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Predictability of noise indices in a high-rise residential environment (L)

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In the present investigation, daily noise level measurements were carried out at 12 independent sites within the closely packed high-rise residential areas in Hong Kong. Various environmental noise indices are calculated. Their cross-relationships and correlations with the population density and the daily traffic volume are also examined. Results suggest that the L_{dn} and L_{den} correlate very well with a multiple regression model, which involves both the population density and traffic volume, for the present site conditions. [DOI: 10.1121/1.1596171]

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I. INTRODUCTION

Environmental noise has long been an important problem for environmentalists, engineers, and town planners. This problem becomes more acute in densely populated cities with limited availability of land, such as Hong Kong. The population density has also a role in the resultant noise levels. The control of noise exposure, and thus the noise pollution, requires an appropriate noise policy from the local authority, knowledge of the right noise parameters to work with, and also a reliable prediction model.

There have been substantial efforts made in the past few decades on survey of noise from traffic which has been regarded as a very important source of noise in an urbanized city. Empirical noise level prediction models, such as the CRTN,[1] have also been set up. Most of these empirical formulas tend to relate L_{A10} and/or L_{Aeq} with traffic flow volume, vehicle speed, and the percentage of heavy vehicles on the road.

The equivalent sound pressure level and the percentile levels L_{A10} and L_{A90} are important for the estimation of the traffic noise index (TNI),[2] which is believed by many researchers to be an effective predictor of nuisance resulted from noise if they are 24-h averages.[3] However, in the authors' point of view, the 24-h average $L_{A10,T=24\mathrm{hr}}$ will be biased by the noise events that occur during day-time where more than half of the noise sensitive receivers (NSRs) concerned are not at the proximity of the measurement locations. The $L_{A90,T=24\mathrm{hr}}$ depends mostly on night-time events, which may therefore affect more the noise annoyance feeling. A parameter that caters to the different tolerance of the NSRs during a different time of day is therefore required. Parameters such as the day-night level, L_{dn}, and the community noise level, L_{den}, appear to be the legitimate choices.[4] In fact, the use of the former in correlating with annoyance feeling due to noise exposure has been studied extensively by large number of researchers (for instance, Fidell *et al.*[5]).

Despite the established importance of the L_{dn} (and probably the L_{den}) as a descriptor of annoyance caused by environmental noise, the prediction model for it is not thoroughly studied. This study summarizes an attempt to clarify the environmental parameters that are important for the estimation of the L_{dn} in a high-rise urban residential environment where the major sources of noise are the traffic and the population. Discussions on their relationships with the 24-hour averages $L_{A10,T=24\mathrm{hr}}$, $L_{A90,T=24\mathrm{hr}}$ and $L_{Aeq,T=24\mathrm{hr}}$, and the derived levels TNI and the noise pollution level, L_{np},[6] are also presented. A simple multiple regression model will be set up.

II. FORMULATION OF REGRESSION MODELS

The major noise sources in the present study are ground traffic and population. In the Hong Kong urban situation, population and traffic are interrelated, but there may not exist a direct relationship between them. One therefore expects that the noise levels will depend on the traffic volume and average vehicle speed as in most of the traffic noise prediction models. The percentage of heavy vehicles, which has been included in many traffic noise prediction model (for example, CRTN[1]), may not be very relevant to the present study in the residential areas as far as 24-h noise level averages are concerned. The inclusion of this parameter into the present regression model will thus complicate the model without much improvement on the standard error. Also, the recent results from a laboratory study of annoyance caused by traffic noise by Versfeld and Vos[7] suggest the annoyance feeling is independent of the percentage of heavy vehicles.

The regression results of Galloway *et al.*[8] obtained in the United States suggest that the L_{dn} varies with the logarithm of the population density while the effects of traffic have not been explicitly taken into account. Some existing noise level prediction models also include the distance effect. However, the high-rise and closely packed built environment in a congested city like Hong Kong with tall buildings erected on the two sides of a road gives rise to a reverberation effect,[9] which tends to reduce the impact of distance significantly. This site condition is referred to as the "enclosed" form by Ko.[10] Therefore and also for the sake of simplicity, the regression model

$$L = a\log_{10} Q + b\log_{10} P + c \quad \text{(model 1)},$$

where L is a 24-h noise index concerned (such as L_{dn} and $L_{Aeq,T=24\mathrm{hr}}$), Q is the daily traffic volume and P is the local

