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ROAD TRAFFIC NOISE PREDICTION TAKING ACCOUNT OF TRANSIENT VEHICLE RUNNING CONDITIONS

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1. INTRODUCTION

In general urban areas, road traffic flow is interrupted by signalized intersections and noise radiation of road vehicles greatly changes according to the transient running condition. Therefore, it is much more complicated to predict the road traffic noise in such areas compared to motorways. We proposed a new prediction method of road traffic noise constructed by combining a model of estimating sound power levels of road vehicles under transient running condition and a simulation model of road traffic flow in urban areas [2]. In this study, to examine the validity of this method, correspondence between the calculated and measured results are investigated for seven different urban areas.

2. SIMULATION OF ROAD TRAFFIC FLOW AND NOISE RADIATION FROM VEHICLES

Prediction of Road Traffic Flow

In order to predict the traffic flow, a dynamic road traffic simulation model taking account of the actual vehicle running pattern measured on arterial roads was used [1,2]. Figure 1 shows the simulated traffic flow in the vicinity of a signalized intersection. In this figure, each curved line indicates a running locus of a vehicle obtained from the relation between time and traveling distance. The solid and dashed lines indicate the vehicles running in opposite direction, respectively. It can be seen that the running patterns of vehicles on urban road with stopping, starting, accelerating, cruising and decelerating conditions are well simulated. By using this model, the location and the speed of each vehicle can be calculated.

Prediction of Noise Radiation Characteristics of Vehicles

The noise radiated from a running vehicle consists of engine-exhaust noise and tire/road noise. By using the data obtained in field experiments, sound

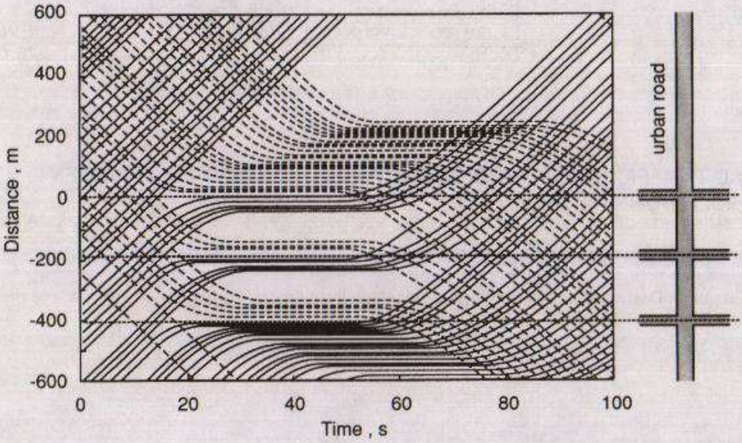

Fig.1. Simulation of traffic flow in an urban area.

power radiation models for engine-exhaust and tire/road noise were constructed for passenger cars, light trucks and heavy trucks as follows.

$$L_{We} = A_0 + A_1 S + A_2 L \tag{1}$$

$$L_{Wt} = B_0 + B_1 \log(V) \tag{2}$$

where L_{We} and L_{Wt} are the A-weighted sound power level of the engine-exhaust noise and that of the tire/road noise, respectively, S is the engine revolution speed, L is percentage of the engine load, V is the vehicle speed and A_0, A_1, A_2, B_0 and B_1 are regression coefficients.

As mentioned above, the location and the speed of each vehicle are calculated by using the dynamic road traffic simulation model. The sound power level of tire/road noise is calculated by substituting the speed obtained from the traffic flow simulation model into Eq.(2). On the other hand, in order to calculate the sound power level of engine-exhaust noise from Eq.(1), it is necessary to obtain engine revolution speed and percentage of engine load. For this purpose, the vehicle motion equation considering the driving mechanism and characteristic were adopted [2].

