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Discussion of the parameters governing noise control and room acoustics are followed by a demonstration on how to achieve a good acoustical environment. Topics emphasized include--(1) design and control objectives, (2) noise sources and propagation, (3) reverberation parameters, (4) noise control factors and parameters, and (5) sound systems. Also included are--(1) a table of area noise criteria factors, (2) five acoustical specification charts, and (3) a forum and question period. (MH)

ACOUSTICAL ENVIRONMENT FOR ACADEMIC BUILDINGS.

By L. J. Lortie, N. J. Pappas & Associates.

INTRODUCTION

During the course of your academic years, you have certainly been subjected to noise. Sometimes, the type of noise combined with the function you attended irritated you. On other occasions, a noise of a totally different nature provoked laughter. No matter what the nature of a noise is, it is distracting and disturbing; otherwise, it would not be termed noise. Aside from noise, you may also have experienced difficulty in speech communication, either in classrooms, halls or amphitheatres, due to either too much reverberation or insufficient loudness or both.

One type of building in which noise must be minimized and intelligibility made at premium is academic type of building.

The aim of this presentation is not to stress the importance of a good acoustical environment in academic buildings but to acquaint you 1) with the parameters which govern noise control and those which govern room acoustics and 2) to demonstrate how a good acoustical environment can be achieved.

NOISE CONTROL AND ACOUSTICAL DESIGN OBJECTIVES

When controlling the acoustical environment of a building in which all the rooms are used for speech communication almost exclusively, the objective is to meet predetermined values of noise criterion and reverberation time; and there are optimum values for both. To achieve physical comfort, in fact, a room must possess a certain amount of noise and reverberation and their optimum value derives from practical experiments conducted by well-known authorities on this subject over a period of several years.

NOISE SOURCES AND NOISE PROPAGATION

To remain in the context of academic buildings and keeping in mind that "noise" is a disturbing sound, the noise sources are many and varied. They may be divided into two categories: internal and external. The most important internal noise sources are the following:

- a) Ventilation equipment.
- b) Air conditioning equipment.
- c) Electrical transformers and fluorescent light fixtures.
- d) Impacts (footsteps, etc.)
- e) Loud conversation.
- f) Plumbing.
- g) Elevators and escalators.

Among the many external noise sources those we are mostly concerned with are the following:

- a) Road, railroad and air traffic.
- b) Sonic booms (nearby explosions).
- c) Road and building construction equipment.

Noise originates in the form of a mechanical vibration. Some of this vibratory energy is immediately translated into a fluctuation of the ambiant air pressure. This is called airborne noise. Part of the vibratory energy is also transmitted to structural components of buildings in its original form with more or less amplification or attenuation, depending on the resonance and damping characteristics of the transmitting media. This is called structure borne noise and is also invariably translated into airborne noise. If of sufficient intensity, airborne noise will sometimes translate itself into structure borne noise as if frequently occurs in the case of sonic booms. This is called air coupled vibrations.

ACHIEVING A COMFORTABLE ACOUSTICAL ENVIRONMENT

At the outset of a project in which proper acoustics are contemplated, it is customary to write an acoustical specification. Other than elaborating on various contractual commitments, the acoustical specification establishes the criteria of acoustics and noise and outlines the general manner in which those criteria will be met.

This brings us to the main purpose of this paper: "How to physically meet the criteria of acoustics and noise".

Those who are assigned the task of designing acoustics and noise control on a project for the first time, are confronted with the question as to whether the acoustical design or the noise control must be considered first. This question can be answered in the following manner:

The intensity of a sound wave in a room decreases inversely with the square of the distance from the sound source. Past a certain distance, however, the intensity ceases to decrease and remains constant. This effect is proportional to the amount of absorption in a room.

On the other hand, the main acoustical design parameter of a room, is reverberation time which is also a direct function of the amount of absorption in a room.

Since, therefore, the acoustical design of a room has an effect on the ability this room has to attenuate the amplitude of sound waves, the acoustical design must be considered first. Proper acoustics in classrooms are relatively easy to achieve. Reverberation time is the important criterion and is calculated as follows:

$$T = \frac{0.049\,V}{S\bar{a}}$$

where T = reverberation time in seconds

V = room volume in cubic feet

S = area of all surfaces in square feet

$\bar{a}$ = average absorption coefficient of the room.

The absorption required to achieve a predetermined amount of reverberation time is generally supplied by 1) the people in the classroom and 2) by acoustical tiles placed on the ceiling. It is also good practice to place acoustical tiles or any absorbing material on the rear wall, thus preventing sound wave reflections from interferring with direct waves.

Lobbys, halls, libraries, cafeterias and offices are also designed to meet a predetermined amount of reverberation time and this is pretty well the only acoustical criterion for these functions.

In the acoustical design of auditoria, other parameters such as diffusion and room modes are involved. These parameters are, however, not discussed in this paper since they generally form the basis for long and elaborate discussions.

