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TECHNICAL MEMORANDUM

DATE: 22 December 2011
TO: Dan Adams, NTP
CC: Tracy Reed, Sound Transit
FROM: Thom Bergen, Derek Watry, Jim Nelson
SUBJECT: Summary of Supply Train Ground-borne Noise and Vibration Measurements
Sound Transit U-LINK, Boyer Basin, E. Blaine St., [REDACTED] and [REDACTED]

This memorandum provides results of ground-borne noise and vibration (GBNV) measurements made at three locations in the Boyer Basin neighborhood in Seattle on the evenings of 18 and 22 November 2011. Ground surface vibration measurements were made on the south side of East Blaine Street above the southbound tunnel, and interior noise and vibration measurements were made in the [REDACTED] residence on 19th Avenue East and in the [REDACTED] residence on Boyer Avenue East. The purpose of the measurements was to document noise and vibration levels produced in the Boyer Basin area by the TBM supply trains (locis) in the U-Link southbound tunnel without mitigation.

A map of the Boyer Basin area is shown in Figure 1. The residences in this neighborhood are designated by number as shown. For the 18 November measurements on Blaine St and in the [REDACTED] home (residence #28), the trains were operated at full speed on the standard track configuration (jointed rail on steel sleepers bolted into the tunnel liner). The [REDACTED] (residence #13) measurements were made on 22 November and included full speed and half speed supply train operation on the standard track configuration. At Boyer Avenue and residence #13 ([REDACTED]), the top of the tunnel is 75 feet deep, but, because of the elevation change going into the Interlaken area, the top of the tunnel is 82 feet deep relative to the elevation at residence #28 ([REDACTED]).

Measurement Set-up

All data were recorded on a two-channel Sony digital recorder in a manner similar to that reported for the October 24 interior measurements in the Shelby/Hamlin neighborhood (Nov 1 memo). Noise was measured using a B&K Type 2230 sound level meter and vibration was measured using an Endevco 7707-1000 piezoelectric accelerometers.

On E. Blaine St., ground vibration was measured in the narrow planting strip between the south curb and sidewalk directly over the centerline of the southbound tunnel (location "V0" indicated in Figure 1) and 50 feet to the west of the centerline (location "V50"). The Blaine recordings were made between 7:10 PM and 7:50 PM.

In the [REDACTED] residence (#28), vibration was measured with an accelerometer located near the center of the main-level living room floor, and groundborne noise was measured with the microphone located near the center of the room about 5 feet above the floor. This is a suspended wood floor with a basement level below. Four (4) supply train passbys were recorded at each locations. The [REDACTED] recordings were made between 8:35 PM and 9:05 PM.

Similar measurements were made in the [REDACTED] (#13) basement (concrete slab) on 22 November in the basement while the trains operated at full and half speed. These recordings were made between 8:15 PM and 10:30 PM.

Summary of Results

The vertical ground vibration velocity levels at the V0 and V50 locations on E. Blaine St. are plotted in Figures 2 and 3, respectively. The energy-averages of the four trains at the two locations are compared in Figure 4, which shows that similar vibration levels are produced by supply trains at 0 ft and 50 ft relative to centerline. While this seems counter-intuitive, elastic wave propagation theory does support this common empirical finding that the ground vibration directly over a deep tunnel is similar to or even slightly less than the ground vibration off to the side. The trains produce vibration levels at the surface in the range of 56 to 60 VdB.

The spike in the V0 spectrum in the 125 Hz band is real, not the result of equipment noise. The source is not known; it could be electrical equipment such as a transformer.

The vertical floor vibration and ground-borne noise levels in the [REDACTED] living room are plotted in Figures 5 and 6. The four supply trains passbys produced floor vibration levels of 59 to 63 VdB (overall) and interior noise levels of 32 to 34 dBA. These levels are comparable to, though slightly higher than, those measured previously in the Montlake neighborhood after installation of the wooden ties. The overall character of the noise (rumbling/thumping) was observed to be essentially the same as in Montlake. During the half hour of recording at the [REDACTED] residence, three aircraft and three vehicles passing on 19th Avenue were observed and all produced average interior noise levels of 34 to 37 dBA. One of the jet aircraft flyovers produced a brief maximum noise level of 43 dBA.

The vertical floor vibration and ground-borne noise levels in the [REDACTED] basement are plotted in Figures 7 and 8, respectively. Average vibration levels for trains traveling at full speed were measured to be 55 to 57 VdB (overall), and 48 to 49 VdB for half speed trains. These levels are significantly lower than on the [REDACTED] living room floor, but were measured on the basement slab and, therefore, do not include the amplifying effects associated with wood frame structures. Much of the noise data presented in Figure 8 includes contribution from frequent aircraft in the frequency bands above 125 Hz and vehicular traffic on Boyer Avenue in the bands below 20 Hz. Without aircraft, the full speed supply train produced an average groundborne noise level of 28 dBA (blue curve), and 24 dBA at half speed (orange curve). In the absence of

trains, passing aircraft produced average noise levels in the [REDACTED] basement of 41 to 45 dBA and maximum levels of 45 to 48 dBA. Vehicles passing on Boyer Avenue produced average interior noise levels of 37 to 38 dBA and maximum noise levels of 40 to 42 dBA. It was observed that individual vehicles passing on Boyer Avenue have a much shorter duration than the supply trains (a few seconds), but are far more frequent (at least one every few minutes). Aircraft appear to be roughly comparable to the supply trains in duration but are more frequent.

The relationship between average and maximum interior noise levels produced by the supply trains is demonstrated in Figure 9. The [REDACTED] data is best suited for this comparison since there was minimal variation in noise level among the four trains and minimal contamination by external sources such as aircraft and traffic. For the [REDACTED] living room data shown in Figure 9, the Leq is the noise level averaged over the duration of the train passby (20 to 30 seconds), and the Lmax is the highest level measured during the passby (1-second analysis rate). The Leq and Lmax each averaged over the four train passbys and plotted together indicate that the maximum noise levels are typically about 5 dB higher than the passby average.

