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Publisher's version / Version de l'éditeur:

Journal of the Acoustical Society of America, 43, 4, pp. 730-733, 1968-03-01

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BY

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Reprinted from
JOURNAL OF THE ACOUSTICAL SOCIETY OF AMERICA
Vol. 43, No. 4, April 1968, pp. 730–733

RESEARCH PAPER NO. 358
OF THE
DIVISION OF BUILDING RESEARCH

OTTAWA

PRICE 10 CENTS

March 1968

NRC 10056

LA TRANSMISSION DU BRUIT DE PAS PAR LES PLANCHERS A SOLIVES EN BOIS ET LES SOLS DE BETON

SOMMAIRE

Les auteurs décrivent une technique d'évaluation de l'isolement acoustique des sols aux bruits d'impact par des comparaisons subjectives de l'intensité des bruits de pas transmis. Ils ont utilisé la méthode d'évaluation subjective comme vérification des résultats de l'évaluation objective obtenue par l'emploi du générateur-type de bruits d'impact de l'ISO. Une étude antérieure a été faite au laboratoire au sujet des irrégularités de comportement d'un sol en dalles de béton armé. D'autres observations ont été faites ensuite, plus spécialement sur les planchers à solives de bois dans des bâtiments typiques. Si au cours de toute l'étude on emploie la forme habituelle du profil de référence, comme la "U. S. Federal Housing Administration" l'a fait, la corrélation entre l'évaluation subjective et les mesures objectives est restreinte. Ce profil accorde trop d'importance à la plus forte proportion de sons aigus produits par le générateur de bruits d'impact par rapport aux bruits de pas, particulièrement sur les sols de bétons à surface dure. On obtient une meilleure corrélation en modifiant le profil actuel de référence de la FHA par la réduction de l'importance accordée aux bruits aigus.

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Assessment of Footstep Noise through Wood-Joist and Concrete Floors

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A technique for rating floors for impact-sound insulation by subjective comparisons of the sounds of transmitted footsteps is described. The subjective judgments were used as a criterion for checking objective ratings obtained with the standard ISO impact machine. A previous study was done in the laboratory on variations of a reinforced concrete-slab floor. Further observations have now been made in typical buildings, with special attention to wood-joist floors. For the whole study, the correlation between subjective and machine ratings is limited in range if the usual shape of reference contour, adopted for example by the U. S. Federal Housing Administration, is used. This contour makes the results, especially for hard-surfaced concrete floors, dependent on high-frequency noise that is characteristic of the machine rather than of actual footsteps. A better correlation is obtained by changing from the present FHA reference contour to one that reduces the emphasis on high frequencies.

AN urgent problem in the design of apartment dwellings is the control of transmission of impact noises such as footsteps through floors into dwelling units below. Despite the urgency, however, progress in the development of standard methods of measurement and control has been slow. Although standards have existed in some European countries for 15 yrs or more,[1] the first proposal on this continent was published by the U. S. Federal Housing Administration as recently as 1963,[2] and its merits are still the subject of argument.

The main facets of the argument might be reviewed. The need for standards is urgent because modern building technology is producing more and more constructions that are limited only by their acoustical performance; it is therefore imperative that acoustical performance be controlled. Whereas the acoustical scientist is concerned with technical limitations of the existing rating procedures, the consumer is concerned with the obvious defects of current construction, and would be willing to accept a less-than-perfect rating system if it were to prevent the worst of these defects. On the other hand, it is argued that a rating procedure that needlessly restricts construction might increase building costs unnecessarily, and this might be as painful to the consumer as the noise he now contends with.

The main technical objection[3] to the existing procedure is that the standard impact machine[4] produces impacts that bear little resemblance to footsteps. If the process were ideally elastic, this would not invalidate the machine technique, provided that the results were suitably interpreted; for some types of floor covering, however, both the impact machine and some kinds of footsteps stress the material into the nonlinear region. It is argued that this substantially reduces the possibility of a satisfactory correlation between the two types of excitation. Indeed it would, if the departure from linearity were sufficient; but there is a question of degree. It remains pertinent to consider what correlation actually exists for a range of practical constructions. This has been the objective of the study reported here.