NOISE CONTROL

Now that the absorption has been calculated to achieve proper acoustics throughout a building, a factor which will be important in the calculations for noise control, can be extracted from the calculations previously performed in the design of room acoustics. This factor is called the room constant and is found as follows:

$$R = \frac{S\bar{a}}{1-\bar{a}}$$

It is this factor which determines what maximum noise level can be tolerated at a noise generating source located in a room in order to meet a predetermined noise criterion for that room. A better understanding of this statement will be gained by inspecting the following formula:

$$SPL = PWL + 10 \log_{10}\left[\frac{1}{4\pi r^2} + \frac{4}{R}\right] + 0.5 \text{ db.}$$

where SPL = Sound Pressure Level at a given distance from a sound source.

PWL = Power Level of the sound source.

If the average absorption is high, R is high and consequently has much effect on the formula. It means that at a relatively appreciable distance from the source, the sound level will have decreased significantly. If, on the contrary, the average absorption is low, at a relatively appreciable distance from a sound source the sound level will have not decreased significantly. Another way of saying it is: "The higher the room constant, the larger the distance between the sound source and the reverberant field".

It is through the use of the above formula that the maximum sound power levels can be established for the noise emanating from diffusers and registers of ventilation systems, and from window and wall surfaces.

Once these maximum levels have been established, it is then a matter of controlling the media which will provide the necessary amount of sound attenuation in order not to exceed those noise levels.

Without enterring the technicalities of the operations performed in noise control, let us examine the means and tools which are available to acousticians to help them control noise.

Ventilation and mechanical equipment noise: - Formulae exist by which the power level of the noise produced by ventilation fans can be calculated. The parameters are the following:

1. The type of fan (centrifugal or axial).
2. The displacement in CFM (cubic feet per minute).
3. The static pressure in inches of water.
4. The speed in RPM and
5. The hose-power of the driving motor.

The attenuation of the ducts connected with a fan can also be calculated in terms of db/foot. One can therefore calculate what the noise level of a ventilation system will be at the various outlets on a ductwork system. If the noise is found to be too high at an outlet, sound absorbing material may be used in the form of lining inside the duct. If the length of duct is insufficient to accommodate the required amount of lining material, a silencer will have to be used. To understand the operation of a silencer, it should first be mentioned that the two main factors which govern the sound attenuation of a duct are 1) the absorption coefficient of the surfaces and 2) the ratio of the perimeter of the duct to its cross-sectional area; the larger this ratio the higher the attenuation. A silencer, therefore, is a section of duct containing splitters which effectively increase the ratio perimeter/area. These splitters are further lined with sound absorbing material to increase the absorption coefficient of the surfaces.

Sound transmission loss of walls:-

As a general rule, the sound transmission loss of a material is proportional to its surface weight. The air space between two whytes of a partition also add to the transmission loss of the partition. In this case the efficiency of the air space increases with frequency. To get a good benefit of an air spaced partition at low frequencies, the latter must be at least four inches.

Impact noise rating of floor/ceiling constructions:-

There exist no valid formulae by which this parameter can be calculated. Suppliers of prefabricated floor elements and governmental research institutions, however supply on request, litterature which contains the impact noise characteristics for various floor/ceiling constructions.

Isolation of mechanical equipment vibration:-

The general rule was, until recently, that when mechanical equipment such as fans, chiller compressors, water pumps, etc... is located in proximity of a critical area such as bedrooms or executive offices, to provide a vibration decoupling efficiency of 95% or better. In all other cases a decoupling efficiency of 85% to 90% was satisfactory. There are numerous tables available which show at a glance the required spring static deflection as a function of RPM and decoupling efficiency. These tables assume that all vibration mounts are undamped but are nevertheless used quite extensively.

A more logical approach to vibration decoupling was recently introduced in the field of engineering and which is derived directly from the dynamics of vibrating structures. The vibration isolation systems are designed as a function of both the dynamic characteristics of the machine which is to be isolated and the dynamic characteristics of the section of the structure where the machine is located.

TABLE OF NOISE CRITERIA APPLICABLE TO THE VARIOUS FUNCTIONS FOUND IN ACADEMIC BUILDING

Function	Noise Criterion
Classrooms	NC-35
Recreation halls	NC-50
Lounges	NC-35
Lobbys and corridors	NC-40
Libraries	NC-25
Cafeterias	NC-45
Auditoria	NC-25
Private offices	NC-30
Secreterial offices	NC-40
Dormitories	NC-30