3. PREDICTION OF ROAD TRAFFIC NOISE

A prediction model of road traffic noise has been constructed by combining the noise radiation model and the traffic flow simulation model. In this model, the data of total traffic volume, percentage of each type of vehicle, intervals of signalized intersections, number of traffic lane and the time period of each signal are used. In order to examine the validity of this model, seven urban areas with different properties (see Fig.2) were chosen and road traffic noise in the vicinity of the signalized intersections

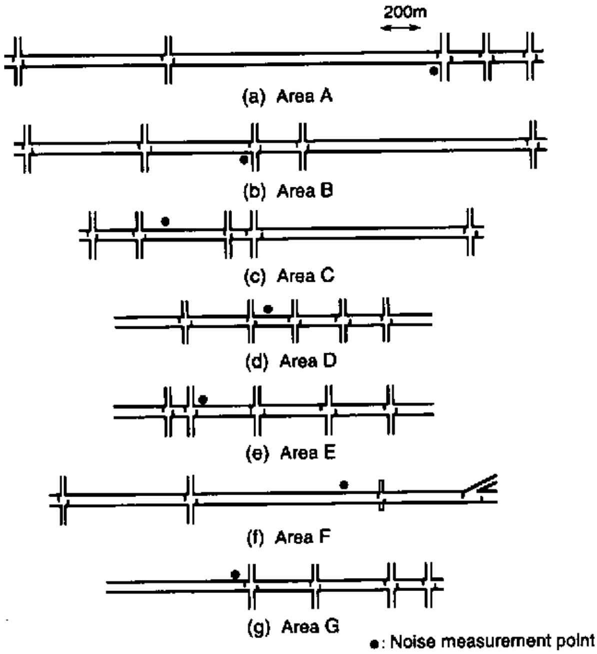

Fig.2. Seven roads in urban area invesitigated in this study.

were calculated. The intervals of signalized intersections are much different among the areas. Area A, B and F, of which intersection interval is longer than the other areas, are in rural cities, and the others are in the center of Tokyo. The number of traffic lane is two in area B and four in the other areas. The road in the area E has 5% gradient and the others are almost flat. The traffic flow in all areas except for F is interrupted by the signals, whereas that of the area F can be considered almost free flow at a speed of about 60km/h.

Figure 3 shows the total traffic volume and number of heavy vehicles in the seven areas. In this figure, the prime indicates the data obtained in weekend. The total traffic volume of the area B was about 1,700 vehicles per hour and was the least among the seven areas, while

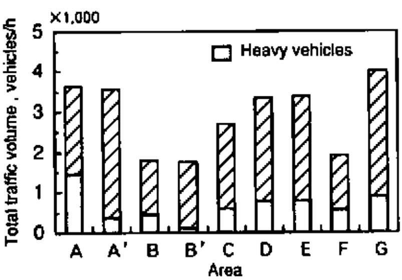

Fig.3. Total traffic volume of the each area investigated in this study. (the prime indicates the data obtained in weekend)

that of area G was about 4,000 vehicles and was the largest. The area G is almost always in traffic jam and the average vehicle speed was less than 30km/h.
The road traffic noise in the areas shown in Fig.2 were calculated from the measured data of total traffic volume, percentage of each type of vehicle, number of traffic lane, intervals of the signalized intersections and time period of each signal. Figure 4 shows the relationship between the calculated and measured L_{Aeq} . We can see that they are in good agreement within 2dB(A) difference. Figure 5 shows the results for noise index L_{50}. In this results, the correspondence between the calculated values and the measured ones is a bit better than the results for L_{Aeq} .

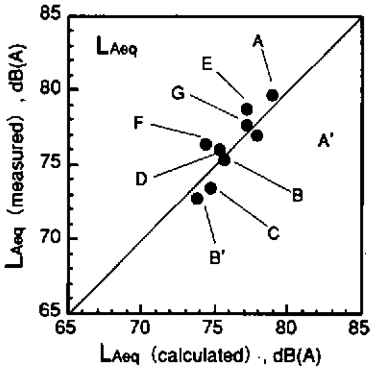

Fig.4. Relationship between the measured and calculated L_{Aeq}.

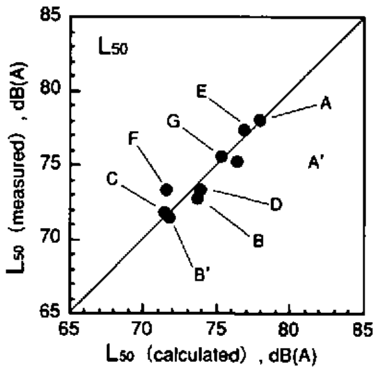

Fig.5. Relationship between the measured and calculated L_{50}.

4. CONCLUSIONS

In order to examine the validity of our road traffic noise prediction model constructed by combining the vehicle noise radiation model and the dynamic traffic flow simulation model, the correspondence between the calculated values and the measured ones was investigated for seven different urban areas. As a result, it has been found that the prediction model is applicable for roads in the urban areas with considerably high accuracy.

