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SUBJECTIVE STUDY OF THE SOUND-TRANSMISSION CLASS SYSTEM FOR RATING BUILDING PARTITIONS

BY

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REPRINTED FROM
THE JOURNAL OF THE ACOUSTICAL SOCIETY OF AMERICA
VOL. 47, No. 3, (PART I), MARCH 1970
P. 676 - 682

RESEARCH PAPER NO. 445
OF THE
DIVISION OF BUILDING RESEARCH

OTTAWA

PRICE 10 CENTS

JULY 1970

NRCC 11463

RAPPORT ENTRE LA FORME DE LA COURBE D'AFFAIBLISSEMENT DU SON ET L'IMPRESSION SUBJECTIVE AU BRUIT

SOMMAIRE

L'usage d'un seul nombre pour indiquer l'indice d'affaiblissement acoustique de divers éléments de bâtiment est très répandu. Par exemple, on a le Sound Transmission Class (STC) et l'indice d'affaiblissement acoustique. Dans la méthode d'évaluation STC, on compare une courbe d'affaiblissement acoustique (TL) de forme irrégulière à une courbe normalisée de référence. L'apport de diverses bandes de fréquence dépend de la forme de la courbe normalisée et du mode de comparaison. Des expériences ont été faites pour déterminer l'importance subjective relative de diverses bandes de fréquence et comment les changements de l'indice subjectif par rapport aux irrégularités d'une courbe TL se compare à l'indice obtenu en faisant usage des courbes et des règles usuelles.

Reprinted from THE JOURNAL OF THE ACOUSTICAL SOCIETY OF AMERICA, Vol. 47, No. 3, (Part 1), 676–682, March 1970

Subjective Study of the Sound-Transmission Class System for Rating Building Partitions

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The use of single number ratings in describing the acoustic performance of various building elements is very common. Examples of this are the sound-transmission class (STC) of a wall or the impact-noise rating of a floor. In the STC rating method, a transmission-loss (TL) curve of irregular shape is compared to a standard-reference curve. The contribution of various frequency bands depends on the shape of the standard curve and the method of comparison. An experiment has been carried out to determine the relative subjective importance of the various frequency bands and how the change in subjective rating due to irregularities in a TL curve compares with the rating obtained by using the standard curve and fitting rules. Results indicate that the present STC rating system is overconservative in rating changes in a TL curve and that narrow coincidence-type dips are not very important.

INTRODUCTION

In recent years, there has been a trend in building technology toward a greater structural continuity and the use of non-load-bearing walls and partitions. This progress, typified by the use of lightweight materials and prefabricated elements, although solving the problems of durability, fire resistance, etc., has produced other serious problems, one of the major ones being the provision of adequate sound insulation. The problem of sound insulation has been further complicated by an increase both in number and in loudness level of many noise sources, both household and external. The combined effect of these two influences has been to push sound insulation into prominence, making it one of the major areas of concern in modern building construction. If a reasonable solution to the problem is to be found, it is becoming increasingly evident that a reliable way of rating the sound-insulation value of a wall or floor construction be established.

Much work has been carried out in recent years, in an effort to establish a theoretical basis for the process of sound transmission through a wall; at the same time, a great deal of effort has been spent in establishing precise standard methods for measuring the transmission loss of a wall, in the laboratory and in the field. Little effort seems to have been spent on finding out what satisfies the apartment dweller or householder. This, since it is the principal reason for providing sound insulation, demands an understanding of the subjective reaction of the populace to various typical noises, and it must play a large part in determining a suitable method for rating walls.

There are, of course, many regulations governing sound insulation, but an examination of their origins reveals that they are not based on much concrete acoustical evidence, and few, if any, reflect an understanding of the subjective response of the individual apartment dweller or householder.

The most realistic approach so far has been to identify by tenant surveys certain constructions that are deemed acceptable by the majority of the occupants in an apartment. Requirements were then devised that reflected the characteristics of these constructions.[1–5] Several developments of this sort have occurred both in Europe and in North America and have culminated in a proposal for an international standard (ISO R717) for the rating of sound insulation between dwelling units. In North America, the present rating scheme developed by an ASTM Standards Committee is essentially the same as this proposal. It bears the designation Sound Transmission Class (STC). In this paper, the STC system is considered in detail, but results would apply equally well to the ISO and similar systems.

