

DYNAMIC MEASUREMENT OF THE SOUND ABSORPTION OF POROUS ROAD SURFACES

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1. INTRODUCTION

Porous road surfaces are increasingly being specified as an effective means of reducing the generation and propagation of noise from road traffic. Although the processes of noise reduction involves a series of complex mechanisms it has been found that for many practical applications, performance can be simply related to the acoustic absorption properties of the surface layer e.g. [1,2,3]. Unfortunately, the porosity of these surfaces can deteriorate over time as the surface voids become clogged with detritus caused by the action of trafficking and exposure to the elements. Associated with this fall in porosity is a gradual reduction in the noise reducing properties. Highway engineers therefore need a means by which porous surfaces can be monitored both after construction, as a means of ensuring compliance with contract specifications, as well as monitoring performance, in use, to inform maintenance and replacement strategies.

To perform in-situ measurements using existing, established techniques such as impedance tube and level difference measurements is difficult, particularly where there is a requirement to sample long lengths of road surface, since a minimum of a single lane closure is required, and limitations arise from the need to either extract core samples or set up test apparatus on the road surface. Clearly this approach would inevitably create congestion, delays and raise accident risk.

For these reasons, there exists a requirement for a mobile technique for measuring the absorption coefficient of porous surfaces which will ideally allow measurements to be taken under dynamic conditions, i.e. without disrupting the flow of traffic. Time domain Maximum Length Sequence (MLS)-based measurement techniques have been demonstrated under static conditions, e.g. [4], to offer advantages over traditional methods due to the short duration of the measurements and the use of apparatus which does not require to be in contact with the road surface. Such apparatus is therefore appropriate for mounting on a mobile platform.

This paper describes a suitable trailer which was developed to be capable of supporting a rigid loudspeaker/microphone system for performing MLS-based measurements. Results are presented for a series of dynamic measurements, towing the trailer at speeds of up to 30 km/h, and comparisons made with results obtained from static measurements using the same apparatus, and impedance tube and level difference measurements.

2. MEASUREMENT SET-UP AND ANALYSIS PROCEDURE

The measurement set-up is shown schematically in Figure 1. The principle of the method is based upon the measurement of two signals, i.e. the sound propagating directly from the source to the receiver and the sound arriving at the receiver following reflection from the ground surface using This set-up conforms to that detailed in the draft ISO standard [5]. Signal generation, measurement and preliminary analysis are performed using a commercial package, MLSSA, which is based upon research carried out by Rife and Vanderkooy [6]. All other analysis is performed using algorithms

developed by TRL in MATLAB. The signal received at the microphone resulting from the generation of an MLS signal through the loudspeaker is measured in the time domain and produces an impulse response similar to that shown in Figure 2. The first peak in the impulse response is the direct wave component, and the second is the reflected wave component.

