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MODEL STUDIES IN ACOUSTICS
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"Fifth Scale Model Studies of Sound Insulation using Simulated Building Elements"

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Model scale measuring techniques have benefits common to any field of research in that elements can be investigated more quickly and studies carried out which cost would make prohibitive in full size. In this respect building acoustics is no exception and can be studied at model scale with remarkable accuracy.

Facilities for such model scale measurements were constructed during 1967/8 in the Sound Research Laboratory of the Dept. of Building at Heriot-Watt University and include a horizontal sound transmission suite and anechoic room. Since the completion of these chambers two research programmes, one on timber framed partitions and the other on concrete ribbed floors, have been carried out with satisfactory results.

The choice of fifth scale was determined partly by the frequency range of the existing acoustical equipment and partly by the practical considerations involved in simulating building elements.

The shape of the reverberant rooms, that is rectangular, was also determined by two factors, the first being the accurate mathematical predictability of the sound field which could prove useful in later research and the second resulting from the intention to use corner microphone positions. The theory of oscillations applied to rectangular rooms shows that for every mode of vibration the distribution is such that the sound pressure is maximum in the corners of the room. It was on this principal that Dammig, Louden and Venzke (Ref.1) based their theory of corner microphone positions which was adapted for the model scale chambers.

The maximum volume was determined largely by the available laboratory space although the eventual design figure of 2m^3 at fifth scale compared favourably with the full scale recommendation of 100m^3 in B.S.2750. At 500 Hz in this volume only 28 natural oscillations occur which could have proved troublesome with the result that it was necessary to ensure that the dimensions were such as to give as even a distribution of these resonances as possible. Several sets of dimensional ratios were analysed by computer so as to compare the mode spacing statistics given by the formula

$$f = \frac{c}{2}\sqrt{\left(\frac{n_x}{l_x}\right)^2 + \left(\frac{n_y}{l_y}\right)^2 + \left(\frac{n_z}{l_z}\right)^2} \qquad (1)$$

(where c is the speed of sound in air, n_y, n_x and n_z are integers and l_x, l_y and l_z are the room dimensions).

with the expression for the number of natural oscillations 'Q' for frequencies between o and f.

$$Q = \frac{4\pi V}{3}\frac{f^3}{c^3} + \frac{\pi S}{4}\frac{f^2}{c^2} + \frac{L}{8}\frac{f}{c} \qquad (2)$$

where V is the volume of the room.
S is the surface area.
$L = l_x + l_y + l_z$

Several sets of ratios were shown to be equally suitable and consequently the dimensions eventually used were chosen so as to allow comparison of results with those obtained from rooms of similar dimensions at the Building Acoustic Department in Goteborg, Sweden.

It was considered desirable to make the test aperture directly proportional to that of the laboratory's full scale transmission suite and thus the dimensions were set at 0.61m square.

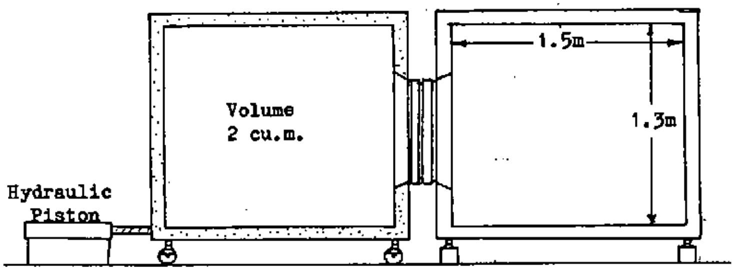

Fig.1 - Vertical Section through Sound Transmission Suite

The reverberant rooms were constructed of 4" thick lightweight cellular concrete with an internal finish of ½" thick 'Keenes' cement plaster.

Suitable isolation at the supports and test aperture was achieved respectively by use of anti-vibration mountings and non porous cellular rubber gaskets.

The reverberation times as measured at one month and one year after construction of the rooms are comparable with full scale rooms when one applies x 5 frequency transformations.

The design of the anechoic room was determined essentially by the cost of the alternatives for internal lining. It was considered uneconomic from the point of view of cost effectiveness to use gradual transition absorbers when polyether or polyester foam panel absorbers are almost as effective in the frequency range 500Hz to 16000Hz.

The absorption coefficients of twenty-one different types of panel absorber including polyether and polyester foams and semi-rigid mineral wool were measured by both reverberation chamber and impedance tube methods, in all cases. Subsequently a 3" thick polyether 'Barafoam' was chosen for the internal lining.

The superstructure was once again constructed with 4" thick cellular concrete except for one wall of 2" thick plywood which is removeable, being suspended from an overhead gantry. At the centre of this wall is constructed a test aperture of similar dimensions to that of the transmission suite.

Structural isolation was provided by a 'carpet' type anti-vibration strip. The finished internal dimensions were as follows

1.6m x 1.5m x 1.7m (L x h x h)

Instrumentation used for transmission loss measurements in the model rooms is essentially similar to that used in full scale work with, however, fewer measuring stations i.e. 3 in each room.

