INFLUENCE OF MOISTURE AND RECYCLED MEDIUM ON THE ACOUSTICAL PROPERTIES OF GREEN WALL CLADDING

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1 INTRODUCTION

There are many advantages of applying vegetated cladding to a structure. Green wall cladding is aesthetically pleasing and it acts like porous media reducing environmental noise levels by absorption. Other mechanisms by which sound levels are reduced involve diffusion and scattering caused by leaves, twigs and wall roughness.

As well as sound absorption through substrate soil and plant roots other benefits of the green cladding include hydrothermal comfort which involves plants maintaining a constant relative humidity. In urban settings that lack the space to develop green areas the green wall has a positive psychological effect and through a system of air circulation the green wall helps improve urban air quality.

This study will focus on the assessment of acoustical effects of recycled porous media on substratum soil. Other aspects that will be investigated include effect of moisture and foliage.

2 ACOUSTICAL PROPERTIES OF THE GREEN WALL

2.1 Effect of soil moisture on acoustic absorption

Soil being a natural form of porous media will be affected by moisture in terms of its absorptive properties. This experiment looked at the influence of moisture on sound absorption; a reduction in absorption coefficient of soil is anticipated as its water content is increased according to Horoshenkov et al[1]. The strength of this effect is examined here through measurements of absorption coefficient under systematic increases in soil water content for two soil types, firstly normal soil and secondly substratum soil developed for the use in green walls by Canevaflor™.

Figure 1 shows absorption coefficients for normal, clay-based soil of thickness 200mm which is used widely by local councils. Water was applied to the top of the soil sample in the impedance tube container. In this way the penetration of water was mainly confined to the top level of soil. The results suggest that the sound absorption is reduced as soil water content is increased. At middle and higher frequencies this effect is more significant for the initial applications of water to the surface. A comparatively small decrease in the sound absorption is produced when the degree of water saturation is high (Sr > 37%). It can be seen in Figure 1 how the soil absorption coefficient levels out at 400 Hz after the addition of the initial water, this indicates that majority of the open pores on the soil surface become blocked by water thus reducing the ability of sound to penetrate the material pores to be absorbed due to the visco-thermal effect.