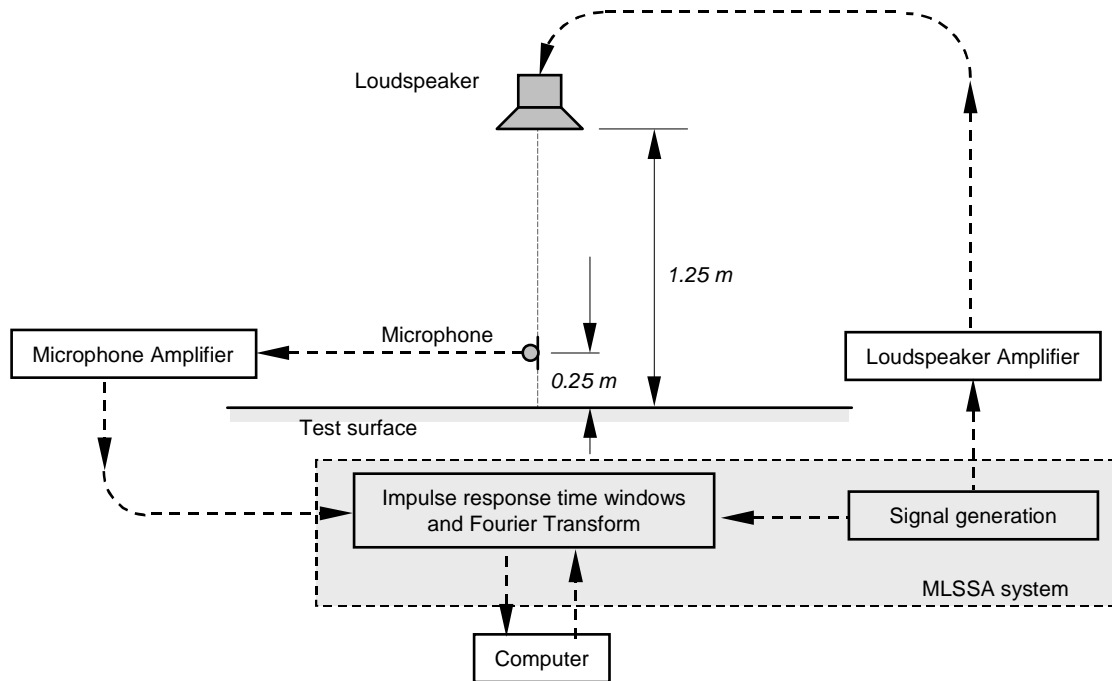


Figure 1: Measurement set-up for road surface absorption

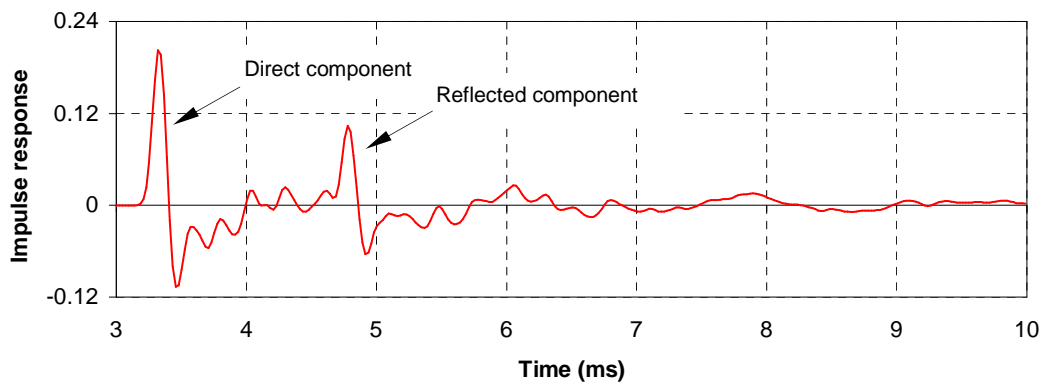


Figure 2: Sample impulse response measured at receiver microphone

A measurement is also taken with the loudspeaker/microphone pairing oriented away from the surface to obtain an equivalent free-field measurement, i.e. the direct component impulse response only, as shown in Figure 3.

