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SOUND TRANSMISSION THROUGH LIGHTWEIGHT PANELS

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DECLARATION

I (Dharm Pal Singh) hereby declare that the Thesis entitled “Sound Transmission Through Lightweight Panels” to be submitted for the Degree of Doctor of Philosophy in Physics is my original work and the Thesis has not been formed the basis for the award of any degree, diploma, associateship, fellowship of similar other titles. It has not been submitted to any other University or Institution for the award of any degree or diploma.

Place: Bulandshahr
Date: May 2012

Signature of the Scholar
(Dharm Pal Singh)
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1. **Introduction**

Sound transmission in buildings is a problem that exists in many countries and many different solutions are adopted to achieve acceptable levels of sound insulation. In recent days usage of light weight building structures are widely used by construction industry for easier and cost effective method. With the expansion of real estate activities and newer building materials the need to attend the sound insulation requirements for both structure borne and airborne sound also assumes greater dimensions. The problem however is closely associated with several aspects of building construction, which include its layout, types of materials used in construction and other building service requirements. Apart from conventional materials, studies have undergone with the use fibre reinforced ferrocement panels in the construction. This type of construction exhibits easier and cost effective optimized solutions. Fibres used with ferrocement panels provide better natural performance on strength and thermal insulation behavior too. This property enhances the energy efficient character of the building; nevertheless in an acoustical sense the studies are not very informative which require deeper investigation.

Annoyance of structure borne and airborne sound are major problems that are faced by people in buildings. Properly designed and constructed methods will always provide a comfortable acoustical environment. All significant paths of transmission must be considered for sound transmission within the building as well as noise intrusion from outside the building.

2. **Review of Literature:**

Sound insulation of partitions has been a subject of systematic, scientific investigation for the last 100 years. The early papers were concentrated on the infinite walls, as they were easier to treat by analytical methods. The treatment of finite size walls with cavities were first concentrated on the high frequency range and statistical description of sound field (the concept of diffuse field) was employed. The low frequency range was long considered as less important in the context of building partitions, as the human sensitivity to sound decreases strongly
at low frequencies. However, the increased amount and efficiency of sources of low frequency sound in buildings has drawn the attention of researchers and the standardization committees to sound transmission. The use of mechanical ventilation systems, increased amount of household appliances in dwellings, improved efficiency of stereo systems, and the ever increasing density of traffic, all contributed to the increase levels of noise in buildings. Some important studies dealing with transmission of sound through structures are due to Cremer and Heckl (1984) [10], Lyon and Dejong (1995) [28] and Craik (1998) [8, 9].

2.1. Studies on Sound transmission prediction models:

The sound insulation in buildings has been studied based on prediction models on the concept of energy balance such as Statistical Energy Analysis (SEA). This concept has been adopted for enhancing accuracy of sound transmission by Craik (1982) [5].

Craik, (1998) [8, 9] investigated the structure borne sound transmission in lightweight buildings using SEA. Reducing the mass as a means of sound transmission in buildings led to the development of lightweight buildings. A higher level of sound insulation was achieved by introducing discontinuities whilst retaining structural integrity. For direct transmission through lightweight partitions the nature of connection between the lightweight cladding and the frame determines the nature of structural coupling. The coupling can be modeled as either a series of point connections or line connections. If flanking transmission was included then the complexity of model increases.

Vigran, (2010) [40] investigated a simple method to account for the effect of point- and line-connections in double-leaf constructions in a transfer matrix setup. To cover the frequency range above the critical frequency of the constituent plates, some new developments as to the forced radiation from plates were considered. A number of comparisons had been performed, mainly with the measured sound reduction index of lightweight double walls with gypsum boards. Cases include walls with cavity filling as well as with empty (air-filled) cavities. In the latter
cases, the energy losses of the cavity were simulated using a model of a porous layer with a minute flow resistivity.

