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UNDERGROUND STATION SCALE MODELLING FOR SPEECH INTELLIGIBILITY PREDICTION

R.J. Orlowski

Arup Acoustics, St Giles Hall, Pound Hill, Cambridge CB3 OAE

1. INTRODUCTION

Speech intelligibility of public address systems on many London Underground stations is poor and this can cause loss of important travel information and misunderstanding of vital instructions during an emergency.

London Underground Limited is actively investigating this problem with the intention of acoustically treating stations to improve speech intelligibility and, at the same time, to reduce train noise. Special attention is being directed to new underground stations on the Jubilee Line Extension, mow under construction, where specific speech intelligibility criteria have been set out.

The work to achieve good speech intelligibility requires an understanding of the behaviour of sound in station-like enclosures and availability of prediction models which account for the relevant characteristics. Unfortunately, Sabine's diffuse field theory is not generally applicable to stations because their shape is highly disproportionate; the long platforms and small cross-sectional areas do not support a diffuse sound field [1].

2. PREDICTION MODELS

The key parameter to be predicted is the Speech Transmission Index (STI) or its simplified version, Rapid Speech Transmission Index (RASTI). The latter has been selected by London Underground Limited for its speech intelligibility work. Reverberation Time and Sound Propagation are also of interest.

Prediction of STI on underground stations can be made using commercially available computer models although such models considerably simplify the behaviour of the sound field. Whether or not these simplifications are acceptable depends on extensive validation which is currently in its infancy. Validation will take some years to provide the detailed comparisons that will give the necessary confidence to users. A particular question is how computer models should account for the complicated interaction between sound waves and complex shapes.

By contrast, acoustic scale models have the potential for recreating sound fields accurately in any shape of enclosure and have undergone comprehensive validation over many years [2]. They are, therefore, well suited for predicting STI on underground stations. However, it would not be feasible to build acoustics scale models of, say, every new station on the Jubilee Line Extension; only acoustically difficult stations merit model investigations. A by-product is that scale modelling results can be compared with those from computer models thereby helping the overall validation process.

A series of scale model investigations has been made recently on both existing tube stations, new tube stations and cut-and-cover stations and this has enabled the optimisation of possible acoustic treatments. The following sections describe two scale modelling exercises, one of a traditional deep tube station and the other of a new Jubilee Line Station.

3. ACOUSTIC SCALE MODELLING

3.1 St John's Wood Station

A scale factor of 1:16 was selected for this model enabling model measurements up to the 4kHz octave at full scale which was considered ample for investigating speech intelligibility.

The model was constructed of plastic piping and varnished timber and was successfully calibrated against full-scale measurements.

Acoustically scaled sound absorptive materials were introduced into the model in a variety of forms and key acoustic response characteristics measured, in particular Reverberation Time and Sound Propagation. These indicated that of the chosen test arrangements, the most effective location for absorptive materials was a zone below the tunnel crown. An 'aerofoil' element, 2.75m wide and 800mm deep suspended centrally and 300mm below the crown of the tunnel, gave the best performance. This incorporated sound absorptive material top and bottom. The arrangement is illustrated in Figure 1. With the model aerofoil in place, model loudspeakers of known directional characteristics were installed at 4m centres on the platform wall. Measurements of STI at various platform locations gave values between 0.6 and 0.8 (ie. good speech intelligibility). More detailed results are shown in Figure 2.

The aerofoil arrangement is now to be installed in the station for full scale trials.

3.2 Canary Wharf Station

The ticket hall and platform at the proposed Canary Wharf Station form a complicated space acoustically because of the large interconnections between the two spaces. This renders calculations of RT and STI, and how they are affected by acoustic treatment, unreliable.

A scale model investigation was undertaken but was restricted to a scale factor of 1:50 owing to space limitations; the full scale station is 230m long. A 1:50 scale factor permits measurements up to the 2kHz octave full scale although results in the highest octave are sometimes limited by ambient conditions. This frequency limit, although restricted for measuring speech intelligibility, was considered acceptable for the scope of this project.

The model was constructed of varnished timber and perspex and absorbent treatment was modelled using calibrated felt.

Measurements were made in the model with the help of the MIDAS analysis system which automatically calculates RT, EDT and STI.