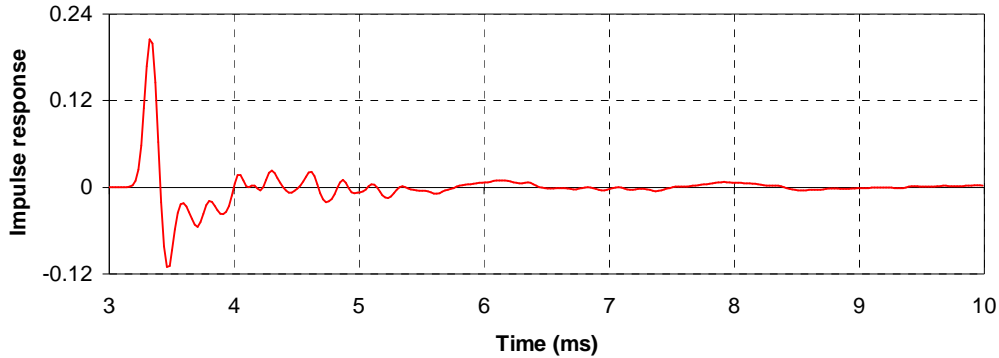


Figure 3: Sample free-field impulse response measured at receiver microphone

The orientation and heights of the microphone and loudspeaker in the measurement set-up (Figure 1) are chosen to allow the use of signal subtraction techniques to extract the impulse response component corresponding solely to that part of the signal reflected from the road surface from the combined impulse response in Figure 2. Algorithms have been developed to allow for phase shifting of non-aligned signals during the subtraction process.

An FFT is applied to the free-field and reflected component impulse responses and the absorption coefficient, α , of the surface calculated from

$$\alpha(f) = 1 - |R(f)|^2 = 1 - \left(\frac{T_r}{T_i} \right)^2 \times \left| \frac{H_r(f)}{H_i(f)} \right|^2$$

where $H_i(f)$ is the frequency response of the direct path impulse response, $H_r(f)$ is the frequency response of the reflected path impulse response and T_i and T_r are the times of arrival of the maximum values of the direct and reflected pulses in the impulse response.

3. DEVELOPMENT OF THE TRAILER SYSTEM

For the purpose of developing a measurement set-up which can be applied to dynamic measurements, the design of the trailer on which the apparatus was to be mounted was influenced by a number of factors:

- i) To minimise the occurrence of parasitic reflections within the time window, the trailer should ideally be a skeletal framework, with a minimum number of large flat surfaces that could reflect sound waves.
- ii) The trailer should be of sufficient length to minimise the occurrence of parasitic reflections from the towing vehicle within the selected time window.
- iii) The trailer dimensions should conform to current Construction and Use regulations [7] regarding maximum length and width.

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- iv) The support mountings for the loudspeaker should be rigid enough to allow the trailer to be towed at suitable speeds during measurements and between different measurement locations.

Testing of a prototype design under both static and dynamic operating conditions resulted in the trailer shown in Figure 4.



Figure 4: Trailer arrangement and towing vehicle used for performing static and dynamic measurements of absorption coefficient

The design is based around a 2.0 x 2.0 m square box-section frame and an A-frame/I-beam combination, shown in Figure 5 from which the loudspeaker and measurement microphone were suspended.

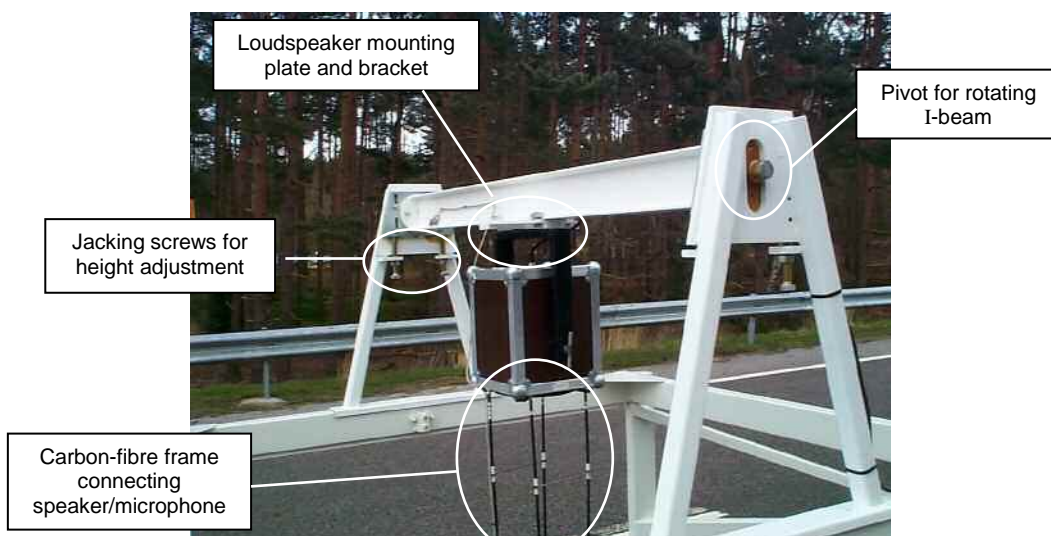


Figure 5: I-beam and A-frame arrangement for supporting the loudspeaker on the trailer

