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SUBJECT Correlation of Sound Absorption Test Methods

The purpose of this note is to review the present state of knowledge regarding the sound absorption of acoustical materials and to discuss a program for evaluating absorption test methods. The note will discuss in particular the significance of the reverberation room measurements of sound absorption and their relationship to other measurements such as acoustic impedance.

It was originally envisaged that the project might include a consideration of the performance of typical rooms. Certainly one should keep in mind that the ultimate application of absorption test results is in room acoustics, but the design of ordinary rooms introduces so many special problems that the present program will be confined to a study of test methods. Let it suffice to say that the most useful quantity in the acoustical design of rooms is the random-incidence absorption coefficient. The objective of Committee C-20 should be to determine how reliable values of this quantity can be obtained.

Impedance Tube Measurements and the Random Incidence Absorption

It is a straightforward matter to measure the normal-incidence acoustical impedance of a small sample of material. In principle, if the material is "locally reacting", one may then calculate the random-incidence coefficient for the material. There are two reasons why this is not a satisfactory general method for evaluating acoustical materials: (1) many materials are not locally reacting. For example most suspended ceiling systems consisting of a perforated surface backed by the absorptive air space would not meet this requirement; (2) the behaviour of many materials depends on the way individual panels of material are mounted, and the small specimens that can be tested in an impedance tube do not demonstrate these effects.

The first difficulty might be overcome by developing methods for measuring the impedance at selected angles. Such methods have been tried experimentally but generally they are applicable only to small samples, whereas departures from the locally-reacting state occur most often when large structures are involved(e.g. suspended ceilings, and systems in which the absorption mechanisms involve diaphragm vibration). The problem might be overcome by making measurements on a large panel in a free field. The largest panel that can readily be dealt with in most free-field rooms would, however, be small enough that diffraction effects would introduce a complication. It is therefore doubted that either technique would be useful as a general practice.

For materials that are locally reacting however, it should be possible to make correlations between tube and reverberation room results. This possibility is explored in a later section.

Reverberation Room Correlations

During the period 1951-1953, a round robin program of measurements was carried out under the auspices of A.S.T.M. C-20. Samples of three different types of acoustical material were carefully prepared and circulated to seven reverberation room establishments in North America. The results of this program will not be discussed in detail but a few general comments may be made. The seven laboratories carried out their tests by using nominally the same method, although at this time no standard document existed. As a result there were many important variations in technique: two laboratories used sample areas smaller than the customary 72 square feet; several laboratories made an empirical area correction; and at least one laboratory failed to mask the edges of the samples. It had been anticipated that the major disagreement would be at the lower frequencies, but this was not the case. Agreement was fair at the lower frequencies, but there were large and inexplicable variations at the higher frequencies.

Two of the participants, Riverbank Acoustical Laboratories and N.R.C. Canada, represented, on the average, the extremes of the observations, and a careful examination was therefore made of the techniques used at these establishments. After a few minor changes an additional series of intercomparisons were made between these establishments and close agreement was found. (It is believed that the major discrepancy originally was due to the fact that the edges of the sample were not masked at N.R.C.) Another complete round robin was contemplated but has not yet been proceeded with. Further experimental work with the same samples has since been done by N.R.C. Canada, in connection with the commissioning of a new reverberation room. Close agreement was obtained between these tests and the earlier comparison. Thus, it appears that Riverbank and N.R.C. obtain good agreement in sound absorption measurements. This, of course, does not guarantee that the quantity being measured is the "random-incidence sound absorption coefficient".

Beginning in 1959 the I.S.O. Technical Committee 43 sponsored a new round robin series in which a large number of European laboratories participated. As in the case of the A.S.T.M. round robin, the results demonstrated forcibly that variations in technique that had been considered unimportant were in fact very important. It was decided to hold a second round robin with more careful control of two of the principal variables: the size of sample, and the diffusing system used in the room. Tests were made on three sample areas: $4m^2$, $8m^2$, and $12m^2$, and under at least three diffusion conditions. In general the results varied in erratic fashion under minimum diffusion conditions, but settled down considerably as the maximum diffusion condition was approached. The recommended diffusion system consisted of a large number of flat plates, totalling an area equal to the floor area of the room, suspended randomly in space. This system greatly reduced the spread in results at high frequencies. There still appeared however to be a variation with volume of test chamber and it was surmised that it was more difficult to obtain the required diffusion condition in a small room, especially with a large sample. A group of laboratories with small rooms were ruled out on this basis. The five remaining laboratories still showed a fairly wide variation in results, but as will be shown later, the average of the results obtained by the five laboratories is probably very close to the "true" sound absorption coefficient.

At N.R.C. Canada, one of the five remaining participants, an additional series of experiments was carried out in a search for the cause of the remaining spread in results. These experiments, which will be discussed more fully later, indicated that alterations in sample position and in the exact arrangement of the "randomly" spaced diffusing panels produced significant changes in the results. (See Figures 3, 7 and 10). Hence it appears that these matters require further study before a specification for satisfactory test conditions can be set down.

Effect of Sample Dimensions on Measured Absorption

One of the complications of the absorption measurement is the fact that the absorption of a patch of material depends on its dimensions. If a patch of material is placed on (or set in) an otherwise highly reflecting surface, the material near the edge of the patch absorbs more than its quota of energy, with the result that the average coefficient for the patch is increased over the value for infinite area. Thus, strictly speaking, in the reverberation chamber we measure the absorption of a particular sized patch of material. The term "absorption coefficient" implies a quantity which is dependent on the material only and not the dimensions of the sample under consideration, but it is customary to assume that this quantity refers to a patch whose dimensions are large enough that diffraction effects are negligible.

Most laboratories have accumulated experimental evidence of the area effect since Chrisler's measurements in 1934. Unfortunately, the uncertainties associated with reverberation room measurements are such that it has been difficult to obtain a reliable quantitative relation. Several attempts have also been made to calculate the diffraction effect. It is proposed to discuss in particular the calculations made at N.R.C. a year or two ago. (Reference 1).

Figure 1 shows the calculated random incidence absorption coefficient as a function of sample dimensions, and the real part of the admittance, and also the available information regarding the effects of the imaginary component of admittance. The oblique straight line to the left of the figure is the limiting value of the absorption coefficient for a very small area. At this limit the coefficient is independent of the imaginary component of admittance. The upper family of curves shown between this limiting value and the infinite area value ((1/ka)= 0) are for materials whose imaginary coefficient is zero. In addition, at the bottom of the figure are plotted another family of curves for infinite area, showing the effect of an imaginary component. At present nothing is known about the effect of the imaginary part for patches of intermediate size. Also it should be remarked that these curves are based on a rather small number of calculated points. It is planned this summer to re-calculate the diffraction effect for additional values of admittance and (1/ka), and possibly also to determine the effect of an imaginary component for a few cases.

In the meantime, these curves have been used to calculate the random-incidence absorption of the I.S.O. round robin material for the areas tested. Some of these results are

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(1) Northwood, T.D., M.T. Grisaru, and M.A. Medcof. Absorption of sound by a strip of absorptive material in a diffuse sound field. Journal, Acoustical Soc. of America., Vol. 31, No. 5, May 1959, p. 595-599. (NRC 5163)

shown in Figures 2 to 10, which will be discussed in detail later. Actually, two calculations have been made. First the upper set of curves of Figure 1 were used to determine absorption coefficient with the imaginary part neglected. This is the upper dashed curve on Figures 2 to 10. The lower dashed curve was obtained by subtracting from the upper one the infinite-area correction due to the imaginary part. Provisionally, until further diffraction calculations are made, it is assumed that the true value will be between these two calculated values (i.e. it is assumed that for finite areas the imaginary component has an effect somewhere between the small-area and infinite-area value).