For STI, specially designed ultrasonic loudspeakers were mounted on totems which were distributed in an array in the West Ticket Hall; the most difficult area acoustically. The arrangement of the array is aimed at giving even coverage over the floor area and is shown in Figure 3. Each totem comprised either two or four loudspeakers mounted at right angles to each other and at a height of 2.75m above floor level. They were angled down by 25° from the vertical.

The directivity of loudspeakers for the actual Ticket Hall has not yet been finalised but for the modelling work the following target was set: beamwidth at 1kHz to - 6dB points: horizontal 90°, vertical 40°.

To build model loudspeakers with the target directivity, an ultrasonic electrostatic loudspeaker was used with a circular diaphragm 20mm in diameter. The frequency response of the unit extends beyond 100kHz. The directivity of the standard unit was adjusted by placing a mask over the diaphragm with different sizes of slot.

Slot dimensions of 6 x 16mm produced a directivity close to the target ie horizontal beamwidth 80°, vertical beamwidth 35° at the equivalent full scale frequency of 1kHz. The approximate Q factor for the modified loudspeaker is around 20 which is comparable with values of commercially available units.

Model measurements were carried out in a variety of configurations and the results for acoustic treatment, for example, on the sidewalls as shown in Figure 4, gave RT values sightly below 3s and STI values around 0.5. By installing additional treatment on 50% of the soffit the STI was increased to around 0.6. Alternatively, large acoustically absorbent 'wings' mounted on each loudspeaker totem also increased STI to around 0.6.

Further tests in collaboration with the architect will lead to an optimum acoustical solution.

4. CONCLUSIONS

The lack of an accepted theory about the behaviour of sound in station-type enclosures means that a number of different models are in use.

Computer models tend to make a number of simplifications to the sound field and to determine whether or not these are acceptable requires extensive validation. A particular question is how computer models should account for the complicated interaction between sound waves and complex shapes.

Acoustic scale models can re-create sound fields accurately in miniature and have undergone comprehensive validation. They are valuable for predicting STI on underground stations with good accuracy at 1:16 scale and reasonable accuracy at 1:50 scale.

Scale models are not intended to be used systemwide on underground networks but they are suited to investigating and optimising generic stations types and certain difficult geometries. The scale modelling process also help in the general development and validation of new theories.

5. REFERENCES

1. Barnett, P. W. Acoustics of Underground Platforms. Proc. 1.O.A. Vol. 16 Part 2 (1994), 433-443.

2. Orlowski, R. J. Scale modelling for predicting noise propagation in factories. Applied Acoustics 31 (1990) 147-171.

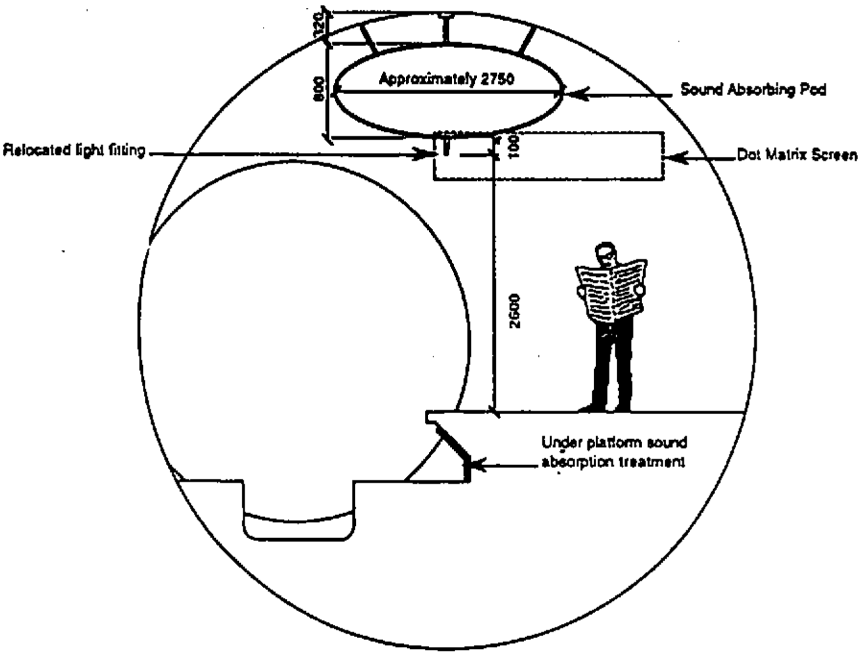

Figure 1. Sketch of station tunnel cross sections showing location of acoustic pods.