The procedure has been to study the performance of many floor constructions as indicated, on the one hand, by impact-machine tests and on the other, by subjective assessments of transmitted footstep noise. The latter procedure is designed to provide a direct subjective measure of the loudness of transmitted footsteps. An alternative approach, used by other investigators of the impact problem,[3] was to calculate the loudness from measured sound spectra, using one of the standard pro-

[1] O. Brandt, Proc. Intern. Congr. Acoust. 4th, Copenhagen 2, 31–54 (1962).

[2] "Impact Noise in Multi-family Dwellings," prepared by Bolt Beranek and Newman Inc. for Federal Housing Administration, FHA No. 750 (1963).

[3] T. Mariner and H. W. W. Hehman, J. Acoust. Soc. Am. 41, 206–214 (1967).

[4] Field and Laboratory Measurements of Air-borne and Impact Sound Transmission, International Organization for Standardization, ISO Recommendation R 140 (1960).

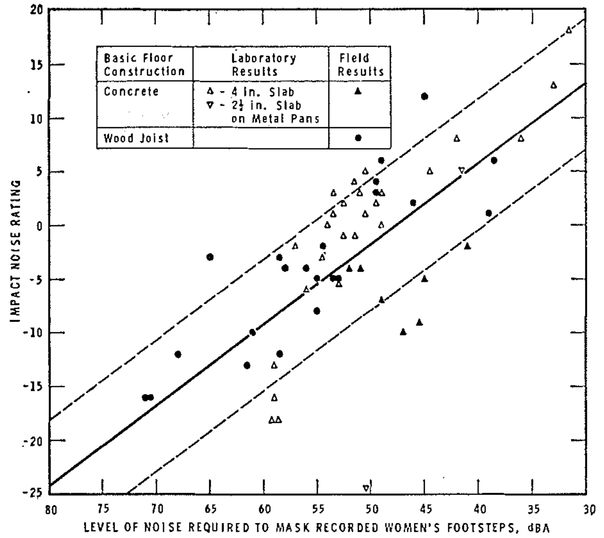

FIG. 1. Floors in laboratory and buildings: level of noise required to mask recorded women's footsteps versus INR.

cedures for steady-state noises.[5] There are some doubts, however, regarding the application of these procedures to isolated impulsive sounds,[6] and a direct subjective method seemed preferable.

A previous paper[7] reported laboratory measurements on a concrete-slab floor with 25 different surface treatments ranging from bare concrete to complicated floating floors. These measurements are now combined with a similar number of field tests, mostly on wood-joist floors.

I. SUBJECTIVE TESTS

In the initial study, a panel of listeners heard, alternately, tape recordings of two sets of footsteps through headphones. They then made gain adjustments in one channel of the system to make the two samples of footsteps sound equally "loud." The gain adjustment in decibels was used as a measure of relative loudness. This was found to give satisfactory repeatability and reproducibility from one observer to another. Although this technique was suitable for the laboratory, where all constructions might be compared with some reference floor—all being constructed in the same environment—it was not readily adaptable to field measurements. This was a serious limitation, since it was believed that the only practical way of investigating structures such as wood-joist floors was to make measurements in the field.

A number of alternative techniques were considered, and one was chosen that agreed closely with the direct comparisons of two sets of footsteps (see Ref. 7, Fig. 6). In this procedure, the listener adjusted the level of a masking signal until it masked the sound of recorded footsteps. The level of the masking signal was then used as a rating figure. The masking signal was random noise modified to correspond in spectrum shape to an NC-40 curve; for purposes of this study, it was evaluated in terms of an A-weighted sound-level reading.

The apparent equivalence of the two subjective methods suggests that our observers' concept of the loudness of footsteps depends largely on the peak value of the individual impulses. No attempt was made, however, to investigate this point in detail.

II. EXPERIMENTAL PROCEDURES

The initial study was made on about 25 surface variations on an 8 ft×8 ft×4-in.-thick reinforced-concrete-slab floor in the laboratory. The new study includes 22 wood-joist and seven concrete-slab floor constructions in actual buildings such as houses, apartments, and a small number of office buildings. Wood-joist floors ranged from simple structures to more elaborate ones with multilayer flooring or resiliently suspended ceilings. The concrete floors were slabs from 3 to 8 in. thick, one of which was cast in place on metal pans supported on steel joists. Upper-surface finishes were common types such as plastic tiles, thin sheet materials with and without sponge backing, wood-block flooring, hardwood, and carpet with and without underlay. Also included are laboratory measurements on an 8 ft×8 ft×2½-in. (minimum thickness) concrete slab on metal pans, with and without a suspended acoustical-tile celing.

