THE EFFECT STREET DIMENSIONS AND TRAFFIC DENSITY ON THE NOISE LEVEL AT DIFFERENT HEIGHTS IN URBAN CANYONS

Fergus Nicol[1], Mike Wilson[1] and John Shelton[2],

[1]. LEARN, University of North London, 40 Holloway Raod, London N7 8JL, UK
[2]. AcSoft Ltd, 8B Wingbury Courtyard, Leighton Road, Wingrave, Aylesbury HP22 4LW, UK

ABSTRACT
Noise measurements were made at 10 locations in 'canyon' streets in Athens with aspect ratio (height/width) varying from 3:1 to 1:1. The main purpose of the measurements was to examine the vertical variation in noise in the canyons to indicate the natural ventilation potential of the buildings. A simple model of the noise level has been developed and calibrated using a linear regression analysis of the measured data. The resulting model can be used to predict the attenuation of the noise level with height above street level. The attenuation is found to be a function of street width and height above the street, but the maximum level of attenuation (at the top of the canyon) is almost entirely a function of the aspect ratio except in narrow streets. Background noise (L_{90}) suffers less attenuation foreground noise (L_{10}) more attenuation with height.

KEYWORDS
Traffic noise, field measurements, noise attenuation, ventilation potential

NOISE IN URBAN CANYONS

Canyon-like streets in cities such as Athens vary considerably in width and in the height of the buildings which border them. The facades themselves also vary considerably, some plain and some with balconies. At ground level the situation can be more complex. The ground floor is often set back with colonnades and paper stalls and other objects litter the pavement.

Between the 13 th and the 18 th of September 2001 measurements were made of noise level outside the windows of buildings in 9 street canyons in thee central area of Athens. The aim of these measurements was to assess the effect of height above canyon floor on the noise level. The measurements were taken in canyons with aspect ratios ranging between 1 and 5 and with a variety of traffic loads.

The rationale behind these noise measurements is that the external noise climate is an important constraint to the opening of windows. This in turn means that the external noise level is a factor in the ventilation potential of an urban site. This paper aims to provide guidance about the effect on the external noise climate of the street width, aspect ratio and the distance of the site above street level. This requires some evaluation of the relative importance of the direct sound path from the source and the reverberant noise level within the street. Also important are the traffic density and its correlation with noise at street level.

Instruments used for the measurements were SIP95 high-resolution logging sound level meters manufactured by 01dB, Lyon and logging 0.125 second L_{eq}. For each measurement four persons were involved.

- First a building was selected for use in the measurement and access to the building was secured.
- One person was deployed on each of two floors of the building. They were positioned by an open window on the street side of the building.

- One person was deployed to measure noise level at street level with the sound level meter mounted on a 1.2m tripod 1m in front of the facade
- The fourth person was deployed across the street to co-ordinate the noise level measurements at the three sites and time the collection of data for 15 minutes at each site.
- The number 1] motorcycles, 2] heavy vehicles and 3] cars and light goods vehicles were counted over the 15 minutes using hand-held counters.
- Data were downloaded onto a project laptop computer.

Because of traffic management policies in Athens heavy goods vehicles are restricted to early deliveries. At the time of the measurements the number of heavy vehicles is very low, being mainly buses, but there is a high incidence of low power motorcycles (around 50% see table 1) which appear to be the major source of noise. Vehicle speeds varied, traffic lights regularly interrupting the flow and the roads were often congested. No sensible estimation of vehicle speed could be made but made little sense anyway with the motorcycles. The noise spectrum in one of the streets was found to be similar to that used in BS/EN1793 but with a smaller contribution at higher frequencies (Nicol et al 2002).

A SIMPLE MODEL OF NOISE IN CANYONS

The road traffic noise as measured at various locations in the canyons is a combination of the direct sound and quasi-reverberation in the canyon. The term quasi-reverberation is used to denote a type of reverberation which is not diffuse but consists primarily of flutter echoes between the facades lining the street.

Thus we could say that:

$$p^2 \propto W(dc + rc) \qquad 1$$

where p is the sound pressure and W is the sound power, dc is the direct component of the sound and rc is the reverberant component.