Reverberation Theories

In reverberation room measurements and in acoustical design, the Sabine reverberation formula is almost universally used. The view is usually held that the Norris-Eyring formula is the correct one but that the Sabine formula is an adequate approximation, considering the other uncertainties of room acoustics. In a recent paper however, R.W. Young takes the view that the Norris-Eyring formula is applicable only for a room in which the boundaries have uniform acoustical properties. In the reverberation room, which represents a drastic departure from this condition, it is usually assumed that each surface material absorbs in proportion to the product of its area and its absorption coefficient (apart from diffraction effects). Young argues that this is an unwarranted assumption and suggests that the geometric mean assumed in the Millington-Sette formula is just as probable. He goes on to point out that the Sabine formula is similar to the Millington-Sette formula except that the coefficient α is replaced by $-\ln(1-\alpha)$.

The theory is offered that the various devices used in a reverberation room to achieve a diffuse sound field might alternatively be regarded as devices to ensure a continuous redistribution of energy among the various components of the sound field. This in turn should ensure that each part of the boundary receives and absorbs its fair share of the total energy. Thus, while we have been struggling to achieve a "diffuse sound field", we have perhaps inadvertently provided a situation in which the arithmetic averaging procedure is legitimate.

The reasons for using the Sabine equation are still cogent, but it will be shown that absorption data calculated by the Norris-Eyring formula agree better with other evidence than the Sabine results.

Experimental Results

The attached figures present in summary the results of the second I.S.O. round robin in which tests were carried out by five laboratories on batches of the same material, Sillian. (This material is similar to Fiberglas Type P F commonly used in North America). It is expected that detailed information about these tests will be published shortly by Professor Kosten, but in the meantime details will be given for only our own establishment, N.R.C. Canada. It may be taken that the effects observed at N.R.C. typify those found generally.

The I.S.O. results are considered particularly valuable (as compared, for example, to the A.S.T.M. round robin,) because the experimental conditions were more uniform than in any previous intercomparison. In particular the effect of diffusing devices has been systematically examined and the condition of maximum diffusion has resulted in a series of measurements that can be compared with impedance tube measurements. The effect of diffusion is illustrated in Figure 7. It will be noted that the standard rotating vane system at N.R.C. Canada produced results substantially lower at high frequencies than those obtained with a diffusion system consisting of a multitude of plates distributed through space. Our tentative conclusion is that our standard condition is inadequate, although no change will be made for standard tests until the matter is considered by other testing laboratories in North America. Since our results agreed with Riverbank previously, it is surmised that a similar effect will be observed at Riverbank.

In Figures 4, 5 and 8, the individual and average results obtained in the five I.S.O. laboratories are plotted, together with the two calculations referred to previously. It will be seen that there is fair agreement between the average reverberation room measurements and the calculated values. The former are slightly higher than the calculations at the upper frequencies, but this discrepancy would largely disappear if the Norris-Eyring reverberation formula were used instead of the Sabine formula. The difference is shown in Figures 2, 6 and 9, in which the N.R.C. results are calculated by both formulae.

The spread in individual results seen in Figures 4, 5 and 8 may be compared with the spread observed at N.R.C. for several variations within the prescribed maximum-diffusion condition of test (See Figures 3, 7, and 10). These included two sample positions and three arrangements of the diffusing plates. Sample Position 1 was near one corner of the room (within about 1m of two walls for the $12m^2$ sample); Position 2 was in the middle of the room. In diffusing conditions a and c the panels were kept about 2m above the floor (and above the sample); in condition b they approached within $\frac{1}{2}$m of the floor. The results reported to I.S.O. were for sample Position 1, diffusion condition a.

Further correlations are planned, with studies of different diffusion arrangements and with other types of absorbing material. One additional result is shown in Fig. 11. The material used for this test was one of the A.S.T.M. round robin materials, a perforated sugar cane fibre tile, $1\frac{1}{4}$" (3.2 cm) thick.

Comments

Measurements have been presented of sound absorption coefficients obtained under carefully controlled conditions in five reverberation rooms. These have been compared with calculations based on impedance tube measurements and the available information regarding the diffraction effect associated with a small sample. The average of the five sets of results is found to agree closely with the calculated values.

Although the average of the five establishments provides good agreement with calculations, there are still large deviations among the individual laboratories. From auxiliary measurements made at N.R.C. Canada, it appears probable that these fluctuations are related to the diffusing system. It is necessary therefore to determine the cause of these deviations and to find a method of prescribing the diffusion condition so that true values will be obtained.

The importance of the sample dimensions is demonstrated.

It follows that conditions at the edges of a sample are also of importance, since the calculations used above are based on the assumption that the face of the sample is in the same plane as the surrounding surface (which is assumed to be perfectly reflecting). Huntley has suggested that if the sample were suspended in space the area effect would be an inverse one, as compared with the effect obtained when the sample is against a reflecting surface. It is probable that this condition would be amenable to calculation. But many samples that are commonly tested in the laboratory constitute an intermediate condition which certainly could not be calculated. Typical suspended-ceiling systems, for example, stand 30 cm or more above the mounting surface. It would be of interest to carry out diffraction studies with a material such as Sillan (on a rigid backing) at various levels from the floor. These would at least provide experimental evidence regarding the dependence of the diffraction effect on this variable.

Inevitably, the area effect calculation will be rather uncertain for many types of materials, either because of the effect mentioned above or because the material is not locally reacting. The calculations will probably give results that are satisfactory for field use but not very satisfying to the testing laboratory, since the objective is to make a precision measurement. It is suggested therefore that wherever possible the sample area should be a standard value and that the published results should be the values for this standard area. The infinite-area calculations might also be made and reported, but it should be made clear that this is an approximation.

It has been suggested that the term "coefficient" should be avoided, especially when referring to measurements made on a small sample since, strictly speaking, one cannot simply multiply an area by a coefficient to obtain total absorption. Moreover, there is the usual problem of explaining values greater than unity. An alternative, suggested by R.K. Cook, is to quote the "absorption cross-section" of the standard sample. Eventually, however, something equivalent to a coefficient is required, and the arguments against continuing to use the term seem academic.

In North America the accepted standard area is 9 feet by 8 feet (2.74m by 2.44m). In the I.S.O. a standard area is just being decided upon, and a size approximately the same as a North American value could be adopted with no inconvenience to European laboratories. For example, a sample 2m by 3 m would have a value of (1/ka) very close to the North American value. A slightly better correspondence could be obtained with a slight modification of one area or the other, without seriously impairing continuity in the North American results.

Apart from this there are two other factors to consider in settling on a standard area. First, the larger the area, the less important the diffraction correction; but the variation is so gradual that this is not an important consideration. Second, the larger the area, the larger the room necessary to make a reliable measurement. The I.S.O. round robin indicated provisionally that a number of European laboratories are "too small", under present test conditions. It is possible that further diffusion studies might permit a lowering of the minimum admissible room volume, but one of the limiting factors will be the sample area.