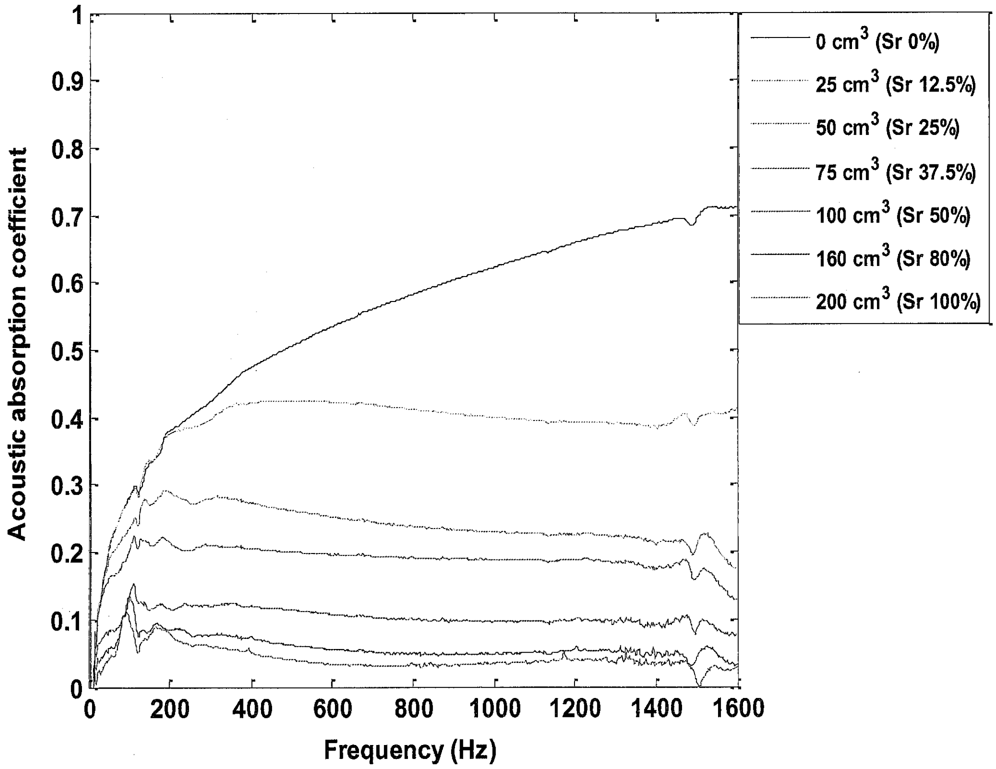


Fig. 1. The effect of varying the moisture level on normal soil of thickness 200mm (% saturation, Sr).

Figure 2 shows the effect of varying the moisture level on substratum used in green walls, substratum water was increased from its normal in-bag level by adding up to 500 cm^3 of water to obtain 50% saturation, because of a water retaining polymer used in the substratum 100% saturation was not achieved. The results in Figure 2 suggest that increases in substratum water content has a tendency to reduce sound absorption but the effect is not as much as normal soil (Figure 1), especially at the lower frequencies. This high performance at lower frequencies can be attributed to the composition of the substratum, which consists of coconut fibres with some perlite and a water retaining polymer. Normal soil required 200 cm^3 of water for 100% saturation whereas substratum soil required 500 cm^3 for 50% saturation for the same thickness.

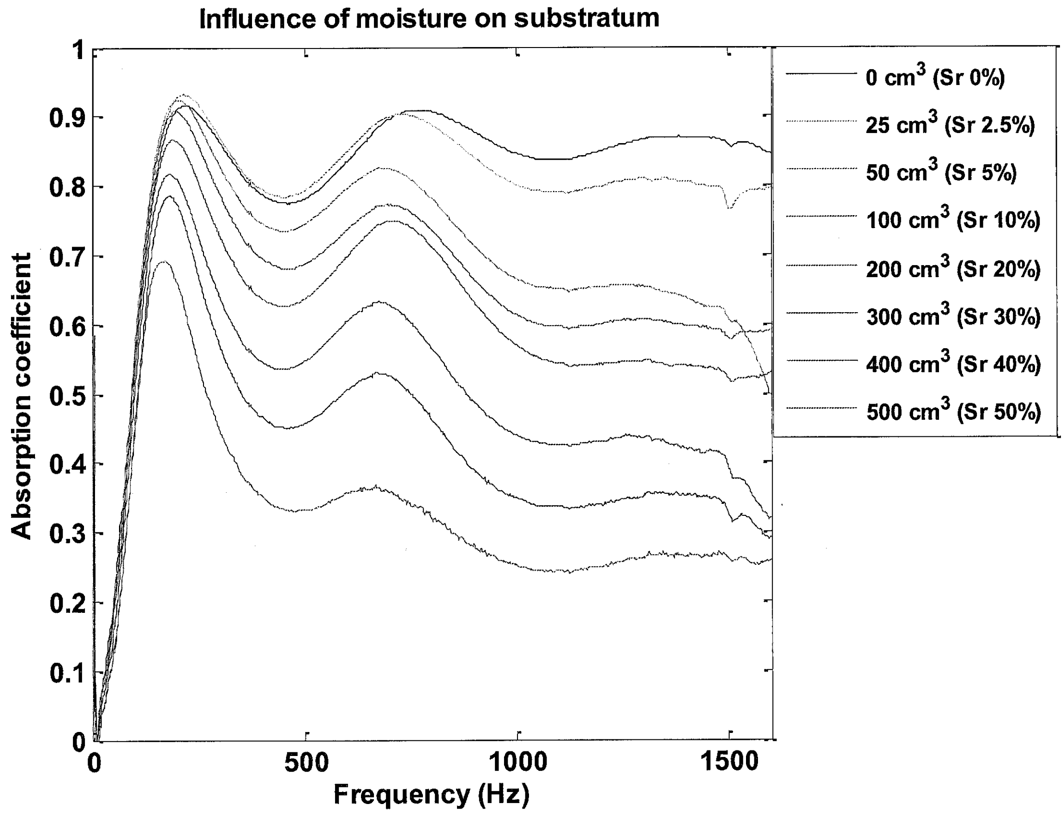
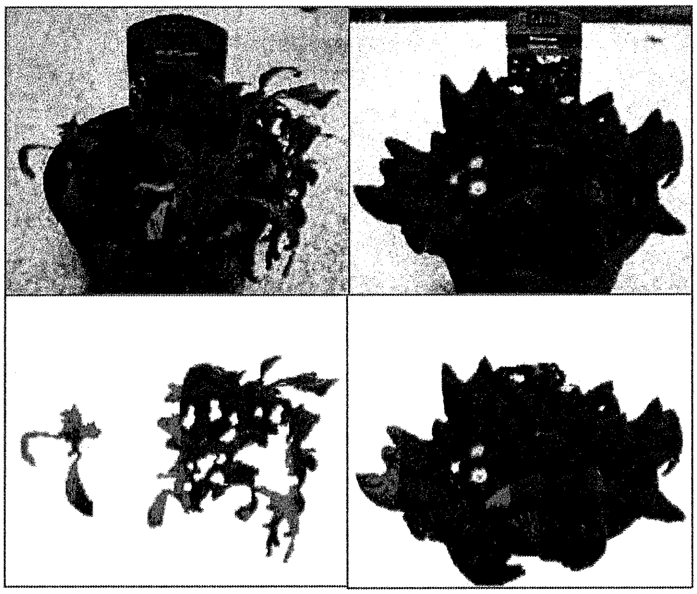