The direct component may be treated in two ways depending on whether the traffic is considered as a line source (where the traffic stream is considered as the source) or point source (where each vehicle was separately responsible for the noise). Both these possible scenarios were considered. For a line source dc is inversely proportional to the distance from the source, for the point source dc is inversely proportional to the square of the distance. If the street width is w and h the height of the measuring position above the ground, assuming a line source in the middle of the road the distance between source and receiver is:

$$d = \left(\left(\frac{w}{2}\right)^2 + h^2\right)^{\frac{1}{2}} \qquad 2$$

For the reverberant sound the noise is approximately inversely proportional to the absorption area[1]. The main area for absorption is the open top of the canyon which is assumed to be a perfect absorber and whose area per metre of street is w, the width of the street. A further sophistication may be to include absorption of the road surface and facades. With an absorption coefficient of 0.05 this would be lead to the absorption area of (1.05w + 0.1H). Alternatively if we use the aspect ratio (AR = H/w) of the street the expression becomes

[1] Strictly this applies to diffuse sound sources clearly only approximate in this context

$$w' = w(1.05 + 0.1 * AR) \quad 3$$

The sound power is assumed proportional to the number of vehicles per hour (n). We have two possible expressions: for line sources (attenuation according to linear distance) or point sources (attenuation according to square of distance). The linear source model was found to correlate best in these data. The expressions were developed into the form:

$$L_p = 10\log_{10} p^2 = 10\log_{10}\left(n\left(\frac{a}{d_1} + \frac{b}{w'} \right) + c \right) \quad 4$$

a, b c are constants where c represents any general environmental noise. In general the contribution of c will be small. Measurements on the rooftop of a building in a pedestrian area behind vehicular streets in the centre of Athens gave LAeq = 55dB. In the vehicular streets few noise levels below L_{Aeq} = 70dB were recorded. L90 averaged 66dB.

The purpose of this investigation is to provide a method for estimating the fall-off in noise level which height of the window opening up the wall of the urban canyon. In equation (4) the value of Lp relates to height above the canyon floor (h) through the variable d1. An estimation the values of the constants a, b and c will enable the change of Lp with h to be determined. The values of the constants a, b and c have been estimated using multiple regression analysis.

CALIBRATING THE THEORETICAL MODEL

In order to determine how these results accord with the theoretical model presented above, values were calculated for n/d (D), n/w (rv) and n/w' (rv_x) (w' as in equation 3 above). In the case of D, different values were calculated depending whether the noise is best considered to be coming from the middle of the road (as in equation 2), or one third, one quarter or two-thirds the way across the street. Regression analyses were performed for p^2 against combinations of these variables, initially to determine which combination has the best explanatory power. Inspection of the regression equations suggests that rv is less important than D in determining p^2. A value for p^2 against D alone has been added.

The exact value of D or rv us not important. The high coefficients of determination (in the region of 0.81) compared to the straight linear regressions for L_{eq} on h and n suggest that the theoretical relationship developed above provides a good model of the spatial variation of p^2. The change in R^2 suggests that there is an advantage in including the term in rv.

The regression equation for p^2 on D_2 and rv_x using the data from the whole 15 minutes is

$$p^2 = 17.4 * 10^4 . D_2 + 6.34 * 10^4 . rv_x - 411 * 10^4 \quad 5$$

$$\text{Where } L_{eq} = 10 * \log_{10} p^2 \quad 6$$

L_{eq} is the noise level at height h above the street. D is a function of three variables, h, w and n, the number of vehicles. n is assumed to be proportional to the noise generated. Two of these variables (n and w) are also included in rv_x together with AR the aspect ratio of the canyon. Figure 1 shows that the measured value is well predicted by the calculated value (R^2 = 0.75).

