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SOUND TRANSMISSION LOSS OF MULTILAYERED ELEMENTS: COMPARISON OF CALCULATED AND MEASURED RESULTS

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ABSTRACT
The impedance model developed by Au and Bryne is one of the few models for prediction of sound transmission loss values of multilayered structures and validated by the measurements using the intensity technique. The model enables calculations for hard materials with or without damping layer and for air or porous material between the layers. This approach was developed as a computerized model for building elements consisting of various layer-structures to be able to facilitate further investigations on sound insulation as well as applications in practice and, the calculated results were in good agreement with the published data. Further comparisons were made with the experimental results by using ISO 140 method in the laboratory. In this paper, some of the findings from this study are presented and the discrepancies between the results are revealed.

1 - INTRODUCTION
High-tech buildings generally have facades composed of various layers such as; curtain wall system, damp-proof membrane, fire-protection coat, thermal insulation, decorative linings etc., in addition to main wall element that can be massive, single or layered construction. Calculation of sound transmission loss values of such multilayered structures is rather complicated and not suitable to apply in practice. Some investigations on this subject have been presented in the literature [1], [2], [3]. Au and Bryne developed a procedure based on input and terminating impedances and pressures for the layered media and their results were validated in the laboratory by using the intensity technique. Ver later summarized this approach by introducing also the Mechel's impedance model for porous layers [4]. Considering that it would be beneficial for further investigations on the effects of varying layer characteristics of building elements (particularly for the facades) especially at design and evaluation stage of sound insulation, a study was carried out to develop a computer model and verify the results with the published data.

2 - ALGORITHM OF THE COMPUTER MODEL BASING ON THE IMPEDANCE CALCULATION PROCEDURE
Transmission of airborne sound through a multilayered partition in the above mentioned model is based on the plane wave theory applying the boundary conditions, i.e; the wave number component parallel to the infinite panel surface is the same for all the layers and the acoustical pressure and the particle velocity at the interfaces of the layers are continuous. The model enables the TL calculations of infinite elements consisting of homogenous layers; any combination of hard material with and without a damping layer bonded, porous material or air in the cavity. The computation procedure is based on the complex wave impedance ratios of both sides of each layer according to the direction of sound incidence and the ratios of the complex sound pressures on each side. Fig. 1 summarizes the model. The sound pressures

at source and receiver sides of the wall and the complex impedance of the input and transmitted sides of the element (Z_I and Z_T), with the Z_s the separation impedance, the complex bending stiffness of the layer (B) depending on the layer characteristics. The thickness, Young modulus, Poisson ratio and the loss factor of the layer itself and of the bonding material should be inserted into the formulas in order to obtain the composite bending stiffness. If there is a porous sound-absorbing layer, the impedance and pressure formulas are differentiated and the flow resistance of the bulk material is also taken into account. If there is only air between any of the two layers, the air-impedance is taken instead of the "complex characteristic acoustical impedance" of the porous material. In this model, the incident sound field is assumed to be a diffuse field, so that the plane waves are incident on the element surface from all directions with equal probability (0-90°). The limiting angle of incidence can be differentiated in the integration according to the real conditions on the source side of the element. An algorithm for the complex calculations have been designed for the computerized model [5]. The program code is written in C++ and a database is utilized for handling the layer information. The executable file is compiled for X86 processors and is functional on operating systems of Win95 or higher. The outputs are either visible on the user interface or in separate files. The input data consists of a database which allows the user to define new layer configurations. The outputs include: A list of one or one-third octave band TL values according to the user's choice, as well as the selected layer characteristics, R_w values together with the adjustment factors for pink noise and traffic noise, as suggested in ISO standards, a chart displaying calculated data that can be edited according to the user's need. Validation of the model was checked by comparing the calculated results with those presented by Au and Bryne as well as with the data published by other investigators. The comparisons resulted in satisfactory agreement as seen in Fig. 2.