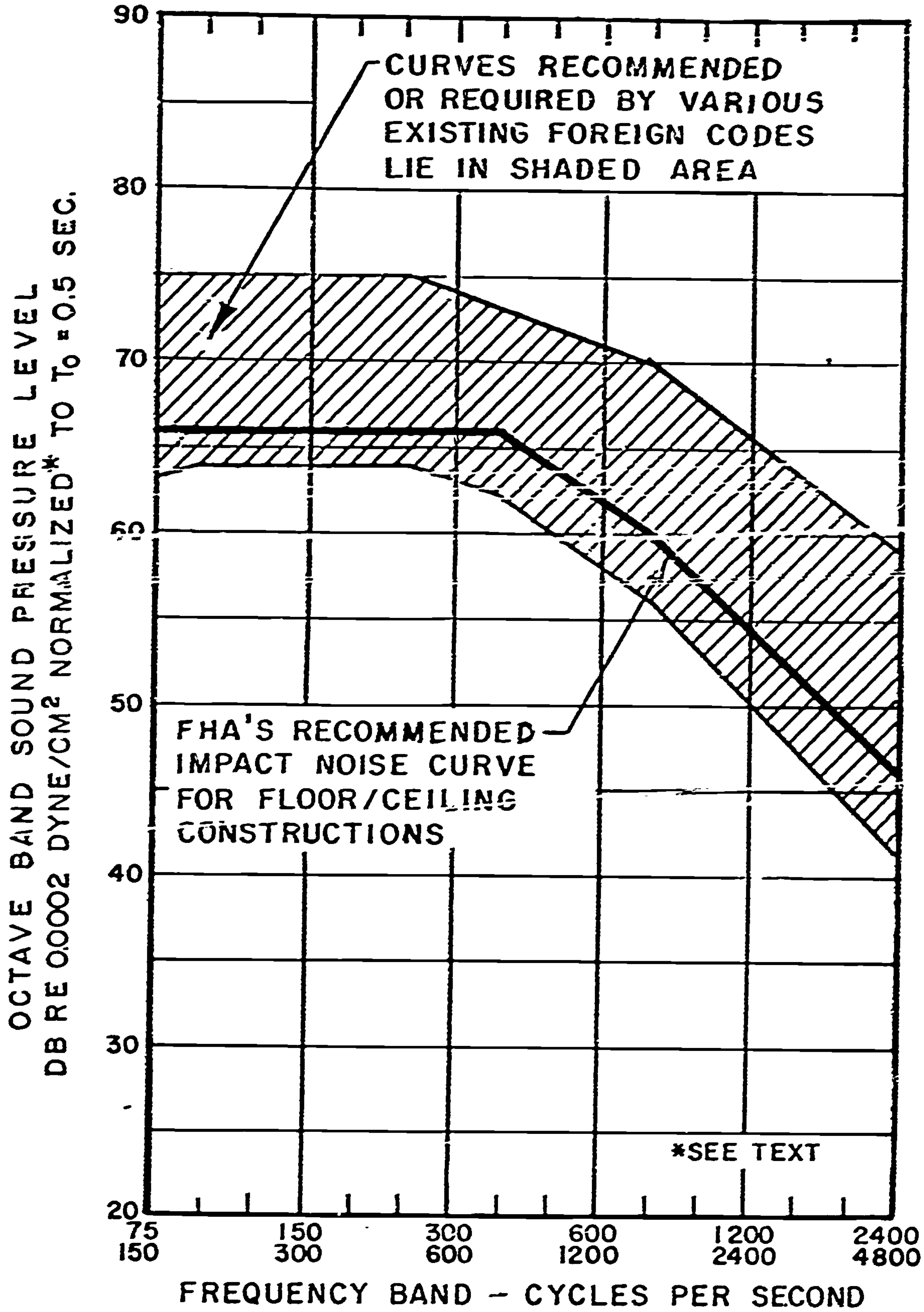
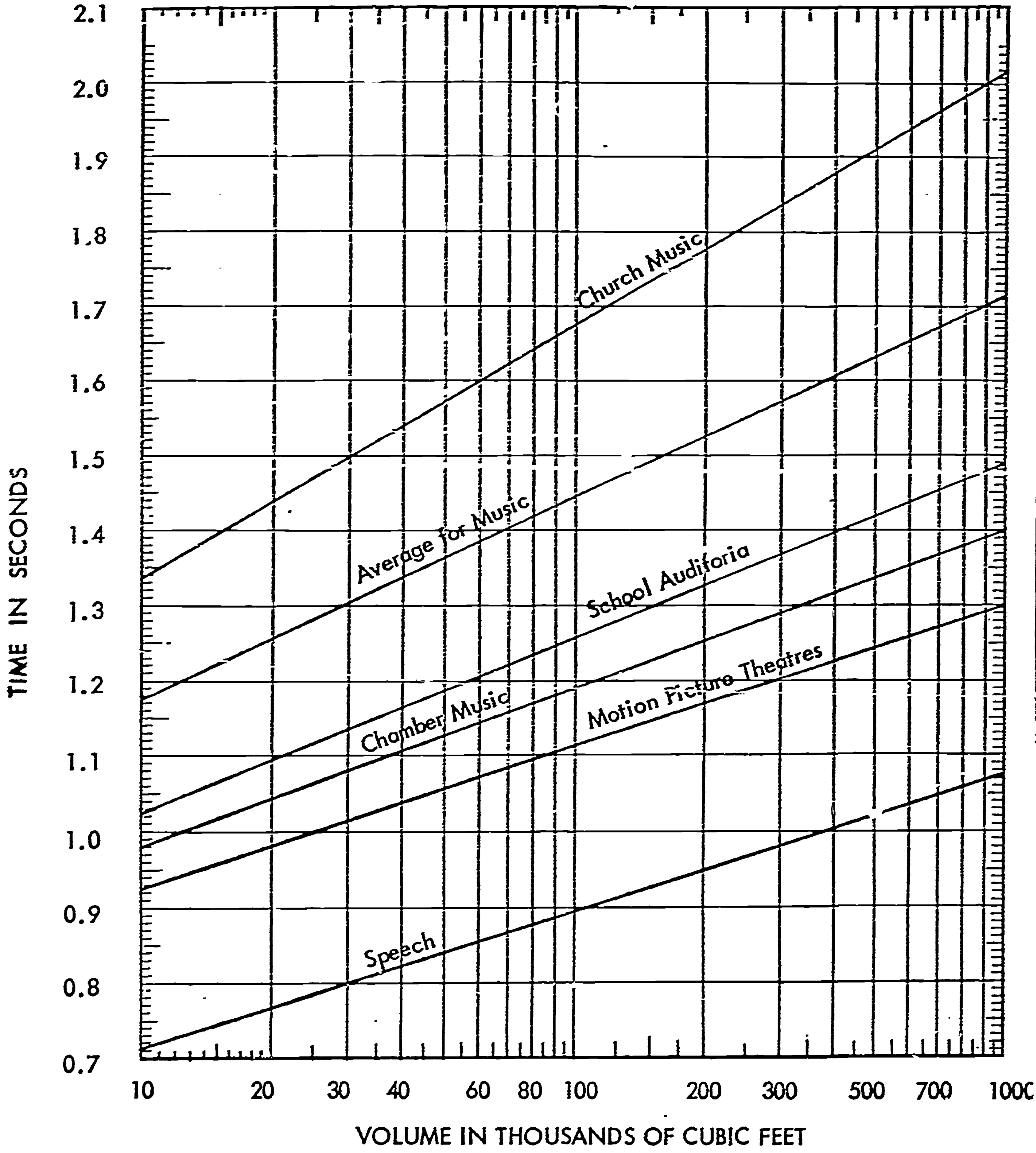


