PREDICTION OF WAYSIDE RAILROAD NOISE

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The recent trends in the revitalization of rail transport in this country have resulted in increased interest in the use of rail rapid transit systems in our cities and high-speed surface rail links between major population centers. Included in the technology assessment of new and improved rail service will be the associated environmental problems, including potentially serious wayside noise problems. The solution to the railroad noise problem requires a valid technique for prediction of wayside noise to assess the benefit of various noise control strategies. This paper describes a graphic method for use when the geometry is rather simple and a computer program for use in situations when track and terrain geometry are complicated.

•RECENT trends in the revitalization of rail transport in this country have resulted in increased interest in the use of rail rapid transit systems in our cities and high-speed surface rail links between major population centers. Indications of revitalization are as follows:

1. Rail rapid transit extensions and improvements are occurring in the nine North American cities that have such systems, and at least five new rapid transit systems are in the planning and engineering stages;
2. Commuter lines are improving rolling stock and planning new extensions; and
3. Railroads in the 17-state northeast and midwest regions have recently been reorganized, and this has focused attention on the future plans of the U.S. Railway Association, such as a response to the need for a high-speed rail line in the densely populated Boston-Washington, D.C., corridor.

Incorporated in the technology assessment of new and improved rail service will be the associated environmental problems, including the serious problem of wayside noise. We can look to experience abroad for indications of the potential problem of noise from high-speed railways. Public criticism of the excessive noise levels associated with the high-speed Shinkansen trains [130.5 mph (210 km/h)] has caused the Japanese National Railways to embark on an extensive noise control program (1). Environmentalists and engineers in Great Britain are concerned about the potential public outcry against the noise from the new high-speed trains that are planned to link England and France through the English Channel tunnel (2). At the recent International Symposium on Transportation Noise at the University of Southampton, England (3), much discussion was directed toward predicting the noise in the environment after the introduction of high-speed trains capable of speeds of 150 mph (241 km/h) or greater.

Concern about the quality of the environment is no less strong in the United States than it is abroad. The Noise Control Act of 1972 has virtually mandated the consideration of the noise effects of any major improvement in rail service. Moreover, the transportation industry is vitally concerned with patron and public acceptance of new rail vehicles and the location of new rail corridors. Excessive noise will detract from the acceptability of such improved service.

SOLUTIONS TO RAILROAD NOISE PROBLEM

Solutions to the problem of wayside railroad noise can be approached in three ways. The first approach is through the control of noise emission by railroad vehicles. This can be accomplished through noise control engineering applied during the design of all components of new locomotives and cars. The recently proposed U.S. Environmental Protection Agency (EPA) regulation on railroad noise is an example of pressure from the federal level to control noise emission levels from railroad vehicles. The second approach involves the control of noise in the community through use of careful land use planning and zoning practices, upgrading of the noise sections of building codes for proposed structures, and funding of noise control treatments to existing structures. The third approach involves track and right-of-way location as a means of minimizing the noise impact of new or improved rail lines. Two of these three approaches require a valid wayside noise prediction technique to assess the benefits of various noise control strategies.

RAILROAD NOISE COMPARED WITH HIGHWAY NOISE

It is worthwhile to compare the characteristics of wayside railroad noise with those of the other major source of noise from surface transportation, vehicles on a highway. The differences are rather obvious. Railroad noise is intermittent, but highway noise tends tends to be nearly continuous. The frequency spectrum of the noise from vehicles in each case is different. For railroad noise, the measure of community annoyance is related to the maximum noise level of single events and depends on the number of events; for highway noise, community reaction can be related to a longer term statistical measure such as the level exceeded for 10 percent of the noisiest hour (4).

Despite these essential differences, a number of similarities exist among the characteristics of railroad noise and highway noise, and these have important implications in the proposed methods for predicting noise in the community from railroad operations. In both cases, a well-defined corridor exists along which the noise is generated. The geometries along the corridor in each case are similar: a curvilinear path at grade, in cut, elevated, or depressed. Moreover, noise propagation characteristics in each case have many similarities: Shielding effects of barriers, ground and vegetation effects, and atmospheric effects can be computed similarly because in both cases the noise source is relatively close to the ground surface. More importantly, the mean energy level or equivalent noise level L_{eq} is a significant measure of noise from both sources and can be related to the quality of life in the neighboring community in both cases (5). These similarities between railroad noise and highway noise enable the use of a wayside noise prediction technique for railroads in which the final parametric dependence is similar to that of highways.

