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Nov., 1967

SUBJECT: REPRINT OF ARTICLE ON APPLICATION OF LEAD FOR SOUND INSULATING PARTITIONS

TO: Members of the Lead Industries Association, Inc.

The Lead Industries Association has just obtained a limited quantity of the enclosed reprint, "Application of Lead for Sound Insulating Partitions." This article originally appeared in the May, 1967, issue of S)V, a magazine on sound and vibration.

Research for this paper, by A.V. Meier, was sponsored by the International Lead Zinc Research Organization. We feel the information contained here will fill a need for a somewhat more technical reply to inquiries from those whose interests, as well as knowledge, are more than preliminary in scope.

Additional copies of this reprint, in quantities up to twenty-five, will be available to our members, free of charge while the supply lasts.

Very truly yours,

E D Martin

Edwin D. Martin, A.I.A.
Manager, Architectural Services

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Lead Ahead with Lead

N 3509

LIA14318

May 1967

sound and vibration

APPLICATION OF LEAD

FOR

SOUND INSULATING PARTITIONS

N 3509.01

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APPLICATION OF LEAD FOR SOUND INSULATING PARTITIONS

A. v. Meier,* Heinrich Hertz Institut für Schwingungsforschung, Berlin

Lead has for some time been known to possess excellent acoustical properties. The author shows here how to get the most sound isolation per pound of wall surface.

THE VERY HIGH DENSITY of lead, $\rho = 11.3$ g/cm³, and its comparatively low Young's modulus, $E = 2.05 \times 10^{11}$ dynes/cm², constitute a most favorable combination for application of this material for acoustical use. Plates made from lead would furnish both heavy weight and limpness, thus providing a nearly ideal sound-insulating performance.

In practice, however, the use of pure lead plates is not practical, mostly for economic reasons, but also because a lead partition would have too low a structural rigidity to comply with architectural demands.

From an economic as well as from a technical point of view it is therefore of interest to investigate how to use lead—especially thin lead sheets—in combination with other cheaper and stiffer materials in such a way that the very high sound-insulating performance of lead adds to the qualities of conventional building materials, which are preferable in other respects.

> Slight differences in usage and technical practices between acoustical engineers in the United States and in Europe must be noted for the sake of exactness and a full understanding of this article.
>
> In the United States, it is more common to talk about sound isolation rather than sound insulation. This has grown out of attempts to eliminate confusion between popular fibrous thermal insulation and any added sound isolation that might occur if it is used in a wall. It is not necessarily so, and on some occasions the added thermal insulation blanket decreases the sound isolation.
>
> Another common term in the United States is sheet of building material. This is referred to as plate by the author.
>
> One last note relates to the frequency range of architectural interest and the lowest allowable coincidence frequency. In Europe, the accepted frequency range of architectural interest is 100 to 3200 c/s. In the United States and Canada, the range is considered to be 125 to 4000 c/s. This would require placing the minimum coincidence frequency at 4000 c/s if the coincidence dip is not to affect the results materially.

General guides for the construction of such lead-combined panels can be outlined. A few practical examples of typical partitions are described with corresponding sound transmission loss data as measured in the laboratory.

Single Leaf Partitions

As is well known, the sound insulation of a single-leaf partition depends mainly on two of its properties:

1. Its *surface weight*:

$$m = \rho h \qquad (1)$$

where h = thickness of plate, and

2. Its *bending stiffness*:

$$B = \frac{E}{(1-\mu^2)} \times \frac{h^3}{12} \qquad (2)$$

where μ = Poisson's ratio
= 0.3 to 0.4

The ratio of bending stiffness to surface weight of a certain plate determines its limiting frequency:

$$f_g = \frac{c^2}{2\pi}\sqrt{\frac{m}{B}} \qquad (3)$$

where c = velocity of sound in air
= 340 m/sec

Within a frequency range up to about one octave below this limiting frequency the sound insulation can be calculated fairly accurately from the mass law:

$$TL = \left(20 \log \frac{2\pi f m}{2Z} - 3\right) \text{ dB} \qquad (4)$$

where TL = sound transmission loss
f = frequency
Z = free field characteristic impedance
= 41 g/cm² sec

Equation 4 as given here is for a mean sound angle of incidence of 45°.

