Anchorage Rail Capacity Improvements
Milepost 110 – 114
Noise and Vibration Study

HMMH Report No. 298680.01
January 2003

Prepared for:

HDR Alaska, Inc.
Anchorage, Alaska

And

Alaska Railroad Corporation
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KEY FINDINGS - NOISE

1. Train noise levels decrease as the distance from the track increases.
2. Highest noise levels occur near grade crossings where whistles are blown.
3. Noise levels near the right-of-way show seasonal variations. Spring and summer noise levels are higher than winter noise levels.
4. Noise levels from ARR rolling stock and horns are consistent with, and often quieter than, those used in Federal Transit Administration's (FTA's) noise prediction methodology.
5. Results confirm the applicability of the FTA noise model for use in the next phase of the study.

KEY FINDINGS - VIBRATION

1. Vibration propagation varies according to soil types during spring and summer, with peat and clay acting as efficient transmission media and sand as less efficient. During winter, with frozen ground, vibration transmission for all soil types is similar to summer propagation in sandy soils.
2. Vibration levels from trains show a seasonal effect. They are higher in summer and lower in winter with frozen ground.
3. Vibration levels from trains are well below those that cause damage to buildings.
4. Vibration levels increase with increasing train speeds and weight. The lighter passenger trains can operate at 35 mph and still generate lower vibration levels than an SD70 locomotive hauling a gravel train at 10 mph.
5. Vibration levels from ARR rolling stock are ranked as follows: SD70 locomotive (highest), loaded gravel cars, GP40 locomotive and passenger train coaches (lowest).
6. Ground-borne vibrations from the SD70 locomotive are perceptible in houses at distances of 150 feet in sandy soil and 300 feet or more in clay and peat. Beyond these distances, the ground-borne path is not likely to be the source of vibrations perceived in a home.
7. Air-borne noise from diesel locomotives may be the source of vibrations in walls that cause rattling of wall-mounted objects. Air-borne noise at low frequencies travels greater distances than ground-borne vibrations and as a result may be the actual source of neighborhood vibration concerns.

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1 INTRODUCTION

The Alaska Railroad (ARR) is investigating alternatives to increase capacity along the mainline track from the Anchorage International Airport Spur to the Anchorage Rail Yard (approximately Railroad Milepost 110 to 114). This four-mile corridor is critical to improving current passenger and freight operations, and in meeting projected future operations. The single track in this area has experienced increasing congestion from existing train traffic (gravel and coal in the summer, mixed freight trains year-round, passengers primarily in the summer, and work trains). Although freight traffic is not projected to increase substantially, passenger traffic has grown dramatically in the past few years and is projected to continue this trend. The alternatives currently under consideration for the Anchorage Rail Capacity Improvements project include additional sidings (passing lanes), installing automated signals and switches, and/or extending the double track currently under construction in south Anchorage.

In 2002, ARR initiated preliminary engineering, various environmental studies required for National Environmental Policy Act (NEPA) documentation, and public involvement activities. Because ARRC is aware of noise and vibration concerns expressed by some residents along the project corridor, a noise and vibration study was initiated in February 2002. The first phase focused on measuring ambient noise levels and train-induced noise and vibration at selected locations during the winter, spring and summer. The objectives of Phase 1 are to determine existing conditions, seasonal variations, impacts at various speeds, and the differences between freight trains and lighter passenger trains.

Harris Miller Miller & Hanson Inc. (HMMH) conducted the noise and vibration monitoring for the project and prepared this report. Since its founding in 1981, HMMH has become the premier noise and vibration control company in the transportation field, providing a full range of acoustical environmental services. HMMH provides noise control consulting in all areas of noise and vibration measurement, analysis, software and hardware design, noise modeling, vibration modeling, sound insulation design, installation, and measurement.

HMMH developed the guidance manual, “Transit Noise and Vibration Impact Assessment,” for the Federal Transit Administration (FTA) in 1995.[1] This guidance document establishes an approach for measuring noise and vibration impacts associated with rail transit projects. It bases analysis of noise impacts on measurement of existing community noise levels, as well as project-generated noise. Vibration projections are based on measurements of ground-borne propagation of vibrations from existing trains. The noise and vibration study (Study) for the Anchorage Rail Capacity Improvements project is being conducted in accordance with that guidance manual.

This report provides the results of noise and vibration measurements taken in March, May, and June 2002 at various locations along the project corridor. This information will be used in Phase 2 to predict future noise and vibration levels associated with the various alternatives under consideration for capacity improvements.

[1] U.S. Department of Transportation, Federal Transit Administration. “Transit Noise and Vibration Impact Assessment,” Report No. DOT-T-95-16, April 1995.

2 MEASUREMENT OF RAILROAD NOISE AND VIBRATION

2.1 Noise

Noise from trains can be discussed in terms of a Source-Path-Receiver environment as sketched in Figure 1. The **source** is the train which generates noise levels along the track, depending on the type of equipment and its operating characteristics. The noise is transmitted along a **path** between the source and the receivers. Along this path the noise is reduced by distance, by intervening obstacles and other factors. Finally the noise reaches a **receiver**, to be heard and sometimes to interfere with receiver activities. The receivers can be people going about their daily activities, talking, sleeping, watching television and listening to the radio, or buildings with interior spaces where quiet is important for various reasons. The Study measured the key aspects of the noise environment to determine existing conditions along the right-of-way.

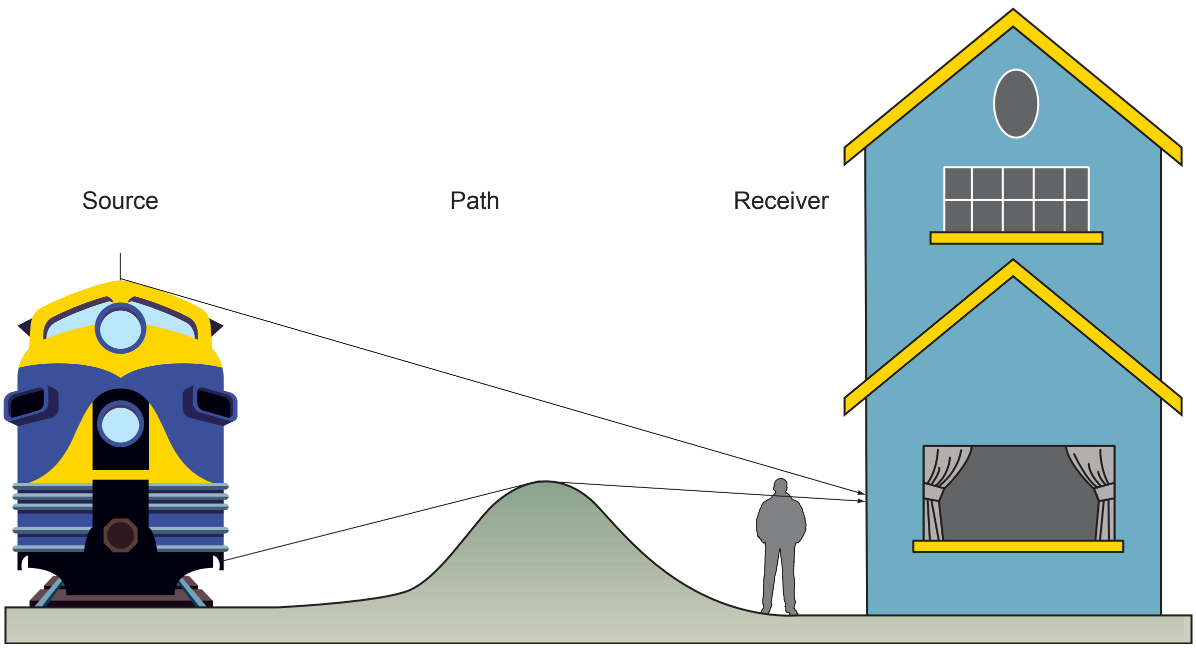


Figure 1. Noise Source-Path-Receiver

2.1.1 Noise descriptors

Environmental noise is made up of the sounds from a wide variety of sources, some close and some far off and many of them occurring at the same time. The distant sources may include traffic, aircraft, industrial activities, animal sounds or wind in the trees. These distant sources create a background noise in which no particular source is identifiable, but is fairly constant from moment to moment and varies slowly from hour to hour. Superimposed on this slowly-varying background noise is a succession of identifiable noisy events of relatively brief duration. Examples include the passby of a train, the overflight of an airplane, or the screeching of brakes. These events may be loud enough to dominate the noise environment at a location for a short time, and when added to everything else, can be responsible for annoyance.