Ran Zhou (2010) [34] has studied the comparisons between the experimental and predicted sound transmission loss values obtained from statistical energy analysis are presented for two foam-filled honeycomb sandwich panels. The accuracy of the prediction of the sound transmission loss using SEA greatly depends on accurate estimates of: (1) the modal density, (2) the internal loss factor, and (3) the coupling loss factor parameters of the structures. A theoretical expression for the modal density of sandwich panels is developed from a sixth-order governing equation. Measured modal density estimates of the two foam-filled honeycomb sandwich panels are obtained by using a three-channel spectral method with a spectral mass correction to allow for the mass loading of the impedance head. The effect of mass loading of the accelerometer is corrected in the estimations of both the total loss factor and radiation loss factor of the sandwich panels.

2.2. Material behaviour study of sound transmission:

In case of lightweight elements direct method was used to measure the sound transmission and the magnitudes of inaccuracies involved in its use were estimated. Testing was conducted on the anechoic chamber and the application of the method to actual constructions was also tested.

There is a lack of published data on fibre reinforced ferrocement panels with sound transmission class (STC) ratings. As part of consideration of Sound transmission many materials like dry walls are attached to the structures to improve their sound insulation. Measurements reported in the literature shows up to 100 Hz or 125 Hz in case of ISO-140-3 (1995) [19]. Low frequency sound is equally annoying and hence sound transmission loss at low frequency is also required.

Ferrocement panels are generally employed as internal partitions as well as high performance walls separating internal to external environment. When properly designed these partitions give reasonably good insulation (DIN4109-1989, [12].
Sometimes the sound reduction index gets affected by joints between the wall structures.

Narang, (1992) [33] determined the acoustic performance of stud-framed lightweight partition walls which are strongly affected by the presence or absence of sound absorbing materials in the cavity. Fibreglass, a commonly used cavity absorbent has come under criticism over potential health hazards owing to its fibrous nature. Here some low cost alternatives that can be used for providing cavity absorption in walls and offer sound insulation similar to fibreglass have been studied. STC rating of 4 points was observed by using different cavity absorbents, with options offering STC ratings similar to those achieved with conventional fibreglass. The effect of adding an extra layer of plasterboard with a corresponding equivalent sound reduction in the stud width was also studied.

The uses of rubber and plastic for sound insulation of party walls and floors have been discussed by Craik, (1992) [7]. They are used as mainly in case of walls and floors in buildings where in sound transmission takes place to a greater extent, by using this material maximum amount of sound insulation is achieved. It was seen that considerable reduction in weight of the building was achieved by the use of resilient layers and these layers have to be designed carefully.

The number of components was relatively large as in the range of possible designs. In either case the typical systems were to be identified and should be included to determine the best method of modeling the coupling.

The consequence of lightweight buildings on sound transmission was investigated by Craik, (1998) [8,9]. Changes in the building practice have led to an increased use of lightweight components in modern buildings. Lightweight walls and floors do not rely on mass to prevent sound transmission, which required the knowledge of lightweight material used and the details of construction. Both experimental and theoretical models are becoming important in the design of lightweight buildings for sound transmission.

Sean Smith, (1997) [38] investigated the sound transmission through lightweight parallel plates made of plasterboard and plasterboard combinations.
Double walls with plasterboard and line connected frame with chipboard and plasterboard as parallel plates were studied using experiments and theoretical approach such as SEA. Experiments were carried out to determine the sound transmission into the double wall cavities and isolated cavities. Parametric surveys were undertaken to analyse changes to the sound transmission through these structures when the material or changes to the sound transmission through these structures when the material or design parameter is altered.

Fringucllino and Sean Smith, (1999) [14] investigated the sound transmission through hollow block walls. They investigated the characteristic features of sound transmission through hollow walls. They used several different types of wall of different thickness and materials and the sound reduction index of the walls were recorded. The effects of additional plaster layers on the wall surface were also discussed. The material properties of the block’s complex web structure may strongly influence the sound reduction index at the low and high frequencies.

Kandaswamy (2003) [26, 27, ] has also investigated the sound transmission through gypsum board panels, wood board panels, cavity ferrocement panels and different type of walls and the sound reduction index, loss factor and transmission loss are investigated.

