Building Science Series 84

IDE for Reducing Transportation Noise in and Around Buildings

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards

STEP H15 TOTAL NOISE LEVEL DUE TO SEVERAL HIGHWAYS

The total noise level at the building site you have selected is determined by summing the components from all highways affecting your site. Summing is done two values at a time, by the same method as used in STEP H14. (Refer to this step for the procedure of summing noise levels.)

Record this value on Highway Worksheet 1.

* * * * *

Now proceed to Sections 5.3 and 5.4 to predict the noise levels due to railways and aircraft. If these two transportation system noise sources do not affect your building site, proceed directly to Chapter 6.

References
Chapter 5
Section 2
Highway Noise

[1] Gordon, C. G., Galloway, W. J., Kugler, B. A., and Nelson, D. L., Highway noise—a design guide for highway engineers, NCHRP Report 117 (Bolt Beranek and Newman Inc., Los Angeles, California 1971). Available from the Highway Research Board, 2101 Constitution Ave., Washington, D.C. 20418.

[2] Wesler, J. W., Manual for highway noise prediction, U.S. Department of Transportation Report No. DOT-TSC-FHWA-72-1 (Department of Transportation, Transportation Systems Center, Cambridge, Mass., March 1972). Available from the National Technical Information Service, Springfield, Virginia, Accession Nos. PB 226-086, PB 226-087 and PB 226-088.

[3] Kugler, B. A., Commins, D. E., and Galloway, W. J., Establishment of standards for highway noise levels: Volume 1—Design guide for highway noise prediction and control, BBN Report No. 2739 (Bolt Beranek and Newman Inc., Los Angeles, California, February 1974).

[4] Kugler, B. A., and Piersol, A. G., Highway noise: a field evaluation of traffic noise reduction measures, NCHRP Report 144 (Bolt Beranek and Newman Inc., Canoga Park, California, 1973). Available from the Highway Research Board, 2101 Constitution Ave., Washington, D.C. 20418.

Chapter 5
Section 3
How to Estimate Railway Passby Noise

Railroad operations can be classified as either line operations or yard operations. Line operations are movements of trains of various types over main line and local track; yard operations are the various activities concentrated in a railway terminal. Railroad yard operations generate noise through the disassembling and recoupling of cars to form new trains, and the maintenance and repair of cars and locomotives. Although a limited amount of research has been devoted to the modeling of noise phenomena in railroad yards, the models are complex since there are so many different types of sound sources operating for various lengths of time on an intermittent basis [1, 2], thus making it very difficult to predict the noise that is generated. For this reason railroad yard noise will not be treated in this design guide.

Railway line operations are a much more common source of railroad noise than yard operations. The noise generated by train passbys is a function of the type of vehicle in use, how it is operated, and the configuration of the trackbed relative to the surrounding terrain. Although there has been a fair amount of research devoted to the modeling of railway line passbys [1–5], there is still much to be learned. Unlike highways, which have been the subject of a great deal more research than railways, no simple nomogram method for predicting passby noise has been developed.

The analytical model * which is used in this design guide for predicting railway noise considers four general types of vehicles as noise sources: locomotives, freight cars, passenger coaches, and rapid transit vehicles. These vehicles, either in combination with one of the other types or by themselves, form three general train categories. These are freight trains, conventional passenger trains, and rapid transit trains. A freight train consists of one or more locomotives, usually diesel-electric, pulling a combination of various types of freight cars. A conventional passenger train is similar to a freight train in that it consists of one or more locomotives pulling several coaches, but one important difference is that the loco-

* *The railway noise model is based on work performed by Wyle Laboratories, El Segundo, California, under the sponsorship of the Association of American Railroads, Washington, D.C. [1]. The design guide's technique for predicting the generated noise levels is modified slightly to include more recently published data and to simplify the necessary calculations.*

motive may either be diesel-electric or all electric.* The third type, rapid transit trains, differs from the other two types in that there Is not a centralized source of propulsion pulling a series of cars, but rather electric motors on the axles of each car. There is a wide variety of different types of vehicles which can be classified as rapid transit trains. As a result, some of the newer vehicles may be quieter than predicted by the methods of this design guide. Also, the prediction procedures are not applicable to underground subway operations or "classic" street cars.

A diesel-electric locomotive utilizes a diesel engine driving an electrical alternator or generator which in turn drives electric traction motors on the wheels. An all-electric locomotive, on the other hand, obtains its electrical power from an external source, normally an overhead line or third rail, to drive its traction motors. The vast majority of trains in the United States are hauled by diesel-electric locomotives—as of 1971, 99% of the 27,000 locomotives in service were diesel-electric, with most of the remainder being all-electric [6].

For noise propagation, the model assumes locomotive is a combination of sounds radiated from the exhaust outlet, the engine casing, the cooling fans, the transmission, the electrical equipment, and the interaction of the wheels and rails—the predominant source of noise is the exhaust outlet. Hence, all-electric locomotives, which have no diesel engine and thus no exhaust, are generally quieter than diesel-electric locomotives.

Having no propulsion system, freight cars and passenger coaches generate noise mainly by the rolling of the wheels on the rails. The magnitude of the noise depends heavily on the condition of the wheels and track, and on the type of vehicle suspension. Modern passenger coaches with auxiliary hydraulic suspension systems in addition to normal springs can be about 10 dB quieter than older passenger coaches or freight cars which have only springs.

The noise of rapid transit trains, even though there are electric motors on each axle that are sources of noise, is also predominantly generated by the interaction of the wheels upon the rails. In fact, because rapid transit vehicles are usually newer and have better suspension systems, they are generally quieter than freight cars or passenger coaches.

** There are also gas turbine locomotives, but these are few in number and will not be considered herein.*

Geographically, the predictive model assumes that the real railway configuration can be approximated by a single "equivalent" track that is straight and infinitely long. It also assumes that this "equivalent" track lies at grade on a level terrain, which means that there is no shielding. The model further assumes that the trains that use this track can be grouped into one of the three general categories (freight, conventional passenger, or rapid transit) and that each of these categories can be characterized by an average speed, an average train length, and an average number of passbys for normal operating conditions.

Freight train noise is analyzed by considering two distinct sources: the diesel-electric locomotive and the freight cars; but conventional passenger trains and rapid transit trains are considered to generate noise primarily through wheel-rail interaction. This means that for conventional passenger trains the locomotive is assumed to be all-electric. Hence, if the conventional passenger train locomotives are diesel-electric a locomotive noise component must be added.

For noise propagation, the model assumes that diesel-electric locomotive equivalent sound level decreases by an A-weighted value of 5.3 dB for every doubling of distance from the railway. The equivalent sound level from freight cars, passenger coaches, and rapid transit vehicles is assumed to decrease by an A-weighted sound level difference of 6.2 dB for every doubling of distance from the railway. These two values of attenuation are applicable only for distances greater than 150 feet from the railway, but it is not anticipated that your building or site would be 150 feet or closer to a railway. The values were determined empirically and include corrections for attenuation due to spreading of the sound waves (divergence), increased duration of the noise at points farther away from the railway, air absorption, and excess ground attenuation [1].

As mentioned previously, the model assumes that the railway lies at grade on a level terrain. If the railway is either elevated or depressed relative to the surrounding terrain, the effect may be to shield the railway from the building site in the same manner as a barrier. Such effects are taken into account by substracting the attenuation due to the shielding from the predicted level. These shielding adjustments are made in STEPS R11, R12 and R13.