Generally the mass law denotes the potential sound insulation of a single-leaf partition. It can be realized only within the low-frequency range, whereas for higher frequencies the stiffness counteracts the mass inertia more and more, thus causing the *TL*-versus-frequency curve to break away from the mass law line and to drop to a more or less pronounced minimum, the well-known *coincidence dip*,

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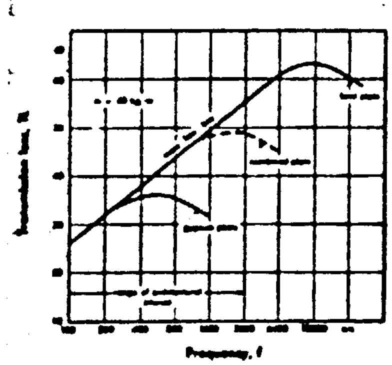


Figure 1. General form of curves of sound transmission loss (TL) versus frequency for plates having the same surface weight but different bending stiffnesses (40 kg/m² = 8.2 lb/ft²).

which occurs somewhat above the limiting frequency.

Figure 1 shows diagrammatically how different limiting frequencies of plates having the same surface weight affect their sound insulation. Owing to the low limiting (coincidence) frequency of the gypsum plate, taken here as a representative example for many other building materials, the *TL* values at medium frequencies are already considerably lower than predicted by the mass law of Equation 4. It is therefore impossible to make full use of the plate's surface weight to obtain high sound insulation within the most important medium frequency range. This effect is even more pronounced when thicker plates with greater surface weight are used, since the limiting frequency is inversely proportional to plate thickness, as follows from inserting Equation 1 and Equation 2 into Equation 3.

The limiting frequency of the lead plate in Figure 1 is, on the contrary, high enough to fulfill the mass law up to frequencies far beyond the range of architectural interest. This means that at high frequencies the sound insulation of a pure lead sheet is better than necessary, as far as insulation from ordinary office, domestic, or traffic noise is concerned.

Referring to the previously stated problem of combining lead with a building material, one can now conclude from Figure 1 that it should be possible to shift the coincidence dip to any position

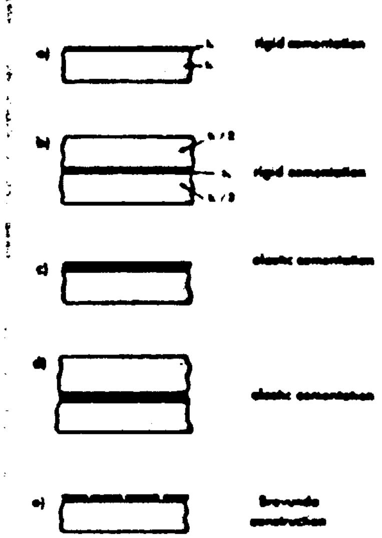


Figure 2. Possible ways of laminating lead with building materials.

between the two extremes shown in the figure—namely, toward higher frequencies when the lead component dominates, and toward lower frequencies when the content of building material increases. In between an optimum exists where, on the one hand, the plate's stiffness is as high as possible and, on the other hand, the sound insulation potential of the lead is fully utilized, but only at those frequencies where high *TL* values are of practical value. This requires the limiting frequency to be set at about f_g = 3000 c/s.

Accordingly, the highest possible *TL* values that are given by the mass law will be provided up to frequencies of about 1500 c/s—that is, within the most important frequency range—whereas, because of the stiffness influence, the *TL* curve will level off at higher frequencies, as indicated in Figure 1 by the dotted line for the combined plate. This behavior generally corresponds to the shape of the standard contours for evaluating the sound transmission class (STC) of a partition.[1] The coincidence dip should lie slightly above the frequency range of interest in architectural acoustics.

This optimal limiting frequency determines the optimal thickness dimensions of lead sheet and building plate to be combined with each other, whereby for a given total surface weight the weight of lead should be a minimum, just sufficient to keep the limiting frequency at $f_g = 3000$ c/s.

The calculation of the layer thicknesses is based on some typical sandwich constructions shown diagrammatically in Figure 2:

Construction a. Lead sheet rigidly adhered to building plate by means of a hard epoxy resin.