Del Coz Díaz J (2010) [11] investigated the most efficient numerical procedure to predict the transmission loss (TL) through a multilayer wall for frequencies ranging from 100 to 5000 Hz. The wall is made of lightweight concrete hollow bricks joined by mortar, with gypsum lining on both faces. A set of tests using source and receiving chambers have been modelled according to the basic requirements of the ISO 140-1[18] standard rule and ISO 717-1[20] standard rule. The convergence and accuracy of the proposed method are then assessed by comparing FEM results with experimental measurements carried out by a certified laboratory. Finally, the numerical procedures implemented in this work are used to evaluate the acoustic behaviour for other structural building elements and reduce the manufacturing time to develop new products in construction.
2.3. Studies on using agricultural waste in building materials

Presently in India, about 960 million tonnes of agricultural waste is being generated annually as by-products during industrial, mining, municipal, agricultural and other processes. Of this 350 million tonnes are organic wastes from agricultural sources; 290 million tonnes are inorganic waste of industrial and mining sectors and 4.5 million tonnes are hazardous in nature (Mannan et al., 2001) [30]. Advances in agricultural waste management resulted in alternative construction materials as a substitute to traditional materials like bricks, blocks, tiles, aggregates, ceramics, cement, lime, soil, timber and paint.

Researchers like Mannan, Daryl, Achyutha, Kurian have carried out in the past used agriculture wastes such as saw dust ash, rice husk ash, palm-oil fuel ash and bagasse ash as a replacement for cement. Natural fibres can be used in concrete to produce particle boards, roofing sheets, and partition panels. Agricultural wastes can also be used in non-load bearing concrete (Mannan et al., 2001) [29] where compressive strength is not important. Recently, an attempt has been made to use Oil Palm Shell (OPS) as coarse aggregate in structural concrete (Mannan et al., 2001) [30]. In low-cost lightweight structures, agricultural waste as coarse aggregate together with cement matrix can meet design specifications (Mannan et al., 2004) [31].

Although these researches are providing encouraging results, the lightweight concrete mixes with coconut shell (CS) aggregate have not been investigated. Concrete with CS as coarse aggregate can be used for the production of hollow-blocks, ferrocement panels, and lightweight concrete and structural members of low-cost houses. Hence, it is necessary to identify the potential use of coconut shell for value added products.

3 OBJECTIVE AND SCOPE OF WORK

The principle objective of the work is to study the sound transmission behavior of newer types of materials used in construction industry with respect to acoustic insulation or transmission properties.
The scope of work includes:

(i) The design and construction of a transmission loss suite to study the transmission properties of building elements.

(ii) The study is limited to the experimental investigation of acoustical transmission behavior and sound insulation properties of coconut shell impregnated hollow blocks and reinforced ferrocement panels and panels lined with wood wool boards and fibre reinforced panels.

(iii) The study is extended to the properties and effects of TL and cross junctions.

(iv) To develop a software program using the principles of Statistical Energy Analysis.

4 DESCRIPTION OF THE RESEARCH WORK

4.1 Experimental Investigation

(Design of Transmission Loss Suite and Experiments)

This chapter deals with the details of the design and construction of transmission loss suite, measurement details in respect of materials studied, and other instrumentation aspects involved. Other than the construction of transmission suite, principal measurements made are sound reduction index of different construction materials, longitudinal wavespeeds in different materials, and loss factors associated with them.

4.2 Details of Transmission Loss Suite (TL Suite)

The plan and layout of the experimental set-up for sound transmission loss suite designed and constructed for experimental investigations are shown in Fig 1(a) and 1(b). The dimensional details are indicated in figures. The TL measurements were carried out by installing the specimens in the specimen frame of normal size 0.94 x 0.64 m between the two reverberation rooms at the Acoustics Section, National Physical Laboratory (NPL). Both the source room and receiving room in the laboratory are irregular in shape with volumes of approximately 257 m$^3$ and 271 m$^3$ and are equipped with stationary diffusers. The floor of the receiver
room is vibration isolated to minimise the flanking transmission. Equipment included a steady sound source of white noise was produced from noise generator. The noise signal was then fed into and enhanced by a power amplifier and finally emitted through a loudspeaker to produce a reverberant sound (diffused) field inside the source room. Sound pressure levels inside the two rooms were sampled by means of two sets of ½ inch calibrated microphones type 1220 each coupled with a microphone pre-amplifier type 1201 and fed to a Norwegian Electronics type 830 dual channel real-time analyzer (RTA-830) for 1/3 octave band spectrum analysis. This arrangement is shown in Fig. 2. A sand layer has been laid over the joists and the flooring is laid over the sand Fig. 3.