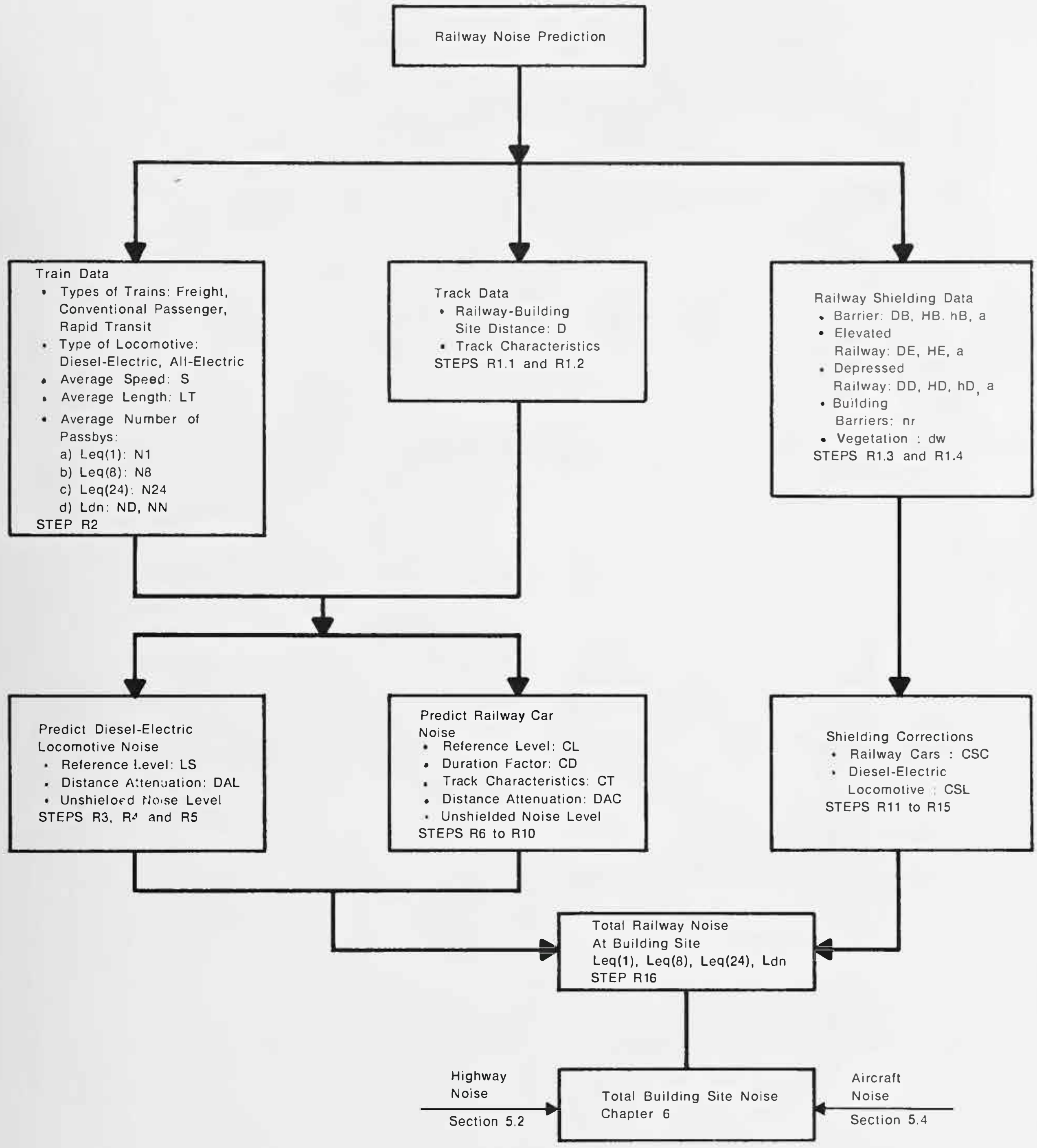


Figure 5.3–1. Railway Noise Prediction Flow Diagram.

Railway Worksheet 1

Building Project ________________ Railway Number ________________

Location ________________ Site point or building room for which sound pressure levels are being estimated ________________

Owner ________ Designer ________ Date ________ Revised ________

Railway—Building Site Distance: D (Feet) ________________

	Freight Trains		Conventional Passenger Trains		Rapid Transit Trains	
Does this type of train use the track being analyzed?						
Diesel-Electric or All-Electric Locomotive		NL		NL		
Average Train Speed, S, mph						
Average number of cars, nc						
Average train length, LT, feet						
Average Number of Passbys						
a) Leq(1) : N1						
b) Leq(8) : N8						
c) Leq(24) : N24						
d) Ldn	ND	NN	ND	NN	ND	NN
Diesel-Electric Locomotive						
Reference Level, LS						
Distance Attenuation, DAL						
Railway Cars						
Reference Level, CL						
Duration Factor, CD						
Track Characteristics, CT						
Distance Attenuation, DAC						

Predicted Noise Levels		Diesel-Electric Locomotive	Railway Cars	Diesel-Electric Locomotive	Railway Cars	Railway Cars
a) Leq(1)	CN1					
	C1					
	Leq(1) No Shielding					
	Total Shielding Correction (Railway Worksheet 2)					
	Leq(1) Corrected for Shielding					
b) Leq(8)	CN8					
	C8					
	Leq(8) No Shielding					
	Total Shielding Correction (Railway Worksheet 2)					
	Leq(8) Corrected for Shielding					
c) Leq(24)	CN24					
	C24					
	Leq(24) No Shielding					
	Total Shielding Correction (Railway Worksheet 2)					
	Leq(24) Corrected for Shielding					
d) Ldn	CN					
	CDN					
	Ldn No Shielding					
	Total Shielding Correction (Railway Worksheet 2)					
	Ldn Corrected for Shielding					
Total Railway Noise						

Figure 5.3–2. Railway Worksheet 1

Railway Worksheet 2

Building Project ____________________

Location ____________________

Owner ____________________

Railway Number ____________________

Site point or building room for which sound pressure levels are being estimated ____________________

Designer ____________________

Date ____________ Revised ____________

Railway--Building Site Distance: D (Feet) ____________

Shielding Geometry	Barrier				Elevated Railway			Depressed Railway			
	DB	HB	hB	a	DE	HE	a	DD	HD	hD	a

Path Length Difference					
	Railway Cars	Ac	Bc	Cc	Lc
	Diesel-Electric Locomotive	Al	Bl	Cl	Ll

Correction For "Infinite" Shielding Element	Railway Cars	Diesel-Electric Loc.
	CSC	CSL

Correction For "Finite" Shielding Element		
	Included Angle Ratio, RA	
	Railway Cars	Diesel-Electric Loc.
	CSC	CSL

Building Barrier	nr		CSB	
Vegetation	dw		CSV	

Total Shielding Correction	Railway Cars	Diesel-Electric Loc.
	CSC + CSB + CSV	CSL + CSB + CSV

Track Characteristics

a		b	c	d		
				Bridgework		
Welded Track	Jointed Track	Presence of Switching Frog or Grade Crossing	Radius of Tight Curve (< 900 Feet) in Feet	Concrete Structure	Steel Girder with Concrete or Open Tie Deck	Steel Girder with Steel Plate Deck

Figure 5.3–3. Railway Worksheet 2.

Before proceeding, you should briefly study the flow diagram of Figure 5.3–1 which outlines the steps necessary to estimate railway noise. Starting at the top of the chart and moving downward, you will first obtain the required train, track and railway shielding input data (STEPS R1 and R2). Then using these data, you will calculate the sound levels corresponding to the diesel-electric locomotive and railway car components of the three types of trains affecting your site (STEPS R3 to R10). Then you will make shielding corrections (R11 to R15) for any barriers. Following this you will determine the total noise level due to this railway by combining the contributions from its various components (STEP R16). All steps should be recorded on Railway Worksheets 1 and 2 shown in Figures 5.3–2 and 5.3–3. A detailed example showing the step-by-step calculations is given in Section 5.5.

Railway Noise Prediction Method

STEP R1 PHYSICAL SITE AND TRACK DATA

Information on railway geometry and track characteristics can usually be obtained from area maps and the appropriate department of the railway company as discussed in Chapter 2. The data should be obtained for each railway that is listed on the Preliminary Source Evaluation Worksheet with a *yes* answer in Column 2. The required data are:

1. Nearest perpendicular distance between the centerline of the railway and the point you have chosen for analysis on the building site, D, in feet.

   See Figure 5.3–4 for an example of how D is determined, and record this value on Railway Worksheets 1 and 2.

2. The physical characteristics of the track:
   a. Type of track: welded or jointed
   b. Presence of switches or grade crossing
   c. Radius of tight (less than 900 feet) curve in feet
   d. Presence of a bridge
      - concrete structure
      - steel girder with either concrete or open tie deck
      - steel girder with steel plate deck

   A switch, grade crossing, tight radius curve, or bridge should only be considered when it is located within a distance of 2D on either side of the point of intersection of the railway with the nearest perpendicular distance. See Figure 5.3–4 for an illustration of this distance requirement. Record this information on Railway Worksheet 2.

3. Location and geometry of any obstruction that visually shields the railway from the building, in feet

   Determine if any barriers, elevated railways, or depressed railways are present, and then obtain the appropriate distances as shown on Figures 5.3–5, 5.3–6 and 5.3–7 and listed below. Distances should be determined as accurately as possible. If there is no shielding, omit this part of STEP R1 and all of STEPS R11, R12 and R13.

Barrier: D, DB, HB, hB, a
Elevated Railway: D, DE, HE, a
Depressed Railway: D, DD, HD, hD, a

   Note that the distances hB and hD can be positive or negative; be sure to record the appropriate sign on Railway Worksheet 2.