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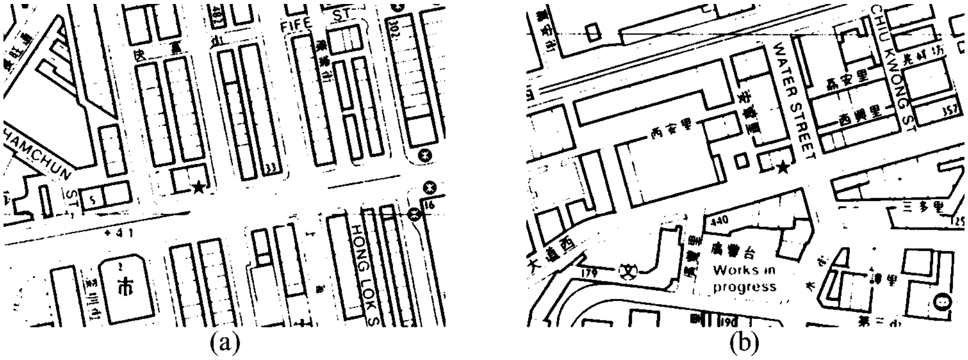

FIG. 1. Typical examples of the selected sites: (a) site D and (b) site E. ⋆: measurement location.

population density, is proposed. The population density in the present study is defined as the number of people living within each square kilometer of area. The coefficient c tends to reflect a prevailing value of L. Correlation of model 1 with various 24-h noise indices will be given and discussed.

III. SITE MEASUREMENTS

In the present site measurement, the sound pressure levels were recorded using the sound level meter Brüel & Kjær 2238F every second at about 1 m from the building façades. Height of measurement varied between low and middle floors. Each measurement lasted for four days, but not on holiday or weekend. A total of 12 sites were surveyed. The sites were all residential ones in the high-rise urban areas or satellite districts of Hong Kong and are basically of the ‘‘enclosed’’ form.[10] Two typical site maps are shown in Fig. 1. They are extracted from the official survey maps issued by the local authority and thus some symbols for local uses and some Chinese characters not related to the present study can be found on them.

All the 24-h average noise indices involved in the present study are then calculated from the recorded sound pressure level time series. The daily macroscopic sound pressure level variation pattern at a particular site does not vary very much, so that all the noise indices concerned can be regarded as reasonably stationary (not shown here). The measurements were carried out from November to March during the autumn and winter periods of Hong Kong. Therefore, the noise from domestic air-conditioning is not significant.

The daily average traffic volume data Q and the population density P in the present study were obtained from the official publications of Hong Kong SAR Government.[11,12] It should also be noted that each selected site is closed to only one major road, which is expected to produce most of the traffic noise. Such a road is horizontal or slightly inclined. In addition, there was no screening device between the roads and the sound level measurement points during the measurement period.

IV. RESULTS AND DISCUSSIONS

The major environmental acoustic indices concerned in the present study are the $L_{Aeq,T=24\text{hr}}$, L_{dn}, L_{den}, TNI and L_{np}. The calculation of the first parameter is straightforward. The following formulas are used in the estimation of the others:

$$L_{dn}=10\log_{10}\{\tfrac{1}{24}[16\times 10^{L_{eq(07:00-23:00)}/10} + 8\times 10^{(L_{eq(23:00-07:00)}+10)/10}]\}, \quad (1)$$

$$L_{den}=10\log_{10}\{\tfrac{1}{24}[12\times 10^{L_{eq(07:00-19:00)}/10} + 4\times 10^{(L_{eq(19:00-23:00)}+5)/10} + 8\times 10^{(L_{eq(23:00-07:00)}+10)/10}]\}, \quad (2)$$

$$\text{TNI}=4(L_{A10,T=24\text{hr}}-L_{A90,T=24\text{hr}})+L_{A90,T=24\text{hr}}-30, \quad (3)$$

and

$$L_{np}=L_{Aeq,T=24\text{hr}}+(L_{A10,T=24\text{hr}}-L_{A90,T=24\text{hr}}). \quad (4)$$

TABLE I. Summary of survey data.