Construction b. Lead sheet rigidly applied at the neutral plane of building plate by the same type of adhesive.

Construction c. Lead sheet elastically applied to building plate by means of an elastomeric resin.

Construction d. Lead sheet elastically applied at the neutral plane of building plate.

Construction e. Small lead tiles adhered to building plate (Brevunda construction) or lead granules bonded with phenolic resin to base plate.

Assuming a limiting frequency of 3000 c/s for all these constructions means that, according to Equation 3 the ratio m/B remains constant. Since the surface weight, m, as well as the bending stiffness, B, is a function of the layer thicknesses, dependent on the different types of construction, Equation 3 represents the general dimensional equation, and it now has to be determined how m and B depend on the thickness, h_1, of building plate and on the thicknesses, h_2, of lead sheet.

The surface weight is simply given by the sum of the individual components:

$$m = \rho_1 h_1 + \rho_2 h_2 \qquad (5)$$

for all constructions.

On the other hand, the bending stiffness of the composite plate is a more complicated function, dependent not only on the layer thicknesses but also on Young's modulus E_1 of building material and E_2 of lead, as well as on the way in which both materials are combined. This can be written generally in the form

$$B/B_1 = \mathcal{F}(h_1/h_2, E_1/E_2) \qquad (6)$$

where B_1 is given by Equation 2.

Furthermore, the bending stiffness for constructions *c* and *d* with elastically adhered lead sheets is also a function of frequency. It increases at low frequencies, thus showing the favorable effect of providing higher stiffness against static loads than against dynamic acoustic excitation. In the latter case the value of the bending stiffness can be assumed, for the purpose of this investigation, as being equal to its limiting value for high frequencies.[9]

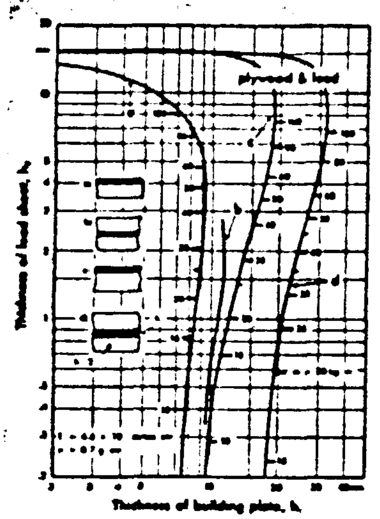
The determination of the function of Equation 6 can be found in the literature;[3,4] for construction *e* the function of Equation 6 represents a simple special case, since the plate's bending stiffness remains unaffected by the adhered small lead pieces, and only the surface weight is increased according to Equation 5. All other constructions require specific evaluation of the function of Equation 6. Then, to calculate the layer thicknesses, the functions of Equation 6 and Equation 5 have to be inserted into Equation 3 after setting $f_g = 3000$ c/s.

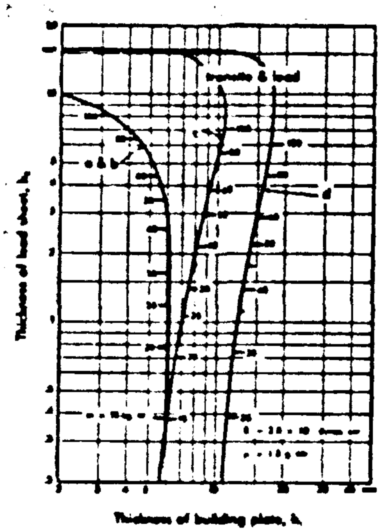
This has been carried out for a selection of common building materials in combination with lead. The results are shown in the curves of Figures 3, 4, and 5, where h_2, the thickness of lead sheet, is plotted against h_1, the thickness of building plate. The surface weight, as the basic figure to assess the expected sound insulation, is given as a parameter by assuming a minimum value for the thickness of lead sheet.