The loudspeaker has been developed by TC226 WG6 Research Group "Adrienne" specifically for performing MLS-based measurements [8] and the microphone is a standard ½" B&K Type 4149 microphone. The two are connected together using a lightweight carbon-fibre support frame to maintain the required separation (1.0 m) between the two.

The 'A'-frame combination has been designed to slide along the length of the trailer and the I-beam rotates to allow the speaker/microphone combination to be rotated vertically upwards for performing free-field measurements. The height of the I-beam above the road surface can also be adjusted independently of the main trailer structure.

All other equipment (i.e. PC, amplifiers and power supplies) is fitted into the towing vehicle in such a manner to allow the system to be operated from within the towing vehicle.

4. STATIC MEASUREMENTS USING THE TRAILER

Measurements were first taken on two porous surfaces on the TRL test track to validate the trailer-based set-up under static conditions. This was achieved by comparing the results with those obtained at the identical measurement locations using two established techniques: impedance tube measurements [9] and level difference measurements [10,11].

One problem normally associated with impedance tube measurements is that large quantities of water are used to lubricate the cutting tool during the extraction of the core sample. This has a tendency to wash away some of the detritus lodged in the sample, such that the core is not representative of the road surface from which it was extracted. To overcome this problem, an extension of the impedance tube method has been developed [12] which allows the tube to be used in-situ, being placed on and sealed to the road surface, eliminating the requirement to extract a core. It is this approach which has been used in this study.

Figure 6 presents a comparison of the results from the different techniques for the different porous surfaces. The secondary peak observed in the MLS-based measurement results is anticipated to be due to reflections occurring late in the time window.

In the case of surface (a), the agreement is very good up to 2 kHz, although the limited frequency range of the impedance tube method restricts the range of comparison which can be made. In the case of surface (b), reasonable agreement between the trailer and impedance tube measurements is observed below 1 kHz.

It is noted that precise agreement between results from the MLS-based method and the level difference approach cannot be achieved since the former results in a normal incidence absorption coefficient, whilst the latter derives an absorption coefficient averaged over a range of angles of incidence. In the case of the impedance tube measurements, the cross-sectional area of the sample (based on 100 mm diameter) is considerably smaller than the sample area used by the MLS-based technique; for the geometry in Figure 1, the effective radius of the test sample is 1.28 m.

Given the fundamental differences in the measurement methods compared, it was concluded that the MLS-based measurement technique does provide acceptably good measurements of the absorption coefficient for porous and semi-porous surfaces.