Fig. 2. The effect of varying the moisture level on substratum soil of thickness 200mm (% saturation, Sr).

2.2 Effect of leaves on acoustic absorption coefficient

The purpose of this study was to measure how sound absorption properties of soil may be modified by different types of leaves. Two plants were studied to show the effect of leaves on acoustic absorption coefficient. The plants are compared in terms of leave area and soil weights in Table 1. The absorption coefficients of two plants (primrose and wallflower) were tested in a standard 100mm diameter impedance tube without any extra addition of water to the soil base (Figure 3). The thickness of soil for both plants was set at 100mm. The plant leaves occupied approximately 100mm space above the layer of soil.



(a) (b)

Fig. 3. Plants studied for acoustic absorption, Primrose (a), Wallflower (b)

To examine the effect of leaves, the leaves were cut by 50% in length in a way that did not disturb the surface soil. Sound absorption was measured for 100%, 50% and 0% leaves. Approximate values for total plant leaf area were calculated from digital images of individual plants, the results are shown in Table 1.

Table 1: Comparison of plant leaves.

Plant	Weight of leaves (g)	Weight of soil (g)	Total weight (g)	Leave area (cm^2)
Primrose	18 (6%)	297.4 (94%)	315.4	416
Wallflower	9.3 (1%)	716.5 (99%)	725.8	93

The results in Figure 4 show that there is a relatively large effect of moisture (see primrose soil moisture vs wallflower soil moisture data in Table 1). As a result, primrose plant shows considerably more acoustic absorption compared to wall flower due to primrose having less moisture in the soil. Not much change in sound absorption is observed in Figure 4 at lower frequencies due to the effect of soil but at mid and high frequencies change in the amount of leaves appears to have a larger effect on sound absorption. All experiments were repeated three times to obtain an average and a standard deviation this is only obvious at higher frequencies for 100% leaves (Figure 4, grey area) due to leave scattering.