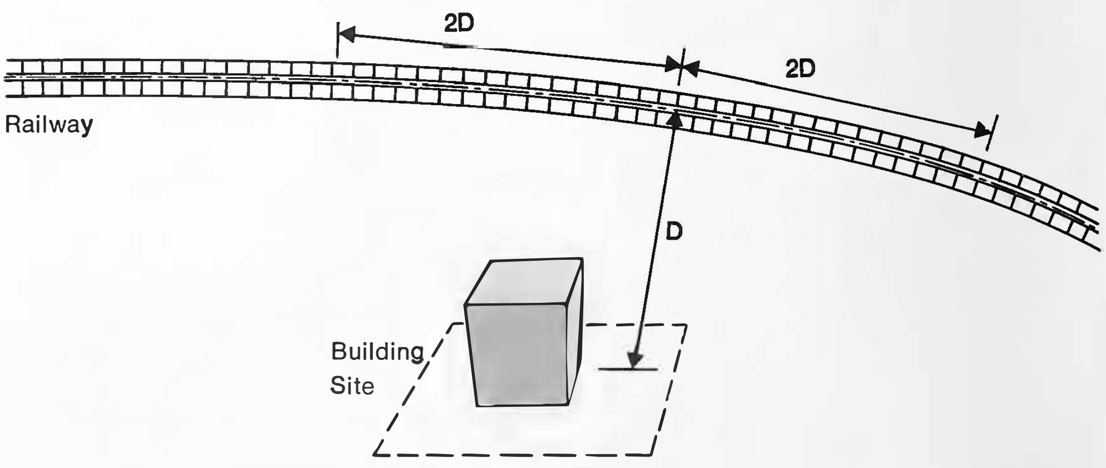


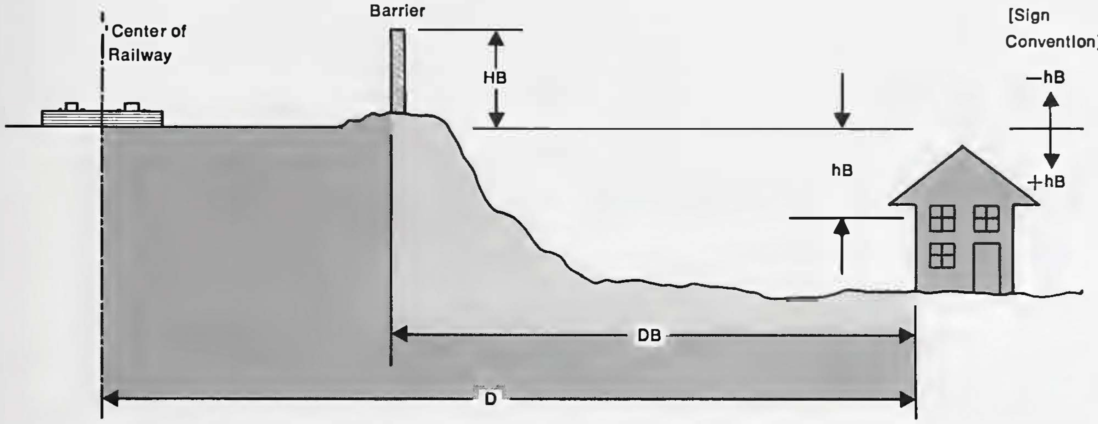
Figure 5.3–4. Railway-Building Site Distance, D.

4. Presence of any rows of buildings or belts of vegetation that shield your building site from the railway

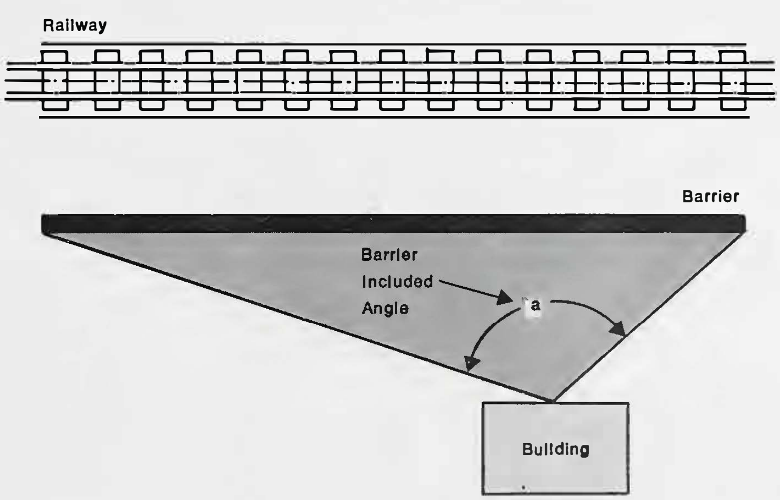
Use the criteria discussed in Section 5.1 to determine if there is any significant shielding due to buildings or belts of vegetation. If there is, gather the data listed below.

a) Buildings as Barriers: nr—number of rows of buildings
b) Vegetation: dw—depth of woods

Record these values on Railway Worksheet 2.

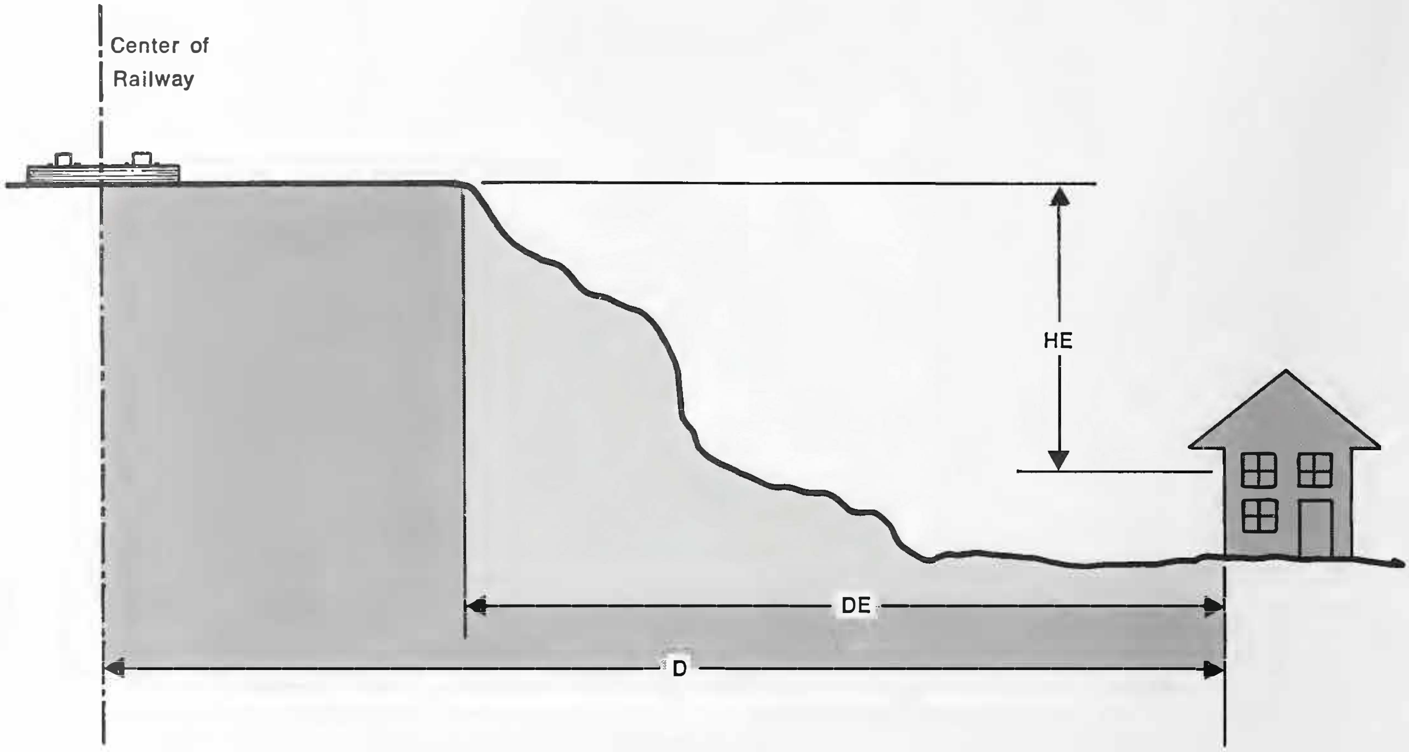


(a) Barrier linear dimensions. *Be sure to note the sign convention for hB; positive below the plane of the railway and negative above.*