The highest noise level reached during one of these single events is called the “maximum level” (Lmax). As illustrated in Figure 2, the sound from an approaching train rises from the background level and falls again when the train passes. At some point during the passby, there will be a maximum noise level achieved, only for a moment. Lmax is used to provide information on how loud is the noise from a single event, such as a train passby. The Lmax in Figure 2 is caused by the locomotive of a gravel train near Nulbay Park. Other typical Lmax's are shown in Figure 3.

Despite the usefulness of the Lmax in describing a single event, there are better measures for assessing the noise environment containing many such events. Special noise descriptors have been adopted by the FTA and other Federal agencies for characterizing a fluctuating noise environment. The ones used in this Study are:

- *A-weighted Sound Level (dBA),* which describes the receiver's noise at any moment in time. Sound level meters are used to display how noise changes from moment to moment.
- *Sound Exposure Level (SEL),* which describes a receiver's cumulative noise exposure from a single noise event. Scientists have found that people relate to noise from single events like train passbys according to a combination of sound level and duration, not just the maximum level. Therefore, the SEL was invented to provide a new descriptor that combines the sound level and duration of a single event. SEL is a computed number, and its magnitude is not shown on all sound meters, but it represents how much sound energy radiates to a receiver during one event.
- *Equivalent Sound Level (Leq),* which describes a receiver's cumulative noise exposure from all noise events that occur in a specified period of time. For example, whereas the SEL describes the sound exposure during one event, the hourly Leq is a measure of the sound exposure over a full hour. Again, the number is a computed number, not anything one would read from moment to moment on a meter, but the magnitude represents how much noise energy is received in that hour. Measurements of the full 24-hour set of hourly Leq's characterizes the time-dependent noise environment at a location. For example, see Figure 4.
- *Day-Night Sound Level (Ldn),* which describes a receiver's cumulative noise exposure from all noise events that occur in a 24-hour period, with events between 10 pm and 7 am increased by 10 decibels to account for greater nighttime sensitivity to noise. The Ldn is used to describe the general noise environment in a location – the so-called "noise climate." Again, the unit is a computed number, not one to be read moment to moment on a meter. Its magnitude is related to the general noisiness of an area. The U.S. Environmental Protection Agency (EPA) developed the Ldn descriptor and now most Federal agencies, including the FTA and Federal Railroad Administration (FRA), use it to evaluate noise impacts.

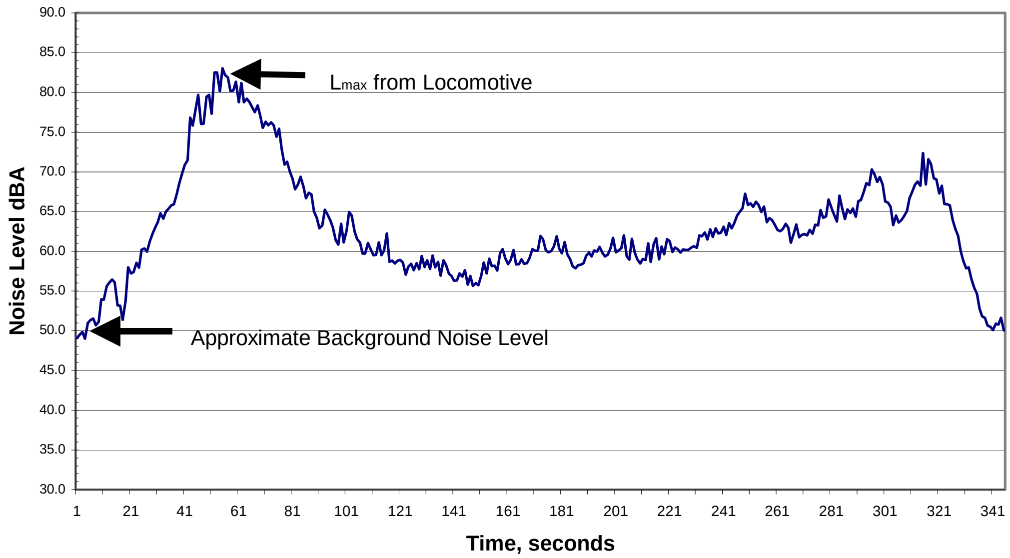


Figure 2. Typical Time History of Noise at 100 feet from a Gravel Train at Nulbay Park

Noise Level dBA	Extremes	Home Appliances 3ft	Speech at 3 ft	Motor Vehicles at 50 ft	Trains at 100 ft
120	Jet aircraft at 500 ft.				
110					
100		Chain saw			Horns
90		Power Lawn mower		Diesel Truck (not muffled)	
80		Shop tools	Shout	Diesel Truck (muffled)	Locomotives
70		Blender	Loud voice	Automobile at 70 mph	Passenger Train
60		Dishwasher	Normal voice	Automobile at 40 mph	Freight Cars
50		Air conditioner	Normal voice (back to listener)	Automobile at 20 mph	
40		Refrigerator			
30					
20					
10					
0	Threshold of hearing				

Figure 3. Typical Lmax Values

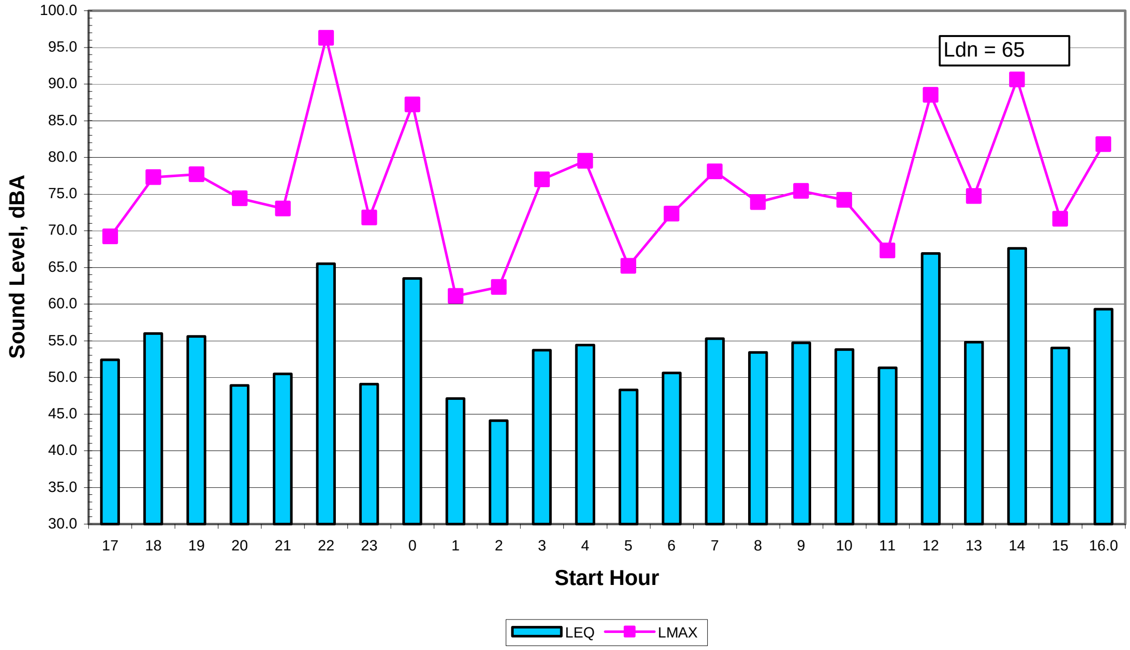


Figure 4. Example of a 24-hour Noise Measurement (Site N1, June 18 – 19, 2002)

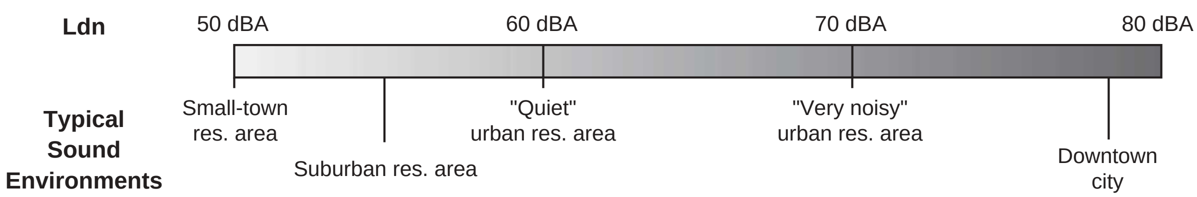


Figure 5. Typical Ldn's for Residential Areas

2.1.2 Measurement of noise

Noise is measured with an instrument called a sound level meter. This instrument consists of a microphone connected to signal processing circuits and a small computer to display and store the sound level over a selected period of time. Noise levels can be measured with small instruments such as a hand-held sound level meter for short-term noise measurements of Lmax or Leq, or with larger automated programmable noise monitoring systems for longer term Leq's and Ldn's. A portable noise monitoring system like those used in the Study is shown in Figure 6. The HMMH self-contained kit shown in the picture includes a battery operated programmable sound level meter and data acquisition system connected to an external microphone. A typical field set-up is shown in Figure 7 where the monitor is shown separated by distance from the microphone stand.