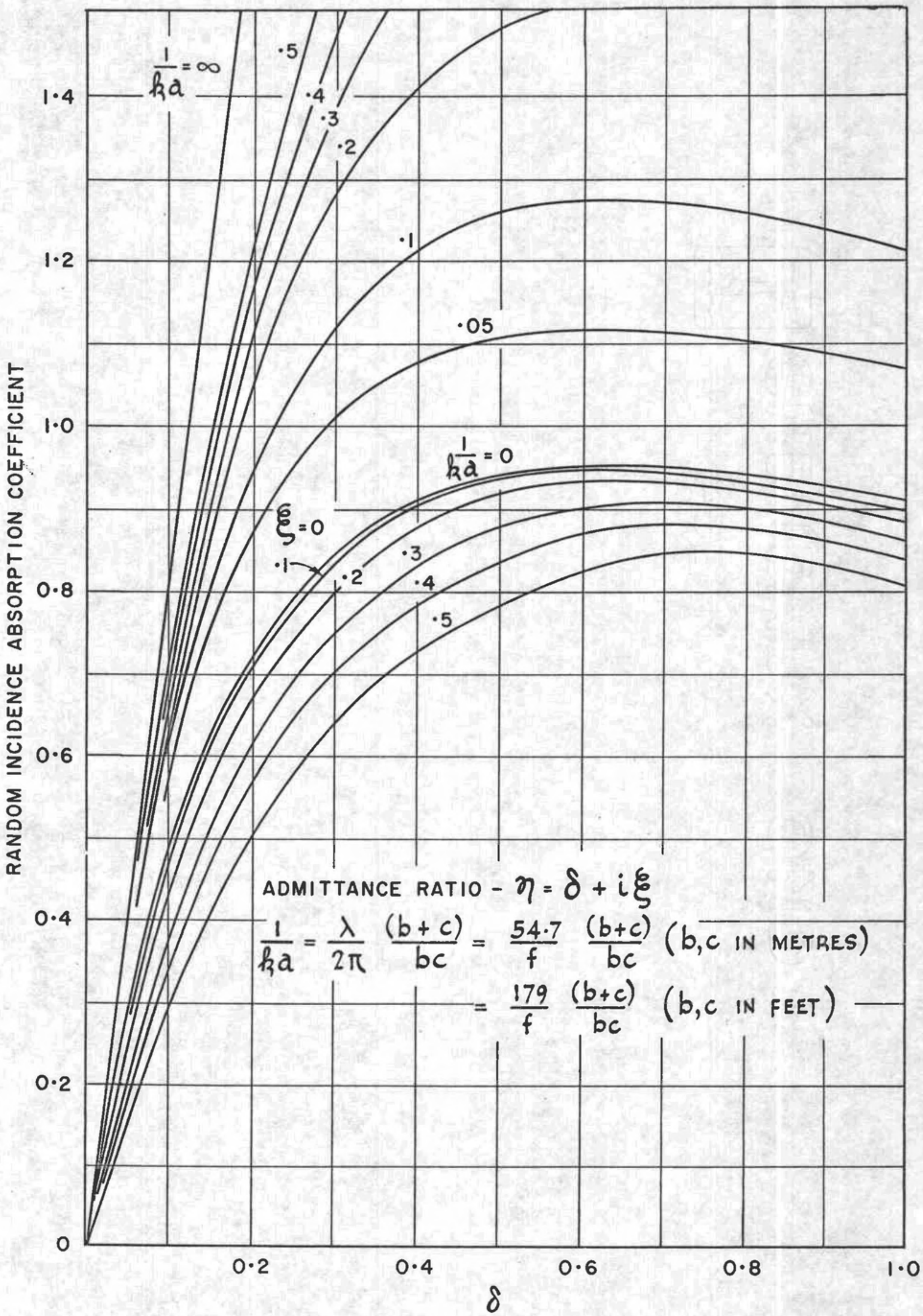

FIGURE 1

RANDOM INCIDENCE ABSORPTION COEFFICIENT FOR RECTANGULAR PATCH OF DIMENSIONS b & c

BR 22R-1

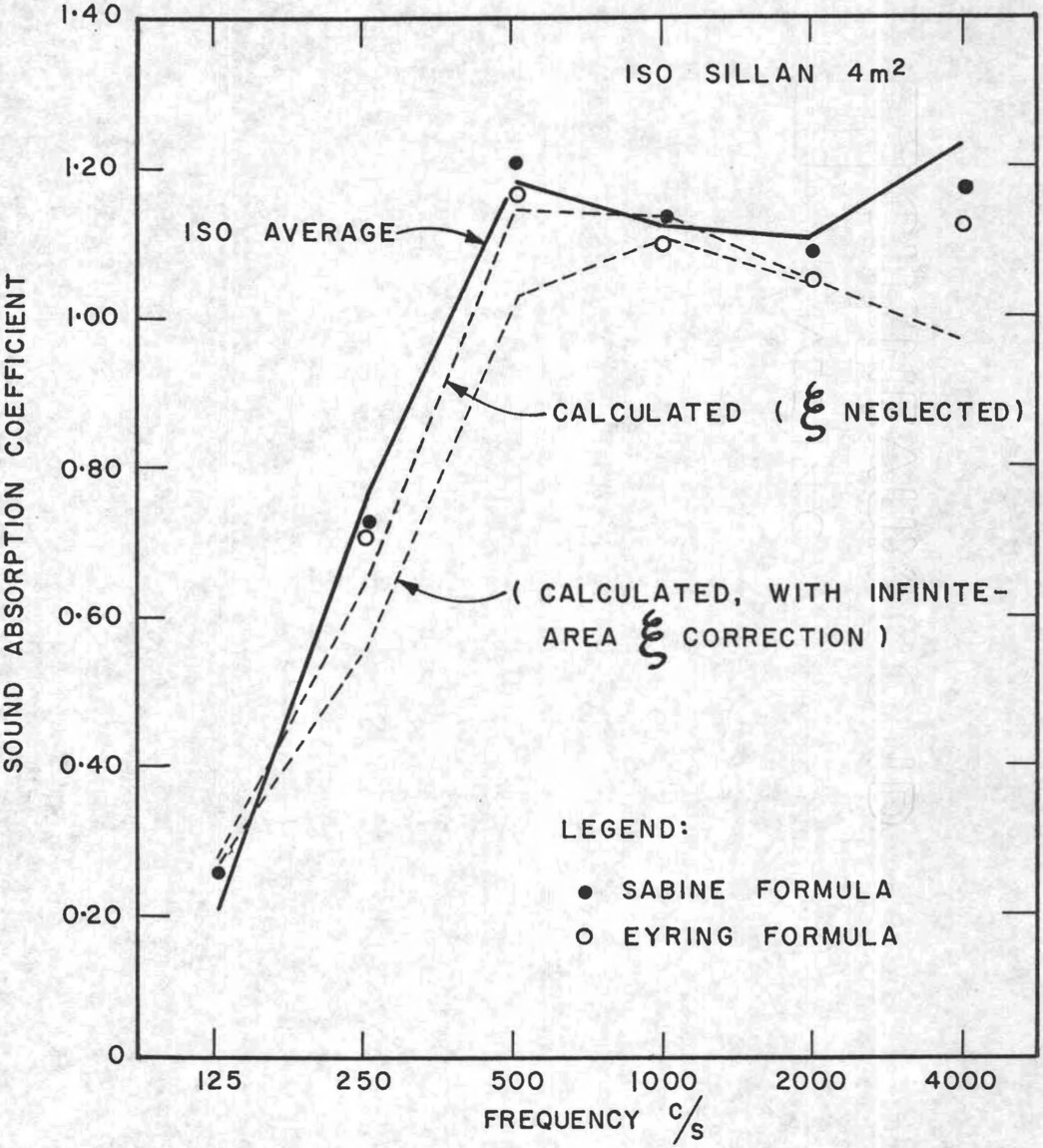

FIGURE 2

ABSORPTION MEASUREMENTS AT ISO ESTABLISHMENT NO. II (NRC)