The STC rating system tries to express in a single number the ability of a wall to provide good sound insulation. As a first step, the transmission loss (TL) of the wall in question is measured according to standard procedures[6] and plotted as a graph of TL against fre-

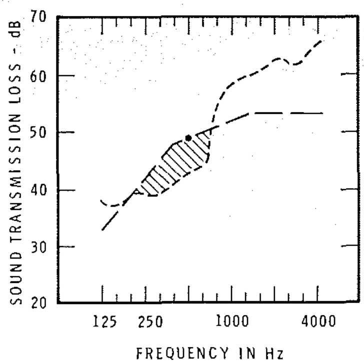

FIG. 1. Example of the rating procedure for a cavity wall, STC=49.

quency. Measurements are made at 16 $\frac{1}{3}$-oct center frequencies. A standard contour, which effectively weights the 16 frequency bands in a predetermined way, is moved vertically up or down the measured TL curve until two conditions are met. First, a limited portion of the measured TL curve is allowed to fall below the STC contour; the allowable value is an average of 2 dB per measuring point or a total of 32 dB. Second, the maximum deficiency at any one point must not exceed 8 dB. When this process has been carried out, the STC rating is given by the value of TL at the intersection of the STC contour and the 500-Hz ordinate.[7] The process is illustrated in Fig. 1.

Although this is a precise rating system with well-defined rules, it is not backed up by a very precise understanding of the acoustics and psychoacoustics involved. The shape of the reference contour has its origin in the shape of the TL curve for a 9-in. brick wall. The idea that a total deficiency of 32 dB should be allowed has a certain amount of scientific backing. Reference 8 reports some work carried out to support this view. This rule effectively allows for a certain amount of interchange between frequency bands; i.e., a deficiency in one band is considered equivalent to the same total deficiency spread out over the whole frequency range. There is no scientific basis, however, to support the idea that the maximum allowable deficiency should be 8 dB. The rule was introduced as insurance against possible problems associated with discrete tones and narrow coincidence dips.

All the arguments and work so far seem to have evoked doubtful assumptions and evaded some of the basic subjective questions. The present paper reports on some systematic experimental studies of these subjective aspects.

I. EXPERIMENTS

There are three important elements in any realistic sound-insulation problem: (1) the character of the intruding noise, (2) the character of the ambient noise, i.e., the noise that the occupants accept as a normal part of their environment, and (3) the occupants' assessment of the annoyance caused by the intruding noise.

It is the third of these factors that forms the principal object of this study, although, obviously, it cannot be divorced from the others. In the experiments described in this paper, Item (2), i.e., the background noise level, was neutral in character and held constant throughout. For Item (1), three different noise sources were used, each providing an intruding noise of different character.

A. First Object

In the STC rating system, as in most others, a definite shape of grading curve is used. The first object of our experiment, therefore, was to determine subjectively the relative importance of the 16 $\frac{1}{3}$-oct frequency bands, which cover the frequency range of interest for each noise source. In other words, does the present STC grading curve give a weighting to the various frequency bands that is compatible with our subjective assessment?

B. Second Object

The second objective was to find out how the subjects reacted to various shapes of TL curve and how narrow-band deficiencies such as coincidence dips, for example, would affect their rating of annoyance. It would then be possible to compare these results with the ratings obtained using the standard grading curve and fitting procedure. Again, does the rating system give an assessment of these various measured TL features that is compatible with our subjective results?

II. PROCEDURE

About 30 people were installed individually in a controlled environment and presented with two alternating intruding noises. The subject was then instructed to make an adjustment to the level of one of the intruding noises until he considered both to be equally annoying.

An anechoic room was selected as the test environment, since it permitted good control over the soundfield and ambient-noise conditions. The background-noise level was simulated using random noise modified to have both the spectrum shape and level of an NC-25 contour. The alternating intruding noises were introduced to the subject via a loudspeaker situated about 3 m distant. The loudspeaker was specially chosen and modified to provide a reasonably flat frequency response (±3 dB) over the range 100 Hz–8 kHz. Figure 2 shows the experimental setup in some detail.