The common opening between the source and receiver room is made up of two independent wall elements with a 15 mm gap. An acoustic caulking is provided in the gap, which minimise the transmission of acoustic energy from source to receiver room. All the experimental specimens have been cast in-situ and are built to the size of the common opening Fig. 4. The other walls of the source and receiver rooms are 230 mm thick.

4.3 Details of Instrumentation and Experiments

The important equipment used in this study are:

- Sound source [Omni-Directional Speaker System]
- Sound level meter (Lactron – SL 4001)
- Level recorder and Vibration meter [PHOTON II signal with FFT analyser]
- ½” inch microphone (DACTRON)
- Accelerometers (DACTRON)

The output of the microphone is connected to the analyser and recorded the signal using analyser software in personal computer and has been used primarily for reverberation time measurements. For vibration velocity measurement includes Tri-axial (sensitivity 10 mV/g) and uni-axial accelerometers (sensitivity 100 mV/g) and
impact hammers with BNC connectors has been used which is connected to the signal analyser which produces an acceleration of 10 m/s\(^2\) to an accuracy of ± 0.2 dB.

Fig. 1(a). Layout of experimental set-up for sound transmission loss
Fig. 1 (b). Measurement of Sound transmission loss, TL, in the laboratory

Fig. 2. Vibration isolation floorings with springs and steel sections
Fig. 3. Vibration isolation flooring filled with sand

Fig. 4. A typical view of the specimen being tested
4.4 Maximum Achievable Sound Reduction Index of the TL Suite

In order to comply with ISO 140-1[18] the sound transmitted by any indirect path as compared to the direct path should be negligible in the TL suite. For measuring the maximum sound reduction index a test wall of 225 mm thick has been constructed between the source and receiver room which is adequate for lightweight structures. With the sound source switched on in the source room the spatial average of spatial average of sound pressure levels is obtained. Similarly the spatial average in the receiver room is obtained. Tables 1 and 2 give the background noise levels and reverberation time of the TL suite. The sound reduction index is then calculated as:

\[ R_W = L_1 - L_2 + 10 \log (S/A) \] (1)

Where, \( S \) = area of the test specimen (m\(^2\))

\( A \) = Equivalent absorption in the receiver room

\( L_1 \) = Spatial average of sound pressure level in the source room

\( L_2 \) = Spatial average of sound pressure level in the receiver room

**Table 1 Background noise levels of the transmission loss suite**

<table>
<thead>
<tr>
<th>Linear (dB)</th>
<th>A-weighted dB(A)</th>
<th>Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>43</td>
<td>25</td>
<td>31.5 63 125 250 500 1K 2K 4K 8K</td>
</tr>
<tr>
<td></td>
<td></td>
<td>35 33 41 28 26 23 24 22 22</td>
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**Table 2 Reverberation time study of the transmission loss suite**

<table>
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<tr>
<th>Linear/ RT (sec)</th>
<th>Frequency (Hz)/RT (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.9</td>
<td>1.9 1.7 1.6 1.4 1.2 1.1 1.2</td>
</tr>
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</table>
For measurement purposes the test signal has been filtered which is 1/3rd octave wide which enables one to generate higher sound pressure levels in the desired frequency band. In each frequency band of interest the sound pressure levels generated should be at least 10 dB higher than the background noise levels in the band. For repeatability a set of six complete measurements are taken, as a function of frequency. They are paired into consecutive measurements without changing the original order of the set. The difference in results between two members of every pair is compared at all frequencies. If these values are exceeded at any one given frequency all the values are rejected and the method of check is repeated. Identical positions of measurements in the source and receiver rooms for measuring sound pressure levels should be avoided for checking the repeatability. The sound reduction index of the test specimen considering the transmission made from the source to receiver room and vice versa is obtained. The velocity levels on all the walls are also measured during the tests. The numbers of location points chosen for measuring the sound pressure levels are five in the source and receiver room. Fig. 5 shows the maximum sound reduction index of the TL suite.