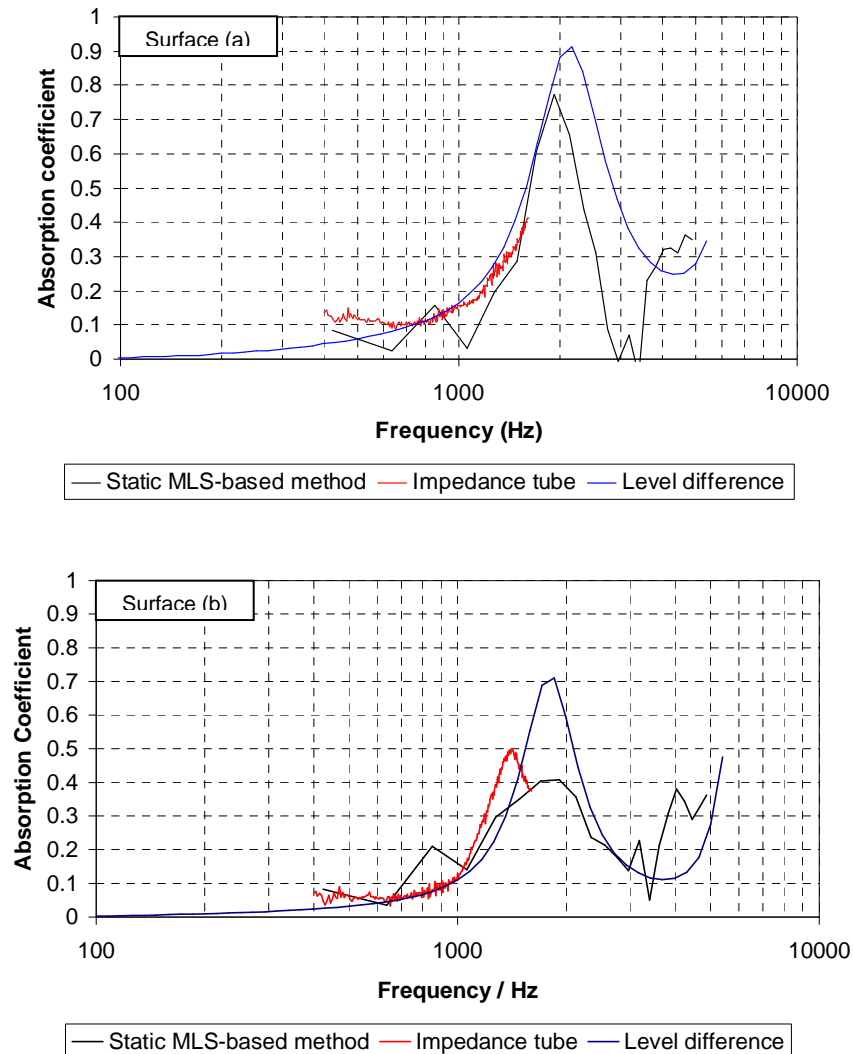


Figure 6: Absorption coefficients on porous surfaces measured using different static in-situ methods

It is anticipated that a more robust validation of the (MLS) trailer system could be carried out using an artificial porous surface with a known porosity and absorption spectra. Measurements could then be carried out under laboratory conditions thereby minimising the effects of variability of the surface materials and the influence of variable weather conditions. It is hoped that further tests will be taken using a matting made from bonded rubber granulate.

5. DYNAMIC MEASUREMENTS USING THE TRAILER

Dynamic measurements using the trailer were restricted to surface (a) on the test track. Figure 7 presents a comparison between initial static and dynamic measurements. The static data is based upon an average of the absorption coefficient measured at two positions, whilst dynamic measurements were taken at towing speeds of 8, 15 and 20 km/h. The software was configured for a fixed measurement duration such that the total length of test surface traversed during the dynamic

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tests was between 26.6 and 66.7 m depending on the speed of the test vehicle, so some variation in results was expected. All of the measurements were taken under dry conditions. Good agreement is observed between the different sets of measurements, the dynamic measurements tending to predict a slightly higher absorption coefficient.

