SUMMARY OF EUROPEAN HIGH-SPEED RAIL NOISE AND VIBRATION MEASUREMENTS

HMMH Report No. 293630-2

April 1996

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hmmh HARRIS MILLER MILLER & HANSON INC.

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SUMMARY OF EUROPEAN HIGH-SPEED RAIL NOISE AND VIBRATION MEASUREMENTS

Noise and ground-borne vibration measurements of European high-speed train operations were carried out during May 1995. The measurements were performed by the staff of Harris Miller Miller & Hanson Inc. (HMMH) for the U.S. Federal Railroad Administration (FRA), under subcontract to De Leuw Cather & Company (DCCO). The purpose of this program was to document wayside noise and vibration levels for representative European high-speed trainsets as a function of distance, speed and consist, with the ultimate objective of developing suitable guidance manual models for high-speed rail noise and vibration projection.

Wayside noise and vibration measurements were carried out on high-speed trains in three countries, including the TGV and Eurostar trains in France, the Pendolino trains in Italy and the X2000 trains in Sweden. The measurement locations, procedures, equipment and results are described below.

1. MEASUREMENT LOCATIONS

High-speed train noise and vibration measurement locations were selected by HMMH based on candidate sites identified by local acoustical consulting organizations acting as project liaisons in each country. These liaisons included Commins Acoustical Workshop in France, Phoneco in Italy and Ingemansson in Sweden. The candidate measurement sites were identified based on guidance provided by HMMH with regard to geographical characteristics, train operations and track configuration.

The guidance provided with regard to site geographical characteristics was based primarily on measurement logistics as follows:

- The sites in each country should be located in the same general region, within a one-hour (or less) drive of each other.
- The sites should be in generally open, level areas that are accessible by van.
- The sites should allow access for the placement of instrumentation within an area extending between 12.5 and 75 meters from the near track centerline, along a 60-meter segment of the railroad line, with no intervening obstacles or major roads.
- The sites should not be very close to sources of significant noise or vibration that could contaminate the measurements, such as major roads, airports, industrial plants, construction sites or agricultural equipment.

Based on the measurement objectives, the desired conditions with regard to train operations and track configuration were as follows:

- One primary site in each country where trains operate at or above grade along a straight section of track at or near the maximum speed for the rail system.
- Additional at-grade or above-grade sites where trains operate at intermediate and low speeds, to investigate the speed dependence of train noise and vibration.

- Sites where trains operate on a high embankment or elevated structure.

- Sites where trains operate in a low cut or behind barriers where the noise sources on the train are shielded from view.

- For tilt-trains (i.e. the X2000 and Pendolino), sites on curves where the tilt mechanisms are fully employed.

The candidate sites were visited by HMMH and liaison consultant representatives during the period from 24 April through 3 May 1995. Based on these visits, the final measurement sites were selected by HMMH. The sites and specific measurement locations in each country are described below. It should be noted that because the sites were selected from a pool of candidate sites, the site designations in each country are not necessarily in consecutive alphabetical or numerical order.

1.1 French Measurement Sites

Measurements were carried out on 9-11 May 1995 at four sites along the French National Railway's TGV Nord line to the north of Paris. The general locations of these sites, designated as sites D, G, H and K, are indicated in Figures 1 and 2. Additional measurements along this line were performed on 12 May 1995 at the TGV Haute Picardie Station. The maximum train speed along this line is 300 kph (186 mph).

Train operations along the TGV Nord line include both single and double TGV consists, as well as Eurostar trains. The standard TGV consist includes 2 power cars, 2 transition cars and eight coaches with a total length of 237.5 meters; the double consists are 475 meters long. In all cases, the pantograph was observed to be raised on the trailing power car of each standard TGV consist. The Eurostar train consist includes 2 power cars and 18 coaches, with a total length of 393.7 meters. For the Eurostar trains, the pantograph was observed to be raised on both the leading and trailing power cars.

The French noise and vibration test sites and measurement locations are described below.

Site D. Site D (see Figure 3), located on the southbound (east) side of the TGV Nord line to the east of the village of Baron, was selected as the primary site in France. At this site, two tracks are located on an embankment approximately 3 meters high, with a track separation of 4.5 meters. The tracks consist of continuous welded rail on 0.5-m spaced concrete ties and ballast. Twenty-five trains were monitored at this site between 12:00 and 18:45 on 10 May 1995, with speeds of 269-296 kph (167-184 mph).

Noise and ground-borne vibration measurements were made along a dirt road running perpendicular to the rail line through a level, cultivated field. In addition to the train measurements, ground vibration propagation tests were also performed by generating ground impacts at points along a line parallel to the tracks near the right-of-way fence. Figures 4A and 4B provide plan and cross-sectional drawings that illustrate the measurement and impact locations. As shown in these figures, train noise measurements were made at distances of 25, 50 and 75 meters from the near (southbound) track center line, at a height of 1.5 meters above ground with an additional 4-meter high position at the 25 meter reference location. Similarly, ground vibration measurements were made at distances of 17.5, 25, 37.5, 50, 62.5 and 75 meters from the near track center line. Vibration propagation tests were made by generating impacts on the ground at points spaced 6 meters apart along a line 60 meters long, centered at the measurement line, at a distance of 17 meters from the near track center line.

Site G. Site G (see Figure 5) was located on the southbound (east) side of the TGV Nord line to the east of Beaulieu le Neuf. At this site, the two tracks are located in a cut approximately 15 meters deep, with a track separation of 4.5 meters. The tracks consist of continuous welded rail on 0.5-m spaced concrete ties and ballast. Twenty trains were monitored at this site between 16:30 and 19:05 on 9 May 1995, with speeds of 154-294 kph (96-183 mph).

Only noise measurements were made at Site G. These were made along tractor paths in a cultivated field, about 150 meters north of a roadway bridge crossing over the tracks. Figures 6A and 6B provide plan and cross-sectional drawings that illustrate the measurement locations. As shown in these figures, train noise measurements were made at distances of 44 and 75 meters from the near (southbound) track center line, at a height of 1.5 meters above ground with an additional 4-meter high position at the 44 meter location. The view of the trains was unshielded at the 44m/4m-high position, partially shielded at the 44m/1.5m- high position and totally shielded at the 75m/1.5m-high position.

Site H. Site H (see Figure 7) was located on the northbound (west) side of the TGV Nord line to the east of the village of Ducy. At this site, the two tracks are located on an embankment approximately 5-meters high, shielded by a concrete barrier wall about 370-m long and 3-m high, mounted on the embankment approximately 5 meters from the near (northbound) track center line. The tracks consist of continuous welded rail on 0.5-m spaced concrete ties and ballast, with a track separation of 4.5 meters. Fifteen trains were monitored at this site between 11:05 and 13:20 on 11 May 1995, with speeds of 267-298 kph (166-185 mph).

Only noise measurements were made at Site H. These were made in an open, uncultivated field along two lines running perpendicular to the rail line. One of these lines was located at the mid-point of the barrier while the other was located about 110 meters north of the north end of the barrier wall. Figures 8A and 8B provide plan and cross-sectional drawings that illustrate the measurement locations. As shown in these figures, train noise measurements behind the barrier were made at distances of 25, 50 and 75 meters from the near (northbound) track center line, at a height of 1.5 meters above ground with an additional 4-meter high position at the 25 meter reference location. At the unshielded location north of the barrier, measurements were made at distances of 25 and 50 meters from the near (northbound) track centerline, at a height of 1.5 meters above the ground.

Site K. Site K (see Figure 9) was located on the northbound (west) side of the TGV Nord line to the west of Charles De Gaulle Airport. At this site, the two tracks are located on an embankment approximately 2-meters high, with a track separation of 4.5 meters. The tracks consist of continuous welded rail on 0.5-m spaced concrete ties and ballast. Fifteen trains were monitored at this site between 16:30 and 19:00 on 11 May 1995, with speeds of 145-216 kph (90-134 mph).

Noise and ground-borne vibration measurements were made in a lightly-cultivated field adjacent to the tracks. Figures 10A and 10B provide plan and cross-sectional drawings that illustrate the measurement locations. As shown in these figures, train noise measurements were made at distances of 25 and 50 meters from the near (northbound) track center line, at a height of 1.5 meters above ground with an additional 4-meter high position at the 25 meter reference location. Similarly, ground vibration measurements were made at distances of 25 and 50 meters from the near track center line.

TGV Haute Picardie Station. This site (see Figure 11) was at a new train station on the TGV Nord line between Paris and Lille. Four tracks pass through the station, with through trains using the two center tracks. Through train noise measurements were performed on the northbound station platform between 18:00 and 18:30 on 12 May 1995 to determine patron noise exposure. Six trains, operating at or near the maximum speed of 300 kph (186 mph) were monitored at distances of about 15 meters from the northbound main line track and 20 meters from the southbound main line track.

1.2 Italian Measurement Sites

Measurements were carried out on 15-18 May 1995 at three sites along the Milano-Bologna segment of the Italian National Railway's main line between the cities of Parma and Reggio Emilia. The general locations of these sites, designated as sites 2, 3 and 4, are indicated in Figure 12. Additional measurements were performed on 18 May 1995 at the Parma Station.

Train operations along the Milano-Bologna main line include a variety of passenger and freight trains. Of primary interest were the Pendolino ETR-450 high-speed tilt trains, which operate at a maximum speed of about 200 kph (125 mph). The standard Pendolino consist includes two end units and seven other cars, with a total length of 236.6 meters. The pantograph was observed to be raised on the sixth car only.

The Italian noise and vibration test sites and measurement locations are described below.

Site 2. Site 2 (see Figure 13) was located on the northbound side of the railroad line near the town of Cade. At this site, three tracks are located at grade, including a two main line tracks located 3.7 meters apart, plus a siding located 5.5 meters from the northbound main line track between the measurement site and the main line. The main line tracks consist primarily of continuous welded rail on 0.6-m spaced concrete ties and ballast, although several rail joints were observed in the southbound track in this vicinity. Three Pendolino trains were monitored at this site between 20:00 and 21:00 on 15 May 1995, with speeds of 190-194 kph (118-121 mph).

Noise and ground-borne vibration measurements at Site 2 were made along a tractor path running perpendicular to the rail line through a level, cultivated field. Figures 14A and 14B provide plan and cross-sectional drawings that illustrate the measurement locations. As shown in these figures, train noise measurements were made at distances of 25, 50 and 75 meters from the near (northbound) track center line, at a height of 1.5 meters above ground with an additional 4-meter high position at the 25 meter reference location. Similarly, ground vibration measurements were made at distances of 12.5, 25, 50 and 75 meters from the near track center line.

Site 3. Site 3 (see Figure 15) was located in an asphalt-paved parking lot on the northbound side of the railroad line, on the inside of a curved section of track in the city of Reggio Emilia. The curve radius at this location was estimated to be 880 meters (about 2,900 feet). At this site, two tracks are located on an embankment approximately 1.5 meters above grade, separated from the measurement site by a grassy ditch. The tracks consist of continuous welded rail on 0.6-m spaced concrete ties and ballast, and welded joints were visible in both tracks near the measurement positions. Four Pendolino trains were monitored at this site between about 20:00 and 21:00 on 17 May 1995, with speeds of 130-154 kph (81-96 mph).

Noise and ground-borne vibration measurements were made at several locations in the parking lot. Figures 16A and 16B provide plan and cross-sectional drawings that illustrate the measurement locations. As shown in these figures, train noise measurements were made at distances of 25, 50 and 75 meters from the near (northbound) track center line, at a height of 1.5 meters above ground with an additional 5-meter high position at the 25 meter reference location. Ground vibration measurements were made at distances of 17.5, 25, 50 and 75 meters from the near (northbound) track center line.

Site 4. Site 4 (see Figure 17), located on the southbound side of the railroad line near the town of Cella, was selected as the primary site in Italy. At this site, two tracks are located on an embankment approximately 1.5 meters high, with a track separation of 3.7 meters. The tracks consist of continuous welded rail on 0.6-m spaced concrete ties and ballast. Eight Pendolino trains were monitored at this site during two periods, between about 9:00 and 17:00 on 16 May 1995 and between about 8:00 and 10:00 on 18 May 1995. Train speeds during the measurements were in the range of 175-196 kph (109-122 mph).

Noise and ground-borne vibration measurements at Site 4 were made in a mowed, grassy field adjacent to the railroad line. In addition to the train measurements, ground vibration propagation tests were also performed by generating ground impacts at points along a line parallel to the tracks on the embankment. Figures 18A and 18B provide plan and cross-sectional drawings that illustrate the measurement and impact locations. As shown in these figures, train noise measurements were made at distances of 25, 50 and 75 meters from the near (southbound) track center line, at a height of 1.5 meters above ground with an additional 5-meter high position at the 25 meter reference location. Similarly, ground vibration measurements were made at distances of 10, 25, 37.5, 50, 62.5 and 75 meters from the near track center line. Vibration propagation tests were made by generating impacts on the ground at points spaced 6 meters apart along a line 60 meters long, centered at the measurement line, at a distance of 3 meters from the near track center line.

Parma Station. This site (see Figure 19) was on the center northbound platform at Parma Station. While most trains stop at the station, some through trains, including most Pendolinos, pass by the station platforms at high speed. Train noise measurements were performed on the center northbound station platform between about 20:00 and 21:00 on 18 May 1995 to determine patron noise exposure. Eleven trains, including four Pendolinos, were monitored at distances of about 4 meters from the northbound track and 8 meters from the southbound track.

1.3 Swedish Measurement Sites

Measurements were carried out on 22-24 May 1995 at six sites along the Stockholm-Goteborg main line of the Swedish State Railway between the cities of Alingsas and Herrljunga. The general locations of these sites, designated as sites 1, 2, 3A, 3B, 4 and 5, are indicated in Figures 20, 21 and 22.

Train operations along the Stockholm-Goteborg main line include a variety of passenger and freight trains. Of primary interest were the X2000 high-speed tilt trains, which operate at a maximum speed of about 200 kph (125 mph). The standard X2000 consist is 140 meters long and includes one power car with raised pantograph, located at the west end of the train, one cab unit, located at the east end of the train, and four coaches.

The Swedish noise and vibration test sites and measurement locations are described below.

Site 1. Site 1 (see Figure 23) was located on the eastbound (north) side of the railroad line in Savelund near Alingsas. At this site, two tracks are located on a tall embankment approximately 4-5 meters above grade, with a track separation of 4.5 meters. The tracks consist of continuous welded rail weighing 50 kg/m, attached to 0.7-m spaced concrete ties with "Hambo" type rail fasteners and supported on stone ballast. Eleven X2000 trains were monitored at this site between 9:20 and 18:50 on 22 May 1995, with speeds of 153-177 kph (95-110 mph). There is a slight curve in the tracks at this location, and westbound trains sometimes emitted brake squeal while passing this site.

Noise measurements only were made at Site 1, in an uncultivated field. Figures 24A and 24B provide plan and cross-sectional drawings that illustrate the measurement locations. As shown in these figures, the measurements were made at distances of 25 and 50 meters from the near (eastbound) track centerline, at a height of 1.5 meters above the ground. At these positions, the edge of the embankment provided some shielding of the westbound track rails.

Site 2. Site 2 (see Figure 25) was located on the eastbound (north) side of the railroad line in Savelund near Alingsas, just east of Site 1. While the track construction is the same as at Site 1, the tracks at Site 2 are located in a cut approximately 4 meters deep. The measurements at Site 2 coincided with the measurements at Site 1 for the same eleven trains.

Noise measurements only were made at Site 2, in an uncultivated field. Figures 26A and 26B provide plan and cross-sectional drawings that illustrate the measurement locations. As shown in these figures, the measurements were made at distances of 20, 40 and 65 meters from the near (eastbound) track centerline at a height of 1.5 meters above the ground, with an additional 5 meter high position at the 40 meter measurement location. At these positions, the edge of the cut configuration provided varying degrees of train noise shielding.

Site 3A. Site 3A (see Figure 27), located on the eastbound (north) side of the railroad line near the village of Torp, was selected as the primary noise measurement site in Sweden. At this site, two tracks are located on a low embankment, about 1 meter high, with a track separation of 4.5 meters. The tracks consist of continuous welded rail weighing 50 kg/m, attached to 0.7-m spaced concrete ties with "Hambo" type rail fasteners and supported on stone ballast. Eleven X2000 trains were monitored at this site between 9:20 and 18:30 on 23 May 1995, with speeds of 159-188 kph (99-117 mph).

The noise measurements at Site 3A were made in a cultivated field. Figures 28A and 28B provide plan and cross-sectional drawings that illustrate the measurement locations. As shown in these figures, the measurements were made at distances of 25, 50 and 75 meters from the near (eastbound) track center line, at a height of 1.5 meters above ground with an additional 5-meter high position at the 25 meter reference location.

Site 3B. Site 3B (see Figure 29), located on the westbound (south) side of the railroad line near the village of Torp and just east of Site 3A, was selected as the primary ground-borne vibration measurement site in Sweden. At this site, the two tracks are located at grade, with a construction similar to Site 3A except that the track separation was 9.3 meters at Site 3B. The measurements at Site 3B coincided with the measurements at Site 3A for the same eleven trains.

Both train vibration measurements and ground vibration propagation tests were performed at Site 3B. For the propagation tests, ground impacts were generated at points along a line parallel to the tracks. Figures 30A and 30B provide plan and cross-sectional drawings that illustrate the vibration measurement and impact locations. As shown in these figures, ground vibration measurements were made at distances of 7.5, 15, 25, 37.5, 50 and 62.5 meters from the near track center line. Vibration propagation tests were made by generating impacts on the ground at points spaced 6 meters apart along a line 60 meters long, centered at the measurement line, at a distance of 4 meters from the near track center line.

Site 4. Site 4 (see Figure 31) was located on the eastbound (north) side of the railroad line in the village of Ugglegardet. At this site, the two tracks are curved and on a 2-meter high embankment, with a track separation of 4.5 meters. The tracks consist of continuous welded rail weighing 50 kg/m, attached to 0.7-m spaced concrete ties with "Hambo" type rail fasteners and supported on stone ballast. Five X2000 trains were monitored at this site between 9:20 and 13:50 on 24 May 1995, with speeds of 72-183 kph (45-114 mph).

Both noise and ground-borne vibration measurements were made at Site 4. The noise measurements were made in a cultivated field beyond the road that runs along the tracks while the ground vibration measurements were made in an uncultivated area between the road and the tracks. Figures 32A and 32B provide plan and cross-sectional drawings that illustrate the measurement locations. As shown in these figures, train noise measurements were made at distances of 25, 50 and 75 meters from the near (eastbound) track center line, at a height of 1.5 meters above ground with an additional 5-meter high position at the 25 meter reference location. The ground vibration measurements were made at distances of 7.5 and 15 meters from the near track center line.

Site 5. Site 5 (see Figure 33) was located on the eastbound (north) side of the railroad line near the village of Holmen, to the west of Herrljunga. At this site, the two tracks are located on a low embankment about 1.5 meters high, with a track separation of 4.5 meters. The tracks consist of continuous welded rail weighing 50 kg/m, on 0.7-m spaced concrete ties and stone ballast. The rails are attached to the ties using "Fist" type rail fasteners on the eastbound track and "Hambo" type rail fasteners on the westbound track. Six X2000 trains were monitored at this site between 16:30 and 19:40 on 24 May 1995, with speeds of 114-187 kph (71-116 mph).

Both noise and ground-borne vibration measurements were made at Site 5, along a dirt road running perpendicular to the tracks. Figures 34A and 34B provide plan and cross-sectional drawings that illustrate the measurement locations. As shown in these figures, train noise measurements were made at distances of 25, 50 and 75 meters from the near (eastbound) track center line, at a height of 1.5 meters above ground with an additional 5-meter high position at the 25 meter reference location. The ground vibration measurements were made at distances of 7.5, 15, 25 and 50 meters from the near track center line.