A summary of average floor vibration and interior noise levels measured in the Boyer Basin homes is presented in Table I. The summary provides a comparison between groundborne noise produced by the supply trains and other exterior environmental noise sources. Similarly, a summary of *maximum* (Lmax) noise vibration levels are included in Table II.

TABLE I Summary Of Time-Averaged Noise And Vibration Levels (Leq)

	[REDACTED] (#28)	[REDACTED] (#13)
Trains: Floor Vibration	59 - 63 VdB	55 - 57 VdB
Trains: Groundborne Noise	32 - 34 dBA	29 - 33 dBA
Other Sources: Ground- and Air-borne		
Aircraft	34 - 37 dBA	41 - 45 dBA
Cars	34 - 37 dBA	37 - 38 dBA
Background (no sources)	28 dBA	23 dBA

TABLE II Summary Of Maximum Noise And Vibration Levels (Lmax)

	[REDACTED] (#28)	[REDACTED] (#13)
Trains: Floor Vibration	63 - 67 VdB	60 - 62 VdB
Trains: Groundborne Noise	35 - 37 dBA	31 - 35 dBA
Other Sources: Ground- and Air-borne		
Aircraft	37 - 43 dBA	45 - 48 dBA
Cars	36 - 40 dBA	40 - 42 dBA
Background (no sources)	28 dBA	23 dBA

Assessment Using Standard Criteria

Groundborne noise from activities in a tunnel is essentially the audible manifestation of groundborne vibration. As such, it is generally addressed in conjunction with vibration. The Federal Transit Administration (FTA) *Transit Noise and Vibration Impact Assessment Manual* states "[f]or evaluating potential annoyance . . . due to construction vibration, the criteria for General Assessment . . . can be applied."¹ The General Assessment criteria for groundborne noise and vibration for residences depends on the number of events per day, and the most stringent is for *frequent events*, defined as more than 70 events per day. Because these criteria were developed for rail transit systems and because there are on the order of 70 supply trains per day, these criteria are well suited for assessing the situation in the Boyer Basin neighborhood.

The respective criteria are:

Groundborne noise:	35 dBA re 20 micro-Pa
Groundborne vibration:	72 VdB re 1 micro-in/sec

Neither of these criteria is predicated upon "imperceptibility." In fact, supply train noise or vibration at the respective criteria level would be distinctly perceptible if the respective background levels were lower, which they are in this situation.

The measured floor vibration levels in the #13 and #28 houses are well below the 72 VdB criterion. In addition, the average levels are below 65 VdB which is the threshold of perception for most people. The maximum vibration level on the floor of the [REDACTED] living room reached 67 VdB, however this was the level integrated over a one second period. Note that the FTA criteria and perceptibility threshold apply to the equivalent level (Leq) averaged over several seconds. Subjectively, the vibration of the floor during supply train passby was not detected.

The background noise levels in the homes when there are no discernible exterior or interior sources is 23 to 28 dBA, so it is not surprising that a noise on the order of 30 or 35 dBA is distinctly audible. Furthermore, the rail joints introduce a "thumping" nature to the audible supply train noise which makes it even more distinctive. In contrast, the increase and decrease of noise from an airplane passing overhead is smoother. The levels averaged over the entire train passage as reported in Table I are below the FTA criterion. In the two Boyer Basin homes tested, noise levels produced by aircraft and vehicle passbys exceed the supply train noise levels.

Conclusions

- Vibration levels are below the threshold of perceptibility in the three homes tested.
- The vibration levels are well below the level that could cause damage to homes. The residents should be assured of this.

¹ *Transit Noise and Vibration Impact Assessment*, FTA-VA-90-1003-06, May 2006.

- Groundborne noise is distinctly audible in both the [REDACTED] and [REDACTED] residences above the background. The average A-weighted noise level during a train passage is 4 to 10 dBA higher than the background.
- The rail joints introduce a "thumping" character to the supply train noise, distinguishing it from other exterior, transportation noise sources.
- The average noise level during a train passage is 29 to 34 dBA, depending on the residence. This is below the FTA groundborne noise criterion.
- The maximum noise levels during a train passage attributable to rail joint thumping is 31 to 37 dBA depending on the residence. The maximum noise levels are not directly comparable to the FTA criterion of 35 dBA. That said, the maximum levels exceed 35 dBA at the [REDACTED] residence somewhat less than 10% of the time during the train passage.
- In both homes, the A-weighted noise level for supply trains is lower than for aircraft and street traffic, but the sound of these three sources are distinctly different (different frequency content). We do not know traffic volumes, or how many airplanes fly over these homes per hour or per day, but the number of "events" does affect how people react to noise sources.
- The reaction of people to noise also depends on their emotions or beliefs about the noise source.