Most of the footsteps used in these studies were generated by a woman wearing shoes with high heels tipped by metal or hard plastic. Several women, varying in weight from about 125 to 140 lb participated

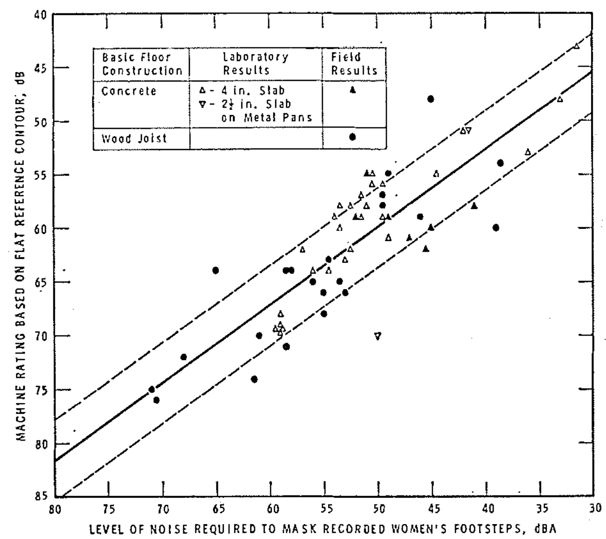

FIG. 2. Floors in laboratory and buildings: level of noise to mask recorded women's footsteps versus machine rating based on flat reference contour.

[5] S. S. Stevens, J. Acoust. Soc. Am. 33, 1577–1585 (1961).
[6] E. L. R. Corliss and G. E. Winzer, J. Acoust. Soc. Am. 38, 424–428 (1965).
[7] D. Olynyk and T. D. Northwood, J. Acoust. Soc. Am. 38, 1035–1039 (1965).

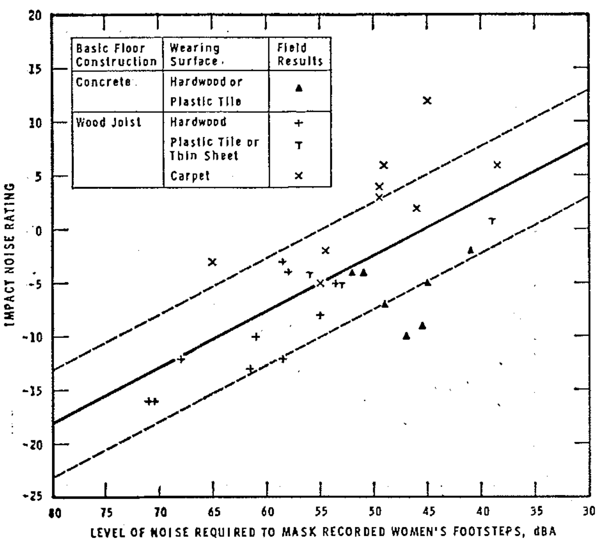

FIG. 3. Floors in buildings: level of noise required to mask recorded women's footsteps versus INR.

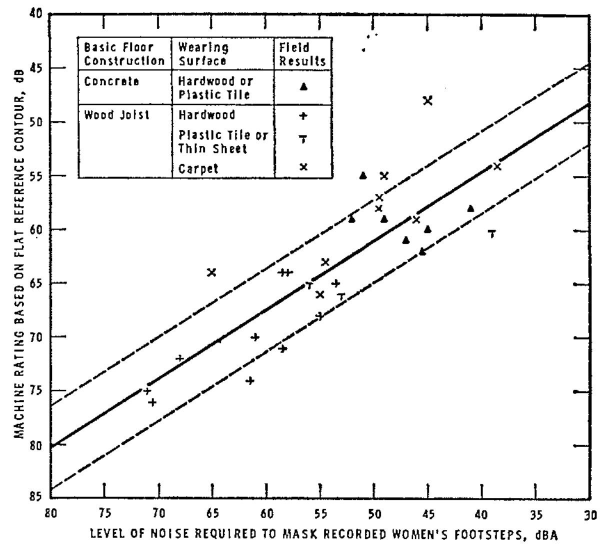

FIG. 4. Floors in buildings: level of noise required to mask recorded women's footsteps versus machine rating based on flat reference contour.