GRAPHIC TECHNIQUE TO PREDICT WAYSIDE NOISE FROM RAILROADS

Prediction techniques do exist for predicting the time dependence of the wayside A-weighted sound level during a train passage in an open area along a straight section of track (6, 7). For environmental impact analyses, one wants to be able to account for the geometry of the terrain (e.g., curves in the track, wayside barriers), the frequency of the train passages, and the length of the trains and to use the method to construct contours of equal noise impact.

A technique is presented below that may be used to predict the noise at a point (in terms of L_{eq} or L_{dn}, day-night noise level) near an aboveground rail right-of-way. Contours of equal noise level can be constructed by making calculations at several points along lines perpendicular to the right-of-way and then by fitting in the proper curve by interpolation. This method may be used when the geometry is not very complicated.

The basic concepts of this technique are as follows:

1. To divide the rail right-of-way into a number of straight-line segments (the train speed and track condition should be the same along the entire length of each segment),
2. To calculate the single event noise exposure level (SENEL) due to the passage of a single two-axle truck over each segment [a truck can be treated as a point source for wayside locations more than 20 ft (6 m) from the track],
3. To account for the attenuation of the noise from any segment blocked by a barrier,
4. To add up the SENEL values for all of the segments, and
5. To determine L_{eq} by accounting for the number of truck passages (+10 long N) and the period of exposure (-10 log T).

A review of available noise data for many systems was performed as part of an investigation of wheel-rail noise for the Transportation Systems Center of the U.S. Department of Transportation (8). These data, normalized to correspond to the pass-by of a single car at 50 ft (15.2 m), are shown in Figure 1. For good systems (i.e., systems that report either that they grind their track or that their track is very well maintained) on welded track, the peak pass-by noise level is given by

$$L_A = 60 + 30 \log (V/15) \tag{1}$$

where V is the speed in miles (kilometers) per hour.

Based on the above information, the noise level from a truck passing along a straight-line segment can be approximated by

$$L_A(t) = 58 + 30 \log \frac{V}{15} - 10 \log \frac{vt^2 + d^2}{50^2} + \Delta \tag{2}$$

where

V = speed in miles (kilometers) per hour,
v = speed in feet (meters) per second,
t = time in seconds,
d = perpendicular distance from an observation point to a rail segment in feet (meters), and
Δ = catchall parameter to account for track condition (e.g., for good bolted track, Δ may be +4 dB).

Figure 2 shows how d is measured; the time t is taken to be zero at the point of closest approach to the observation point.

SENEL for the passage of a truck along a segment is as follows:

$$SENEL_i = 10 \log\left(\int_{t_1}^{t_2} 10^{L_A t/10}\, dt\right) \tag{3}$$

where i is used to denote the i th segment.

Substituting equation 2 into equation 3 gives

$$SENEL_i = 23 + 30 \log V_i + \Delta_i + 10 \log \frac{50^2}{d_i v_i}\, \theta_i \tag{4}$$

where $\theta_i = \tan^{-1}(vt_2/d) - \tan^{-1}(vt_1/d)$, the angle in radians from the observation point subtended by the rail segment (Figure 2).

The energy equivalent noise level at a fixed observation point is then given by

$$L_{eq} = 10 \log \left(\sum_i 10^{SENEL_i/10} \right) + 10 \log 2N - 10 \log T \quad (5)$$

where N is the number of train car passages in time period T in seconds, and the summation is over the various segments that make up the right-of-way.

The assignment of a value to the parameter Δ requires some judgment. For example, for a well-maintained bolted track, Δ may be +4 dB; for a steel elevated structure, Δ may be +15 dB. Portions of track behind barriers should be treated as separate segments, and the noise reduction should be calculated separately by standard techniques (9) and lumped into the Δ term.