BR 2228-1

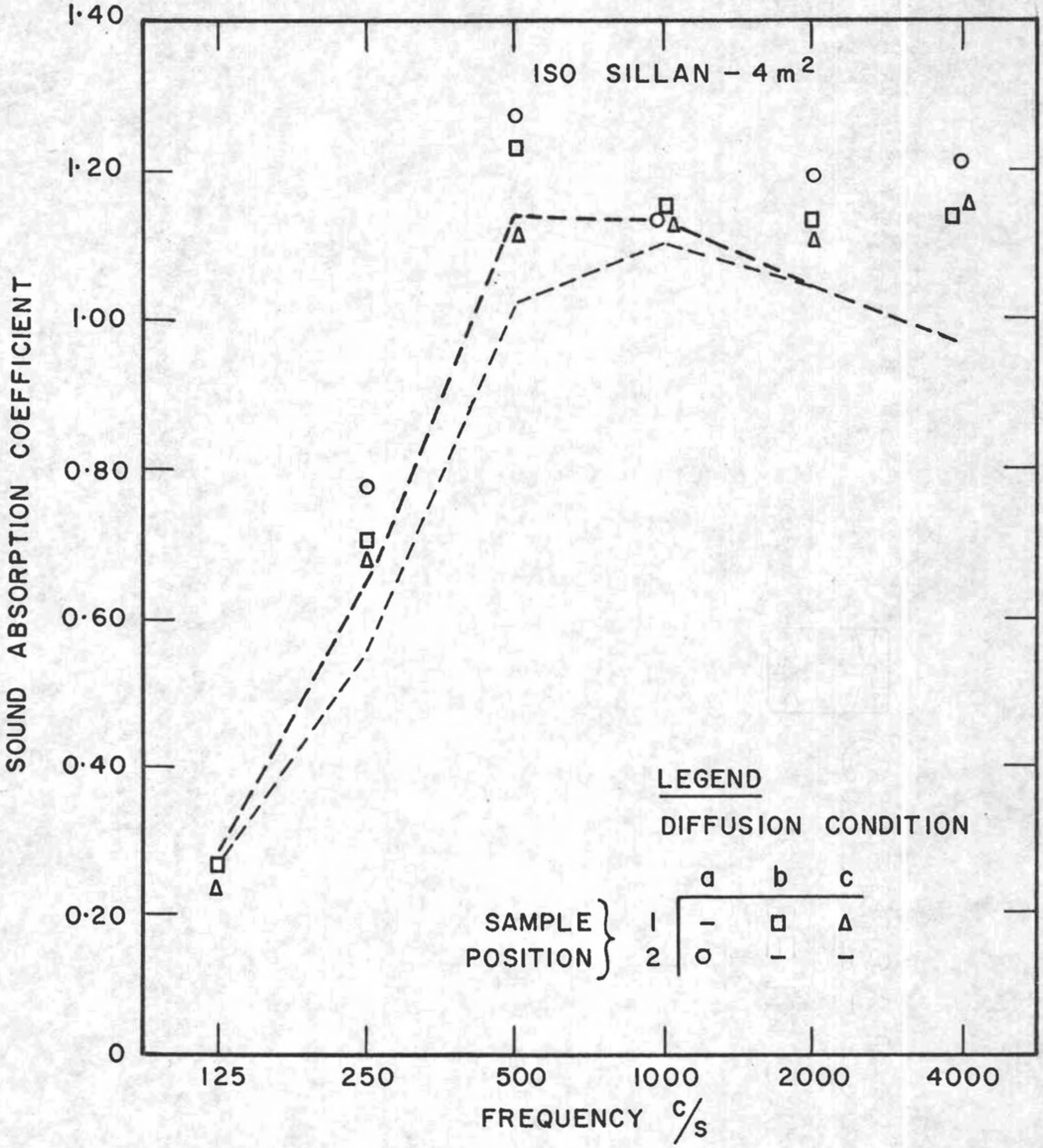

FIGURE 3

ABSORPTION MEASUREMENTS AT ISO ESTABLISHMENT NO. 11 (NRC)

