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16. ABSTRACT

Several studies have been made and reports prepared on the amount of noise developed on modern highways. Reports of sound studies employ terms and units which may not be clearly understood by those unfamiliar with acoustical engineering. The following discussion was originally prepared and issued to the Districts as an informational memo (FNH/ #9) on August 2, 1955. This memo revises and brings the original information up to date and with your permission copies are being forwarded to the District Engineers.

The question of noise or the effect of noise upon people is becoming a matter of concern to many agencies and individuals. With the spread of industrialization and the more rapid tempo of modern life there is increasing resentment toward unnecessary noise and a consciousness of need for peace and quiet. Many noise and a consciousness of need for peace and quiet. Many manufacturing firms are giving serious consideration to the problem of noise reduction in their operations. And as a result the demand for acoustical engineers far exceeds the supply. Quoting from an article called "Noise and your Nerves" condensed from the publication "Weekend": "This continuing -- and increasing -- assault on our ears is causing grave concern among those people who specialize in sound. Occupational deafness is shaping up as a major issue in the compensation claims of disabled workmen. A report of the American Standards Association discloses that after five years' exposure to 88 decibels of noise there is an appreciable hearing loss." As will be shown later the figure 88 decibels is less than the noise generated by heavy truck traffic on a modern industrial highway.

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State of California
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Materials and Research Department
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November 1961

Highway Noise

To: Mr. J. C. Womack

From: Mr. F. N. Hveem

Several studies have been made and reports prepared on the amount of noise developed on modern highways. Reports of sound studies employ terms and units which may not be clearly understood by those unfamiliar with acoustical engineering. The following discussion was originally prepared and issued to the Districts as an informational memo (FNH/#9) on August 2, 1955. This memo revises and brings the original information up to date and with your permission copies are being forwarded to the District Engineers.

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Highway engineers in the metropolitan areas of the state are aware that large segments of the public are something less than enthusiastic about living close to a major highway or freeway and we are informed by the Right of Way Department that often the objection to potential traffic noise is one of the major obstacles to be overcome by those who must purchase rights of way for highway construction. A brief resume of the nature of sound and some illustrations of the more commonly used acoustical terms may be of help in understanding the reports which highway engineers will undoubtedly be called upon to study and evaluate more often as time goes on.

THE NATURE OF SOUND

As commonly used the word has two meanings. According to Webster's dictionary under a. Psychophysics, sound is the sensation due to stimulation of the auditory nerves and auditory centers of the brain, usually by vibrations transmitted in a material medium, commonly air. Under b. Physics, sound is vibrational energy which occasions such a sensation.

Sound waves in the air consist of alternate compactions and rarefactions of air pressure (Fig. 1b). Sound waves may be set up by any vibrating substance - gaseous, liquid or solid (Fig. 1a), and while they may be transmitted through water or through solid bodies we are here primarily concerned with sound waves transmitted through the air.

As sound waves tend to radiate from the source in all dimensions, they are usually spherical in shape and travel at a definite speed. At 70 degrees F, sound velocity in the air is about 1126 feet per second. If the frequency of the waves lies somewhere between 20 and 16,000 cycles per second and is of sufficient intensity, they will register on the auditory nerves and produce the sensation of hearing. Whenever the frequency of the sound is doubled, the pitch is raised by one octave. Conversely, whenever the frequency is cut in half the pitch is lowered by one octave and the acoustical engineers have recognized the octave series as is customary in scales and notation of musical sounds (Fig. 2). The octave series most commonly used in acoustical engineering is 62.5, 125, 250, 500, 1000, 2000, 4000, and 8000 cycles per second.

Sounds of steady repetition rate (frequency) have a definite pitch or tone. Musical sounds are usually made up of two or more frequencies whose combination is pleasing to the ear. Noise that is lacking in tone-like quality is made up of random vibrations which are not of constant frequency (or frequencies). However, noise may also be described as any unwanted sound. Highway traffic, which produces noises that are definitely non-musical, radiates an extremely large number or broad band of random and constantly shifting frequency components.

NOISE MEASUREMENTS

Sound level meters measure or express the intensity level of sound in decibels (abbreviated "db"). By agreement between various technical groups, zero decibels represents a sound pressure of 0.0002 microbar which is a reference sound level that can just barely be distinguished by sensitive normal hearing in a very quiet location such as an anechoic chamber.

Unless the zero reference level is stated, the decibel figure represents only a means for expressing the ratio between two amounts of acoustical energy or its electrical equivalent. The number of decibels denoting the ratio of any two sound intensities is defined as 10 times the logarithm to the base 10 of that ratio:

Example:

I_1 = Sound intensity number 1

I_2 = Sound intensity number 2

N = Ratio, in decibels

Then:

$$N = 10 \log_{10} \frac{I_1}{I_2}$$

Therefore if I_1 is 1000 times I_2, the logarithm of their ratio, 1000, is 3, and the number of decibels is 3 times 10 or 30. We say that the intensity I_1 is 30 db above intensity I_2.

As stated, the zero reference level for sound level measurement has been agreed upon as 0.0002 microbar. One microbar equals a sound pressure of one dyne per square centimeter. In average surroundings anything below 24 decibels can be considered so nearly inaudible as to be of no importance. Typical sound levels in decibels are shown in Figure 3. In the scale shown in Figure 3 the threshold of sound that can be detected by those having acute hearing is rated as zero decibels. The gentle rustle of leaves in a light breeze is approximately 18 decibels. The average home is somewhere around 40 to 45, ordinary speech at 65, and the threshold of pain from noise is at about 120 decibels.

The least difference in loudness that the average ear can detect is about 1 decibel. Doubling a given sound power raises the level only 3 decibels. But doubling the power does not double the sound. It requires about 9 decibels or approximately 8 times as much actual sound power to double the sound heard by our ears. Figure 4 shows this relationship of decibels to sound intensity changes and is seen to be approximately logarithmic.