			Noise indices (dBA)								
Site	Q	P (people/km^2)	$L_{Aeq,T=24\text{hr}}$	$L_{A10,T=24\text{hr}}$	$L_{A90,T=24\text{hr}}$	L_{dn}	L_{den}	TNI	L_{np}	L_d	L_n
A	37 020	67 171	69.4	73.7	59.0	74.4	74.9	87.8	84.1	70.0	67.9
B	37 580	26 984	70.8	74.6	59.6	74.8	75.3	89.6	85.8	71.7	67.9
C	14 600	80 451	69.0	72.1	60.9	73.5	73.9	75.7	80.2	69.8	66.8
D	31 860	104 305	71.0	75.7	58.1	74.8	75.5	98.5	88.6	72.0	67.6
E	9340	99 508	70.7	74.1	59.3	74.3	74.9	88.5	85.5	71.8	67.0
F	112 750	71 023	73.2	77.3	62.0	76.3	77.0	93.2	88.5	74.5	68.6
G	19 590	38 674	69.1	73.5	59.6	72.6	73.2	85.2	83.0	70.3	65.3
H	10 630	12 793	69.4	73.7	60.5	73.2	73.8	83.3	82.6	70.4	66.1
I	67 670	33 166	71.1	75.3	58.5	73.8	74.5	95.7	87.9	72.4	65.7
J	28 220	926	65.7	70.0	55.9	68.1	69.4	82.3	79.8	66.9	61.0
K	13 160	7411	67.2	69.8	54.3	69.6	70.3	86.3	82.7	68.7	61.0
L	23 680	46 325	69.2	71.5	65.4	73.5	74.0	59.8	75.3	70.1	66.7

TABLE II. Correlations between noise indices.

	$L_{Aeq,T=24\text{hr}}$	$L_{A10,T=24\text{hr}}$	$L_{A90,T=24\text{hr}}$	L_{dn}	L_{den}	TNI	L_{np}	L_d	L_n
$L_{Aeq,T=24\text{hr}}$	1								
$L_{A10,T=24\text{hr}}$	0.944	1							
$L_{A90,T=24\text{hr}}$	0.476	0.325	1						
L_{dn}	0.936	0.869	0.616	1					
L_{den}	0.950	0.897	0.600	0.997	1				
TNI	0.443	0.618	0.542	0.298	0.298	1			
L_{np}	0.689	0.800	0.292	0.516	0.550	0.954	1		
L_d	0.992	0.934	0.418	0.886	0.902	0.483	0.721	1	
L_n	0.843	0.793	0.680	0.973	0.967	0.139	0.382	0.769	1

Two additional noise levels, namely the day level L_d and night level L_n, are also calculated in the present study as supplementary data and are discussed whenever necessary. Their definitions are

$$L_d = L_{eq(07:00-23:00)} \quad \text{and} \quad L_n = L_{eq(23:00-07:00)}. \tag{5}$$

The definitions of day and night here follow the local legislation.

Table I summarizes the data obtained in the present study. Site J is a new high-rise town and the population there at the time of measurement had not yet reached its expected steady-state value. One can verify immediately that there is no correlation between $\log_{10} Q$ and $\log_{10} P$ ($R=0.12$, $p=0.7$). The magnitudes of the linear correlation coefficients, R, between any two listed indices are presented in Table II. It can clearly be observed that the correlation between the L_{Aeq} and L_{dn} (and also L_{den}) is very high. Since the L_{dn} and L_{den} have good correlations with annoyance due to noise exposure,[5] the present correlation result appears to be consistent with the findings of Versfeld and Vos[7] which show that the L_{Aeq} is a good indicator for noise annoyance. The correlations between TNI and other indices are in general very weak.

The correlations between the present listed noise indices and $\log_{10} Q$ are in general not strong. The higher correlation coefficients are those with the L_d and $L_{A10,T=24\text{hr}}$, which are only around 0.3 (Table III). This indicates that the ground transportation does not dominate the overall acoustical environment of the residential areas. However, the correlation data does suggest Q is slightly more important in affecting the noise level during daytime (07:00 to 23:00). The corresponding correlations with $\log_{10} P$ are more impressive as shown in Table III. The relatively higher correlations with P are probably due to the noise sources related to the mixed modes of businesses being carried out in the residential areas. These businesses include shops (usually at ground levels), markets, schools, and restaurants. Sometimes, one can find shopping malls of various scales in these residential areas. Reverberation in the street canyons is also one of the reasons. The higher the population density, the closer the packing of buildings expected. Speeds of vehicles in these areas are under stringent control. Certainly, further investigation will be helpful on this aspect.