BR 2228-2

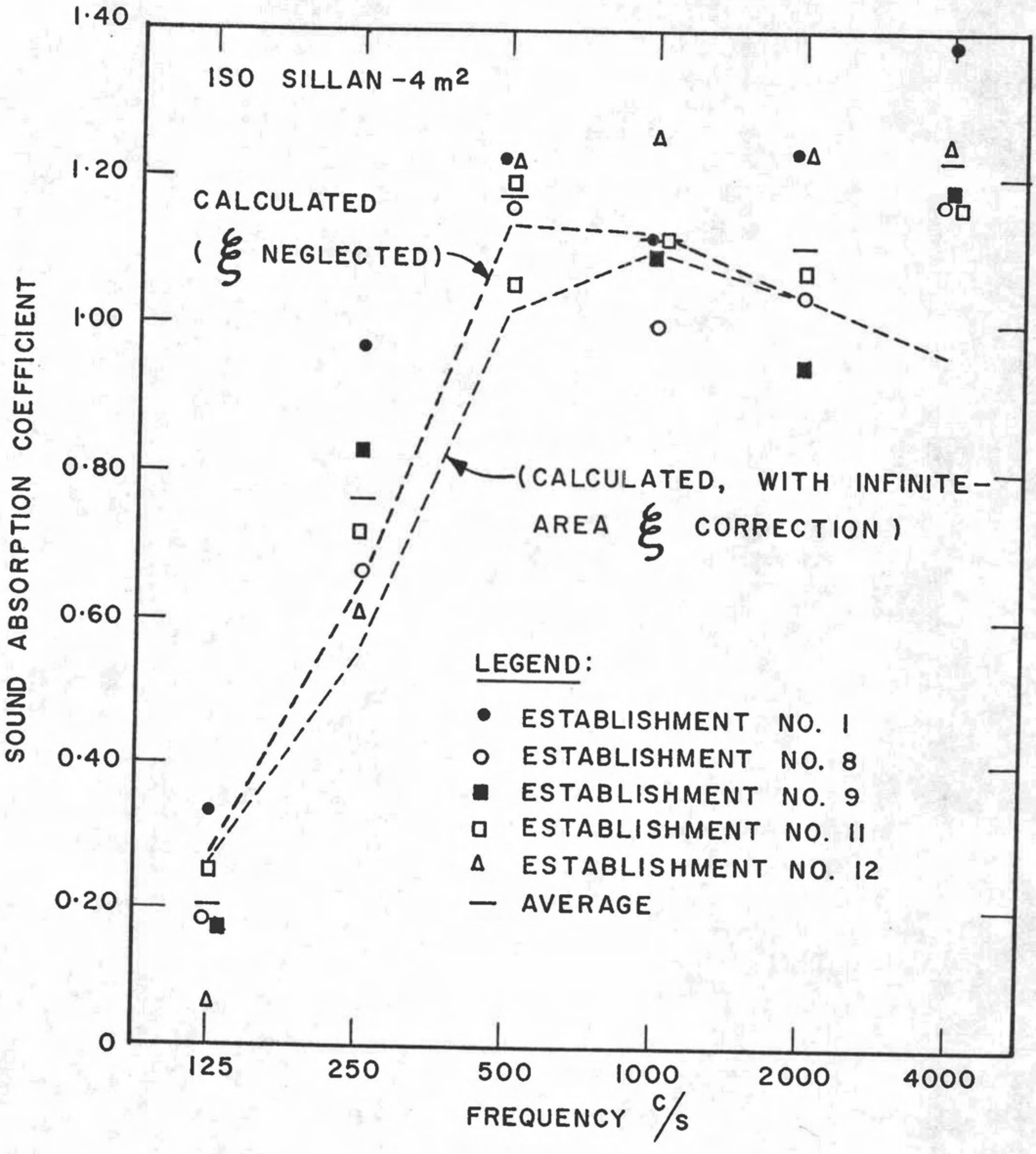

FIGURE 4

ABSORPTION MEASUREMENTS AT ISO FIVE LARGE REVERBERATION ROOMS

BR 2228-3

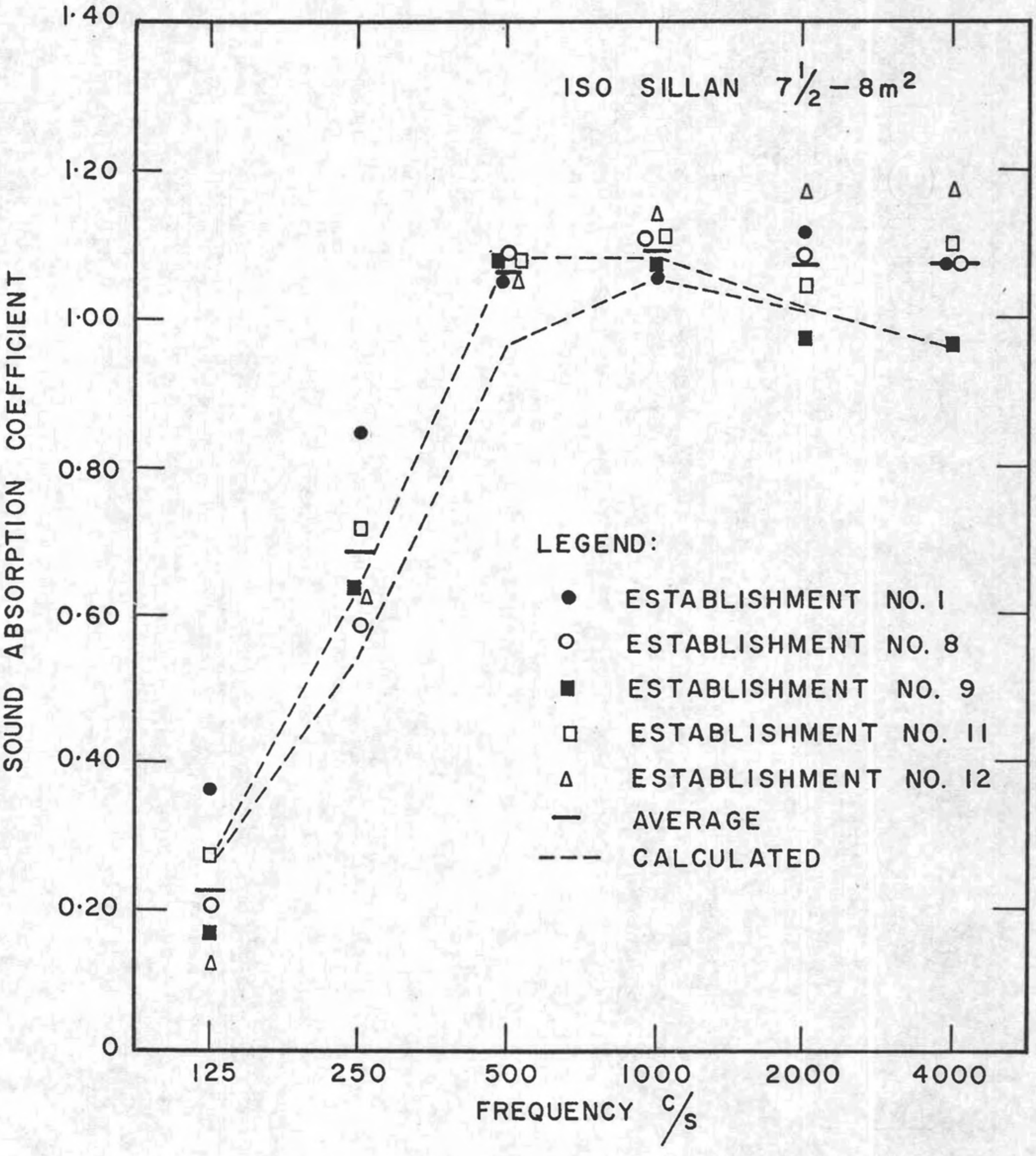

FIGURE 5

ABSORPTION MEASUREMENTS AT ISO FIVE LARGE REVERBERATION ROOMS

BR 2228-4

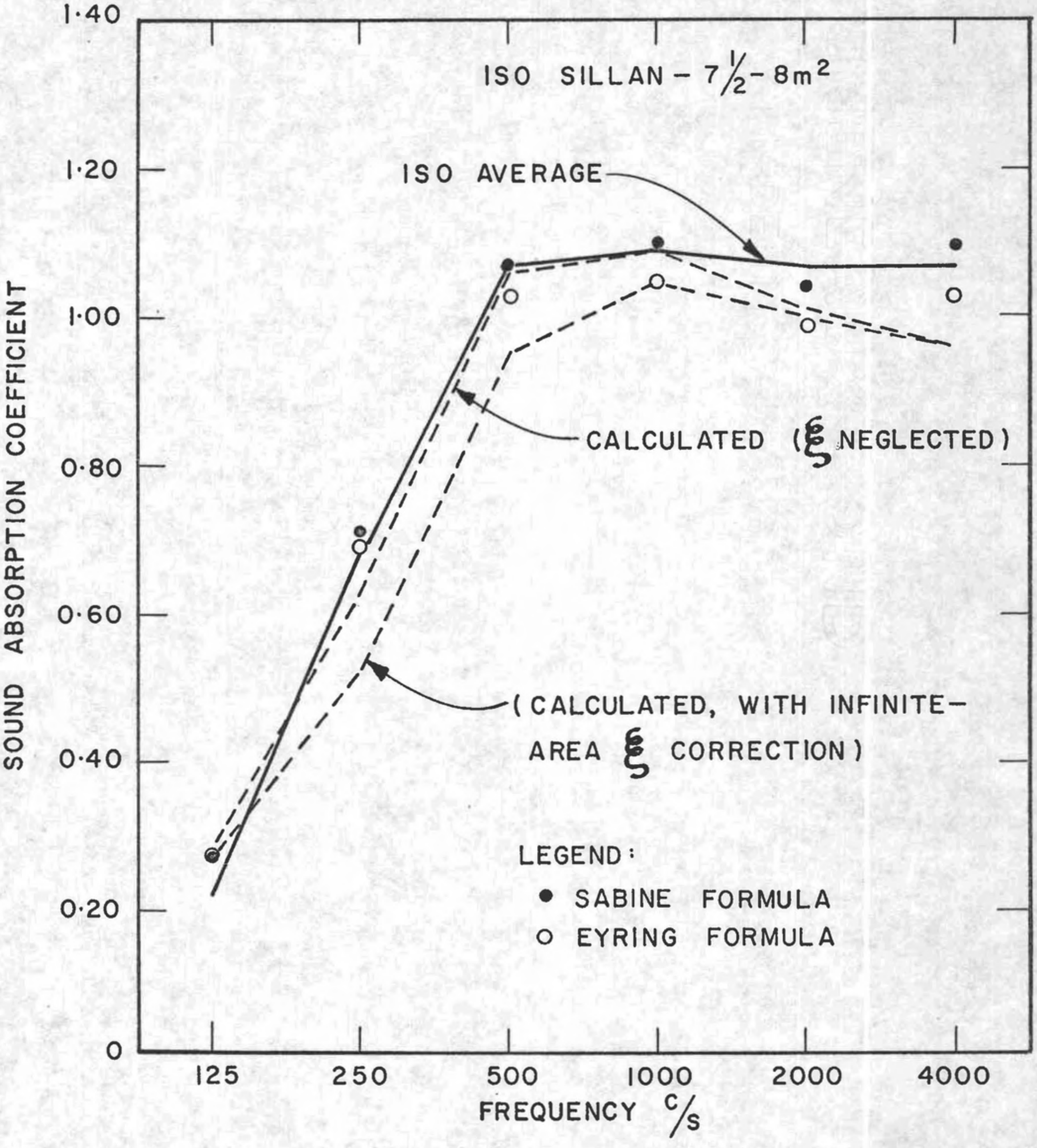

FIGURE 6

AVERAGE OF 5 ABSORPTION MEASUREMENTS ISO ESTABLISHMENT NO. II (NRC)