As soon as a layman or an engineer other than one of the acoustical variety begins to read reports on sound measurements he is often confused by the fact that there are three different scales in common use identified as A, B, and C scales. The question has been asked, Why do sound level meters have A, B, and C scales and what do they mean? Studies have shown that the human ear does not respond equally to sound pressures or intensity at all points on the scale and a series of isobars have been drawn known as equal-loudness contours (Fig. 5). These curves show the amount of sound needed at the various frequencies to produce apparently equal sound to a series of reference levels at 1000 cycles per second.

The newly revised weighting networks (A.S.A. S1.4-1961) for A, B, and C scales are shown on Figure 6. Originally, the A-scale was intended for measurements below 55 db, the B scale for measurements between 55 db and 85 db, and the C scale for measurements above 85 db, in reasonable accord with the equal-loudness contours at these levels.

While the translation of sound into these arbitrary scales does not make the sound level meter "hear exactly like a human ear", it is a more or less reasonable rationalization in that direction. (For the purpose of measuring truck and automobile noise, the A scale has some unique advantages that will be discussed later.)

The equal-loudness contours show that the ear is most sensitive to sounds between 1000 and 6000 cycles per second. It follows that noise which contains a high percentage of these frequencies can cause more annoyance or discomfort than a similar level of noise made up of frequencies below 500 cycles per second. Fortunately, the noise above 1000 cycles per second is more easily reduced or absorbed by mufflers, embankments and sound absorbent materials of any kind.

TRAFFIC NOISE

Noise produced by traffic on the highways naturally is composed of a composite of all frequencies and a wide range of intensities. Pure musical tones are virtually non-existent. Vehicular noise studies in the City of Milwaukee led to the enactment of an ordinance in June 1954 to control the noise level. A number of tests were made and meter readings compared to the opinion of a selected jury. Traffic noises were rated as either noisy or "reasonable". The jury response was quite consistent with the meter readings and agreed that vehicle noises above 95 decibels were "noisy" and objectionable while traffic sounds below that level were considered "reasonable". Further discussion led to the conclusion that a transition zone or tolerance range was necessary for practical enforcement, as a level substantially below 95 decibels was obviously needed to evaluate unreasonable noises for a residential neighborhood in the middle of the night. As a result the Milwaukee ordinance provides:

"1. In terms of s. 85.36, Wis. Stats., that no motor vehicle should be operated unless equipped with a muffler to prevent excessive or unusual noises or annoying smoke.

2. That to determine whether a vehicle is producing excessive or unusual noises:

   (a) A decibel meter measurement (on the B scale) showing noises in excess of 95 decibels (at a distance of 20 feet from the right rear wheel) shall constitute and be admitted as prima facie evidence that the vehicle was producing excessive or unusual noises.

(Ed. note: This is practically equal to A scale values of 88 dba at 25 feet or 82 dba at 50 feet.)

(b) Similar evidence that a vehicle was emanating less than 95 decibels but more than 85 decibels shall be relevant evidence in determining whether or not the vehicle was emanating excessive or unusual noises.

(c) Evidence that a vehicle was emanating sound of 85 decibels or less is conclusive that the vehicle was not emanating excessive or unusual noises.

The ordinance provides that the measurement should be made either:

(1) At a point 20 feet from the right rear wheel of the vehicle while the vehicle is parked with its motor running at its highest speed, or

(2) At a point not less than 20 feet from the right rear wheel of a vehicle in motion as the vehicle passes the meter. For purposes of enforcement the second procedure is being used."

It is interesting to note that the Milwaukee ordinance based upon jury findings appears quite logical when compared to the scale shown as Figure 3.

NOISE CONTROL OR REDUCTION

So far as we are aware the Milwaukee example is the first attempt to control noise by law or by ordinance in which a definite meter reading in terms of decibels has been established, and it seems most probable that the increasing public resentment toward unnecessary noise will lead to further enactments or legislation, especially for residential areas along heavily traveled highways. The insulation of buildings against sound and the erection of noise barriers are other possibilities. It is axiomatic, of course, that noise reduction at the source is more effective and almost certain to be less costly than the erection of noise barriers.

In conclusion, it should be mentioned that the decibel unit is not everywhere regarded as satisfactory for expressing the loudness of sounds. Work done at M.I.T. led to a scheme of rating loudness known as "the equivalent tone method". This method has been simplified by personnel of the Armour Research Foundation and loudness is expressed in terms of units called "sones". [1,4] Sones are claimed to be simple units for the layman to deal with because their value is such that 20 sones sound twice as loud as 10 sones, and 5 sones sound one-half as loud as 10 sones.

The sone method of rating loudness is not a direct one. It involves octave band analysis and comparison with equal-loudness contours on especially prepared charts. No simple formula is applicable and no meters have been approved for reading these values directly from a scale. However, Donald P. Loye[2] has shown that sones can be graphically related to dba with reasonably good accuracy when the noise is from trucks or automobiles. This relationship is shown on Figure 7. The variation is seen to be within ± 2 decibels. For comparison, Figure 8 shows that C scale readings (dbc) are not suited to translation into sone values. The variation is ± 7 decibels. The error for B scale readings is not presented here, but the variation is about ± 5 decibels. The advantage clearly favors the A scale. Recognition of this advantage probably influenced the U. S. delegation at the International Organization for Standardization (I.S.O.) meeting at Rappallo, Italy, in March 1960. During this meeting Technical Committee No. 43 on Acoustics changed the recommended weighting network from B to A for measurement of vehicular noise. This change was made because of the strong stand taken by the U. S. delegation preferring the A-weighting network and the experimental evidence they presented.

The foregoing is intended to give only a few of the relationships involved in the numerical expression of sound. For those interested in further information, the latest edition of the "Handbook of Noise Measurement" published by General Radio Company, Cambridge 39, Massachusetts, is recommended.