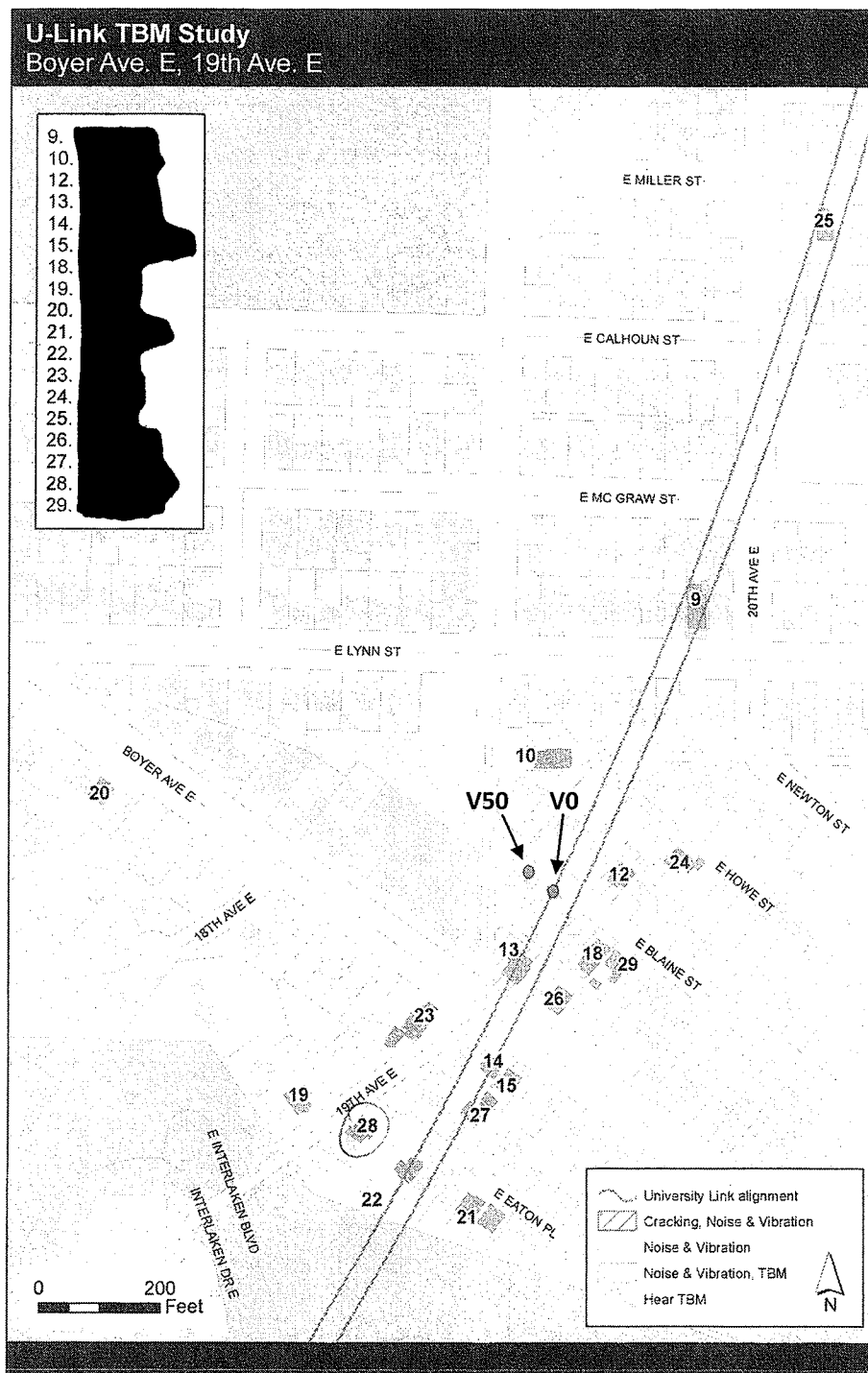


Figure 1 Map of Boyer Basin area showing affected residences and measurement locations