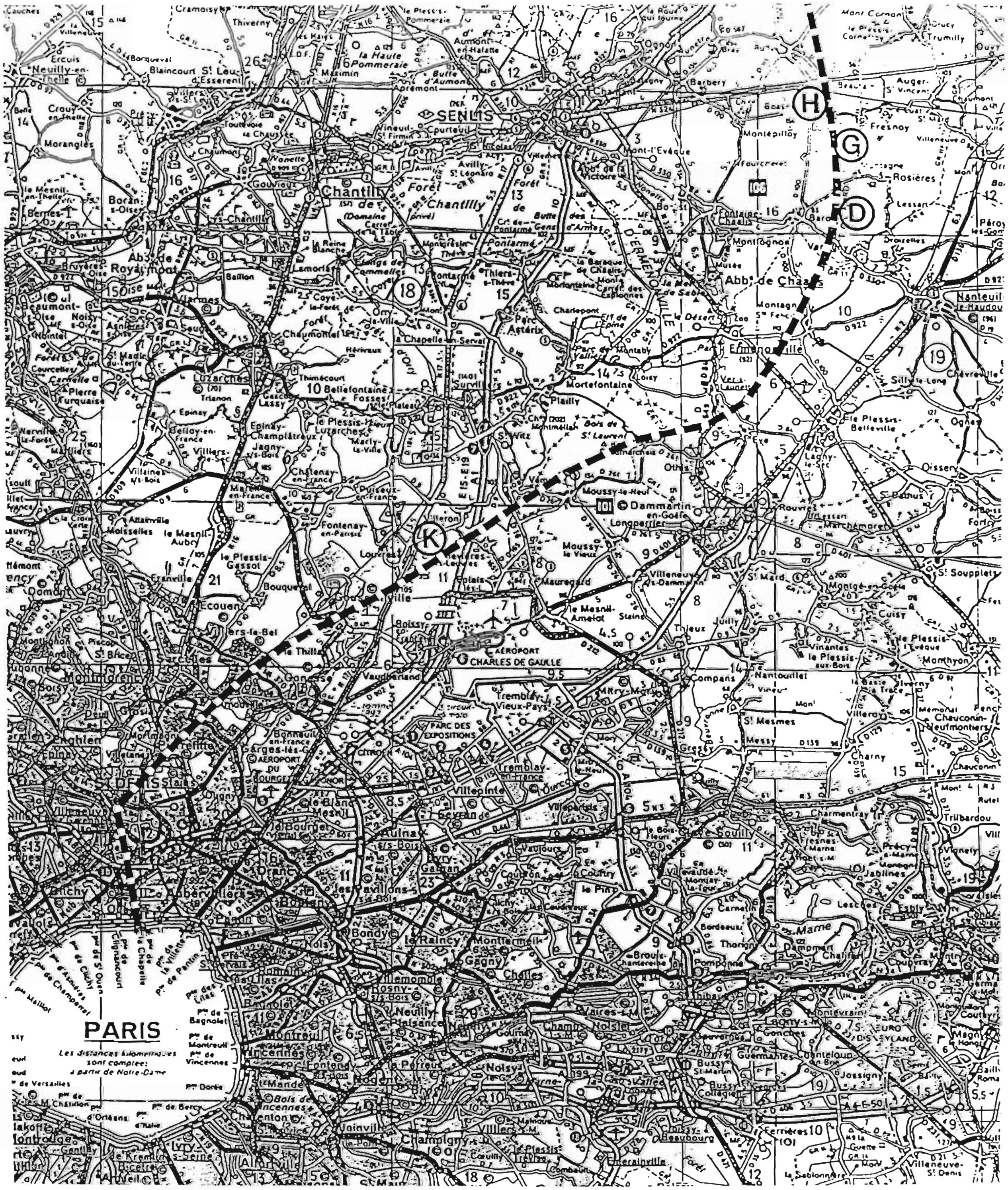


FIGURE 1. FRENCH MEASUREMENT SITE VICINITY MAP

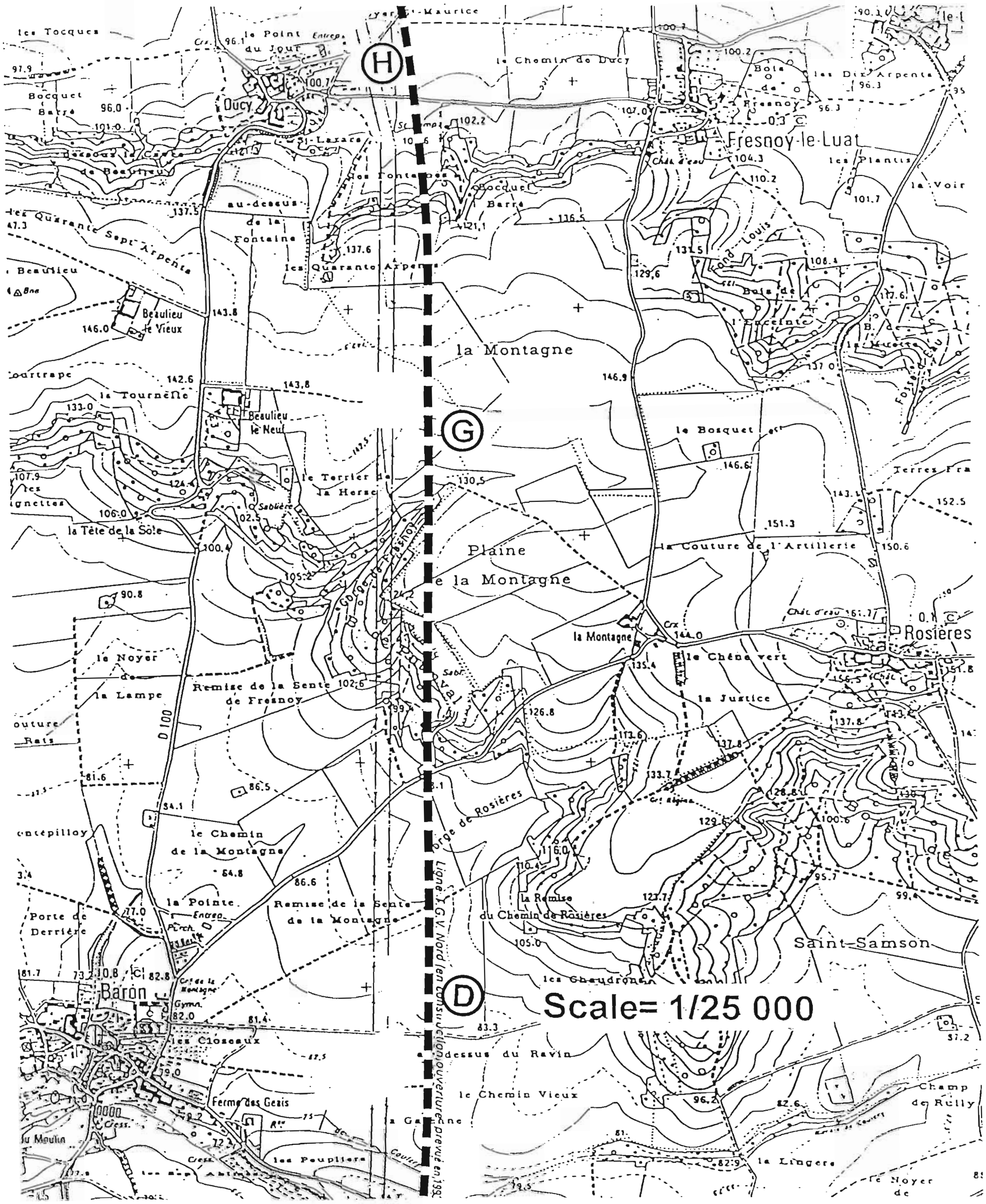


FIGURE 2. LOCATION MAP OF FRENCH MEASUREMENT SITES D, G AND H

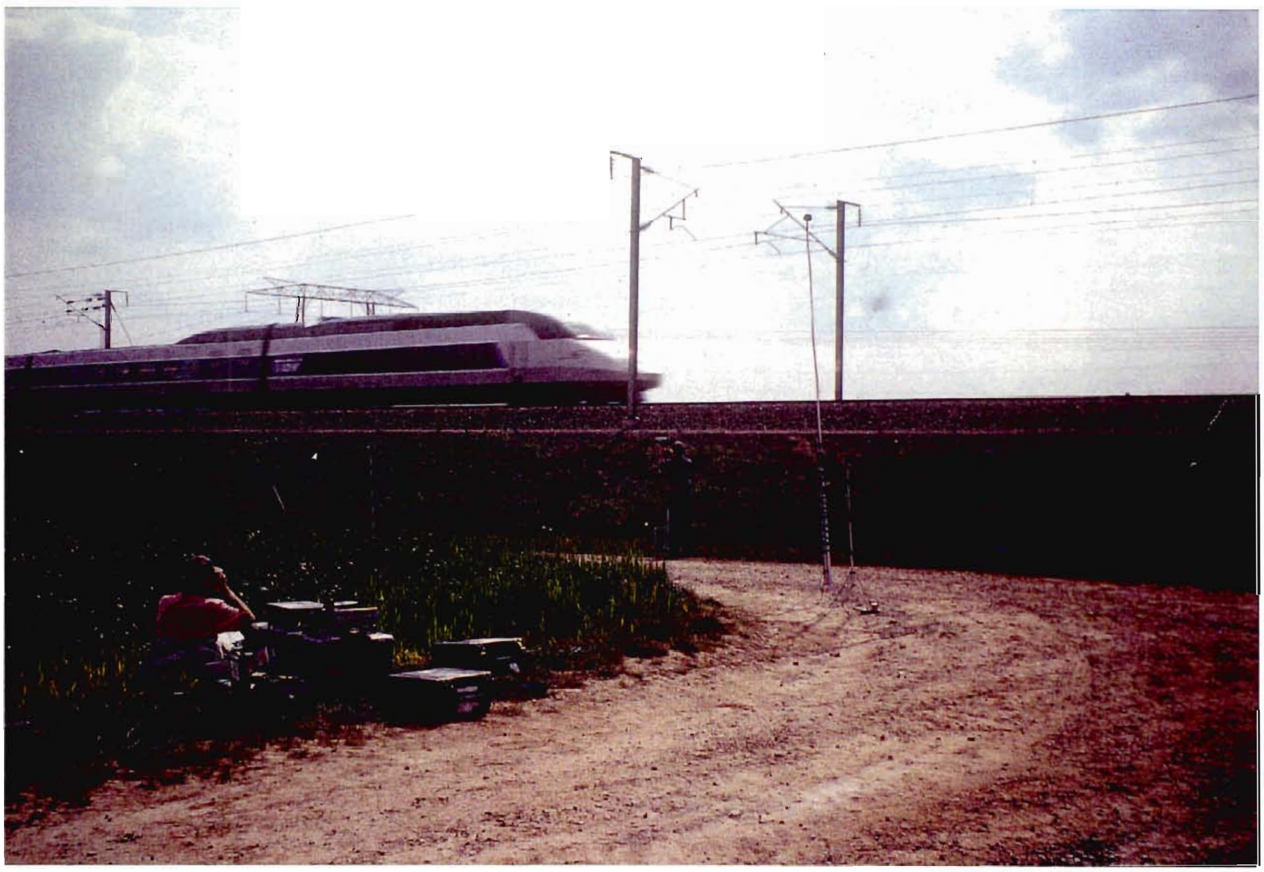


FIGURE 3. PHOTOGRAPH OF FRENCH MEASUREMENT SITE D

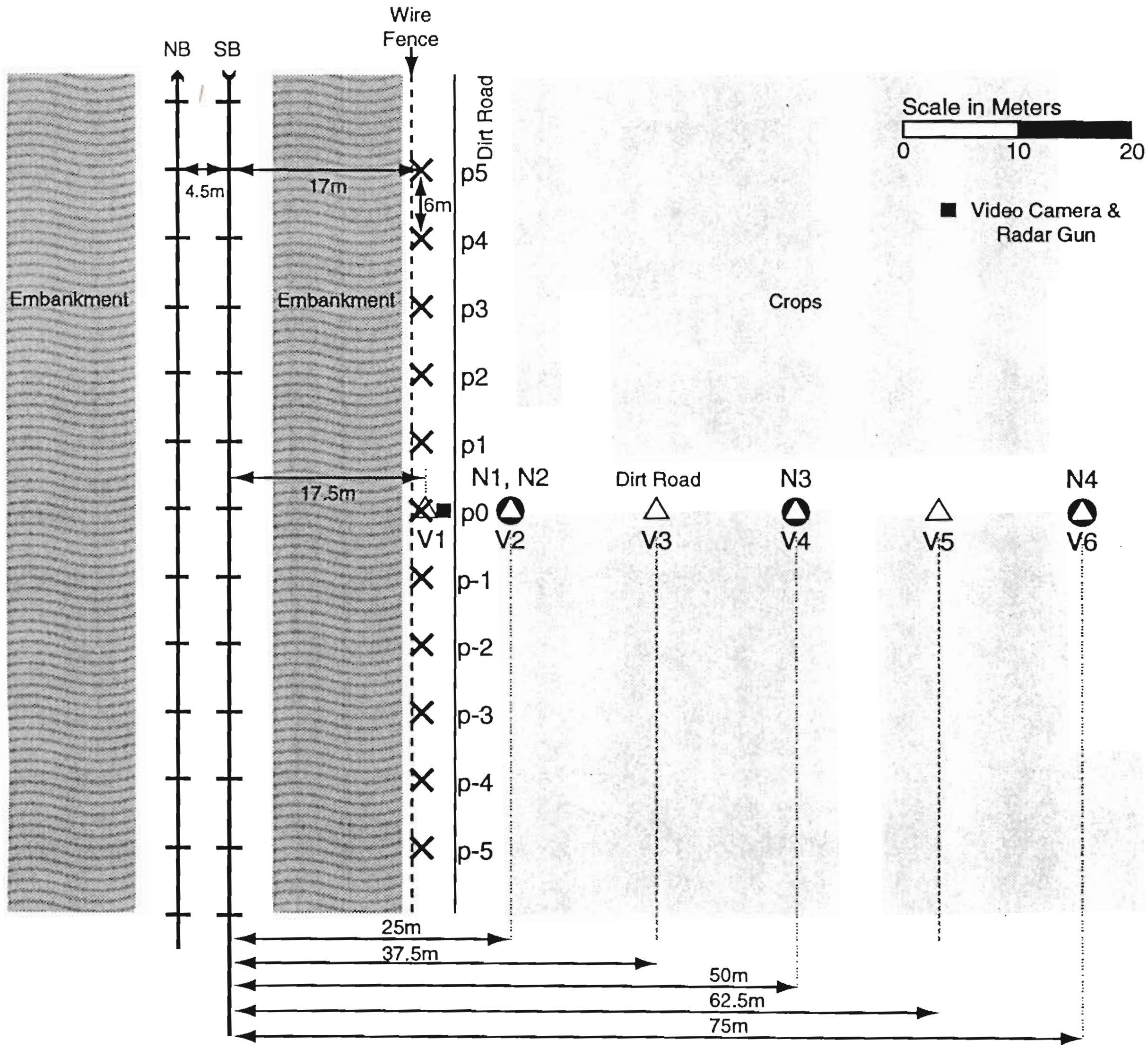


FIGURE 4A. PLAN VIEW OF FRENCH MEASUREMENT SITE D

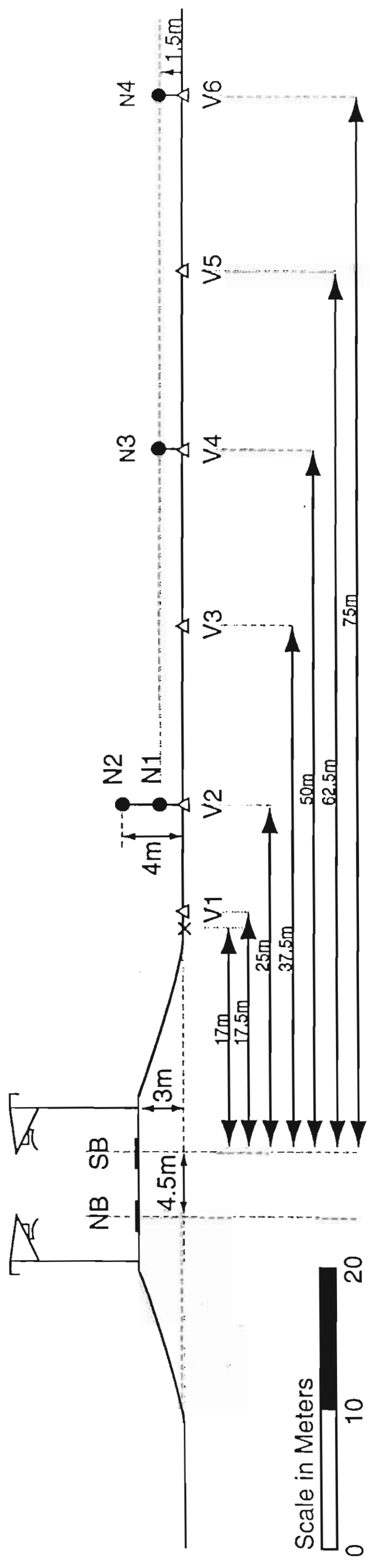


FIGURE 4B. CROSS-SECTIONAL VIEW OF FRENCH MEASUREMENT SITE D

FIGURE 5. PHOTOGRAPH OF FRENCH MEASUREMENT SITE G

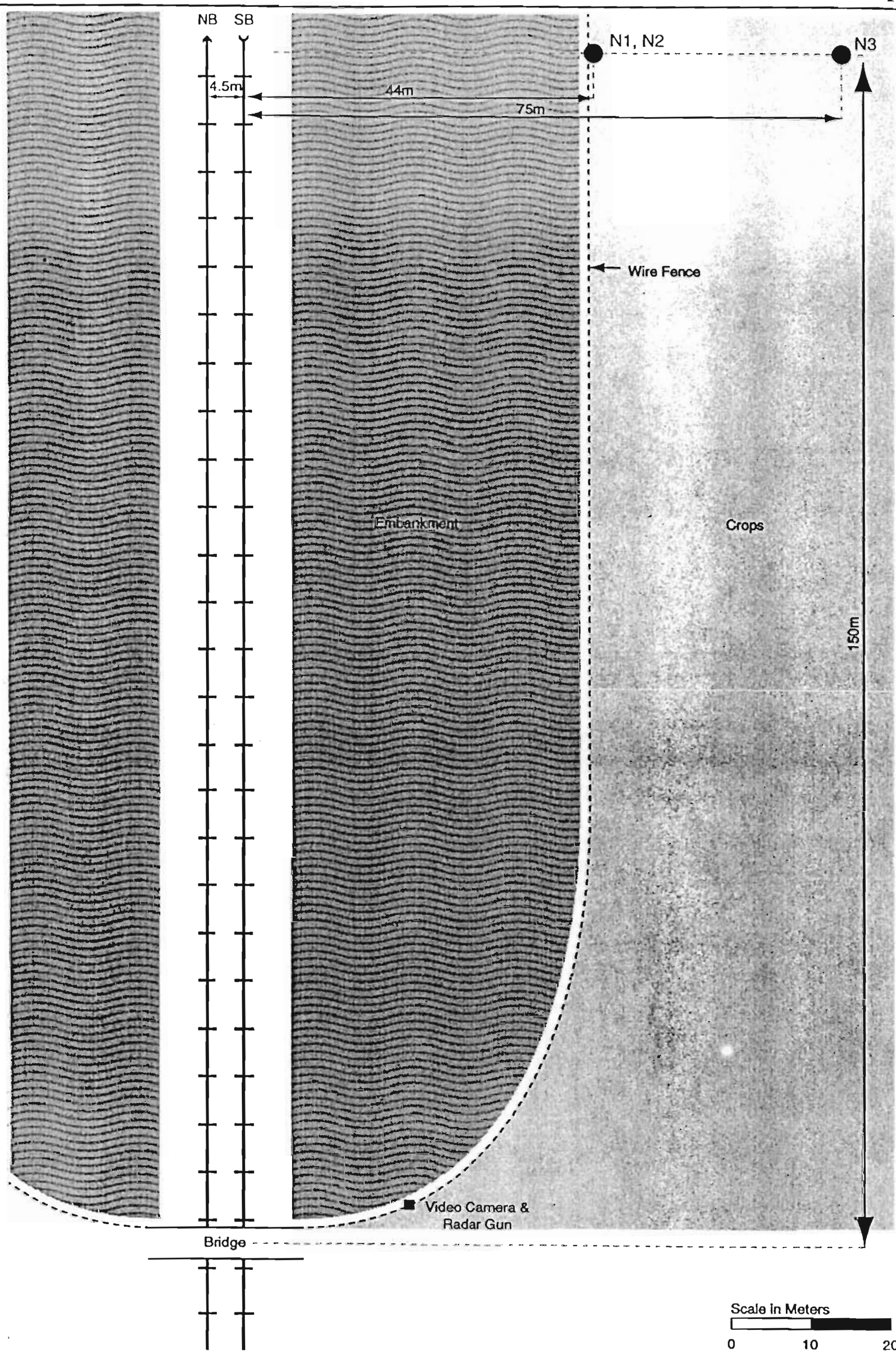


FIGURE 6A. PLAN VIEW OF FRENCH MEASUREMENT SITE G

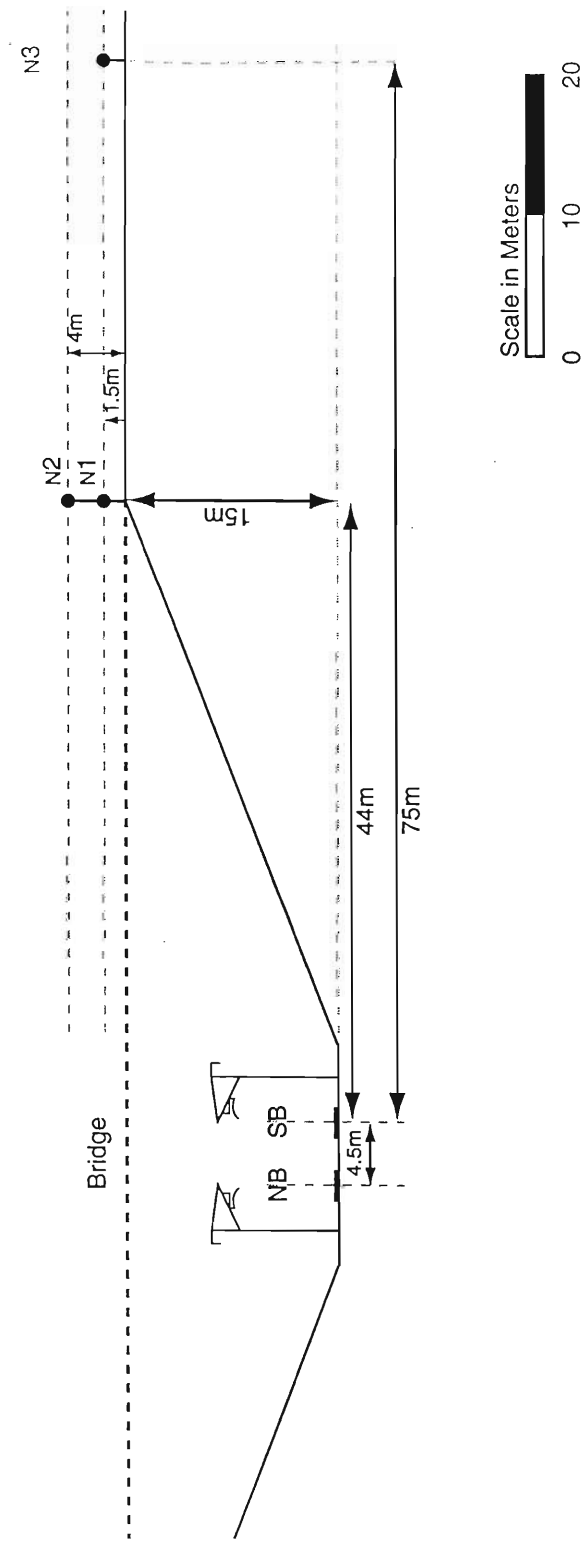


FIGURE 6B. CROSS-SECTIONAL VIEW OF FRENCH MEASUREMENT SITE G

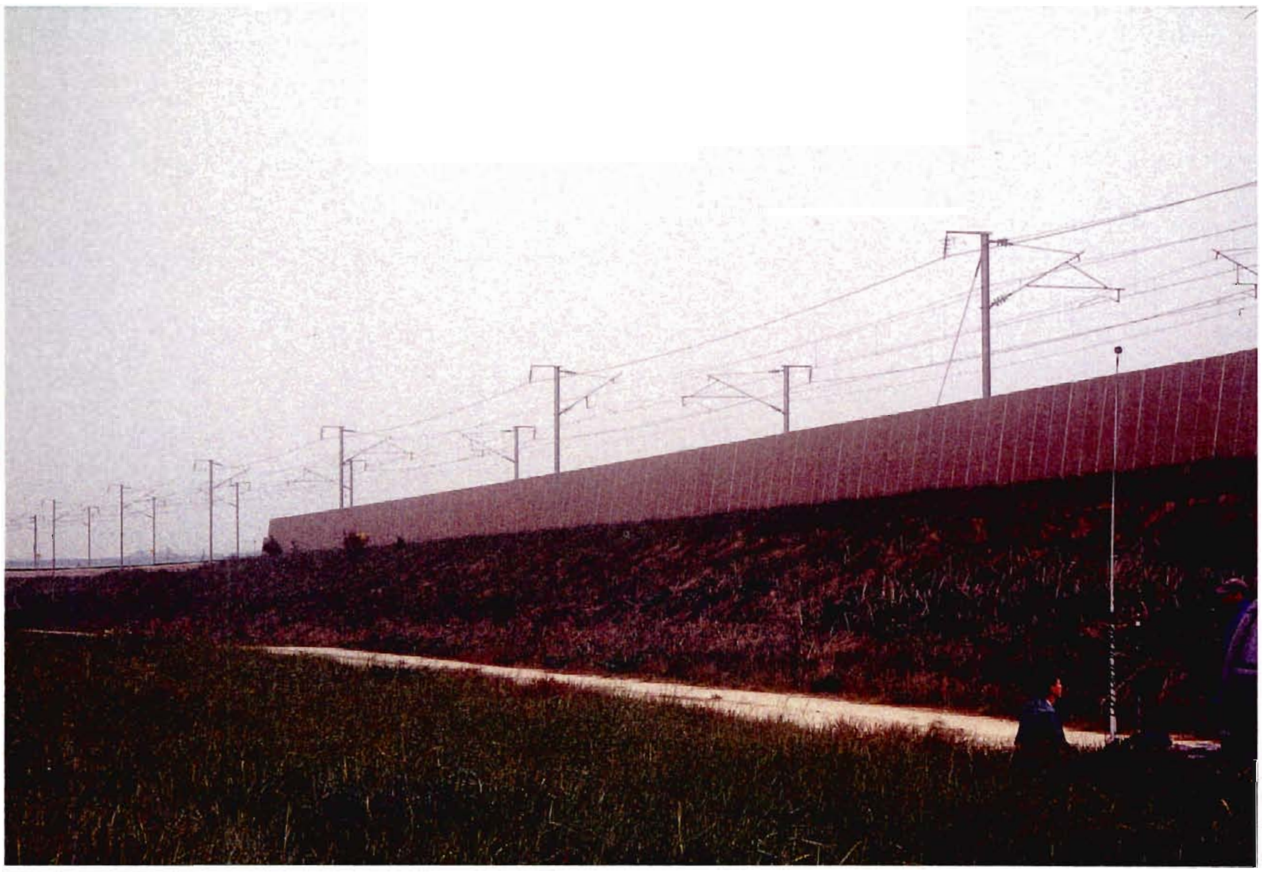


FIGURE 7. PHOTOGRAPH OF FRENCH MEASUREMENT SITE H

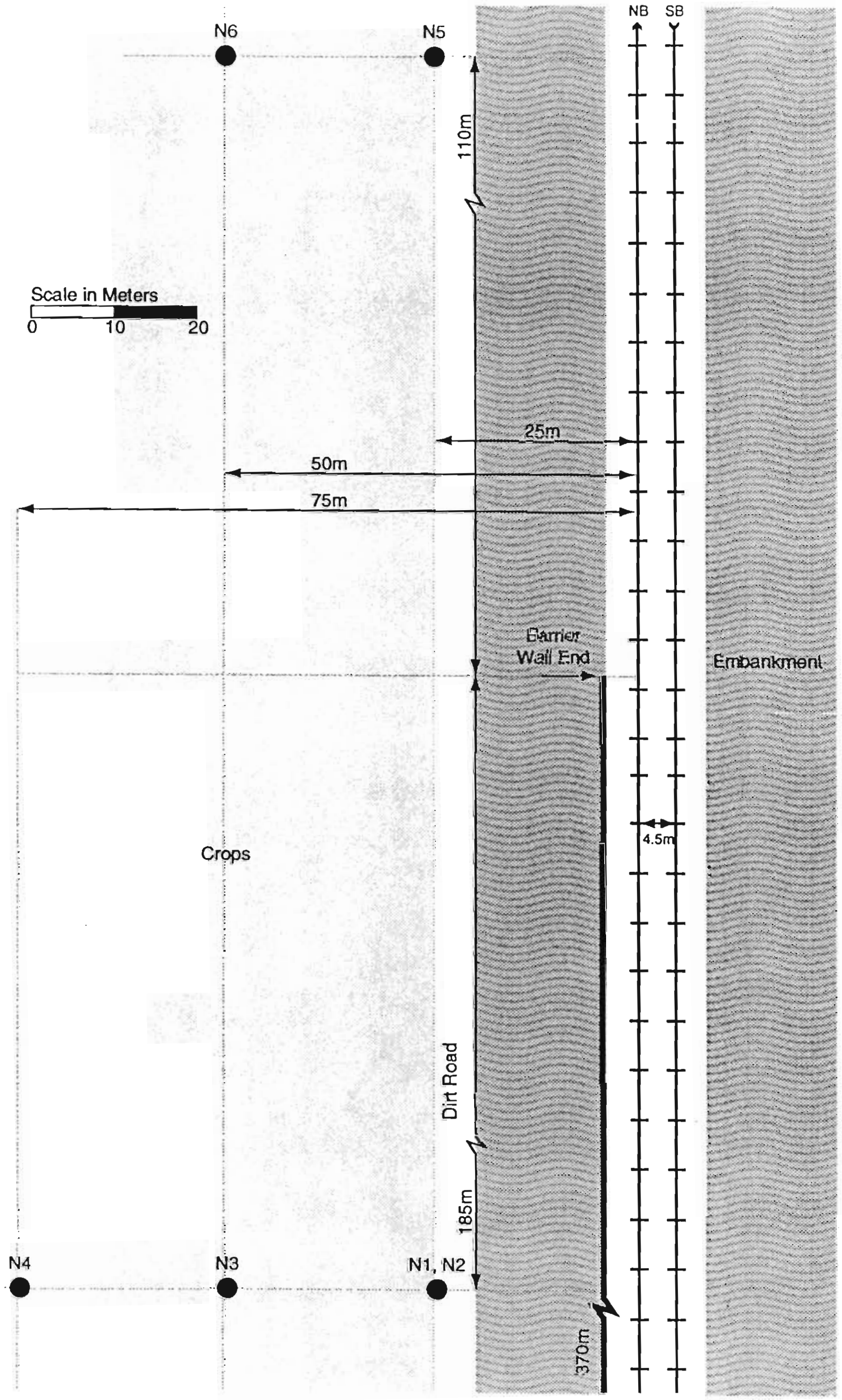


FIGURE 8A. PLAN VIEW OF FRENCH MEASUREMENT SITE H

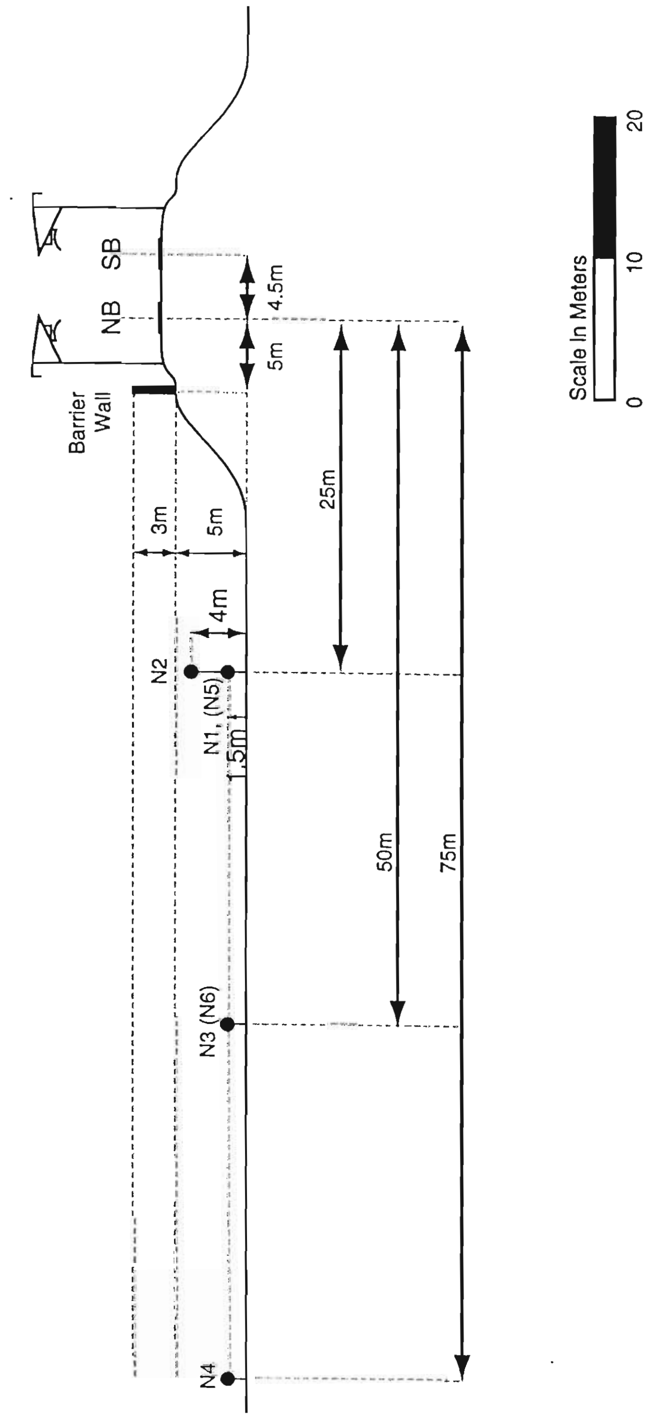


FIGURE 8B. CROSS-SECTIONAL VIEW OF FRENCH MEASUREMENT SITE H

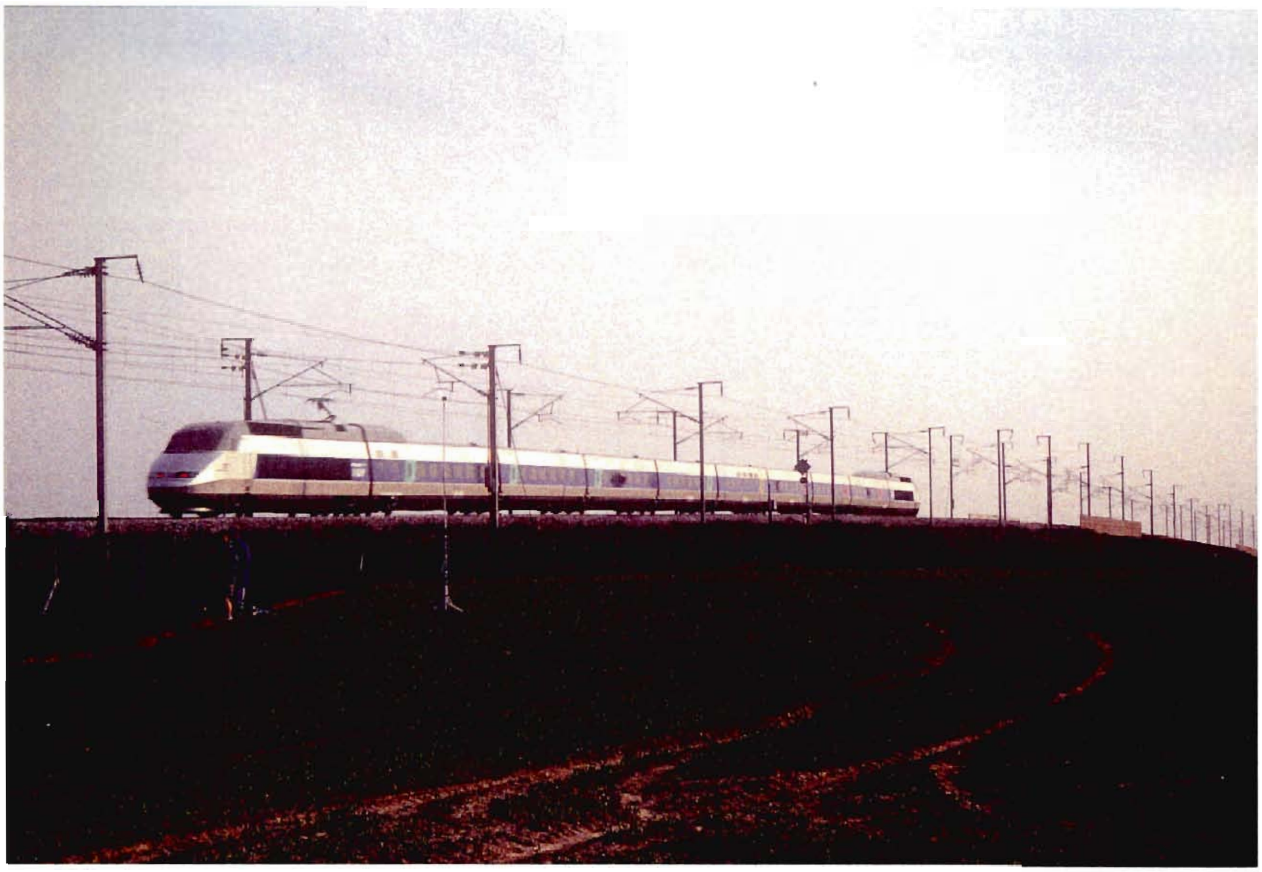


FIGURE 9. PHOTOGRAPH OF FRENCH MEASUREMENT SITE K

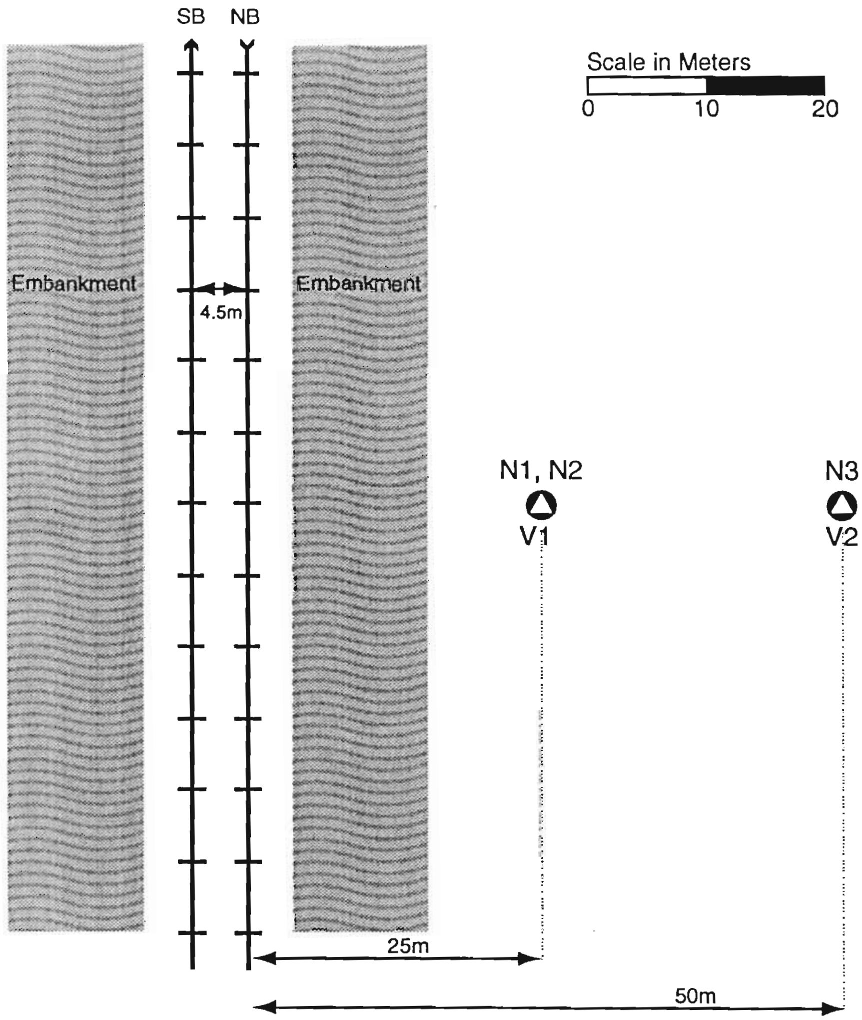


FIGURE 10A. PLAN VIEW OF FRENCH MEASUREMENT SITE K

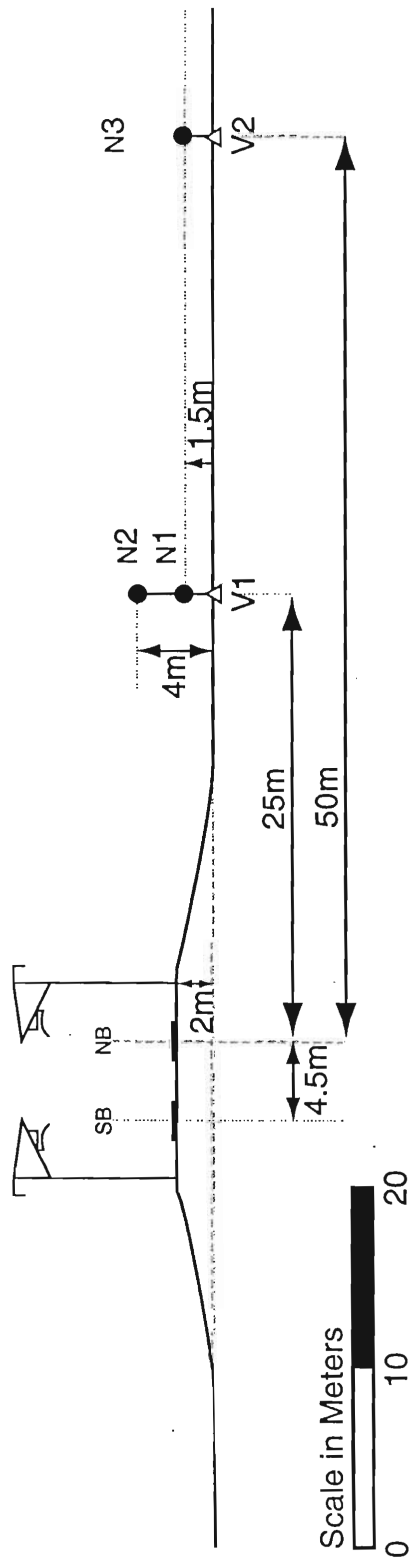


FIGURE 10B. CROSS-SECTIONAL VIEW OF FRENCH MEASUREMENT SITE K

FIGURE 11. PHOTOGRAPH OF TGV HAUTE PICARDIE STATION

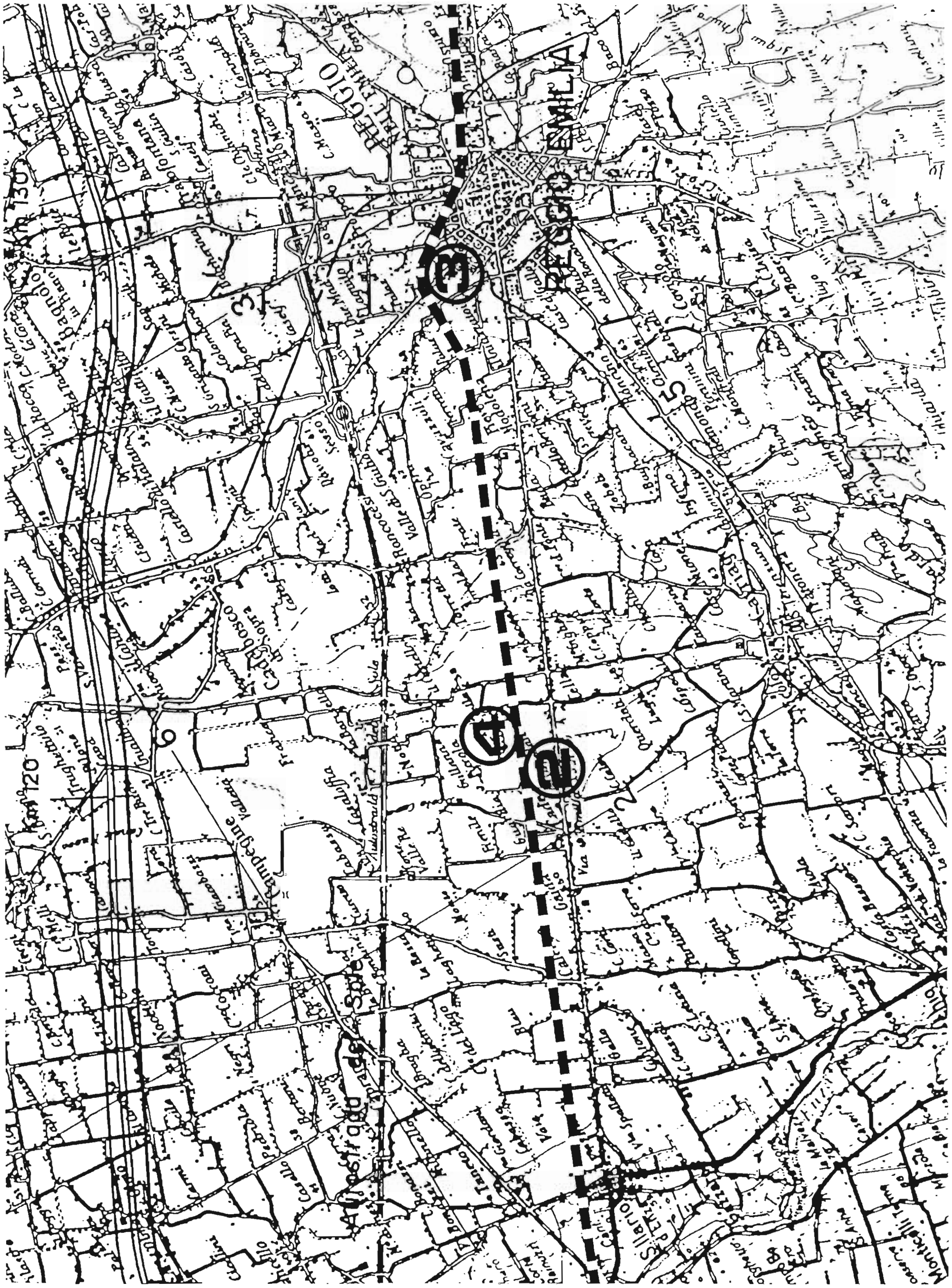


FIGURE 12. ITALIAN MEASUREMENT SITE VICINITY MAP

FIGURE 13. PHOTOGRAPH OF ITALIAN MEASUREMENT SITE 2

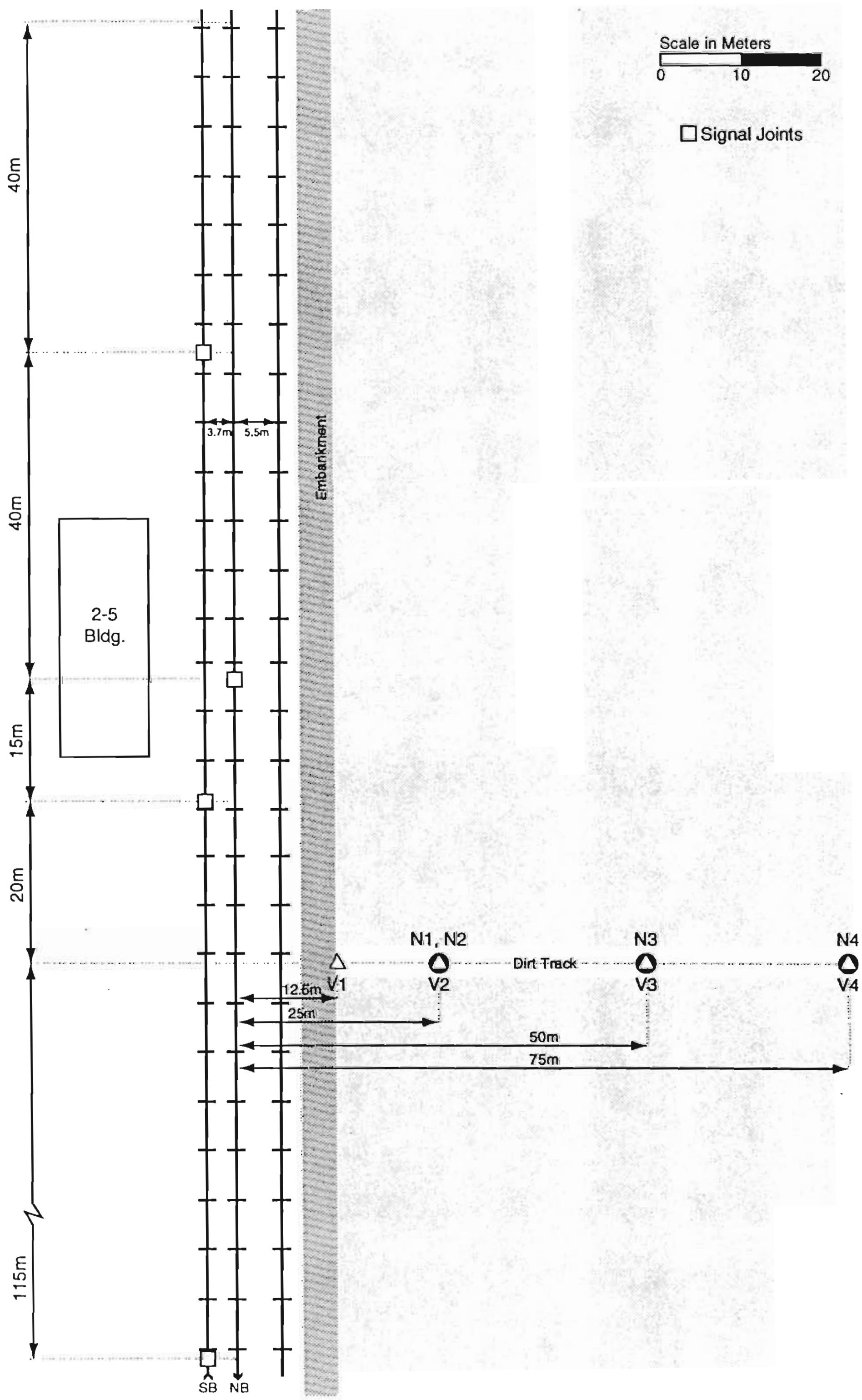


FIGURE 14A. PLAN VIEW OF ITALIAN MEASUREMENT SITE 2

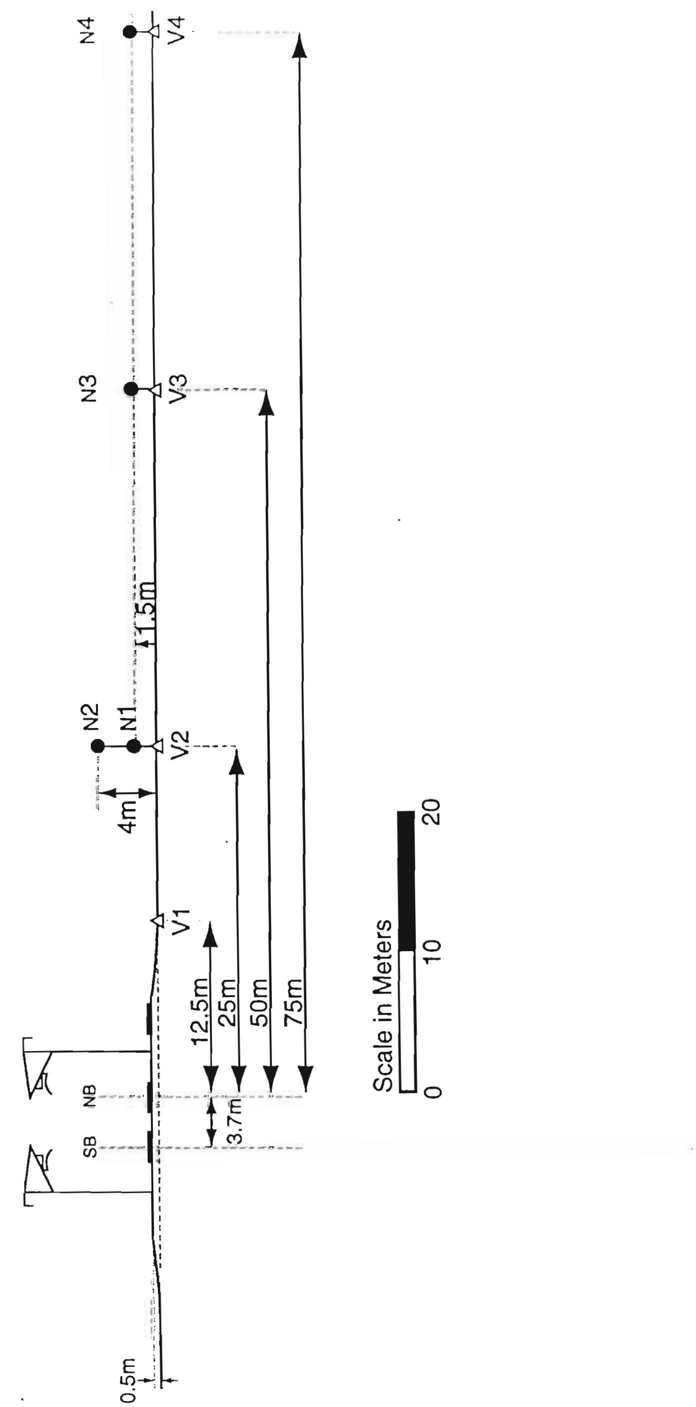


FIGURE 14B. CROSS-SECTIONAL VIEW OF ITALIAN MEASUREMENT SITE 2

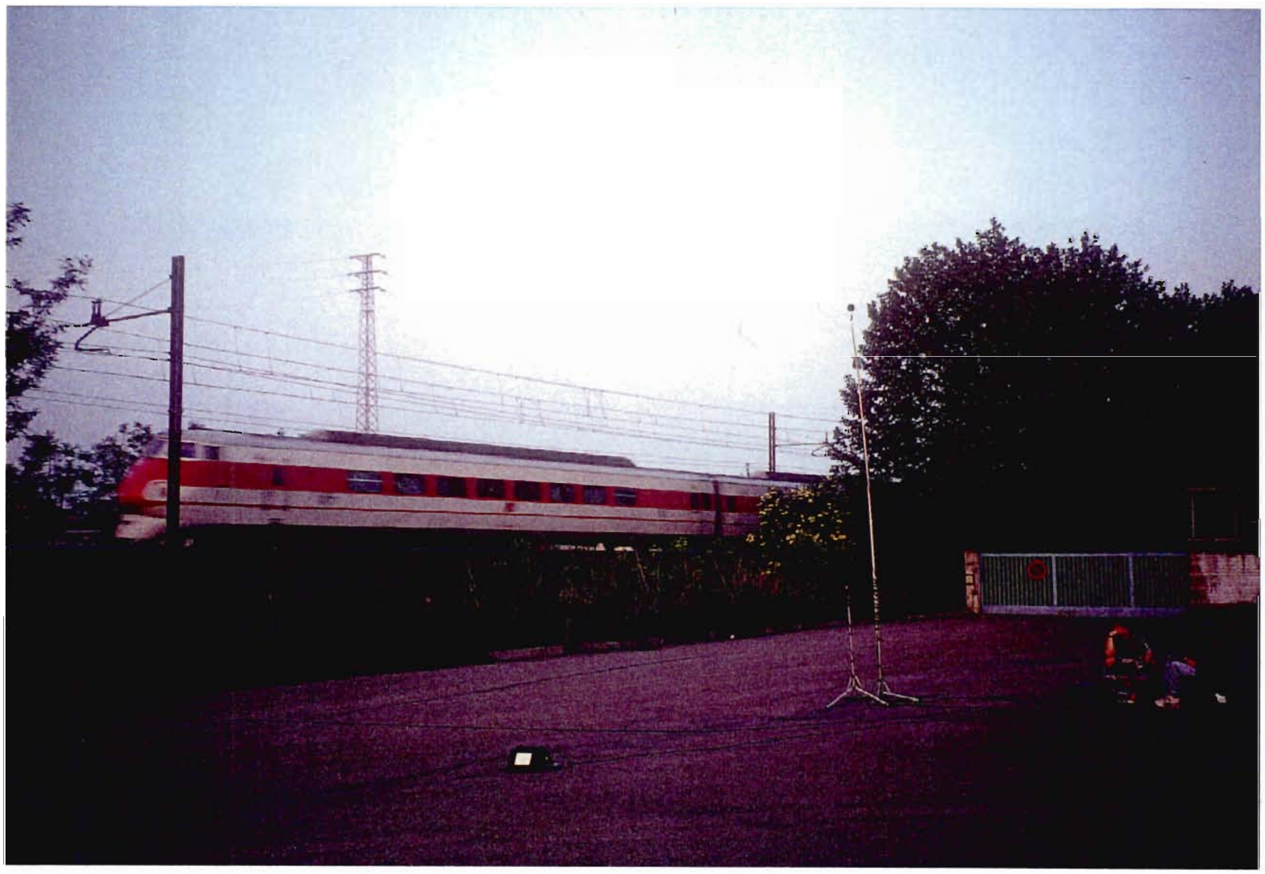


FIGURE 15. PHOTOGRAPH OF ITALIAN MEASUREMENT SITE 3

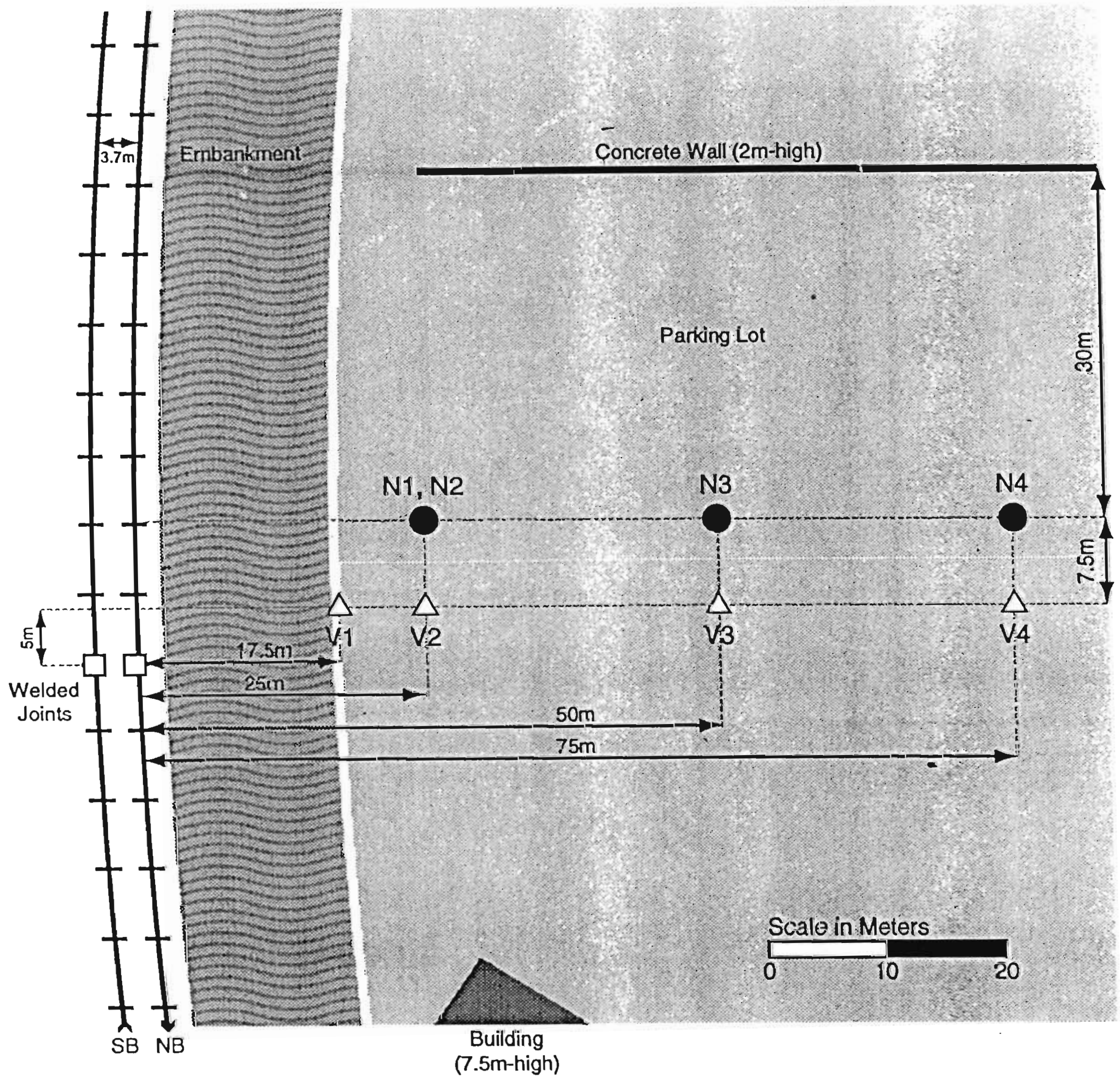


FIGURE 16A. PLAN VIEW OF ITALIAN MEASUREMENT SITE 3

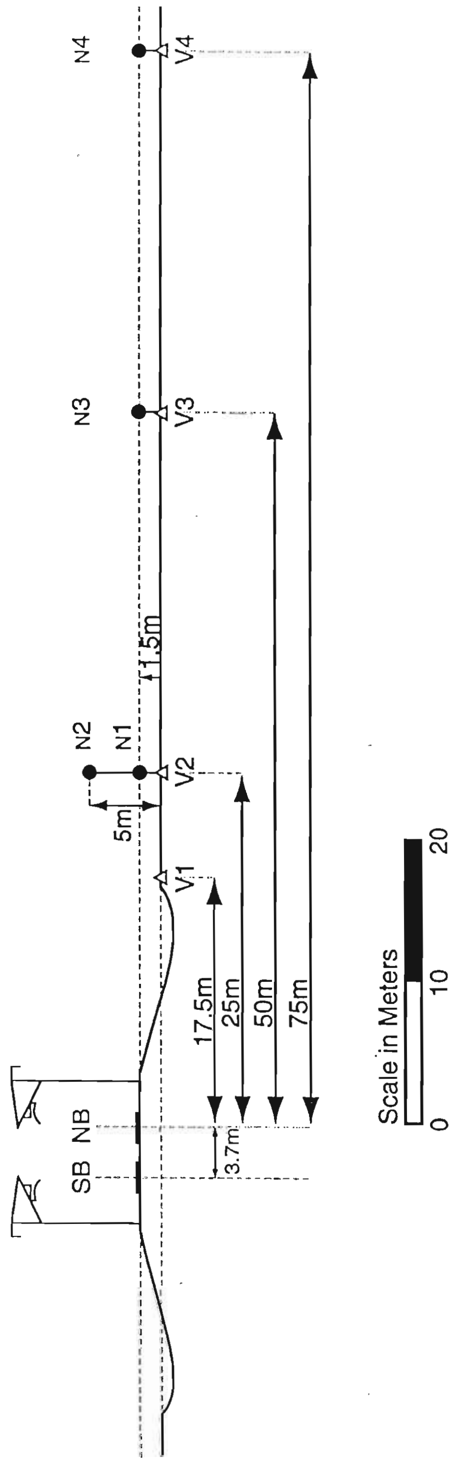


FIGURE 16B. CROSS-SECTIONAL VIEW OF ITALIAN MEASUREMENT SITE 3

FIGURE 17. PHOTOGRAPH OF ITALIAN MEASUREMENT SITE 4

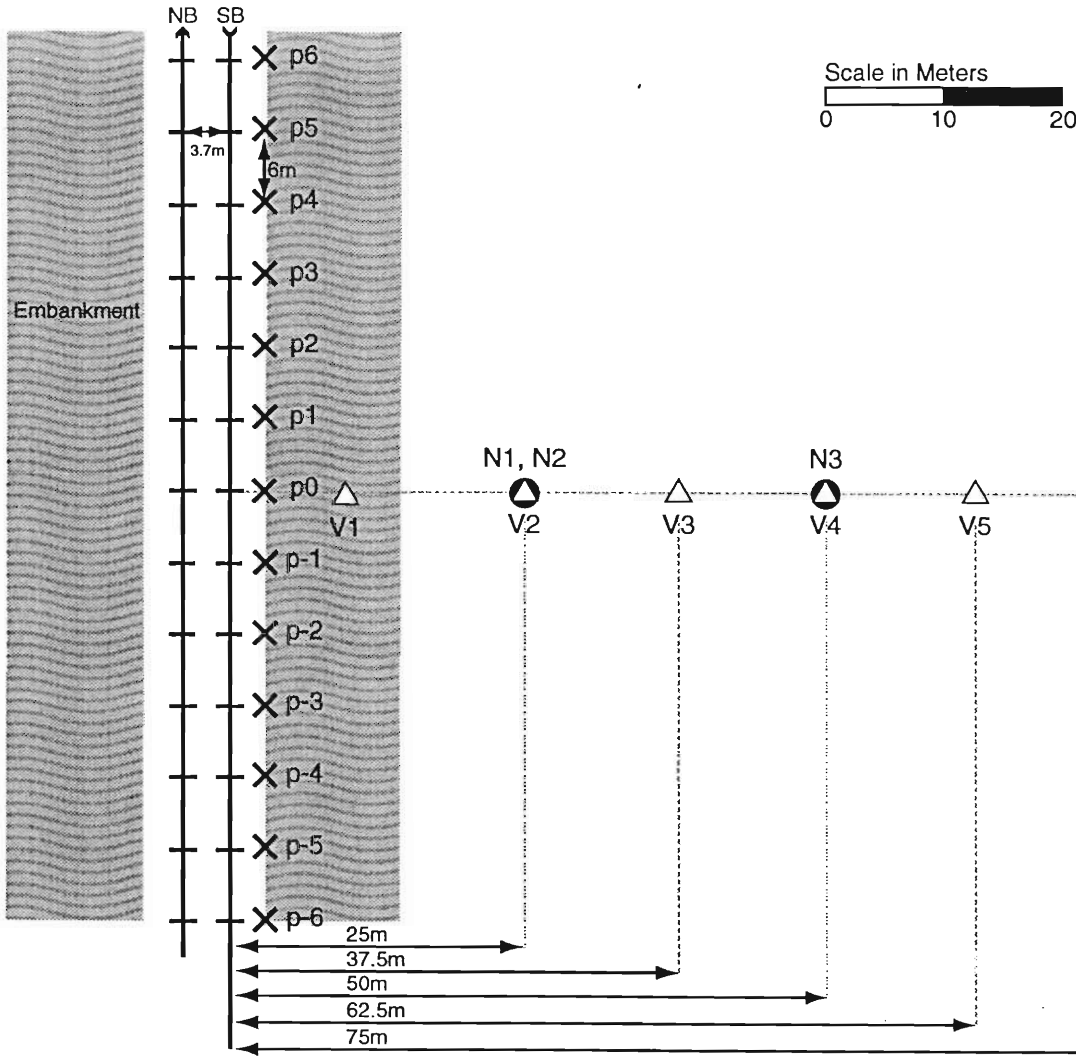


FIGURE 18A. PLAN VIEW OF ITALIAN MEASUREMENT SITE 4

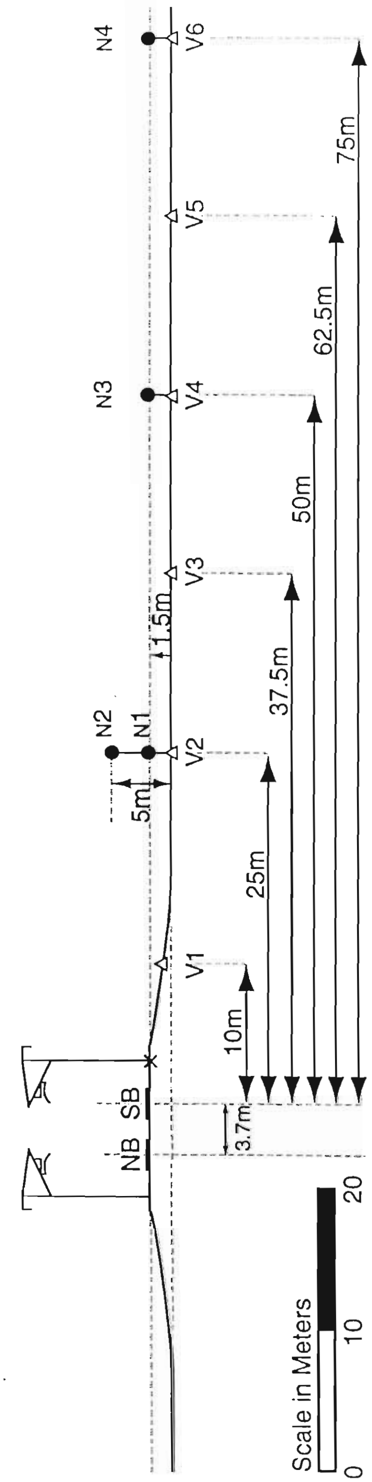


FIGURE 18B. CROSS-SECTIONAL VIEW OF ITALIAN MEASUREMENT SITE 4

FIGURE 19. PHOTOGRAPH OF PARMA STATION

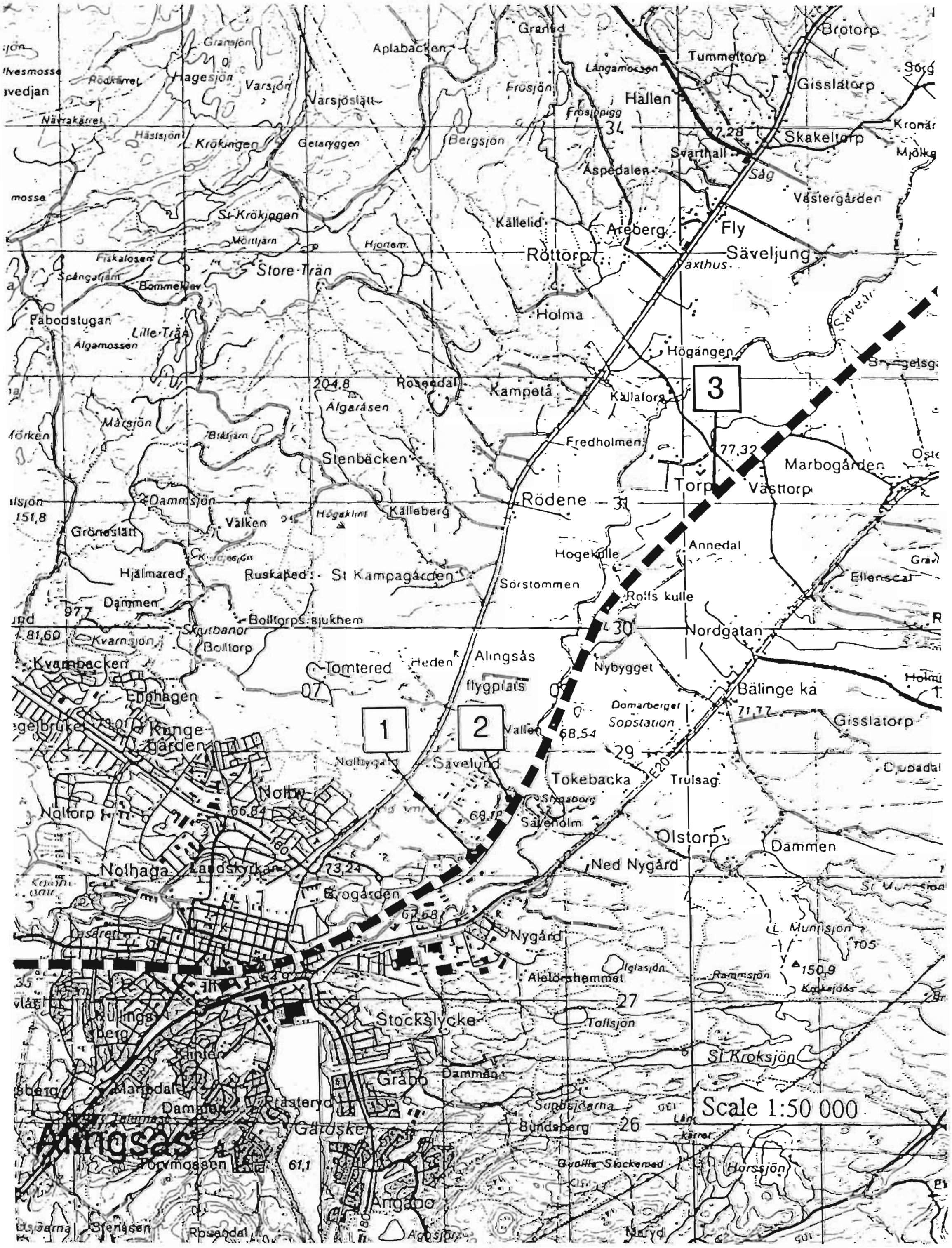


FIGURE 20. LOCATION MAP FOR SWEDISH MEASUREMENT SITES 1, 2 AND 3

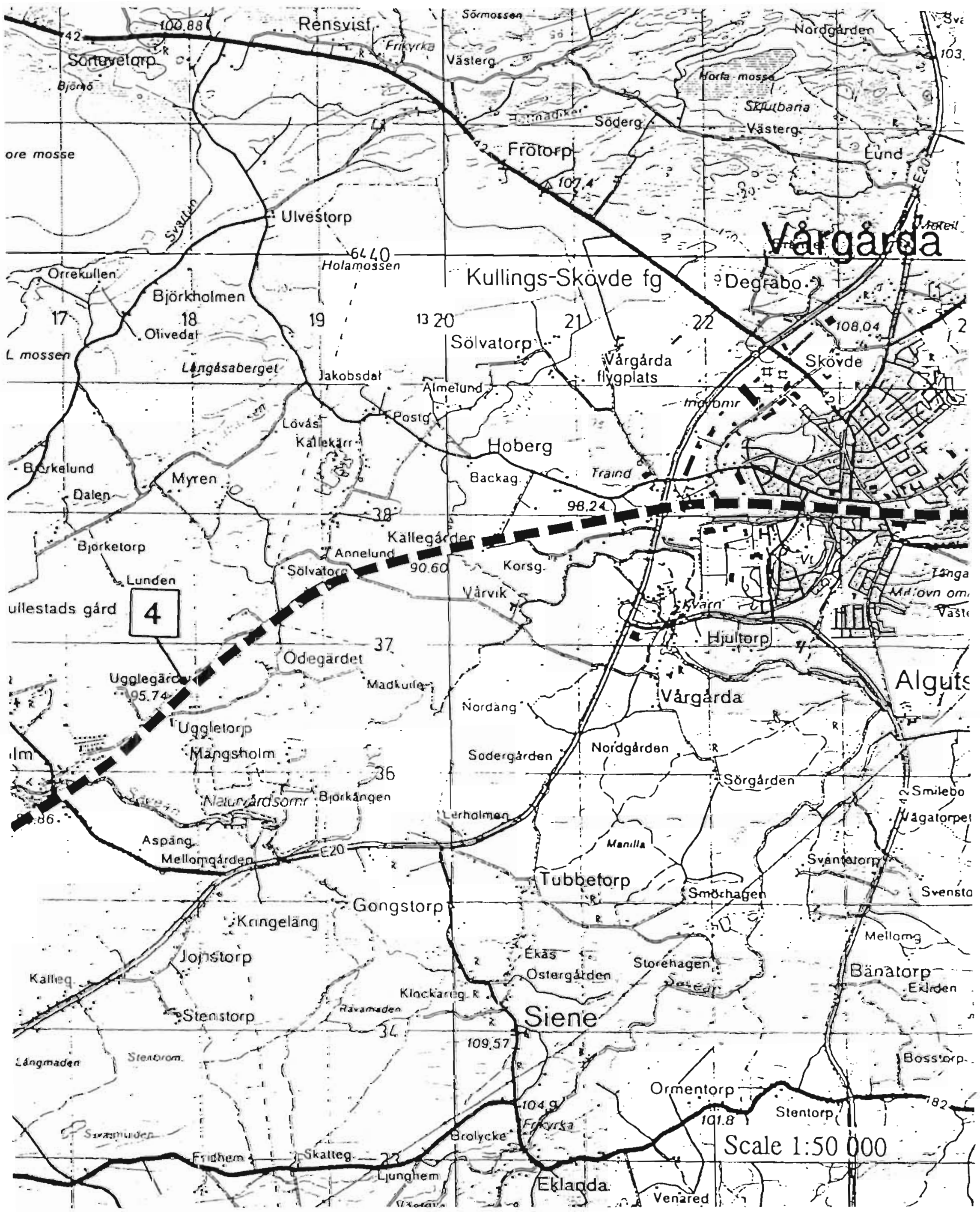


FIGURE 21. LOCATION MAP FOR SWEDISH MEASUREMENT SITE 4

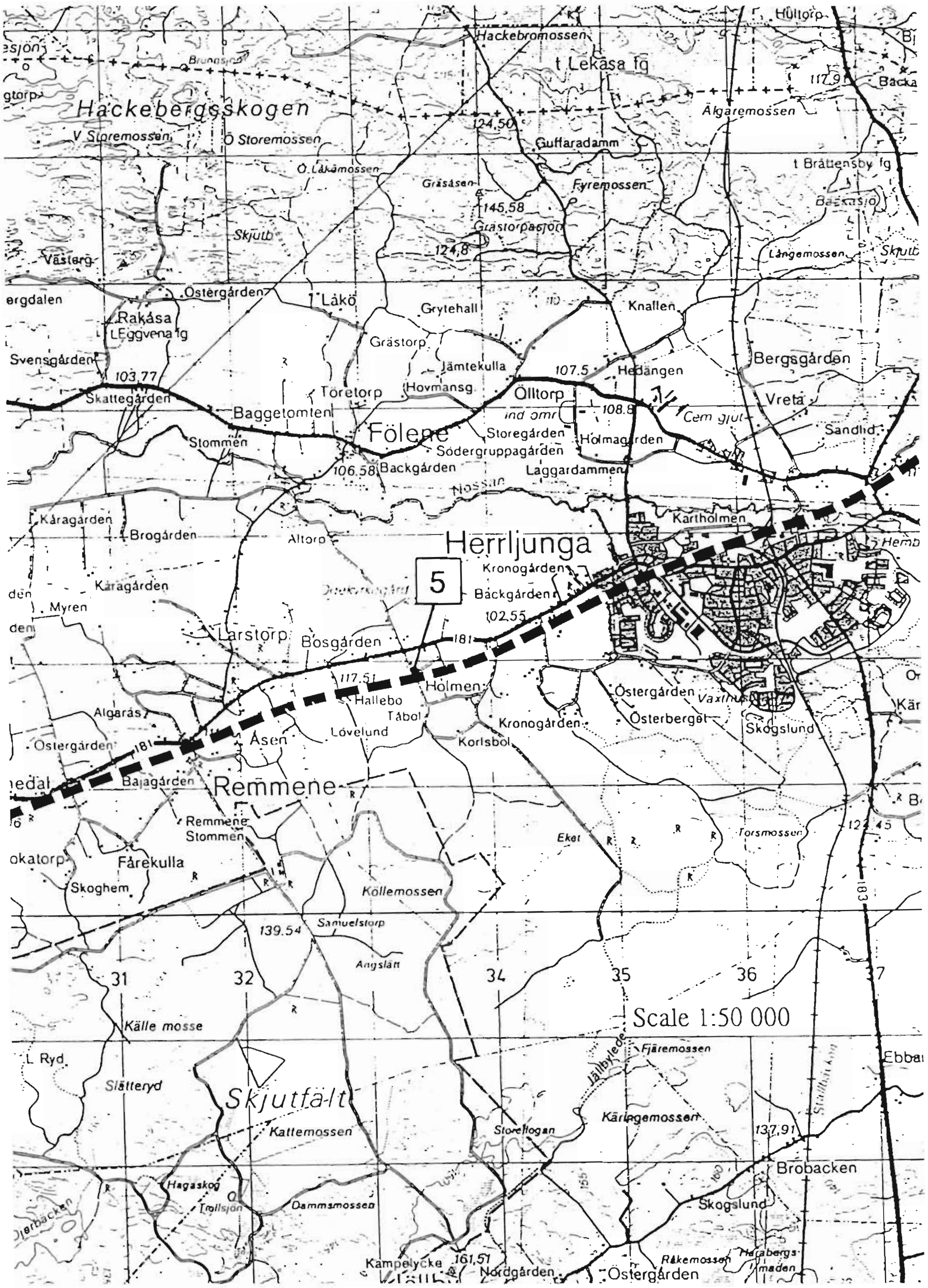


FIGURE 22. LOCATION MAP FOR SWEDISH MEASUREMENT SITE 5

FIGURE 23. PHOTOGRAPH OF SWEDISH MEASUREMENT SITE 1

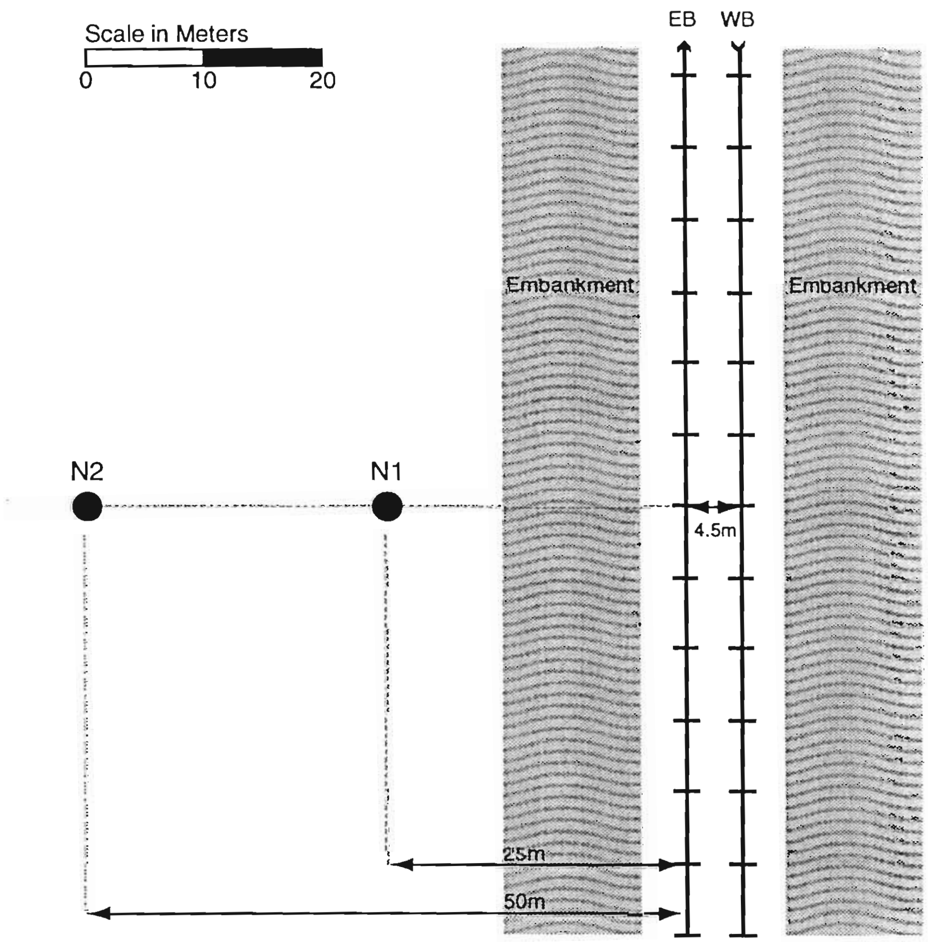


FIGURE 24A. PLAN VIEW OF SWEDISH MEASUREMENT SITE 1

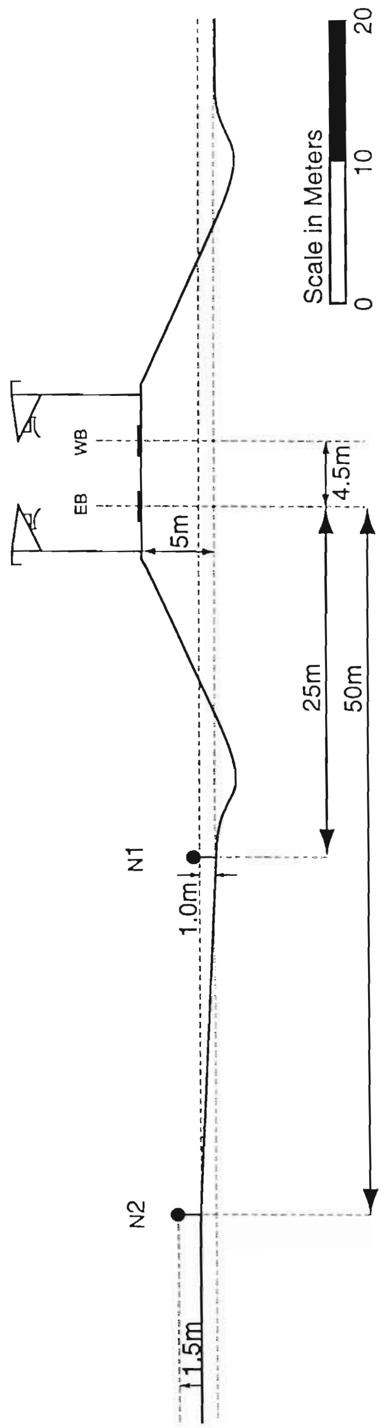


FIGURE 24B. CROSS-SECTIONAL VIEW OF SWEDISH MEASUREMENT SITE 1

FIGURE 25. PHOTOGRAPH OF SWEDISH MEASUREMENT SITE 2

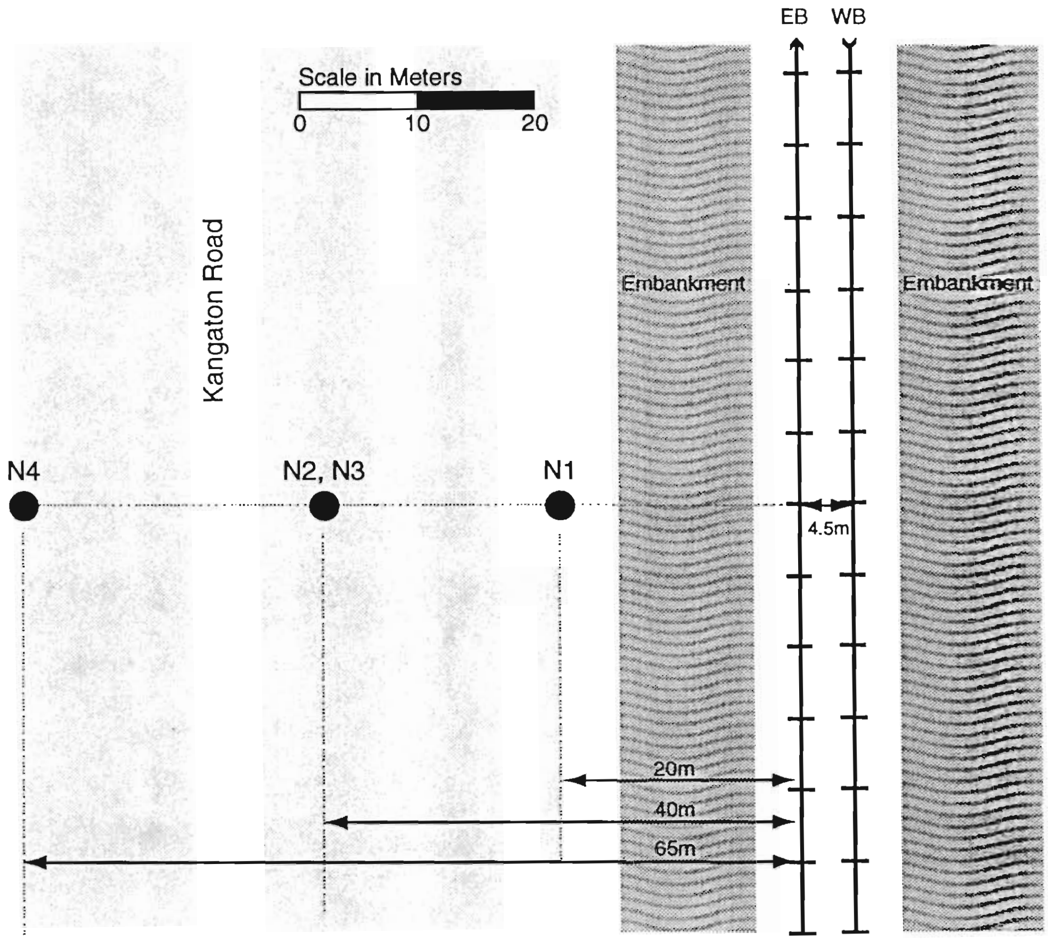


FIGURE 26A. PLAN VIEW OF SWEDISH MEASUREMENT SITE 2

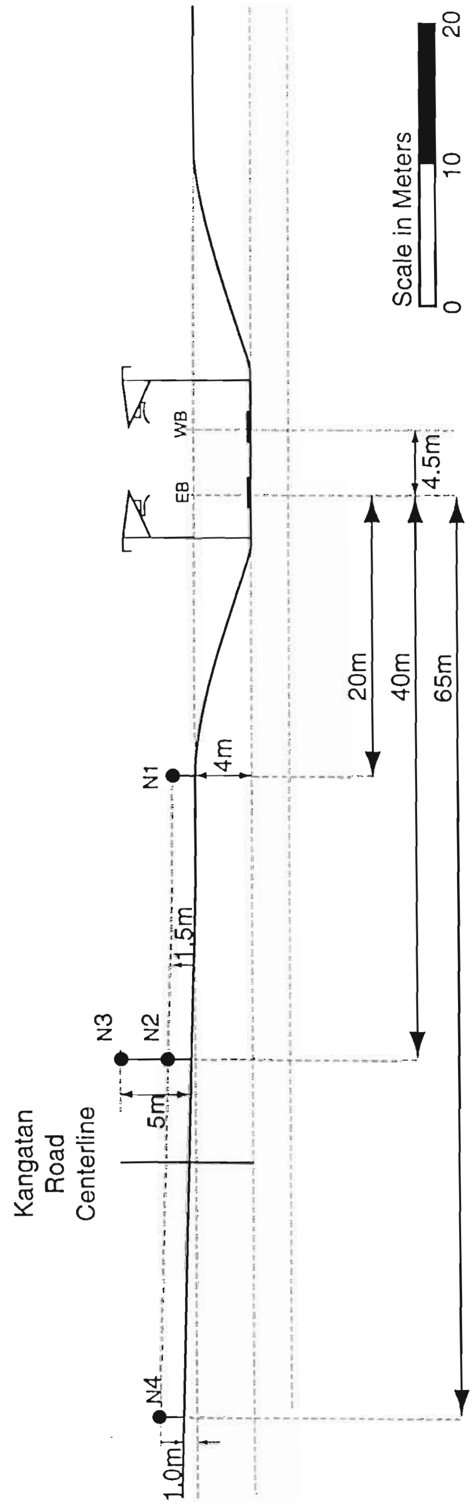


FIGURE 26B. CROSS-SECTIONAL VIEW OF SWEDISH MEASUREMENT SITE 2

FIGURE 27. PHOTOGRAPH OF SWEDISH MEASUREMENT SITE 3A

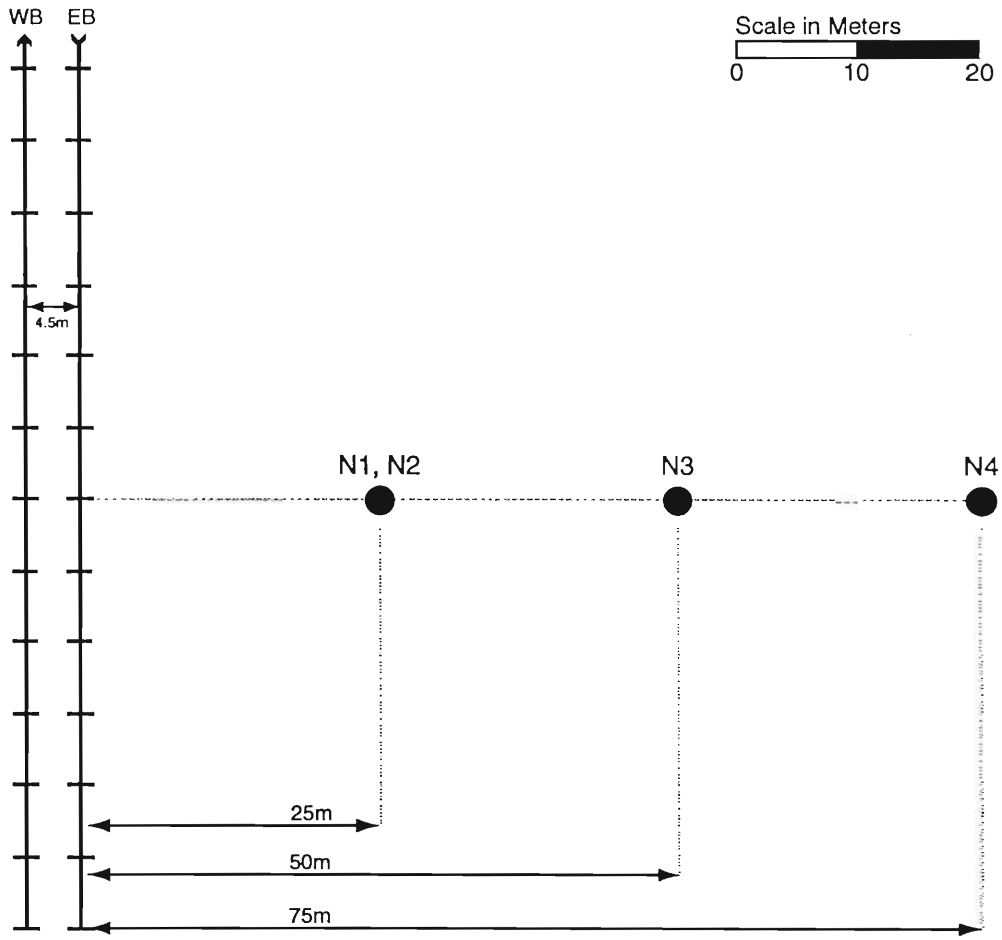


FIGURE 28A. PLAN VIEW OF SWEDISH MEASUREMENT SITE 3A

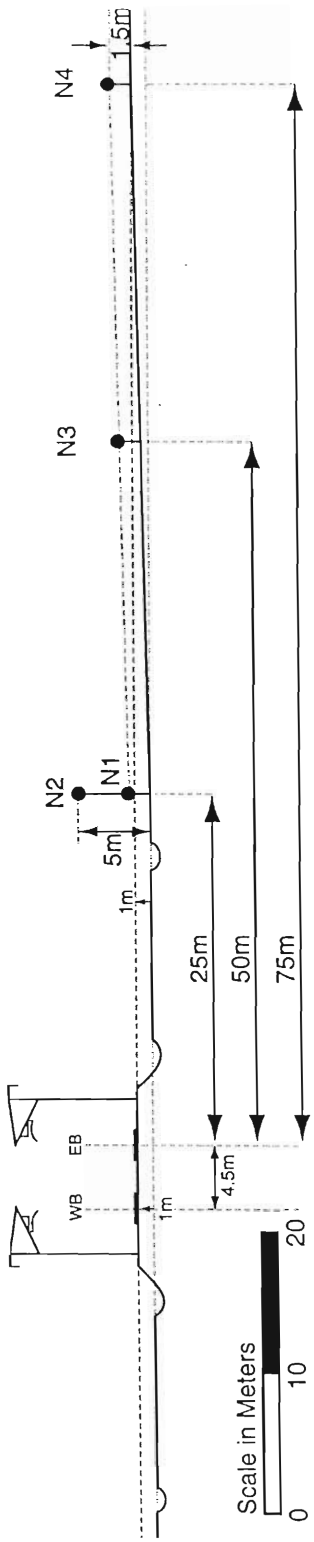


FIGURE 28B. CROSS-SECTIONAL VIEW OF SWEDISH MEASUREMENT SITE 3A

FIGURE 29. PHOTOGRAPH OF SWEDISH MEASUREMENT SITE 3B

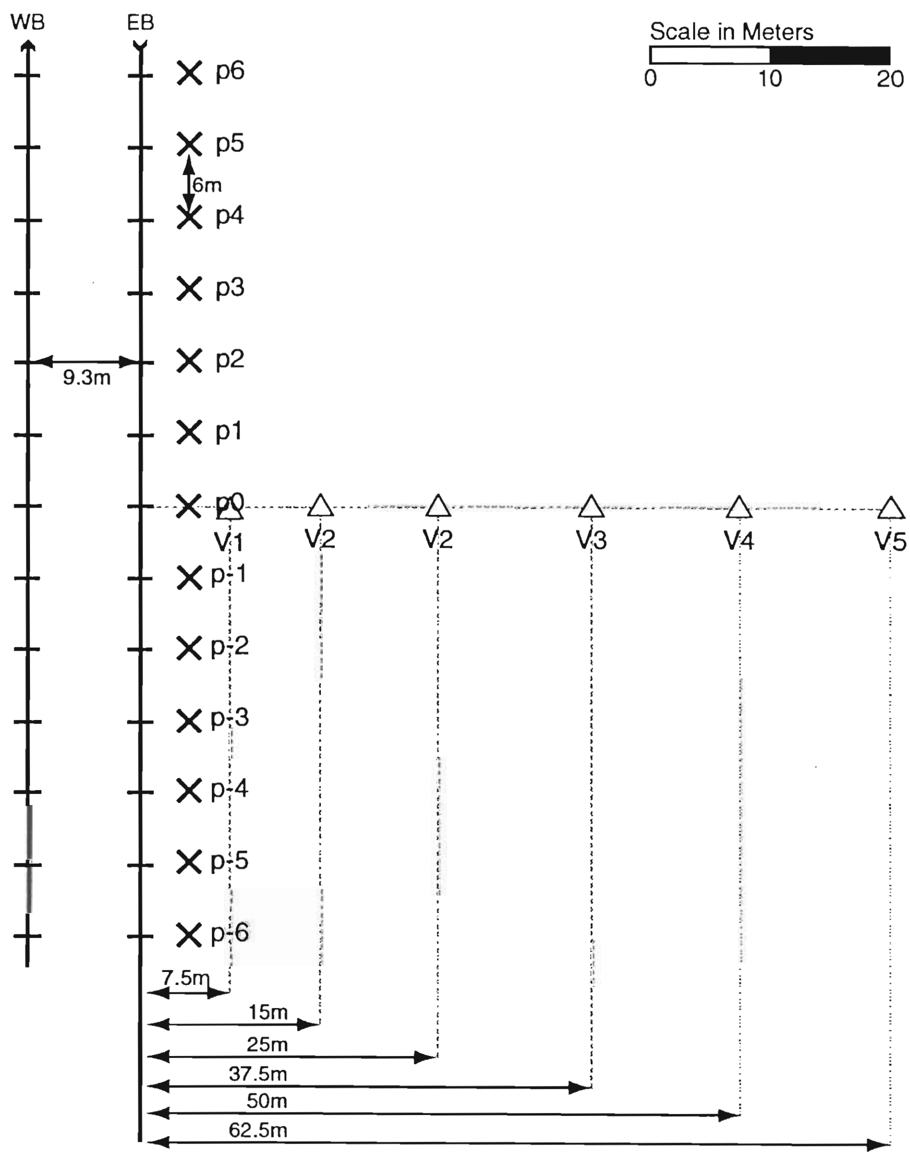


FIGURE 30A. PLAN VIEW OF SWEDISH MEASUREMENT SITE 3B

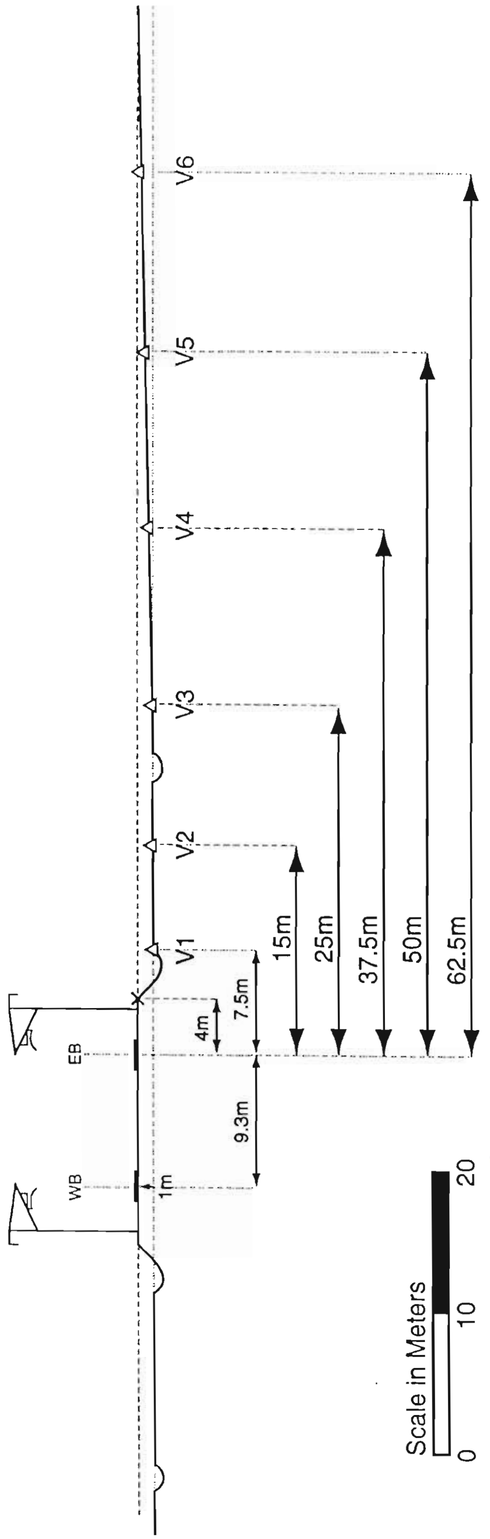