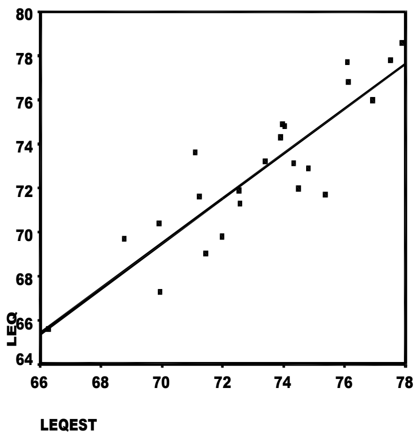

Figure 1: showing the measured Leq (LEQ) against the predicted (LEQEST) (dB).(R^2 = 0.75))

In order to help with the visualisation a simplifying assumption has been made that the traffic level is a function of street width. In these data the correlation between n (vehicles per hour) traffic flow and street width w (m) was 0.88 and the regression relationship was

$$n = 137*w - 306 \quad 7$$

Using this simplifying assumption, the expected noise level becomes purely a function of the geometry of the street. Figure 2 shows the expected noise levels in Athens at different street widths and heights above the street streets.

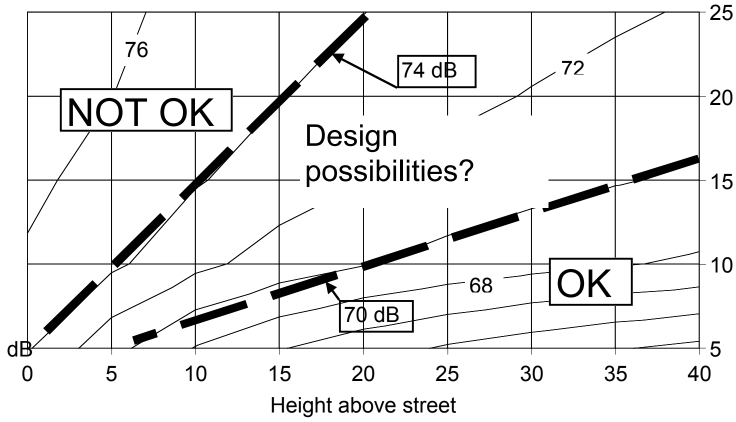

Figure 2 contours of noise level at different heights above the street and street widths. Configurations in which natural ventilation is possible are indicated (OK) as are those in which it is ruled out (NOT OK). Between these two extreemes is a region in which there are possiibilities for design solutons.

Results from the EU SCATS (Nicol and McCartney 2001) project suggests that the tolerable noise level in European offices to be around 60dB (Wilson & Nicol 2001). At the same time the noise attenuation at an open window is accepted as 10dB. Thus outdoor noise of 75dB or less is likely to be acceptable. Using special methods a further 3-5 dB attenuation is may bwe possible. In Figure 2 the implications of these rules-of-thumb are indicated. Street widths that will give acceptable conditions at heights above the street are indicated (OK). Street widths that will give unacceptable conditions for buildings with open windows near street level are indicated (NOT OK). Between these two there are possibilities for acceptable condition with careful design.

Calculating the attenuation IN L_{eq}, L_{10} and L_{90} at different heights in the Canyon.

Using the calculation for noise level at different heights in the canyon it is possible to calculate the noise attenuation from street level at different heights in the canyon. For a given value of the aspect ratio there is a maximum value of the attenuation at the top of the canyon. This maximum value can be calculated using the theoretical approach presented above. Consider the difference between L_{eq} at the top of the canyon (h = H) and the bottom (h = 0). Because L_{eq} is a logarithmic function, the difference is in fact $10Log_{10}$ of the ratio of the two values of p^2.

$$dleq_H = leq_0 - leq_H = 10\log_{10}\left({p^2}_0 \big/ {p^2}_H \right) \tag{10}$$

$$dleq_H = 10Log_{10}\left(\frac{(2a + b/(1.05 + 0.1 * AR) + cw/137w - 306)}{\left(a\Big/\sqrt{\left(AR^2 + (1/2)^2\right)} + b/(1.05 + 0.1 * AR) + cw/137w - 306 \right)} \right) \tag{13}$$

Note that though dleq $_H$ is a function of AR and w its variation depends principally on AR (see figure 3) except where the width of the street is small.