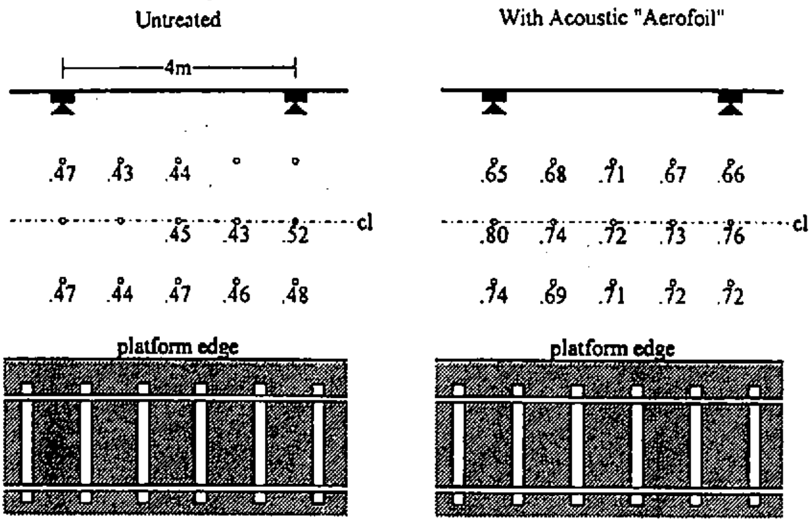

Figure 2. Speech Transmission Indices measured in scale model for loudspeaker array at 4m spacing.

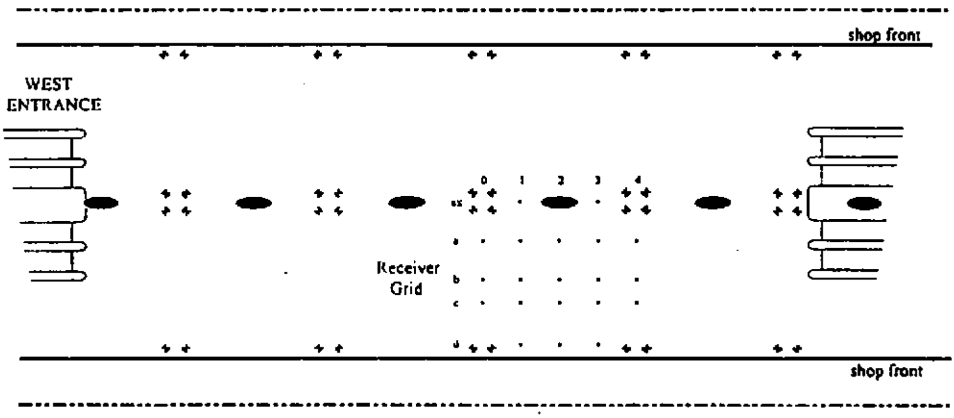

Figure 3. Plan of West Ticket Hall, Canary Wharf Station, showing loudspeaker array and measurement grid.

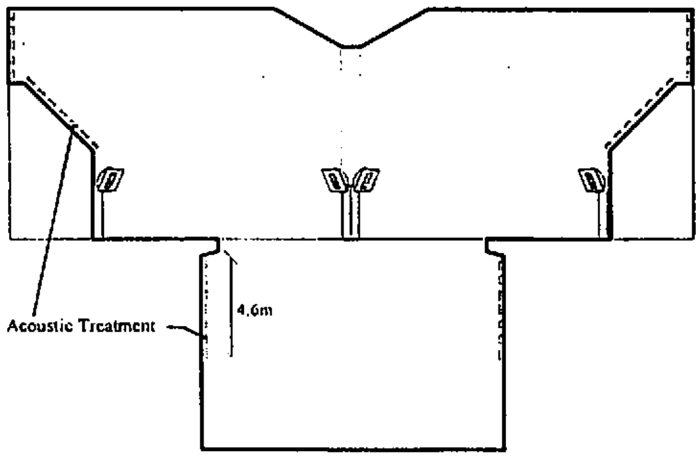

Figure 4. Sketch section showing acoustic treatment in ticket hall and platform area beneath.