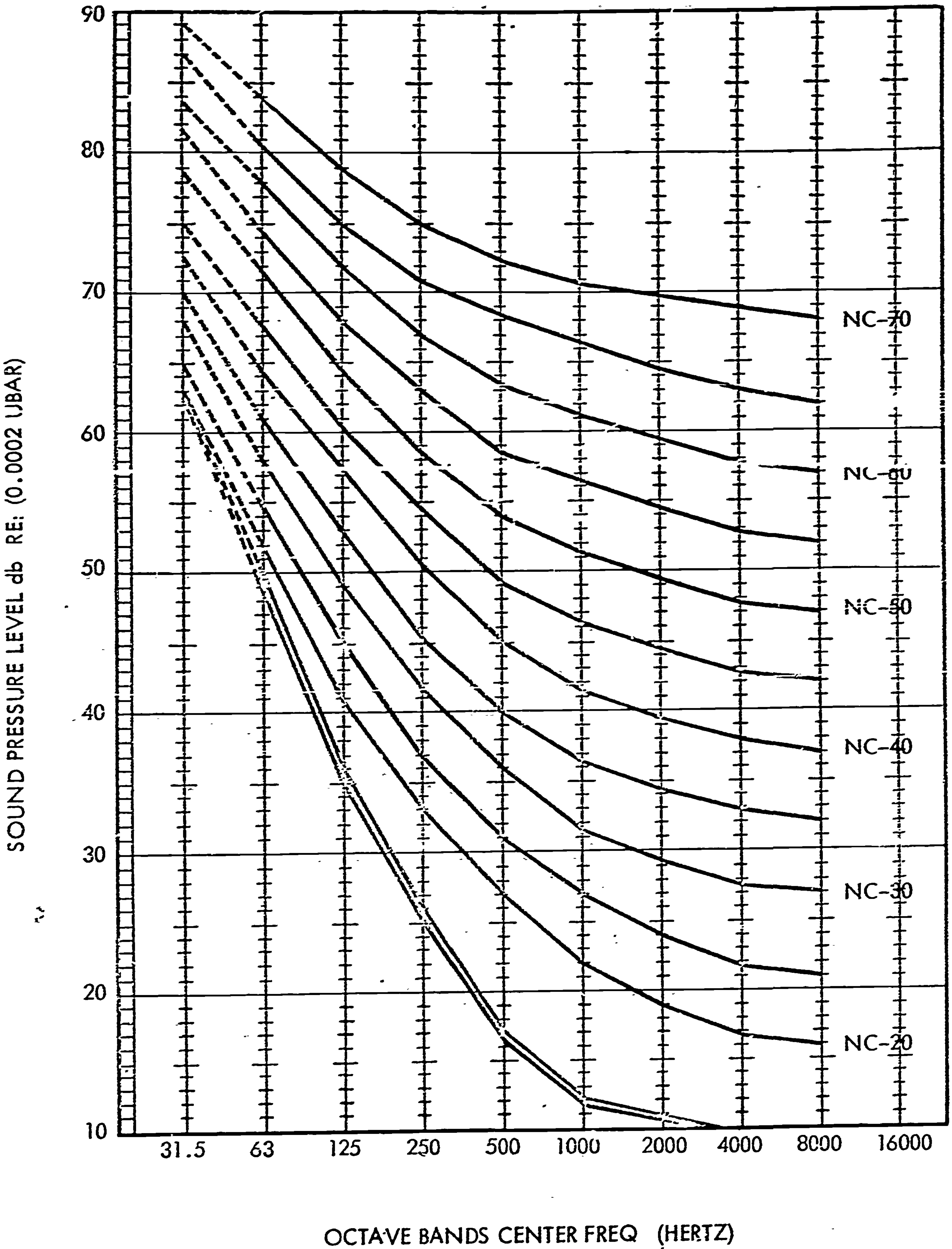
Fig. 1 Field Measurements of Sound Pressure Levels in the room underneath a floor construction on which a standard tapping machine is operating should not exceed this curve by more than the tolerances specified in section III-A-3 of the text.