$$Z_S = j(\omega\rho_S - Bk_x^4/\omega)$$

$$Z_I = Z_T + Z_s \quad N.s/m^3$$

$$Z_I = Z_T + \left[j(\omega\rho_s - \frac{1}{\omega}(B_x k_x^4 + 2B_{xy} k_x^2 k_y^2 + B_y k_y^4) \right]$$

$$p_I = p_T \frac{Z_I}{Z_T} \quad N/m^2$$

$$\tau(\omega,\theta) = p_t^2 / p_i^2$$

$$\tau_R(\omega) = \int_0^{\pi/2} \tau(\omega,\theta) \sin 2\theta \, d\theta$$

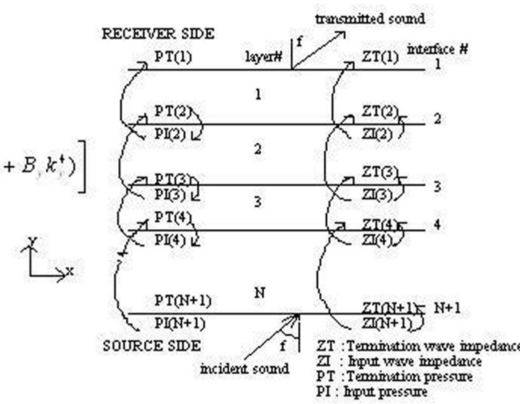

Figure 1: Main formulation and the process of the impedance model.

3 - EXPERIMENTAL STUDY

Although the model had been verified in the laboratory by using the intensity technique, it was also considered to compare the results with the experimental data to be obtained by applying the conventional method. The acoustical tests were performed in the Riverbank Acoustical Laboratories (USA) by constructing a set of sample walls with the edges simply supported within the openings. The 28 test walls were designed with varying gapwidth and layer compositions, with air and porous material in the cavities. The materials used were gypsum boards, steel plates, vinyl damping layer and glasswool. The gapwidth was changed as 5 and 10cm. Samples were grouped as; single elements (gypsum board and steel plate) and double elements with identical and non-identical layer combinations. Both small (2.88 m^2) and large size (11.3 m^2) test samples were used in the experiments [5].

4 - COMPARISON OF THE RESULTS AND DISCUSSION

Below given consequences can be observed from the comparisons of the calculated and the measured results:

1. For the single elements, the results indicate satisfactory agreement, if the physical characteristics of the materials used in the calculations correspond to the real values (Fig. 3).

2. For the multilayered elements, calculated TLs are lower than those measured up to a certain frequency range and above this range, the contrary is observed (Figs. 4 and 5).

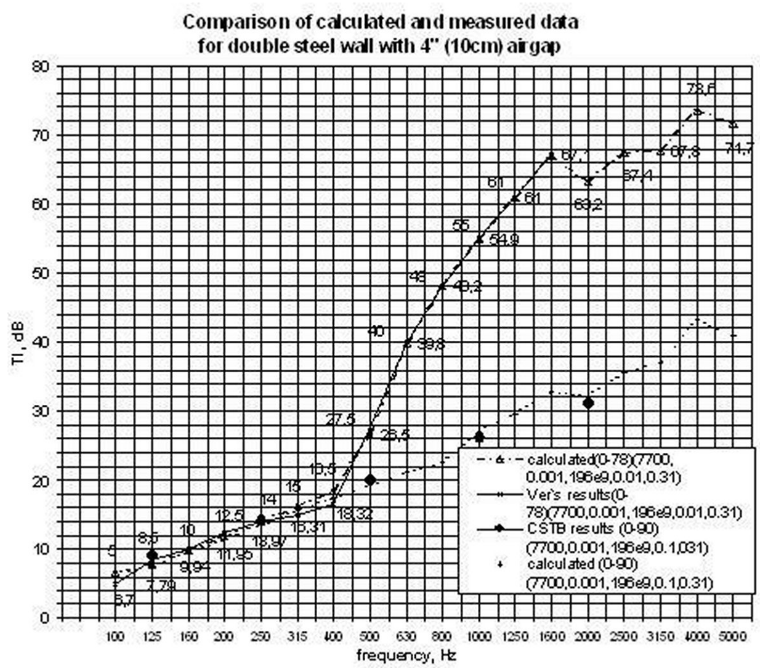

Figure 2: Comparison of TLs between obtained by Ver [4], CSTB (with private communication) and this study.