Figure 6. Portable noise monitor

Figure 7. Portable Noise Monitor in Field Application

2.2 Vibration

Ground-borne vibration can cause buildings to shake and rumbling sounds to be heard inside homes. As in the noise example above, the key elements of the vibration environment can be described with the Source-Path-Receiver concept shown in Figure 8. The **source** of vibration is the train wheels rolling on the rails that create vibration energy transmitted through the tracks into the ground. The amount of vibration energy created depends on many factors, including the weight and speed of the train, the smoothness of the wheels and the rails, and the presence of joints and gaps at switch points and crossovers.

The **path** taken by vibrations is through the ground and into nearby buildings. Propagation characteristics of the ground depend on the soil type and the presence of underlying rock layers. The **receivers** are people or vibration-sensitive activities in the buildings into which the vibrations pass. Vibration of the floors and walls of the building may cause perceptible vibrations or rattling of windows or dishes, or even a rumbling noise heard by people inside. The rumbling noise is termed “ground-borne noise”, as opposed to the air-borne noise from the train heard outside the house, or inside with the windows open. This Study measured all three key elements of train vibrations.

People often confuse low-frequency sounds with vibrations, especially sounds from diesel locomotives. Low-frequency sound can cause windows to rattle and walls to shake in a manner similar to the effects of ground-borne vibrations. This phenomenon is termed “noise-induced vibrations.”

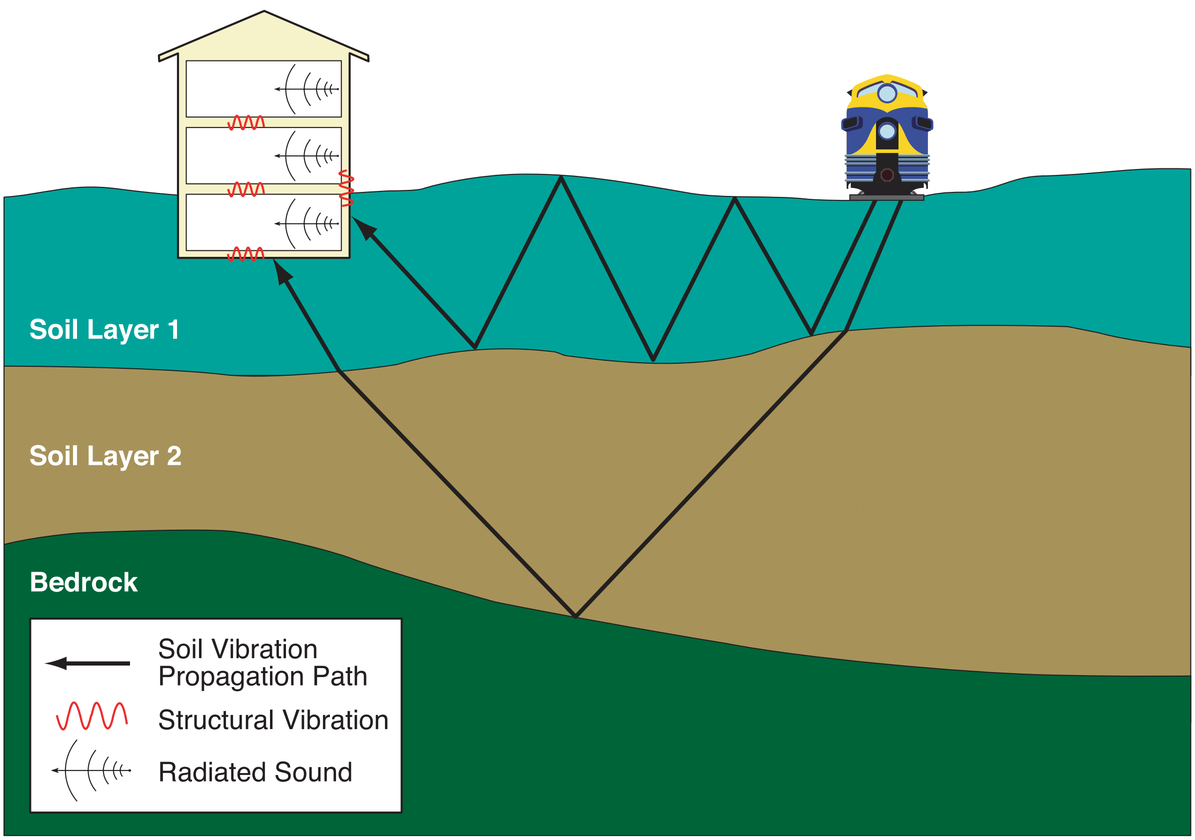
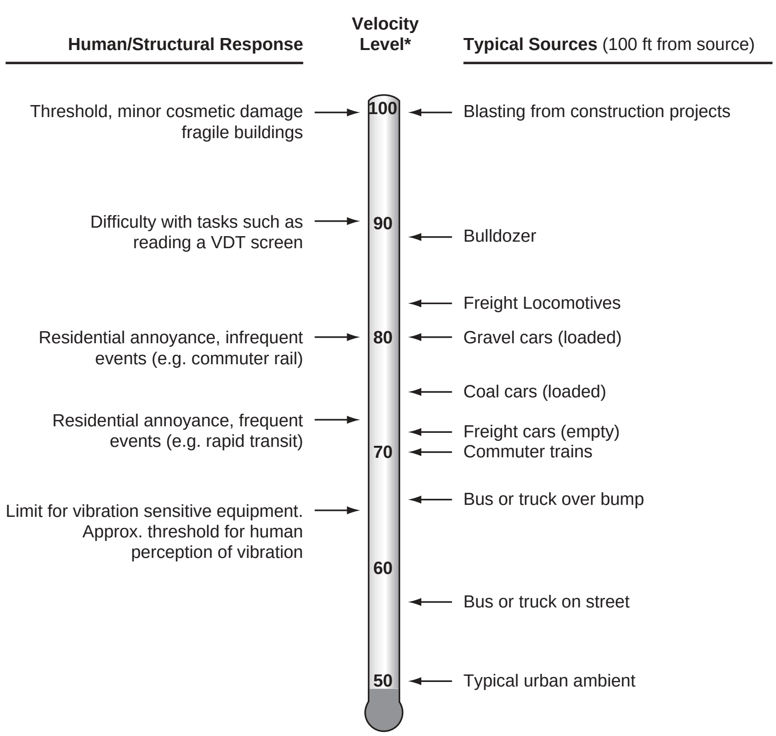


Figure 8. Ground-borne Vibrations from Trains

2.2.1 Vibration descriptors

Vibration is an oscillatory shaking motion of the ground, a building surface, or a mechanical component. In contrast to noise, vibration is not generally perceptible in the environment more than a few hundred feet from a train track or a street or highway. Moreover it is almost never annoying to people who are outdoors. Consequently, the concept of background or cumulative effect is not generally applicable to describing the effects of vibration. Rather, the effects are expressed in terms of the maximum vibration levels generated during a single event, such as the passby of a single train. Sometimes the analysis of an event is broken into separate components, such as locomotives separately from the cars.

Vibration is described in terms of the maximum root mean square (RMS) velocity level that occurs during the event, Lv, and with units of vibration decibels, VdB. The "V" is used to differentiate "vibration decibels" from "noise decibels." A scale of typical vibration velocity levels is shown in Figure 9. The threshold of perception, below which people usually cannot feel vibrations, is 65 VdB. Vibrations start to become annoying inside homes at 80 VdB as long as the events are infrequent (less than 70 events per day). ARR current operations of 12 to 20 trains/day would be considered "infrequent" according to FTA's guidelines. The threshold for minor cosmetic damage is about 100 VdB.