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BARRIER DIFFRACTION AND SOUND PROPAGATION IN USDOT'S NEW TRAFFIC NOISE MODEL

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OVERVIEW OF THE TRAFFIC NOISE MODEL

The U.S. Department of Transportation's Federal Highway Administration has undertaken the development of a Windows-based PC computer model to compute road traffic noise with substantially more precision than the current STAMINA 2.0 model [1]. The three-dimensional Traffic Noise Model (TNM) [2] includes a new vehicle noise emissions data base in ⅓-octave bands, which incorporates slow-speed and accelerating vehicles, bus and motorcycle data, vehicles on grade, and vehicles on different pavement types. The TNM computes A-weighted L_{eq}, L_{dn}, or L_{den} depending on user selection. Traffic control devices can be inserted, and the TNM computes vehicle speeds and emission levels accordingly. Noise contours are computed if requested.

Roadway line sources are modeled as finite line segments, with the detailed propagation calculations performed with the two endpoints of each segment.

Overview of Ground and Shielding Elements

The TNM incorporates state-of-the-art sound propagation and shielding algorithms. These algorithms are based on recent research on sound propagation over ground of different types and the shielding effects of barriers, berms, ground, buildings, and trees. All propagation calculations are performed in ⅓-octave bands. The TNM does not account for atmospheric effects such as varying wind speed/direction or temperature gradients. The TNM propagation algorithms assume neutral atmospheric conditions. Characteristics of the propagation algorithms include:

- Ground location and type is incorporated in the TNM. Users input terrain lines to define ground location, and select from a list of ground types to set effective flow resistivity.

- Earth berms can be defined, with user-selectable heights, top widths and side slopes; they are computed within TNM as if they were ground lines.
- Rows-of-buildings attenuation is included, with user-definable height and percentage of area blocked.
- Tree zones can be defined; attenuation is per the ISO standard for dense foliage.
- Reflecting barriers can be defined, with an associated Noise Reduction Coefficient (NRC). Reflected paths are computed and attenuated based on the NRC. Multiple reflections between barriers are not computed in the three-dimensional TNM. (The effects of multiple reflections can be computed within the TNM, on a two-dimensional cross-section geometry with a ray-tracing module.)
- Double-barrier diffraction is included. The net effect of diffraction from the most effective pair of barriers, berms or ground points that interrupt the source-receiver line of sight is computed. Other such objects that interrupt the path are ignored.

BASIS OF THE ACOUSTICAL MODEL

Reflection from ground of finite impedance is based on the work of many researchers including Chessell [3] for computation of the reflection coefficient, Delany and Bazley [4] for the definition of the normal acoustic impedance by the effective flow resistivity (EFR), and Embleton, Piercy, and Daigle [5] for determining appropriate values of EFR for various ground types.

The diffraction model is based on Fresnel diffraction theory, as described by De Jong, Moerkerken, and Van der Toorn [6]. Their formulation incorporates diffraction from wedges, berms, barriers and impedance discontinuities on the ground (such as where pavement meets grass). The TNM incorporates all of the components of De Jong's formulation for diffraction. The TNM expands De Jong's approach to multiply-reflected and multiply-diffracted propagation paths, to allow significantly more complicated terrain.

ELEMENTS IN THE PROPAGATION PATH

Ground points and segments

The TNM uses "ground points" to define the ground location. User-input terrain lines define the ground explicitly and become ground points. Other elements in the geometry define ground points, including edges of roadways, barriers, berms, rows of buildings, and ground zone boundaries. In the calculations, berms are converted to four ground points; two define the base of the berm and two define the top.

Ground points define ground segments in which reflections can occur. The TNM allows users to enter various ground types, which are based on the effective flow resistivity measured by Embleton [4]. The available ground types and associated EFR are given below. Users may also input any desired EFR.

Effective Flow Resistivity for TNM Ground Types

Ground Type Name	Effective Flow Resistivity (cgs Rayls)
Pavement	20,000
Water	20,000
Hard Soil (& dirt road)	5,000
Loose Soil (& gravel)	500
Lawn	300
Field Grass	150
Granular Snow	40
Powder Snow	10

Impedance discontinuities

Impedance discontinuities occur where one ground type changes to another, such as at the edge of the roadway when the default ground type is "lawn." Discontinuities also occur where a user has entered a "ground zone" with a different ground type from the default. Diffraction components are often computed at impedance discontinuities; the model requires these components to maintain continuity of the reflected path across the discontinuity.