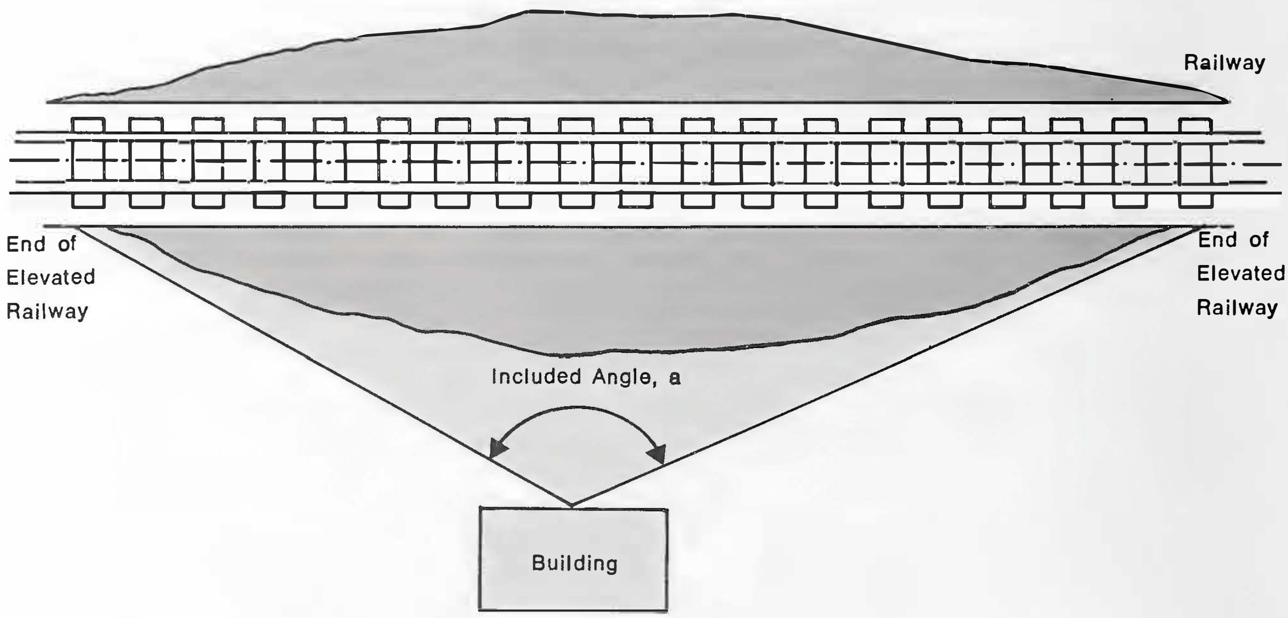


(b) Barrier included angle.

Figure 5.3–5. Dimensions for Shielding by a Railway Barrier.

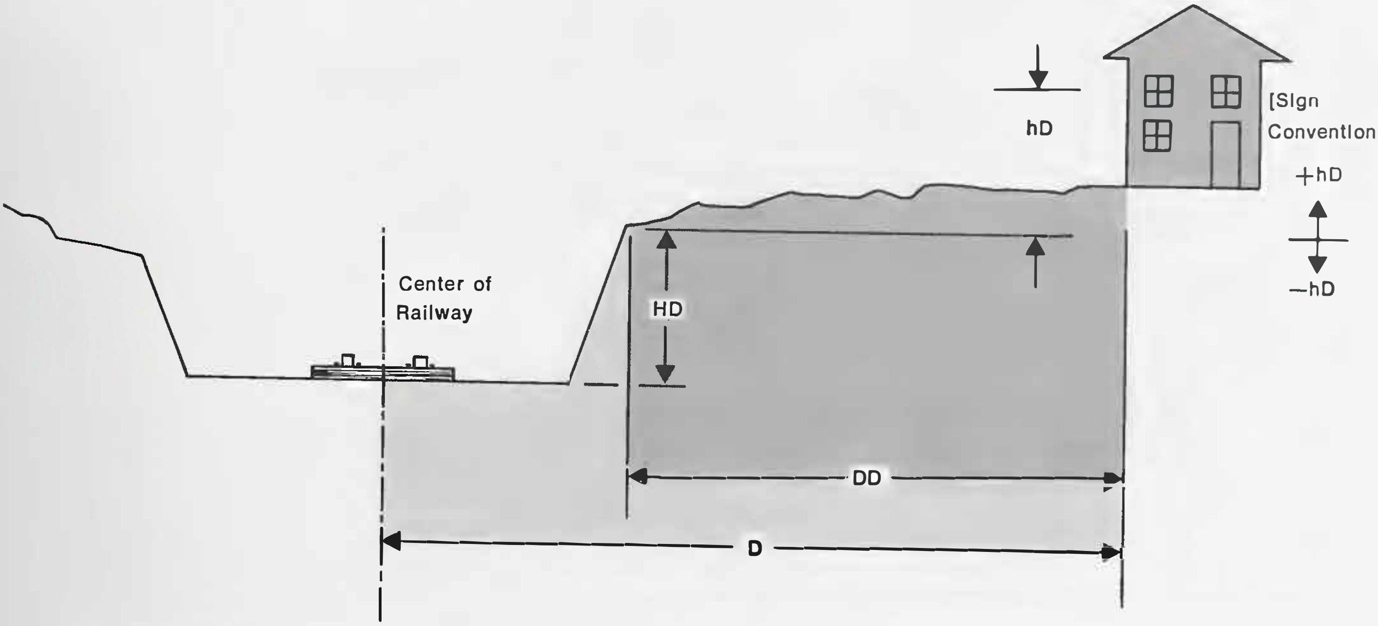


(a) Elevated railway linear dimensions.

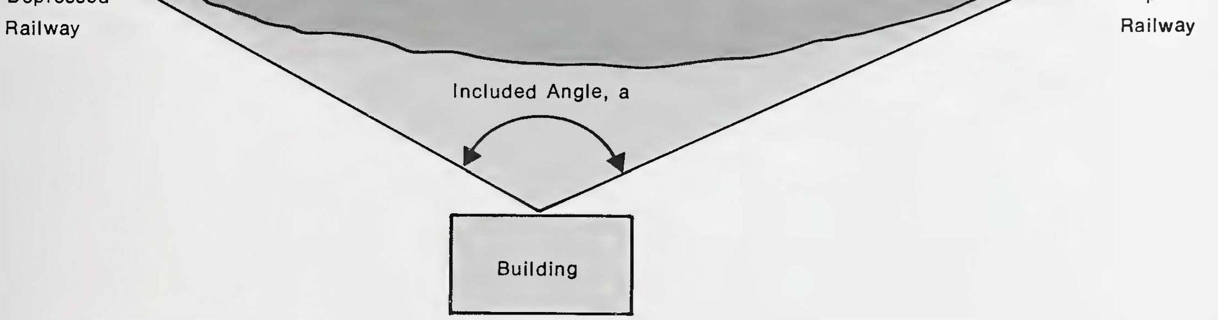


(b) Elevated railway included angle.

Figure 5.3–6. Dimensions for Shielding By an Elevated Railway.



(a) Depressed railway linear dimensions. *Be sure to note the sign convention for hD; negative below the top of the depression and positive above—different from barrier notation.*



(b) Depressed railway includeu angle.

Figure 5.3–7. Dimensions for Shielding By a Depressed Railway.

STEP R2 TRAIN DATA

The information that is required on trains can be obtained from the agencies listed in Chapter 2. These data should be gathered for each railway listed on the Preliminary Source Evaluation Worksheet with a *yes* answer in Column 2. The values should be the average for all tracks and should be based on typical operating conditions. The required data to be recorded on Railway Worksheet 1 are:

1. Types of trains which normally use the track.

   If there are no freight trains, or no conventional passenger trains, or no rapid transit trains write "NONE" in the appropriate space on Railway Worksheet 1 for that train type.

2. Type of locomotive which normally is used to pull the train: diesel-electric or all-electric. This information on locomotions is only needed for freight trains or conventional passenger trains. If this information is not readily available, assume the locomotive to be diesel-electric since this is the predominant type, and the worst case acoustically. Also determine the average number of diesel-electric locomotives, NL, used to pull the train.

3. Average train speed, S, in miles per hour for each type of train.

4. Average train length, LT, in feet for each type of train.

   If the average length is not available, determine the average number of cars, nc, in the train. The length is then obtained by multiplying nc by 55 feet for freight cars and by 75 feet for passenger coaches and rapid transit vehicles [7].

5. Average number of passbys for each type of train.

   The time period for which the typical number of operations is determined depends upon the metric being used for the noise criterion for your proposed building: Leq(1), Leq(8), Leq (24), or Ldn. Obtain only the data required to calculate the metric you are using.

   - **Leq(1)**

     Determine the average number of passbys during the one selected hour of critical building (or outdoor activity area) use, N1.

   - **Leq(8)**

     Determine the average number of passbys during the eight hours of building use, N8.

   - **Leq(24)**

     Determine the average number of passbys during a typical twenty-four hour day, N24.

   - **Ldn**

     Determine the number of passbys during the "daytime" (7 A.M. to 10 P.M. and the "night time" (10 P.M. to 7 A.M.), ND and NN, respectively.

* * * * *

Now you have the necessary input data for the prediction of railway noise. This prediction, outlined in the following steps, consists of determining various factors which are combined to give the estimated noise level. The factors are based on the railway model discussed previously and are normalized to a reference distance of one-hundred feet. Noise levels for the idealized model are then corrected to account for actual conditions. Computations are simplified as much as possible by graphs, charts, and tables.

The remainder of this section is divided into four separate subsections. Subsection A contains the directions for estimating the unshielded noise level of freight trains, conventional passenger trains and rapid transit trains. Subsection B contains the predictive steps for calculating diesel-electric locomotive noise and railway car noise. Shielding adjustments are made in subsection C; and in subsection D, separate noise contributions are combined to get the total railway noise.

Your approach should be to use Subsection A to determine which steps of the noise production computations you must perform. Estimate the unshielded noise level for diesel-electric locomotives and cars in B. Then in C, estimate the shielding corrections, if any, and finally, in D combine the noise levels generated by each type of train to get the total railway noise at your building site. Record the calculated values on Railway Worksheets 1 and 2 as directed.