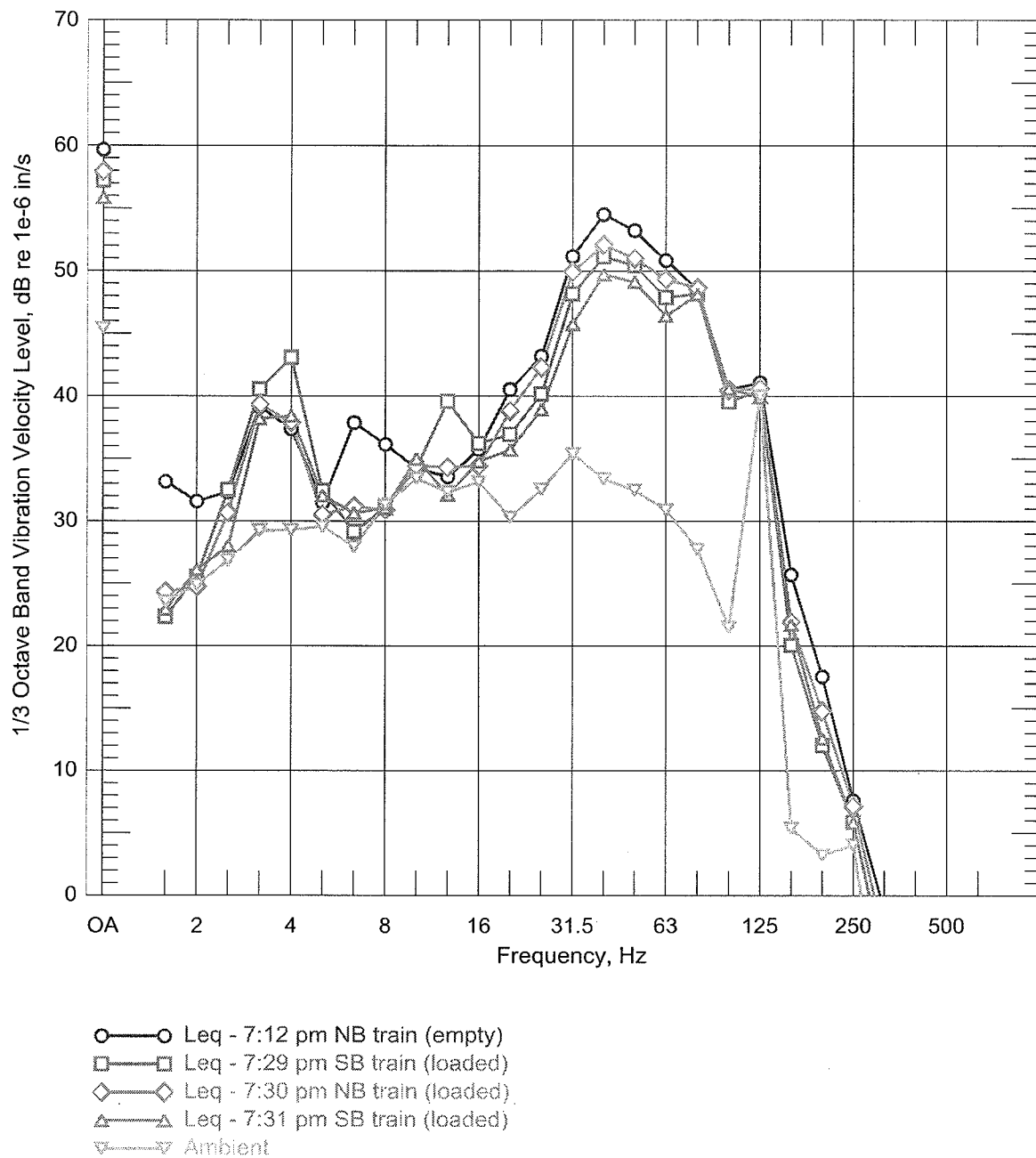


Figure 2 Average vibration velocity levels (vertical) for four train passbys in southbound tunnel on south side of E. Blaine St. directly below the southbound tunnel centerline (V0)

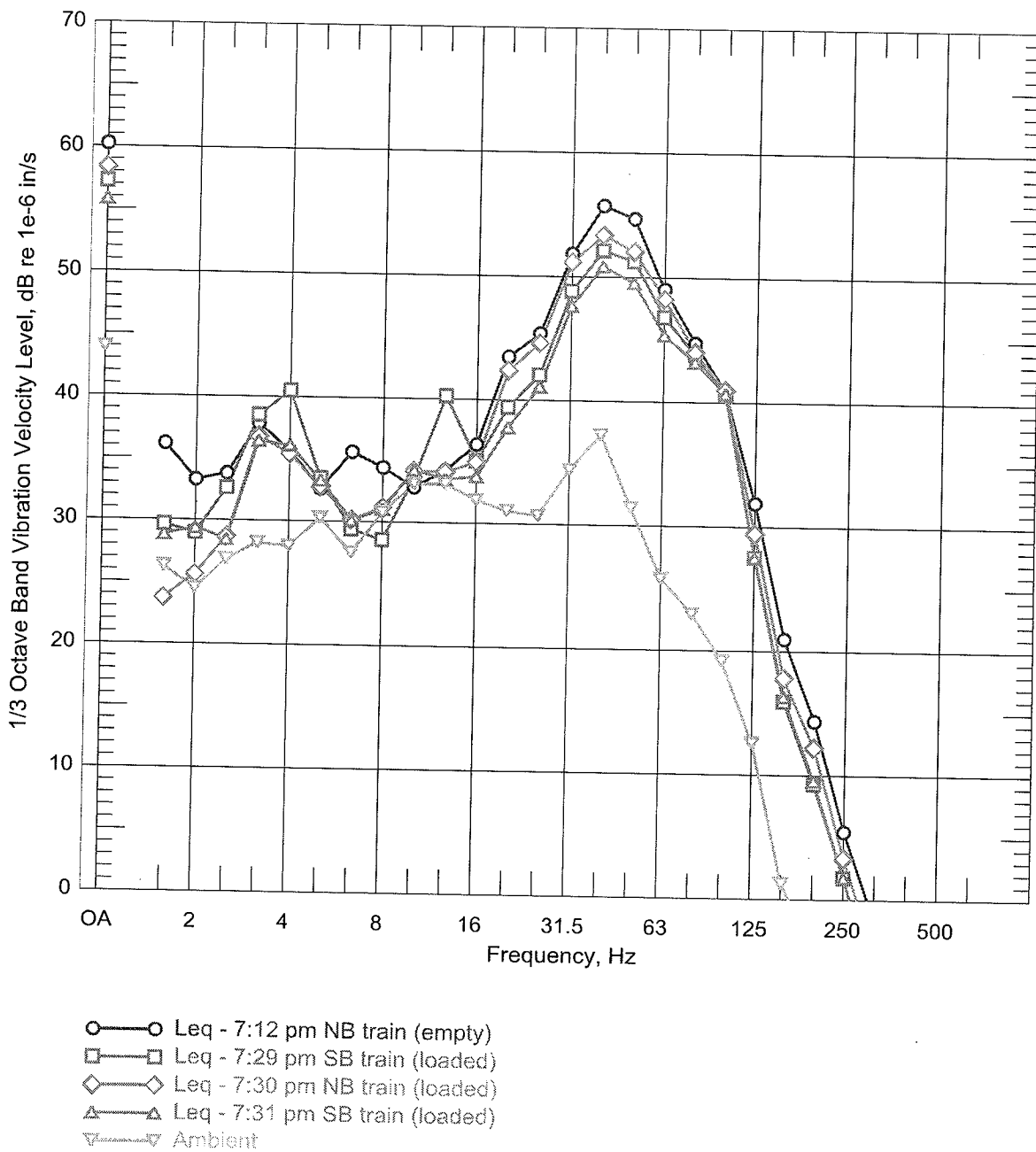


Figure 3 Average vibration velocity levels (vertical) for four train passbys in southbound tunnel on south side of E. Blaine St. at 50 ft west of the southbound tunnel centerline (V50)