BR 2211-6

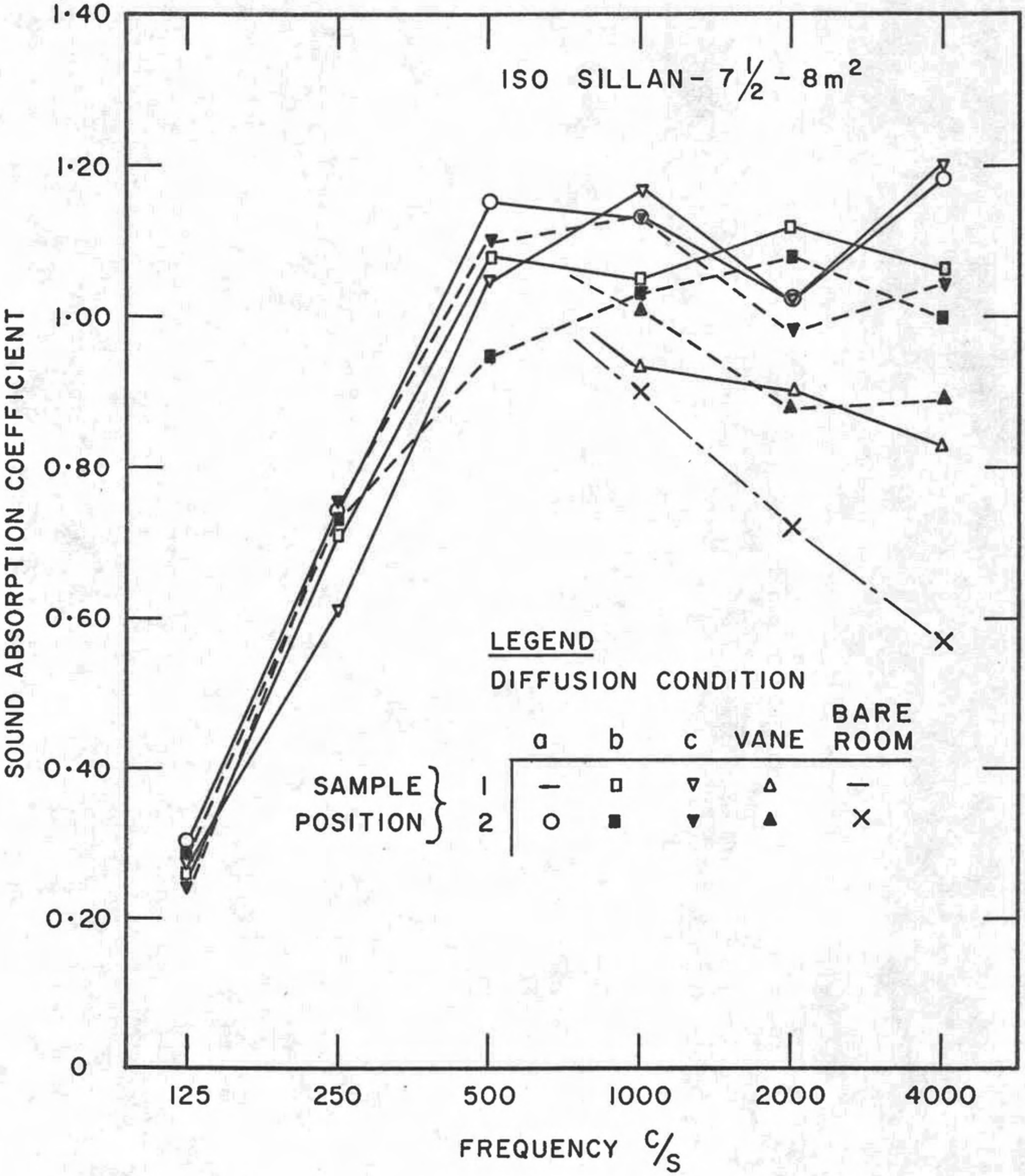

FIGURE 7
ABSORPTION MEASUREMENTS AT NRC FOR VARIOUS ARRANGEMENTS OF DIFFUSERS AND SAMPLE

BR 2211-7

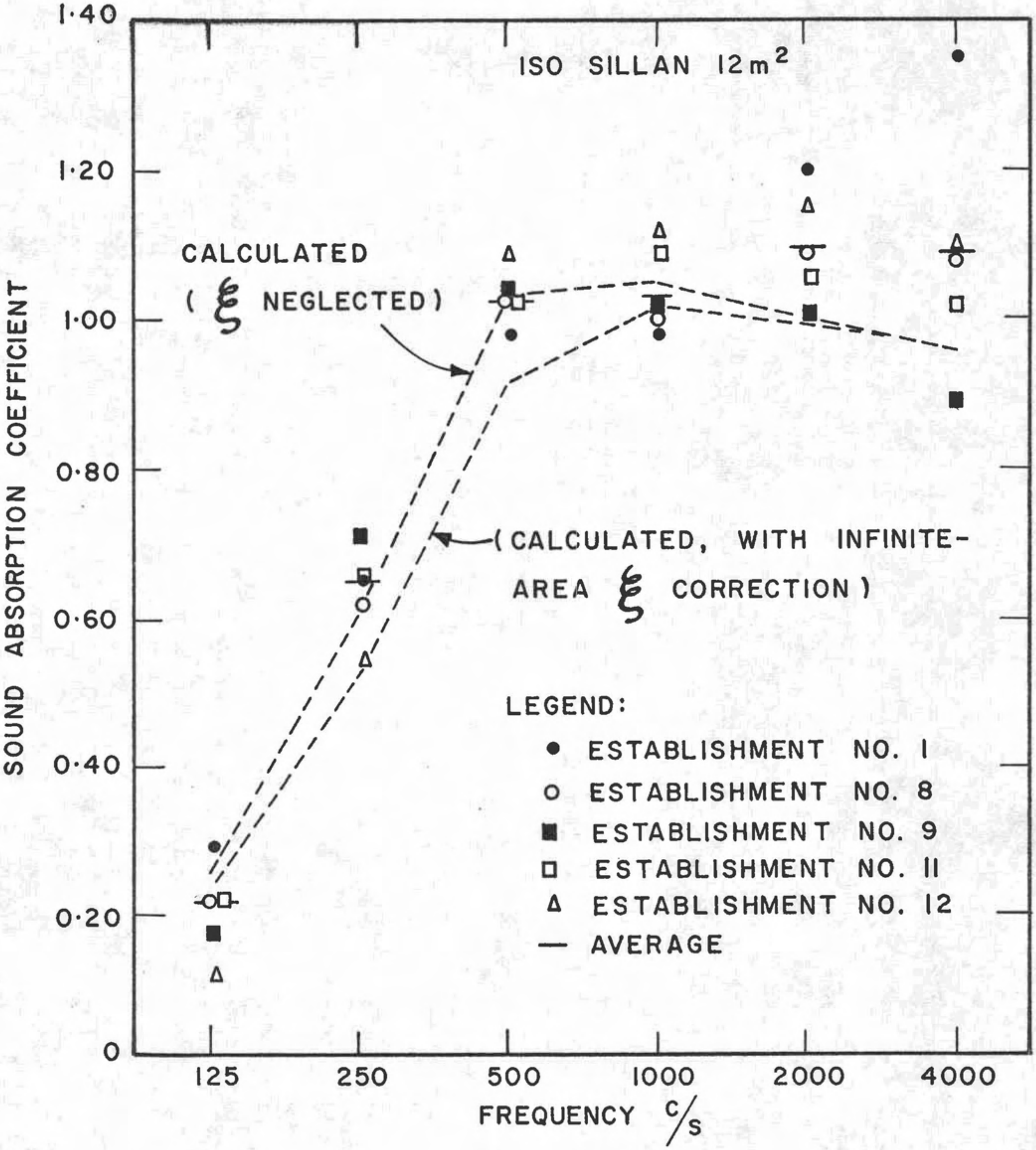