F. N. Hveem

F. N. Hveem
Materials and Research Engineer

Attach.

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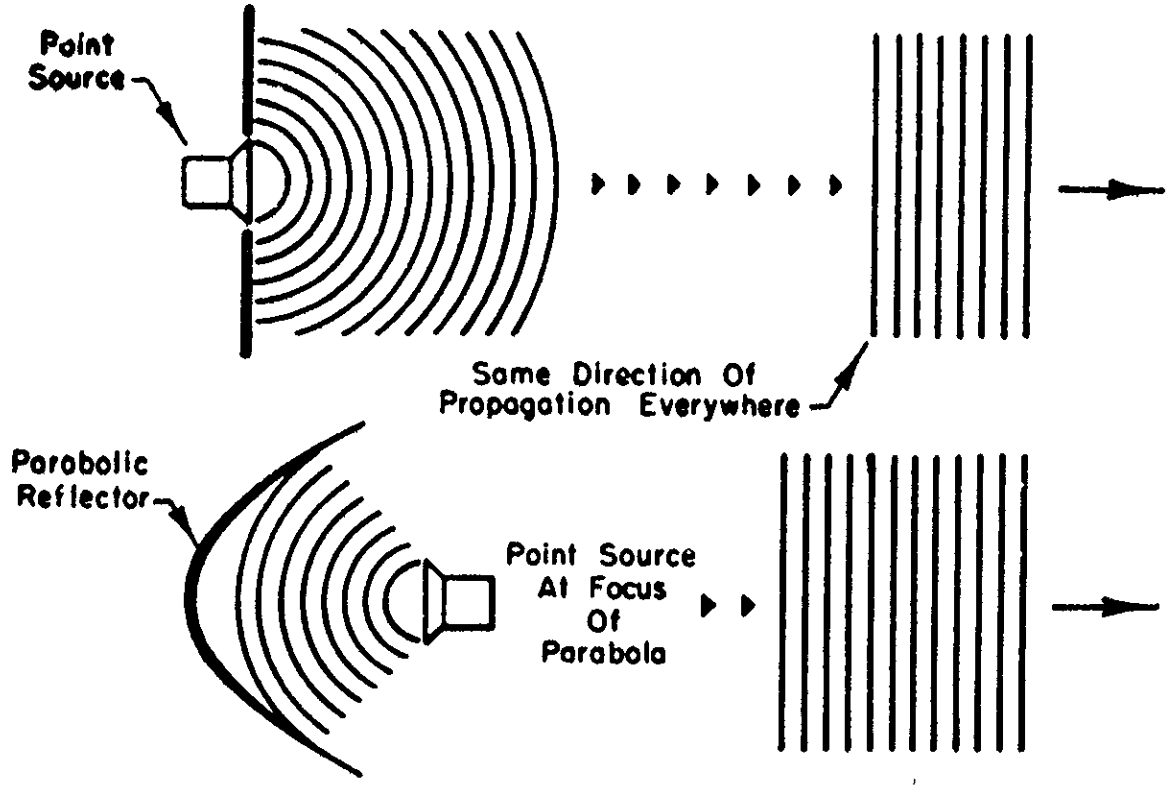


Fig. 1a
Generation of plane acoustic waves.

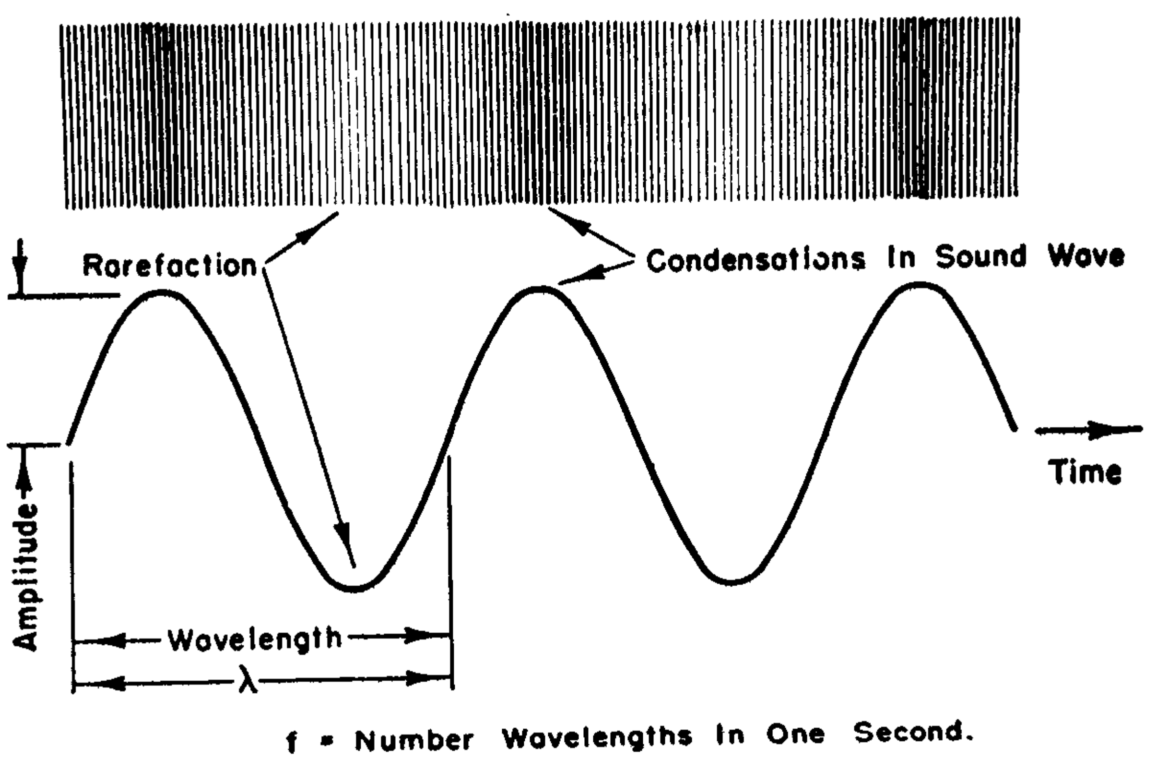


Fig. 1b
Sinusoidal sound wave.