FIGURE 30B. CROSS-SECTIONAL VIEW OF SWEDISH MEASUREMENT SITE 3B

FIGURE 31. PHOTOGRAPH OF SWEDISH MEASUREMENT SITE 4

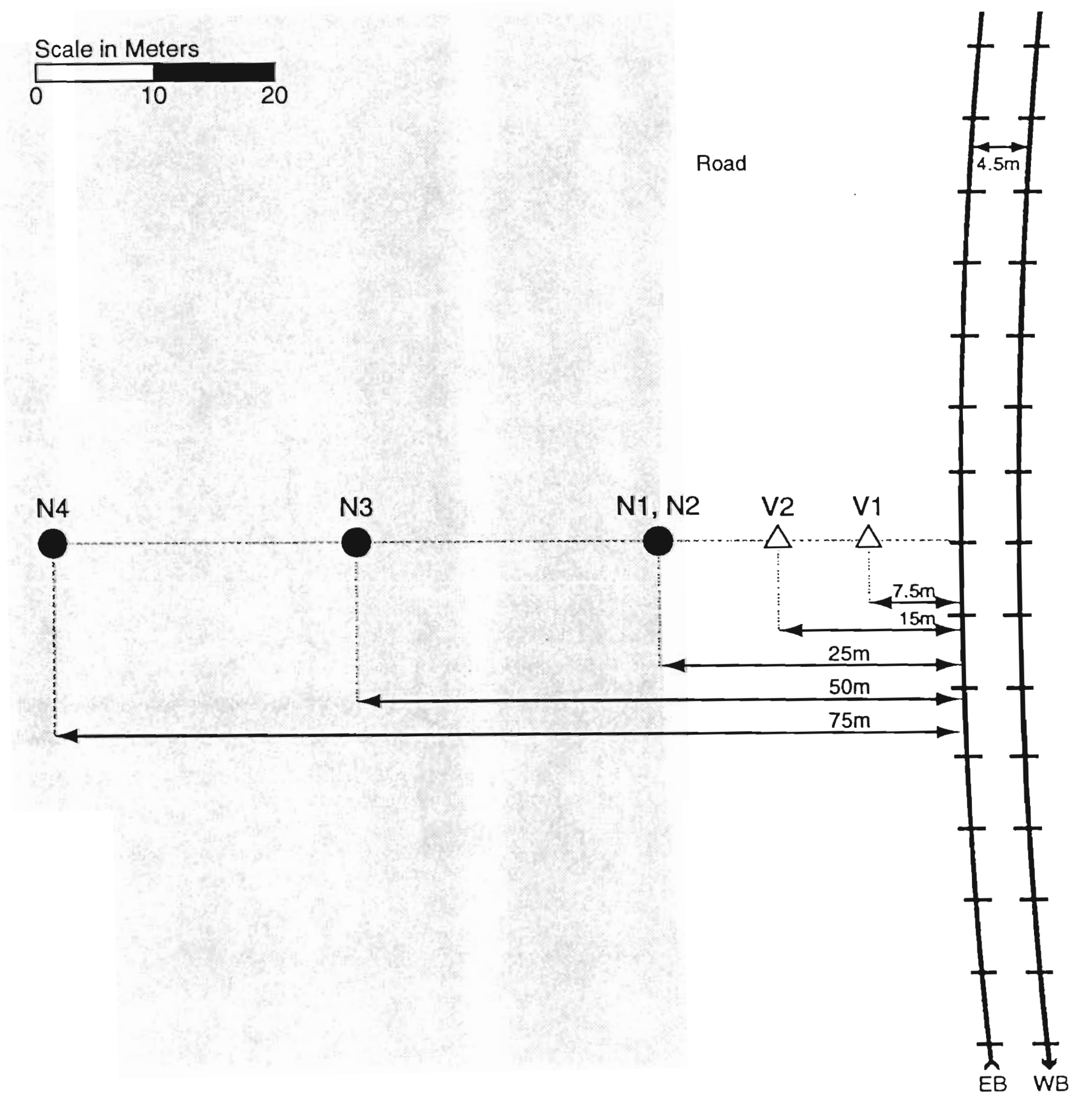


FIGURE 32A. PLAN VIEW OF SWEDISH MEASUREMENT SITE 4

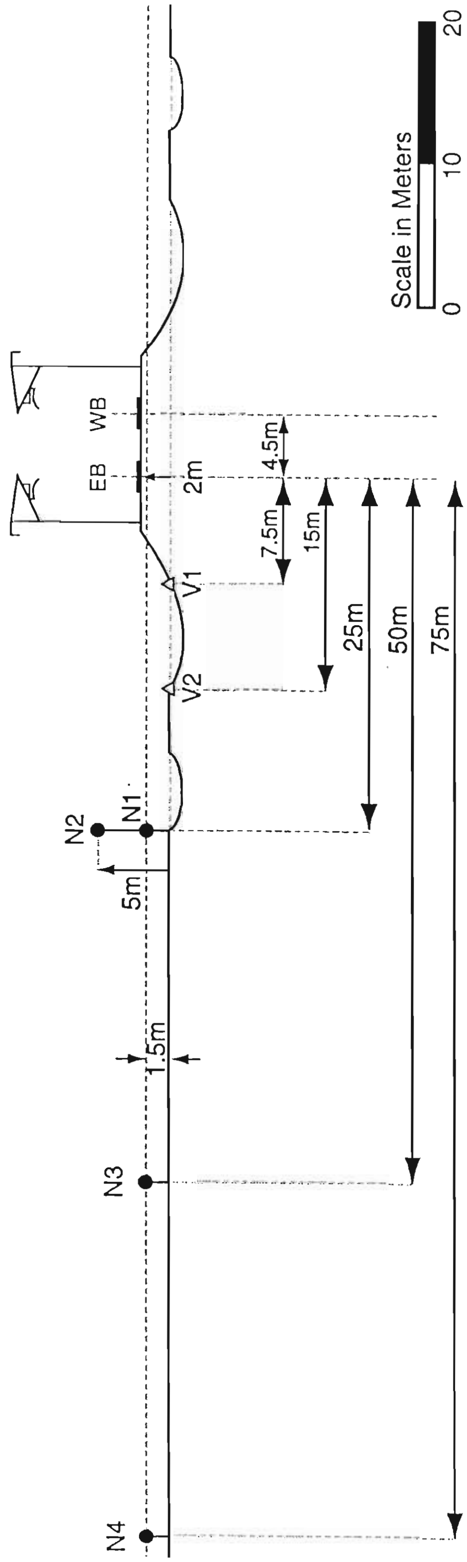


FIGURE 32B. CROSS-SECTIONAL VIEW OF SWEDISH MEASUREMENT SITE 4

FIGURE 33. PHOTOGRAPH OF SWEDISH MEASUREMENT SITE 5

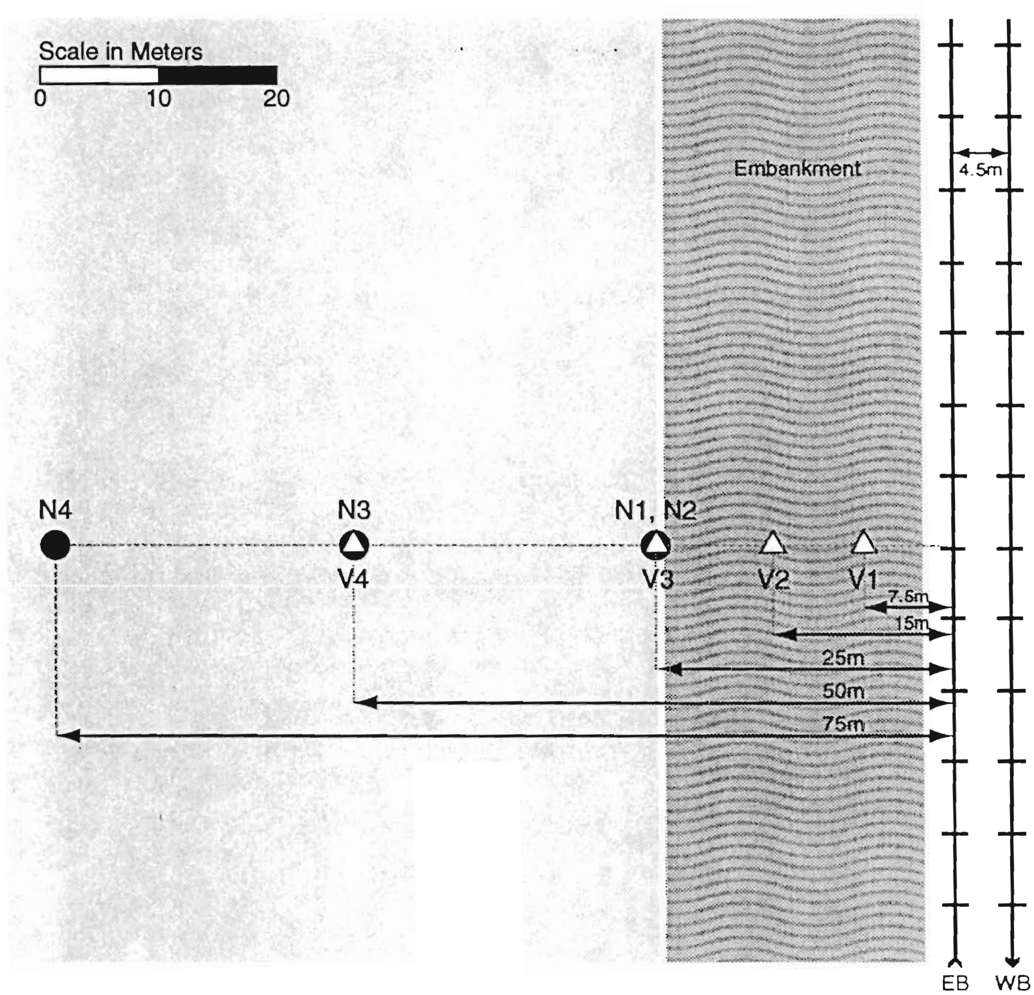


FIGURE 34A. PLAN VIEW OF SWEDISH MEASUREMENT SITE 5

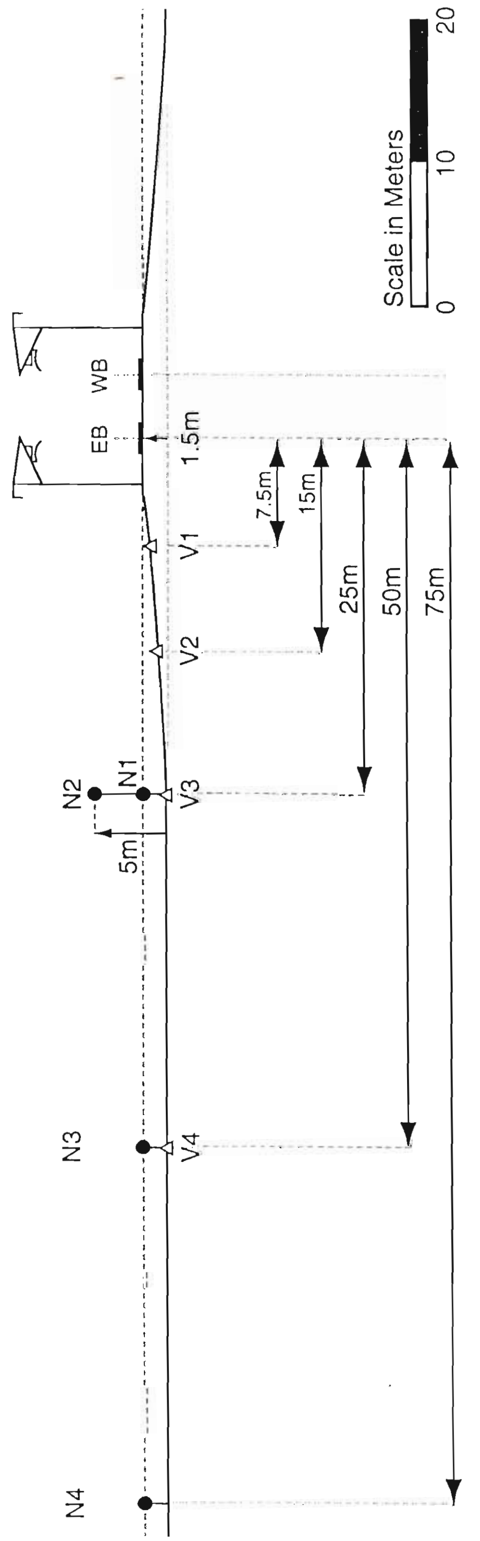


FIGURE 34B. CROSS-SECTIONAL VIEW OF SWEDISH MEASUREMENT SITE 5

2. MEASUREMENT PROCEDURES AND EQUIPMENT

2.1 Noise Measurements

All noise measurements were made using one-half inch pre-polarized condenser microphones with pre-amplifiers and/or amplifiers, protected by a windscreen. All microphones were supported by a tripod with a mast extending to the required height, except for the in-station measurements where hand-held sound level meters were used.

The amplified noise signals from the measurement microphones were recorded on magnetic tape, using multi-channel digital audio tape (DAT) recorders for subsequent laboratory analysis. Calibrations, traceable to the U.S. National Institute of Standards and Technology (NIST), were carried out before and after each set of measurements using an acoustical calibrator.

Train speeds were measured using a radar speed detector, and each train event was also documented on videotape to provide a record of specific train consist details. Additional documentation was provided on field data sheets and by voice annotations on the audio and video recordings.

A list of the field instrumentation, including manufacturers, models and serial numbers, is provided in Table 1. Tables 2, 3 and 4 indicate the specific instrumentation used in France, Italy and Sweden, respectively, at each measurement site and position, referenced to the equipment codes in Table 1.

TABLE 1. FIELD INSTRUMENTS USED FOR TRAIN NOISE MEASUREMENTS

EQUIPMENT TYPE	EQUIPMENT CODE	MANUFACTURER	MODEL	SERIAL NUMBER
Microphone	M1	Bruel & Kjaer	4155	1095134
	M2	Bruel & Kjaer	4155	1786100
	M3	Bruel & Kjaer	4155	1817577
	M4	Bruel & Kjaer	4155	1683358
	M5	Bruel & Kjaer	4155	1329799
	M6	Bruel & Kjaer	4155	1769646
	M7	Bruel & Kjaer	4155	1675641
Pre-Amplifier	PA1	GenRad	1972-9600	DA1S
	PA2	GenRad	1972-9600	DA2
	PA3	GenRad	1972-9600	DA3
	PA4	GenRad	1972-9600	DA4
	PA5	GenRad	1972-9600	DA5
	PA6	GenRad	1972-9600	DA6
Amplifier	A1	EPAC	60/10 LN	0A
	A2	EPAC	60/10 LN	68
	A3	EPAC	60/10 LN	69
	A4	EPAC	60/10 LN	114
	A5	EPAC	60/10 LN	115
	A6	Bruel & Kjaer	2230	1082914
Tape Recorder	T1	TEAC	RD-130TE	512546
	T2	SONY	TCD-D7	67865
Calibrator	C1	GenRad	1987	2894
	C2	GenRad	1987	1096287007

TABLE 2. INSTRUMENTS USED FOR TRAIN NOISE MEASUREMENTS IN FRANCE

Meas. Location		Code for Instrument Used*				
Site	Pos.**	Mic.	Pre-Amp.	Amp.	Tape Rec.	Cal.
D	N1	M1	PA1	--	T1	C1
	N2	M2	PA2	--	T1	C1
	N3	M3	PA3	A1	T1	C1
	N4	M4	PA4	A2	T1	C1
G	N1	M1	PA1	A1	T1	C1
	N2	M2	PA2	A2	T1	C1
	N3	M3	PA3	A3	T1	C1
H	N1	M1	PA1	A1	T1	C1
	N2	M2	PA2	A2	T1	C1
	N3	M3	PA3	A3	T1	C1
	N4	M4	PA4	A4	T1	C1
	N5	M5	PA5	--	T2	C1
	N6	M6	PA6	--	T2	C1
K	N1	M1	PA1	A1	T1	C1
	N2	M2	PA2	A2	T1	C1
	N3	M3	PA3	A3	T1	C1
TGV H.P. Station	Northbound Platform	M7	--	A6	T2	C2

* See Table 1 for instrument code descriptions.

** See Figures 4, 6, 8, and 10 (A&B) for measurement positions at Sites D, G, H and K, respectively.

TABLE 3. INSTRUMENTS USED FOR TRAIN NOISE MEASUREMENTS IN ITALY

Meas. Location		Code for Instrument Used*				
Site	Pos.**	Mic.	Pre-Amp.	Amp.	Tape Rec.	Cal.
2	N1	M1	PA1	--	T1	C1
	N2	M2	PA2	--	T1	C1
	N3	M3	PA3	A1	T1	C1
	N4	M4	PA4	A2	T1	C1