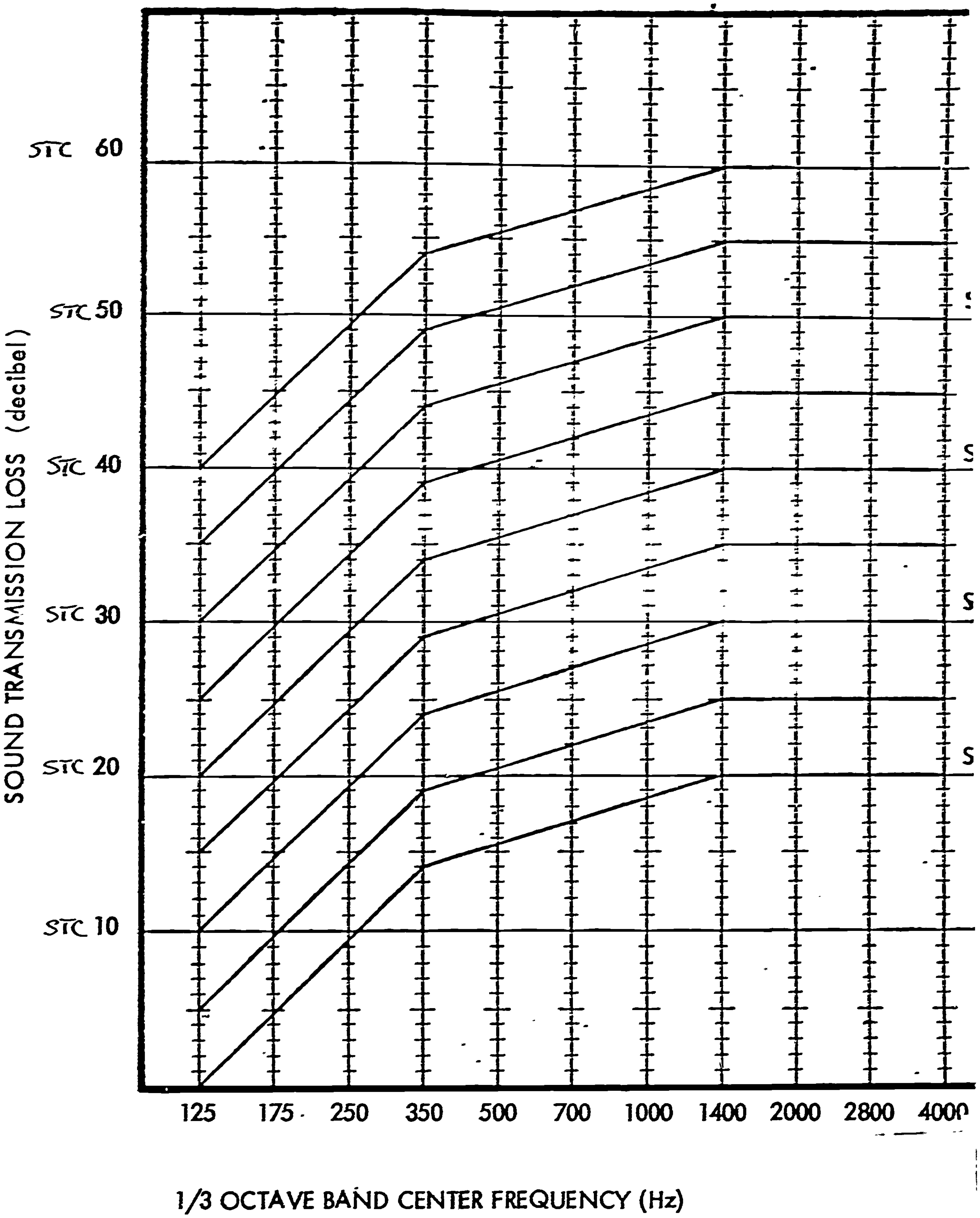
OPTIMUM REVERBERATION TIME AT 512 CYCLES