A. Steps for Predicting Railway Noise

Freight Trains

Freight train noise has two distinct components: diesel-electric locomotive noise and freight car noise. These two components must be treated separately. Follow STEPS R3, R4 and R5 to get the locomotive component, and STEPS R6 through R10 to get the car component. Use the appropriate input data from Railway Worksheet 1 for freight trains.

Conventional Passenger Trains

Conventional passenger train noise depends upon the type of locomotive. If it is all-electric, treat the locomotive as another passenger coach and perform STEP R7 through R10.

If diesel-electric locomotives are the predominant type, a locomotive component must be included. Perform STEPS R3, R4 and R5 to get the locomotive component, and STEPS R6 through R10 to get the car component. Use the appropriate input data from Railway Worksheet 1.

Rapid Transit Trains

Rapid transit train noise is predominantly wheel-rail noise, with no locomotive component. Perform STEPS R6 through R10 using appropriate input data from Railway Worksheet 1.

B. Noise Prediction Calculations

STEP R3 DIESEL-ELECTRIC LOCOMOTIVES—REFERENCE LEVEL

Compute the factor LS for the diesel-electric locomotives at the reference distance of 100 feet from the centerline of the railway. LS is determined by locating on the horizontal axis of Figure 5.3–8, the speed, S, for this type of train. Read up until intersecting the curve. The value of LS can be read off the vertical axis directly left of the intersection.

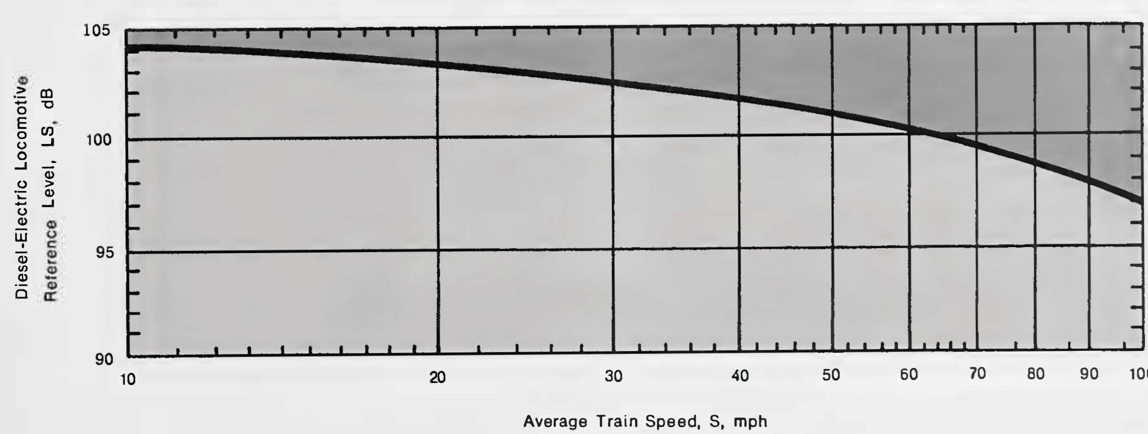


Figure 5.3–8. Diesel-Electric Locomotive Reference Level, LS, at 100 feet [1].

STEP R4 DIESEL-ELECTRIC LOCOMOTIVES—DISTANCE ATTENUATION

Compute the distance attenuation factor, DAL for diesel-electric locomotive noise.

DAL is determined by locating on the horizontal axis of Figure 5.3–9 the distance, D. Read up until intersecting the curve for the locomotive correction. The value of DAL can be read off the vertical axis directly left of the intersection.

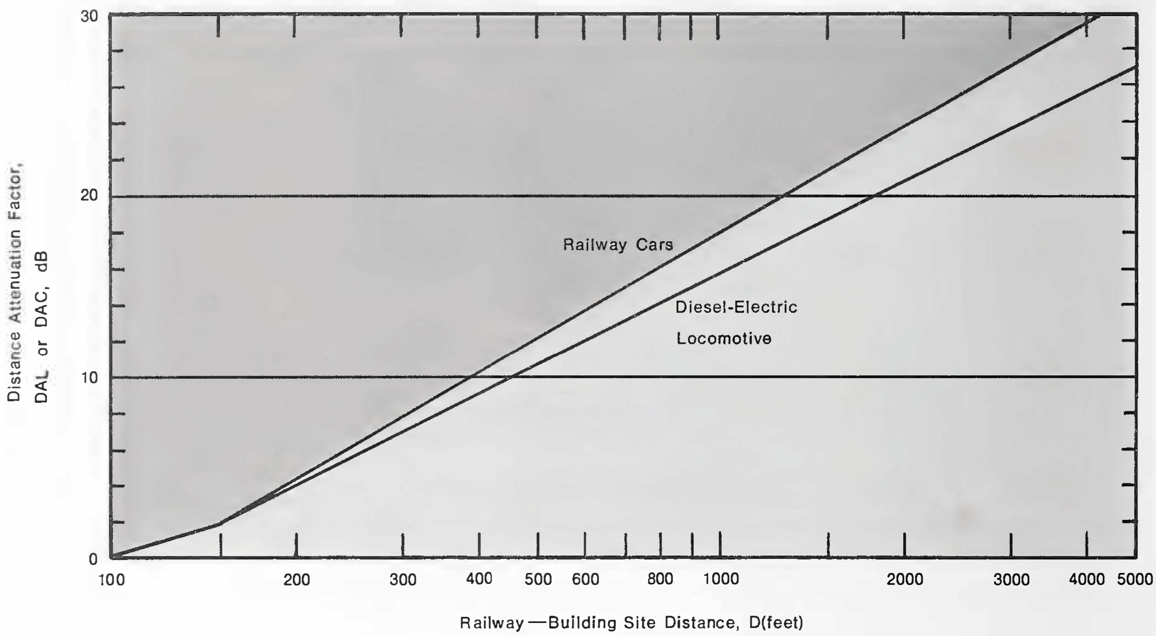


Figure 5.3–9. Railway Noise Attenuation With Distance [1].

STEP R5 DIESEL-ELECTRIC LOCOMOTIVES—UNSHIELDED NOISE LEVEL

Perform the calculations appropriate for the noise criterion, or metric, for your proposed building. Record all values on Railway Worksheet 1.

Leq(1)

Compute C1, which is a correction for the number of passbys during the selected hour of critical building use. C1 is determined from the total number of passbys, CN1, defined as,

$$CN1 = N1 \times NL,$$

where N1 is the average number of passbys for this type of train during the selected hour, and NL is the average number of diesel-electric locomotives pulling the train. On the horizontal axis of Figure 5.3–10 locate the value of CN1 for this type of train. Read up until intersecting the curve. Read the value of C1 from the vertical axis directly left of the intersection. Using this value and the values of LS and DAL, calculate Leq(1) from the following equation:

$$Leq(1) = LS + C1 - DAL - 36.$$

Leq(8)

Compute C8, which is a correction for the number of passbys during the eight hours of building use. It is determined from the total number of passbys, CN8, defined as,

$$CN8 = N8 \times NL.$$

where N8 is the average number of passbys by this type of train during the eight hours, and NL is the average number of diesel-electric locomotives pulling the train. Locate on the horizontal axis of Figure 5.3–10, the value of CN8 for this type of train. Read up until intersecting the curve. Read the value of C8 from the vertical axis directly left of the intersection. Using this value and the values of LS and DAL, calculate Leq(8) from the following equation:

$$Leq(8) = LS + C8 - DAL - 45.$$

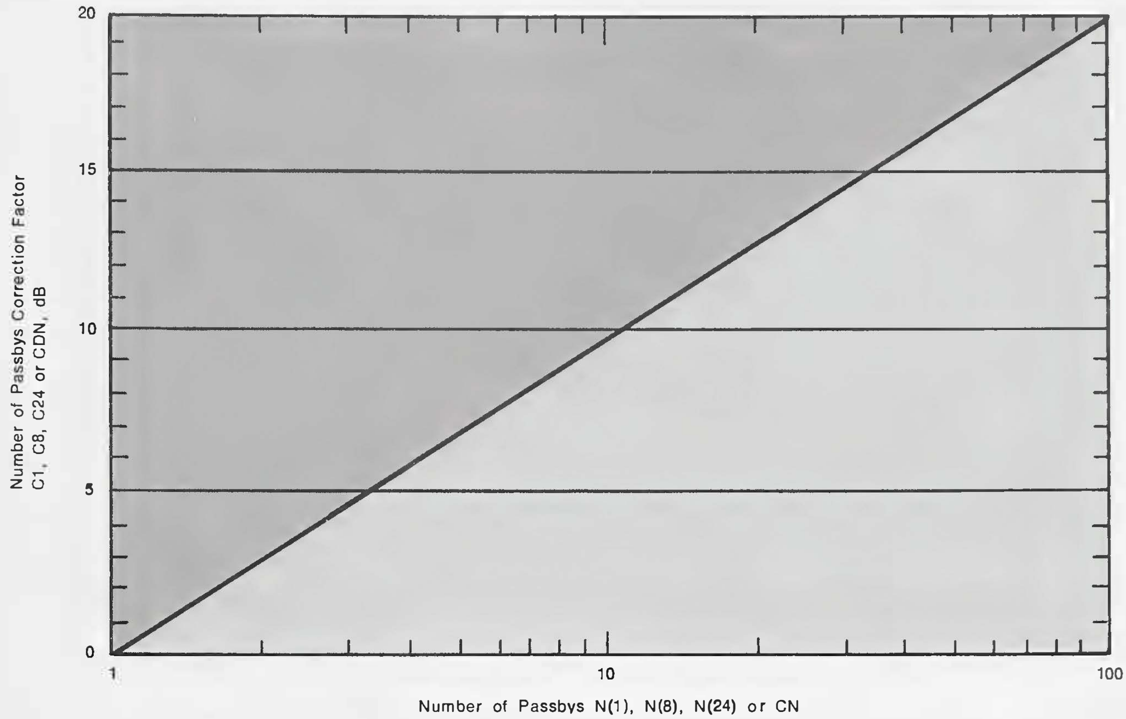


Figure 5.3–10. Correction for the Number of Passbys.