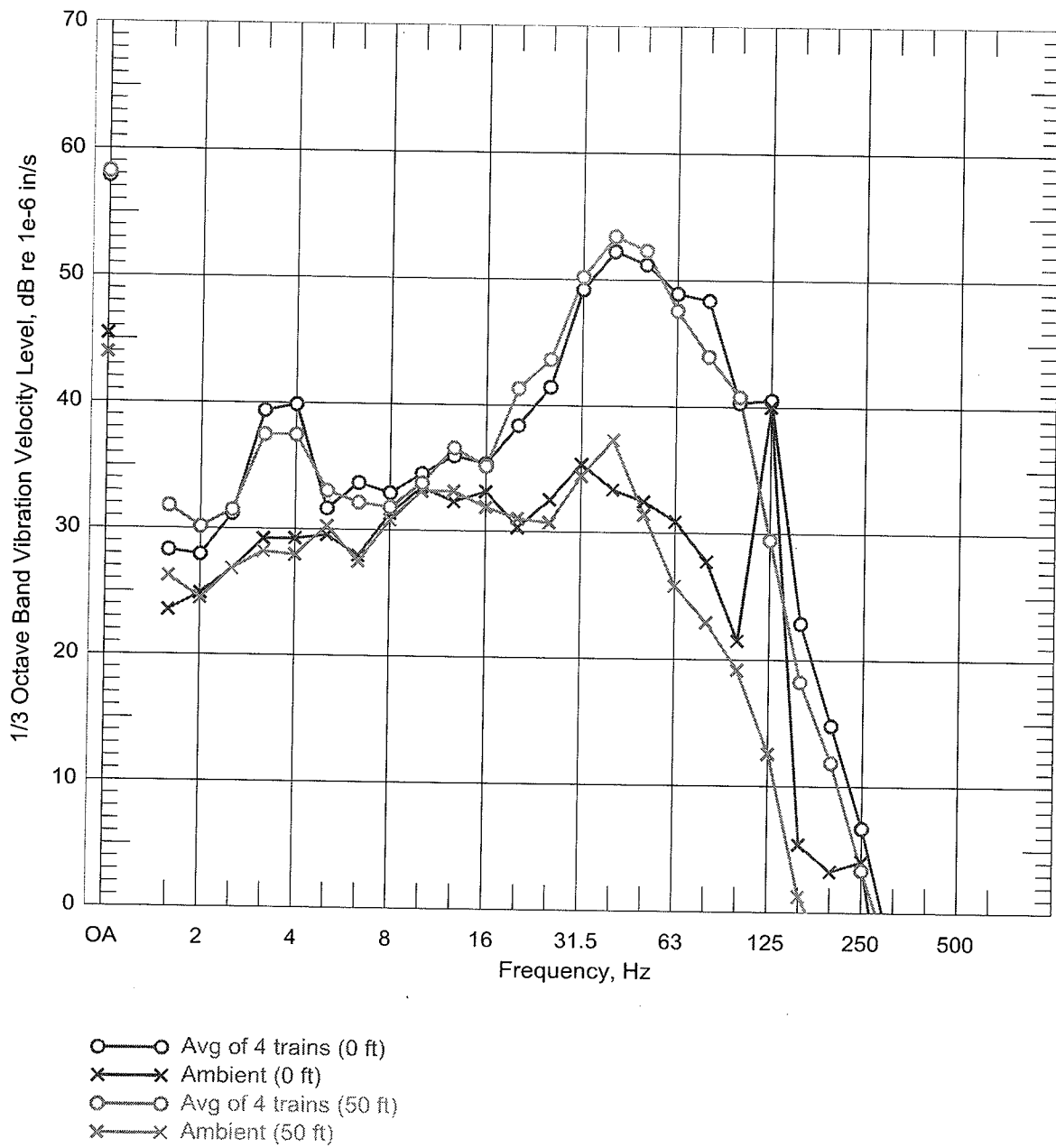


Figure 4 Comparison of E. Blaine St. vibration levels produced by supply trains at the 0 ft (V0) and 50 ft (V50) locations