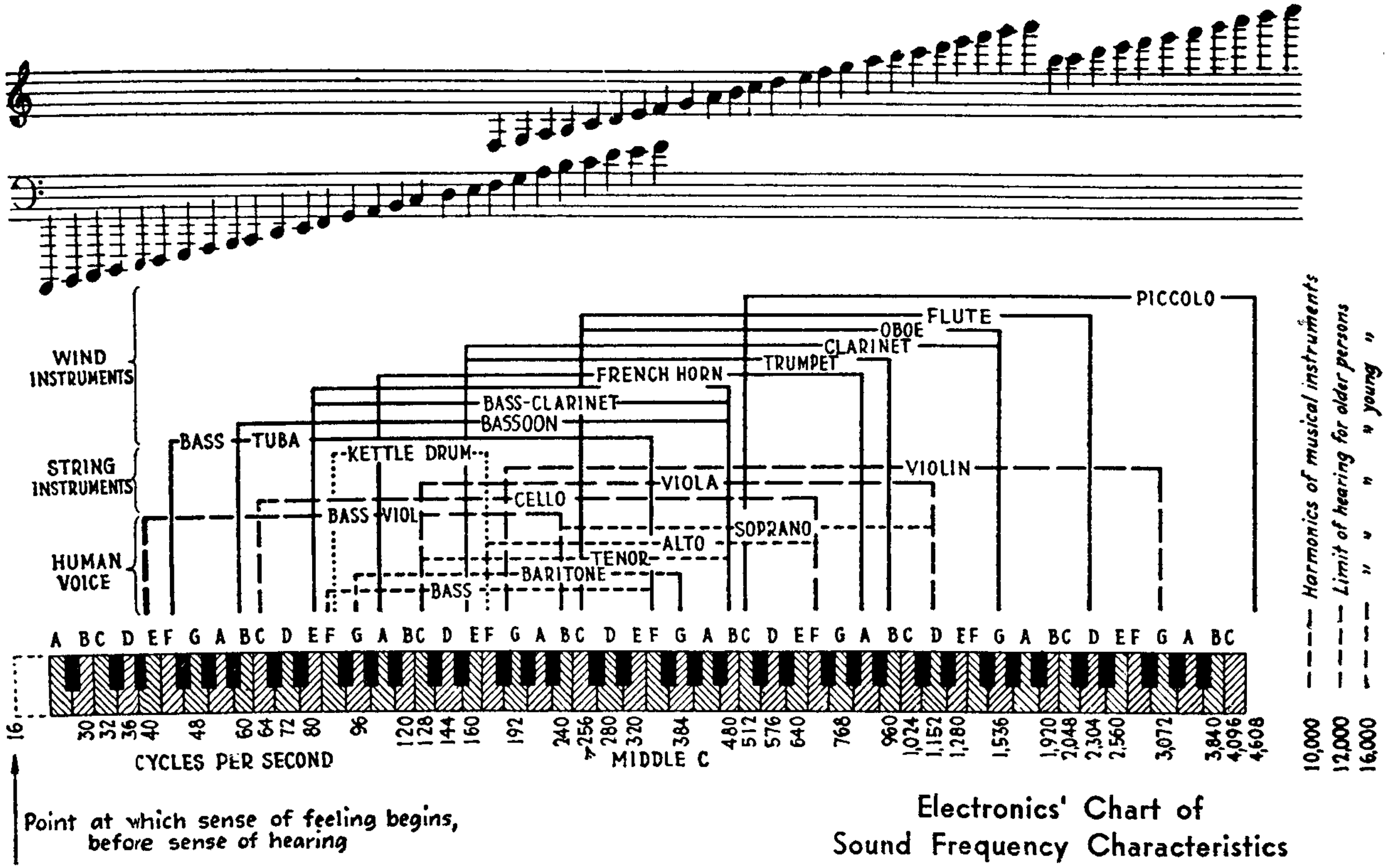


Fig. 2
Frequency ranges of various sounds and sound-reproducing devices.