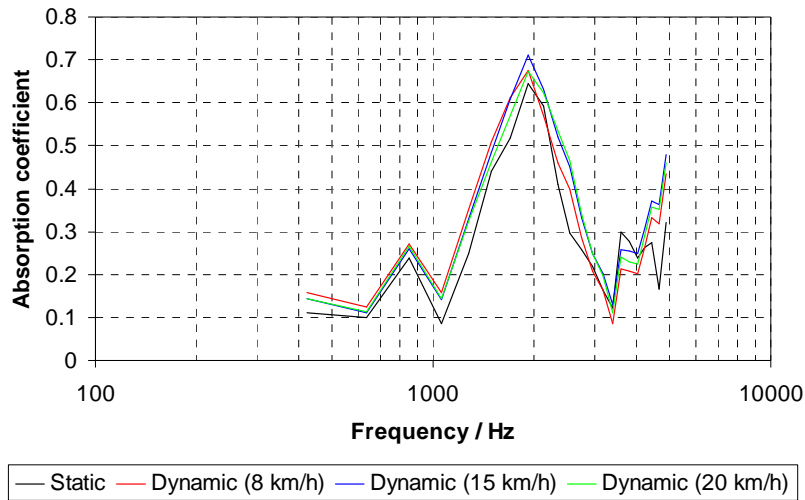


Figure 7: Comparison of absorption coefficients for surface (a) determined using static and dynamic MLS-based measurements

It was considered that since the dynamic measurements are effectively an average over the traversed length of track, then a more accurate comparison might be achieved by taking static measurements at regular intervals along the test surface. Figure 8 shows the potential requirement for taking this approach, showing the mean, minimum and maximum absorption coefficient spectra for surface (a) based on measurements taken at 5 m intervals along the length test surface traversed during the dynamic measurements.

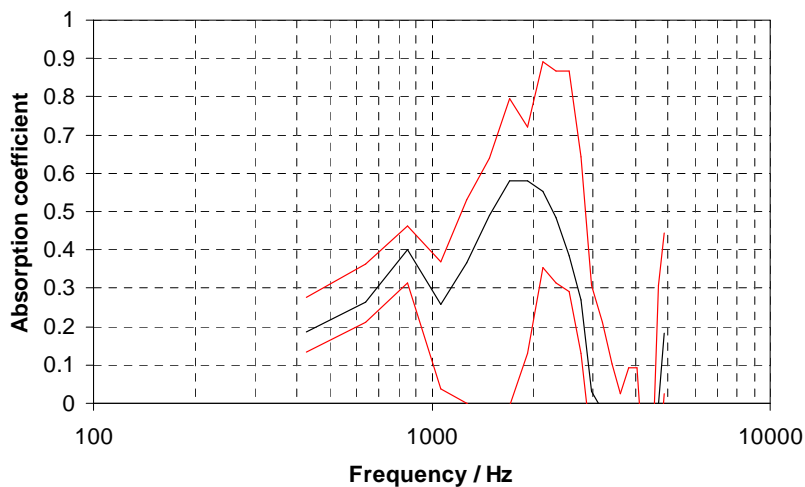


Figure 8: Mean, minimum and maximum absorption coefficient spectra for surface (a) based on spectra measured at 5 m intervals using static MLS-based measurements

A further series of measurements were taken at towing speeds between 8 km/h and 30 km/h. Static measurements were taken at 5 m intervals during the same session. Figure 9 presents the absorption coefficient spectra at 8 km/h, with the mean and limiting spectra from the static measurements. Measurement conditions were not ideal; the track was not completely dry. However, the dynamic measurement falls within the limiting curves, and good agreement between the dynamic and mean static spectra is observed up to 3 kHz.

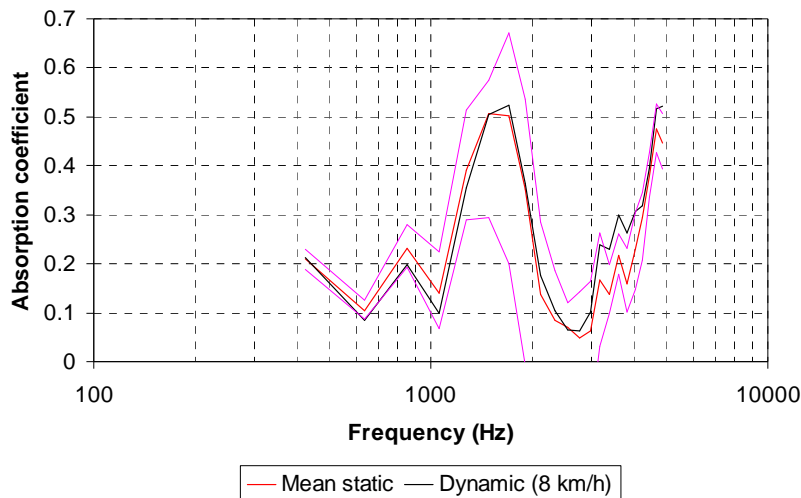


Figure 9: Absorption coefficient spectra for surface (a) determined using dynamic MLS-based measurements (speed = 8 km/h). Mean and limiting values based on static measurements at 5 m intervals