FOR 2/3 CAPACITY AUDIENCE FOR DIFFERENT TYPES OF ROOMS

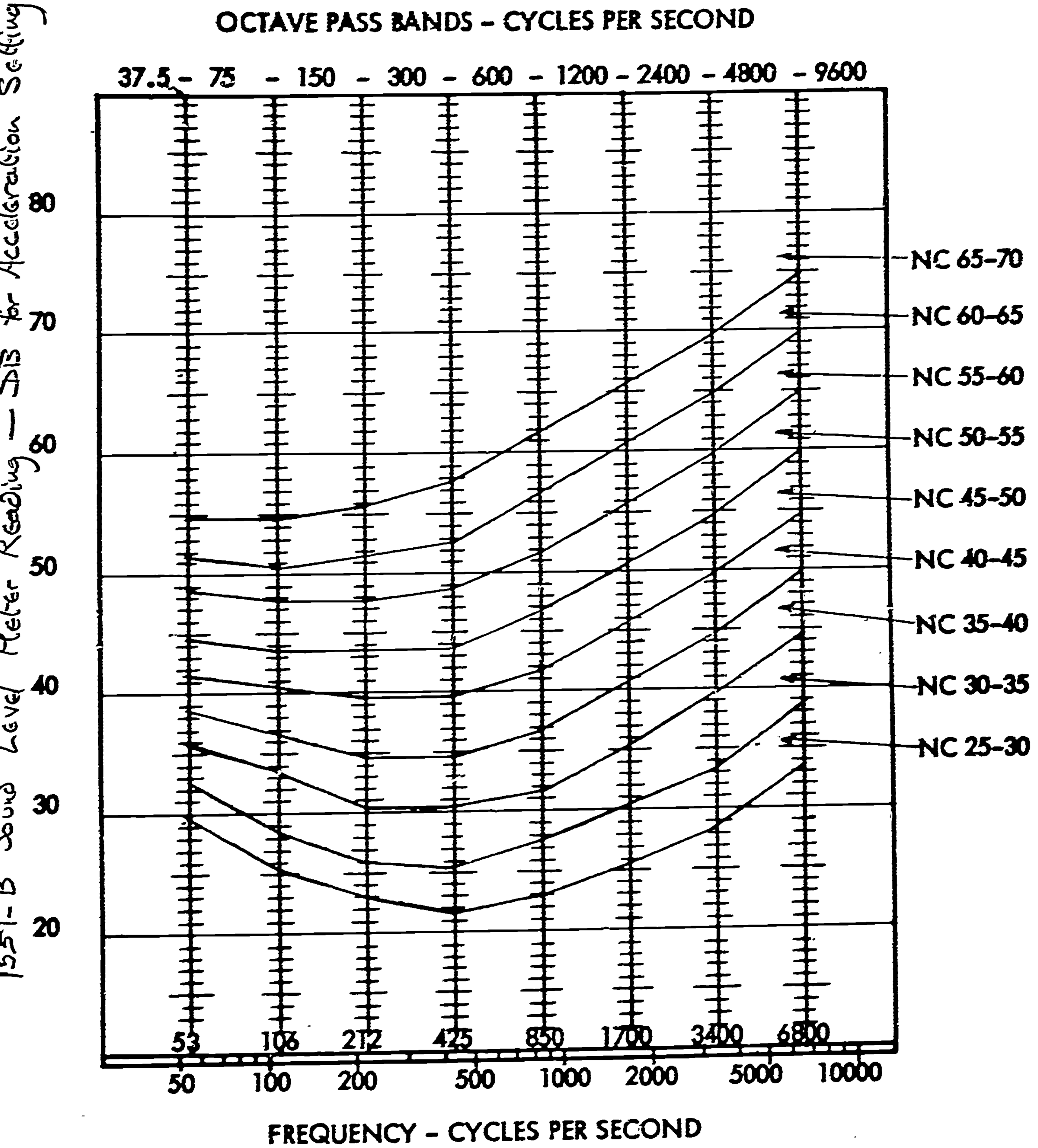
AS A FUNCTION OF ROOM VOLUME



90
80
70
60
50
40
30
20
10
SOUND PRESSURE LEVEL db RE: (0.0002 UBAR)
NC-70
NC-60
NC-50
NC-40
NC-30
NC-20
31.5
63
125
250
500
1000
2000
4000
8000
16000
OCTAVE BANDS CENTER FREQ (HERTZ)



SOUND TRANSMISSION CLASS CONTOURS.