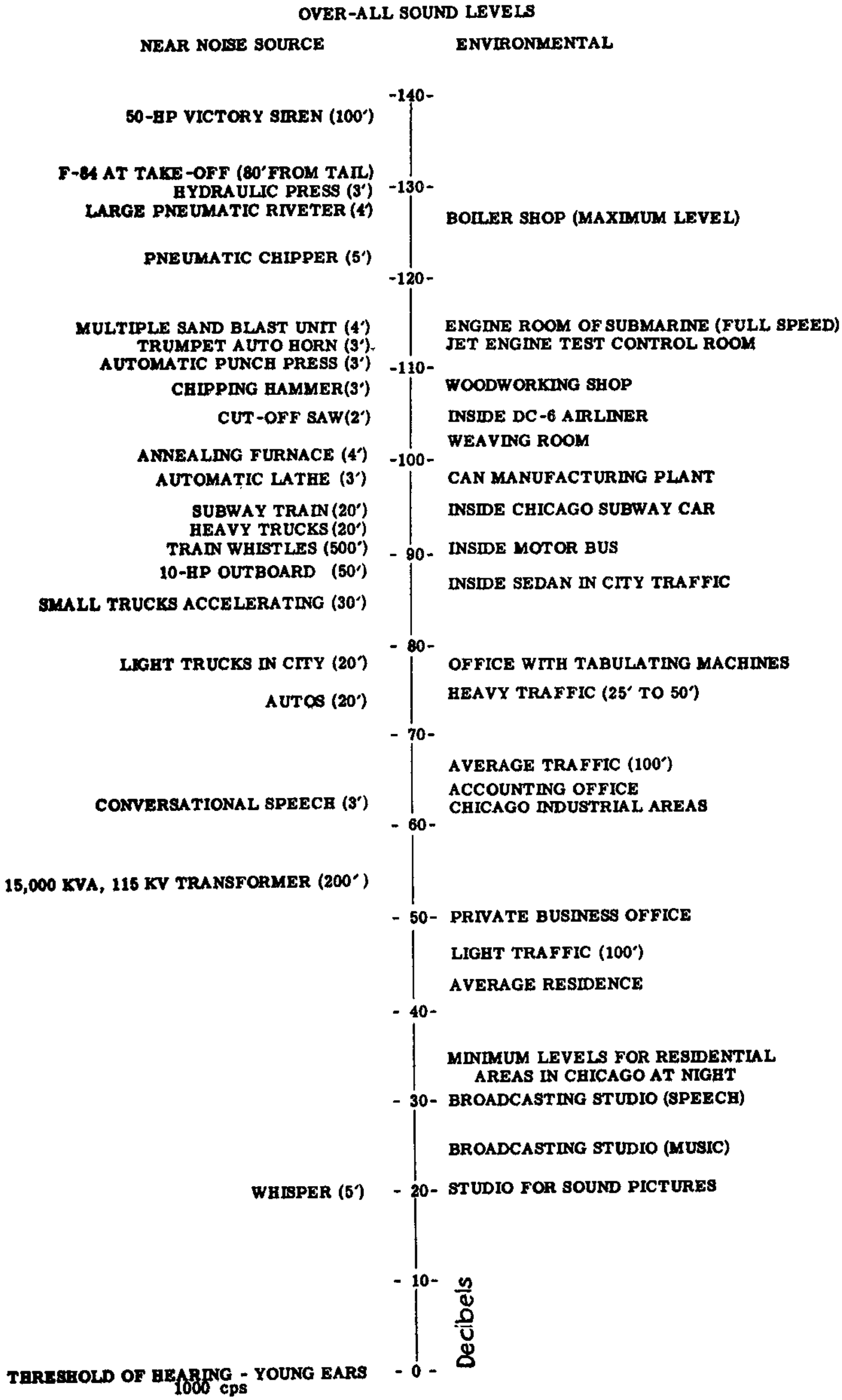
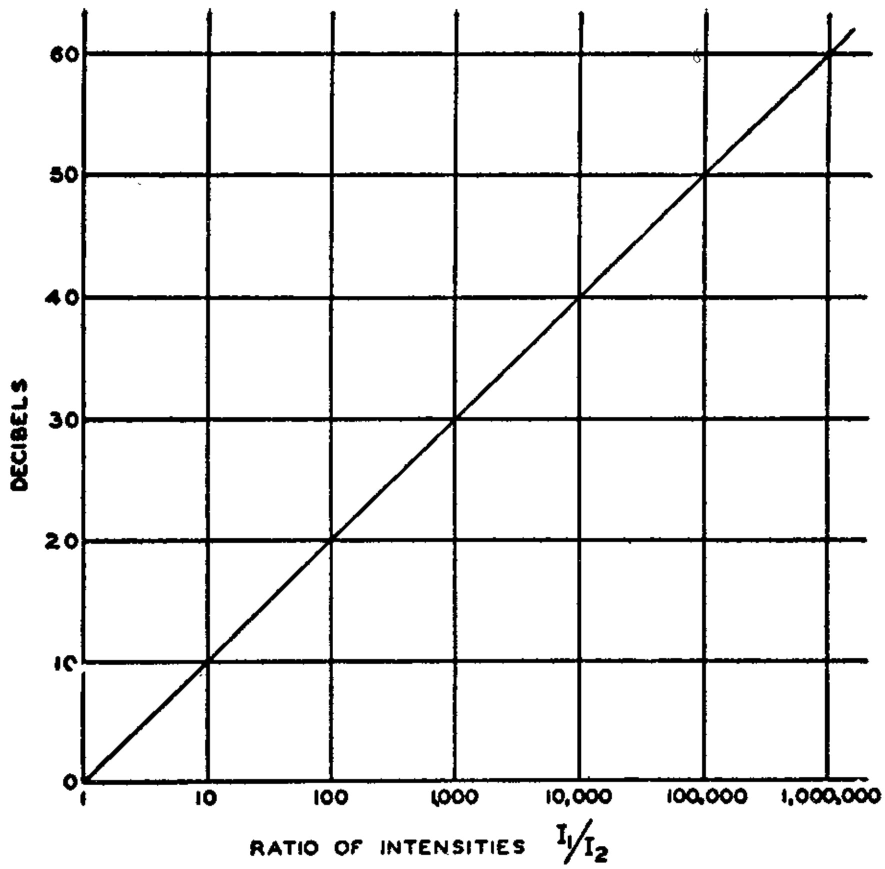
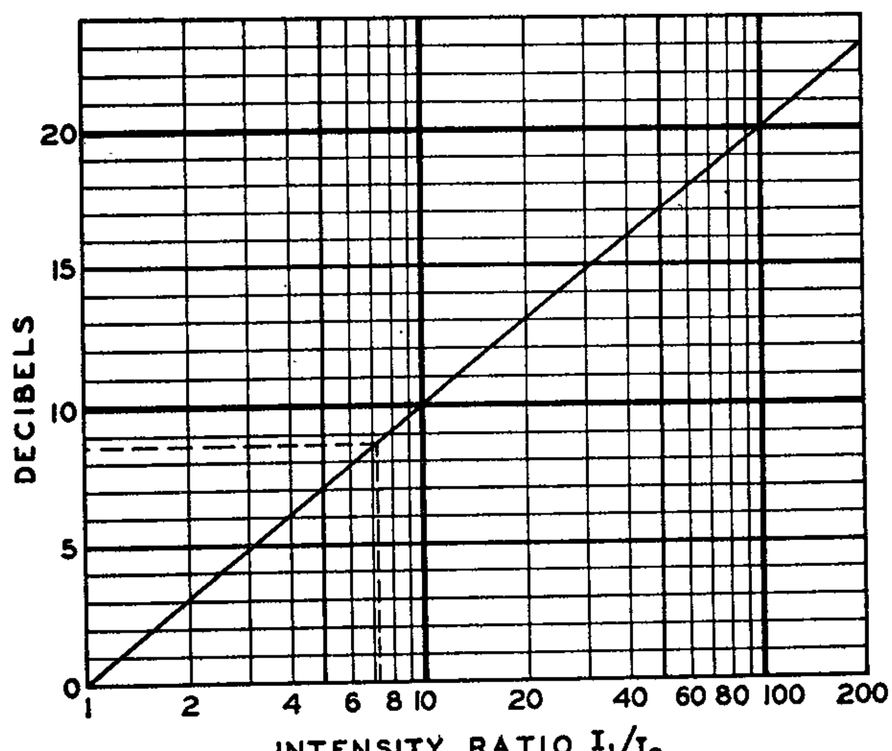