3	N1	M1	PA1	A1	T1	C1
	N2	M2	PA2	--	T1	C1
	N3	M3	PA3	A3	T1	C1
	N4	M4	PA4	A4	T1	C1
4	N1	M1	PA1	--	T1	C1
	N2	M2	PA2	--	T1	C1
	N3	M3	PA3	A1	T1	C1
	N4	M4	PA4	A2	T1	C1
Parma Station	Northbound Platform	M7	--	A6	T2	C2

* See Table 1 for instrument code descriptions.

** See Figures 14, 16, and 18 (A&B) for measurement positions at Sites 2, 3 and 4, respectively.

TABLE 4. INSTRUMENTS USED FOR TRAIN NOISE MEASUREMENTS IN SWEDEN

Meas. Location		Code for Instrument Used*				
Site	Pos.**	Mic.	Pre-Amp.	Amp.	Tape Rec.	Cal.
1	N1	M5	PA5	A1	T2	C1
	N2	M6	PA6	A5	T2	C1
2	N1	M1	PA1	--	T1	C1
	N2	M2	PA2	A2	T1	C1
	N3	M3	PA3	A3	T1	C1
	N4	M4	PA4	A4	T1	C1
3A	N1	M1	PA1	--	T1	C1
	N2	M2	PA2	--	T1	C1
	N3	M3	PA3	A1	T1	C1
	N4	M4	PA4	A2	T1	C1
4	N1	M1	PA1	--	T1	C1
	N2	M2	PA2	--	T1	C1
	N3	M3	PA3	A1	T1	C1
	N4	M4	PA4	A2	T1	C1
5	N1	M1	PA1	--	T1	C1
	N2	M2	PA2	--	T1	C1
	N3	M3	PA3	A1	T1	C1
	N4	M4	PA4	A2	T1	C1

* See Table 1 for instrument code descriptions.

** See Figures 24, 26, 28, 32 and 34 (A&B) for measurement positions at Sites 1, 2, 3A, 4 and 5, respectively.

2.2 Ground Vibration Measurements

All ground vibration measurements were made using high-sensitivity accelerometers as vibration transducers, each with their own power supply. All accelerometers were oriented to measure vibration in the vertical direction. For measurements on soil, the accelerometers were mounted on top of ground-driven stakes using putty to secure them to the top plates of the stakes. For measurements on asphalt, the accelerometers were mounted directly to the asphalt surface using putty.

The accelerometer signals were amplified using low-noise amplifiers, and recorded on an 8-channel digital audio tape (DAT) recorder for subsequent laboratory analysis. The amplifiers were set for optimum signal-to-noise ratio, and the amplifier and tape recorder gain settings were recorded on field data sheets and voice annotated on the tapes. A 1-Volt peak reference signal at a fixed frequency of 1000 Hz, generated by the tape recorder, was recorded on each tape for calibration of the system, based on the specific sensitivities of the accelerometers.

Train speeds were measured using a radar speed detector, and each train event was also documented on videotape to provide a record of specific train consist details. Additional documentation was provided on field data sheets and by voice annotations on the audio and video recordings.

A list of the field instrumentation, including manufacturers, models and serial numbers, is provided in Table 5. Tables 6, 7 and 8 indicate the specific instrumentation used in France, Italy and Sweden, respectively, at each measurement site and position, referenced to the equipment codes in Table 5.

TABLE 5. FIELD INSTRUMENTS USED FOR GROUND VIBRATION MEASUREMENTS

EQUIPMENT TYPE	EQUIPMENT CODE	MANUFACTURER	MODEL	SERIAL NUMBER
Accelerometer	AC1	PCB	393B	162
	AC2	PCB	393C	2480
	AC3	PCB	393C	2481
	AC4	PCB	393C	2482
	AC5	PCB	393C	2876
	AC6	PCB	293C	3179
Power Supply	PS1	PCB	480C06	1550
	PS2	PCB	480E09	18974
	PS3	PCB	480E09	18975
	PS4	PCB	480C02	2366
	PS5	PCB	480C02	2367
	PS6	PCB	480C02	2368
Amplifier	A2	EPAC	60/10 LN	68
	A3	EPAC	60/10 LN	69
	A4	EPAC	60/10 LN	114
	A5	EPAC	60/10 LN	115
Tape Recorder	T3	TEAC	RD-130TE	723965

TABLE 6. INSTRUMENTS USED FOR VIBRATION MEASUREMENTS IN FRANCE

Meas. Location		Code for Instrument Used*			
Site	**Pos.****	**Accel.**	**Pwr. Supply**	**Amplifier**	**Tape Rec.**
D	V1	AC1	PS1		T3
	V2	AC2	PS2		T3
	V3	AC3	PS3		T3
	V4	AC4	PS4	A4	T3
	V5	AC5	PS5	A5	T3
	V6	AC6	PS6	A3	T3
K	V1	AC2	PS2	A4	T3
	V2	AC3	PS3	A5	T3

* See Table 5 for instrument code descriptions.