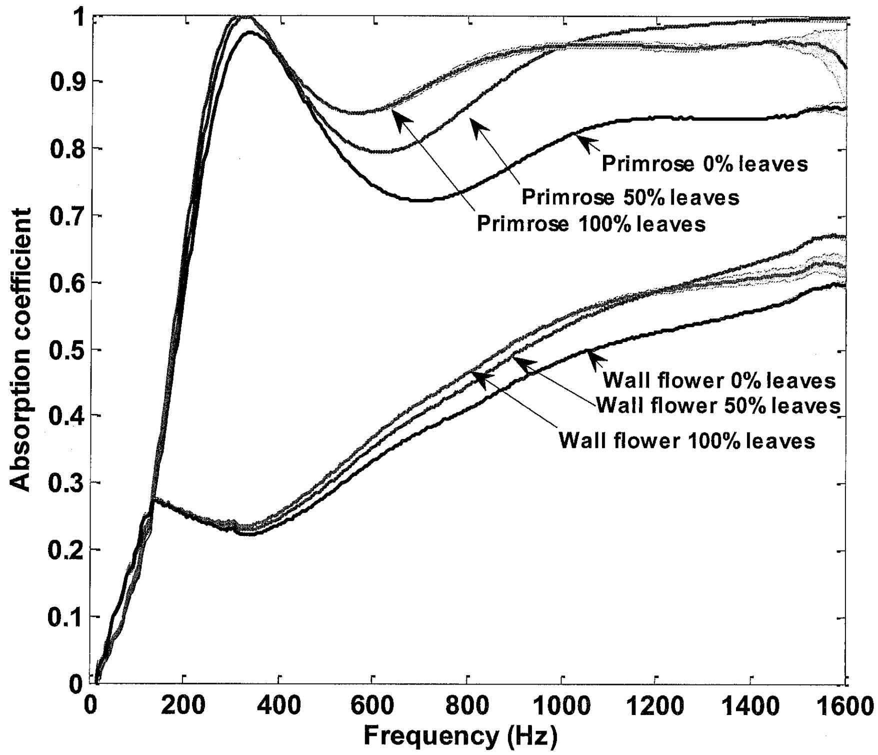


Fig. 4. Effect of leaves on acoustic absorption for two plant types

If we consider primrose and wall flower leaves, the weight of primrose leaves is almost twice as much as wallflower leaves. This is reflected in the absorption graph in Figure 4. Because primrose plant leaves have an area over four times that of wallflower leaves, their ability to absorb more sound is apparent. The differences in absorption between 100% and 0% leave area for the two plant types are approximately three fold in the medium and high frequencies compared.

2.2.1 Influence of recycled material layer on the acoustic properties of substratum

The purpose of this experiment was to integrate a recycled material layer made from polymeric waste on the surface of the green wall. To examine the effect of recycled layer with substratum, experiments were conducted using a 40mm layer of recycled material made from PVC granules and placed on top of a layer of substratum of thickness 160mm. Full description of the experimental method used to produce the recycled layer can be found in author's previous work[2].