FIGURE 8

ABSORPTION MEASUREMENTS AT ISO FIVE LARGE REVERBERATION ROOMS

BR 2228-5

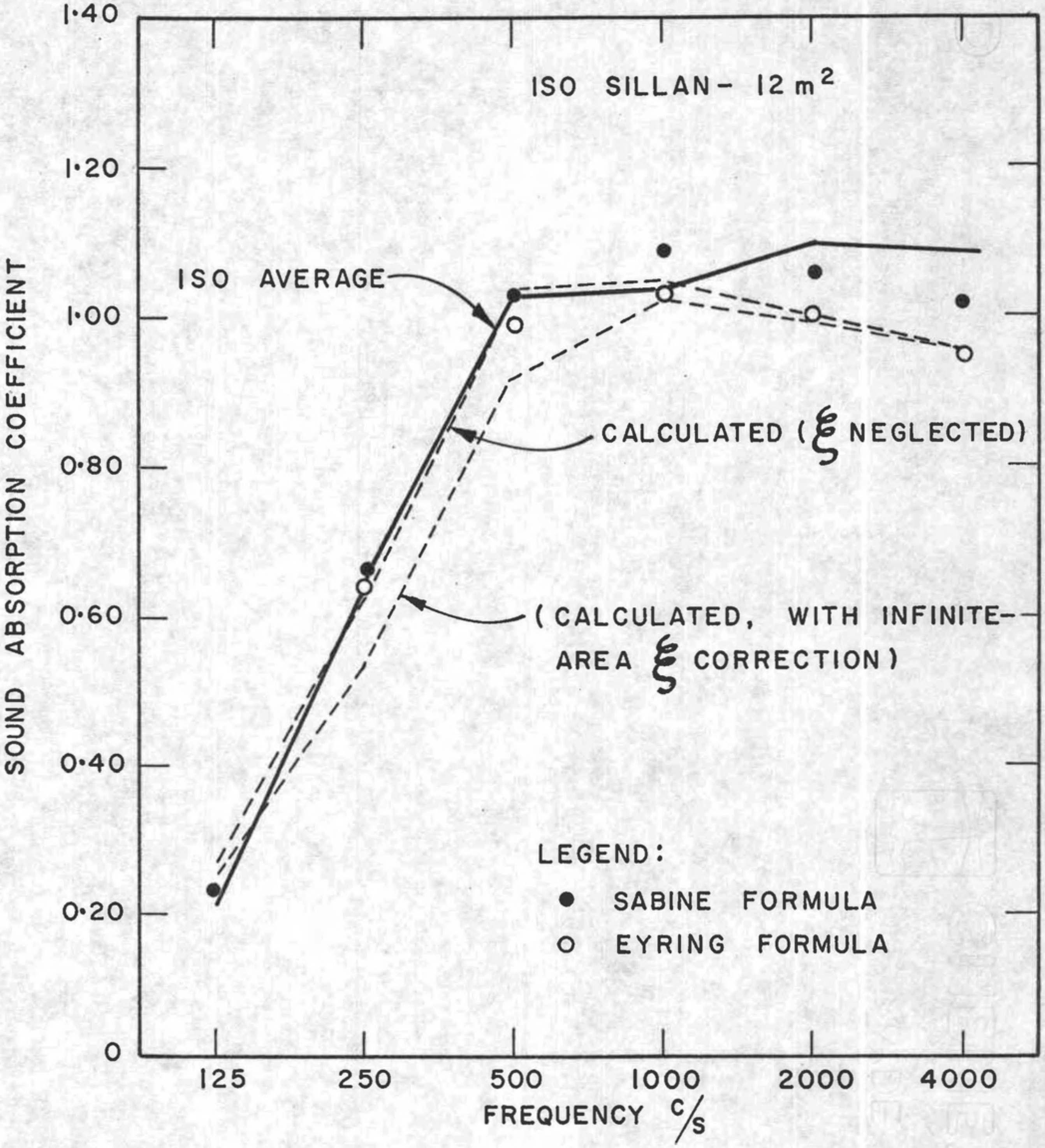

FIGURE 9

ABSORPTION MEASUREMENTS AT ISO ESTABLISHMENT NO. II (NRC)