** See Figures 4 and 10 (A&B) for measurement positions at Sites D and K, respectively.

TABLE 7. INSTRUMENTS USED FOR VIBRATION MEASUREMENTS IN ITALY

Meas. Location		Code for Instrument Used*			
Site	Pos.**	Accel.	Pwr. Supply	Amplifier	Tape Rec.
2	V1	AC2	PS2		T3
	V2	AC3	PS3		T3
	V3	AC4	PS4	A3	T3
	V4	AC5	PS5	A4	T3
3	V1	AC2	PS2		T3
	V2	AC3	PS3		T3
	V3	AC4	PS4	A2	T3
	V4	AC5	PS5	A5	T3
4	V1	AC1	PS1		T3
	V2	AC2	PS2		T3
	V3	AC3	PS3		T3
	V4	AC4	PS4	A3	T3
	V5	AC5	PS5	A4	T3
	V6	AC6	PS6	A5	T3

* See Table 5 for instrument code descriptions.

** See Figures 14, 16, and 18 (A&B) for measurement positions at Sites 2, 3 and 4, respectively.

TABLE 8. INSTRUMENTS USED FOR VIBRATION MEASUREMENTS IN SWEDEN

Meas. Location		Code for Instrument Used*			
Site	Pos.**	Accel.	Pwr. Supply	Amplifier	Tape Rec.
3B	V1	AC1	PS1		T3
	V2	AC2	PS2		T3
	V3	AC3	PS3		T3
	V4	AC4	PS4	A3	T3
	V5	AC5	PS5	A4	T3
	V6	AC6	PS6	A5	T3
4	V1	AC5	PS5	A4	T3
	V2	AC6	PS6	A5	T3
5	V1	AC2	PS2		T3
	V2	AC3	PS3	A3	T3
	V3	AC4	PS4	A4	T3
	V4	AC5	PS5	A5	T3

* See Table 5 for instrument code descriptions.

** See Figures 30, 32 and 34 (A&B) for measurement positions at Sites 3B, 4 and 5, respectively.

2.3 Vibration Propagation Tests

One of the key factors in projections of ground-borne vibration is how local geologic conditions will affect the propagation of vibration energy from the track support system to the foundations of adjacent buildings. Experience has shown that using standard geologic descriptors is rarely sufficient to define propagation characteristics. Therefore, tests were performed at the primary site in each of the three countries where high-speed train noise and vibration measurements were carried out. These included Site D in France, Site 4 in Italy and Site 3B in Sweden. The purpose of these tests was to obtain propagation data that could be used to normalize the ground-borne vibration measurement results by eliminating site-specific variables so that the vibration emission characteristics of the different types of high-speed trains could be compared on an equal basis.

The vibration propagation test procedure is illustrated in Figure 35. It basically consists of dropping a heavy weight on the ground and measuring the resulting vibration pulses at various distances from the impact. The force was measured using a Sensotec Model 41/574-03 load cell (Serial No. 286906), mounted on the ground below the weight. The force was applied to the ground at a series of points along a line running parallel to the railroad line, as close as possible to the tracks, as described in Section 1. The resulting vibration pulses were measured using accelerometers as described in Section 2.2, positioned along a line perpendicular to the tracks and bisecting the impact line as described in Section 1. Both the impact force and the vibration pulses were recorded using an instrumentation tape recorder as described in Section 2.2, for subsequent laboratory analysis. The relationship between the force caused by dropping the weight and the vibration pulse is called the transfer mobility.

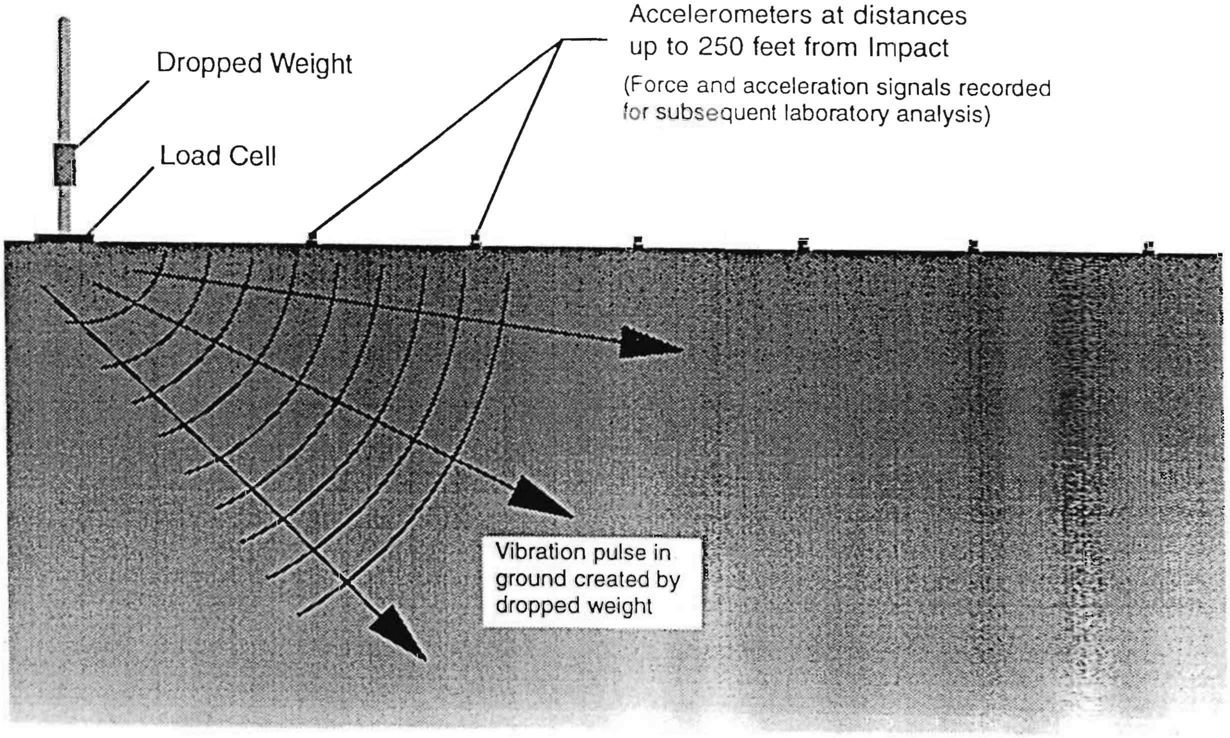


FIGURE 35. GROUND-BORNE VIBRATION PROPAGATION TEST PROCEDURE

3. NOISE MEASUREMENT RESULTS

3.1 Noise Data Analysis Procedures

Analysis of the field data was carried out in the HMMH laboratory. For this analysis, the A-weighted maximum noise level (L_{Smax}) and Sound Exposure Level (SEL) for each train event were obtained directly from the tape-recorded data using a B&K Type 2230 sound level meter set at "slow" response. At the same time, a Rion Model LR-04 graphic level recorder, set at the "fast" writing speed, was used to obtain time-history graphs of each train event as well as the L_{Fmax}. The maximum noise level obtained using the "slow" averaging time (L_{Smax}) is better correlated with the SEL and is more appropriate for modelling train noise mathematically. However, the maximum noise level obtained using the "fast" averaging time (L_{Fmax}) is required to evaluate compliance with the U.S. Federal Railroad Noise Emission Standards.

Frequency analysis was carried out for selected recorded events, using multi-channel FFT spectrum analyzers to obtain one-third octave band sound pressure level spectra, averaged over intervals of maximum event noise levels. First, the noise signals were fed into the narrow-band analyzers at a maximum sampling rate for 20 kHz input bandwidth, and post-processing software was used to combine the narrow-band results into one-third octave noise spectra.

3.2 A-Weighted Train Noise Levels

The results of the wayside noise measurements are listed in Appendix A in terms of the following A-weighted noise level descriptors: L_{Smax}, L_{Fmax} and SEL. These results are given at each measurement position for each train event at each site, along with the measurement date and time, train type and length, and train speed.

To provide an overview of the results, representative European high-speed train noise levels at a variety of speeds are plotted in Figures 36 and 37. Figure 36 provides a graph of L_{Smax} as a function of train speed, normalized to a reference distance of 100 feet (30.5 meters). This normalization was based on interpolation between the measurement data obtained at 25 and 50 meters from the near track center line for the microphones located 1.5 meters above the ground. Figure 37 provides similar results in terms of SEL, with the data normalized to a reference distance of 100 feet and to a reference train length of 740 feet. Also shown on these graphs are train noise level versus speed curves generated by the noise model recently developed as part of the U.S. Northeast Corridor Project. These model curves are based on measurements conducted in the U.S. for several newer-technology trainsets including the German ICE, Swedish X2000 and the U.S./French RTL-2 Turboliner.

The results in Figures 36 and 37 indicate that the European train measurement data generally fall within the range of the train noise curves developed for the Northeast Corridor Project. The results also suggest that the TGV trains are typically the quietest of the trains tested in Europe, with noise emissions similar to the ICE and RTL-2 trains tested in the U.S. Wayside noise levels for the X2000 and Pendolino trains averaged about 5 decibels higher, with noise emissions similar to the X2000 train tested in the U.S. The data for the Eurostar trains showed the greatest variation, with noise levels scattered over the range for the other trains. However, we understand that there are two versions of the Eurostar trains currently in operation, and that this may account for the wide spread in the noise data for this equipment.

Other observations based on the A-weighted noise data are as follows:

- Regarding maximum wayside noise levels, the L_{Fmax} were generally 1-2 decibels above the L_{Smax}, with greater differences for measurements made closer to the track and for higher-speed trains.

- The noise levels measured at the high microphone position averaged about 1 decibel greater than the noise levels measured at the low microphone position at 25 meters from the near track.

- The measurements at French Site H indicated that the 3-meter high noise barrier at this site provided an insertion loss ranging from about 6 decibels at 50 meters from the near track to about 9 decibels at 25 meters from the near track, at a 1.5 meter-high receiver position.

- Although the higher speed French trains appeared to generate additional low-frequency noise of an aerodynamic nature, this noise did not appear to significantly affect the A-weighted noise levels for trains at speeds up to nearly 300 kph (186 mph). This observation is supported by Figures 36 and 37 which show that the higher speed noise data follow the noise model curves previously developed based on lower-speed noise measurements for the Northeast Corridor Project.

Finally, the results suggest that the trains measured in Europe would generally be expected to comply with the U.S. Federal Railroad Noise Emission Standard. The relevant standard for the operation of such trains is a L_{Fmax} of 93 dBA, with a 2-decibel tolerance, yielding an absolute limit of 95 dBA. Based on the measurement data, this corresponds to a limit of 93 dBA in terms of L_{Smax}. Of the representative data shown in Figure 36, only one Eurostar train exceeds this limit.

3.3 Train Noise Spectral Analysis

Noise spectra for selected train events are included in Appendix B.

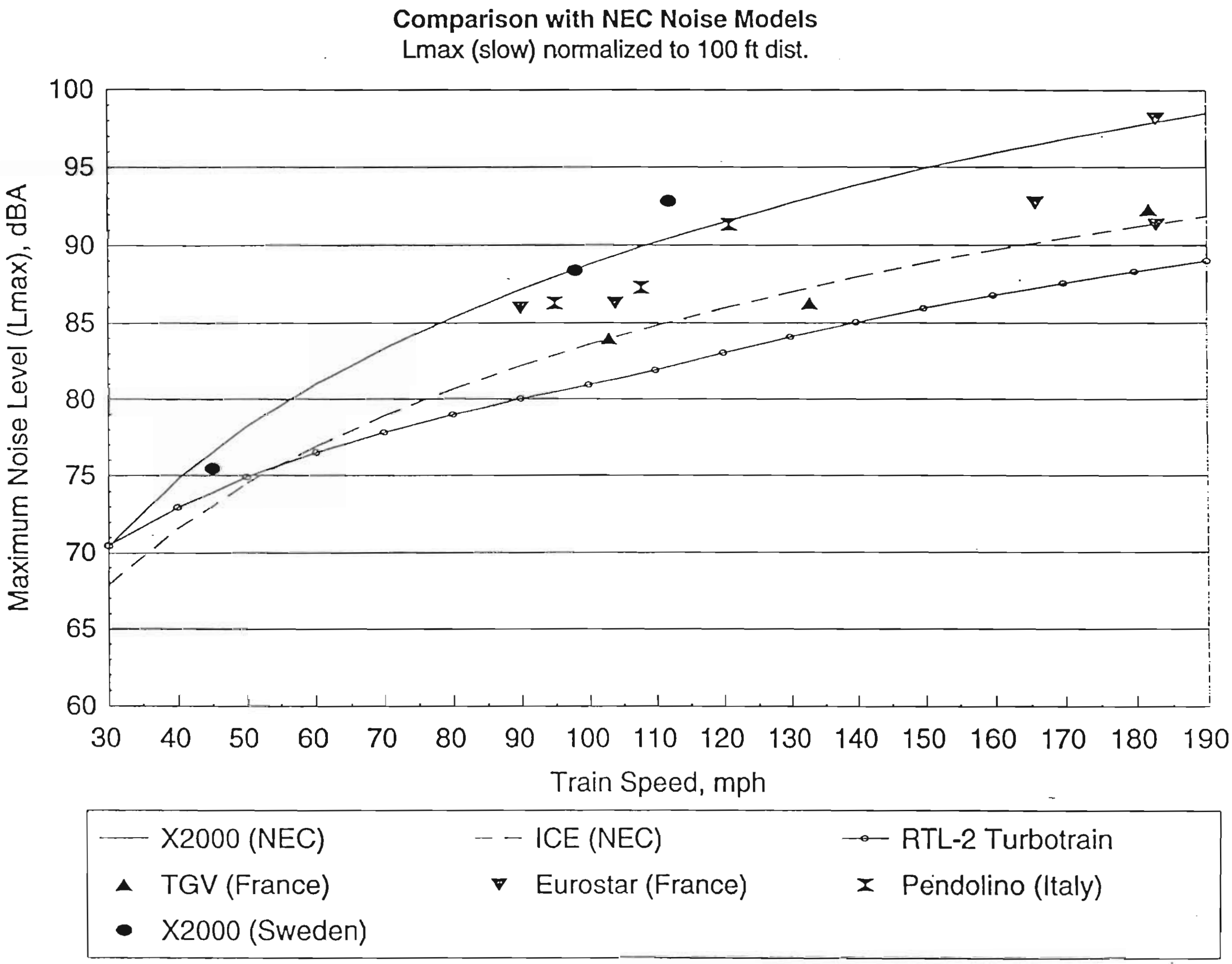


FIGURE 36. HIGH-SPEED TRAIN MAXIMUM NOISE LEVEL VS. SPEED

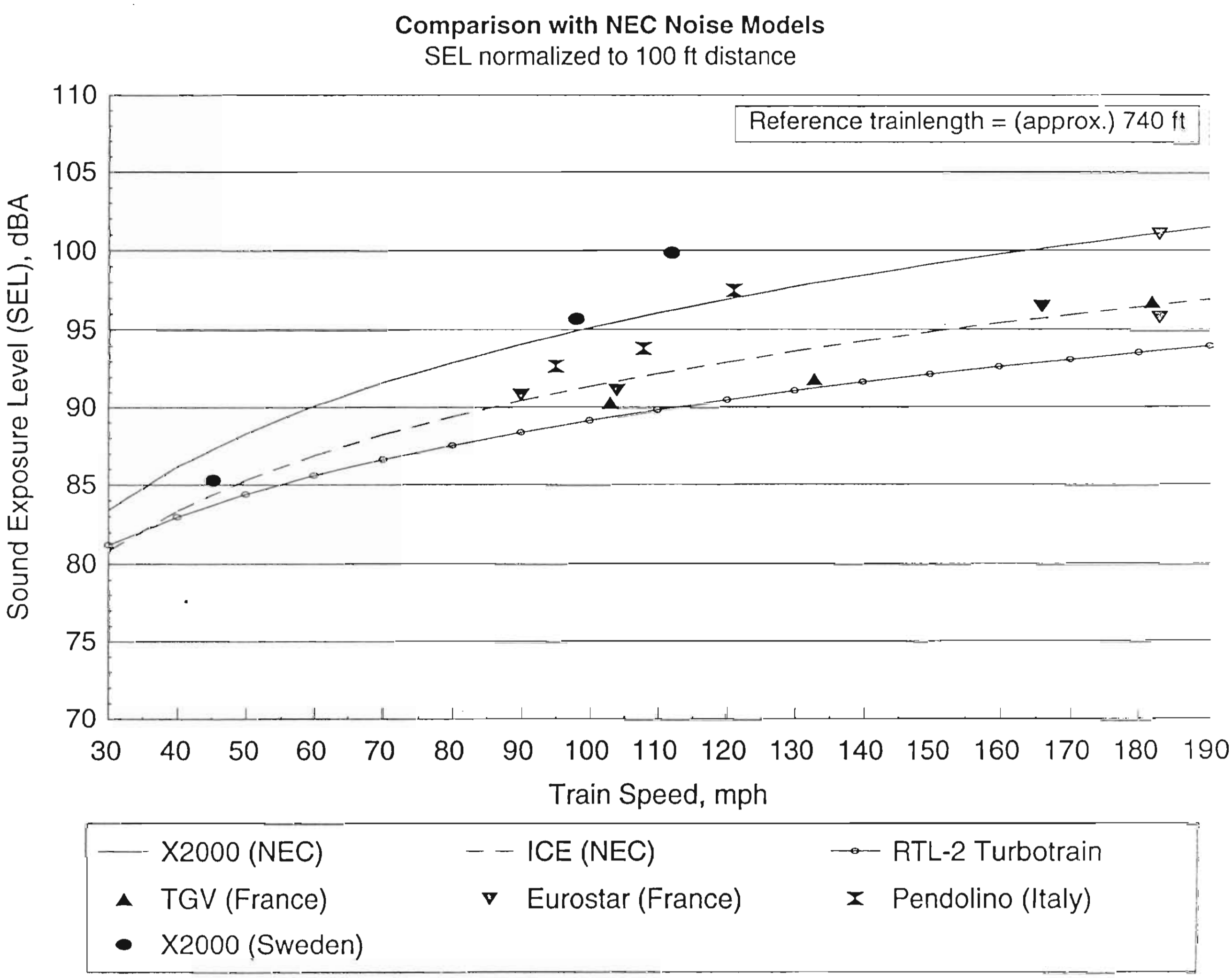


FIGURE 37. HIGH-SPEED TRAIN SOUND EXPOSURE LEVEL VS. SPEED

4. GROUND-BORNE VIBRATION MEASUREMENT RESULTS

4.1 Vibration Data Analysis Procedures

Analysis of the field data was carried out in the HMMH laboratory. The recorded acceleration signals were integrated to obtain vibration velocity, using a B&K Model 2635 amplifier and signal conditioner. The resulting signals were fed into a Rion Model LR-04 graphic level recorder to obtain strip charts of the root mean square (RMS) vibration velocity as a function of time. The RMS time constant on the level recorder was set for one second, which is equivalent to the "slow" response setting on a standard sound level meter, and the maximum vibration level for each train event was read from the strip charts. Although experience suggests that the RMS vibration velocity level correlates best with human response to vibration, the peak velocity is often measured by geotechnical engineers to evaluate structural effects on buildings. Therefore, a B&K Type 2230 sound level meter was used in parallel with the graphic level recorder to obtain peak velocity data.

Frequency analysis was carried out for selected events, using multi-channel FFT spectrum analyzers to obtain one-third octave band spectra averaged over intervals of maximum vibration levels for each event. The acceleration signals were fed into the narrow-band analyzers set up for 500 Hz input bandwidth, and post-processing software was used to integrate the narrow-band data and combine the narrow-band results into one-third octave band vibration velocity spectra.

4.2 Overall Train Vibration Velocity Levels

The results of the ground vibration measurements are listed in Appendix C in terms of vibration velocity level expressed in decibels (VdB) relative to one micro-inch per second. Maximum vibration velocity levels are provided in terms of both RMS velocity (RMSV) and peak particle velocity (PPV), all in the vertical direction. These results are given at each measurement position for each train event at each site, along with the measurement date and time, train type and length, and train speed.

To provide an overview of the results, representative European high-speed train RMS vibration velocity levels are plotted in Figure 38. These levels are plotted as a function of distance, and have been normalized to a reference speed of 90 mph, assuming that ground-borne vibration varies proportional to 20 times the common logarithm of train speed. Also shown in this figure are best-fit vibration level vs. distance curves developed from measurements conducted in the U.S. for several newer-technology trainsets including the German ICE, Swedish X2000 and the U.S./French RTL-2 Turboliner.

The results in Figure 38 indicate that the TGV and Eurostar trains generated nearly identical ground vibration levels at the same site (French Site D). These levels were roughly 10 decibels lower than measured in the U.S. for the X2000 and RTL-2 trainsets, which generated the lowest ground vibration levels of the trains tested at the Northeast Corridor site. Furthermore, the vibration attenuation rate with distance at the French site was similar to that for the Northeast Corridor site. Figure 38 also shows that the ground vibration levels for Pendolino operation at Site 4 in Italy were all below the vibration levels measured for the trains in the U.S. However, the attenuation rate with distance at the Pendolino site appears to be more gradual at greater distances from the track. The highest ground vibration levels were generated by the X2000 trains at Site 3B in Sweden. At a distance of 100 feet, the levels are comparable to those measured for the X2000 in the U.S., but there appears to be very little attenuation with distance.

Due to the significant effects of ground composition on wayside train vibration levels, it is difficult to interpret the results in Figure 38, given the site variables involved. To be able to compare the results for the different sites, it is necessary to examine the results of the vibration propagation tests. These results are described below in Section 5.

4.3 Ground-Borne Train Vibration Spectral Analysis

Ground-borne vibration spectra for selected train events are included in Appendix D.

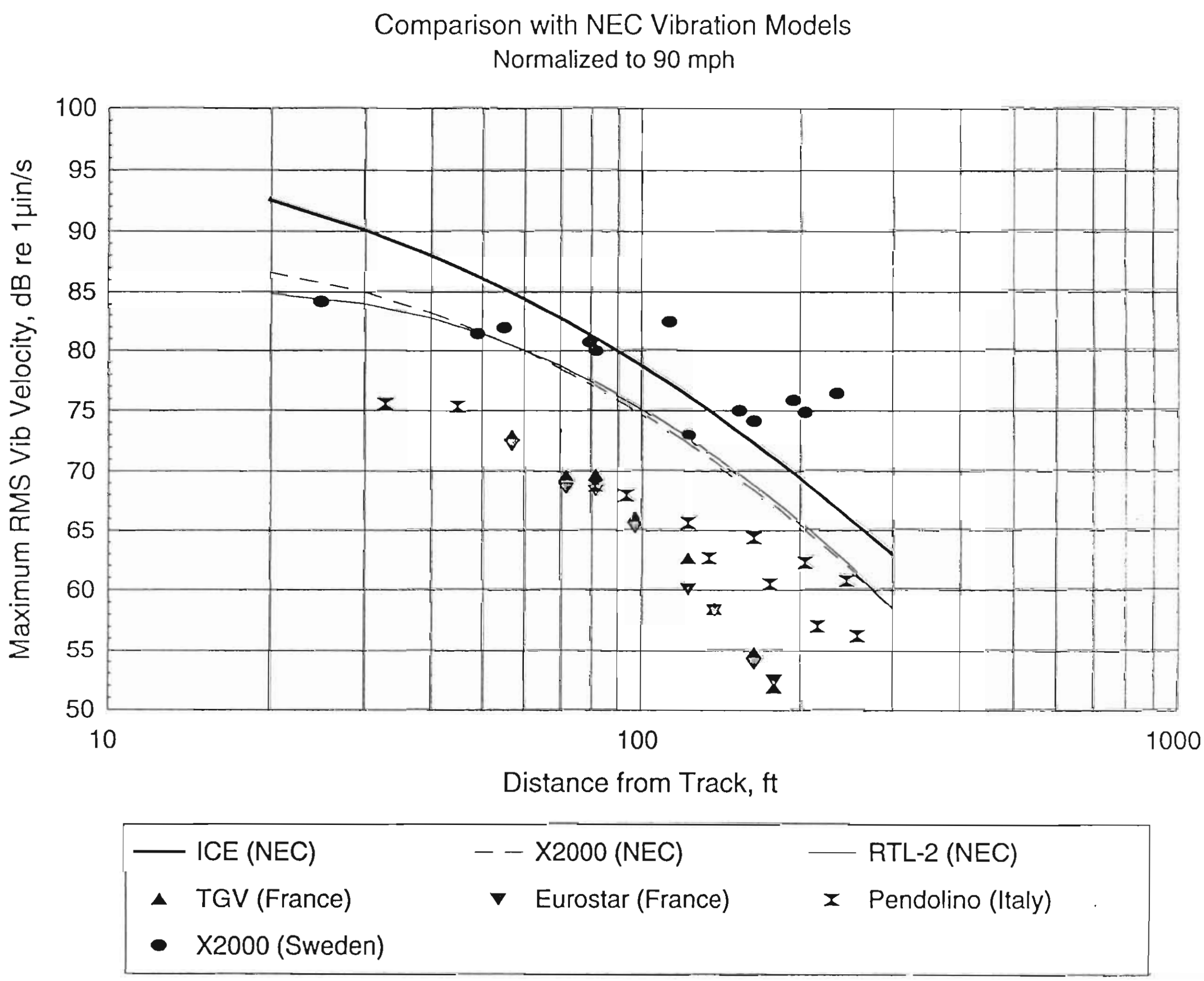


FIGURE 38. HIGH-SPEED TRAIN VIBRATION LEVELS VS. DISTANCE

5. GROUND-BORNE VIBRATION PROPAGATION TEST RESULTS

5.1 Test Analysis Procedures

The steps used to analyze the train vibration and transfer mobility data to derive force densities were:

1. A narrowband spectrum analyzer was used to obtain transfer functions for each transfer mobility test and 1/3 octave band spectra for each train passby.

2. The narrowband transfer mobility spectra were used to calculate equivalent 1/3 octave band transfer mobilities.

3. The point-source transfer mobilities for each test site accelerometer were combined to approximate line-source transfer mobility.

4. The 1/3 octave bands for both the train and the propagation measurements were used to obtain best-fit curves of level vs. distance for each 1/3 octave band. These curves result in approximate line-source transfer mobility and train vibration spectra as a function of distance from the source.

5. The difference between the 1/3 octave band spectrum for train vibration and the transfer mobility at the same distance is the force density. The force density should not be a function of distance. In practice, force density was calculated at each measurement distance, and the average force density was used to characterize each type of trainset. For all of the trainsets, the force densities at the six measurement distances were well clustered around the average. The typical range between the highest and lowest was 3 to 4 decibels.

The end result of the analysis was a force density to characterize each type of trainset, line-source transfer mobility functions characterizing each of the primary test sites, and the trainset 1/3 octave band ground-borne vibration as a function of distance.

5.2 Summary of Test Results

As suggested by the results in Section 4.2, it is likely that much of the difference in ground-borne vibration between the trainsets is due to geology rather than differences in suspensions or wheel conditions of the trainsets. The line source transfer mobility spectra for the three different measurement sites are shown in Figure 39. The transfer mobilities are very different. For example, at 100 Hz the transfer mobility at Site 3B in Sweden is 8 decibels higher than at Site D in France and about 30 decibels higher than at Site 4 in Italy. All of the sites were in rural areas where relatively little is known about the specific geology at the test sites. These differences in transfer mobility are fairly consistent out to 100 meters from the vibration source.

The force density functions derived for X2000, Pendolino, TGV, and Eurostar trainsets, all normalized to a speed of 150 mph are shown in Figure 40. The force densities are very different, but the differences are not as large as the differences in the measured vibration levels. The TGV and Eurostar force densities are close enough to be considered the same. The X2000 and the Pendolino are surprisingly similar considering the large difference in the vibration spectra.

The four force density functions can be combined with the transfer mobility from one site to approximate what the vibration levels would be if all of the trainsets were operating on the same track. The resulting overall vibration levels using the transfer mobility from Site D in France are shown in Figure 41 and the same results using the transfer mobility from site 3B in Sweden are shown in Figure 42. Both figures show that using the same transfer mobility substantially reduces differences in the overall vibration levels. With the transfer mobility from Sweden, the TGV, Eurostar, and X2000 are all within about 2 decibels, and the Pendolino is 3 to 4 decibels lower. In this case, ground-borne vibration from the different trainsets is between 75 and 80 VdB at 30 meters from the track. With the transfer mobility from France, the TGV and Eurostar are 2 to 3 decibels lower than the Pendolino and the X2000 is about 4 decibels higher than the Pendolino. The levels are between 65 and 73 at 30 meters from the track centerline. The overall conclusion is that all of the trains would have significantly higher vibration levels at the Swedish test site than at the French site.

To further illustrate the strong effects of the transfer mobility, Figure 43 shows vibration level vs. distance applying the X2000 force density to the three transfer mobility functions. This shows that close to the trade centerline, the projected vibration levels are all relatively high. However, the levels with the transfer mobility from Site 3B in Sweden show considerably slower attenuation with distance than with the other two transfer mobilities.