4.5 MEASUREMENT OF FLANKING TRANSMISSION

The flanking transmission is determined by measuring the average velocity levels on the specimen and on the flanking surfaces in the receiver room. By generating the sound field in the source room, the acceleration level has been measured. From this the velocity levels have been obtained corresponding to seven positions on the test wall. With the assumptions of radiation efficiency of unity, (Schmitz, etal., 1999) [35, 36] which is valid above the critical frequency the sound reduction index is calculated as:

\[ R = L_s - L_v - 6.3 \text{ dB for } f > f_c \]  \hspace{1cm} (2)

Where, \( L_s \) is the sound pressure level in the source room, \( L_v \) is the velocity level on the surface of the test element.
The comparison of sound transmission calculated according to Eq. (2) in comparison to the conventional method could detect the possible flanking transmission. As Eq. (2) is valid only for frequencies above \( f_c \), differences should only be examined above 2000 Hz. Therefore it is seen that the flanking transmission is minimal for the transmission suite constructed.

4.6 EVALUATION OF SOUND REDUCTION INDEX

According to the standard ISO 140-3-1995 [19] the sound reduction index for a partition in a building element is

\[
R_W = L_1 - L_2 + 10 \log (S/A)
\]  

(3)

This holds well under the assumption of diffuse sound fields.

Where, 
- \( L_1 \) = Mean sound pressure level in the transmitting room or source room
- \( L_2 \) = Mean sound pressure level in the receiving room
- \( S \) = Area of the wall specimen
- \( A \) = Absorption in the receiving room

![Fig. 5. Maximum sound reduction index (\( R_{\text{max}} \)) of the TL suite](image-url)
By measuring the reverberation time $T$ in the receiving room the absorption area in the receiving room is

$$A = 0.163 \frac{V}{T}$$

(4)

Fig.5. Shows the maximum sound reduction index of the TL suite.

4.7 MEASUREMENT OF LONGITUDINAL WAVE SPEED ($c_L$)

The simplest way to excite a longitudinal wave on a structure is to strike it on an edge with a plastic head hammer. Two accelerometers were mounted onto the specimen at 2 m distance. (Fig.6) Each accelerometer is connected to a digital signal FFT analyser. As a longitudinal wave is detected by the first and second accelerometer, the analyser stores the respective pulses and the time interval between the pulses is measured. Knowing the distance and time interval the longitudinal velocity, $c_L$ is computed.

![Diagram of longitudinal wave speed measurement](image)

Fig.6. Measurement of longitudinal wave speed if the structure is along the edge

4.8 MEASUREMENT OF LOSS FACTOR ($\eta$)

In this investigation two types of loss factors are measured. One is the internal loss factor and the other is the total loss factor. The internal loss factor is
the fraction of energy lost as heat in one radian cycle whereas the total loss factor is the sum of the coupling and internal loss factor. Fig. 7 shows the experimental arrangement for measuring the internal loss factor. The accelerometer is fixed to the panel by using beeswax or anabond glue. The panel is excited from a plastic head hammer and the vibration velocity output is detected and recorded. The signal from the accelerometer is fed into conditioning amplifier and passed through tunable band bass filter. The signal is further fed to the recorder, which records the structural reverberation time decay. The loss factor (\( \eta \)) is evaluated as

\[
\eta = \frac{2.2}{f T_{60}} \tag{5}
\]

---

5 Experimental studies on transmission of sound through materials and building components

5.1 Materials Details

The materials studied in the TL suite for sound transmissions are:

(i) Coconut shell impregnated Hollow blocks (120 mm, 170 mm, 220 mm)
(ii) Coconut shell impregnated Hollow blocks (120 mm, 170 mm, 220 mm) lined with absorbtive material 

(iii) Coconut shell Hollow blocks (120 mm, 170 mm, 220 mm) double wall with cavity thickness of (100 mm, 150 mm, 200 mm) 

(iv) Coconut fibre impregnated Ferrocement lined with composite straw board panels. 

(v) Coconut fibre impregnated Ferrocement panels lined with wood wool boards. 