Leq(24)

Compute C24, which is a correction for the number of passbys during a twenty-four hour day. It is determined from the total number of passbys, CN24, defined as,

$$CN24 = N24 \times NL,$$

where N24 is the average number of passbys by this type of train during the twenty-four hours, and NL is the average number of diesel-electric locomotives pulling the train. Locate on the horizontal axis of Figure 5.3–10 the value of CN24 for this type of train. Read up until intersecting the curve. Read the value of C24 from the vertical axis directly left of the intersection. Using this value and the values of LS and DAL, calculate Leq(24) from the following equation:

$$Leq(24) = LS + C24 - DAL - 49.$$

Ldn

Compute CDN, which is a correction for the number of "daytime" and "nighttime" passbys. It is determined from the corrected number of passbys, CN, defined as

$$CN = (ND + 6NN)\ NL$$

where ND is the number of "daytime", and NN is the number of "nighttime" passbys for this type of train, and NL is the average number of diesel-electric locomotives pulling the train. Locate on the horizontal axis of Figure 5.3–10 the value of CN. Read up until intersecting the curve. Read the value of CDN from the vertical axis directly left of the intersection. Using this value and the values of LS and DAL, calculate Ldn from the following equation:

$$Ldn = LS + CDN - DAL - 49.$$

STEP R6 RAILWAY CARS— REFERENCE LEVEL

Compute the factor CL at the reference distance of 100 feet from the centerline of the railway. CL is determined by locating on the horizontal axis of Figure 5.3–11 the speed, S, for this type of train. Read up until intersecting the appropriate curve for this type of railway car. The value of CL can be read off the vertical axis directly left of the intersection.

STEP R7 RAILWAY CARS—PASSBY DURATION

Compute the passby duration factor CD. CD is determined by locating on the horizontal axis of Figure 5.3–12 the train length, LT, for this type of train. Read up until intersecting the curve corresponding to the speed, S, for this train category. The value of CD can be read off the vertical axis directly left of the intersection.

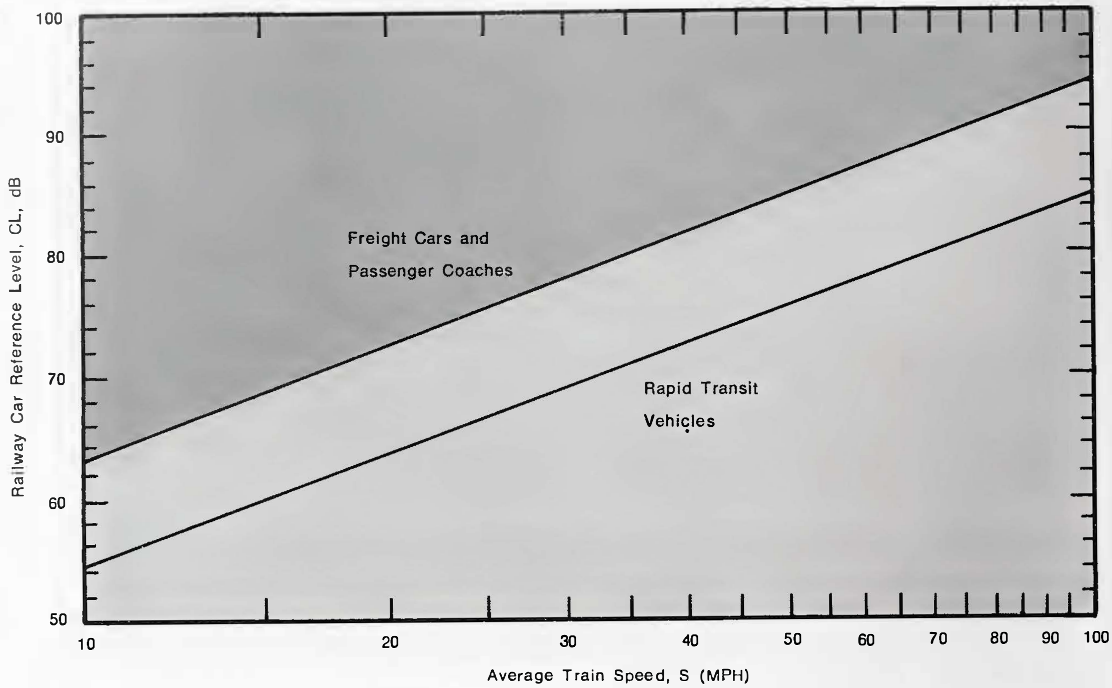


Figure 5.3–11. Railway Car Reference Level at 100 feet [2].

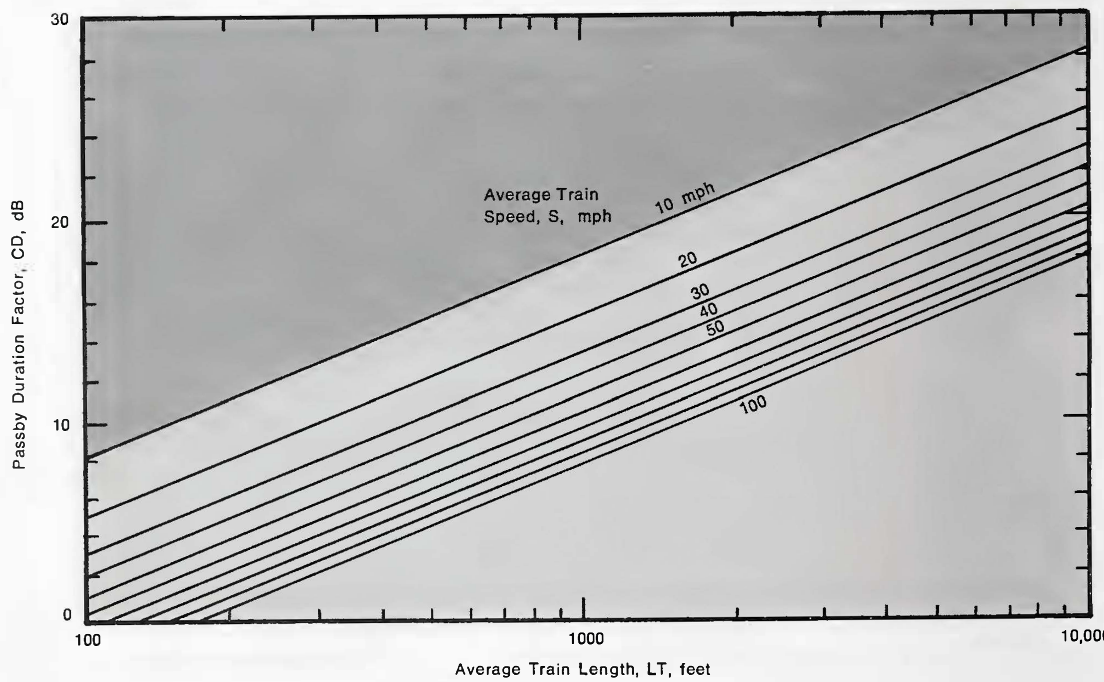


Figure 5.3–12. Duration Correction for Train Passbys.

STEP R8 RAILWAY CARS—TRACK CHARACTERISTICS

Compute the track adjustment factor, CT. This factor accounts for track characteristics other than the standard, straight, mainline, welded track [1, 4, 8]. This adjustment should be made only if the track variation occurs within a distance of 2D on either side of the point of intersection of the railway with the nearest perpendicular distance. See Figure 5.3–4 for an illustration of this distance requirement. From Table 5.3–1 select the appropriate value of CT corresponding to the physical characteristics of the track segment under investigation. In case of simultaneous occurrence of these variations the *single largest correction* should be used.