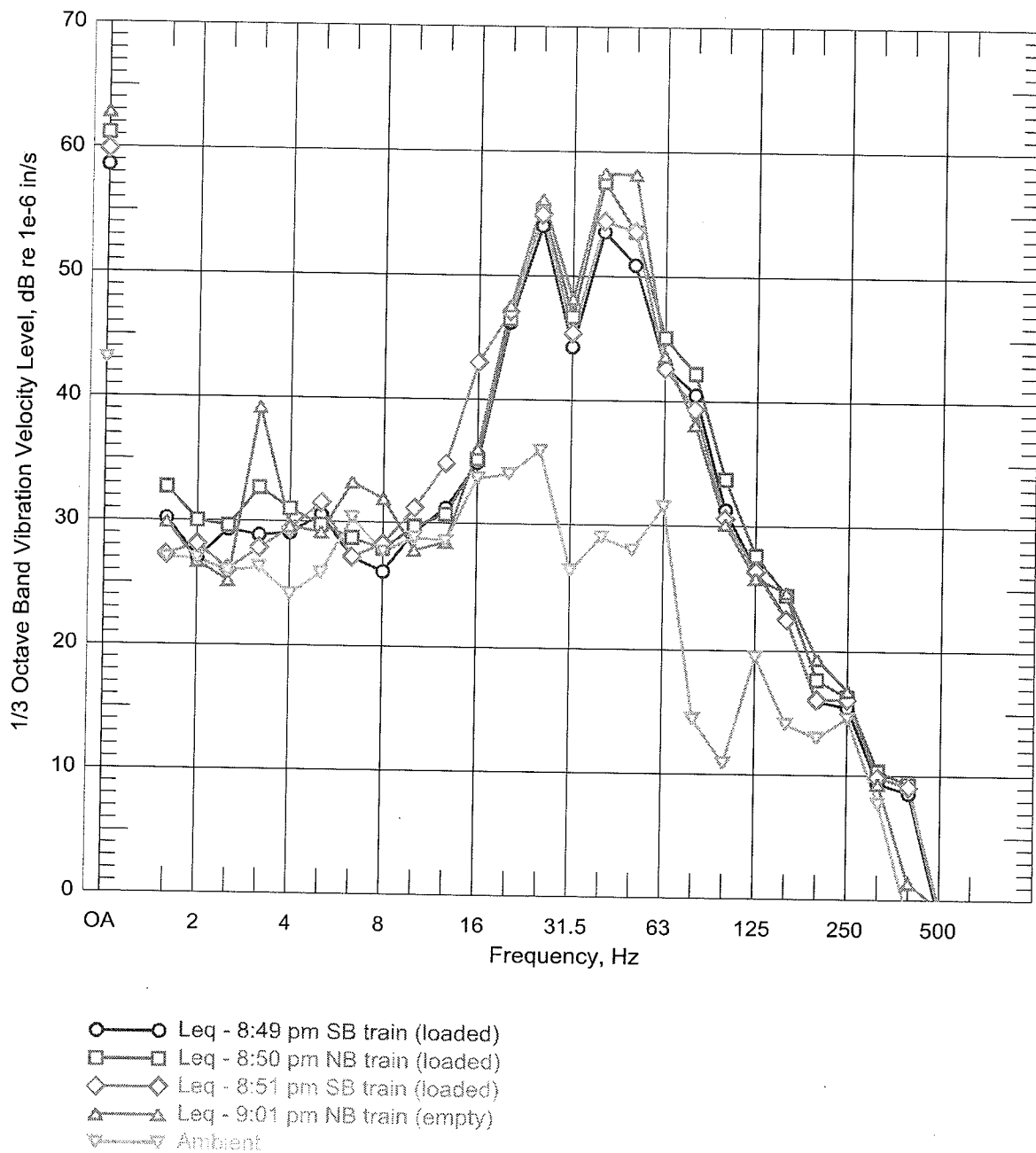


Figure 5 Average vibration velocity levels (vertical) on [REDACTED] living room floor during four train passbys in southbound tunnel at full speed (residence #28)

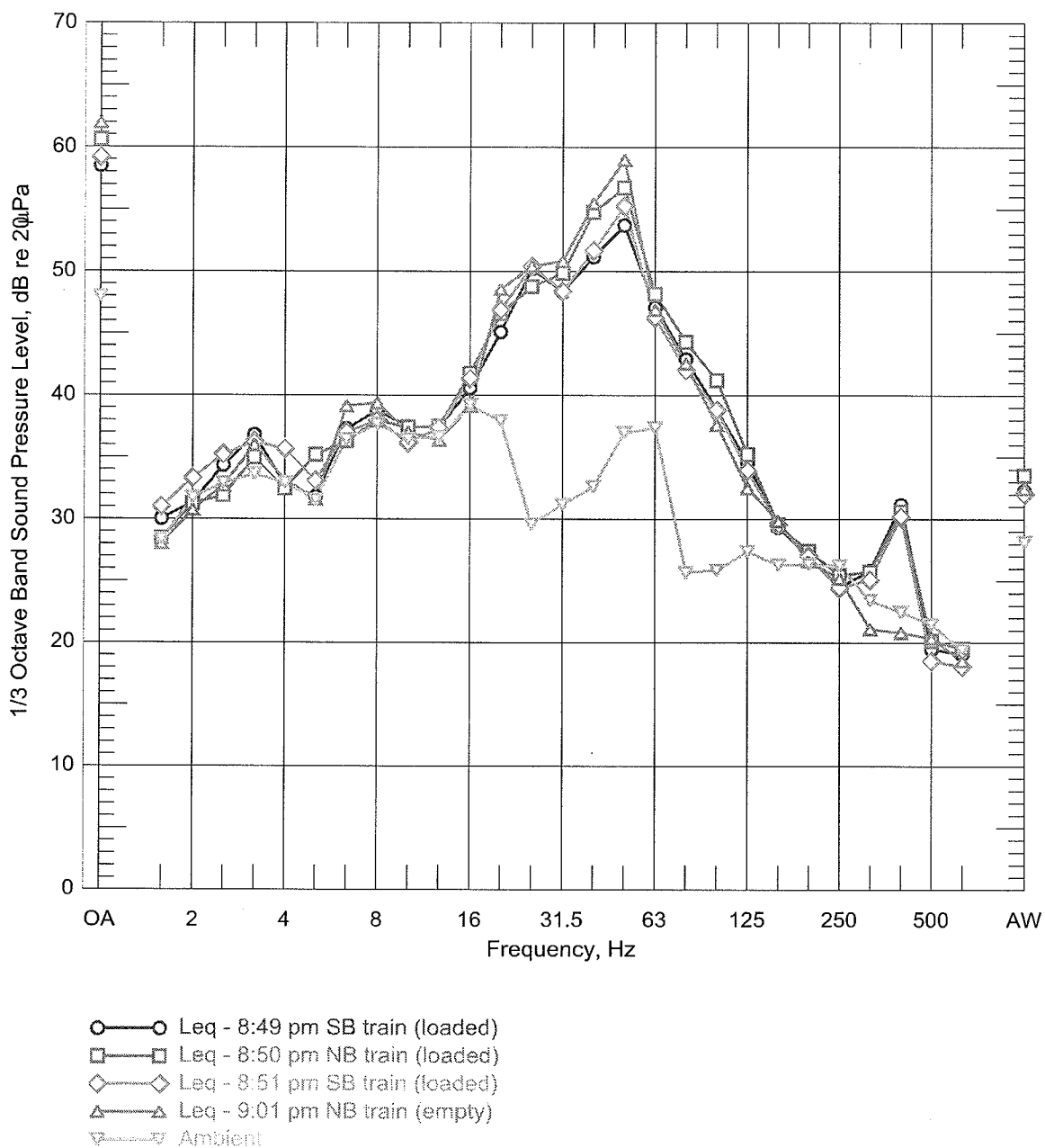


Figure 6 Average ground-borne noise levels in [REDACTED] living room during four train passbys in southbound tunnel at full speed (residence #28)