The intruding noise began as a tape loop of signal that could be passed through either of two frequency-weighting channels. Switching from one channel to the other could be carried out automatically or controlled by the subject.

The frequency response of the first channel was designed so that it corresponded to that of the standard STC contour, whereas the second channel could be varied to simulate any desired TL curve, including coincidence dips of various widths, depths, and center

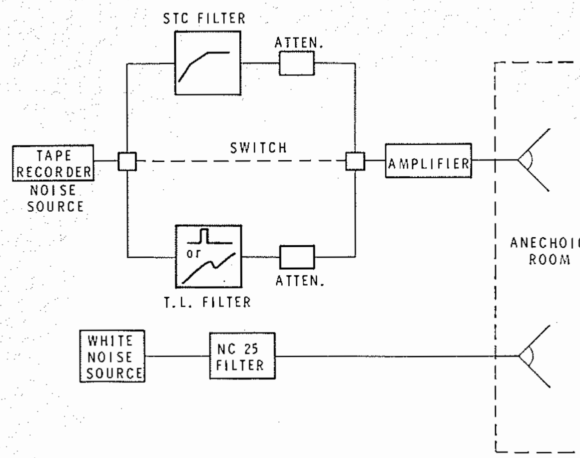

FIG. 2. Block diagram of experimental equipment.

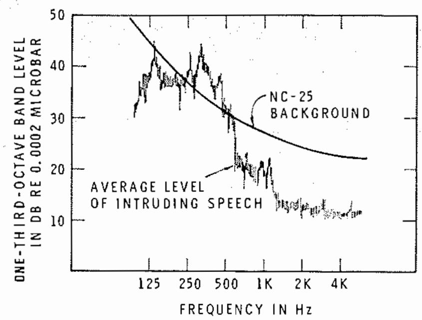

FIG. 4. Speech level and background-noise level in the anechoic chamber.

frequencies. It was also possible to pass only $\frac{1}{3}$- or 1-oct bands of the noise in this channel when required.

In the first part of the experiment, the subject was asked to vary the level of the $\frac{1}{3}$- or 1-oct bands of noise until the annoying effect they produced was equal to that produced by the noise signal passing through the STC channel. During this part of the experiment, the attentuation in the STC filter channel was kept constant; the signal passing through served as a reference noise, for purposes of comparing the different bands. The relatively "neutral" character of this reference signal was found to give less scatter in results than a direct comparison between different frequency bands.

For the second part of the experiment, the simple $\frac{1}{3}$- or 1-oct filter was replaced by a complete TL curve, including a variety of dips. It was found convenient, in this case, for the subject to vary the level of signal coming through the STC channel until he had satisfied himself that both noises were equally annoying. In effect, the subject, while making adjustments, was moving the STC contour (channel) up and down in the vertical direction; he was thus carrying out subjectively the process whereby measured TL curves are rated by the use of the STC grading curve and the standard mechanical fitting rules. The simulated TL curve resembled the STC contour except for a $\frac{1}{3}$- or 1-oct dip variable in depth and frequency.

The level at which the intruding noise was presented to the subject was carefully controlled. It was thought that sound insulation becomes very critical in the region where peaks in the noise signal coming through a wall are just audible above background. It is in this region that variations and coincidence dips in the TL of a wall have their greatest effect on the rating. Accordingly, in setting up the experiment, the intruding noise signal passing through the basic simulated wall (i.e., no dips) was adjusted in level until it could just be perceived against the background noise. Experiments[9] have shown that, for speech, the annoying effect produced is very dependent on the signal-to-noise ratio per band, or, more exactly, the articulation index (AI). It was found in the above experiment that, at the onset of annoyance, the AI was only of the order of 0.05. The level of the intruding noises was measured and plotted as shown in Figs. 3–5. Three different noise sources were used: male speech, music (popular variety), and vacuum-cleaner noise. The figures show the average spectra of the noises as presented to the subject in the room. It should be emphasized that these are *average* spectra; for the speech and music, short-term values fluctuate 10–15 dB above and below these values. The final tape loops containing the different noise signals were between 1 and