(vi) Coconut fibre impregnated Ferrocement panels lined with absorbtive materials 

(vii) Coconut fibre impregnated Ferrocement panels with cavity thickness of (100 mm, 150 mm, 200 mm) 

5.2. Test conditions:

1. Effect of plastering (10, 15, 20 mm) 
2. Effect of cavity (100, 150 & 200 mm) 
3. Effect of ties in ferrocement panels (8, 10 & 12 ties) 
4. Effect of Junctions 

In this study the coconut shell is been partially used by replacing with aggregates used for construction. The coconut shell of similar age which is stored in completely dried condition is used for the study. The crushing machine is designed with sieves of 4.75, 2.36, 1.7 and 1.18 mm in order to get shell sizes similar to aggregates used. Crushed coconut shell passing 4.75 mm and retained in 2.36 mm sieve are used for this study. 50% of weight of the coarse aggregate has been replaced with crushed coconut shells. The coconut shells are cured in water for 24 hrs in order to avoid the water absorption from the required water cement ratio. The cured coconut shell is dried and external water is removed in atmospheric condition before an hour for construction. 

The required compressive strength of hollow block using is achieved at 1:1.25:1.02 weight ratio of cement, fine aggregate (sand), coarse aggregate and
water cement ratio of 0.4, where 10% of weight of cement is replaced with fly ash and 51% of weight of coarse aggregate ie, quarry dust is being replaced with coconut shell. The hollow blocks with standard dimensions of 380 mm x 190 mm with thickness of 150 mm, 170 mm and 220 mm are made. The study focuses on the sound reduction index characteristics of coconut shell impregnated hollow blocks made with coconut shell. The sound reduction index (SRI) has been measured for twelve different wall surfaces.

Sound reduction index measurements have been made on the samples constructed inside the transmission loss suite. In case of block walls, studies have been made on the samples with and without plastered layers and with and without cavity. Sound reduction index is calculated by taking the spatial average of the sound pressure levels both in the source and receiver rooms.

**Hollow blocks:** Hollow blocks made of using coconut shell of three different thicknesses have been studied. The test walls have been assembled and constructed inside the transmission loss suite. Fig.8. gives the types of hollow blocks with the airspace configurations, which is the important feature influencing the sound transmission. For plastering, mortar thickness of 10 mm, 15 mm and 20 mm thick was applied on either sides of the wall. Figs.13, 14, 15 shows the sound reduction index (SRI) of the hollow blocks. The straight web geometry of the blocks is resulting in higher sound insulation which is in conformity with other work (Scholl and Weber, 1998 [37]; Fischer et al, 1998 [13]).

**Ferrocement Panels:** Fibre impregnated ferrocement panels made of using coconut shell are tested. The panels are cast in-situ and erected for experimentation. The material by itself has a better performance than the conventional brickwork and concrete of high flexural strength and modulus of elasticity. The panel consists of two layers of chicken mesh of 22 gauge thick with hexagonal opening wound over on the top of one layer of weld mesh of 10 mm x 10 mm opening (10 gauge thick). Cement mortar of 1:2 ratios has been used in casting the specimens. The sizes of the panels cast for testing are 3 mm x 2.1 mm x 20 mm thick. Ferrocement panels with
different structural systems have been studied for sound transmission. Systems of ferrocement panels studied are as follows:

- Single fibre impregnated ferrocement panel.
- Fibre impregnated Panel with cavity
- Fibre impregnated Panel with cavity insulation. High density fibre glass wool of 50 mm thick (48 kg/m³)

Fig.13 shows the measured sound reduction index of the Fibre impregnated ferrocement. Fig.14 Shows the loss factor measurements on the panel. Fig.15 shows the sound reduction index of the cavity ferrocement panel. Figs. 16, 17, 18 shows the sound reduction index of the panel with cavity of 100 mm, 150 mm and 200 mm respectively. Fig. 19 shows the loss factor measurements of the panel with cavity.

Fig. 8. Types of hollow blocks studied

All dimensions are in cm
5.3. **Theoretical prediction model using SEA**

The theoretical computations have been computed by developing software through Statistical Energy Analysis approach. The Programme is written in Visual Basic. Statistical Energy Analysis permits calculation of energy flow between connected resonant structures such as plates, beams and reverberant sound fields in an enclosure. The term statistical refers that averages are involved and randomness is assumed in excitation, the distribution of resonance frequencies and matching condition and principles are employed considering the coupled systems. The model showing the power flow between the subsystems is shown in Fig.9. [6]. The flow chart for the SEA model is shown in Fig.10 (a, b).