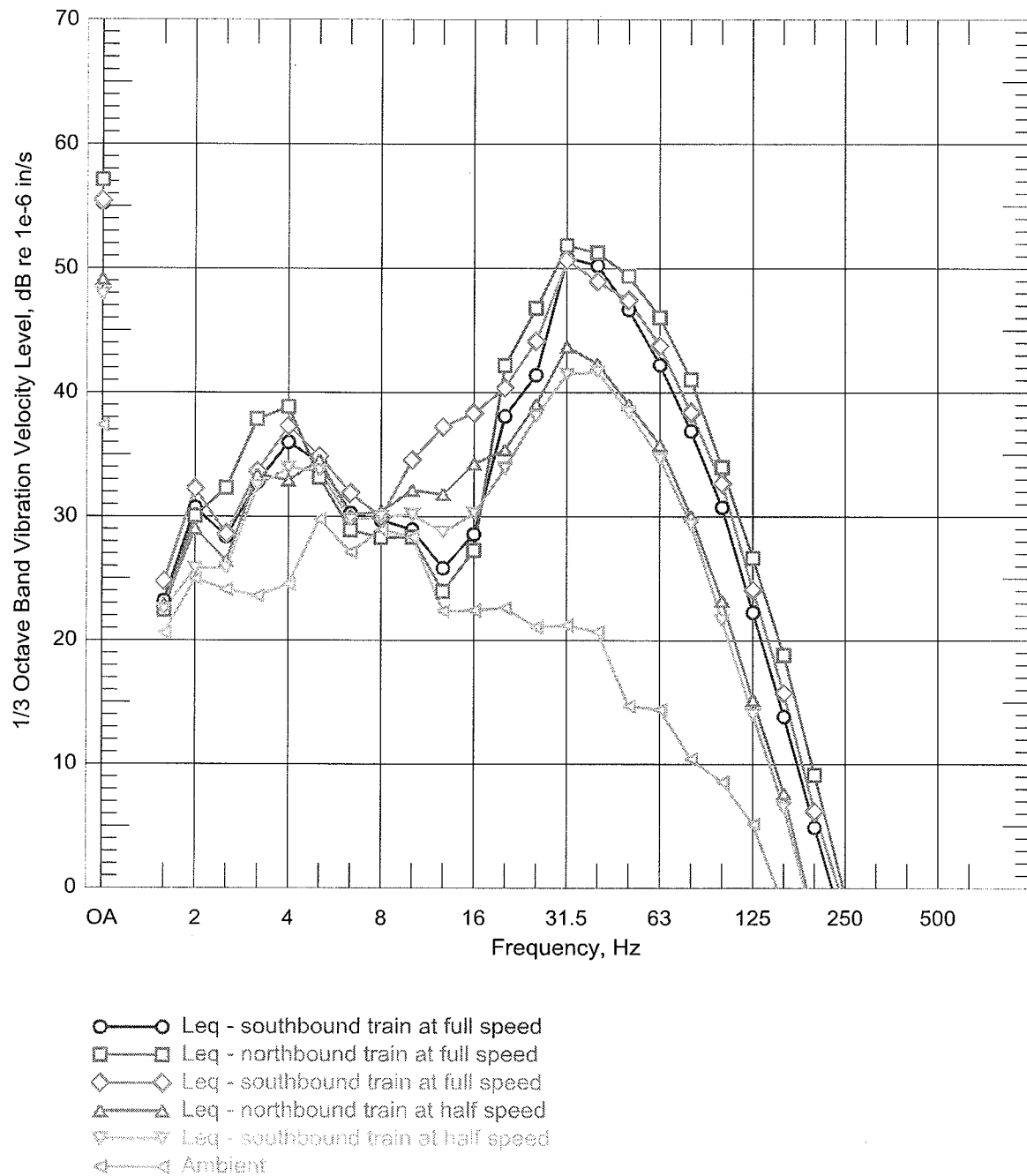


Figure 7 Average vibration velocity levels (vertical) on [REDACTED] basement floor during train passbys in southbound tunnel at full and half speed (residence #13)