Figure 3 Typical sound levels.



A



B

Fig. 4

Relation of decibel scale to intensity ratios. Graph B is a magnification of the lower left portion of Graph A.

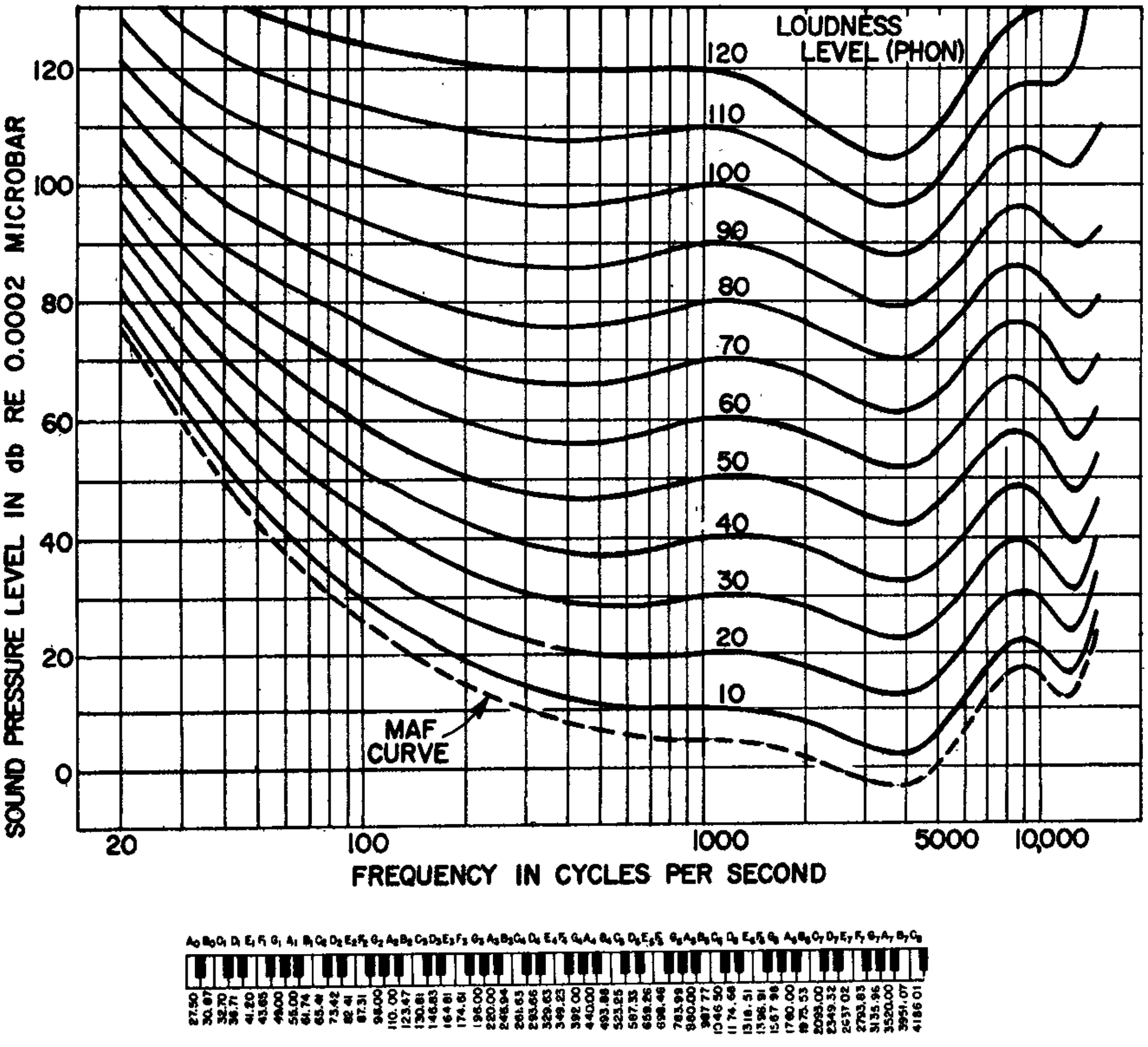


Figure 5 Free-field equal-loudness contours for pure tones, determined by Robinson and Dadson at the National Physical Laboratory, Teddington, England. Piano keyboard helps identify the frequency scale. Only the fundamental frequency of each piano key is indicated.