Table IV summarizes the results of the present multiple regressions at 95% confidence level. The corresponding statistical F-test parameter for the multiple regression $F_{2,9,0.95}$ is 3.01 and the numbers in parentheses refer to the standard errors of the respective regression coefficients. The coefficients with noise indices having $p<0.05$ in general survive the statistical t-test (not shown here) and their percentage errors are usually relatively small. One can find immediately that, despite the possibility of variations in site conditions, the correlations related to $L_{Aeq,T=24\text{hr}}$, L_{dn}, and L_{den} are very high. One can also notice from Tables III and IV that the corresponding correlations are improved when both Q and P are taken into account together, suggesting that the contributions from Q and P in the overall acoustical environment are competitive. The inclusion of nominal vehicle speed V into the regression model 1 deteriorates considerably the correlations (not shown here). This may be due to the small range of $\log_{10} V$ in the present study ($50\,\text{km/h} \leqslant V \leqslant 80\,\text{km/h}$) and/or the effects of V have been already catered for by Q and/or P under the long term noise level averaging. The partial coefficients of correlations suggest that the population density P is relatively more dominating in affecting the energy based noise indices, such as $L_{Aeq,T=24\text{hr}}$ and L_{dn}.

V. CONCLUSIONS

Twenty-four-hour noise level measurements were carried out at 12 independent sites within the closely packed high-rise residential areas of Hong Kong, where the major sources of noise were the ground traffic and the population. Each measurement lasted for four consecutive days. Various noise indices are calculated and their correlations with the population densities P and the daily traffic volume Q are examined. Sites with noise screening devices were excluded from the present study.

It is found in the present survey that the population density is in general better correlated with the energy based

TABLE III. Correlations between noise indices with site parameters Q and P.

	$L_{Aeq,T=24\text{hr}}$	$L_{A10,T=24\text{hr}}$	$L_{A90,T=24\text{hr}}$	L_{dn}	L_{den}	TNI	L_{np}	L_d	L_n
$\log_{10} Q$	0.519	0.575	0.149	0.393	0.437	0.387	0.476	0.531	0.329
$\log_{10} P$	0.763	0.647	0.535	0.874	0.850	0.140	0.362	0.712	0.850

TABLE IV. Multiple regression results (model 1: $L = a \log_{10} Q + b \log_{10} P + c$).

Noise index	Regression formula coefficients[a]			Partial correlation coefficient		Standard error (dB)	Statistical test parameters		
	a	b	c	$r_{L \cdot \log_{10} Q \mid \log_{10} P}$	$r_{L \cdot \log_{10} P \mid \log_{10} Q}$		R	F	P
$L_{Aeq,T=24\text{hr}}$	2.59 (0.98)	2.33 (0.54)	47.7 (4.7)	0.428	0.704	0.6	0.874	14.62	0.0015
$L_{A10,T=24\text{hr}}$	3.51 (1.35)	2.23 (0.74)	48.0 (6.5)	0.499	0.581	0.8	0.818	9.07	0.0070
$L_{A90,T=24\text{hr}}$	0.74 (11.75)	2.50 (1.34)	45.0 (11.8)	0.084	0.520	1.5	0.514	1.87	0.2098
L_{dn}	2.04 (0.93)	3.23 (0.51)	49.8 (4.4)	0.287	0.832	0.6	0.920	24.90	0.0002
L_{den}	2.22 (0.90)	2.92 (0.49)	51.0 (4.3)	0.334	0.802	0.6	0.914	22.74	0.0003
TNI	11.83 (9.68)	1.44 (5.30)	26.9 (46.3)	0.374	0.083	5.9	0.396	0.837	0.4641
L_{np}	5.37 (1.86)	2.07 (3.40)	50.7 (16.3)	0.434	0.306	2.1	0.566	2.116	0.1765
L_d	2.71 (0.60)	2.16 (1.09)	49.1 (5.2)	0.447	0.651	0.7	0.840	10.82	0.0040
L_n	1.77 (0.68)	3.49 (1.24)	42.6 (5.9)	0.226	0.815	0.8	0.879	15.35	0.0013

[a]Numbers in parentheses are the standard errors of the regression coefficients.

noise indices like the day level, night level, $L_{Aeq,T=24\text{hr}}$, L_{dn}, and L_{den}, especially the latter two, which have been proposed to be highly related to the human annoyance by other researchers. An important observation in the present study is the substantial improvement in the correlations between the noise indices L_{dn} and L_{den} and the environmental parameters Q and P when both Q and P are taken into account by a simple multiple regression model. The inclusion of vehicle speed results in weaker correlations. It is also found that the energy-based noise indices are more sensitive to a change in the population density.

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