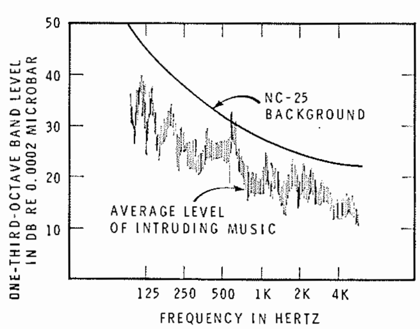

FIG. 3. Music level and background-noise level in the anechoic chamber.

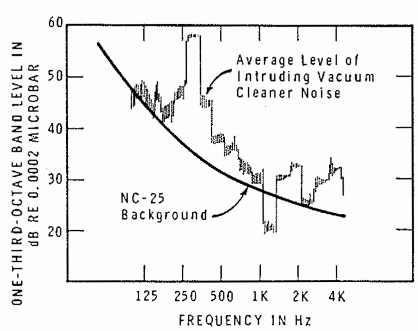

FIG. 5. Vacuum-cleaner-noise level and background-noise level in the anechoic chamber.

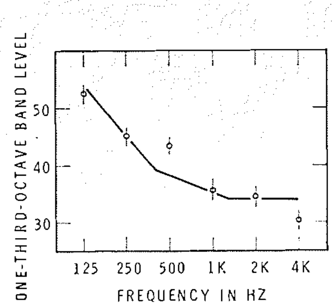

FIG. 6. One-third-octave band levels of speech giving equal annoyance. The solid line represents an inverted STC contour.

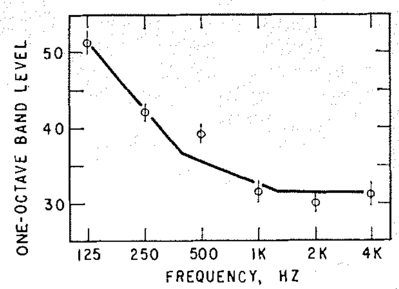

FIG. 7. One-octave band levels of speech giving equal annoyance. The solid line represents an inverted STC contour.

2 min in duration and selected so that there was no significant long-term fluctuation in the character of the signal over its length.

Because of the low levels of intruding noise being considered, it was felt that the intruding noise should carry some kind of message or intelligence; otherwise, it would not be intrinsically annoying. It is difficult to define what is meant by intelligence. Taking speech, for example, the tone of the voices may be annoying even though the words cannot be understood.

One important aspect of the experiment concerns the meaning that the word "annoying" conveys to the various subjects. Is it possible for our subject to differentiate between loudness and annoyance? Recent work[10] has shown that subjects, when asked to judge a series of paired noises on the criterion of loudness and then on *noisiness*, do show a definite difference. One other recent paper[11] has also shown that, when subjects were asked to judge various noises on loudness and then on annoyance, a definite difference in reaction was obtained, amounting to 7 dB in some cases.

To help the subjects in this matter, they were asked to imagine themselves, for example, sitting in their living room reading a book or playing chess and to gauge the annoyance of the intruding noise in such a situation. A written set of instructions containing the above information was presented to each subject.

No detailed audiometric screening of the subjects was carried out, but none were aware of any hearing difficulties. All subjects were personnel working in the laboratories of the Division of Building Research. Their ages ranged from 20 to 55 years, and, apart from initial test runs, all were male. The number of subjects used in each part of the experiment varied between 15 and 30 depending on the amount of scatter present in the results. A 95% confidence interval of $\pm 1\frac{1}{2}$ dB on the mean value was considered necessary for meaningful results. The same basic group of people was used throughout the various different test runs. This meant that, during the initial tests, the group members had all become familiar with any mechanical intricacies involved in adjusting the attenuator and switching from one weighting channel to another.