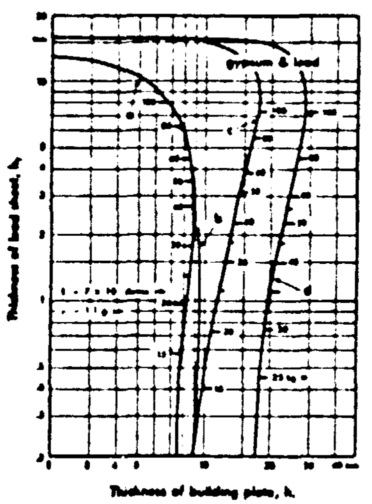
For practical application of these diagrams some important conclusions can be drawn. There is only a relatively small range of variation in h_1 (thickness of building material) for an efficient use of the applied lead sheet. On the other hand, the thickness, h_2, of the lead can be varied widely, practically from about 0.2 mm up to 6 mm, whereby the application of thicker lead sheets results in greater surface weights and in correspondingly better sound insulation. Furthermore, by comparing the curves of the different sandwich constructions, construction *d* appears as the most favorable with regard to a low ratio of weight of lead to weight of building material.

The diagrams also allow a rough estimate to be made of layer thicknesses for sandwiches using other building materials than those selected here, provided that the values E_1 and ρ_1 indicated on each of the diagrams are approximately equal to those of the material under consideration.

The diagrams of Figures 6 and 7 show results of *TL* measurements on panels designed according to curve *a* of Figure 3 and curve *d* of Figure 5, respectively. They confirm the expected sound insulating behavior—that is, validity of the mass law at low and medium frequencies, decreasing slope at higher frequencies, and the coincidence dip just above the frequency range of practical interest. The same general frequency response is observed for all other sandwich constructions. A variation in surface weight merely results in a vertical shift of the whole *TL* curve. Hence it follows that a definite relation can be found between the surface weight of the panel and its sound transmission class.[1] The latter is also determined by a parallel shifting of a frequency-dependent grading curve.







Figures 3–5. The three charts show the relationship between building material and lead sheet at a coincidence frequency of 3000 c/s with the construction shown at the top left. The combined plate weights are shown along each curve (1 dyne/cm² = 1.45 × 10⁻⁵ psi; 1 g/cm³ = 62.4 lb/ft³; 1 kg/m² = 0.205 lb/ft²).

A comparison of a great number of *TL* curves of sandwich plates yield the following equation:

$$\mathrm{STC} = 28 + 20 \log (m/10) \qquad (7)$$

where m is in kilograms per square meter, with a tolerance of about ±1.5.

Equation 7 associates the panel's sound transmission class (STC) with its surface weight; the required layer thicknesses are found from the diagrams of Figures 3, 4, and 5.

Double-Leaf Panels

The lead-laminated panels described above may be used not only as single-leaf partitions but also most efficiently as constituents of double-leaf constructions. In doing so, the well-known design principles for double walls have to be applied, such as the correct choice of the resonant frequency, damping of the resilient interspace, and prevention of sound bridges.[9] Figure 8 shows an example of such a double-leaf construction consisting of two lead-lami-

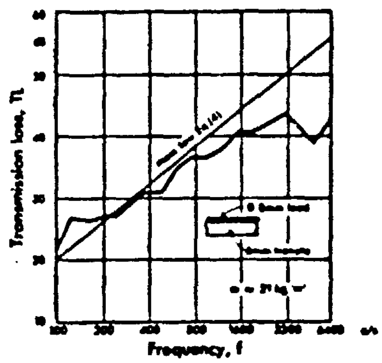


Figure 6. TL-versus-frequency curve for a lead-laminated plate construction a. Test area: 3 m² (30 ft²).

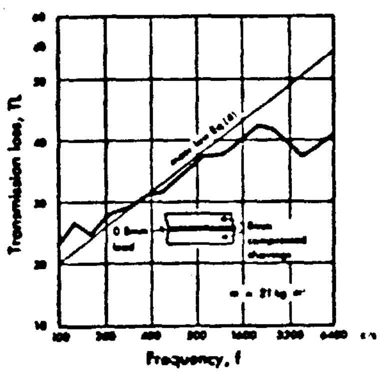


Figure 7. TL-versus-frequency curve for a lead-laminated plate, construction d. Test area: 3 m² (30 ft²).