Having established, within the limitations of the test conditions, the accuracy of the measurements, it was important to establish the stability of the dynamic measurements with increasing towing speed, the ideal objective being to achieve a towing speed that would obviate the need for a mobile lane closure. Figure 10 compares the absorption spectra calculated from dynamic measurements at speeds between 8 and 30 km/h, with the limiting envelope from the static measurements.

There is very good agreement between the different curves over the full frequency range, the effects of the different speeds only being evident between 2-3 kHz.

The analysis used to generate these curves was based on the use of a static free-field measurement. The stability of the results suggests that the effect of wind turbulence at the microphone was not a problem over this speed range. However measurements performed at higher speeds resulted in poorer agreement between the dynamic and static results indicating that turbulence may be a problem at speeds above 30 km/h. Analysis performed using dynamic free-field measurements showed decreasing stability with increasing speed; this was considered to be a result of turbulence around the microphone due to the microphone being above the roof line of the towing vehicle.

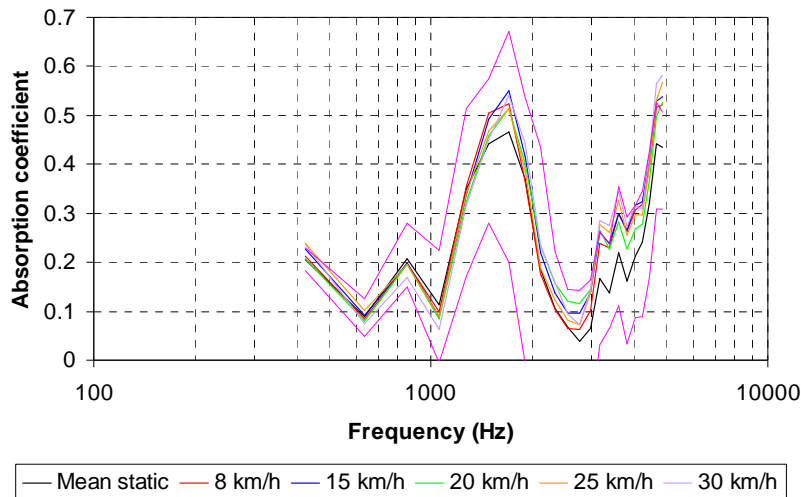


Figure 10: Comparison of absorption coefficients for surface (a) determined using static and dynamic MLS-based measurements

6. CONCLUSIONS

1. An MLS-based measurement method has been demonstrated to be a suitable method for performing non-destructive measurements of the acoustic absorption of porous and semi-porous road surfaces.
2. The test apparatus has been mounted onto a trailer for towing behind a vehicle, offering increased portability for static measurements and the potential for performing dynamic measurements without disrupting the traffic flow.
3. Static measurements used the method have been validated with results obtained using impedance tube and level difference methods. Taking into account limitations imposed by the traditional techniques, reasonable agreement between the results was achieved.
4. Dynamic measurements have been validated by comparison with static measurements averaged over the length of the test surface. The stability of the dynamic results was maintained for towing speeds up to 30 km/h, and good agreement was achieved with the static measurements, allowing for significant variations in the quality of the test surface over its length.
5. Based upon the limited number of surfaces tested, the study has demonstrated the system to provide the basis of a new measurement tool which can be used to test the conformity of porous road surfaces with design standards and to inform maintenance and replacement strategies for the network as a whole.

7. REFERENCES

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