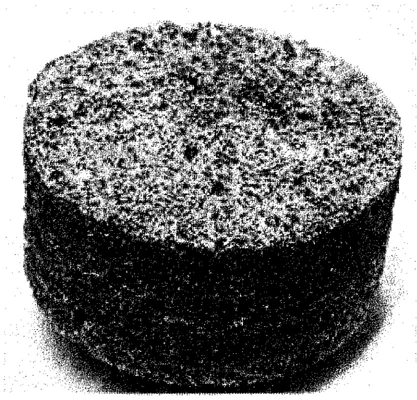


Fig. 5. Recycled layer made from PVC granules and nylon fibres

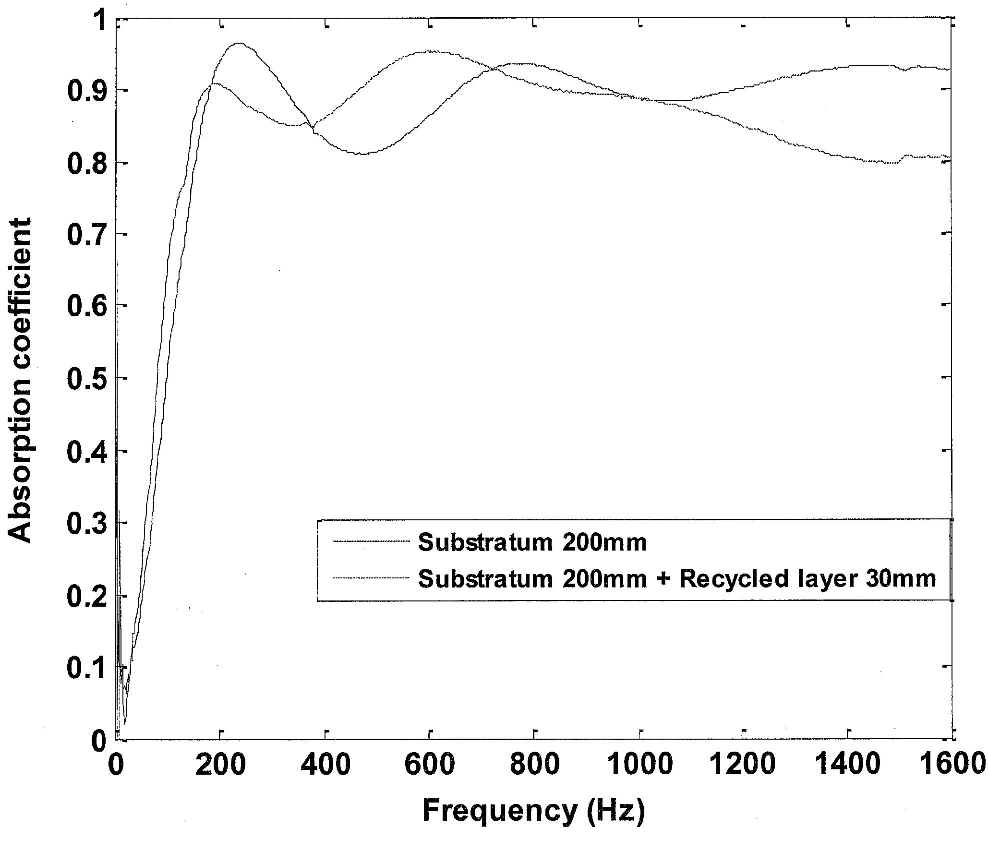


Fig. 6. Effect of recycled layer on substratum.

From Figure 6 the difference in acoustic absorption with the recycled layer can be seen, the effect of the recycled layer is more profound for frequencies below 800 Hz, the performance of the substratum is relatively good but addition of the recycled layer can help when the moisture levels alter in the substratum.

2.3 Modelling the acoustic absorption of bag substratum

2.3.1 Acoustic absorption of a single layer: Pade approximation model

The Pade approximation model can be used to predict the acoustic admittance and absorption coefficient of a homogeneous layer of rigid-frame porous medium [Horoshenkov & Swift, 2001][3]. This model requires the knowledge of the material porosity (Ω), flow resistivity (σ), tortuosity (α_∞) and the standard deviation of the log-normal distribution in the material pore size ($\delta\phi$). It is able to provide a very close fit (2-5%) to the measured data for loose and consolidated granular media. The model assumes that the frequency dependence of the dynamic density and complex compressibility in a material with log-normal pore size distribution can be described by the following relations

$$\rho_b(\omega) = \frac{\alpha_\infty}{\Omega}\left(\rho_0 - \frac{\Omega\sigma}{i\omega\alpha_\infty}F(\omega)\right) \qquad \textit{Eq. 1}$$

and

$$C_b(\omega) = \frac{\Omega}{\gamma P_0}\left(\gamma - \frac{\gamma - 1}{1 - \frac{\Omega\sigma}{i\omega\alpha_\infty\rho_0 N_{\mathrm{Pr}}}F(\omega N_{\mathrm{Pr}})}\right) \qquad \textit{Eq. 2}$$

where $N_{\mathrm{Pr}} \cong 0.709$ is the Prandtl number for air and $F(\omega)$ is the viscosity correction function originally proposed by Biot. In the case of materials with pore size distribution close to log-normal the viscosity correction function can be predicted with the following rational (Pade) approximation