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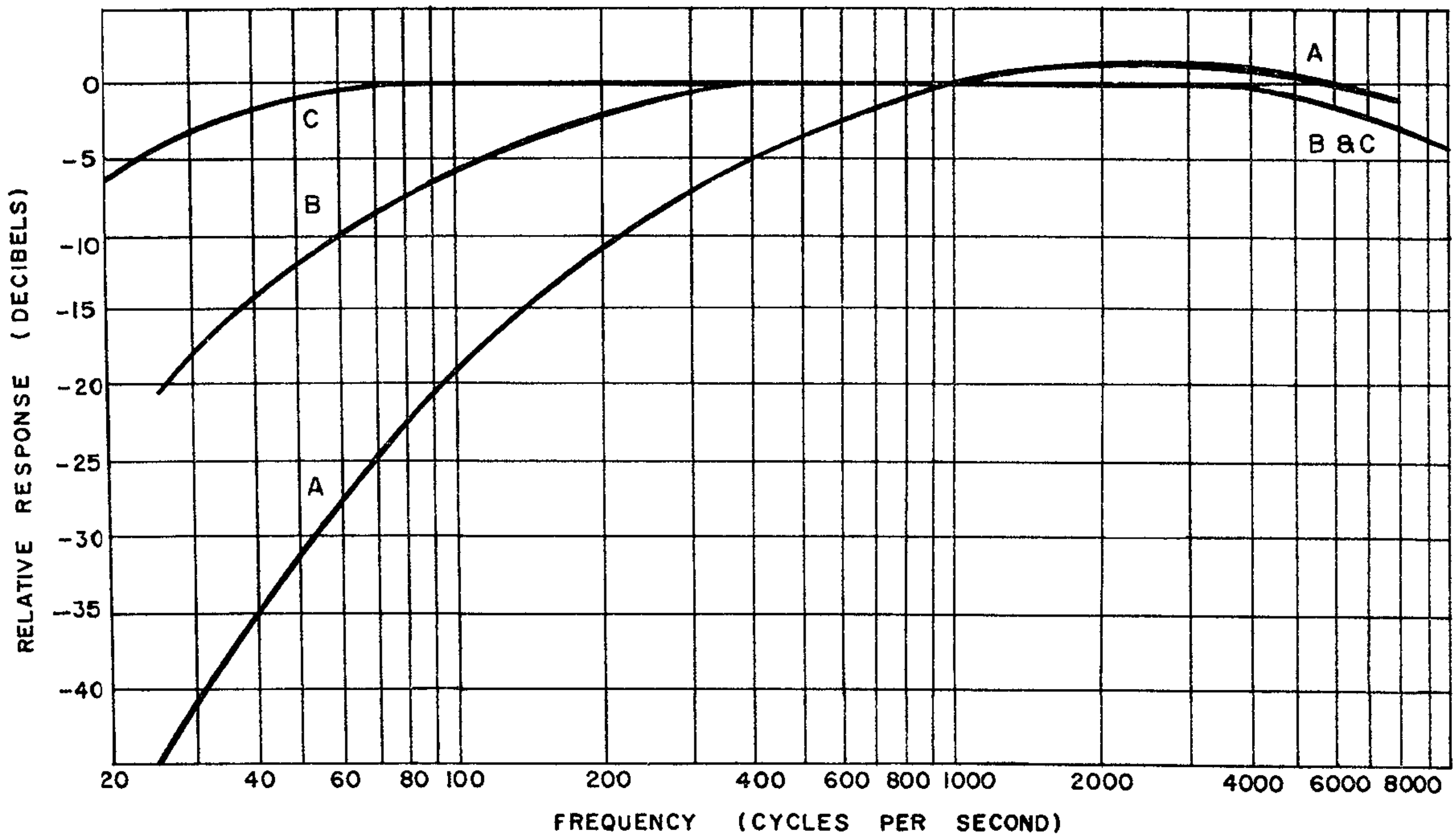