Relation Between Floor Vibration and Noise Level in Room Below

SOUND SYSTEMS

Sound systems find more and more use in academic buildings. They are used to provide music in cafeterias and lounges and to address students in classrooms, amphitheatres and gathering halls. Intercommunication systems are also used to a large extent.

More than often, sound systems are not adequate from a point of view of uniformity of sound distribution and intelligibility, because the acoustical characteristics of the rooms in which the loudspeakers are installed were not properly accounted for. The number, the location and the acoustical power of the loudspeakers are directly related to the acoustical properties of rooms and their function. Sound systems must therefore be designed by system engineers working in close cooperation with acousticians.

CONCLUSIONS

Working in a pleasant environment is certainly more fruitful in all respects than working under adverse conditions of comfort. Acoustics in academic institutions rank on the same level as appearance, lighting and climatic conditions to provide comfort. These four conditions must work as a group. If any one is at fault the value of the others is badly impaired.

MR. BLOUIN: Thank you, Mr. Lortie. I am sure many of us now know a little more about vibrations and acoustics than before and it should be very helpful in planning our next buildings.

FORUM AND QUESTION PERIOD

CHAIRMAN: Jean Blouin, Université de Montréal.

PANELISTS: L.J. Lortie, N.J. Pappas & Associates.
R. Yeo, Western University of Ontario.
L. Doelle, Consulting Engineer.
J. Hamel, Université de Sherbrooke.

MR. BLOUIN: We have now reached the question period and I will ask the members of the panel to say a few words on the subject.

MR. YEO: Mr. Blouin asked me this morning to say a few words on this subject. We do not seem to start soon enough, in the planning of our buildings, to handle the acoustic problems that come along. So we recognize these difficulties only when we have them and then we have to do some expensive alterations or live with them. We can learn to recognize these problems perhaps if we have similar situations. It seems difficult to recognize the problems in new projects. Every building, every project is different. What we need is a method of finding the problems, new types of equipment, new types of construction. Probably noise control is one of our more serious problems. We must start earlier in our planning. I think the follow up on the installation is a point.

MR. HAMEL: I think Mr. Yeo had just about the same ideas as I have. I have taken notice of what was said this morning that there was a lack of communication from the start. I would like to add that the many problems we have with acoustics are very expensive to correct once the whole thing is done. Mr. Blouin was saying, they called in a consultant after this auditorium was finished. It is much better to have the consultant before.

MR. DOELLE: The subject of acoustic has been quite well treated by Mr. Lortie. I would just like to make a few comments particularly on room acoustics, because as you listen to the speech of Mr. Lortie, these are the two main problems, achievement for good hearing and the reduction of noise. Mr. Lortie pointed out the importance of speech intelligibility in an auditorium. What is speech intelligibility? When we provide good reception for the spoken word do we know what we are doing? We are tuning the auditorium for speech. We tune the auditorium in exactly the same way the violin makers tune their violins. We tune it to the sound of speech so that you understand the speech. I think that the tuning of an auditorium in an academic building is very important. The academic building auditorium is the instrument of education. It is the instrument of examination, of knowledge, and experience, and furthermore the instrument of friendship, mutual understanding, mutual respect, which is so important in this world to-day.

Another thing I would like to emphasize, in the provision of good acoustic conditions in an auditorium, the installation of a sound system is very important. It must be remembered that, in an auditorium in an academic building, there must be provided a two-way communication. One communication from the lecturer to the audience, and one from the audience back to the lecturer. If you are sitting in an auditorium it is different from a theatre or a concert hall. If you are sitting in a theatre you are a member of a large audience and you do not want to be identified. In a lecture hall you want to maintain your identity. You are an individual; you want to ask questions and these questions must be well heard and understood by the lecturer. This cannot be done where there is no two-way communication. How do you provide this? From the ceiling. The ceiling must be properly shaped in an auditorium, the room shape and the finish are all extremely important.

These where just a few remarks in this very short time and I conclude that the welfare of the academic buildings for which you are responsible are in very capable hands.

CHAIRMAN: The meeting is now open to questions from the floor.

MR. LEBEAU, NORTHEASTERN UNIVERSITY: Do you say that reverberation is about 8/10ths of a second in speech?

MR. LORTIE: It is dependent on the volume of the room, on a typical size of 4,000 c.ft.

QUESTION: There is one factor, I believe, you have no control over and that is the fixed relationship between the sound source and the reverberation sound except as a matter of distance.

MR. LORTIE: This is function of the room. It is mostly concerned in the design of the auditorium.