$$F(\varepsilon) \cong \bar{F}(\varepsilon)\frac{1 + a_1\varepsilon + a_2\varepsilon^2}{1 + b_1\varepsilon}, \qquad \textit{Eq. 3}$$

where $a_1 = b_1 = \theta_1/\theta_2$ and $a_2 = \theta_1$, $\theta_1 = 4/3e^{4c} - 1$, $\theta_2 = \sqrt{1/2}e^{3/2c}$, $c = (\delta\phi\log(2))^2$ are some real coefficients and $\varepsilon = \left(\frac{-i\omega\alpha_\infty\rho_o}{\sigma\Omega}\right)^{1/2}$ is the frequency-dependent parameter.

It is common to use absorbing lining to treat a surface that is otherwise highly reflective. In this case, the acoustic admittance and absorption of the porous layer are given by

$$\beta(\omega) = \beta_b(\omega)\coth(-ik_b(\omega)h) \text{ and } \alpha(\omega) = 1 - \left|(1-\beta(\omega))/(1+\beta(\omega))\right|^2, \qquad \textit{Eq. 4}$$

respectively. Here $\beta_b(\omega) = \rho_0 c\sqrt{\frac{C_b(\omega)}{\rho_b(\omega)}}$ and $k_b(\omega) = \omega\sqrt{\rho_b(\omega)C_b(\omega)}$ are the characteristic admittance and complex wavenumber, respectively.

Table 2 presents the data associated with modelling with the Pade approximation approach. Experimental data was used in the prediction; non-acoustical parameters were not adjusted to improve the fit between the measured and predicted data (see Fig. 7).

Table. 2. Summary of the parameters used in Pade approximation for substratum.

Material	Density (kg/m^3)	Resistivity (N.s/m^4)	Porosity (%)	Tortuosity	Stand dev.	Thickness (m)
Substratum soil	251	6,680	0.76	1.0	1.02	0.2

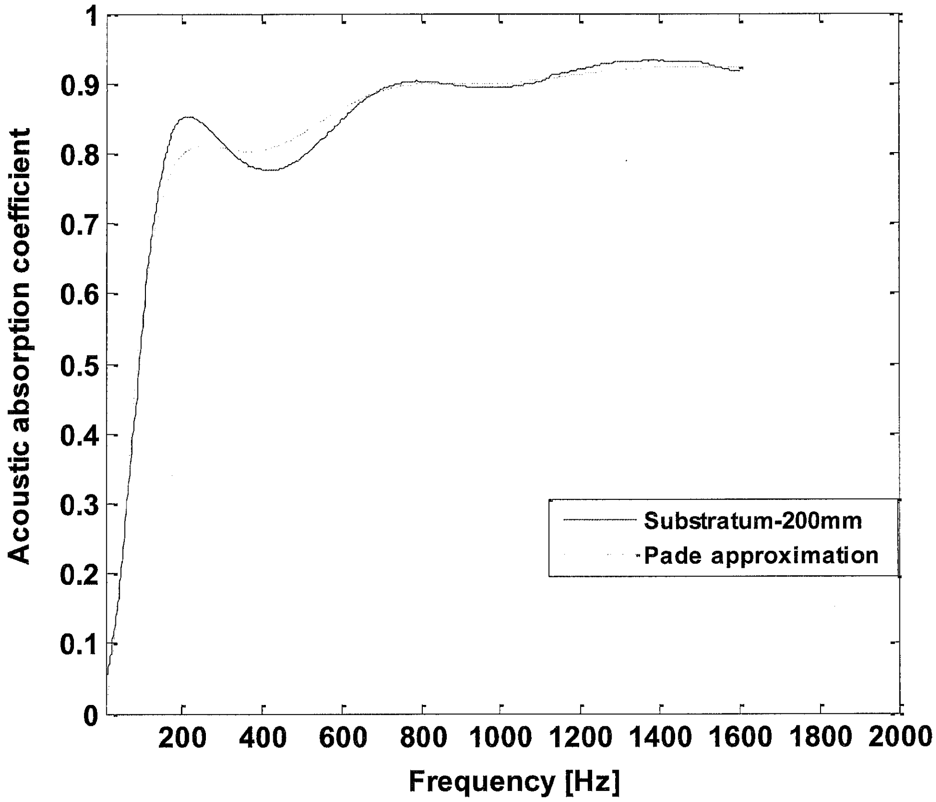


Fig. 7. Pade approximation fit of the substratum.