COMPUTER-AIDED COMPUTATION METHODS

To fully assess the noise from rail operations, one needs a valid method for predicting wayside railroad noise in situations with complicated track and terrain geometry. Such situations call for computer-aided methods such as those available for use by highway engineers (10, 11). One of these (10), the Transportation Systems Center (TSC) highway noise computer program, authorized for use in environmental impact statements by the Federal Highway Administration, is currently being modified by Bolt Beranek and Newman, Inc., for use in railroad noise prediction by some rather basic changes in the input parameters for the noise source. These parameters include source height, source spectrum, and a change in the rate of vehicle passage to correspond to the speed and length of trains. An additional change has been incorporated to account for the effect of barriers on source spectra other than trucks and cars, but the strong point of this computer program, its geometry subroutines, remains. Thus, track geometry, barrier segments, and ground absorption strips can be input in the usual way. The output of the program gives the equivalent A-weighted noise level L_{eq} for the period of time under consideration at any number of receiver points. From such information, equivalent noise level contours can be drawn by interpolation.

An example of the use of the modified TSC program is shown in Figures 3, 4, and 5. A hypothetical terrain and track configuration is assumed for analysis (Figure 3) and features a tunnel, a steel bridge, and an area of land shielded from the track by a natural landform barrier. Two parallel tracks are assumed to carry one train in each direction in the hour of interest; each train consists of two 3,600-hp (2685-kW) road locomotives at throttle 8 and pulls 40 loaded freight cars at a speed of 33 mph (53 km/h).

The terrain and track configuration and the locations of receiver points are modeled as shown in Figure 4. As in the original TSC highway noise computer program, the receivers and the endpoints of track segments and barrier segments are located by coordinates: z-coordinate relative to the ground level and x- and y-coordinates based on arbitrarily chosen axes. All input source spectra were taken from the Serendipity Inc., report (6).

The predicted equivalent A-weighted sound levels L_{eq} from this hypothetical example are shown as contours in Figure 5. The shielding effect of the natural barrier is shown in the reduced noise levels in the bottom left side of the figure. Another result worth noting is the widened 80-dB equivalent sound level contour region in the vicinity of the steel bridge.

CONCLUSIONS

Although initial evaluation of the program has only just begun, the potential usefulness

Figure 1. Noise from welded-track systems normalized to single car at 50 ft (15.2 m).

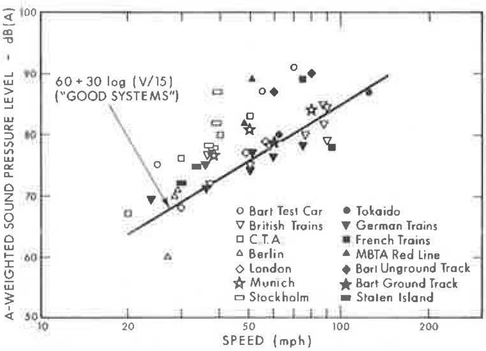


Figure 2. Geometry for short method.

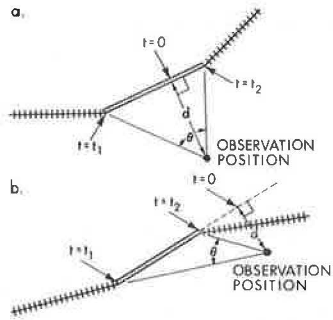


Figure 3. Terrain for rail model example.

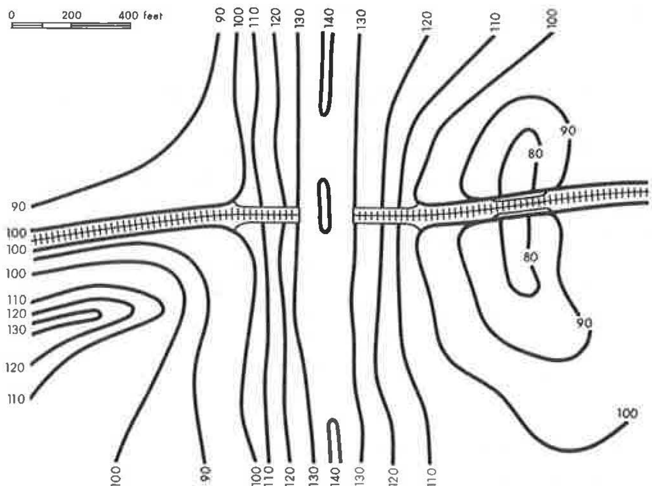


Figure 4. Computer input geometry for rail model example.