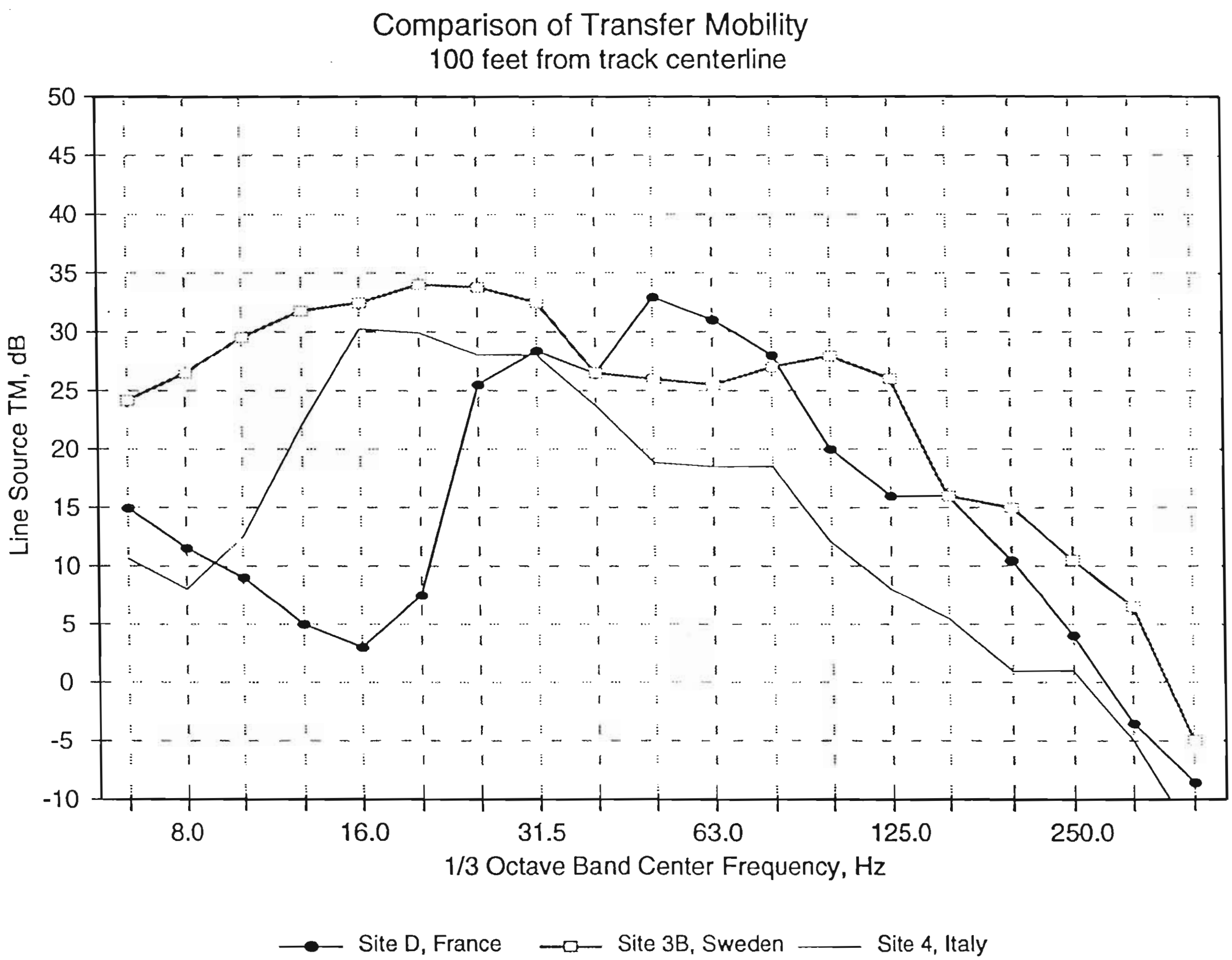


FIGURE 39. LINE-SOURCE TRANSFER MOBILITY AT THE TEST SITES

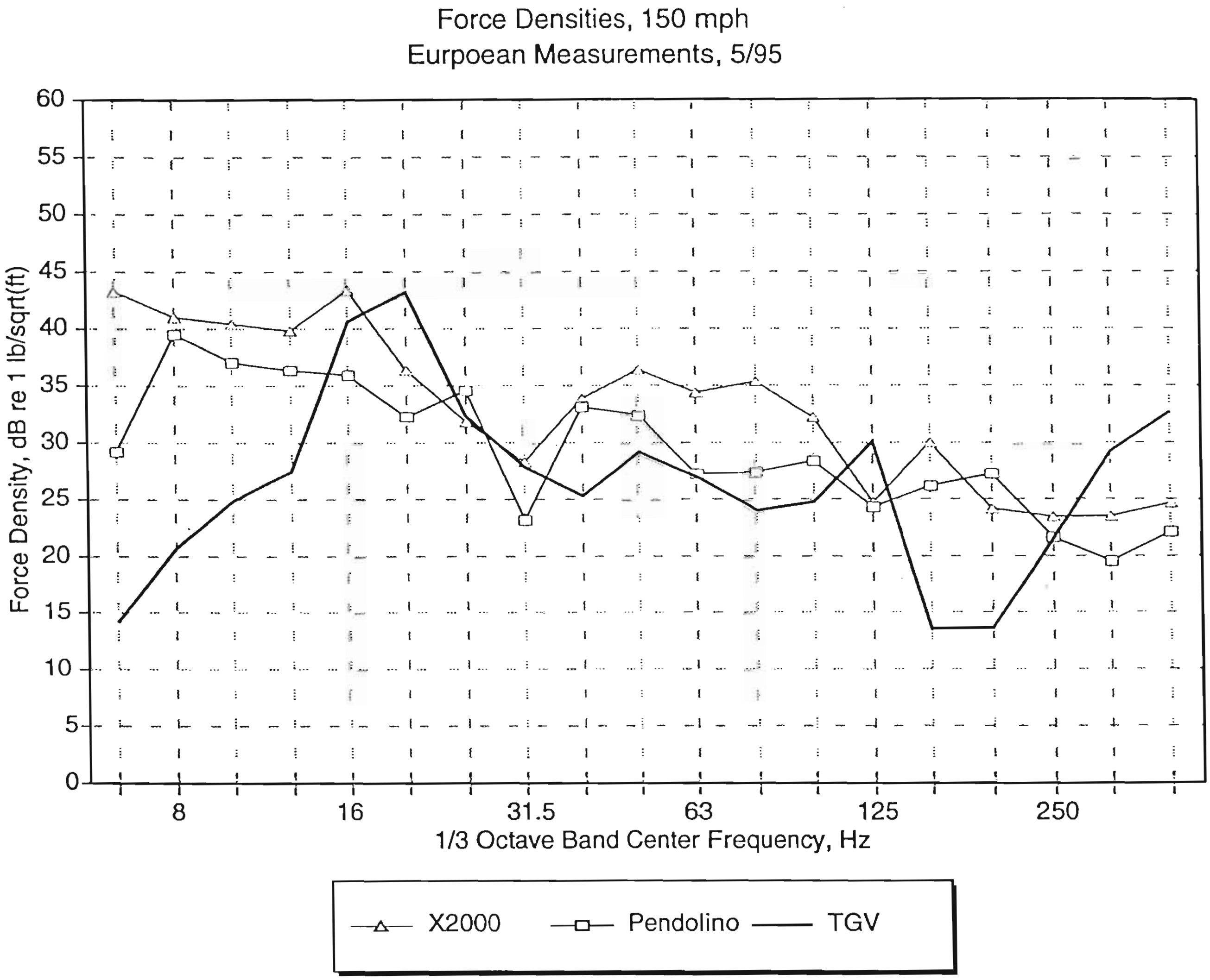


FIGURE 40. NORMALIZED TRAINSET FORCE DENSITY FUNCTIONS

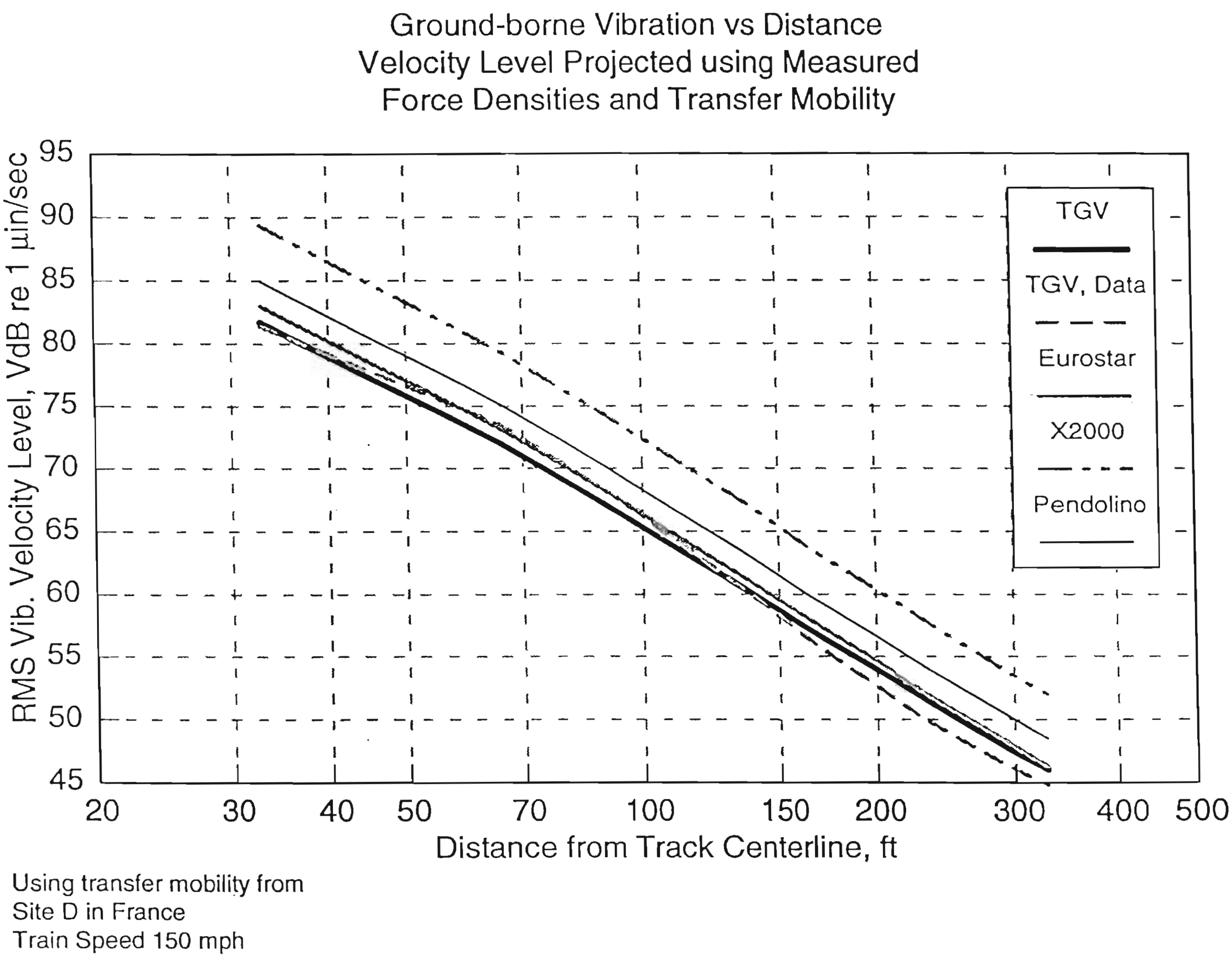


FIGURE 41. PROJECTED VIBRATION - SITE D (FRANCE) TRANSFER MOBILITY

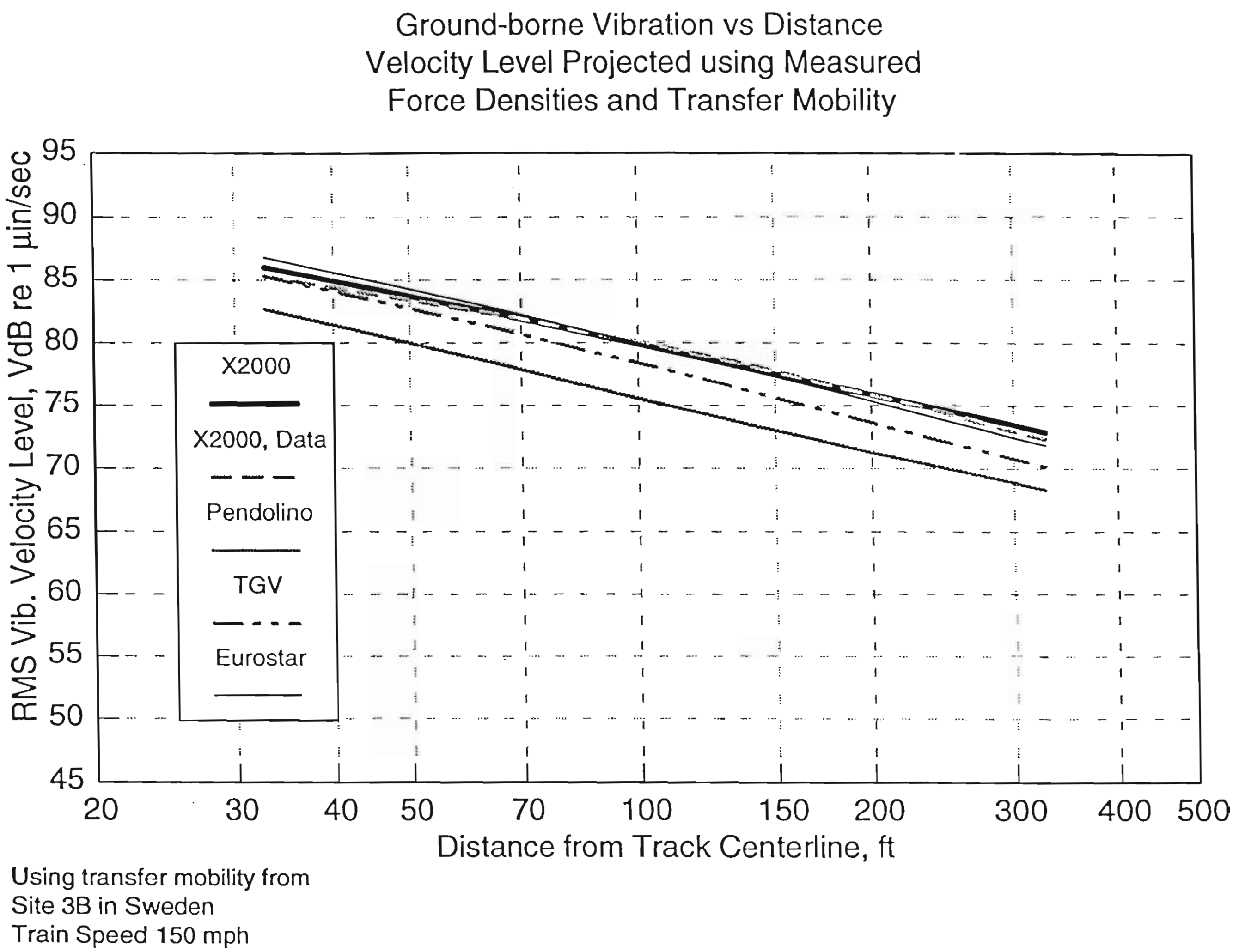


FIGURE 42. PROJECTED VIBRATION - SITE 3B (SWEDEN) TRANSFER MOBILITY

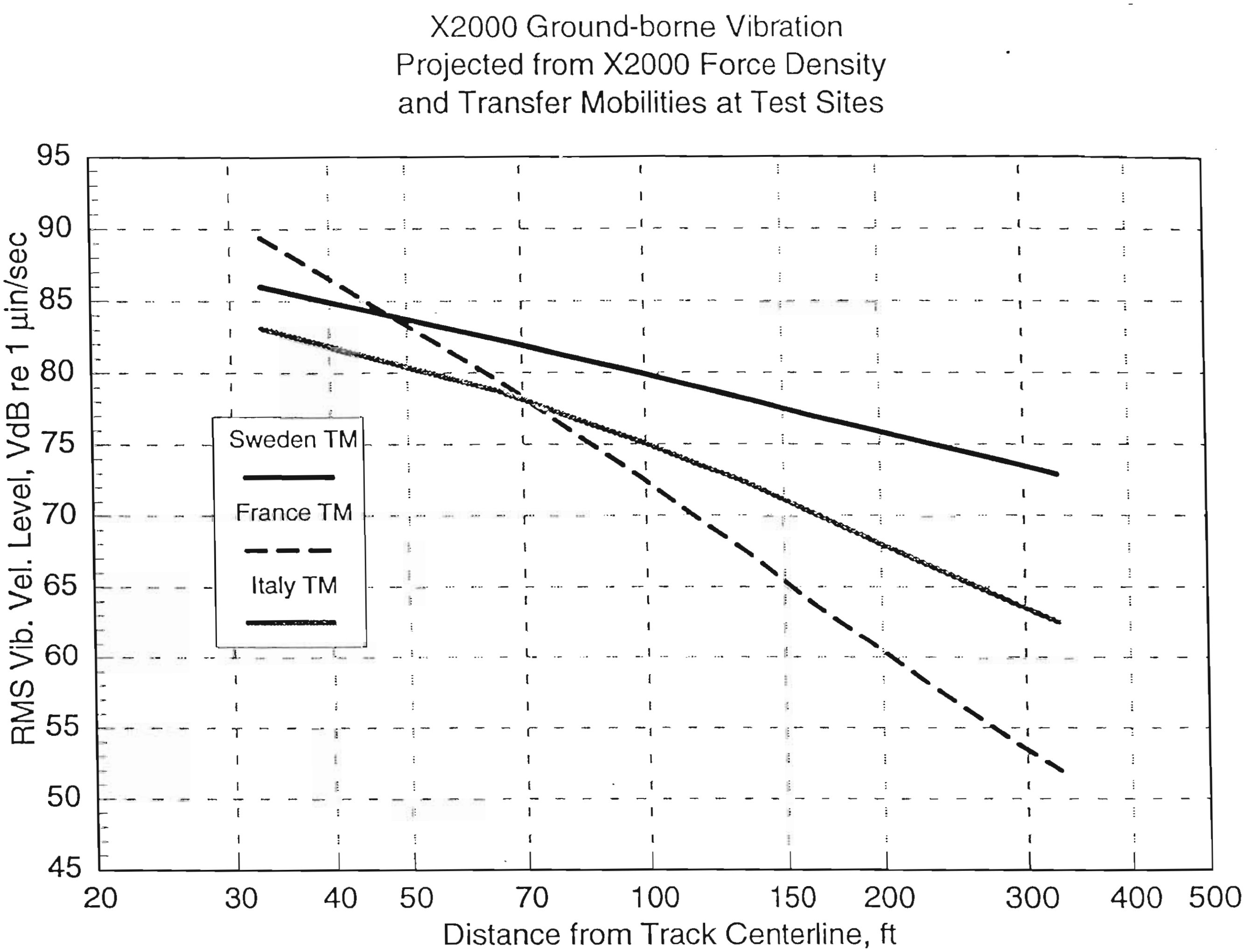


FIGURE 43. PROJECTED VIBRATION VELOCITY USING X2000 FORCE DENSITY

APPENDIX A: A-WEIGHTED TRAIN NOISE MEASUREMENT DATA

HIGH-SPEED TRAIN NOISE DATA: FRANCE - SITE D (PRIMARY SITE) - MAY 10, 1995

EVE	TIME	TRAIN DESCRIPTION				MEASURED A-WEIGHTED SOUND LEVEL (dBA)											
NO.	OF DA	Type	Dir.	Length	Speed	Ch1(25mSB/29.5mNB/1.5mH)			Ch2(25mSB/29.5mNB/4.0mH)			Ch3(50mSB/54.5mNB/1.5mH)			Ch4(75mSB/79.5mNB/1.5mH)		
				(m)	(kph)	Lmax(s)	Lmax(f)	SEL	Lmax(s)	Lmax(f)	SEL	Lmax(s)	Lmax(f)	SEL	Lmax(s)	Lmax(f)	SEL
1	12:18	TGV	NB	237.5	290	86.8	89.1	97.2	89.6	89.4	93.8	88.5	85.0	96.9	82.5	83.0	87.8
3	12:54	TGV-2	NB	475.0	294	88.2	89.6	100.5	89.7	91.3	96.0	85.6	87.0	92.0	84.5	85.0	91.6
4	12:58	TGV	SB	237.5	290	93.1	95.7	97.6	92.7	96.0	97.8	88.5	90.3	94.4	87.7	88.7	93.4
5	13:10	TGV	SB	237.5	293	92.6	95.2	97.5	92.2	95.0	97.2	88.4	89.6	94.3	87.1	88.3	93.3
6	13:15	TGV	SB	237.5	296	96.2	99.3	101.2	95.4	98.9	100.5	92.2	94.0	97.9	91.7	93.1	97.4
7	13:17	TGV	NB	237.5	293	87.1	89.1	91.8	88.4	91.5	93.7	84.3	85.2	90.0	83.3	84.2	89.3
8	16:25	TGV	SB	237.5	296	93.0	94.7	96.8	92.3	94.0	96.4	88.6	89.0	93.5	87.1	87.8	92.5
9	16:33	Eurostar	SB	393.7	269	93.9	97.1	99.8	93.6	96.8	100.3	90.2	91.8	96.7	88.6	89.8	95.6
10	16:40	TGV	NB	237.5	294	89.4	92.2	94.5	91.0	92.7	95.8	86.5	87.1	92.0	85.6	86.2	90.6
11	16:44	TGV	SB	237.5	290	91.4	92.3	95.5	90.7	91.5	95.4	87.3	87.9	92.0	85.9	86.8	90.5
12	16:51	TGV-2	SB	475.0	293	93.0	93.7	99.3	92.3	93.1	98.9	88.7	89.7	95.4	86.9	87.3	94.1
13	17:30	Eurostar	NB	393.7	293	89.3	91.8	95.3	90.3	93.1	97.2	85.8	88.0	92.8	83.9	86.1	91.3
14	17:31	Eurostar	SB	393.7	296	99.5	102.6	104.4	98.4	101.9	—	94.8	97.1	—	93.4	96.1	—
15	17:35	TGV	NB	237.5	286	87.4	89.5	92.5	89.6	92.2	94.9	84.4	86.1	90.2	82.5	83.5	88.5
16	17:39	TGV	NB	237.5	266	85.6	86.6	90.5	86.9	88.0	91.2	82.1	83.2	97.8	81.1	81.9	86.6
17	17:43	TGV	SB	237.5	294	92.7	94.9	96.8	91.9	94.6	96.8	87.8	89.0	93.3	85.1	86.7	92.1
18	17:52	TGV	NB	237.5	296	87.5	89.9	92.8	89.7	91.6	94.6	84.6	85.5	90.5	82.7	83.4	88.5
19	18:06	TGV	NB	237.5	283	91.3	95.2	93.9	95.0	100.0	97.4	91.0	94.2	94.0	92.1	96.0	94.8
20	18:07	TGV	SB	237.5	293	93.0	95.5	97.2	92.7	95.0	97.1	88.6	89.4	94.1	87.2	88.0	92.9
21	18:10	TGV	NB	237.5	294	89.2	91.0	94.2	90.9	93.2	95.4	86.5	88.0	91.8	85.9	88.1	90.8
22	18:13	TGV	SB	237.5	296	92.3	93.1	97.0	91.7	93.0	96.5	88.2	88.7	93.5	86.5	87.1	92.0
23	18:30	TGV	SB	237.5	293	95.5	99.0	100.1	94.5	98.0	99.3	91.1	92.2	96.5	89.7	90.9	95.2
25	18:42	TGV	NB	237.5	296	87.7	89.7	92.8	89.1	90.6	94.2	85.0	85.5	90.8	83.1	83.7	89.3
26	18:44	TGV	SB	237.5	296	95.9	99.0	99.8	95.5	98.2	99.5	92.8	96.5	96.6	91.2	94.2	95.0
AVG		TGV	SB	237.5	294	93.6	95.9	98.0	93.0	95.4	97.7	89.4	90.7	94.6	87.9	89.2	93.4
			NB	237.5	289	88.0	90.3	93.4	90.0	92.1	94.6	85.9	86.6	92.7	84.3	85.6	89.6
AVG		TGV-2	SB	475.0	293	93.0	93.7	99.3	92.3	93.1	98.9	88.7	89.7	95.4	86.9	87.3	94.1
			NB	475.0	294	88.2	89.6	100.5	89.7	91.3	96.0	85.6	87.0	92.0	84.5	85.0	91.6
AVG		Eurostar	SB	393.7	283	96.7	99.9	102.1	96.0	99.4	96.8	92.5	94.5	91.8	91.0	93.0	89.8
			NB	393.7	293	89.3	91.8	95.3	90.3	93.1	93.1	85.8	88.0	88.0	83.9	86.1	86.1

HIGH-SPEED TRAIN NOISE DATA: FRANCE - SITE G (CUT SITE) - MAY 9, 1995

EVE NO.	TIME OF D	TRAIN DESCRIPTION Type	Dir.	Lengt (m)	Speed (kph)	MEASURED A-WEIGHTED SOUND LEVEL (dBA) Ch1(44mSB/48.5mNB/1.5m Lmax(s)	Lmax(f)	SEL	Ch2(44mSB/48.5mNB/4.0m Lmax(s)	Lmax(f)	SEL	Ch3(75mSB/79.5mNB/1.5m Lmax(s)	Lmax(f)	SEL
8	16:34	Eurostar	SB	393.7	257	76.5	78.4	84.2	---	---	---	64.6	68.0	72.0
10	16:41	TGV	NB	237.5	293	77.7	78.9	83.2	---	---	---	60.3	61.5	67.9
11	16:44	TGV-2	SB	475.0	285	76.8	78.3	83.1	---	---	---	60.6	61.3	69.3
12	16:50	TGV-2	SB	475.0	290	78.5	79.1	89.6	---	---	---	65.8	68.2	73.0
13	16:56	TGV	SB	237.5	294	77.8	80.0	83.4	---	---	---	61.3	62.1	68.2
15	17:01	TGV	SB	237.5	154	66.5	67.0	74.2	---	---	---	---	---	---
17	17:24	TGV	NB	237.5	291	77.8	79.7	84.2	90.8	92.9	---	61.2	62.0	70.1
18	17:28	Eurostar	NB	393.7	264	77.4	79.0	85.5	87.8	90.0	95.7	60.0	61.3	68.8
20	17:38	TGV	NB	237.5	293	76.5	77.2	81.9	87.0	88.1	92.5	59.9	61.3	70.8
21	17:43	TGV	SB	237.5	291	79.1	79.9	84.3	86.2	87.8	92.4	66.3	67.9	72.3
22	17:51	TGV	NB	237.5	288	79.5	80.2	84.8	87.3	88.3	92.9	61.3	62.3	70.7
23	18:03	TGV	NB	237.5	294	81.7	83.1	86.4	90.4	92.1	97.8	64.6	66.2	71.8
24	18:07	TGV	SB	237.5	291	77.9	79.0	83.0	87.0	88.0	92.5	68.0	73.0	74.1
25	18:13	TGV	SB	237.5	288	74.6	75.0	80.3	87.7	88.5	92.8	61.6	63.0	68.6
26	18:16	TGV-2	NB	475.0	294	79.1	80.8	89.0	89.3	90.0	96.2	63.4	64.5	72.1
27	18:31	TGV	SB	237.5	267	75.9	77.7	81.7	85.8	87.0	91.4	63.0	65.8	70.8
28	18:38	Eurostar	NB	393.7	286	78.9	79.1	86.3	88.2	89.8	95.7	62.6	63.2	71.3
29	18:41	TGV	NB	237.5	270	79.9	81.5	84.9	86.6	87.8	92.1	61.3	62.1	69.4
30	18:42	TGV	SB	237.5	288	78.5	79.7	83.7	86.2	86.9	91.7	66.4	69.5	73.0
31	19:05	TGV	NB	237.5	293	81.1	82.4	86.1	88.4	90.3	93.3	65.1	66.3	71.9

HIGH-SPEED TRAIN NOISE DATA: FRANCE - SITE H (BARRIER SITE) - MAY 11, 1995

EVE	TIME	TRAIN DESCRIPTION				MEASURED A-WEIGHTED SOUND LEVEL BEHIND BARRIER (dBA)											
NO.	OF DA	Type	Dir.	Length	Speed	Ch1(25mNB/29.5mSB/1.5mH)			Ch2(25mNB/29.5mSB/4.0mH)			Ch3(50mNB/54.5mSB/1.5mH)			Ch4(75mNB/79.5mSB/1.5mH		
				(m)	(kph)	Lmax(s)	Lmax(f)	SEL	Lmax(s)	Lmax(f)	SEL	Lmax(s)	Lmax(f)	SEL	Lmax(s)	Lmax(f)	SEL
28	11:09	TGV	SB	237.5	—	76.5	78.4	81.7	78.9	81.1	84.1	77.3	78.5	83.6	75.8	76.7	82.6
29	11:18	TGV	NB	237.5	—	83.1	84.8	88.3	83.7	85.5	89.0	82.7	85.2	88.4	81.3	83.1	87.0
30	11:25	TGV	NB	237.5	290	82.7	84.3	87.4	83.1	85.0	88.3	82.9	84.9	88.3	81.3	82.8	87.2
31	11:27	Eurostar	SB	393.7	267	77.2	79.0	84.4	77.9	81.0	86.1	78.4	79.8	85.3	76.1	78.1	84.6
32	11:35	TGV-2	NB	475.0	294	84.3	86.1	90.7	84.9	86.8	91.3	85.0	87.3	90.9	83.2	85.0	90.0
33	11:40	TGV	SB	237.5	294	75.9	77.6	81.7	78.5	80.0	84.2	77.4	79.0	84.1	76.6	78.0	83.0
34	11:42	TGV	SB	237.5	298	78.4	80.2	83.2	80.7	82.7	85.6	78.8	80.0	84.9	77.5	79.7	84.0
35	12:02	Eurostar	SB	393.7	283	78.3	80.3	85.4	80.3	82.6	87.5	77.2	79.6	85.4	76.5	78.1	84.4
37	12:11	TGV	NB	237.5	294	83.5	85.0	88.4	84.4	85.8	89.4	82.3	83.1	88.1	81.5	83.0	87.7
38	12:18	TGV	NB	237.5	293	82.9	84.4	87.6	83.3	85.0	88.2	81.3	82.2	87.2	79.5	80.6	88.4
39	12:32	Eurostar	NB	393.7	296	85.3	88.4	91.4	85.9	89.1	92.5	84.7	87.2	91.8	82.4	84.2	90.0
40	12:54	TGV-2	NB	475.0	294	85.0	87.0	91.1	86.0	88.1	92.0	84.2	85.7	90.7	82.5	83.2	89.6
41	13:08	TGV	SB	237.5	298	78.4	79.6	83.8	80.4	81.9	85.9	78.5	80.0	85.1	78.7	80.3	85.1
42	13:14	TGV	SB	237.5	293	77.2	78.4	82.2	79.7	81.4	84.8	78.2	79.1	84.2	78.0	79.4	83.6
AVG		TGV	NB	237.5	292	83.0	84.6	87.8	83.6	85.3	88.6	82.2	83.4	87.9	80.8	82.1	87.8
			SB	237.5	296	77.5	79.0	82.7	79.8	81.5	85.1	78.2	79.5	84.6	77.7	79.4	83.9
AVG		TGV-2	NB	475.0	294	84.7	86.6	90.9	85.5	87.5	91.7	84.6	86.5	90.8	82.9	84.1	89.8
AVG		Eurostar	SB	393.7	275	77.8	79.7	84.9	79.1	81.8	86.8	77.8	79.7	85.4	76.3	78.1	84.5

HIGH-SPEED TRAIN NOISE DATA: FRANCE - SITE H (EMBANKMENT SITE) - MAY 11, 1995

EVE NO.	TIME OF DA	TRAIN DESCRIPTION Type	Dir.	Length (m)	Speed (kph)	MEASURED A-WEIGHTED SOUND LEVEL - UNSHIELDED (LCh(25mNB/29.5mSB/1.5mH Lmax(s)	Lmax(f)	SEL	RCh(50mNB/54.5mSB/1.5mH Lmax(s)	Lmax(f)	SEL
3	11:25	TGV	NB	237.5	290	91.8	93.5	96.5	87.9	88.4	96.3
4	11:27	Eurostar	SB	393.7	267	86.2	88.9	97.9	82.7	85.0	90.3
5	11:40	TGV	SB	237.5	294	87.2	89.2	92.2	84.7	85.9	90.1
6	11:42	TGV	SB	237.5	298	87.2	89.0	92.1	85.3	86.1	90.3
7	12:02	Eurostar	SB	393.7	283	86.7	89.1	93.3	84.0	85.5	91.5
8	12:11	TGV	NB	237.5	294	94.0	96.0	98.7	90.7	92.9	95.8
9	12:18	TGV	NB	237.5	293	91.0	92.2	95.5	87.0	88.0	92.0
10	12:32	Eurostar	NB	393.7	296	92.5	96.0	99.1	88.6	90.8	96.1
11	12:55	TGV-2	NB	475.0	294	94.9	96.7	80.6	92.3	93.4	98.1
12	13:09	TGV	SB	237.5	298	87.8	90.0	92.9	86.8	88.0	92.0
13	13:13	TGV	SB	237.5	293	86.3	87.7	91.1	84.5	85.3	89.7
14	13:19	TGV	NB	237.5	294	90.9	93.0	95.9	88.0	88.7	93.5
AVG		TGV	NB	237.5	293	91.9	93.7	96.7	88.4	89.5	94.4
			SB	237.5	296	87.1	89.0	92.1	85.3	86.3	90.5
AVG		Eurostar	SB	393.7	275	86.5	89.0	95.6	83.4	85.3	90.9

HIGH-SPEED TRAIN NOISE DATA: FRANCE - SITE K (LOW-SPEED SITE) - MAY 11, 1995

EVE NO.	TIME OF D	TRAIN DESCRIPTION Type	Dir.	Lengt (m)	Speed (kph)	MEASURED A-WEIGHTED SOUND LEVEL (dBA) Ch1(25mNB/29.5mSB/1.5m Lmax(s)	Lmax(f)	SEL	Ch2(25mNB/29.5mSB/4.0m Lmax(s)	Lmax(f)	SEL	Ch3(50mNB/54.5mSB/1.5m Lmax(s)	Lmax(f)	SEL
48-1	16:30	TGV	SB	237.5	193	81.0	82.4	87.2	83.6	85.0	89.7	78.5	80.0	85.0
50-2	16:35	TGV	NB	237.5	198	88.2	89.5	93.5	88.2	89.7	93.9	85.0	86.0	90.8
51-3	16:40	Eurostar	SB	393.7	206	85.0	87.2	91.5	86.4	88.6	93.2	82.0	83.9	89.1
52-4	16:49	TGV	SB	237.5	201	80.3	81.0	86.0	83.3	84.4	88.9	78.2	78.6	84.3
53-5	16:52	TGV-2	SB	475.0	185	83.0	84.9	89.3	85.7	87.3	92.1	80.7	82.2	87.6
53-7	17:25	Eurostar	NB	393.7	145	87.0	89.0	93.9	86.6	88.8	94.1	83.5	85.5	91.3
54-8	17:33	Eurostar	SB	393.7	169	88.3	90.1	93.9	90.8	92.9	96.5	86.9	88.5	92.5
55-9	17:36	TGV	NB	237.5	193	88.3	89.2	96.7	87.8	89.1	93.7	84.5	86.3	90.5
55-1	17:45	TGV	NB	237.5	198	88.3	89.9	93.9	88.6	89.9	94.2	85.4	86.1	91.3
56-1	17:50	TGV	SB	237.5	201	82.5	83.1	88.7	85.4	87.0	91.5	81.1	82.6	87.4
56-1	18:02	TGV	NB	237.5	196	88.6	90.9	94.6	88.8	90.0	94.5	86.1	88.0	91.8
57-1	18:12	TGV	SB	237.5	182	81.7	83.2	87.5	83.8	85.3	89.9	78.9	80.1	85.7
57-1	18:30	Eurostar	NB	393.7	169	87.2	89.0	94.1	87.3	89.0	94.7	84.2	86.0	91.9
58-1	18:33	TGV	NB	237.5	216	87.1	89.0	92.7	87.4	88.5	93.1	84.4	85.6	90.2
58-1	19:00	TGV	NB	237.5	166	85.0	87.8	91.4	85.6	88.0	92.0	81.4	83.3	88.4
AVG		TGV	NB	237.5	195	87.6	89.4	93.8	87.7	89.2	93.6	84.5	85.9	90.5
			SB	237.5	194	81.4	82.4	87.4	84.0	85.4	90.0	79.2	80.3	85.6
AVG		Eurostar	NB	393.7	157	87.1	89.0	94.0	87.0	88.9	94.4	83.9	85.8	91.6
			SB	393.7	188	86.7	88.7	92.7	88.6	90.8	94.9	84.5	86.2	90.8

HIGH-SPEED TRAIN NOISE DATA: FRANCE - TGV HAUTE PICARDIE STA
(NB PLATFORM) MAY 12, 1995

EVE NO.	TIME OF D	TRAIN DESCRIPTION Type	Dir.	Lengt (m)	Speed (kph)	MEASURED SOUND LEVEL LCh(15mNB/20mSB/1.5mH) Lmax(s)	Lmax(f)	SEL
17	18:00	TGV	SB			96.2	98.2	100.8
19	18:07	TGV	NB			100.6	103.1	106.6
20	18:14	TGV	SB			97.3	98.6	103.1
21	18:19	TGV	NB			98.1	101.0	102.5
22	18:22	TGV	NB			99.3	103.4	103.7
23	18:27	TGV	SB			95.3	97.0	99.9

HIGH-SPEED TRAIN NOISE DATA: ITALY - SITE 2 (AT-GRADE SITE) - MAY 15, 1995

EVE	TIME	TRAIN DESCRIPTION				MEASURED A-WEIGHTED SOUND LEVEL (dBA)											
NO.	OF DA	Type	Dir.	Length	Speed	Ch1(25mNB/28.7mSB/1.5mH)			Ch2(25mNB/28.7mSB/4.0mH)			Ch3(50mNB/53.7mSB/1.5mH)			Ch4(75mNB/78.7mSB/1.5mH)		
				(m)	(kph)	Lmax(s)	Lmax(f)	SEL	Lmax(s)	Lmax(f)	SEL	Lmax(s)	Lmax(f)	SEL	Lmax(s)	Lmax(f)	SEL
76	20:19	Pendolino	NB	236.6	194	90.2	91.6	96.3	—	—	—	85.6	86.2	93.5	83.6	84.2	92.1
77	20:34	Pendolino	SB	236.6	—	86.3	87.5	92.6	—	—	—	83.0	83.8	89.5	81.2	82.0	87.9
80	20:49	Pendolino	SB	236.6	190	—	88.3	—	—	90.0	—	—	83.2	—	80.6	81.1	88.3

HIGH-SPEED TRAIN NOISE DATA: ITALY - SITE 3 (CURVE SITE) - MAY 17, 1995

EVE	TIME	TRAIN DESCRIPTION				MEASURED A-WEIGHTED SOUND LEVEL (dBA)											
NO.	OF DA	Type	Dir.	Length	Speed	Ch1(25mNB/28.7mSB/1.5mH)			Ch2(25mNB/28.7mSB/5.0mH)			Ch3(50mNB/53.7mSB/1.5mH)			Ch4(75mNB/78.7mSB/1.5mH)		
				(m)	(kph)	Lmax(s)	Lmax(f)	SEL	Lmax(s)	Lmax(f)	SEL	Lma:(s)	Lmax(f)	SEL	Lmax(s)	Lmax(f)	SEL
7	20:03	Pendolino	NB	236.6	132	84.7	86.0	92.0	85.9	87.0	93.4	84.7	83.1	93.7	90.3	90.8	97.8
11	20:36	Pendolino	SB	236.6	148	78.1	78.8	85.2	81.7	82.3	88.5	76.2	77.0	83.1	74.6	75.0	80.8
14	20:48	Pendolino	SB	236.6	130	76.2	77.0	83.5	79.3	80.1	86.6	74.6	75.2	82.0	72.6	73.0	80.1
16	20:54	Pendolino	NB	236.6	154	87.0	88.2	93.5	88.5	89.7	95.9	84.7	85.7	91.5	82.2	83.0	89.2

HIGH-SPEED TRAIN NOISE DATA: ITALY - SITE 4 (PRIMARY SITE) - MAY 16 & 18, 1995

EVE	TIME	TRAIN DESCRIPTION				MEASURED A-WEIGHTED SOUND LEVEL (dBA)											
NO.	OF DA	Type	Dir.	Length	Speed	Ch1(25mSB/28.7mNB/1.5mH)			Ch2(25mSB/28.7mNB/5.0mH)			Ch3(50mSB/53.7mNB/1.5mH)			Ch4(75mSB/78.7mNB/1.5mH)		
				(m)	(kph)	Lmax(s)	Lmax(f)	SEL	Lmax(s)	Lmax(f)	SEL	Lmax(s)	Lmax(f)	SEL	Lmax(s)	Lmax(f)	SEL
MAY 16, 1995																	
91	8:58	Pendolino	SB	236.6	175	87.7	88.0	94.4	87.4	88.0	94.0	86.3	87.2	93.1	83.1	83.8	90.0
95	9:59	Pendolino	NB	236.6	190	88.4	89.3	—	91.3	93.0	—	87.2	88.4	—	81.6	82.4	—
99	14:02	Pendolino	SB	236.6	195	88.2	88.9	97.3	87.8	88.9	94.4	86.3	87.3	92.7	83.0	84.0	89.1
105	16:59	Pendolino	NB	236.6	193	85.9	87.0	92.4	87.3	87.4	93.6	84.3	86.0	90.7	81.1	81.8	87.8
MAY 18, 1995																	
24	7:57	Pendolino	SB	236.6	182	89.9	90.8	95.2	89.3	90.8	94.8	87.4	89.0	92.9	—	82.8	—
27	8:59	Pendolino	SB	236.6	196	92.3	93.0	98.6	91.6	92.3	97.9	89.1	90.0	95.4	83.2	84.9	89.5
31	9:18	Pendolino	SB	236.6	185	88.4	89.2	94.3	88.1	89.5	94.2	85.3	86.8	91.4	79.8	81.0	86.2
36	10:00	Pendolino	NB	236.6	192	89.5	90.7	95.2	92.1	93.0	97.6	85.3	86.5	91.1	77.6	79.0	83.5
AVG		Pendolino	SB	236.6	187	89.3	90.0	96.0	88.8	89.9	95.1	86.9	88.1	93.1	82.3	83.3	88.7
			NB	236.6	192	87.9	89.0	93.8	90.2	91.1	95.6	85.6	87.0	90.9	80.1	81.1	85.7