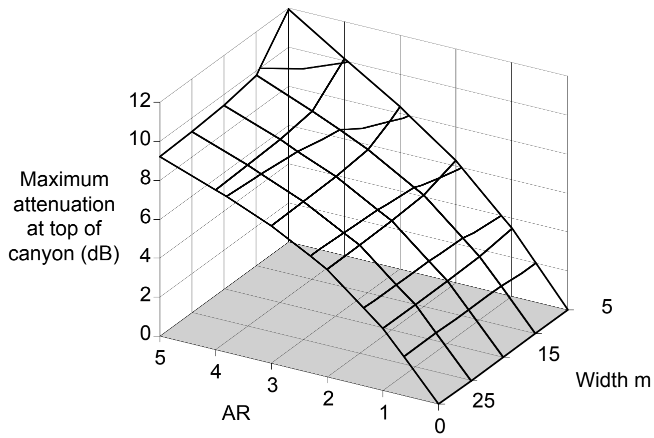

Figure 3. Variation of $dleq_H$, the maximum value of the attenuation at the top of buildings bordering on an urban canyon, with the aspect ratio AR and the street width in metres

A similar analysis to that above can be applied to the data for L $_{10}$ and L_{90}. Table 5 gives the values of the constants a, b and c for the three different measures of noise. In the cases of L_{eq} and L_{10} the terms for b are not statistically significant, suggesting that the direct component of noise predominates. In L_{90} both terms are significant.

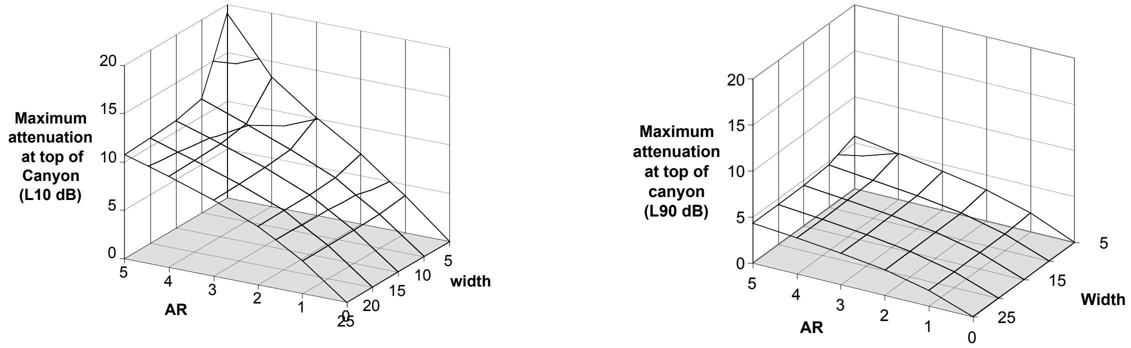

Figure 4. variation of maximum level of attenuation of L10 and L90 with aspect ratio (AR) and street width (m)

CONCLUSIONS

This is an initial study of the traffic noise measurements in urban canyons in Athens. Further work is necessary, but from this study it is possible to draw a number of tentative conclusions.

1. High levels of noise can be found in these canyon-type streets and show a predominance in the low-frequency end of the noise spectrum
2. The noise level in canyon streets increases with traffic density and decreases with height above the canyon floor
3. The attenuation in noise level compared to that at street level increases with the distance from the canyon floor, but decreases with increasing street width.
4. These relationships are well represented by a simple model of noise level comprising a direct component and a reverberant component.
5. The direct component is assumed to be from a line source at or near the centre of the road whose power falls off with the inverse of the distance from this source
6. The reverberant component is assumed to act as if the street were a two-dimensional room with the canyon roof acting as a perfect absorber.
7. In addition there may be a small additional noise component from the general environmental noise.
8. The simple model, calibrated from the measured data, shows that the noise attenuation (L_{Aeq}) is almost entirely a function of street width and height above the canyon floor (Figure 7)
9. The maximum value of the attenuation is almost entirely a function of aspect ratio (Figure 9) with a small effect of street width in narrow streets.
10. Similar considerations apply when predicting the attenuation of L10 and L90. Relative to L_{eq}, the rate of attenuation with height is greater for L10 and less for L90.

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