QUESTION: I wonder if the relationship is in the placement of your speakers. Arrange them in a manner that you would have an infused relationship so that your speech would not be interfered by the reverberation?

MR. LORTIE: Definitely. A sound system, as designed by a sound engineer, is one of the instruments to make the fusing of the loud speakers so that the distance between the speakers is counted and will not cause interference.

MR. HANSEN, UNIVERSITY OF HAWAII: You said there was a problem with this auditorium. I find it very comfortable. What was wrong and what did you do?

MR. LORTIE: This auditorium at this end is not very wide, and the problem is that when we talked here we did know if our voice carried. We had the impression that you could not hear us.

MR. THOMAS, CARNEGIE INSTITUTE OF TECHNOLOGY: If you have done everything you can to build a perfect room and to install a perfect sound system, what can be done to educate the person at the microphore to use the microphone as he should?

MR. LORTIE: Implement a training, I would suggest, and if you put this in the new rules for the auditorium and paste it on the door, then it might work.

Incidentally, I gave a talk along these lines. The editor of the university newspaper was interested and I have written an article in which I go after the people who refuse to co-operate with the P.A. man and I hope that it is widely read.

QUESTION: We are in the process of building a Science school. We are a very small school. We are going to have a lecture hall of 350 capacity and a P.A. system. How do you take care of the acoustics for a small group and for a lecturer?

MR. DOELLE: If you have an auditorium for 350, which is very small, I do not think that, once the room has been designed to carry the sound properly from sound source and a reasonable amount of acoustical material well chosen and suitably located, you will have no problem. A 350 auditorium is going to be about 60-65,000 cubic feet or less and this is a small room. If your lecturer has had some practice and is a trained speaker, you do not need a sound system. But the room shape must be properly designed, acoustical materials must be properly distributed.

MR. SIRE, SIR GEORGE WILLIAMS UNIVERSITY: I have a problem which is a little too difficult. We have air conditioning and ventilation systems which are well isolated as far as sound inside the building. But how can you eliminate noises to the street? We have many complaints. We turned to our consultants. They came up with an answer, but it amounted to $10,000. which is more than the equipment is worth. Is there an answer?

MR. LORTIE: First of all, it must be established what is the source of noise responsible for this amplification outside the building. If it is found, then the first thing is to put a silincer on the fan, the duct that gives transition reverse on the street and then the equipment may also need treatment.

MR. WRIGHT, UNIVERSITY OF OREGON: What effect does carpeting have?

MR. DOELLE: Carpeting is usually used along the floor but you do not need an acoustic treatment along the floor because the audience supplies to eliminate footsteps which might be irritating. From that point of view you do not add to the acoustical qualities of the room, or reverberation, but you do benefit by the elimination of shuffling noises.

QUESTION: You have developed formulas for controlling noise inside the building. Have you developed sound formulas for traffic noises, exterior noises, is there anything you can do about them?

MR. LORTIE: Usually noises from external sources are attenuated by the construction of the exterior walls of the building. Now in the case where you do have a noise source outside the building which is disturbing inside one way to counteract this is by adding noise to it in what is called masking noise. This is probably what Mr. Newman referred to by "perfume". The noise should be of such a nature that, even if it is low in level, it may be sufficient to mask the outside noise, Masking can also be provided by background music.

MR. DOELLE: I would like to point out that, since this is an extremely noisy world, we should not be too sensitive to noise because, on the one hand we cannot do too much about it, and on the other some people definitely enjoy noise. If you have ever entered a discotheque, and seen the future generation; how they enjoy the total environment in which there is noise and music on a very high level. I can assure you that the future generation will not be so sensitive to noise, and the noise criteria that has been so well detailed are going to be changed. We shall tolerate higher noise levels. So we better live with the noise.

MR. WEBER, UNIVERSITY OF MARYLAND: I understand that in the classroom, one place where you do not use acoustic was in the ceiling?

MR. LORTIE: Not in the case of classrooms. When we refer to classrooms we have in mind a room to accommodate 30 people in which case we do not use the ceiling to carry the voice, but the walls. The length of the room in a classroom is such that we can carry the sound waves without special treatment. But in the case of an auditorium or an amphitheatre, then the ceiling is used to carry the sound waves to the back. But generally, not in classrooms.

MR. DOELLE: If you would ask me what is the most important recommandation for good acoustics in an auditorium, I would say that requirement No. 1. would be acoustic treatment of the ceiling.

MR. MCKAY, UNIVERSITY OF TENNESSEE: Can you give a statement of the tolerable noise for a telephone office which might be located next to our equipment area. Is this a realm of high tolerable noise?

MR. LORTIE: As quoted in the Index of noise control, for proper telephone conversation NC 40 is about the limit, at 45 it becomes difficult and at 50 or over it is impossible. NC 40 would be the minimum tolerable noise where telephones are used.

CHAIRMAN: I would like to thank the members of the panel for their participation.