HIGH-SPEED TRAIN NOISE DATA: ITALY - PARMA STATION
(NB PLATFORM) MAY 18, 1995

EVE NO.	TIME OF D	TRAIN DESCRIPTION Type	Dir.	Lengt (m)	Speed (kph)	MEASURED SOUND LEVEL(dB LCh(4mNB/8mSB/1.5mH) Lmax(s)	Lmax(f)	SEL	LEQ
1	19:54	Freight				99.6	102.0	111.1	
2	20:01	Inter-City	NB			103.4	104.8	110.4	
3	20:02	Freight	SB			99.5	100.2	109.6	
4	20:15	Loc.(IC)	--		0	---	87.5	---	85.0
5	20:19	Pendolino	--		0	---	83.0	---	77.0
6	20:22	Pendolino	SB			97.8	98.9	107.5	
7	20:32	Pendolino	SB			98.9	104.5	105.5	
8	20:56	Inter-City	SB			100.7	104.0	107.6	
9	20:57	Inter-City	NB			105.7	108.5	112.1	
10	21:04	Inter-City	SB			99.7	103.4	107.4	
11	21:06	Pendolino	NB			102.4	103.7	108.7	

HIGH-SPEED TRAIN NOISE DATA: SWEDEN - SITE 1 (EMBANKMENT SITE) - MAY 22, 1995

EVE	TIME	TRAIN DESCRIPTION				MEASURED A-WEIGHTED SOUND LEVEL (dBA)					
NO.	OF DA	Type	Dir.	Length	Speed	LCh(25mEB/29.5mWB/1.5mH			Ch2(50mEB/54.5mWB/1.5mH		
				(m)	(kph)	Lmax(s)	Lmax(f)	SEL	Lmax(s)	Lmax(f)	SEL
1	9:20	X2000	WB	140.0	164	79.6	81.5	84.2	83.4	86.0	88.2
3	9:42	X2000	WB	140.0	153	75.7	77.5	81.1	79.8	80.9	85.0
6	10:38	X2000	WB	140.0	177	81.5	84.5	85.2	84.3	86.3	88.9
9	11:31	X2000	EB	140.0	171	91.9	95.0	96.9	89.7	91.4	95.0
11	13:29	X2000	EB	140.0	169	91.7	94.8	96.0	88.1	90.1	93.0
13	13:53	X2000	WB	140.0	167	82.5	85.2	86.8	86.5	88.1	90.9
15	16:28	X2000	EB	140.0	177	85.3	89.4	89.9	82.4	85.0	87.8
17	16:47	X2000	WB	140.0	175	79.9	82.7	84.3	81.3	83.2	86.5
18	17:29	X2000	EB	140.0	177	89.9	94.5	94.7	86.7	89.1	92.1
19	18:29	X2000	EB	140.0	169	85.1	87.3	89.0	82.8	83.7	88.2
21	18:48	X2000	WB	140.0	171	82.7	84.2	87.2	86.1	88.1	90.2
AVG		X2000	EB	140.0	173	88.8	92.2	93.3	85.9	87.9	91.2
			WB	140.0	168	80.3	82.6	84.8	83.6	85.4	88.3

HIGH-SPEED TRAIN NOISE DATA: SWEDEN - SITE 2 (CUT SITE) - MAY 22, 1995

EVE NO.	TIME OF DA	TRAIN DESCRIPTION Type	Dir.	Length (m)	Speed (kph)	MEASURED A-WEIGHTED SOUND LEVEL (dBA) Ch1(20mEB/24.5mWB/1.5mH Lmax(s)	Lmax(f)	SEL	Ch2(40mEB/44.5mWB/1.5mH Lmax(s)	Lmax(f)	SEL	Ch3(40mEB/44.5mWB/5.0mH Lmax(s)	Lmax(f)	SEL	Ch4(65mEB/69.5mWB/1.5mH Lmax(s)	Lmax(f)	SEL
45	9:20	X2000	WB	140.0	164	92.2	93.6	101.5	76.1	77.0	82.1	84.6	85.8	90.3	69.7	70.2	76.9
46	9:42	X2000	WB	140.0	153	92.2	95.0	97.8	79.6	81.9	84.2	84.0	85.3	89.8	73.9	75.0	83.7
48	10:38	X2000	WB	140.0	177	93.1	94.5	98.3	75.8	76.9	81.6	84.8	85.7	90.0	70.6	71.9	77.1
51	11:31	X2000	EB	140.0	171	96.2	97.2	101.1	76.7	78.2	81.5	82.6	84.0	87.5	71.6	73.0	77.3
53	13:29	X2000	EB	140.0	169	96.0	97.0	100.8	76.5	78.0	81.2	82.0	83.9	87.0	70.9	72.0	77.0
55	13:53	X2000	WB	140.0	167	92.9	95.0	98.5	75.5	76.9	81.5	84.7	86.0	90.5	69.6	70.2	76.3
56	16:28	X2000	EB	140.0	177	96.2	97.5	100.6	76.4	77.2	81.6	82.5	83.8	87.4	71.1	71.9	76.8
58	16:47	X2000	WB	140.0	175	95.0	95.9	100.0	78.2	79.2	84.6	86.4	87.1	91.8	71.9	73.0	78.6
59	17:29	X2000	EB	140.0	177	97.4	99.1	101.6	78.8	79.9	83.8	84.4	85.8	89.1	73.8	75.9	79.2
61	18:29	X2000	EB	140.0	169	96.2	97.3	104.3	78.2	79.0	83.4	82.9	83.8	87.9	71.9	72.7	77.7
63	18:48	X2000	WB	140.0	171	93.7	95.0	99.1	78.5	79.9	84.5	84.7	85.2	90.3	72.4	73.9	78.7
AVG		X2000	EB	140.0	173	96.4	97.6	101.7	77.3	78.5	82.3	82.9	84.3	87.8	71.9	73.1	77.6
			WB	140.0	168	93.2	94.8	99.2	77.3	78.6	83.1	84 9	85.9	90.5	71.4	72.4	78.6

HIGH-SPEED TRAIN NOISE DATA: SWEDEN - SITE 3A (PRIMARY SITE) - MAY 23, 1995

EVE	TIME	TRAIN DESCRIPTION				MEASURED A-WEIGHTED SOUND LEVEL (dBA)											
NO.	OF DA	Type	Dir.	Length	Speed	Ch1(25mEB/29.5mWB/1.5mH			Ch2(25mEB/29.5mWB/5.0mH			Ch3(50mEB/54.5mWB/1.5mH			Ch4(75mEB/79.5mWB/1.5mH		
				(m)	(kph)	Lmax(s)	Lmax(f)	SEL	Lmax(s)	Lmax(f)	SEL	Lmax(s)	Lmax(f)	SEL	Lmax(s)	Lmax(f)	SEL
72	9:22	X2000	WB	140.0	183	91.3	92.0	96.7	93.3	94.6	98.5	88.4	89.8	93.9	84.9	85.7	90.7
74	9:48	X2000	WB	140.0	185	91.3	92.5	96.5	93.3	94.5	98.7	88.6	90.0	94.1	83.2	84.3	88.9
78	10:43	X2000	WB	140.0	185	92.8	93.6	97.7	95.0	96.0	100.1	89.4	90.6	94.6	80.2	81.0	85.8
79	11:32	X2000	EB	140.0	159	89.1	89.5	94.3	91.5	92.0	97.0	86.5	87.8	92.0	80.5	81.2	86.7
80	13:31	X2000	EB	140.0	182	94.4	95.0	99.1	94.5	95.0	99.2	90.9	92.0	96.1	82.7	83.4	88.2
82	14:04	X2000	WB	140.0	185	92.0	93.1	97.2	94.2	95.5	99.3	88.5	89.9	94.2	83.9	84.5	90.1
83	16:32	X2000	EB	140.0	185	94.9	96.0	99.4	95.2	96.5	99.8	91.8	93.3	96.7	—	—	—
85	16:55	X2000	WB	140.0	185	92.0	92.7	97.0	94.0	95.0	99.1	89.7	90.7	95.2	87.0	87.6	92.6
86	17:30	X2000	EB	140.0	182	93.0	93.9	97.6	93.0	94.0	97.8	90.0	90.8	95.1	85.8	86.8	91.3
87	18:31	X2000	EB	140.0	180	93.0	93.3	98.0	93.2	93.9	98.2	90.3	91.1	95.6	87.8	88.5	93.4
AVG		X2000	EB	w/o#79	182	93.8	94.6	98.5	94.0	94.9	98.8	90.8	91.8	95.9	85.4	86.2	91.0
			WB		185	91.9	92.8	97.0	94.0	95.1	99.1	88.9	90.2	94.4	83.8	84.6	89.7

HIGH-SPEED TRAIN NOISE DATA: SWEDEN - SITE 4 (CURVE SITE) - MAY 24, 1995

EVE NO.	TIME OF DA	TRAIN DESCRIPTION Type	Dir.	Length (m)	Speed (kph)	MEASURED A-WEIGHTED SOUND LEVEL (dBA) Ch1(25mEB/29.5mWB/1.5mH Lmax(s)	Lmax(f)	SEL	Ch2(25mEB/29.5mWB/5.0mH Lmax(s)	Lmax(f)	SEL	Ch3(50mEB/54.5mWB/1.5mH Lmax(s)	Lmax(f)	SEL	Ch4(75mEB/79.5mWB/1.5mH Lmax(s)	Lmax(f)	SEL
100	9:19	X2000	WB	140.0	175	80.8	83.9	87.1	86.1	88.0	91.0	77.8	78.9	84.1	77.0	77.5	83.3
101	9:42	X2000	WB	140.0	174	83.2	84.3	89.0	87.8	89.1	92.4	79.8	80.9	84.9	77.8	78.6	87.4
109	11:33	X2000	EB	140.0	174	86.9	88.5	91.3	87.4	89.2	91.7	82.5	83.6	87.4	78.9	79.9	84.6
110	13:35	X2000	EB	140.0	72	77.0	78.0	84.4	77.6	78.4	85.1	71.7	72.1	80.2	68.0	68.0	76.9
111	13:51	X2000	WB	140.0	183	84.9	86.0	90.0	89.2	90.0	94.3	80.3	81.0	86.1	80.0	80.2	86.2
AVG		X2000	WB	140.0	177	83.0	84.7	88.7	87.7	89.0	92.6	79.3	80.3	85.0	78.3	78.8	85.6

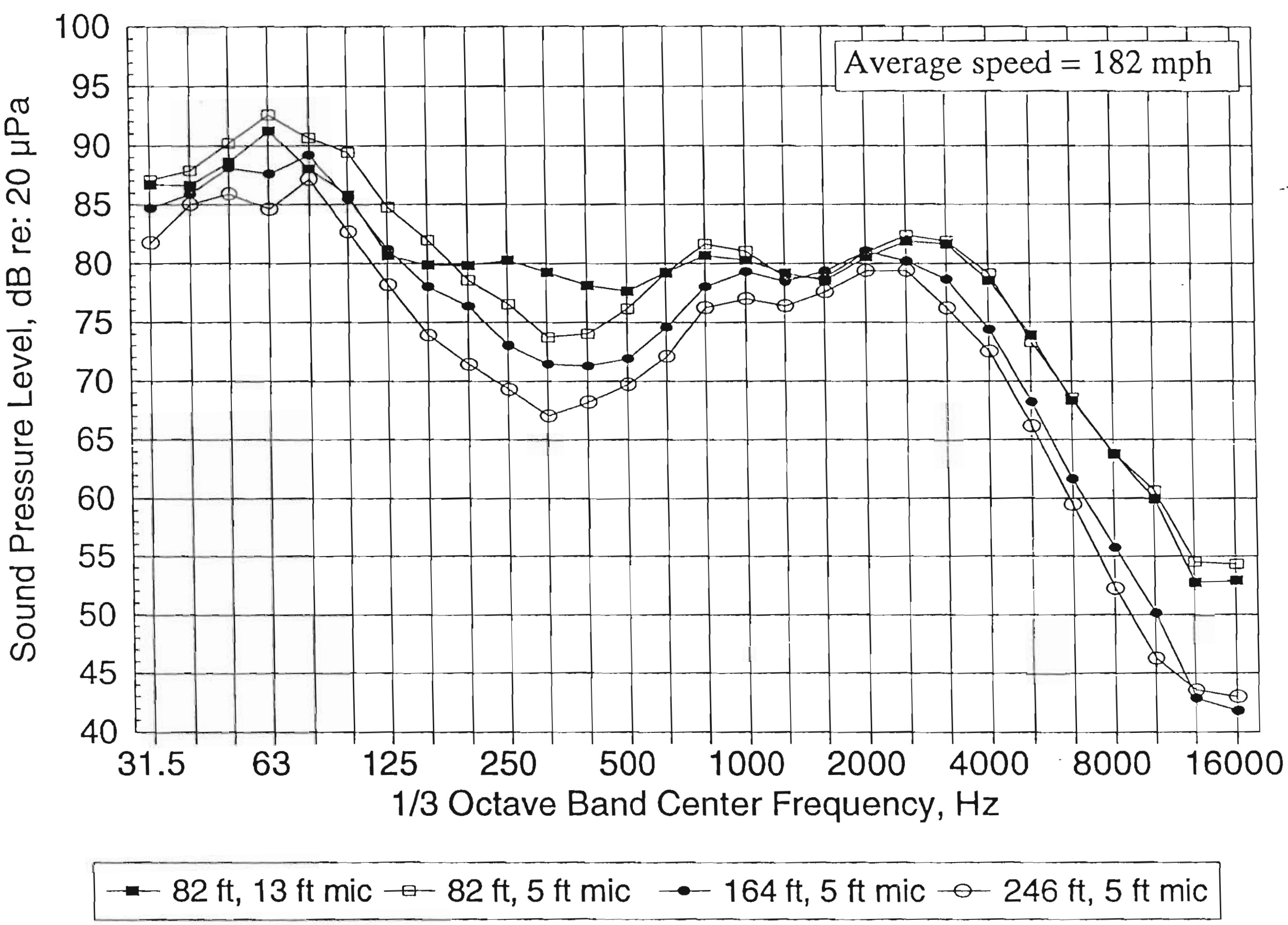
HIGH-SPEED TRAIN NOISE DATA: SWEDEN - SITE 5 - MAY 24, 1995

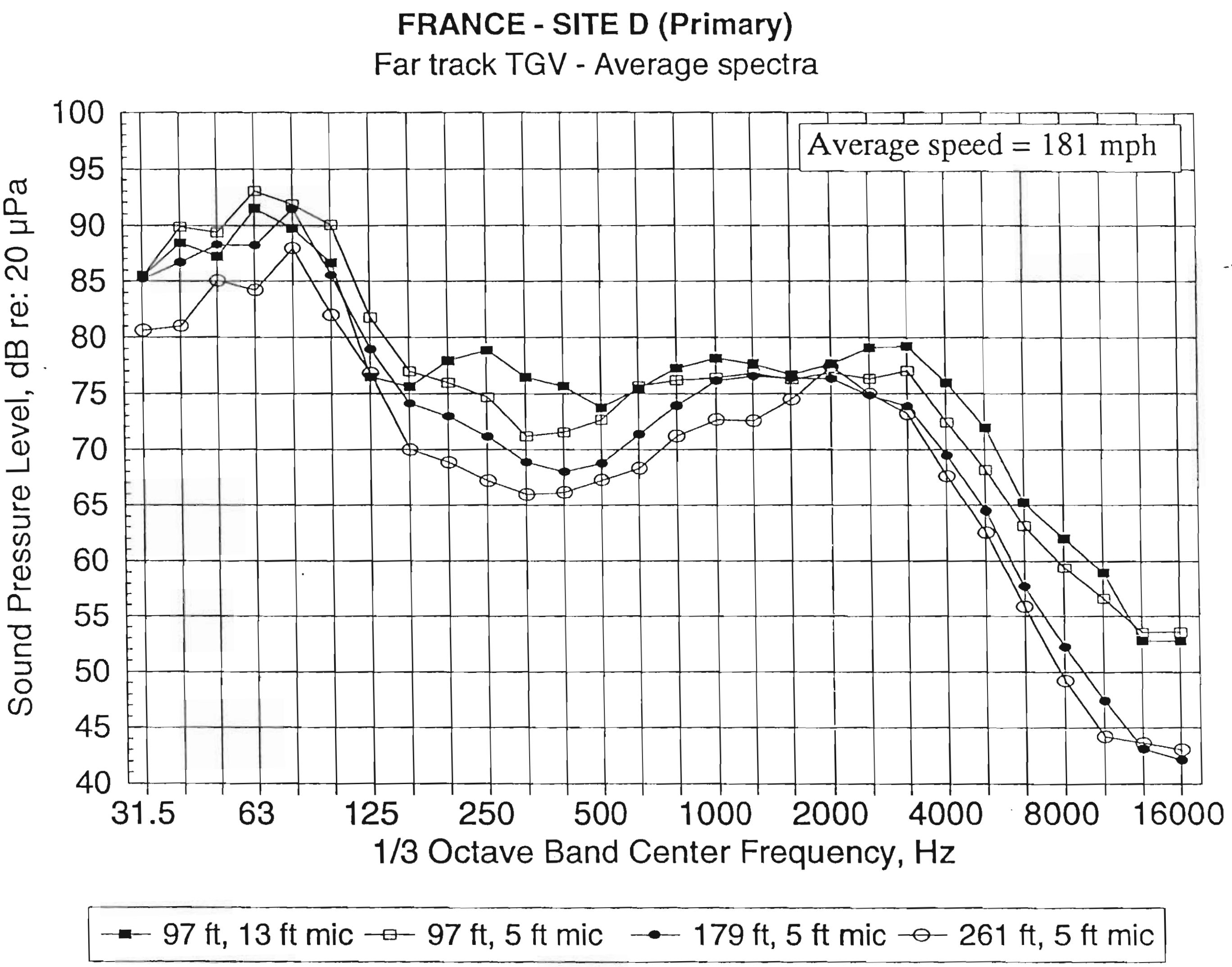
EVE	TIME	TRAIN DESCRIPTION				MEASURED A-WEIGHTED SOUND LEVEL (dBA)											
NO.	OF DA	Type	Dir.	Length	Speed	Ch1(25mEB/29.5mWB/1.5mH			Ch2(25mEB/29.5mWB/5.0mH			Ch3(50mEB/54.5mWB/1.5mH			Ch4(75mEB/79.5mWB/1.5mH		
				(m)	(kph)	Lmax(s)	Lmax(f)	SEL	Lmax(s)	Lmax(f)	SEL	Lmax(s)	Lmax(f)	SEL	Lmax(s)	Lmax(f)	SEL
121	16:38	X2000	EB	140.0	183	93.6	94.1	88.5	93.8	94.7	98.8	91.6	92.1	96.5	89.8	90.2	95.0
122	16:44	X2000	WB	140.0	177	85.7	87.7	95.0	89.7	91.2	95.2	83.9	85.5	89.6	82.7	83.1	88.4
124	17:38	X2000	EB	140.0	187	93.4	94.4	97.8	93.8	95.2	98.9	91.6	92.9	96.3	89.8	90.3	95.2
125	18:37	X2000	EB	140.0	187	93.1	94.5	97.6	93.5	94.3	98.0	89.6	90.0	94.8	88.3	89.0	94.0
126	18:42	X2000	WB	140.0	174	86.5	88.1	91.7	89.5	91.2	95.2	83.2	84.1	88.9	82.0	82.6	87.7
128	19:38	X2000	WB	140.0	114	82.2	83.4	88.0	85.4	86.8	91.9	79.1	79.7	85.9	78.7	80.1	85.7
AVG		X2000	EB	140.0	186	93.4	94.3	94.6	93.7	94.7	98.6	90.9	91.7	95.9	89.3	89.8	94.7

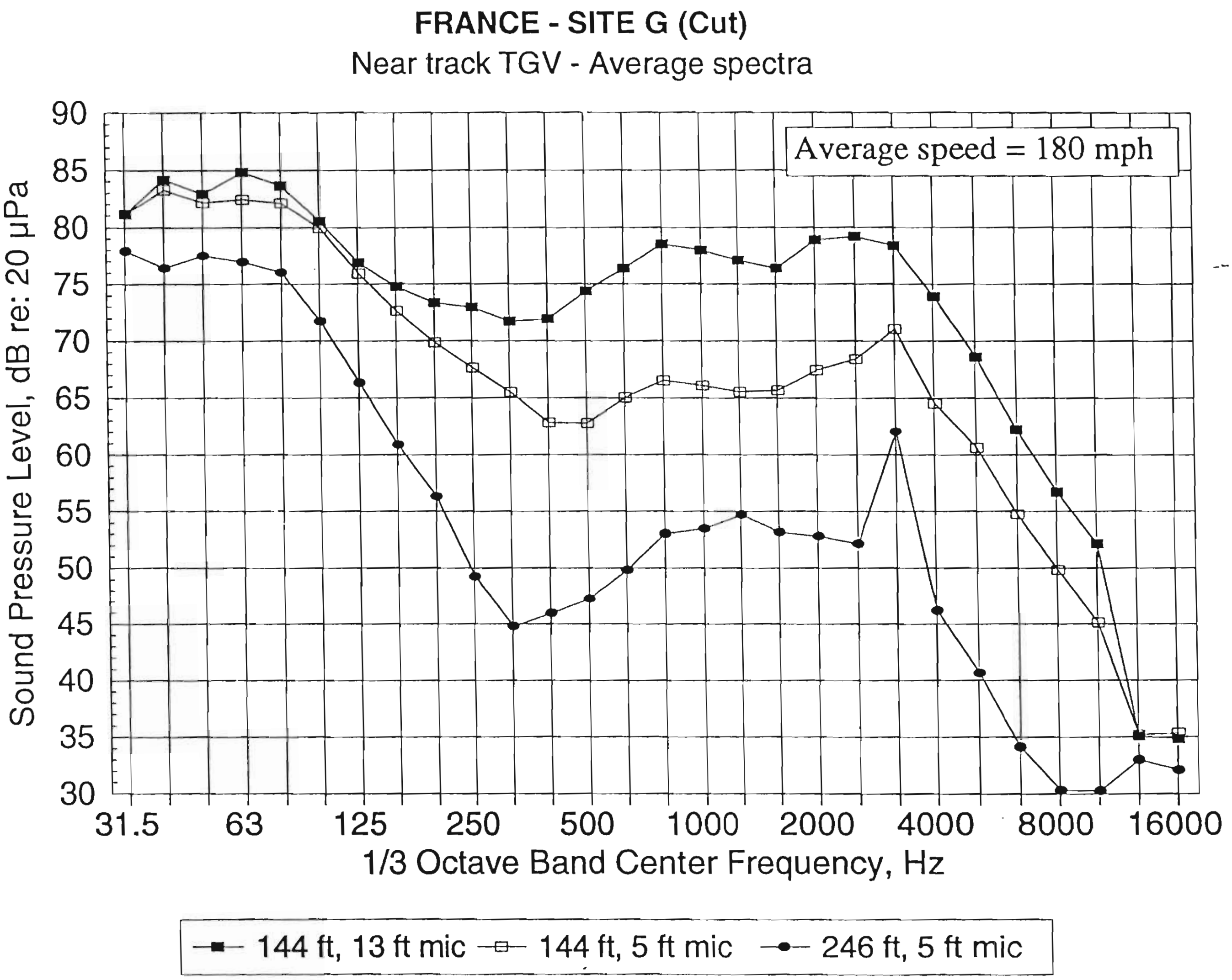
APPENDIX B: TRAIN NOISE SPECTRA

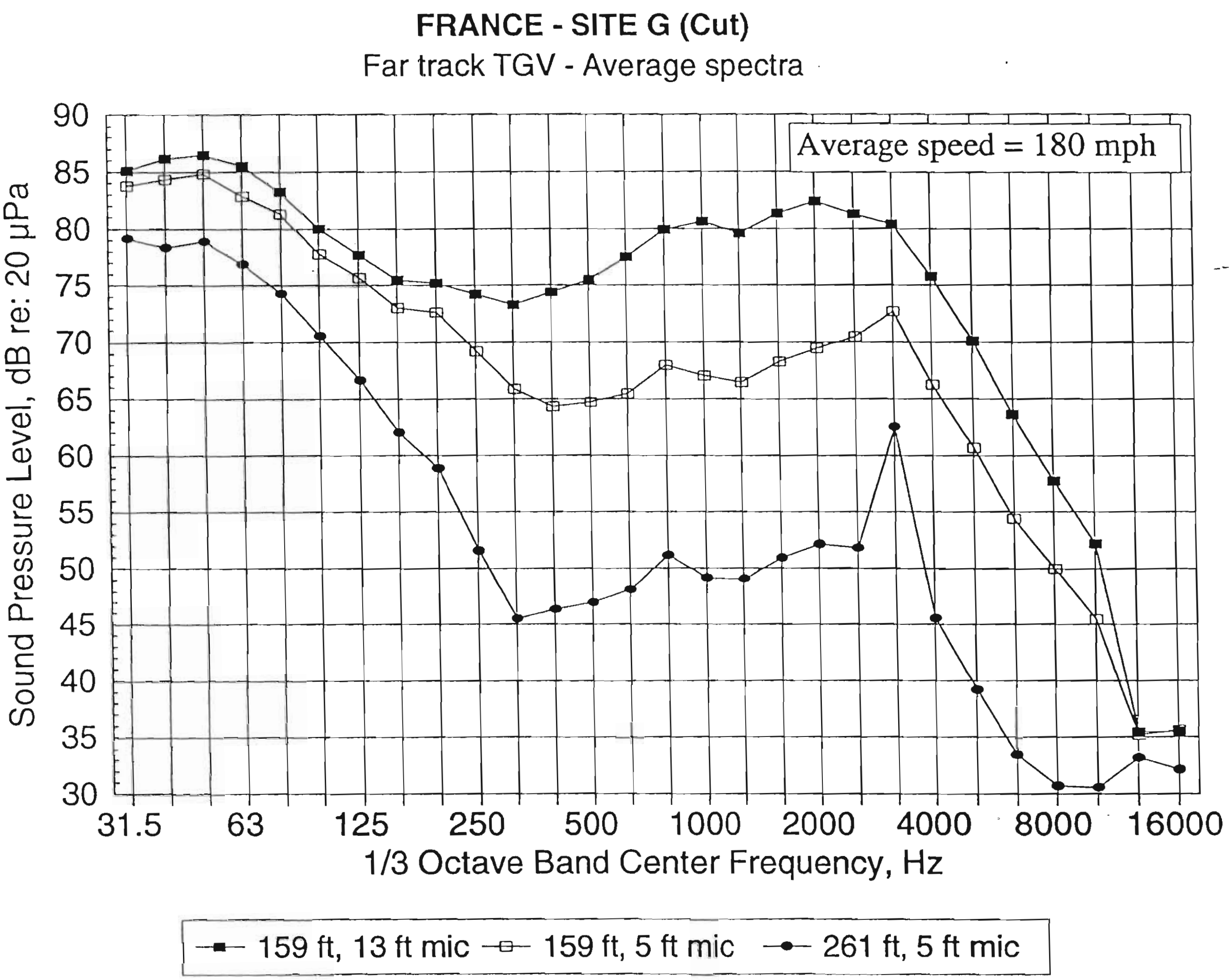
FRANCE - SITE D (Primary)

Near track TGV - Average spectra




FRANCE - SITE D (Primary)
Far track TGV - Average spectra
Average speed = 181 mph
Sound Pressure Level, dB re: 20 μPa
100
95
90
85
80
75
70
65
60
55
50
45
40
31.5
63
125
250
500
1000
2000
4000
8000
16000
1/3 Octave Band Center Frequency, Hz
97 ft, 13 ft mic
97 ft, 5 ft mic
179 ft, 5 ft mic
261 ft, 5 ft mic


FRANCE - SITE G (Cut)
Near track TGV - Average spectra
Average speed = 180 mph
Sound Pressure Level, dB re: 20 μPa
90
85
80
75
70
65
60
55
50
45
40
35
30
31.5
63
125
250
500
1000
2000
4000
8000
16000
1/3 Octave Band Center Frequency, Hz
144 ft, 13 ft mic
144 ft, 5 ft mic
246 ft, 5 ft mic



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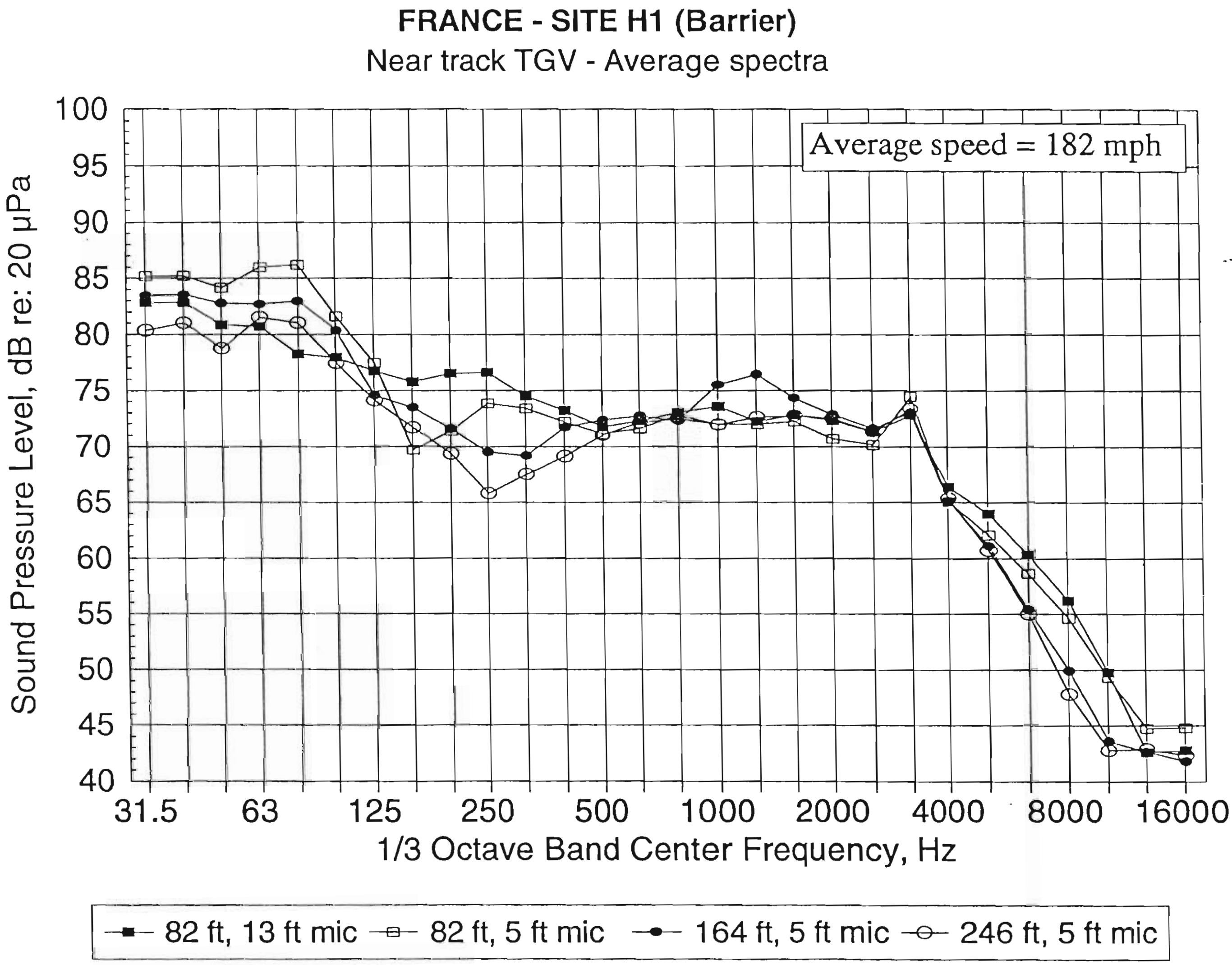