Barriers

Barriers are vertical and have base (ground) points, height, and Noise Reduction Coefficient (NRC) values associated with their sides. Barriers may be specified with multiple heights for barrier design comparisons. The TNM computes diffraction components from the barrier top(s) and also from base points on both sides if the contributions are likely to be significant.

The De Jong model [5] requires computation of reflections in the barrier surfaces to compute single barrier diffraction properly. In this way, the model accounts for the pressure doubling that occurs at the barrier top on the source side. The absorption coefficient (NRC) on the barrier's surface influences the diffracted sound energy through these reflections.

Reflecting barriers

Reflecting barriers are special structures within the TNM. Users specify a barrier as "reflecting" and specify the source roadways that are to be reflected in the barrier. The TNM will compute single reflections from the specified sources to the reflecting barrier and then to a receiver. All of the propagation elements that are handled normally by TNM will be handled in the path to and from reflecting barriers. Absorption coefficient (NRC) is specified for the barrier and used to compute a reflection coefficient.

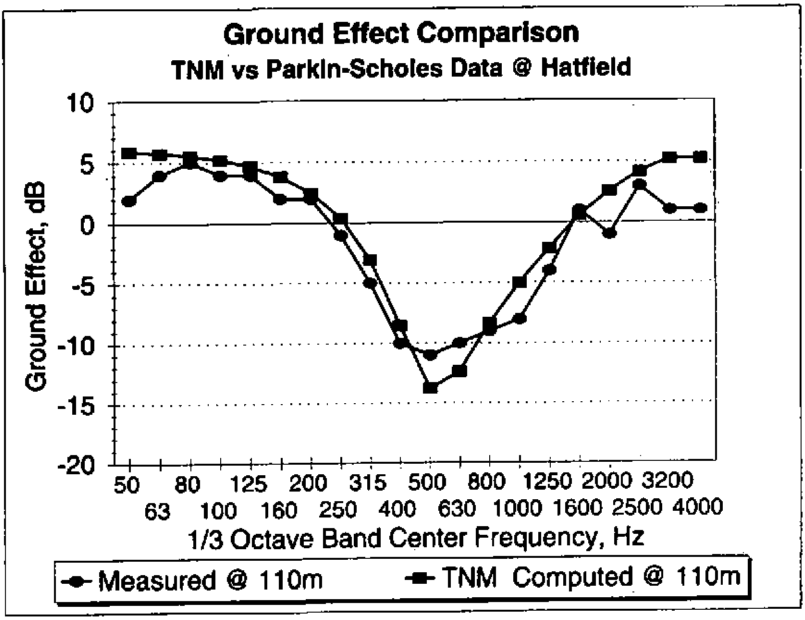
Berms
To the TNM's acoustical calculations, berms are simply a series of ground points. Users have the option of entering berms as a type of barrier, with heights, top widths, and side slopes. In that case, the TNM computes the location of the intersections between the bases of berms and the ground. Those intersections then become ground points. Berms assume the default ground type or, if a berm is inside a ground zone, the type of ground defined for that zone. Therefore, if the default ground type is "lawn" or "field grass," berms will be earth berms and diffraction will be computed accordingly. If the default ground type is "pavement," berms will be acoustically hard.

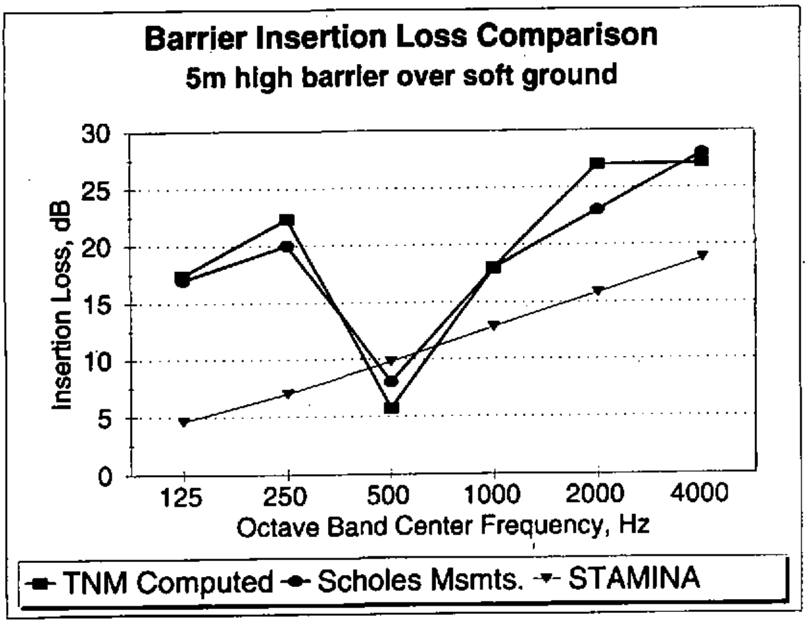
Tree zones
Tree zones may be included as propagation path elements. Tree zones define ground points at their edges, and have heights associated with them. The TNM algorithms compute the distance the propagation paths travel through tree zones, and the 1994 ISO standard for dense foliage is used for attenuation (ISO/DIS 9613-2.2).