STEP R9 RAILWAY CARS—DISTANCE ATTENUATION

Compute the distance attenuation factor, DAC, for railway car noise. DAC is determined by locating on the horizontal axis of Figure 5.3–9 the distance D. Read up until intersecting the appropriate curve for railway cars. The value of DAC can be read off the vertical axis directly left of the intersection.

Table 5.3–1. Adjustment Factors for Track Characteristics [1, 4, 8].

TRACK CHARACTERISTICS		CT
1	Straight, Mainline, Welded Track	0
2	Straight, Jointed Track	4
3	Presence of Switches or Grade Crossing	4
4	Tight Radius Curve	
	Radius < 600 Ft.	4
	Radius 600 Ft. to 900 Ft.	1
	Radius > 900 Ft.	0
5	Presence of a Bridge	
	Concrete	0
	Steel Girder with Either Concrete or Open Tie Deck	5
	Steel Girder with Steel Plate Deck	14

STEP R10 RAILWAY CARS—UNSHIELDED NOISE LEVEL

Depending upon the type of noise criterion, or metric, for your proposed building, perform the calculations listed below.

Leq(1)

Compute the factor C1, which is a correction for the number of passbys during the one selected hour of critical building use. C1 is determined by locating on the horizontal axis of Figure 5.3–10 the value of N1 for this type of train. Read up until intersecting the curve. The value of C1 can be read off the vertical axis directly left of the intersection. Using this value and the values of CL, CD, CT, and DAC calculate Leq(1) from the following equation:

$$\mathrm{Leq}(1) = CL + CD + CT + C1 - DAC - 36.$$

Leq(8)

Compute the factor C8, which is a correction for the number of passbys during the eight hours of building use. C8 is determined of Figure 5.3–10 by locating on the horizontal axis the value of N8 for this type of train. Read up until intersecting the curve. The value of C8 can be read off the vertical axis directly left of the intersection. Using this value and the values of CL, CD, CT and DAC, calculate Leq(8) from the following equation:

$$\mathrm{Leq}(8) = CL + CD + CT + C8 - DAC - 45.$$

Leq(24)

Compute the factor C24, which is a correction for the number of passbys during a typical twenty-four hour day. C24 is determined by locating on the horizontal axis of Figure 5.3–10 the value of N24 for this type of train. Read up until intersecting the curve. The value of C24 can be read off the vertical axis directly left of the intersection. Using this factor and the values of CL, CD, CT, and DAC, calculate Leq(24) from the following equation:

$$\mathrm{Leq}(24) = CL + CD + CT + C24 - DAC - 49.$$

Ldn

Compute the factor CDN, which is a correction for the number of "daytime" and "nighttime" passbys. It is determined from the corrected number of passbys, CN, defined as

$$CN = ND + 6NN,$$

where ND is the number of "daytime", and NN is the number of "nighttime" passbys for this type of train. CDN is determined by locating on the horizontal axis of Figure 5.3–10 the value of CN.

Read up until intersecting the curve. The value of CDN can be read off the vertical axis directly left of the intersection. Using this value and the values of CL, CD, CT, and DAC, calculate Ldn from the following equation:

$$Ldn = CL + CD + CT + CDN - DAC - 49.$$

* * * * *

C. Shielding Adjustments

The previous steps assumed that there was no shielding between the railway and the building site. If there is any shielding due to a barrier, elevated railway, depressed railway, rows of buildings or a belt of vegetation, it must be taken into account. This is done in STEPS R11 through R15.

The corrections for shielding due to barriers, elevated railways and depressed railways are a function of the railway vehicle type, because of the different locations of the major noise sources. For freight cars, conventional passenger coaches, and rapid transit vehicles, the predominant noise source is the wheel-rail interaction located close to the ground; while for diesel-electric locomotives, the major source of noise is the exhaust outlet located approximately fifteen feet above the rails. Thus, there are two shielding corrections; one for railway cars, CSC, and one for diesel-electric locomotives, CSL. These corrections are determined by calculating the path length differences for railway cars and for diesel-electric locomotives using STEP R11 for the type of shielding present. For these calculations, this design guide assumes that the frequency spectrum for railway car (wheel-rail) noise is similar to highway traffic noise, and employs 500 Hz as the frequency. However, a frequency of 125 Hz is used for diesel-electric locomotive noise. To account for these frequencies being different, a factor of ¼ (125 ÷ 500) is used in calculating path length difference, L*l*. Using these values of L, CSC and CSL are determined for an "infinitely" long barrier in STEP R12. If the barrier is "finite" in length, the necessary adjustments are made in STEP R13.

The shielding corrections for rows of buildings which act as barriers and for vegetation are related to the physical layout of the railway and the location of your proposed building. The correction for shielding due to rows of buildings which act as barriers, CSB, is computed in STEP R13. The correction for shielding due to vegetation, CSV, is computed in STEP R14. Note that the attenuation due to rows of buildings which act as barriers, and to vegetation is added to the attenuation due to barriers and elevated or depressed railways. For example, if the A-weighted sound level attenuations of a barrier, two rows of buildings and a 100 feet of dense woods are 5, 6, and 5 dB, respectively, the total A-weighted sound level attenuation is 16 dB.

After these shielding corrections are determined, the individual noise contributions are calculated and combined to get the total railway noise in STEP R16.

If there are no barriers, the noise levels calculated in the previous steps are the values to be used to predict noise levels in your building and on its site. Omit STEPS R11 through R15 and proceed to STEP R16 to get the total noise due to railways.

STEP R11 PATH LENGTH DIFFERENCE

Compute the path length difference for railway cars, LC, and for diesel-electric locomotives, L*l*, for the type of barrier present. Be sure the obstruction blocks the line-of-sight between the source and receiver, being careful about diesel-electric locomotives which have the noise source located fifteen feet above the railway. If the line-of-sight is not blocked, there will be no attenuation.

1. Barrier:

$$Ac = \sqrt{HB^2 + (D - DB)^2}$$
$$Al = \sqrt{(HB - 15)^2 + (D - DB)^2}$$
$$Bc = Bl = \sqrt{(HB + hB)^2 + DB^2}$$
$$Cc = \sqrt{hB^2 + D^2}$$
$$Cl = \sqrt{(hB + 15)^2 + D^2}$$

2. Elevated Railway:

$$Ac = [D - DE]$$
$$Al = \sqrt{225 + (D - DE)^2}$$
$$Bc = Bl = \sqrt{HE^2 + DE^2}$$
$$Cc = \sqrt{HE^2 + D^2}$$
$$Cl = \sqrt{(HE + 15)^2 + D^2}$$

3. Depressed Railway:

$$Ac = \sqrt{HD^2 + (D - DD)^2}$$
$$Al = \sqrt{(HD - 15)^2 + (D - DD)^2}$$
$$Bc = Bl = \sqrt{hD^2 + DD^2}$$
$$Cc = \sqrt{(HD + hD)^2 + D^2}$$
$$Cl = \sqrt{(HD + hD - 15)^2 + D^2}$$

From these values the path length differences are calculated from the following equations:

$$Lc = Ac + Bc - Cc$$
$$Ll = .25\,[Al + Bl - Cl].$$

Record these values on Railway Worksheet 2 and proceed to the next step.

STEP R12 SHIELDING CORRECTION— "INFINITE" BARRIER

Compute the shielding corrections CSC and CSL. These values are determined from the path length differences calculated in the previous step [9]. If the path length difference is negative or less than 0.01 ft, there is no appreciable shielding and the correction is zero; if the path length difference is positive and greater than 0.01 ft, the shielding correction is determined by locating on the horizontal axis of Figure 5.3–13 the value of the path length difference. Read up until intersecting the curve. The value of the shielding correction can be read off the vertical axis directly left of the intersection. This procedure is followed using Lc to determine CSC, and L*l* to determine CSL. Record these values on Railway Worksheet 2. If the included angle, a, is less than 170, the barrier is of "finite" length, and you must proceed to STEP R13. But if the included angle, a, is greater than 170, no adjustment to the shielding corrections is needed. Omit STEP R13 and continue the design guide analysis.