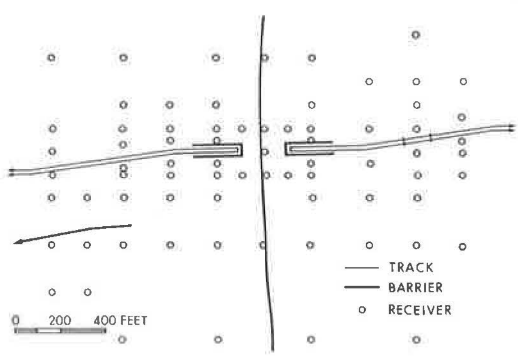
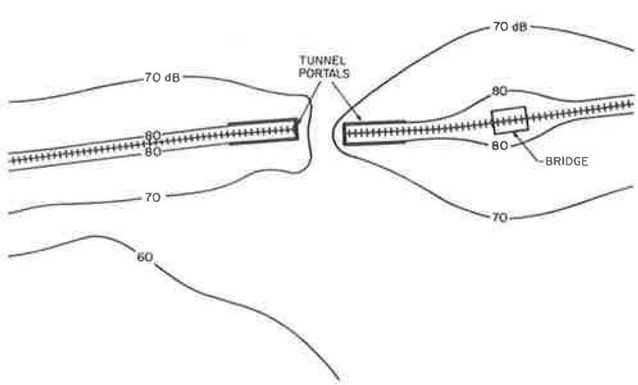


Figure 5. Predicted railroad equivalent A-weighted sound level contours.



of the approach is already evident in problems such as the noise analysis of joint railroad and highway corridors. Additional features, such as inclusion of enough track segment coordinates to obtain a time history of a single pass-by of a train, could make the program even more useful in applications. Moreover, for noise control purposes it is useful to know which segment of track is critical in contributing to the noise at a given receiver. Finally, given the critical segment of track, one wants to know the effect of various noise control measures, such as barriers, in controlling the noise from that segment. A number of these features have already been incorporated in the computer program recently developed by Bolt Beranek and Newman, Inc. (11). Should this computer program be similarly modified for railroad noise prediction, engineers would have at their disposal a useful tool for environmental noise analyses of various transportation alternatives.

REFERENCES

1. K. Miyaji. Noise Control on Shinkansen. Railway Gazette International, Vol. 129, No. 7, July 1973.
2. J. G. Walker, G. Allen, and J. B. Large. Planning and Railway Noise. 2nd Interagency Symposium on University Research in Transportation Noise, North Carolina State Univ., Raleigh, June 1974.
3. Proc., Symposium on Noise in Transportation. Univ. of Southampton, July 1974.
4. T. J. Schultz. Development of an Acoustics Rating Scale for Assessing Annoyance Caused by Wheel/Rail Noise in Urban Mass Transit. U.S. Department of Transportation, Rept. UMTA-MA-06-0025-74-2, Feb. 1974.
5. Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare With an Adequate Margin of Safety. U.S. Environmental Protection Agency, Rept. 550/9-74-004, March 1974.
6. A Study of the Magnitude of Transportation Noise Generation and Potential Abatement—Train System Noise. Serendipity, Inc., Rept. OST-ONA-71-1, Vol. 5, Nov. 1970.
7. S. Peters. The Prediction of Railway Noise Profiles. Journal of Sound and Vibration, Vol. 32, No. 1, 1974, pp. 87-89.
8. Wheel/Rail Noise. Bolt Beranek and Newman, Inc., interim rept.
9. L. L. Beranek. Noise and Vibration Control. McGraw-Hill Book Co., New York, Chapter 7, 1971.
10. J. R. Wesler. Manual for Highway Noise Prediction. U.S. Department of Transporation, Rept. DOT-TSC-FHWA-72-1, 1972.
11. P. E. Rentz, L. D. Pope, B. A. Kugler, G. S. Anderson, D. E. Commins, A. A. Piersol, S. D. Pecora, and R. Winfrey. Highway Noise—Sources, Propagation, Models, Control, Impact-Reducing Measures, and Economic Evaluation. Research agency final rept., NCHRP Project 3-7/3, 1974.