This frequency range varies with the layer material, limiting angle, loss factor, gapwidth, having air or glasswool in the cavity and, for double gypsum boards, it remains in 500-800 Hz for air, 250-500 Hz for glasswool in the cavity, whereas it is above 800 Hz for the double steel plates with air. This crossover between the calculated and measured TL curves is observed at about the first cross-cavity resonance frequency for the double-layered walls. Variation of the differences can be explained as the finite size of the test specimens even for the larger test size of 11 m^2. At f<<fc, it is normal to obtain higher TLs for the smaller element due to that the forced waves are dominant in the sound transmission and the radiation factor decreases with the increasing size. At f<fc, both the resonant transmission inversely related to the size and the radiation ratio for the forced waves increasing logarithmically with the frequency, give lower "measured TLs" or on contrary, the "calculated TLs" for infinite size elements exhibit a steeper increase, as can be seen in the figures. This can be valid for each layer independently resulting in a greater difference. On the other hand, the likelihood of the discrepancies to be caused by the edge conditions, sound penetrations or flanking through the edges at high frequencies or by the differences between the measurement techniques, is very low. However, the precision of materials' physical characteristics used in the calculations and the right value of maximum angle of incidence are of importance in calculations.

5 - CONCLUSION

Impedance model can be a useful tool in design of multilayered building elements especially by means of this computerized version developed in this study. The results gave satisfactory agreement with those obtained by the other investigations and the test data with the use of the intensity technique. However, comparisons with the measured results by using ISO140 indicated some important discrepancies, since the calculated results were for infinite panels. Consequently, the necessity of some further studies on the radiation factor of the finite-size multilayered structures and on their critical frequency are apparently justified. The standard size of 10 m^2 proposed for the test specimens should be reconsidered for the multilayered walls to eliminate the size effect and to be able to provide correspondence to the infinite elements.

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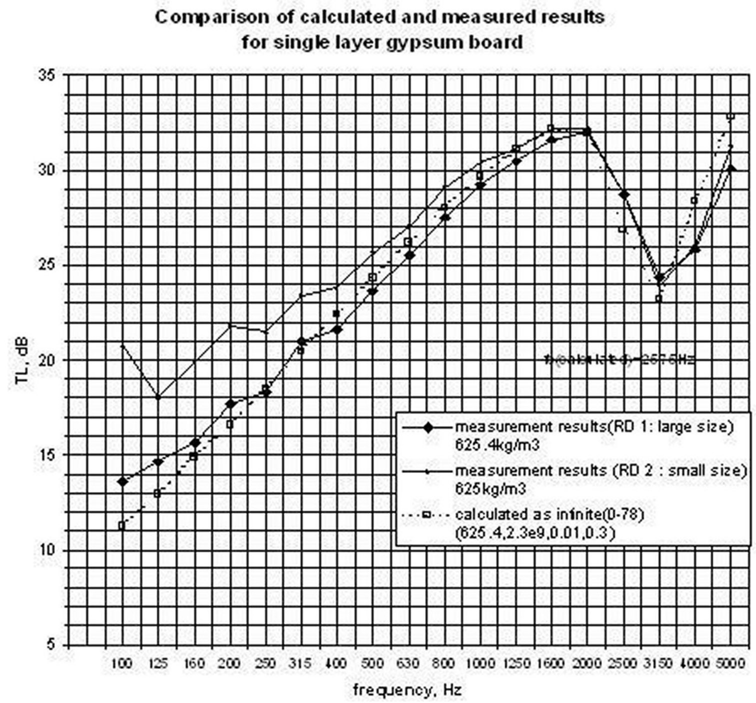

Figure 3: Comparison of calculated and measured results for single gypsum board.