* Root Mean Square Vibration Velocity Level in VdB relative to 10^{-6} inches/second

Figure 9. Typical Vibration Levels

2.2.2 Measurement of ground-borne vibration from trains

Vibration is measured with motion-sensitive sensors mounted on the ground or on a building floor or wall. Instruments called *accelerometers* were used in this Study. These sensors were attached firmly to the ground for outdoor measurements (see Figure 10) or to the floor or wall for indoor measurements (see Figure 11). Vibrations picked up by the sensors are amplified and transmitted through cables to a digital tape recorder for later analysis.

For measurement of vibration propagation through the ground, a series of accelerometers are placed in a line perpendicular to the tracks, out to distances of more than a hundred feet. The reduction of vibration levels with distance is a measure of propagation characteristics of the ground at that location. Because the ground effects vary depending on the soils at various locations, a measurement of propagation characteristics is usually performed for each different ground type in the study area.

Where vibrations are measured inside buildings, the usual approach is to mount sensors on the ground outside the building and on a floor and wall inside the first floor room closest to the source of vibrations. In this way, the vibration propagation can be monitored through the entire path, leading to where the vibrations are usually felt inside the building.

Figure 10. Accelerometer mounted on ground

Figure 11. Accelerometer mounted on floor

3 MEASUREMENT PROGRAM

This Study was performed to provide baseline noise and vibration data for the environmental analysis of planned capacity improvements by the ARR. The program involved noise and vibration measurements during winter season conditions with frozen and snow-covered ground, spring season with partially thawed ground conditions, and finally summer conditions, all done to quantify if there are seasonal effects of environmental conditions. In addition, the train operations changed seasonally so different kinds of trains were measured during each period.

This section describes the site selection criteria, a description of each site, and the measurement method.

3.1 Measurement sites

The measurement sites were selected to provide baseline noise and vibration conditions in a study area extending from approximately the location of the Anchorage Depot to International Airport Road. This baseline will be used in the environmental analysis related to the ARR Capacity Improvements Project. Three types of measurements were conducted as part of this study:

- long term noise measurements for 24 hours or more to obtain all the noise events that occur in the environment at selected locations;
- reference noise source levels from specific trains for use in the noise prediction models; and,
- ground-borne vibration levels from specific trains and propagation characteristics of the soil types found in the study area.

The distribution of sites is shown on Figure 12. Site designation prefixes provide guidance to the type of measurements performed: N= noise site; V= vibration site (two of the four vibration sites had reference noise measurements also); and H= house noise and vibration site. Table 1 summarizes pertinent information about monitoring sites used in the Study.

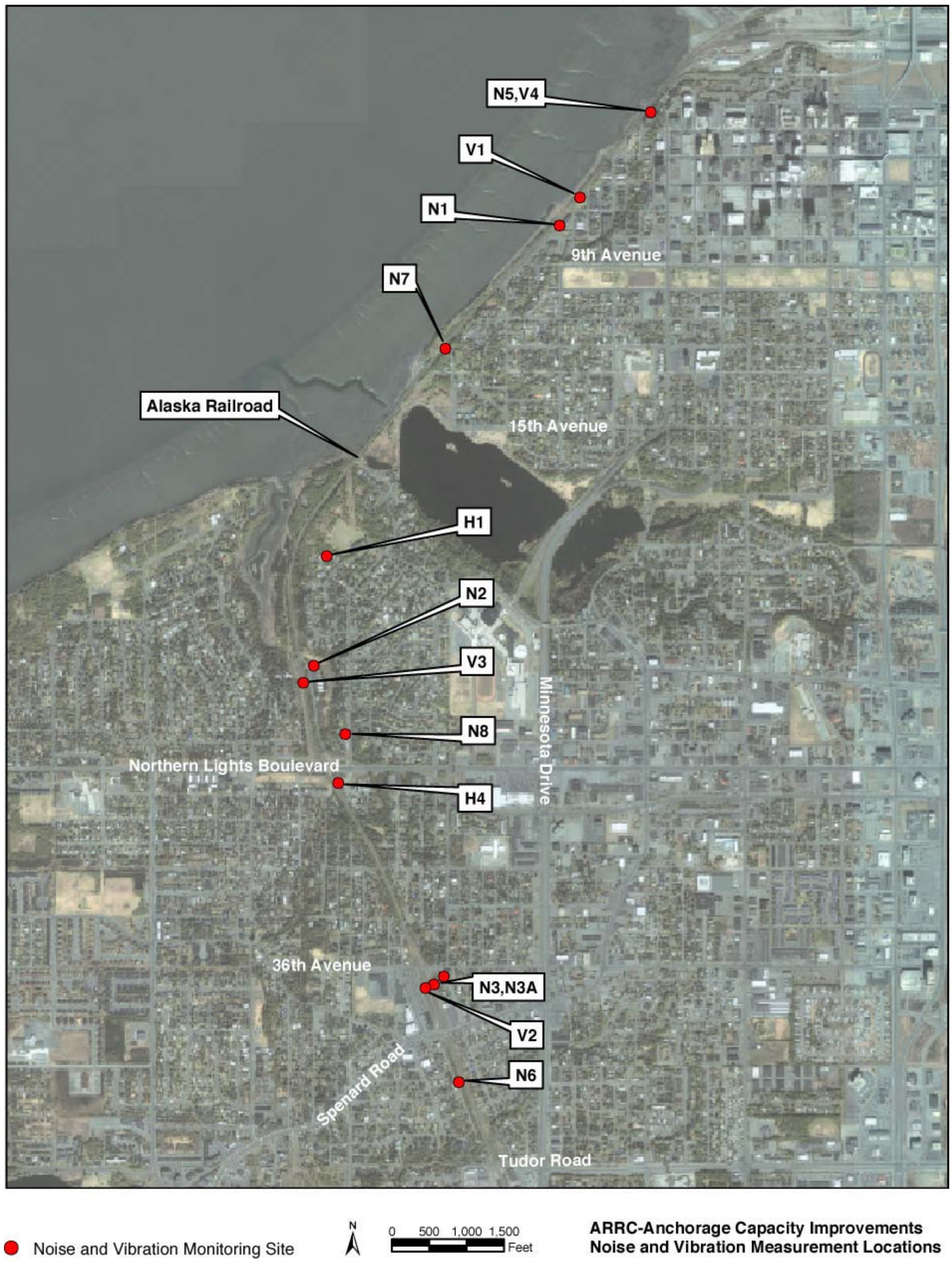


Figure 12. Measurement Site Locations

Table 1. Measurement Site Descriptions

Site No.	Location	Dist. (ft)	Type of Monitoring	Dominant Noise/Vibration Sources	Purpose for Selection of Site
N1	ROW[1],condominiums at 8th Av. and Stolt Lane.	66	Long-term noise	Trains, local traffic, aircraft	Residential area in northern section of study area.
N2	Fish Creek embankment at setback of homes on LaHonda Dr.	200	Long-term noise	Trains, aircraft	Residential area in middle section of study area.
N3	ROW fence between 36th Av. and Spenard Rd.	100	Long-term noise	Trains, train horns at road crossing, traffic	Residential area near grade crossing.
N3A	Lois Avenue near 36th Av.	300	Long-term noise	Trains, crossing horns and bells, traffic	Residential area behind one row of buildings from N3.
N4	ROW fence near LaHonda Mobile Home Park	40	Long-term noise	Trains, traffic on Northern Lights Blvd.	Residential area in middle section of study area.
N5	Residence near Elderberry Park	60	Long-term noise	Trains, distant aircraft	Nearest residence in north section of study area.
N6	Wooded buffer area along Harding Dr. at Lincoln Av.	70	Long-term noise	Trains, train horns, local traffic	Residential area in south section of study area.
N7	ROW fence at gate for AWWU access road.	60	Long-term noise	Trains, horns, local traffic.	Residential area in north section of study area.
N8	Back yard 2544 Forest Park Dr.	500	Long-term noise	Trains, local traffic	Residential area one street away from tracks.
V1	Nulbay Park	40,100,135	Vibration, reference noise levels	Specific trains	Vibration propagation in clay soil in north end of study area. Site qualifies for ref. noise measurements.
V2	Between 36th Avenue and Spenard Rd.	25,50, 100	Vibration, reference noise levels	Specific trains, train horns	Vibration propagation in “old bog” peaty soil in south end of study area. Site qualifies for ref. noise measurements.
V3	LaHonda Dr.	25,75, 100	Vibration only	Specific trains	Vibration propagation in sandy soil in middle section of study area. Site is not suitable for ref. noise measurements.
V4	Residence near Elderberry Park	40, 60, 70	Vibration only	Specific trains	Nearest residence in north section of study area.
H1	Residence at 2409 Marilane Dr.	430	Vibration, noise	Specific trains	Test house for outside/inside measurements.
H2	Residence on 31st Av. at Willow.	100, 125	Vibration, noise	Specific trains	Test house for outside/inside measurements.