III. DISCUSSION OF RESULTS

A. Contour Shape

The shape of the present STC contour was arrived at in a fairly arbitrary way. From a practical point of view, however, it did follow closely the measured TL curve for a 9-in. brick wall, a not unreasonable choice to make. The experiments were designed to find out how the subjective annoyance rating for various sound sources varied with frequency and how this compared with the existing rating curve.

Figures 6 and 7 show the results for $\frac{1}{3}$- and 1-oct bands of speech. For comparison purposes, an inverted STC contour is superimposed. The results show a remarkable degree of fit. The vertical lines on the results represent the 95% confidence limits for the observations and thus give a measure of the scatter. Figure 8 shows the results obtained with music as a sound source; again, there is a close fit to the STC contour. The general trend of the results was not surprising: loudness contours, noise rating curves, and the A-weighting curve have all shown that the middle and high frequencies are more important than the low frequencies and that the ear would appear to respond in this way. The individual may also have been conditioned by the simple act of living in apartments and houses where the acoustical performance of the dividing walls shows a similar trend, i.e., good attenuation at high frequencies and poor attenuation at low frequencies. The important thing to note, however, is the closeness of the experimental points to the STC contour, which suggests that the shape of the STC contour for grading the acoustical performance of walls is

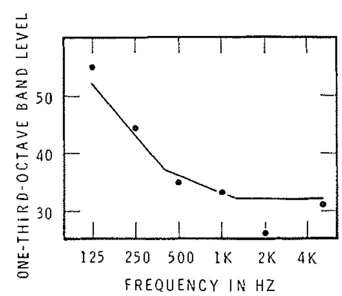

FIG. 8. One-third-octave band levels of music giving equal annoyance. The solid line represents an inverted STC contour.

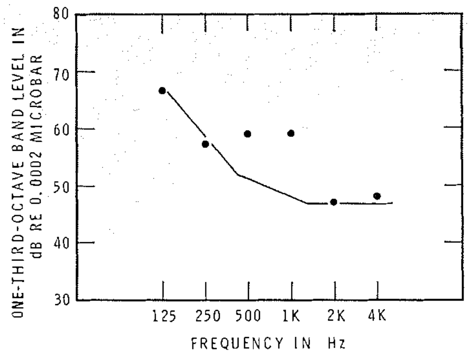

FIG. 9. One-third-octave bands of vacuum-cleaner noise giving equal annoyance. The solid line represents an inverted STC contour.

reasonably correct, especially when considering speech and music as the disturbing element.

The next two figures (Figs. 9 and 10) show results obtained while using vacuum-cleaner noise as a sound source. In this case, there are large discrepancies from the assumed STC shape. This result should not be allowed to detract, however, from those obtained using speech and music. There are some quite basic differences between speech, music, and vacuum-cleaner noise. It has been argued that the noise must be inherently annoying; i.e., it must carry some kind of message. Speech and music both have a very distinctive character when compared to vacuum-cleaner noise; e.g., in speech and music, there are large fluctuations from the average level, whereas with the vacuum cleaner this is not the case. These large fluctuations mean that at one point in time the signal is below background, whereas at another it is above. The vacuum-cleaner noise was steady in character during this study; as a true indication of the annoyance of vacuum-cleaner noise, it should have been under a typical fluctuating load and thus carrying a more characteristic sort of "message."

For speech and music, two of the most important types of signal in sound insulation problems, our results indicate that the STC contour shape was a good choice to use in rating the acoustical performance of walls.

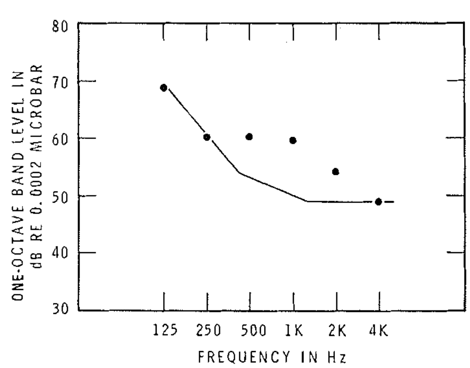

FIG. 10. One-octave bands of vacuum-cleaner noise giving equal annoyance. The solid line represents an inverted STC contour.