![Fig. 9. SEA model for three subsystems](image)

Measured and predicted results correlate well and the difference is just 2-3 dB between the measured and predicted values. Figs. 13, 15 and 18 shows the predicted and measured sound reduction index also. The methodology and the software provide the advantage of selecting the materials for desired sound transmission loss in a user friendly way. [1]
Fig. 10(a). Flow chart of SEA model
Fig. 10(b). Flow chart of SEA model
5.4. **Real time simulation results using ODEON**

The calculation of transmission through walls including auralization in receiving room is done using the room acoustic simulation software Odeon version 9. The room acoustic simulation software Odeon is based on ray tracing in combination with a secondary source radiation method for reflections after a certain transition order, typically 0 – 3 order of reflection [22, 23, 24]. In the Odeon model the particles are treated as carries of sound energy that is reduced after each reflection with the frequency dependent reflection coefficients of the surfaces.

In the following tests the decay curves and integrated squared impulse responses have been investigated at the 1 kHz octave band in the source room as well as in the receiver room. The source room with dimensions 8.3m X 2.3m X 2.5 m and receiver room with dimensions 5.4 m X 3.6 m X 2.5 m and the transmitting surface of 63 m² is modeled as in the experimental model as shown in Fig.11. The white noise is produced for auralization in the model. The receiver and source position are placed as per ISO 140-3-1995 [19] and recorded results are analyzed. Hence the real time simulation is carried on using Odeon software and the results are compared with experimental results and theoretical results.

![Fig. 11. 3D model created Using ODEON for real time analysis](image)
6. Results and Discussions

The sound insulation characteristics of fibre impregnated hollow block depend on block design structure of the webs and holes. In study a constant web thickness and holes are considered with varying thickness of block. Fig.12 shows the sound reduction index for 120, 170 and 220 mm respectively. The sound reduction index (SRI) for all the three thickness of the fibre impregnated hollow block wall has a broader dip between 50 Hz to 250 Hz. At higher frequencies; there is another dip at 1250 Hz, which is not very predominant for 170 and 220 mm. The dip is attributed due to the coincident frequency associated with the thin surface layers of fibres and the coconut shell which is used in hollow blocks. The SRI of fibre impregnated hollow blocks exhibits 38, 40 and 43 dB at 500 Hz for 120, 170 and 220 mm respectively.

As expected when the total wall thickness decreases the critical frequency increases and the overall sound insulation decreases. Similar dips appear at the higher frequencies due to the thin surface layer of fibre impregnated hollow block. All the three types of fibre impregnated hollow are made from the same manufacture using same material and mixing ratios. Straight webs inside the fibre impregnated hollow block provide higher bending stiffness.

Two important mechanisms for the fibre impregnated hollow block walls is that the block undergoes pure bending and hence the bending wavespeed increases with frequency due to the effect of fibres. The density and the curves in coconut fibre decreases the intensity flow of longitudinal and bending waves which increases the transmission loss factor of the hollow block and as well as the ferrocement panels. The limit of regarding the block when the bending wavelength is six times the plate thickness, given by $f = c_t/20h$ for homogenous plates. Generally the bending wave speed is slightly lower than transverse wave speed [2] where the difference is related by the poisson ratio.

Other important parameters include, total loss factor (TLF), the longitudinal wavespeed of the panel and the acceleration level difference on either side of the wall for an airborne source. The total damping (TLF) of the wall was calculated
using the measured standard decay rate of the wall, where the source was an acoustic hammer, an average of 6 positions was recorded [1].

Plaster layers are applied to walls to seal the face of the blocks. This can increase the total mass of the wall and also increases the air flow resistance leading to improved sound insulation properties. In order to study the effect of plaster layers on sound insulation of hollow block walls, plaster thickness of 5, 10 and 15 mm has been applied on all the blocks.

Figs.13, 14 and 15 shows the sound reduction index of the fibre impregnated hollow blocks of 120, 170 and 220 mm with plaster layers of 5, 10 and 15 mm respectively. The curve shows dip at low frequency range of 125-250 Hz. At high frequency of 3150 Hz there is another dip occurring which can be attributed due to the critical frequency.