[1] Right-of-way

3.1.1 Long term noise sites

Eight long term noise measurement sites were selected to characterize the existing ambient noise levels adjacent to the right-of-way based on the distribution of noise sources in the study area. Train passby noise was common to all the sites, but variations included sites with a range of traffic noise contribution as well as horn blowing. Table 1 describes the locations of the long term noise measurement sites.

3.1.2 Reference noise sites

Two sites were selected for measurement of train reference noise levels to be used in prediction calculations and analysis of future conditions. Reference noise source levels are expressed in terms of sound exposure levels (SEL's) for locomotives and cars separately.

A reference noise site should be open and free from large reflective surfaces, a clear exposure to the rails, and with ground cover limited to low-growing vegetation. The microphone is placed 100 ft from track centerline in accordance with the FRA railroad noise emission compliance regulations.[2] Two sites in the study area that qualify are Nulbay Park (V1) and the cleared ROW south of 36th Avenue crossing (V2). The Nulbay Park site provides noise characteristics of locomotive passbys, freight cars and passenger coaches. The 36th Avenue site is at a grade crossing, thereby providing reference levels on horn blowing in addition to the other sources. These sites coincide with two of the four ground-borne vibration sites described in the next section.

3.1.3 Ground-borne vibration sites

The vibration measurements were focused on determining the propagation of ground-borne vibrations for the various soil types found in the study area during three different seasons: winter with frozen ground, spring with partially frozen ground, and summer with unfrozen ground. Geological information suggests that the study area encompasses three different soil types.[3] At the north end extending from the depot area (MP 114.1) to Fish Creek outlet (MP 112.2), the ground is clay to the depth of about 150 ft. In the middle, from approximately Fish Creek (MP 112.2) to 36th Avenue (MP 111.3) the ground is mostly sand. At the south end, from approximately 36th Avenue (MP 111.3) to 44th Avenue (MP 110.7) the ground is "old bog" with peat to a depth of 35 ft.

Sites were found to be suitable for ground-borne vibration propagation measurements representative of each of the three soil types in the study area. In addition, three residential sites were selected for vibration measurements due to owners' descriptions of vibrations from trains perceived inside the house. All sites are marked on the map in Figure 12.

3.2 Measurement method

Three kinds of measurements were made during the Study, each requiring specialized equipment. This section describes the measurement procedures. All noise measurements were made using instrumentation systems that conform to American National Standards Institute (ANSI) Standard S1.4 for precision (Type 1) sound level meters. The measurement microphones were protected by foam windscreens, and supported by tripods at a height of 5 feet above the tripod base. Calibrations,

[2] U.S. Federal Railroad Administration, *49CFR 210: Railroad Noise Emission Compliance Regulations.*

[3] Telephone conference with Shannon & Wilson geologist Fred Brown and HDR's Anne Leggett, 6 March 2002.

traceable to the U.S. National Institute of Standards and Technology (NIST), were carried out in the field before and after each set of measurements using acoustic calibrators.

For the reference noise and the ground-borne vibration measurements, train passbys were observed to obtain information on locomotive types, number and type of cars, and speed. Specific locomotive operating conditions, including speed and throttle settings, were made available by ARR for some of the locomotives with recording instrumentation. Train speeds were monitored using calibrated radar guns and timers.

3.2.1 Long-Term noise measurements

The long-term measurements were made using Larson Davis Model 870 portable noise monitors. The monitors are programmed to record hourly interval data, including the maximum sound level (Lmax), the equivalent (energy-average) sound level (Leq) and the statistical percentile sound levels (Ln, representing the sound level exceeded n-percent of each hour). The day-night equivalent sound level (Ldn) is computed from the hourly Leq values for a continuous 24-hour period.

3.2.2 Reference noise measurements

The reference noise measurements were obtained using a B&K Model 4189 one-half inch electret condenser microphone with a Larson-Davis PRM900C preamplifier. The acoustic signals are amplified and recorded on magnetic tape on one channel of an 8-channel TEAC RD135T Digital Audio Tape (DAT) recorder.

The noise recordings are analyzed in the HMMH laboratory using a Larson-Davis Model 2900 Digital Analyzer. Data are stored on spreadsheets on computer files.

3.2.3 Ground-borne vibration

Ground-borne vibration is measured with accelerometers firmly attached to the ground. During the spring and summer measurements, this involves attaching an accelerometer to a steel stake driven into the ground. In wintertime conditions with frozen ground and temperatures below freezing, the most practical method was to set the accelerometer onto a film of water that subsequently froze to provide a strong bond with the ground.

The accelerometers used are PCB Type 393C. Vibration signal conditioning is provided by a PCB power supply at the location of the accelerometer and an EPAC line amplifier at the tape recorder. Signals are recorded on the 8-channel TEAC RD135T DAT recorder.

The vibration recordings are analyzed in the HMMH laboratory using a Larson-Davis Model 2900 Digital Analyzer. Data are stored on spreadsheets on computer files.

3.3 Train operations during measurements

3.3.1 Number of trains measured

The measurement program occurred over three one-week periods in March, May and June 2002. During this time the train operations varied considerably, allowing the characterization of all the train types operated by Alaska Railroad during a typical year. The resulting information serves both as a baseline for comparison with future conditions and as reference data for prediction methods in the future. Reference noise and vibration levels were measured on a total of 86 trains. The break down of train types in each period is shown in Table 2:

Table 2. Number of Trains Measured for Reference Level Determination

Train type	Measured number in period		
	March 2002	May 2002	June 2002
Coal, loaded	6	2	No operations
Gravel, loaded	No operations	16	19
Gravel, empty	No operations	10	0
Freight, mixed	8	5	4
Passenger	No operations	14 (test train)	10
Other (work, RDC)	2	2	4

Table 2 shows 14 passbys of a "test train" during the May measurement period. This refers to a special set of tests in which ARR operated a dedicated passenger test train for a series of controlled speed runs between mileposts 111.5 and 114. The train consist included one GP40 locomotive and six empty passenger cars. Noise and vibration measurements were made in order to compare with those of gravel and coal trains as well as to obtain source reference levels for future analysis.

Besides the specific trains measured for the purpose of obtaining source reference levels, noise from every train passing the long-term sites was recorded by the noise monitors. Consequently, the contribution of noise from all trains passing the sites was taken into account for documenting the ambient noise conditions. Approximately 200 trains contributed to the measurement of ambient noise conditions during the three periods.

3.3.2 Speeds of trains measured

Speeds were documented only for the trains measured for reference noise and vibration levels. The speeds were obtained using a combination of radar gun and stopwatch timing methods at the side of the tracks. Speed readings were checked against ARR locomotive strip chart recordings where available. A histogram showing the distribution of measured train speeds is shown in Figure 13.

The special passenger train tests in May were run at speeds ranging from 15 mph to 35 mph. These were the exception, however. Freight trains were much slower, typically ranging from 9 mph to 15 mph, with an average of 11.5 mph. The passenger trains, other than the test trains, ranged in speed from 10 mph to 21 mph, with an average of 15.4 mph.

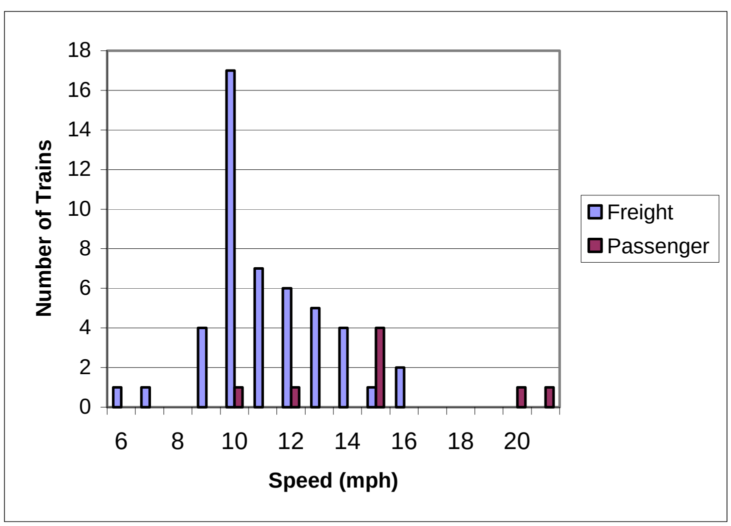


Figure 13. Measured Train Speed Histogram

4 MEASUREMENT RESULTS

4.1 Noise

The results of the noise measurements will be used in the environmental analysis of the planned capacity improvements. The Ldn's will be used as a baseline against which to compare any changes in the noise climate in neighborhoods along the right-of-way. The Lmax's will be used in the Phase 2 Study to estimate sound propagation effects, as well as to provide additional information on the magnitude of individual sources. Finally, the reference SEL's will be used in the Phase 2 Study to calculate future noise conditions from proposed changes in operations. This section summarizes the noise measurement results.