The comparison between the experimental results and prediction show that the model can provide a good agreement with the experimental results for the substratum.

2.3.2 Acoustic absorption of a stack of acoustic layers: Transfer matrix model

It is common to stack several porous layers to improve the absorption performance of an acoustic liner as illustrated in Figure 8.

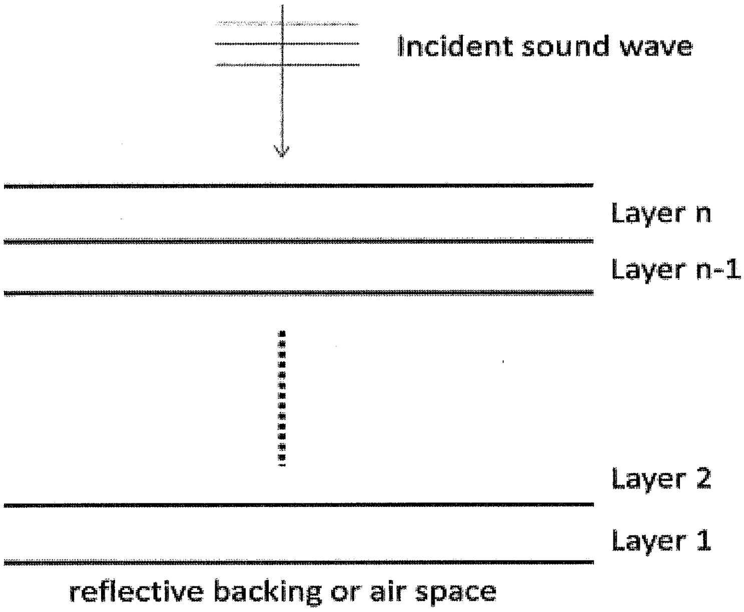


Figure 8. Illustration of the problem with a stack of acoustic absorbing layers.

This improvement is normally attained by matching carefully the impedances of the consecutive layers in the stack. The resultant impedance of a stack of N porous layers is obtained from the following equation

$$z_{in}^{(n)}(\omega) = z_{n-1} \frac{z_{in}^{(n-1)} - z_{n-1} \tanh(ik_{n-1}h_{n-1})}{z_{n-1} - z_{in}^{(n-1)} \tanh(ik_{n-1}h_{n-1})}, \qquad \text{Eq. 5}$$

where z_n, k_n and h_n are the characteristic impedance, wavenumber and the thickness of the n-th layer. This formula is applied recursively starting with layer 1 that is typically rests on a perfectly reflecting wall or loaded with a semi-infinite air space. In the case, of the rigid termination, the impedance at the interface between the bottom of the 2nd and the top of the 1st layers in the stack is given by $z_{in}^{(2)}(\omega) = z_1 \tanh(ik_1h_1)$. The characteristic impedance and the wavenumber in eq. (5) can be determined from the Pade approximation model detailed in the previous section.
The proposed model has been validated against measured data for a stack a recycled layer 30mm on top of substratum 200mm. The non-acoustical properties used to predict their characteristic impedance and complex wavenumber are for substratum: (i) $\sigma = 6,680$ Pa s m^{-2}, $\Omega = 0.76$, $\alpha_\infty = 1.00$, $\delta\phi = 1.02$ for recycled layer; (ii) $\sigma = 8000$ Pa s m^{-2}, $\Omega = 0.9$, $\alpha_\infty = 1.6$, $\delta\phi = 1.06$. The result of this validation exercise is presented in Figure 8. It illustrates that the agreement between the predicted and measured data is within ±5% in the frequency range of interest.