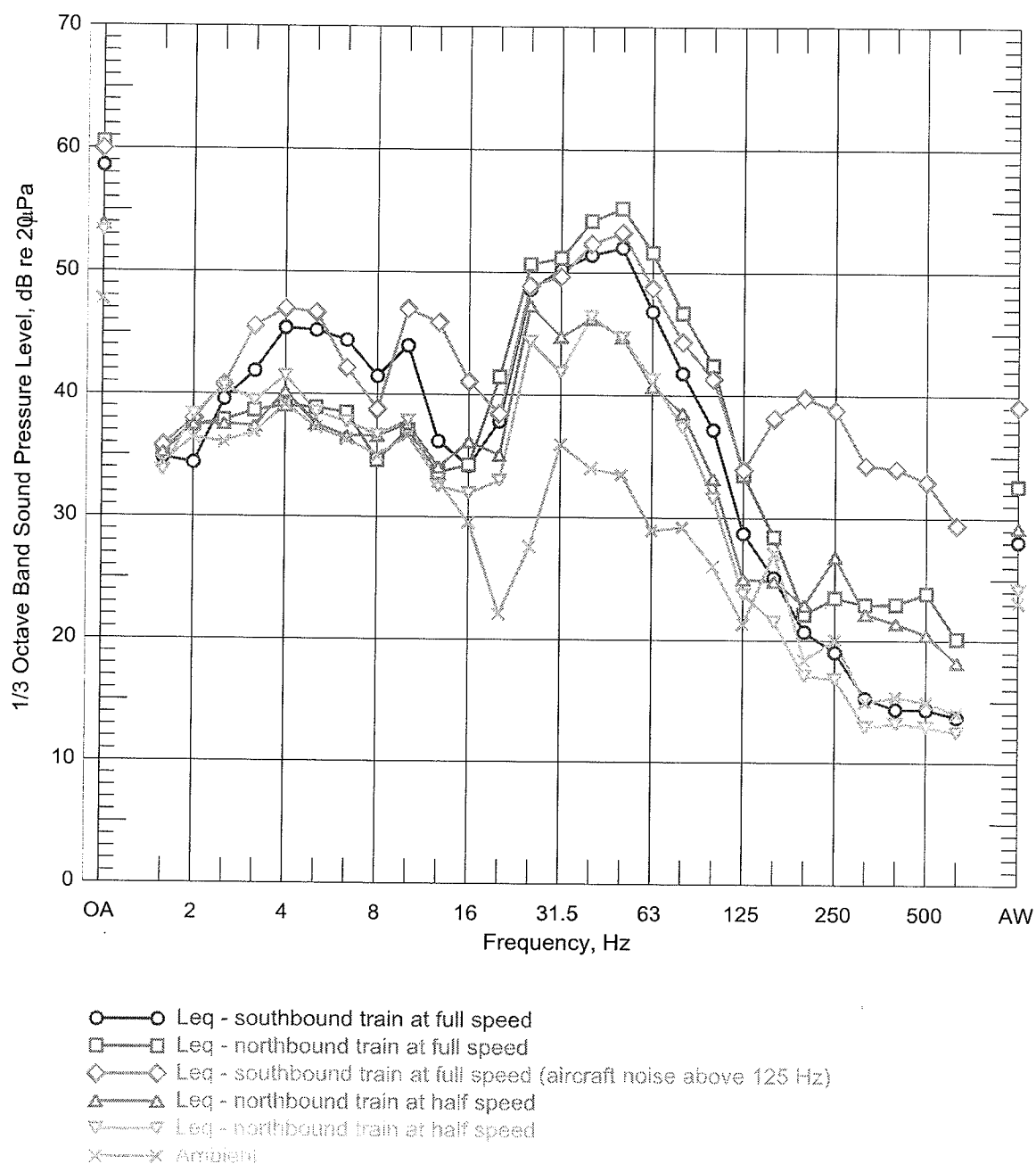


Figure 8 Average groundborne noise levels in [REDACTED] basement during train passbys in southbound tunnel at full and half speed (residence #13)

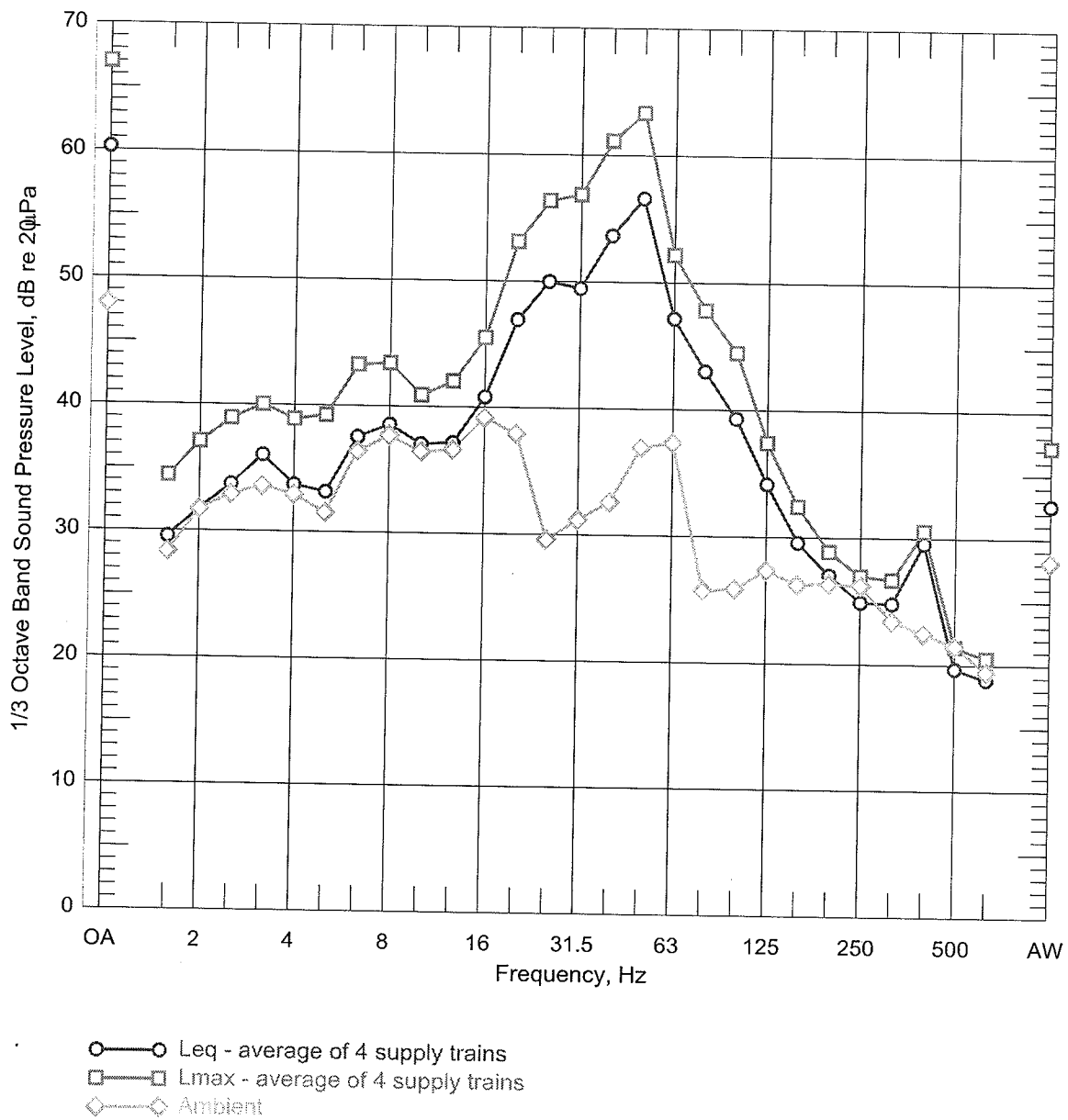


Figure 9 Comparison of average noise level (Leq) and maximum noise level (Lmax) in the [REDACTED] living room averaged over four supply train passbys in the southbound tunnel (residence #28)