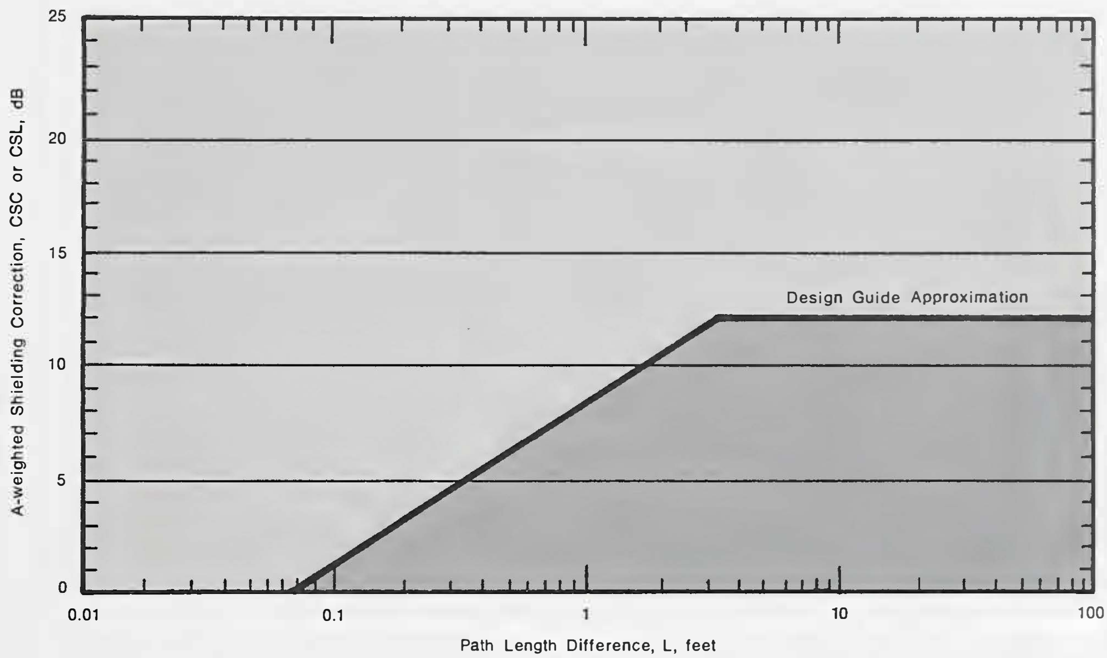


Figure 5.3–13. A-weighted Shielding Correction Versus Path Length Difference for Barriers.

Table 5.3–2. Shielding Corrections for a Finite Barrier.

Infinite Barrier Shielding Correction CSC or CSL	RA = a/180°										
	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
1	0	0	0	0	0	0	1	1	1	1	1
2	0	0	0	1	1	1	1	1	2	2	2
3	0	0	0	1	1	1	2	2	2	3	3
4	0	0	1	1	1	2	2	2	3	3	4
5	0	0	1	1	1	2	2	3	3	4	5
6	0	0	1	1	2	2	3	3	4	5	6
7	0	0	1	1	2	2	3	4	4	6	7
8	0	0	1	1	2	2	3	4	5	6	8
9	0	0	1	1	2	3	3	4	5	7	9
10	0	0	1	1	2	3	3	4	6	7	10
11	0	0	1	1	2	3	3	4	6	8	11
12	0	0	1	1	2	3	4	5	6	8	12

STEP R13 SHIELDING CORRECTION—"FINITE" BARRIER

Compute the adjusted values of CSC and CSL to account for shielding elements of finite length. These adjusted corrections are determined from the factor RA, which is calculated from the included angle, a (in degrees), by using the following equation:

$$RA = \frac{a^\circ}{180}\,.$$

Now go to Table 5.3–2 and enter the first column at the value of CSC and read across that row to the column corresponding to the value of RA. This is the adjusted value of CSC. Repeat this procedure using the value of CSL to get the finite shielding correction for diesel-electric locomotives. Record these adjusted shielding corrections on Railway Worksheet 2, and continue the design guide analysis.

STEP R14 SHIELDING CORRECTION—BUILDINGS ACTING AS BARRIERS

Calculate the correction, CSB, for rows of buildings which shield the railway from your building. This correction depends on the number of rows of intervening buildings, nr, and is determined from Table 5.3–3. Record this correction on Railway Worksheet 2, and continue the design guide analysis.

Table 5.3–3. Shielding Corrections for Buildings Acting as Barriers [8].

Number of Rows	Shielding Correction, CSB
1	4.5
2	6.0
3	7.5
4	9.0
5 or more	10.0

STEP R15 SHIELDING CORRECTION—VEGETATION

Calculate the correction, CSV, for a belt of vegetation of depth, dw, which shields the railway from your building. This correction is simply an A-weighted sound level attenuation of 5 dB for the first 100 feet of woods and 10 dB for woods over 200 feet in depth. Interpolation between these values is left to the discretion of the user of this design guide. Record this correction on Railway Worksheet 2 and continue the design guide analysis.

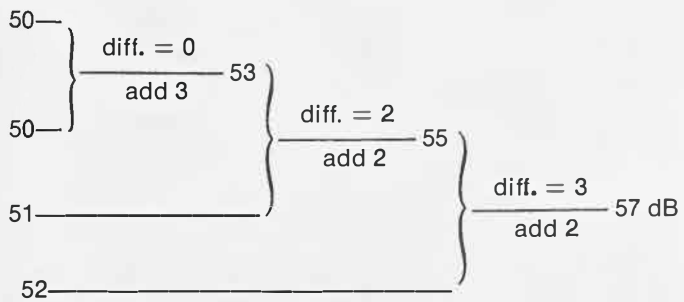
STEP R16 TOTAL RAILWAY NOISE

Compute the total noise at the building site due to the railway. First sum the shielding corrections on Railway Worksheet 2. Subtract these total shielding corrections from the unshielded noise levels to get the individual components of the total railroad noise at the building site. Since these levels are logarithmic, they cannot be simply added together or averaged to get the total noise level. Instead, they must be combined, two values at a time, with the use of Table 5.3–4. Start with the two smallest levels, and subtract one from the other to get the difference.

Table 5.3–4. Level Adjustment for Summing Noise Levels.

Difference of Two Noise Levels, dB	Level Adjustment (To be Added to the Larger of the Two Values)
10 or more	0
4–9	1
2–3	2
0–1	3

With this value go to Table 5.3–4 and determine the level adjustment which is to be added to the larger of the two original noise levels. Now repeat this procedure with this adjusted level and another of the railway noise components. Continue this computation until all components have been combined into one value. For example, if the A-weighted levels of the diesel-electric locomotives and railway cars for freight trains are 50 and 52 dB respectively, and the A-weighted sound levels of the diesel-electric locomotives and passenger coaches for conventional passenger trains are 51 and 50 dB respectively, the total noise is,



Record this total noise level on Railway Worksheet 1.

* * * * *

This completes the prediction of railway noise. These procedures should be repeated for each railway that is listed on the Preliminary Source Evaluation Worksheet with a *yes* answer in Column 2, and for each point on the site or building room that you analyze. The total noise at any point on the building site due to all railways is the summation of the noise contributions from each railway. This summation is accomplished by the same method as used in STEP R16. Refer to this step for the procedure of summing noise levels. Record the total noise level on Railway Worksheet 1.

Now proceed to Section 5.4 and predict the noise level due to aircraft. If aircraft do not affect your building site proceed directly to Chapter 6.

References Chapter 5 Section 3 Railway Passby Noise

[1] Swing, J. W., and Pies, D. B., Assessment of noise environments around railroad operations, Wyle Laboratories Report WCR73-5 (Wyle Laboratories, El Segundo, California, July 1973).

[2] Bender, E. K., Ely, R. A., Remington, P. J., and Rudd, M. J., Railroad environmental noise: A state of the art assessment, BBN Report No. 2709 (Bolt Beranek and Newman Inc., Cambridge, Massachusetts, January 1974).

[3] Anon., A study of the magnitude of transportation noise generation and potential abatement: Volume V — train system noise, U.S. Department of Transportation Report OST-ONA-71-1 (Serendipity, Inc., Arlington, Virginia, November 1970). Available from the National Technical Information Service, Springfield, Virginia, Accession No. PB-203-186.

[4] Manning, J. E., Cann, R. G., and Fredberg, J. J., Prediction and control of rail transit noise and vibration—a state-of-the-art assessment, CC Report No. 74-1 (Cambridge Collaborative, Inc., Cambridge, Massachusetts, March 1974).

[5] Peters, S., Predictions of rail-wheel noise from high speed trains, Acustica, *28* (6), 318-321 (June 1973).

[6] Anon., Transportation noise and noise from equipment powered by internal combustion engines, U.S. Environmental Protection Agency Report No. NTID 300.03 (Wyle Laboratories, El Segundo, California, December 1971). Available from the U.S. Environmental Protection Agency, Washington, D.C. 20460.

[7] Anon., Background document for railroad noise emission standards, EPA Report No. EPA-550/9-76-005 (U.S. Environmental Protection Agency, Washington, D.C., December 1975).

[8] Swing, J. W., Simplified procedure for developing railroad noise exposure contours, S/V Sound and Vibration, *9* (2), 22-23 (February 1975).

[9] Kugler, B. A., and Piersol, A. G., Highway noise: a field evaluation of traffic noise reduction measures, NCHRP Report 144 (Bolt Beranek and Newman Inc., Canoga Park, California, 1973). Available from the Highway Research Board, 2101 Constitution Ave., Washington, D.C. 20418.

[10] Fath, J. M., Blomquist, D. S., Heinen, J. M., and Tarica, M., Measurements of railroad noise—line operations, yard boundaries and retarders, EPA Report No. 550/9-74-007 (National Bureau of Standards, Washington, D.C., December 1974).