in the work, but comparisons showed little variation from person to person in the footstep noise produced. For very hard surfaces such as bare concrete, there was a slight variation between steel and plastic tips (Ref. 7, Fig. 4), but this was a minor source of scatter in the over-all study. A few experiments were made with male walkers wearing rubber-heeled shoes; these gave different results, which will be reported later.

Impact-machine noise was generated with the machine placed usually in three positions within the floor area utilized for the walking tests. The machine conformed to the specifications given in ISO R-140.[4]

Corrections for receiving-room absorption were made for both footstep and machine results by normalizing to 0.5-sec reverberation time in order to conform to the FHA procedure. This was done on a band-by-band basis for the impact-machine data, but a single correction only was possible in adjusting the subjective results for footsteps. This single correction was made on the basis of absorption in the 500-Hz band for the laboratory tests, in which this band was generally the most important. Field data were similarly corrected on the basis of absorption in the band of highest sound-pressure level.

III. RESULTS

Comparisons between machine ratings and subjective assessments are shown in Figs. 1–4. A least-squares analysis was used to fit the best straight lines, shown solid in the Figures. The region bounded by the parallel broken lines contains points within one standard error of estimate. The spacing of these lines thus is an indication of the degree of correlation: There is about a two-thirds probability that a correlation point will fall within this region.

A one-to-one correspondence might be expected—i.e., a shift of 1 dB in the level of machine noise should correspond to a shift of 1 dB in the subjective tests. This was found to be nearly the case for female footsteps, though not for male footsteps.

Figure 1 shows the correlation between subjective results and the FHA Impact Noise Rating (INR). One of the objections to the INR is that it gives a large spread in ratings for certain constructions that are subjectively nearly the same—i.e., concrete floors with thin surface finishes, as compared with bare concrete. This is exemplified by some of the concrete-slab results in the laboratory where a 2-dB improvement, according to subjective reactions, is equivalent to a 20-dB improvement in INR. These floors would be unacceptable in any case where impact insulation is desirable. The problem of overrating such constructions, however, can be resolved by altering the present method of evaluating machine data. In place of the FHA reference contour, a flat reference contour (invariant with frequency) is used. It is fitted to the measured noise spectrum by the same rules as before (a total deficiency of 32 dB for the sixteen $\frac{1}{3}$-oct bands and a maximum of 8 dB in any one band), and the rating is determined by the ordinate value corresponding to the position of the contour. A similar procedure was tentatively proposed in Ref. 7, although a different labeling arrangement was used at that time.

The flat reference contour is used to evaluate machine data for all the floors (Fig. 2). It will be seen that, as compared to the INR, this gives a better correlation with footsteps, especially for the group of concrete floors mentioned earlier. The standard error of estimate is reduced from 6.1 dB, for INR, to 3.7 dB for the flat rating. This is consistent with the observations of Fasold[8] and of Mariner and Hehman,[3] for concrete floor specimens. As a matter of interest, a least-squares

[8] W. Fasold, Acustica 15, 249–306 (1965).

analysis was made on the data of Mariner and Hehman, and standard errors of estimate of 5.5 and 4.1 dB were found when their loudness calculations were correlated with INR and flat contours, respectively.

Figures 3 and 4 present machine and subjective data for field constructions only. The floors are further classified as to the nature of wearing surface. Attention is drawn to two wood-joist floors that deviate significantly from the least-squares line. There is a 4-dB difference by either machine method, which compares with a difference of 26 dB by the subjective method. These floor constructions are essentially the same except for the type of wearing surface, one being a carpet (no underlay), the other a thin sheet material with sponge backing. The discrepancy appears to be related to the nature of the wearing surface and the area of contact during impact. For the carpeted floor, women's stiletto heels, unlike the machine hammer, are able to penetrate the surface covering to the subfloor, resulting in greater excitation of the main-floor construction. No explanation can be offered for the exceptional low level of masking noise required for women's footsteps on the sponge-backed material.