4.1.1 Environmental noise

4.1.1.1 Seasonal Variation

Baseline environmental noise levels are expressed in terms of Ldn. The results of the measurements during the three different periods are shown in Table 3. The same sites were measured each time in order to provide an estimate of the seasonal variation. In general, the Ldn's were the lowest in the winter, a result of fewer trains and less outdoor activity. Spring and summer Ldn's were nearly the same throughout the area. It is not uncommon to observe variations of 5 dB or more in the Ldn from day to day during field measurements. For example, Site N3 had fewer train passbys in May than in June (10 vs. 12), but had two unusually noisy hours from unknown sources that dominated the 24-hour noise exposure, one during the daytime and one at night. Consequently, the Ldn was 5 dB higher. The highest Ldn's are recorded near grade crossings where whistles are blown (N3, N6 and N7).

Table 3. Summary of existing ambient noise measurement results

Site No.	Measurement Location Description	Noise Exposure Ldn (dBA)		
		March	May	June
N1	8th Avenue and Stolt Lane	59	66	65
N2	Fish Creek	56	58	59
N3	36th Avenue Grade Crossing	66	76	71
N3A	Lois Ave. near 36th Avenue	N/A	N/A	61
N4	La Honda Mobile Home Park	61	68	67
N5	Residence near Elderberry Park	59	67	67
N6	Harding Drive	61	71	69
N7	Waterworks Gate (U and 12th)	66	63	71
N8	Forest Park Drive	N/A	N/A	57

4.1.1.2 Maximum Noise Levels

Maximum noise levels were recorded at each long-term site as part of the hourly interval data. In general, the Lmax's could be related to the times of train passbys because the monitoring sites were on or near the right-of-way. Attributing Lmax to trains required some approximation based on train schedules and correlations between maximums measured during the same hours at different sites. Table 4 gives the Lmax's attributed to train operations at each long-term site.

Table 4. Maximum noise levels attributed to trains at long-term sites

Site No.	Measurement Location Description and Distance	Maximum Noise Level Lmax (dBA)		
		March	May	June
N1	8th Avenue and Stolt Lane, 66’	93	100	96
N2	Fish Creek, 200’	77	88	85
N3	36th Avenue Crossing, 100’	102 (horn)	107 (horn)	105 horn)
N3A	Lois Ave. nr. 36th Avenue, 250’	N/A	N/A	89 (horn)
N4	La Honda Mobile Home Pk, 40’	88	92	92
N5	Residence,. Elderberry Pk 60’	84	104	97
N6	Harding Drive, 70’	87	107 (horn)	107 (horn)
N7	Waterworks Gate, 60’	107 (horn)	100 (horn)	107 (horn)
N8	Forest Park Drive, 500’	N/A	N/A	84

4.1.1.3 Effect of distance from track

Noise levels from trains decrease as distance from the track increases. To provide information about the propagation of sound into the neighborhoods, two new long-term sites, N3A and N8, were added in the June measurement period. Site N3A was selected to complement Site N3 so as to obtain a simultaneous measurement of the reduction of horn noise at greater distances from the track and behind a row of houses. Sound propagation models used in the FTA calculation method would show a reduction of 10 dB for this case, and that is what was measured. The other site, N8, was selected to complement site N2 at a further distance from the track on the opposite side of Fish Creek. The sound propagation path from the tracks to Site N8 was complicated with some screening by trees and a row of houses off to the side and its elevation with respect to N2. Despite the measurements not being simultaneous – they were taken on two different days – there was general agreement with the prediction method. The prediction model would estimate a 3 dB reduction whereas the measurements indicate a 2 dB reduction between the two sites. These results provide validation of the FTA model which will be used in Phase 2 to predict train noise in the neighborhoods during the analysis of the capacity improvements.

4.1.2 Reference levels for noise models

Reference SEL’s of ARR locomotives and cars were measured for use in the FTA prediction method during Phase 2. The FTA method provides standard reference noise levels at a distance of 50 ft and a speed of 50 mph for use in prediction models for projects in which measurements are not made. None of the trains measured in this Study were going as fast as 50 mph, nor were they measured at a distance of 50 ft. However, FTA provides adjustment factors for other than the reference conditions. Comparison of the standard FTA reference levels with those measured on ARR rolling stock is shown in Table 5. There is general agreement between the measured reference levels and those provided by FTA. The measured ARR SEL’s will be used in the Phase 2 noise analysis.

Table 5. Reference Noise Levels, SEL (dBA) at 50 ft, 50 mph

ARR Equipment	ARR adjusted SEL’s	FTA reference SEL’s
Locomotive (SD70)	90	92
Locomotive (GP40)	85	92
Gravel cars (loaded)	83	82
Coal cars (loaded)	80	82
Pass. Train (GP40 + 6 coaches)	93	94
Rail Diesel Car	91	85
Horn (SD70)	103	108

4.2 Vibration

4.2.1 Environment

The general assessment method in FTA's guidance manual provides for two different ground-borne vibration propagation characteristics for soil, "efficient" and "normal." The three types of ground in the study area can be placed in the two categories. Clay and peat as found in Sites V1 and V2 are generally considered "efficient" propagation media, whereas sand as in Site V3 has more damping and would be considered "normal." Although the FTA method makes no provision for seasonal differences, this Study showed that propagation characteristics varied substantially from winter to summer. In winter, ground-borne vibration propagation was similar for all three soil types, roughly corresponding to the summer results for sandy soil.

The ground-borne vibrations from the SD-70 locomotive are typically the highest of all ARR's rolling stock. Using the vibrations from the SD-70 as an example, the measurements demonstrated the differences among the three soil types for the spring measurements as shown in Figure 14. Vibration at Sites V1 (clay) and V2 (peat) propagate further at a higher level than those from Site V3 (sand). However, there is a definite seasonal effect. Taking the SD-70 locomotive again as an example, vibrations measured in the summer had the highest levels, with spring levels slightly lower, and with the winter levels the lowest. This is illustrated in Figure 15 for Site V1. Moreover, during the winter measurements when the ground was frozen, there was no significant difference in vibration propagation among the three different soil types. This interesting result indicates that frozen ground propagates vibration the same for all the soil types.

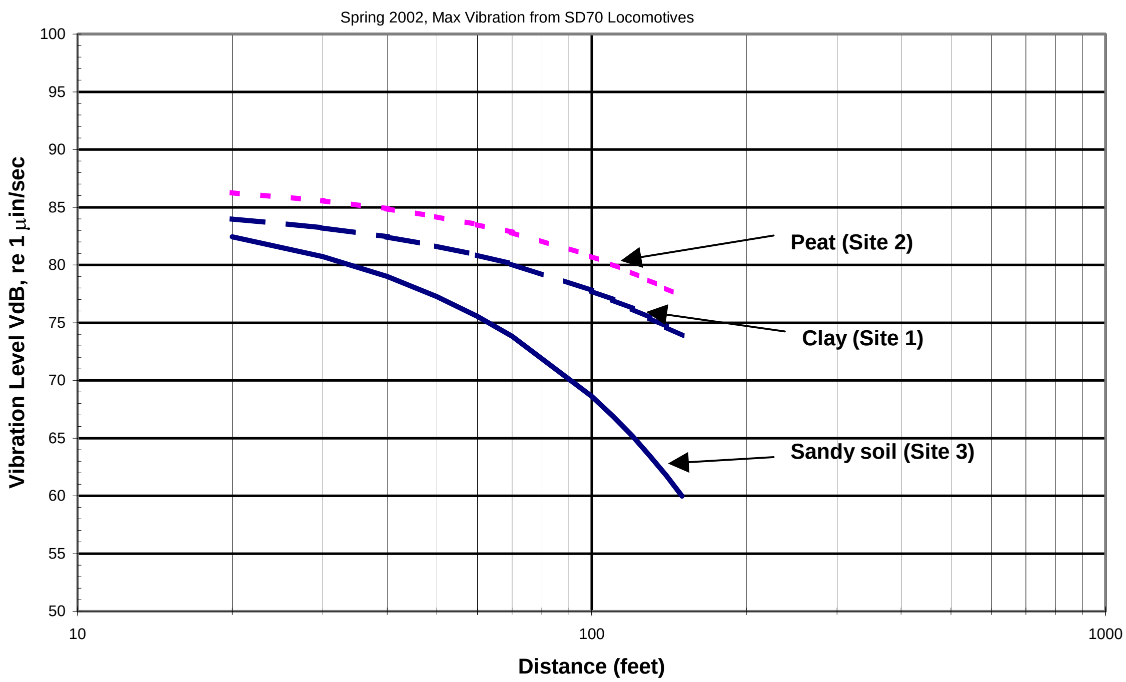


Figure 14. Propagation of Vibrations from SD-70 for Different Soil Types (Spring Results Shown)