B. Effect of Dips in TL Curve

In this part of the experiment, the subject had to compare the sound passed through the STC filter with that passed through the TL network. The TL network was variable, so that any shape of curve could be derived. Of special interest in this part of the experiment was the effect of narrow dips, characteristic of the coincidence dips found in certain TL curves. This was achieved by studying the effects of $\frac{1}{3}$-oct and 1-oct dips varying in depth from 0 to 20 dB in a prescribed TL curve.

In Fig. 11, the results are plotted for a $\frac{1}{3}$-oct dip in the TL curve, assuming music and speech to be the two sound sources. The solid line shows how the rating would be affected using the standard fitting rules, and the dotted line shows the rating when the 8-dB limit for a single deficiency is ignored. It appears from these results that the standard method of rating is overconservative in assessing the effects of a $\frac{1}{3}$-oct dip. There is reasonable correspondence if the 8-dB limitation is ignored.

The results shown in Fig. 12 are for a dip 1 oct wide. In this case, because of the width of the dip, the 8-dB rule becomes less significant when considering the original rating method. There is fair agreement with the experimental results, although, again, the standard method of rating tends to be overconservative. From this figure, it can be seen that the rating method gives closer results for the music sample than it does for the speech, especially at the higher frequencies. On examining Figs. 3 and 4, it can be seen that at the high-fre-

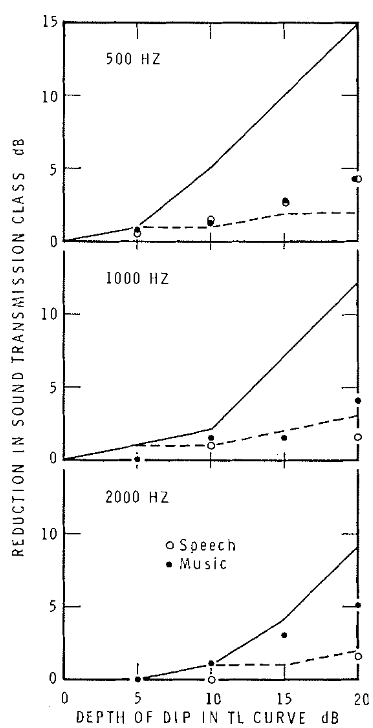

FIG. 11. Change in subjective rating due to a $\frac{1}{3}$-oct dip in the TL curve for speech and music.—Standard STC rating method.- - - STC rating method, ignoring the 8-dB limitation.

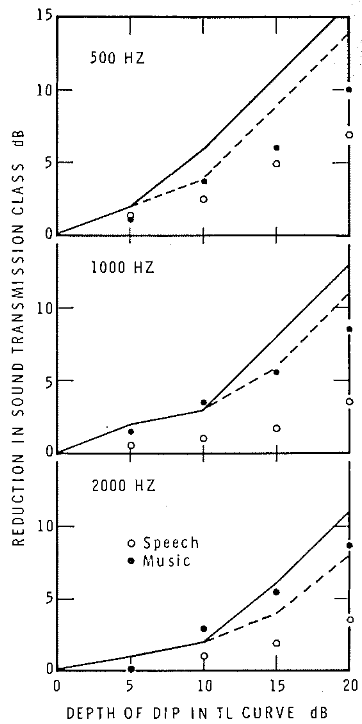

FIG. 12. Change in subjective rating due to an octave dip in the TL curve for speech and music. ——Standard STC rating method. - - - STC rating system ignoring the 8-dB limitation.