Fig. 6

Random-Incidence Response
Of Sound Level Meter
For Different Networks

ASA S1.4-1961

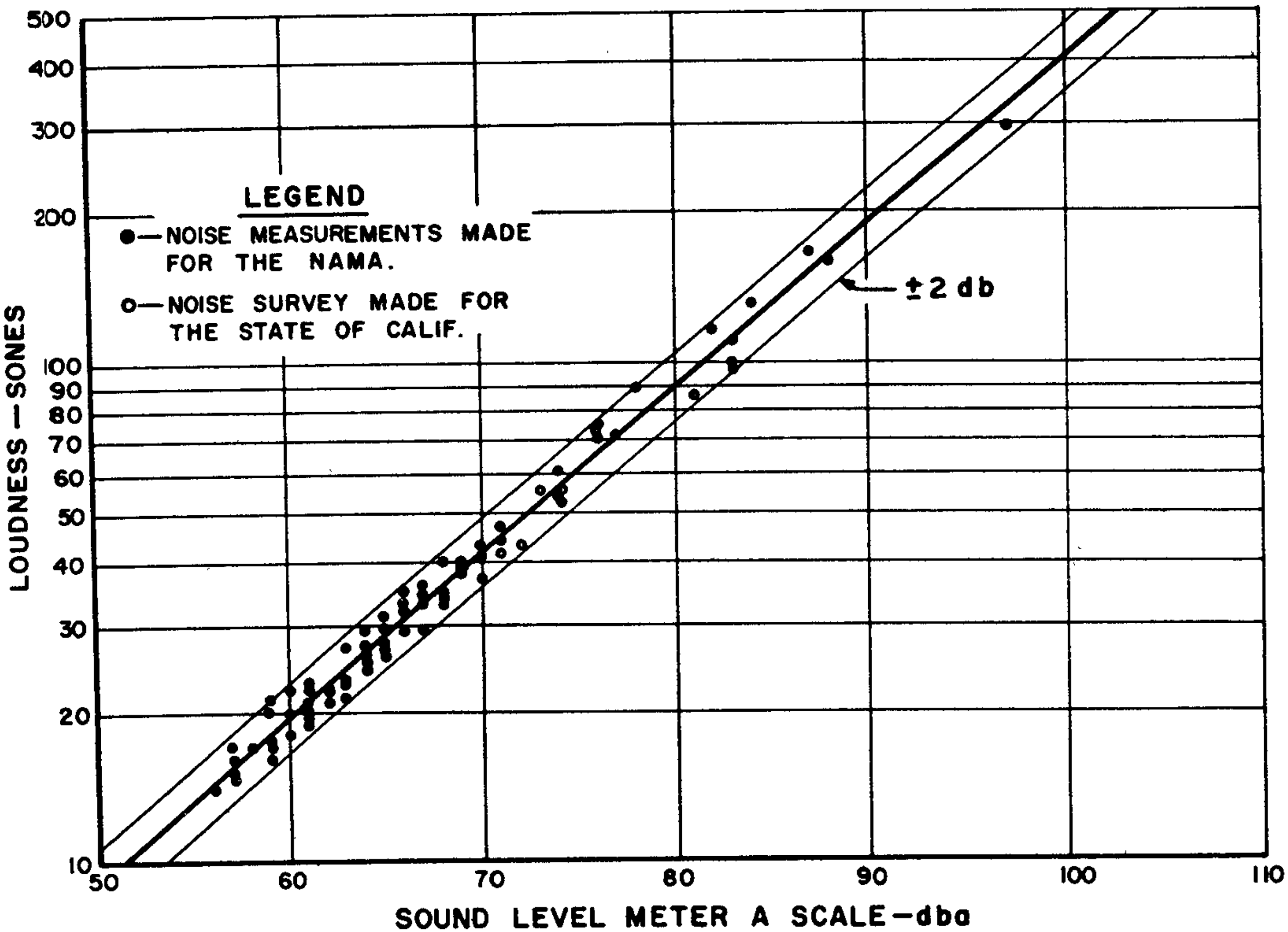

Fig. 7. Relationship between loudness in sones and A-scale noise measurements.

(after Donald P. Loye[2])

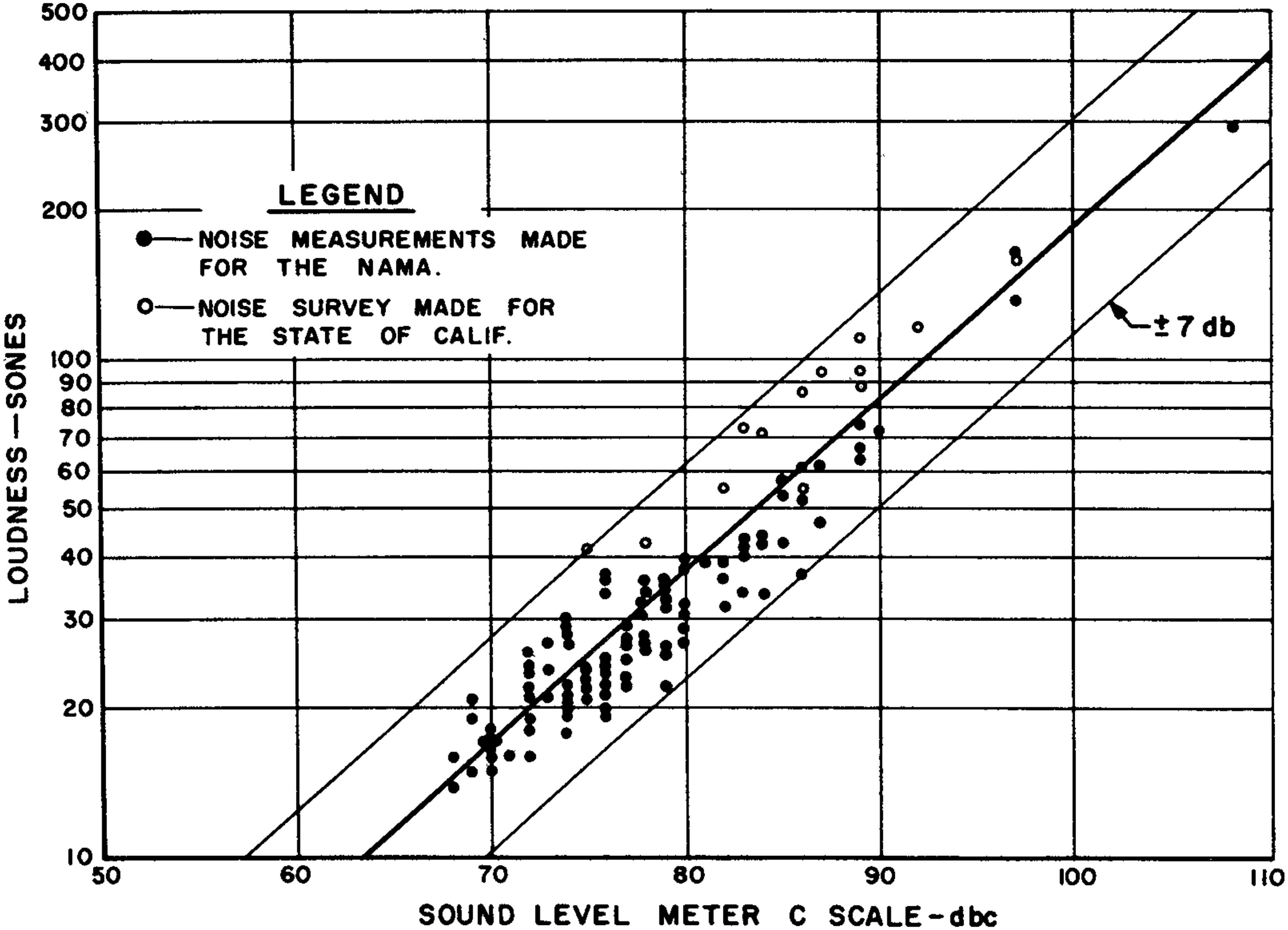

Fig. 8. Relationship between loudness in sones and C-scale noise measurements.

(after Donald P. Loye[2])