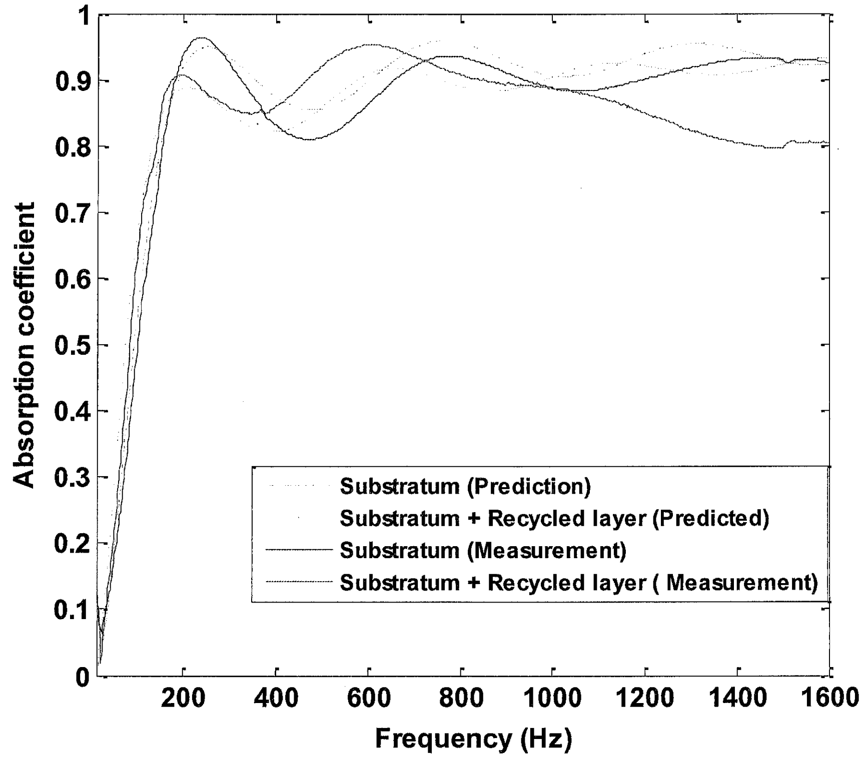


Fig. 9. Validation of the model for the acoustic properties of a stack of porous layers.

The model has been used to estimate the effect that a 30mm layer of recycled porous material makes on the absorption coefficient of a 200mm layer of soil substrate (Figure 9).

3 CONCLUSIONS

In this study measurements were carried out to examine the effects of moisture and recycled layer on the acoustical properties of substratum soil. It has been shown that effects of moisture on the substratum soil is small in comparison to normal soil, also the effects of leaves are not as significant compared to the overall water content of the soil. The experimental results with the leaves show that leaves with high density and large surface area have positive effects on noise absorption mainly at higher frequencies.

The results on the effect of recycled layer placed on top of the substratum suggest that the addition of recycled material improves the sound absorption. In order to model the frequency dependant behaviour of the sound absorption Pade approximation model was adopted to predict the acoustic performance of the substratum. The Pade approximation model is based entirely on a set of four measurable non-acoustic parameters, which are the porosity, flow resistivity, tortuosity and the standard deviation. Table 2 presents the data associated with modelling with the Pade approximation approach. Experimental data was used in the prediction; non-acoustical parameters were not adjusted to improve the fit between the measured and predicted data.

4 REFERENCES

1 Kirill V. Horoshenkov and Mostafa H. A. Mohamed. Experimental investigation of the effects of water saturation on the acoustic admittance of sandy soils, J. Acoust. Soc. Am. 120, 1910 (2006).

2 Khan, A, K. V. Horoshenkov, H. Benkreira. Controlled Extrusion of Porous Media for Acoustic Applications, CD-ROM Proc. Int. Symp. Acoust. Poroelastic Materials, Lyon, France, 7-9 December 2005.

3 Horoshenkov K. V. and Swift M. J.,. The acoustic properties of granular materials with pore size distribution close to log normal, Journal of the Acoustical Society of America, Vol. 110, number 5. 2001.