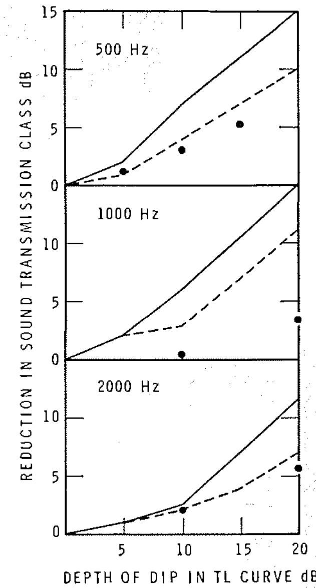

FIG. 13. Comparison of subjective ratings for 1-oct and $\frac{1}{3}$-oct dips in the TL curve. Music was the sound source.

quency end of the spectrum, the average level of the speech sample is well below background, and the percentage of time during which the speech is above background is smaller than that for music. This could account for differences evident in Figs. 11 and 12. Figure 13 gives a comparison between the effects of a $\frac{1}{3}$-oct dip and a 1-oct dip in the TL curve at a frequency of 2 kHz. When the dips are deep enough to have substantial effect on the transmitted sound, the $\frac{1}{3}$-oct band is about 5 dB less annoying than the equivalent octave band. Similar effects can be observed for the other two frequencies.

The results for the experiment using vacuum-cleaner noise as a source are sufficiently different to be considered separately. Figure 14 illustrates the results for a dip $\frac{1}{3}$ oct wide. The most obvious result is that the standard rating method is overconservative and that, when the 8-dB limitation is ignored, the correspondence between experiment and rating is good. The actual shifts in rating are fairly small, and if a realistic dip is considered, probably no more than 10–15 dB deep, the change in subjective rating is almost insignificant. Figure 15 shows the 1-oct band results. A similar trend is evident here, in that the results are matched closer to the line representing the rating where the 8-dB limitation has been ignored. The result at 1000 Hz is curious in that it is far removed from the dotted line in both graphs. There is no obvious reason for this deviation.

IV. CONCLUSIONS

The studies described in this paper indicate that the reference contour now used in the ASTM and similar rating systems gives a frequency weighting for complex sounds like speech and music that is close to the subjective requirement of the populace. It would also appear that the fitting rule that allows a free distribution of the 32-dB total deficiency gives a conservative assessment of the STC rating of irregular TL curves. This also applies to curves with narrow coincidence dips. For noises of the type considered here, it appears that the second rule limiting the deficiency in any one band to 8 dB is unnecessary.

It should be noted that this second rule, which comes into play only occasionally in the rating of actual partitions, is a vestigial remnant of an earlier version of the

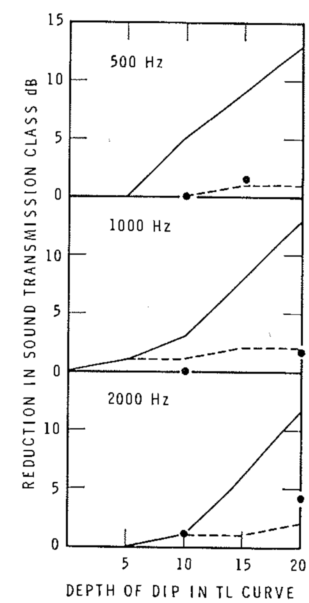

FIG. 14. Change in subjective rating due to a $\frac{1}{3}$-oct dip in the TL curve using vacuum-cleaner noise as source. —— Standard STC rating method. - - - STC rating method ignoring the 8-dB limitation.

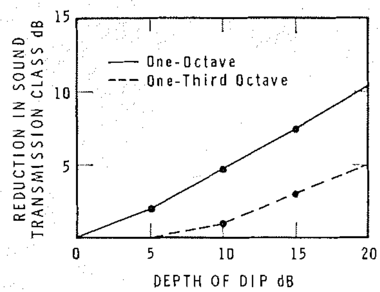

FIG. 15. Change in subjective rating due to a 1-oct dip in the TL curve using vacuum-cleaner noise as source. ——Standard STC rating method. - - - STC rating method ignoring the 8-dB limitation.

ASTM Sound Transmission Class as it appeared in ASTM E90-61T. References 4 and 5, describing the earlier version, reflect the concern at that time with possible effects of deep dips in TL curves. This concern resulted in a rating procedure that depended, usually, on the TL in one frequency band, the lowest band relative to the standard contour. The present subjective studies may therefore be taken as further evidence that the change in rating procedure was a good one.

ACKNOWLEDGMENT

This paper is a contribution of the Division of Building Research, National Research Council of Canada, and it is pubilshed with the approval of the Director of the Division.

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