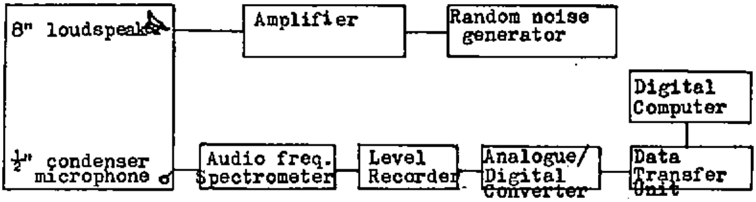

Fig.2 Diagram showing instrumentation used in transmission loss measurements

The receiving room reverberation time measured for normalisation purposes is obtained electronically and fed directly into the data transfer unit without manual interpretation of the decay curve.

This is possible owing to the smooth nature of the short decay curves. A purpose made slider, containing 'trigger' strips spaced 30dB apart, is fitted to the graphic level recorder and the signals fed directly into a high speed counter on the Data Transfer Unit. Care must be exercised, however, when using this method to ensure that the middle section of the decay curve is monitered each time.

Measurements of vibration acceleration levels are carried out using the same system as for sound pressure level measurement except at the transducing stage where very small e.g. 1.5gm piezo electric accelerometers are used.

With regard to actual measurement, the relationship between model scale and full size partitions can be shown by reference to the equation for wall impedance.

$$Zr = j\omega\rho h \left[1 - \left\{ \frac{\omega h E^{\frac{1}{2}}}{12^{\frac{1}{2}} c_o^{2} \rho^{\frac{1}{2}}} \right\}^2 \right] + \eta \omega \rho h \left\{ \frac{\omega h E^{\frac{1}{2}}}{12^{\frac{1}{2}} c_o^{2} \rho^{\frac{1}{2}}} \right\}^2 \qquad (3)$$

In each of the three terms, the frequency appears in a product with the wall thickness. From this it can be said that a wall of a certain thickness is a direct frequency scale model of a wall of similar material but proportional thickness. In other words provided the dynamic modulus of elasticity, density, damping loss factor and boundary conditions are not changed the transmission loss of a wall measured in the range 100-3150Hz can be accurately reproduced with a panel of one fifth thickness in the range 500-16000Hz.

Although simulation is not restricted to single homogeneous walls additional care must be taken when working with more complex walls, e.g. stud partitions, to ensure that every detail has been copied exactly.

It is not always possible to use the same material and in the case of materials such as plasterboard an alternative material must be found. In this respect acrylic sheet, although expensive, has proved an ideal material for scale work.

Elvhammar (Ref.2) has given the theoretical correction factors for sound transmission loss corresponding to changes in material constants as follows

Dynamic Modulus T.L. change $= 5 \log \frac{E_1}{E_2}$

Density T.L. change $= 15 \log \frac{\rho_1}{\rho_2}$

$$\text{Damping loss factor} \quad \text{T.L. change} = 10 \log \frac{\eta_1}{\eta_2}$$

$$\text{Thickness (homogeneous panels)} = 30 \log \frac{h_1}{h_2}$$

Once having established that simulation is accurate, there is generally little requirement to continue verification throughout a research programme, with work being carried out at scale on a completely relative basis.

Research, at scale, during the last year has included a programme in which the material components of stud partitions were systematically redistributed until an optimum design was achieved. During this programme in which approximately 150 partitions were measured, the acoustic response of the leaves, the studs, and the cavity were examined separately and then as a coupled system.

Similar work has been carried out on orthotropic floor slabs for which the same material, i.e. concrete, has been used at scale. This has involved scaling down the fine and coarse aggregate exactly although the cement could not be similarly reduced. In this study the affect upon transmission loss of different slab stiffness due to prestressing or reinforcing has been examined.

The difficulty in scaling cement is only one of a number of problems which have given rise to possible error in measurement. The effect of air absorption becomes more critical at higher frequencies and care must be taken to ensure constant air temperature and humidity. With regard to humidity two alternatives are possible for the environmental conditions, complete dehydration or constant high humidity. As a result of the difficulties inherent in maintaining a dry atmosphere it was decided to work at a constant humidity of 80%.

As of yet no work has been carried out at scale on the effect of absorbents in the cavity although theoretically no problems should be involved provided physical details are carefully simulated.

It is anticipated that future work in the rooms will involve not only panel investigation but also room panel coupling effects. The effect upon the sound transmission loss of having two identical rectangular rooms will be examined.

The anechoic chamber will continue to be used for detailed studies of laminated panel vibration from sound waves at oblique incidence.

<u>References</u>

(1) Acustica - 1961; Vol.11; p.304-311 Dammig et al.

(2) Account of the 6th I.C.A. Tokyo P.E153 Elvhammar et al.