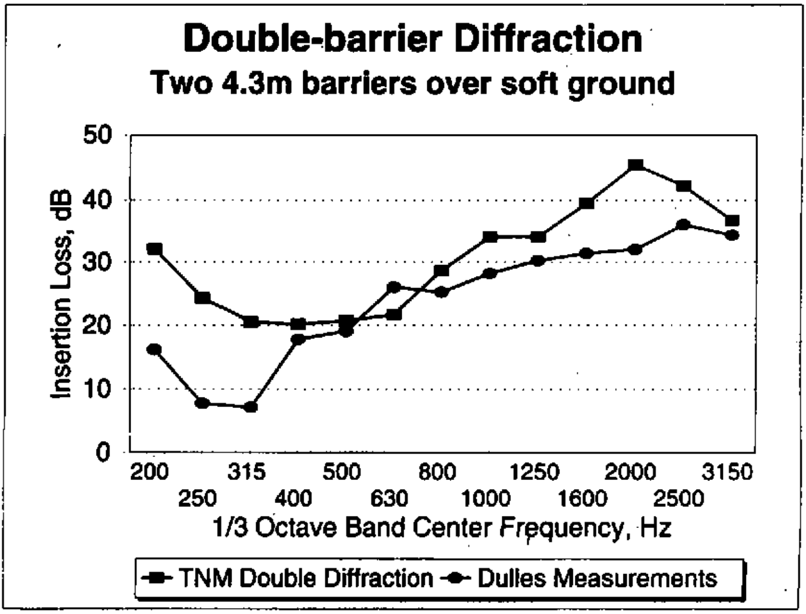
Building rows
Rows of buildings may be incorporated as elements in the propagation path. Like tree zones, they define the ground location and have user-defined height. Rows of buildings are characterized by a "building percentage": the percentage of area in a row that is blocked by buildings. The building percentage and the height are both used in computing the attenuation of the most effective intervening row, according to the equation of the German rail industry standard. The number of rows of buildings also factors into the total attenuation, adding 1½ dB for each additional row after the most effective, up to a maximum of 10 dB, total. Rows of buildings are treated differently from barriers within the TNM, in that propagation paths are allowed to go through building rows.

COMPARISON WITH MEASUREMENTS

Numerous comparisons with measurements have been performed to verify the TNM's accuracy. Three examples are given below, each showing results as a function of frequency. The first shows the computed soft ground-effect attenuation at 110m distance, compared with Parkin and Scholes' measurements at Hatfield [7]. The second compares the TNM barrier diffraction model with Scholes' measurements of a 5m-high barrier, also at Hatfield; STAMINA results are also shown. The third graph compares computed double-barrier diffraction with measurements by Fleming at a test site near Dulles Airport in Virginia.


Ground Effect Comparison
TNM vs Parkin-Scholes Data @ Hatfield
Ground Effect, dB
10
5
0
-5
-10
-15
-20
50 80 125 200 315 500 800 1250 2000 3200
63 100 160 250 400 630 1000 1600 2500 4000
1/3 Octave Band Center Frequency, Hz
Measured @ 110m
TNM Computed @ 110m


Barrier Insertion Loss Comparison
5m high barrier over soft ground
Insertion Loss, dB
30
25
20
15
10
5
0
125 250 500 1000 2000 4000
Octave Band Center Frequency, Hz
TNM Computed
Scholes Msmts.
STAMINA



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