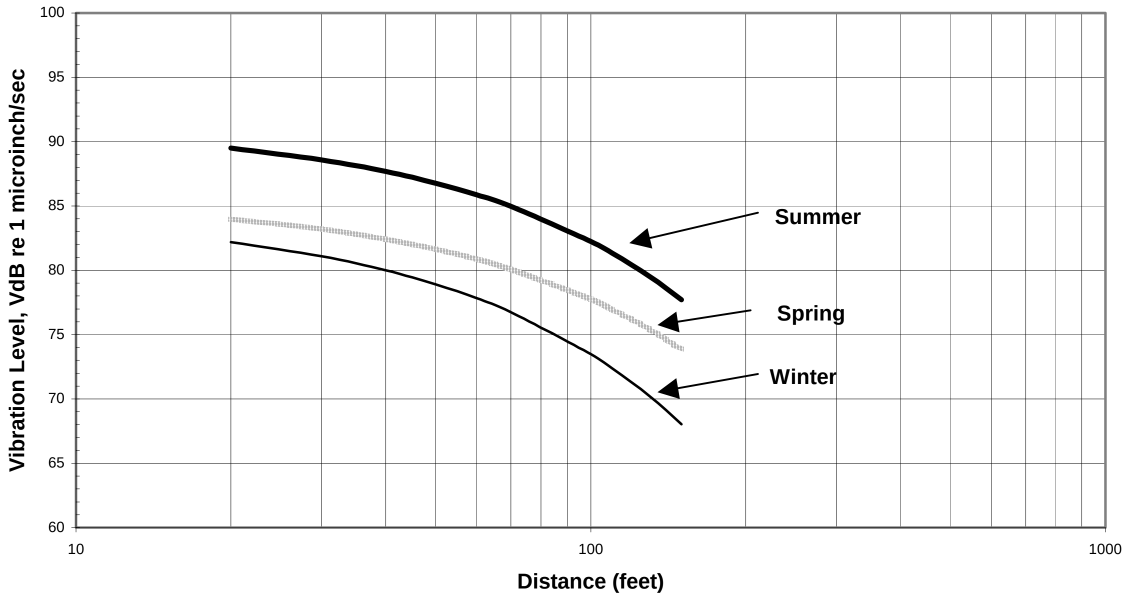
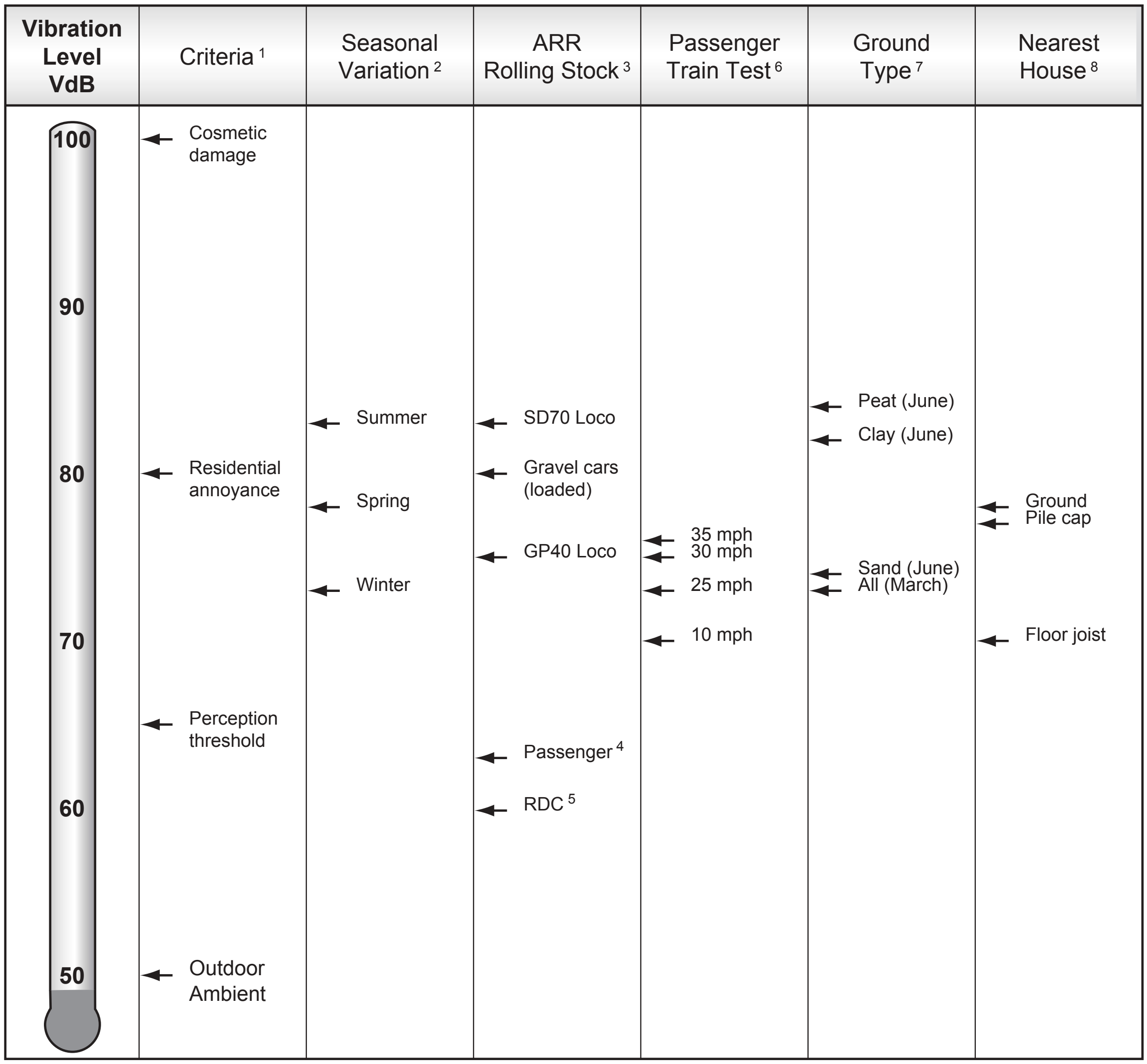


Figure 15. Seasonal Propagation of Vibrations from SD70 Locomotive at Nulbay Park (Site V1)

4.2.2 Summary of Vibration Results

The vibration measurement results provide reference vibration levels for ARR train equipment and reference levels for typical environments in the study area. These levels are shown in Figure 16 and compared with accepted criteria for vibration effects ranging from the threshold of human perception to the threshold of cosmetic damage. As shown in the figure, the measured vibration levels were far below those that could cause even the lowest level of cosmetic damage – slight cracks in the interior plaster of a typical residence.

The data also show the effect of weight on vibrations, with the heavy SD70 locomotive pulling a gravel train topping the list and the light-weight passenger trains coming in the lowest. Speed makes a difference also, as shown by the passenger train test results where vibrations increase with increasing speed. However, the results indicate that a passenger train with a locomotive and six coaches can operate at 35 mph and still generate lower vibration levels than an SD70 locomotive hauling a gravel train at 10 mph. A rank ordering of the ARR rolling stock is indicated, with the SD70 locomotive pulling a gravel train in the summer as highest and the short, slow-moving Whittier passenger train with one locomotive and two coaches as lowest.