Figure 5 compares footsteps of women wearing hard-heeled high-heeled shoes, with those of men wearing rubber-heeled leather-soled shoes for a limited number of floors (a few floor constructions have been added to those previously given in Ref. 7). In general, women's footsteps are subjectively louder over most of the range, although men's footsteps become more important with better floors. There is one anomalous point for the laboratory installation of a metal-pan-and-concrete ($2\frac{1}{2}$-in. minimum thickness) floor. Note that there is not a one-to-one relation between the two kinds of footsteps. Consequently, it appears that the slope of the correlation line for machine ratings would be steeper for male than for female footsteps, i.e., that for a given change in machine rating, the subjective change would be less for male than for female footsteps. It is interesting to note, although the number of observations is too small to warrant a least-squares calculation, that the correlation between two types of footsteps is no better than that between women's footsteps and machine ratings.

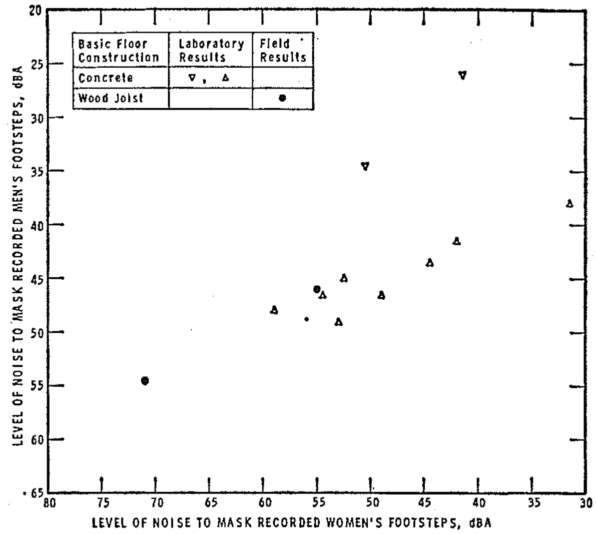

FIG. 5. Floors in laboratory and buildings: level of noise to mask recorded women's footsteps versus level of noise to mask recorded men's footsteps.

IV. DISCUSSION

These studies, like those of Fasold and of Mariner and Hehman, indicate that a slightly better correlation is obtained between tapping machine and footstep data if a flat reference contour is used instead of the FHA contour.

It remains to consider the significance of this degree of correlation. The first question is whether the noise of women's hard-heeled footsteps is representative of the variety of impact noises that give trouble. It was noted that women's hard heels are generally noisier than men's rubber heels, especially on poorer floors. Casual observation and inquiry indicate, however, that women do not habitually wear high heels in the home. Furthermore, some surveys indicate that ordinary footsteps are less disturbing in dwellings than other impact sounds such as the noises of children at play.[9] Hence, although women's hard-heeled footsteps have the experimental advantage of producing maximum noise, they do not constitute the major impact-noise problem.

It is therefore important to note that the correlation between machine ratings and the subjective ratings of women's footsteps is at least as good as the correlation between men's and women's footsteps. This is not surprising when one considers the variety of interactions possible between various impactors (people as well as machines) and various floor structures and floor coverings. Consequently, there seems little point in striving for any better correlation than is now available. A shift to the flat contour is probably warranted, as this avoids a recognizable limitation of the existing FHA procedure and improves the correlation with respect to both kinds of footsteps. With or without this refinement, it appears that the impact machine and rating procedure provide useful guidance in rating floors.

Further research is desirable on the subjective aspects, both to determine which types of impact are most commonly disturbing and to establish a reasonable subjective criterion of floor performance. With these data in hand, it may then be appropriate to look for a more refined objective rating procedure.

ACKNOWLEDGMENT

This paper is a contribution from the Division of Building Research of the National Research Council of Canada and is published with the approval of the Director of the Division.

[9] "Noise in Three Groups of Flats with Different Floor Insulations," Natl. Bldg. Studies, Res. Paper No. 27 (Her Majesty's Stationery Office, London, 1958).