. The reference values both for airborne and impact sound insulation follow closely the equivalent curves in the ISO-Recommendation R 717, although the absolute values have been chosen somewhat differently. The impact sound insulation, according to this standard, is expressed in an insulationindex I_{co} (this index is not comparable with the ISO-index, but with the ISO-margin!). The index is determined by comparing tapping machine levels in the 250 to 2000 Hz octave-bands with the reference values, the levels being normalized to an absorption of 10 m^2.

This comparison is done with respect to three points:

a - the average difference between reference values and normalized levels over the four octave bands

b - the biggest difference in any one band allowing for 4 dB deviation

c - the mean of the two biggest differences, allowing for 2 dB deviation.

The most unfavourable value of these three is the asigned impact sound insulation index I_{co}.

The standard distinguishes two classes, a minimum class "moderate" whose limit is I_{co} = 0 dB and a class "good" at a 3 dB higher level.

According to the Draft Revision of the standard (November 1973) the I_{co} is determined from the impact sound levels in the octave bands 125 to 2000 Hz, with normalization to a reverberation time of 0.5 s, on the basis of the here proposed new reference curve.

The class "good" is made more severe by changing the difference with the class "moderate" to 5 dB.

APPENDIX B

Group 1: Homogeneous floors

This group consists of 25 concrete floors varying in weight from 250 to 720 kg/m^2. In half of the cases the floors are bare or have same kind of thin finish. In the other cases the floors have coverings like linoleum, cork, hard wood, mat or carpet.

Group 2: Floors with concrete floating slabs

The bearing construction of these 23 floating floors is in general concrete with a weight of 250 to 300 kg/m^2. The middle layer consists of rock wool slabs, glass fibre slabs or polystyrene foam. The floating concrete slabs have weights around 80 kg/m^2.
In two cases the floating construction was deliberately short circuited.

Group 3: Floors with wooden floating slabs

These 18 floors have bearing constructions of 100 to 130 mm concrete and in two cases a steel construction with concrete filling and a suspended ceiling. The floating slab is board, fiberboard or hard wood, in some cases with cork or linoleum covering.
The middle layer consists of wood-woll cement, cork, felt, polystyrene foam, mineral wool, corugated card-board or rubber isolators.