BR 2228-6

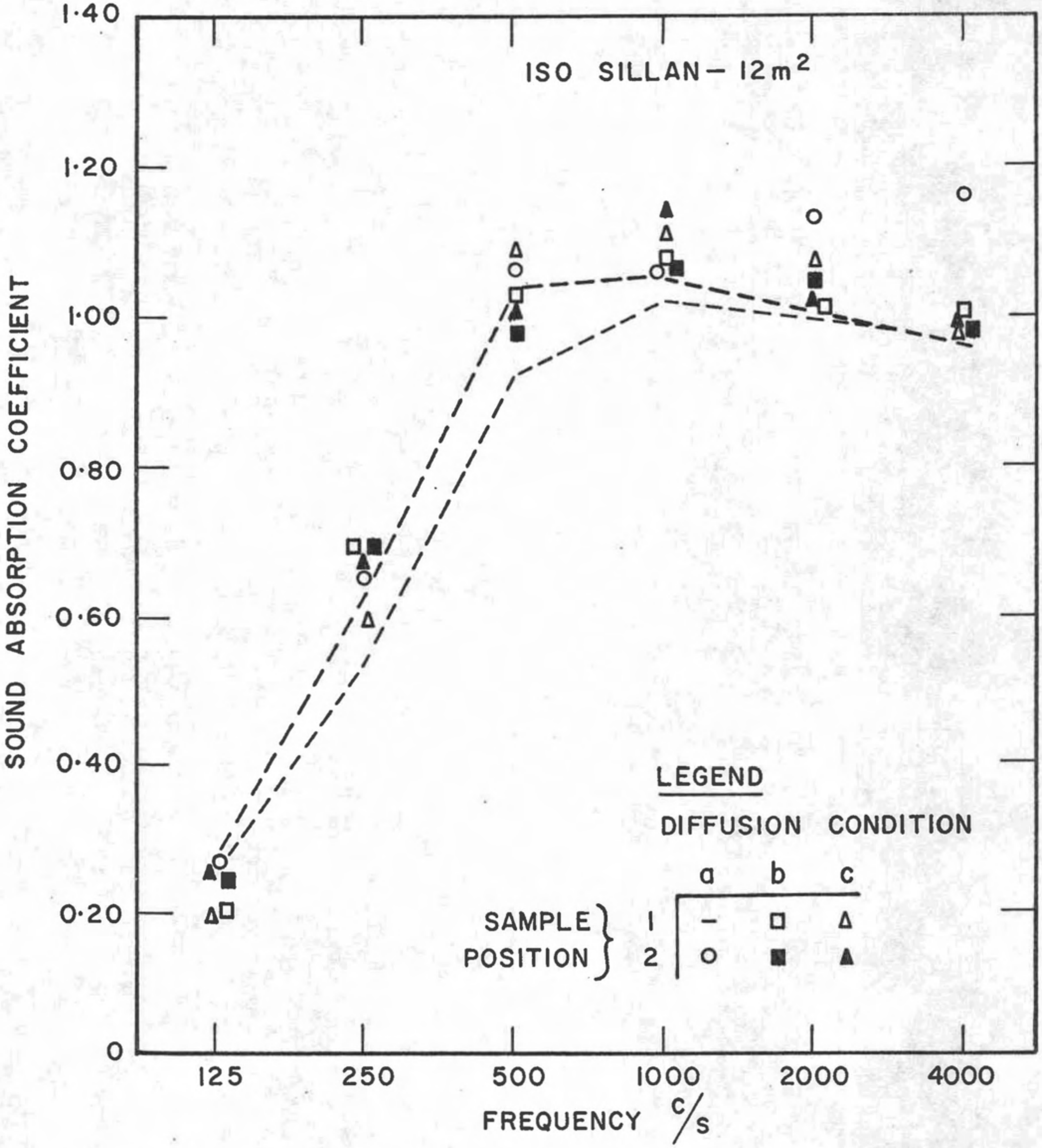

FIGURE 10

ABSORPTION MEASUREMENTS AT ISO ESTABLISHMENT NO. 11 (NRC)

BR 2228-7

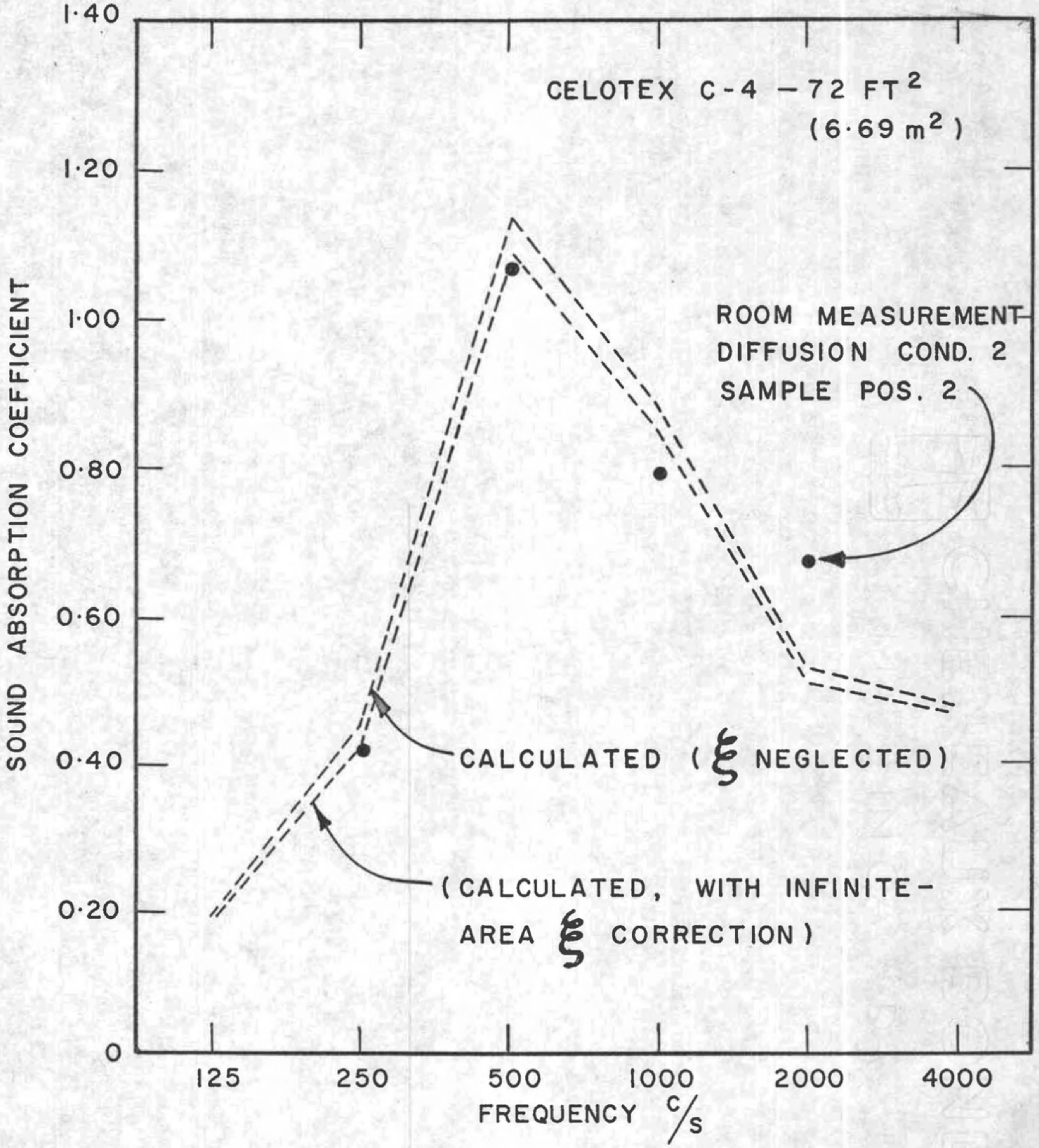

FIGURE 11

ABSORPTION CORRELATION FOR CELOTEX C-4 NRC OTTAWA

BR 2228-8