From Fig.16, It is seen that the sound reduction index of the fibre impregnated panel with cavity shows prominent dips at low frequency at 75 Hz which are due to the cavity resonance. This in turn matches well with the predicted cavity resonance values which were around 75 Hz. At high frequency regions coincidence dips predominate at 1500 Hz which again coincides with the predicted value. Critical frequency value of the fibre reinforced ferrocement panel behaves like a thin plate. The measured results all tend to level off at very high frequency due to other transmission paths.

In case of cavity with absorptive material the sound reduction index gradually increases due to the presence of material inside the cavity thereby increasing the coupling of the cavity with the material. From Fig.17 it is seen that the dips are more predominant at high frequency regions at 1250 Hz, is due to the first cross cavity resonance of the air. This value coincides with the predicted frequency value of around 1250 Hz from Fig.18. The agreement between the measured and predicted results improves as the material has been added to the panel. Fig.19. shows the measured loss factor of coconut fibre reinforced ferrocement panel. It is clearly seen that the total loss factor of the panel with
absorptive material shows higher loss factor than the cavity fibre reinforced ferrocement panel.

The results are then compared with the theoretical investigation using SEA approach. Fig.16 and Fig.17 shows the experimental value coincides with the predicted frequency value of around 1250 Hz. The agreement between the measured and predicted results improves as the material has been added to the panel.

![Graph of Sound Reduction Index (SRI) for different hollow blocks](image)

**Fig.12: Measured Sound Reduction Index (SRI) of hollow blocks**

![Graph of Sound Reduction Index (SRI) for 120 mm hollow block with plastering](image)

**Fig. 13: Measured Sound Reduction Index (SRI) of 120 mm hollow block with plastering.**
Fig. 14: Measured Sound Reduction Index (SRI) of 170 mm hollow block with plastering

Fig. 15: Measured Sound Reduction Index (SRI) of 220 mm hollow block with plastering
Fig. 16: Measured sound reduction index of ferrocement panel 20 mm thick (♦) and fibre reinforced ferrocement panel of 20 mm thick (■).

Fig. 17: Measured sound reduction index of ferrocement panel with cavity of 50 mm (Δ), 100 mm (□), 200 mm, (◊) with experimental values (-------) and predicted values using SEA (--------).
Fig. 18. Measured sound reduction index of coconut fibre reinforced ferrocement panel with cavity and absorptive material 50 mm (Δ), 100 mm (□), 200 mm (◊), with experimental values (——) and predicted values using SEA (--------).

Fig. 19: Measured loss factor of ferrocement panel (◊) and with absorptive material (□)
7. Conclusion

A study on sound transmission performance characteristics of coconut shell hollow blocks, Coconut fibre impregnated ferrocement panels and other building systems has been carried out in this work. From the studies conducted in this suite it has been observed that the coconut shell hollow blocks of 120, 170, 220 mm thick exhibit a sound reduction index of 38, 40, 43 dB respectively at 500 Hz. Which is 6 dB higher than normal hollow blocks. There is a considerable difference of SRI of the blocks with and without plastering. The difference is order of 7-8 dB depending on the thickness of the block. A comprehensive experimental study on Coconut fibre impregnated ferrocement panels for sound transmission performance has been investigated. The SRI of the panels (20 mm thick) is 30 dB whereas for cavity panel it increased by 5 dB. Fibre reinforced ferrocement panel with 50 mm cavity and double triangle ties exhibits 40, 35, 33 dB of sound reduction index at 500 Hz with two, four and eight ties respectively. As the numbers of ties are increased from 2, 4, 8 the sound reduction index value decreases at high frequency. This is because of the fact that greater transfer of energy occurs due to the presence of ties. But there is a good increase at 125 Hz with maximum number of ties. Theoretical predictions and comparisons using Statistical Energy Analysis approach has been done and experimental results agree well. The difference is of the order of 2 – 4 dB between experimental and theoretical values. From the investigation it is seen that the using natural coconut fibres in building components like hollow blocks and fibre reinforced ferrocement panels can be explored as noise insulating elements.
8. REFERENCES


24. **Jens Holger Rindel & Claus Lynge Christensen.,** (2008), Modelling Airborne Sound Transmission between coupled rooms,


Visible Research Output:

LIST OF PUBLICATIONS