1 Reference FTA
2 SD70 Loco at Site VI @ 10 mph at 100 ft.
3 Summer measurements at Site VI, 100 ft.
4 Whittier train, GP40 Loco and two coaches, 10 mph, 100 ft.
5 Rail Diesel Car, 10 mph, 100 ft.
6 GP40 Loco and six coaches, Site VI, 100 ft.
7 SD70 Loco at 10 mph, 100 ft.
8 Residence near Elderberry Park, 60 ft from tracks.

Figure 16. Summary of Vibration Measurements

4.2.3 House Vibrations

Mitigation of vibrations in houses near railroad tracks depends on whether the vibrations are caused by air-borne noise or by ground-borne noise. The difference between the two causes is described in Section 2.2. Detailed outside/inside measurements were made at H1 and H2 to determine whether vibration perceptions in these houses were based on low frequency air-borne noise from the diesel locomotives or from vibrations from the track transmitted through the ground. To monitor vibrations, accelerometers were mounted on the ground outside the house foundation, inside on the floor and inside on the wall facing the track. To measure the air-borne sound from the trains, a microphone was mounted outside the façade facing the tracks. An example of the vibrations measured at one of the houses is shown in Figure 17.

Floor vibration. Floor vibration levels on the first suspended floor (e.g., first floor over a basement) should be about the same as the ground just outside the foundation according to the prediction method in the FTA guidance manual. As shown in Figure 17, the vibration measurements at H1 agree with the FTA manual. Results at H2 were about the same. The vibration levels on the floors were within –0.5 to +1.0 VdB of the level on the ground outside both houses. The conclusion is that floor vibrations in these houses are related to ground-borne vibrations from the trains.

Wall vibration. In contrast to the floor, the walls facing the tracks were measured to have +5 to +10 VdB greater vibration levels than the outside ground vibration levels. These amplified vibrations may be responsible for shaking of wall-mounted features and related rattling and buzzing sounds. In order to determine the source of these vibrations, further analysis was performed on the measured signals.

A frequency analysis was performed on the measured noise and vibration from the locomotives and cars to compare the frequency spectra of the wall vibrations with those of the ground vibrations and of the sound from the diesel engines and the cars. A typical result from an SD70 locomotive is shown in Figure 18. Above 40 Hz, the frequency spectrum of the wall vibrations rises in the same frequency range as does the spectrum of the noise from the locomotive measured outside the house. This correspondence implies that the walls are quite responsive to the noise from the engines above 40 Hz, especially the noise around 80 Hz, which is usually the locomotive exhaust component. The wall response in this frequency range could be the cause of rattling of wall hangings. At very low frequencies, below 40 Hz, the wall vibrations appear to correspond to the ground-borne vibrations in a manner similar to the floors. Therefore, the walls show effects from both ground-borne vibration and air-borne noise from trains.

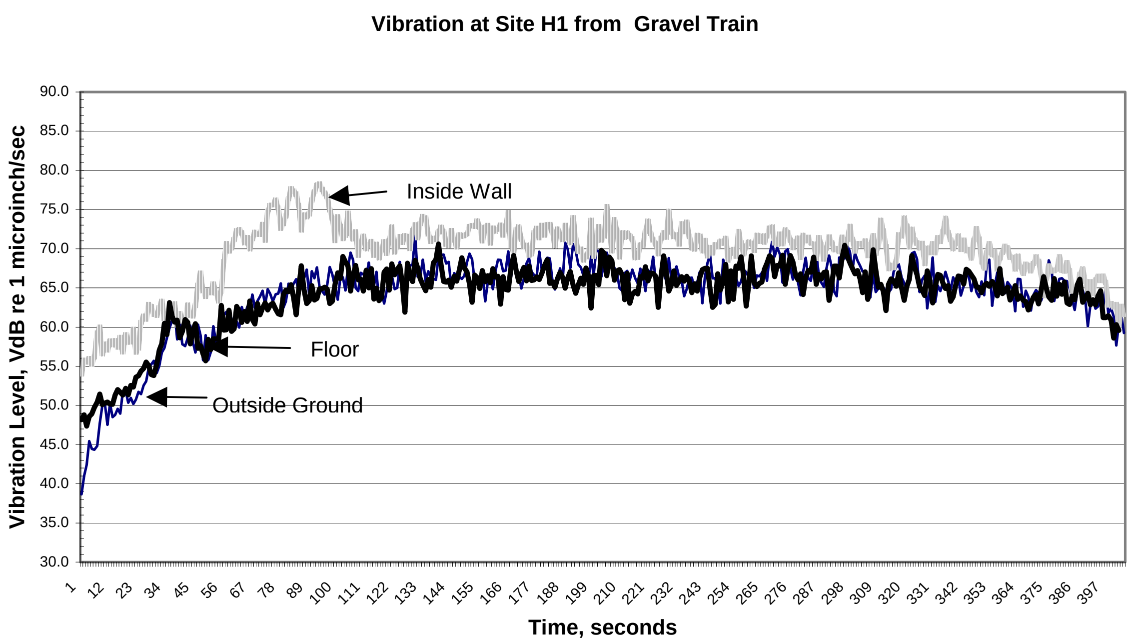


Figure 17. Typical Vibrations from a Gravel Train Measured at House H1

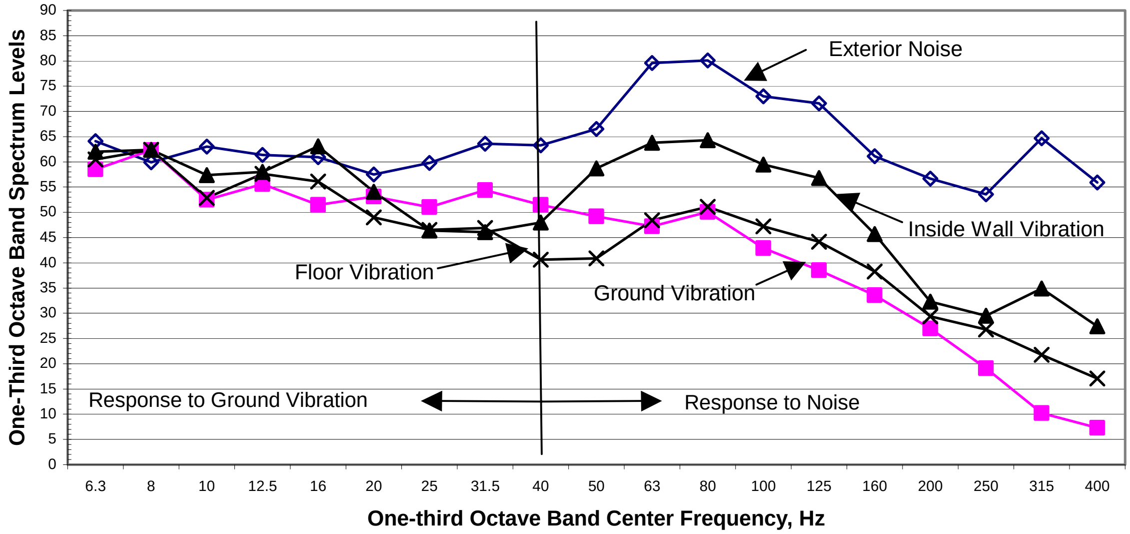


Figure 18. SD70 Locomotive Noise and Vibration Spectra in House H1

4.2.4 Conclusion from House Vibration Measurements

The floors of these houses tend to respond to ground-borne vibrations, with interior floor vibration levels about the same as the exterior ground vibration levels. Consequently, the results of this Study can be used to estimate how far from the tracks ground-borne vibrations could be perceived inside a house. As indicated in Figure 16, the threshold of perception of vibrations is 65 VdB. Referring to Figures 14 and 15 and observing where the 65 VdB level is crossed by the various curves, homes within about 150 feet from the tracks with sandy soil and about 300 feet from the tracks in clay and peat soils could have perceptible floor vibrations generated by the SD70 locomotive. Beyond those distances, the ground-borne path is not likely to be the source.

It is possible that low frequency noise from the diesel engines could be the cause of perceived vibrations beyond the distances described above. Air-borne noise propagates a great deal further than ground-borne vibrations. The results from the measurements in the test houses indicated a correlation between the noise from the engines and the higher frequency vibrations in the walls. These noise-induced vibrations in the walls of homes may cause perceptible secondary vibration effects, such as rattling of wall-mounted fixtures or shaking of windows.