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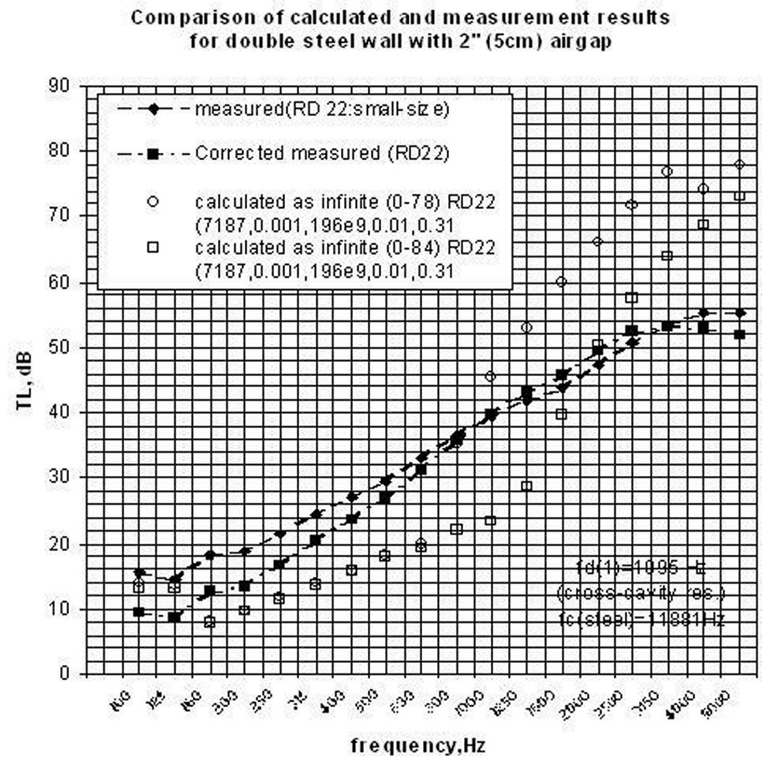

Figure 4: Comparison of calculated and measured results for double steel plates with 5 cm airgap.

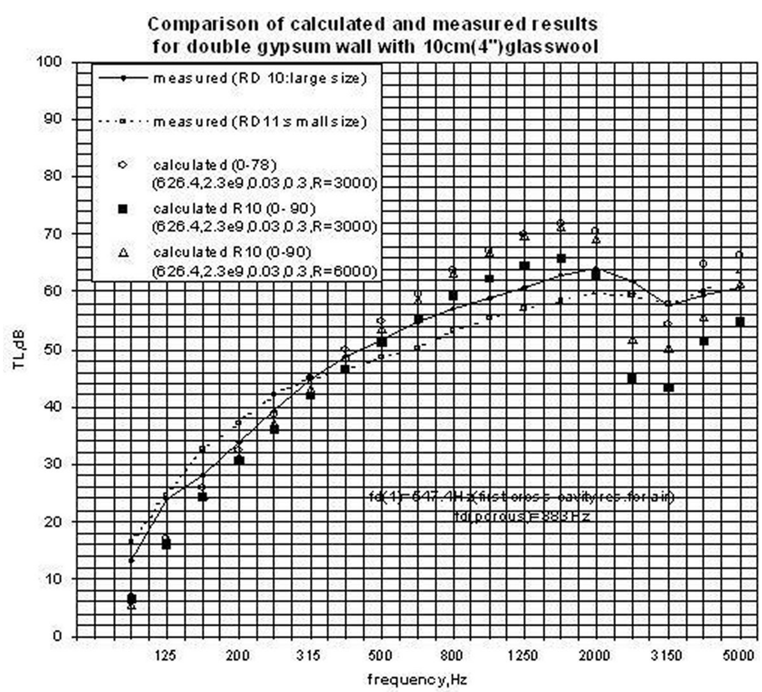

Figure 5: Comparison of calculated and measured results for double gypsum boards with 10 cm glasswool.