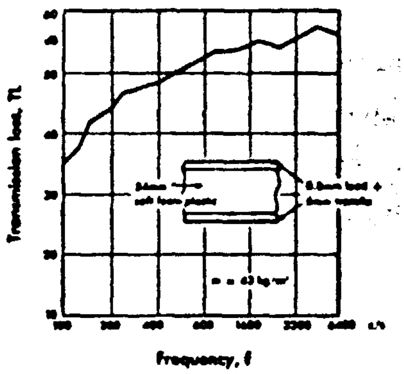


Figure 8. TL-versus-frequency curve for a double-leaf panel. Test area: 3 m² (30 ft²). STC = 53.

nated panels of the type shown in Figure 6. For a total surface weight of 43 kg/m² the sound transmission class obtained amounts to 53. However, this remarkable result is extremely sensitive to sound bridges, as are all conventional double-leaf partitions. On the other hand, a certain number of rigid connections between the two leaves are inevitable for structural reasons and often most desirable for improving the *rigidity* of a partition.

The use of lead sheets without stiffening lamination presents a unique possibility to construct double-leaf partitions that are very insensitive to sound bridges of any kind. It can be shown that, because of its exceptionally low stiffness-to-weight ratio, an unlaminated lead sheet has very poor sound-radiating properties, because the radiated sound power is directly proportional to the ratio B/m, when a plate is set into vibration by, for example, a single point excitation. If the sound bridges in a double wall are considered as such point excitation sources, it can be expected that the sound power radiated into the receiving room will be very low, if at least one leaf of the partition is a lead sheet. This means that the energy portion that bypasses the double-leaf barrier via the sound bridges is nearly negligible, and that the transmission loss of the partition remains unimpaired.[8] This unique property of a lead sheet in comparison with other metals is clearly brought out when one considers the fact that the ratio B/m of a

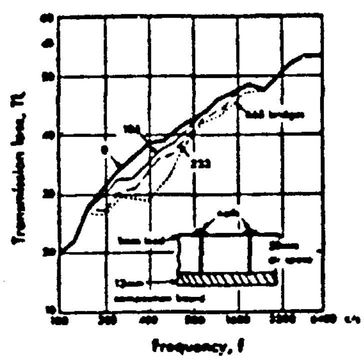


Figure 9. Influence of sound bridges on the sound transmission loss of a double-leaf construction. Test area: 3 m² (30 ft²).

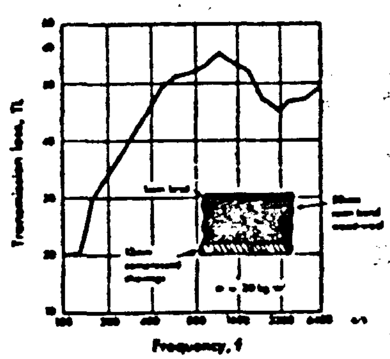


Figure 10. TL-versus-frequency curve for a double-leaf construction of high structural rigidity. Test area: 3 m² (30 ft²). STC = 46.

steel sheet is about thirty times as great as that of a lead sheet of the same weight. An experimental proof of these considerations is given in Figure 9, which shows the *TL* curves for a double wall, one leaf of which is a lead sheet connected to the other leaf by a definite number of sound bridges. A deterioration of the sound insulation becomes noticeable only when the number of sound bridges exceeds 30 per square meter (3 per square foot). Even when the number of bridges is increased to 150 per square meter (15 per square foot), the sound insulation still remains higher than for a single-leaf partition of the same weight, for which validity of the mass law is assumed.

On the basis of these findings, Cremer[9] suggested a practical double-leaf construction shown diagrammatically in Figure 10 together with its *TL* curve. Like the construction of Figure 9, one leaf of this panel consists of a lead sheet without stiffening lamination. The other leaf is a comparatively stiff wooden plate. Both leaves are adhesively applied onto the rough surface of a porous and stiff core material which thus simultaneously provides a great number of stiffening rigid connections between the outer skins (that is, sound bridges) and the necessary air cushion given by the porosity of the core material.

The measured *TL* curve yields a STC of 46, complying with the requirements for a good sound-insulating office partition. The application of this panel construction for doors seems especially promising because of its considerable structural rigidity.

Acknowledgments

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