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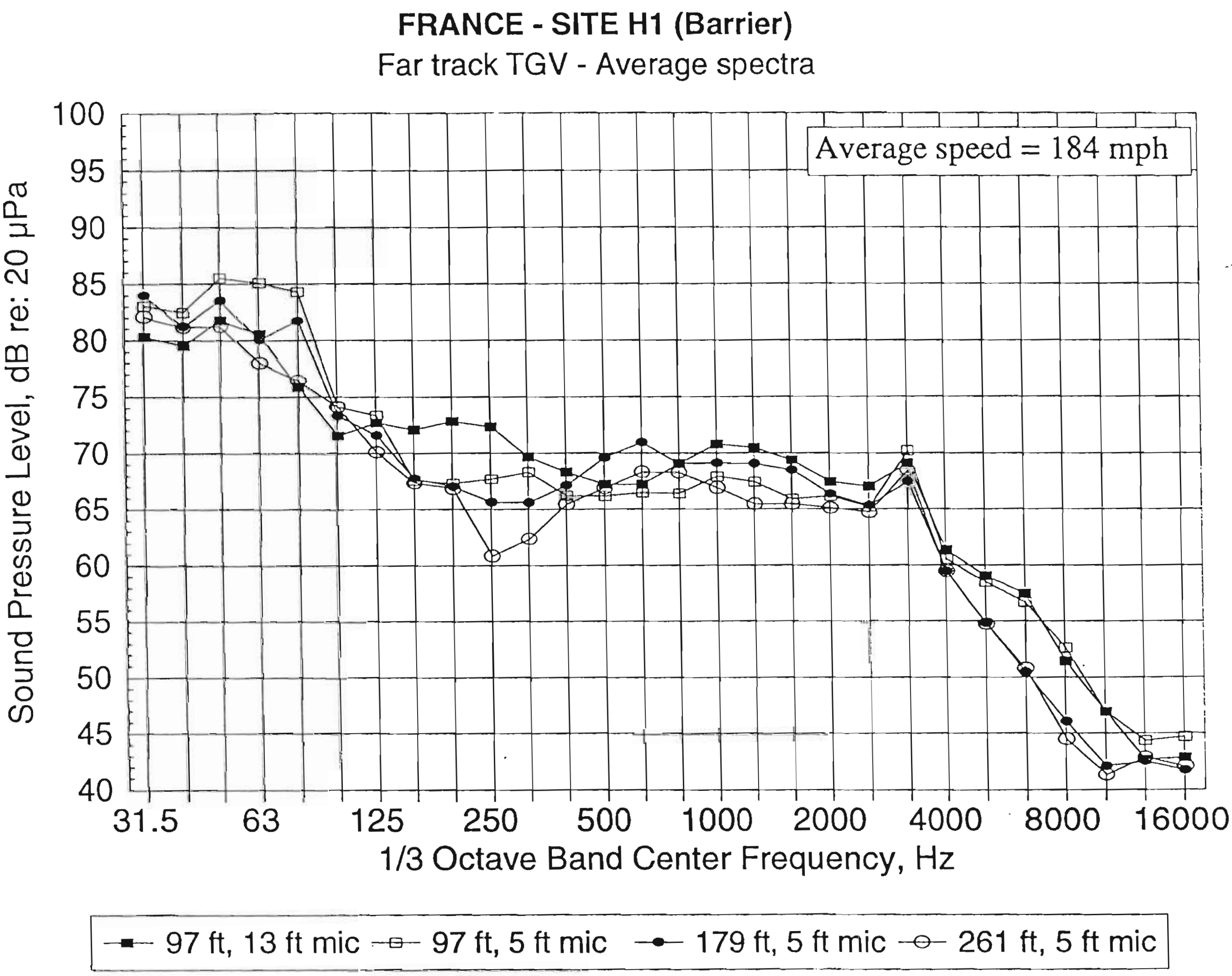
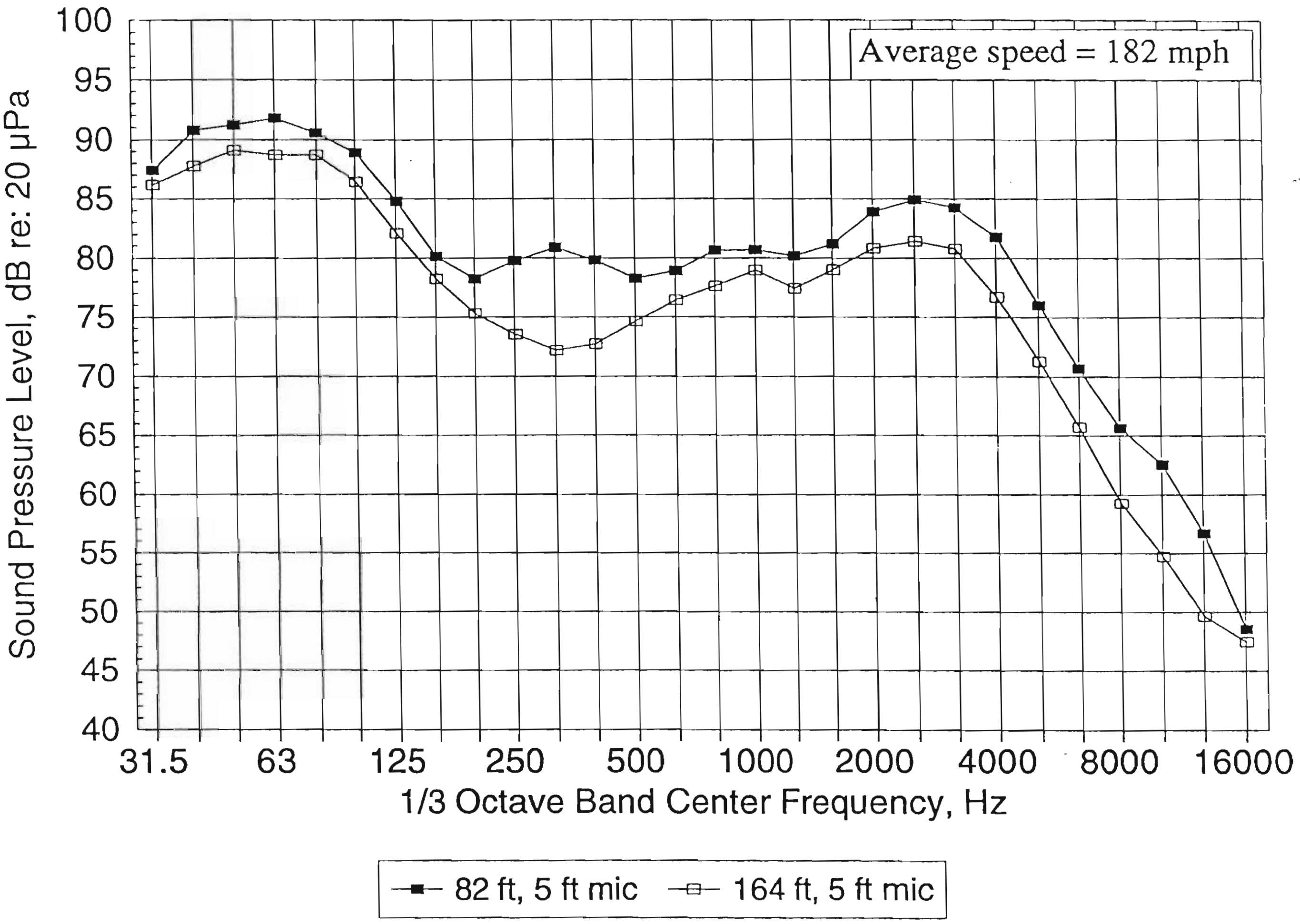
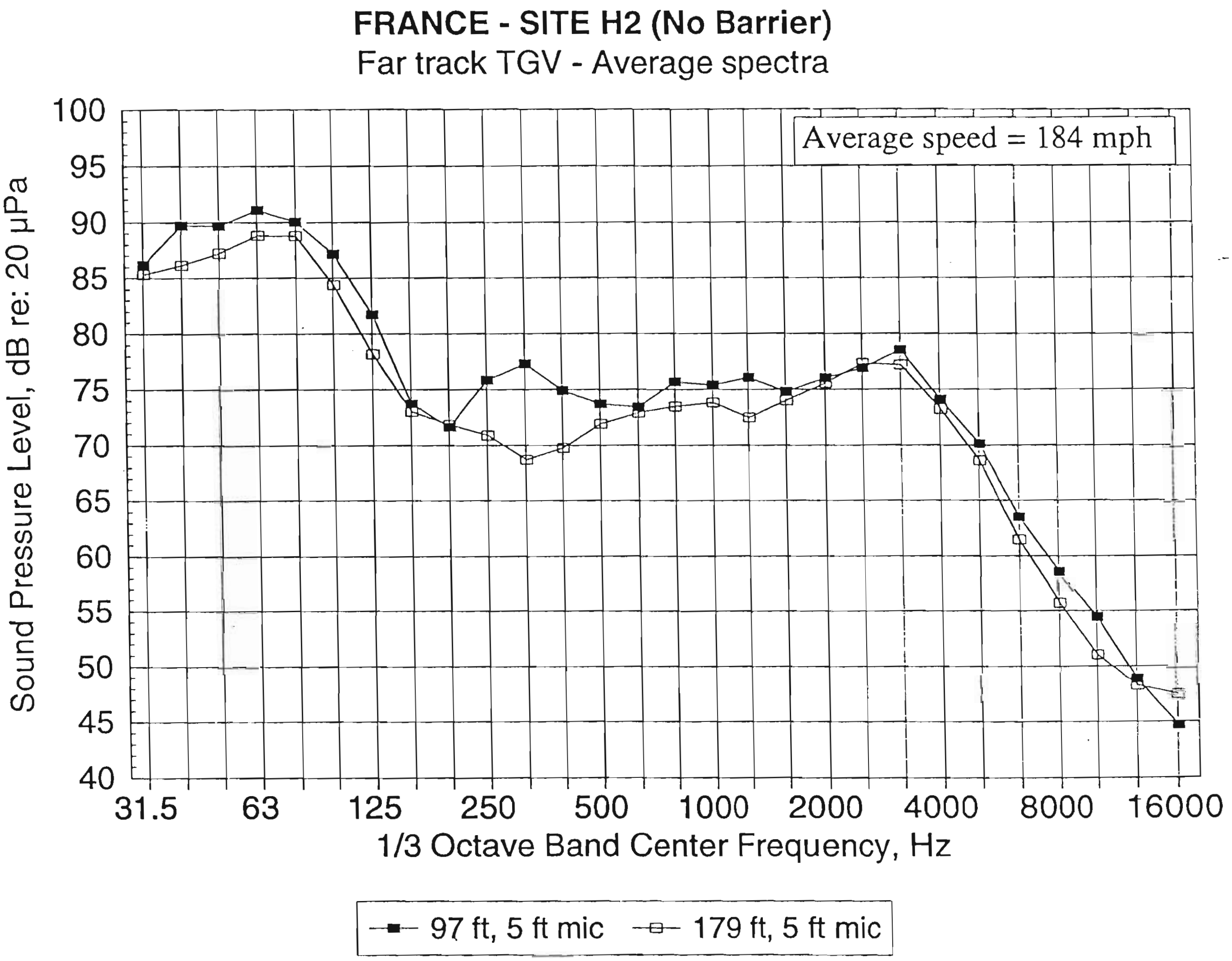
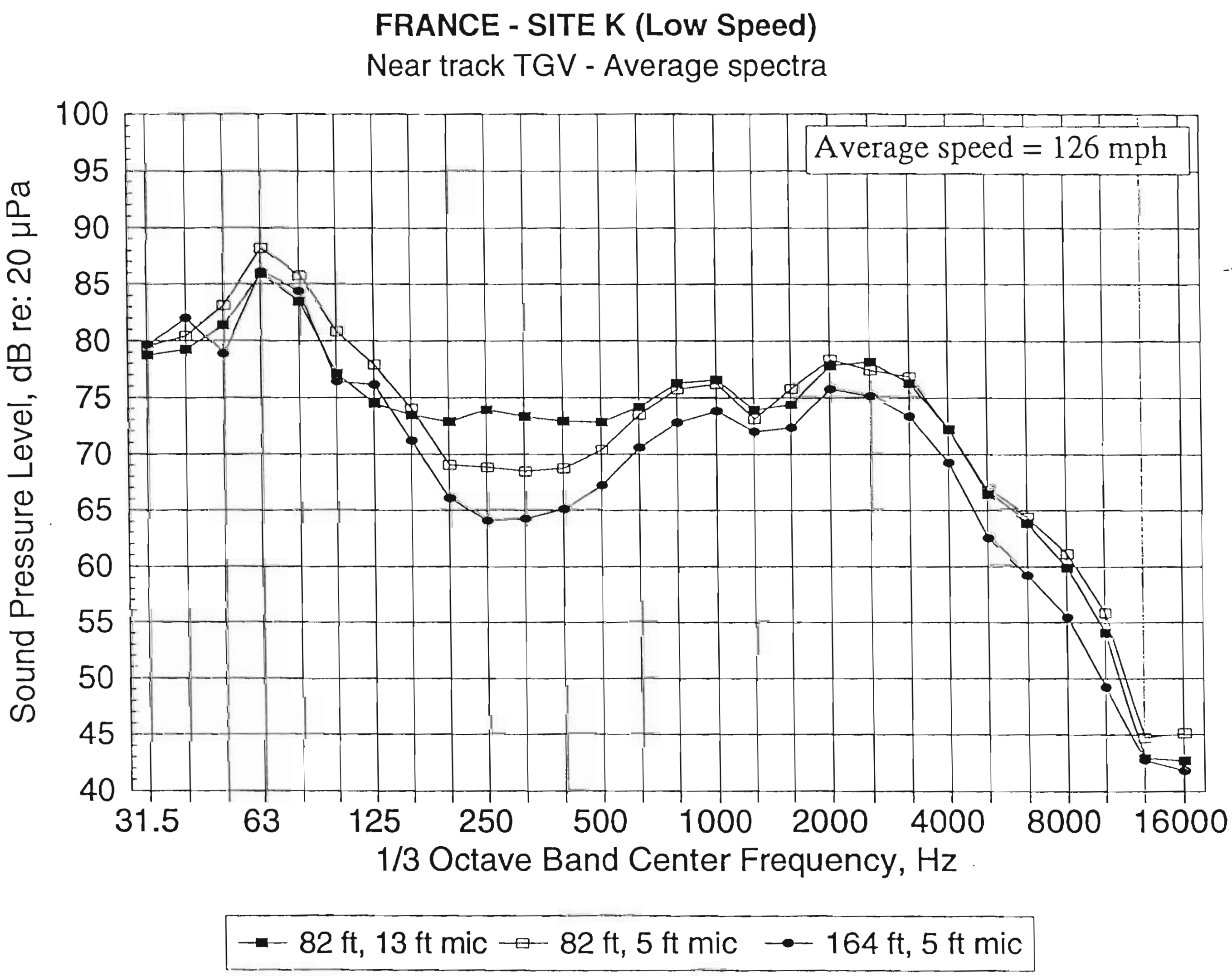

FRANCE - SITE H1 (Barrier)
Far track TGV - Average spectra
Average speed = 184 mph
Sound Pressure Level, dB re: 20 μPa
100
95
90
85
80
75
70
65
60
55
50
45
40
31.5
63
125
250
500
1000
2000
4000
8000
16000
1/3 Octave Band Center Frequency, Hz
97 ft, 13 ft mic
97 ft, 5 ft mic
179 ft, 5 ft mic
261 ft, 5 ft mic

FRANCE - SITE H2 (No Barrier)
Near track TGV - Average spectra



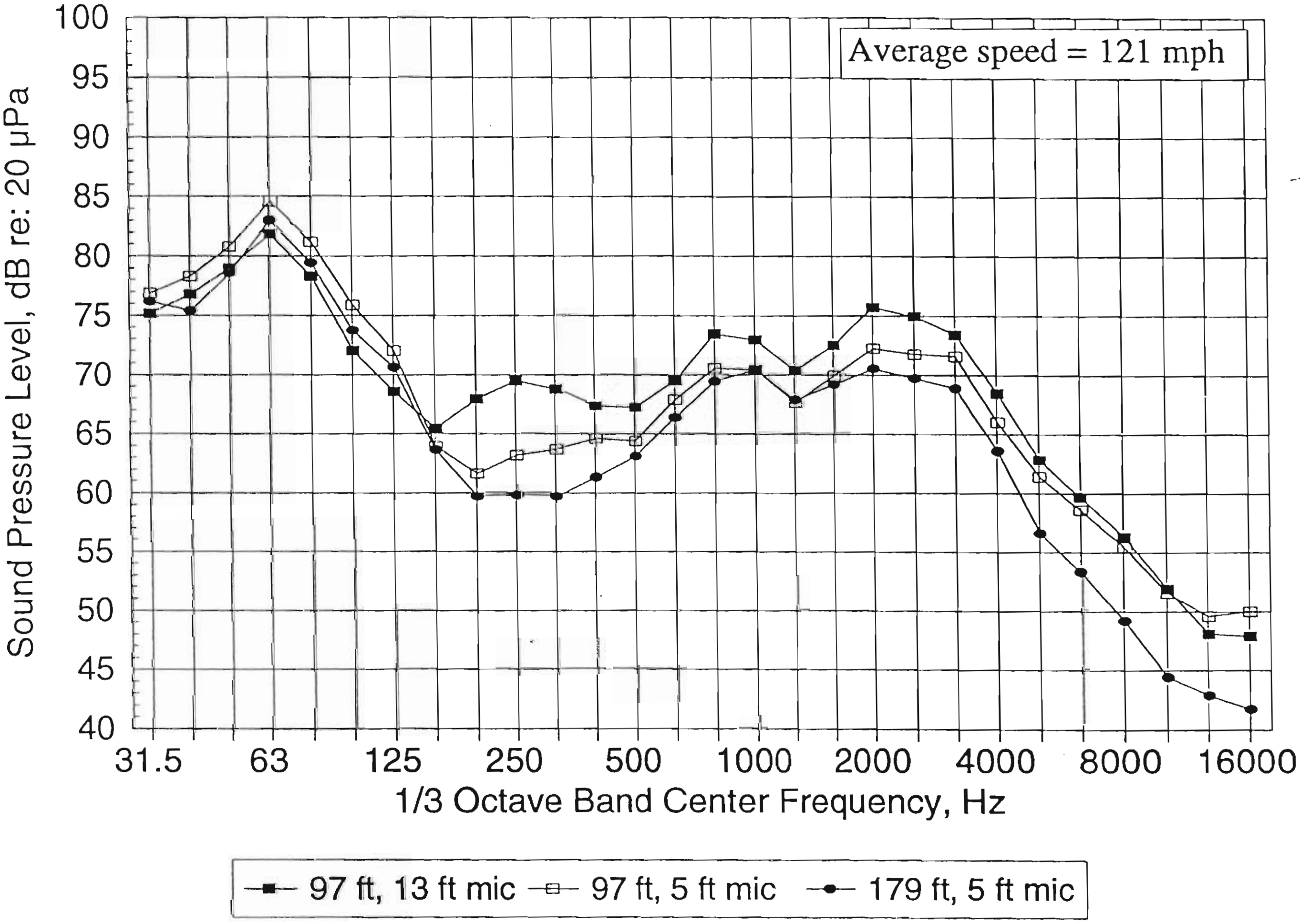


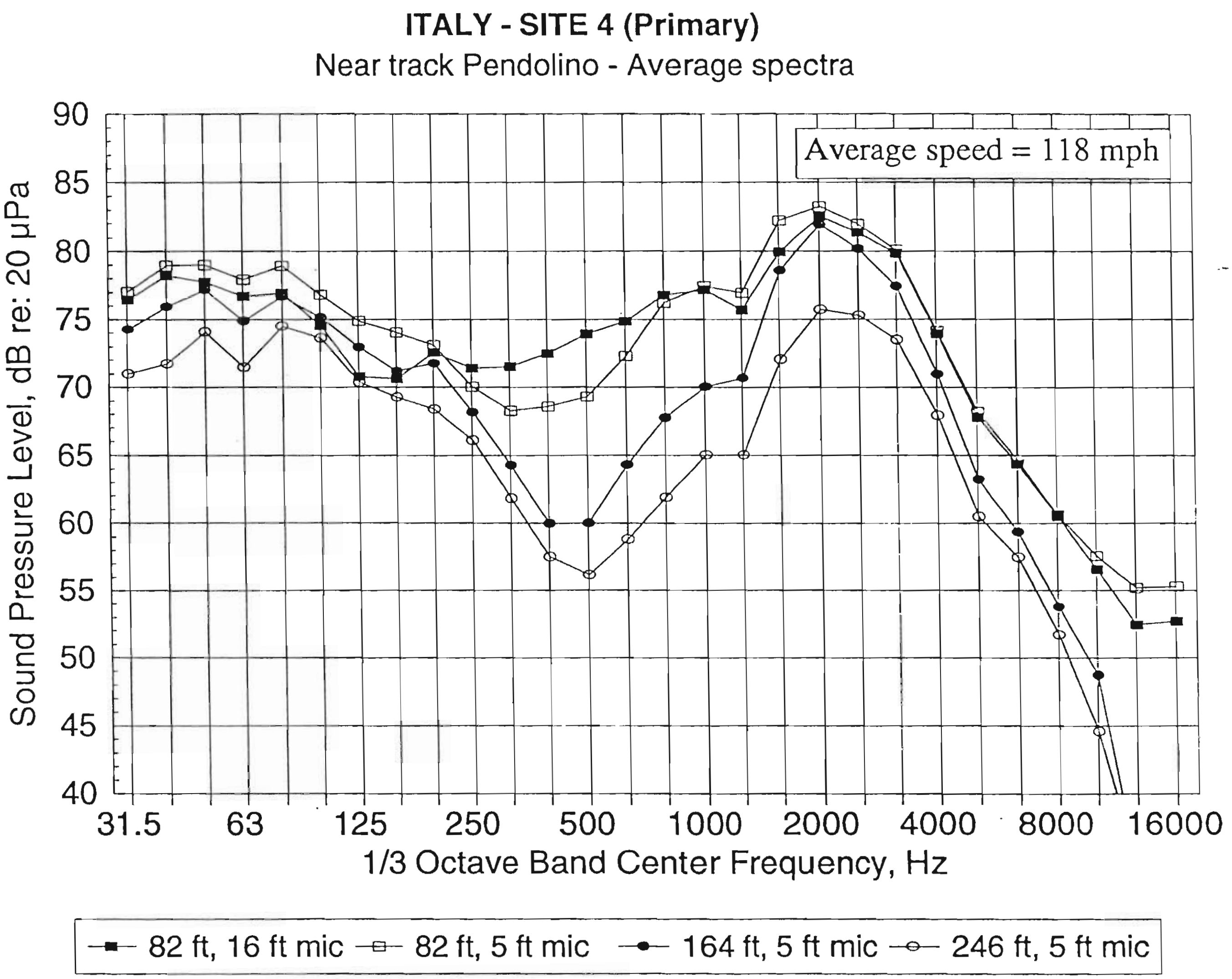
FRANCE - SITE H2 (No Barrier)
Far track TGV - Average spectra
Average speed = 184 mph
Sound Pressure Level, dB re: 20 µPa
100
95
90
85
80
75
70
65
60
55
50
45
40
31.5
63
125
250
500
1000
2000
4000
8000
16000
1/3 Octave Band Center Frequency, Hz
97 ft, 5 ft mic
179 ft, 5 ft mic



FRANCE - SITE K (Low Speed)
Near track TGV - Average spectra
Average speed = 126 mph
Sound Pressure Level, dB re: 20 µPa
100
95
90
85
80
75
70
65
60
55
50
45
40
31.5
63
125
250
500
1000
2000
4000
8000
16000
1/3 Octave Band Center Frequency, Hz
82 ft, 13 ft mic
82 ft, 5 ft mic
164 ft, 5 ft mic

FRANCE - SITE K (Low Speed)
Far track TGV - Average spectra

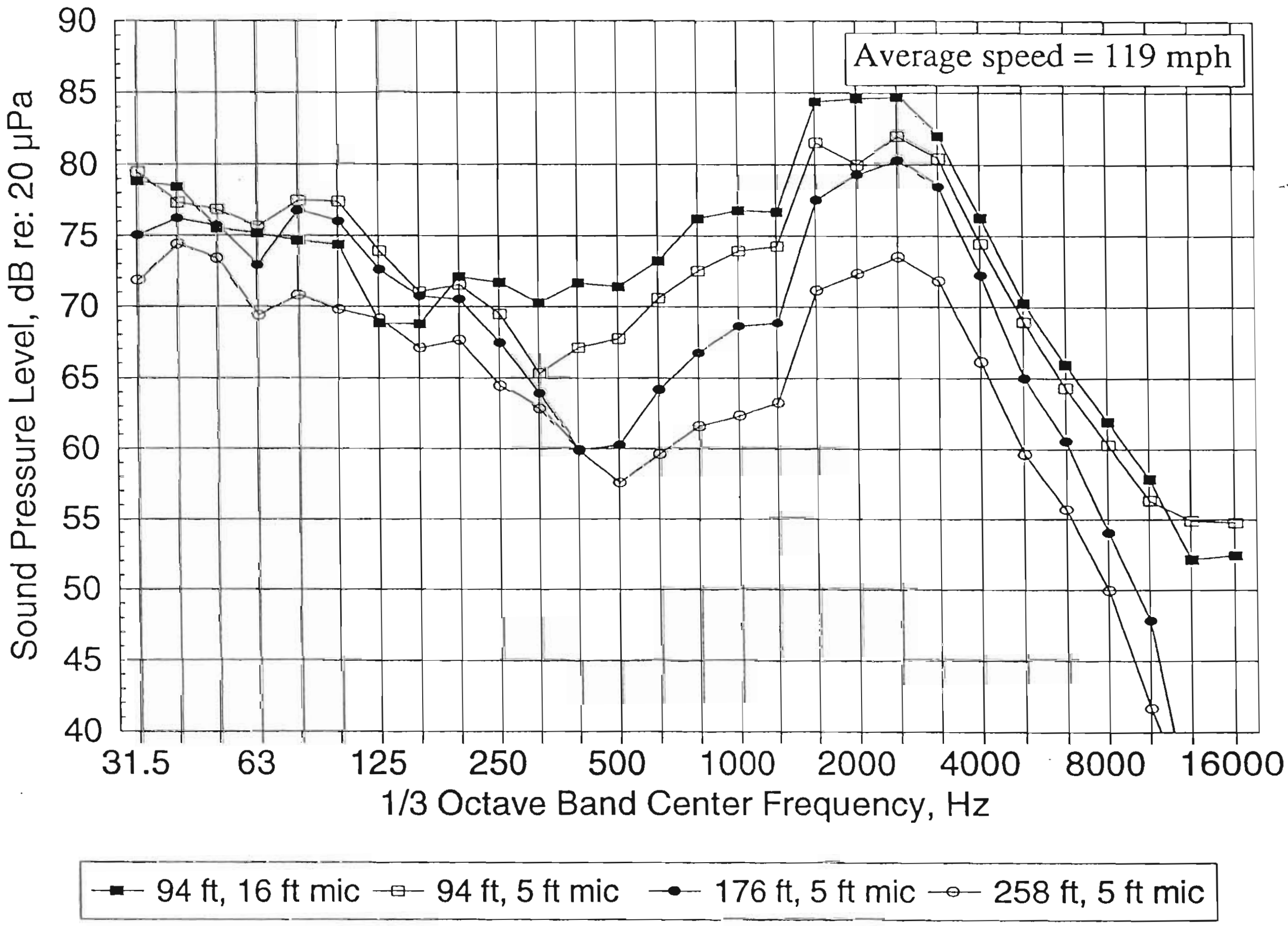


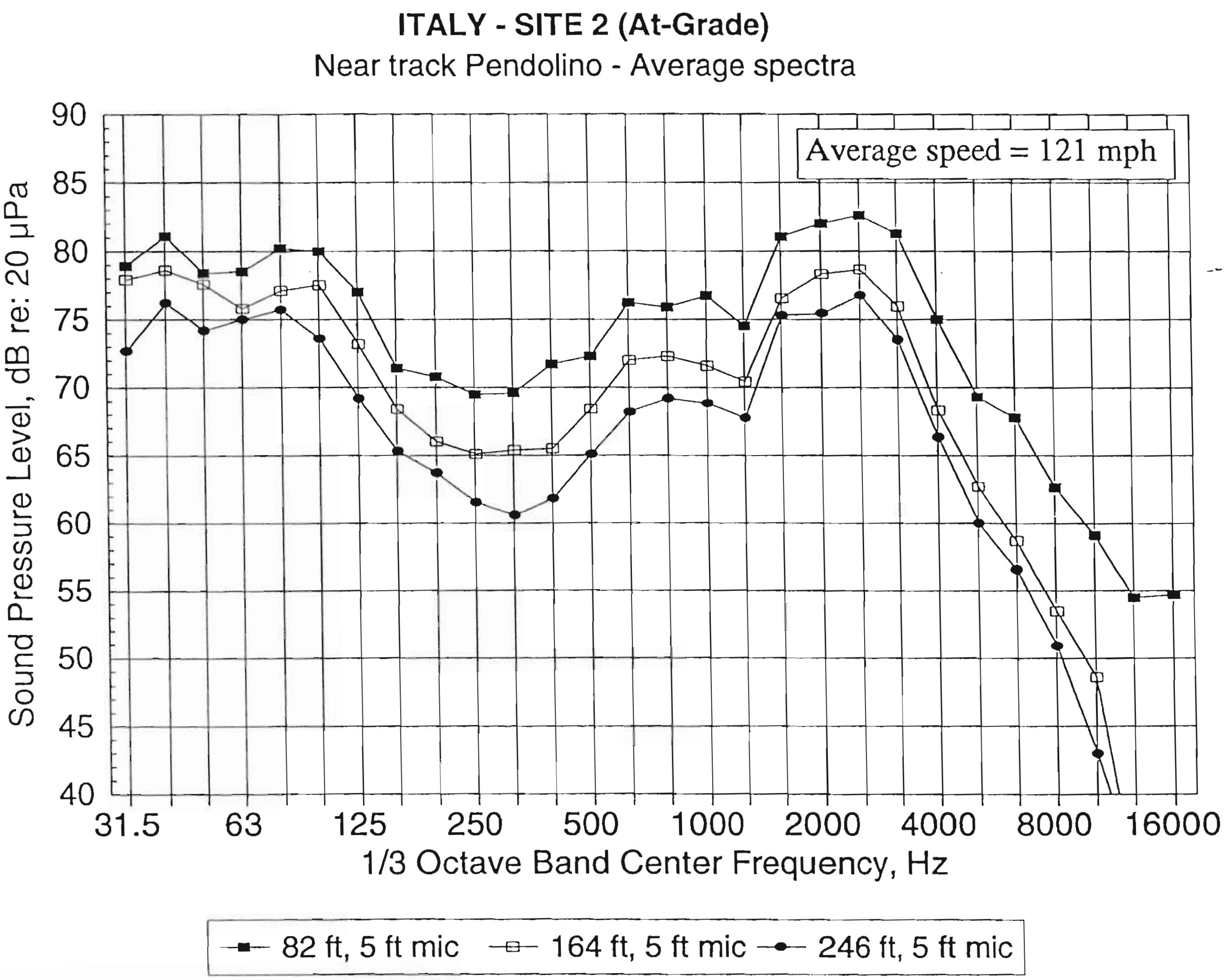


ITALY - SITE 4 (Primary)
Near track Pendolino - Average spectra
Average speed = 118 mph
Sound Pressure Level, dB re: 20 µPa
90
85
80
75
70
65
60
55
50
45
40
31.5
63
125
250
500
1000
2000
4000
8000
16000
1/3 Octave Band Center Frequency, Hz
82 ft, 16 ft mic
82 ft, 5 ft mic
164 ft, 5 ft mic
246 ft, 5 ft mic

ITALY - SITE 4 (Primary)

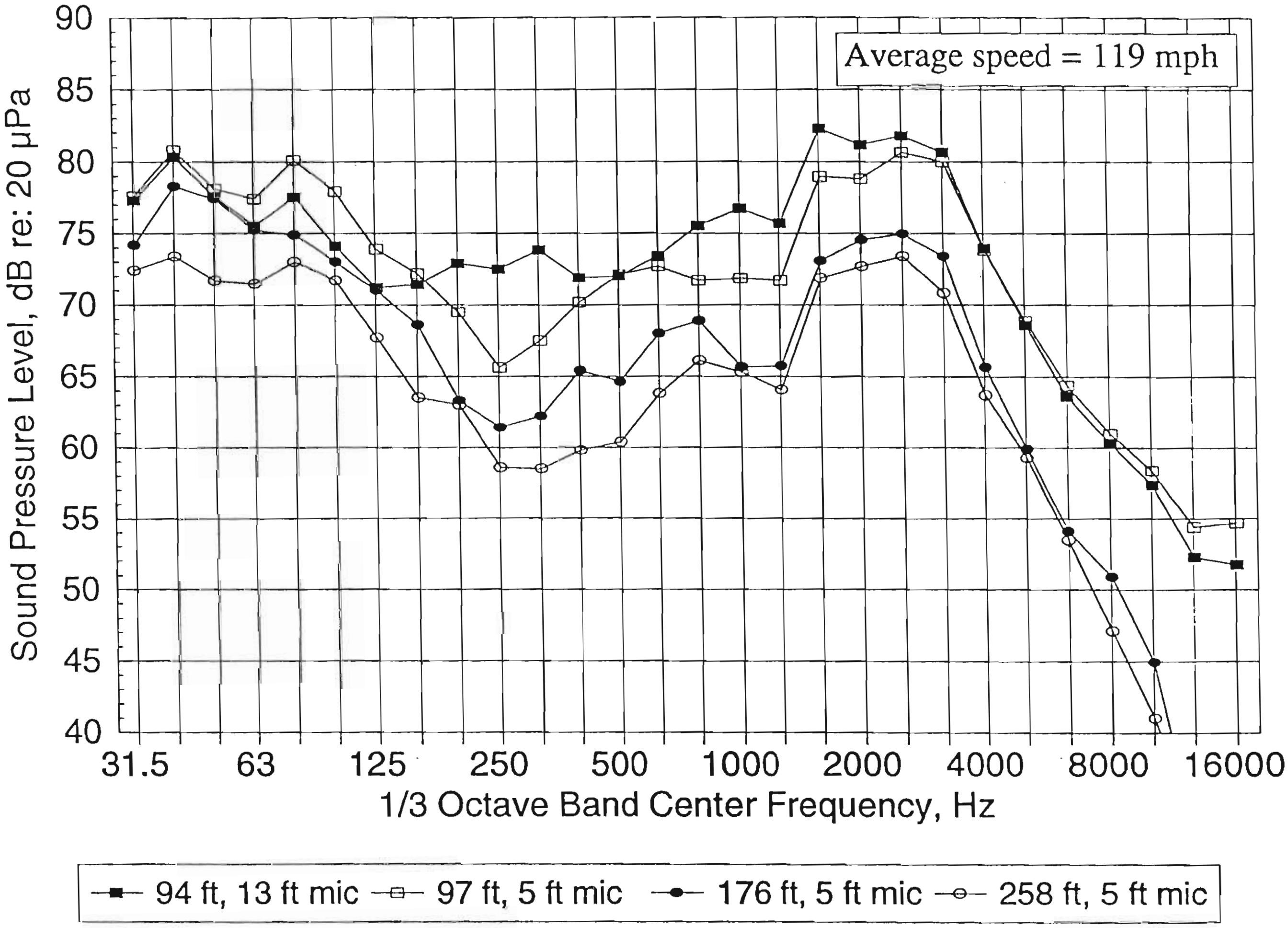
Far track Pendolino - Average spectra




ITALY - SITE 2 (At-Grade)
Near track Pendolino - Average spectra
Average speed = 121 mph
Sound Pressure Level, dB re: 20 μPa
90
85
80
75
70
65
60
55
50
45
40
31.5
63
125
250
500
1000
2000
4000
8000
16000
1/3 Octave Band Center Frequency, Hz
82 ft, 5 ft mic
164 ft, 5 ft mic
246 ft, 5 ft mic

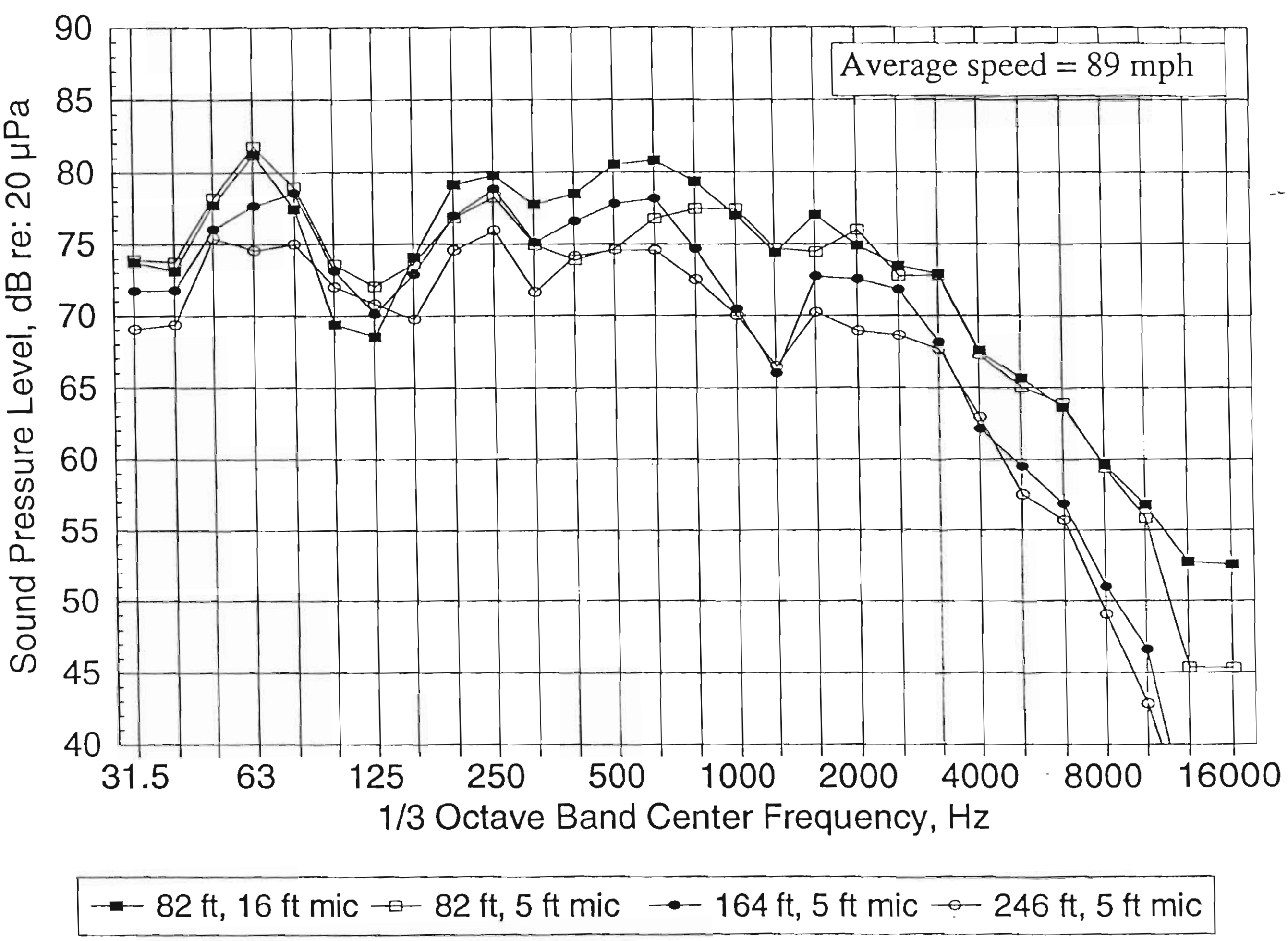
ITALY - SITE 2 (At-Grade)

Far track Pendolino - Average spectra



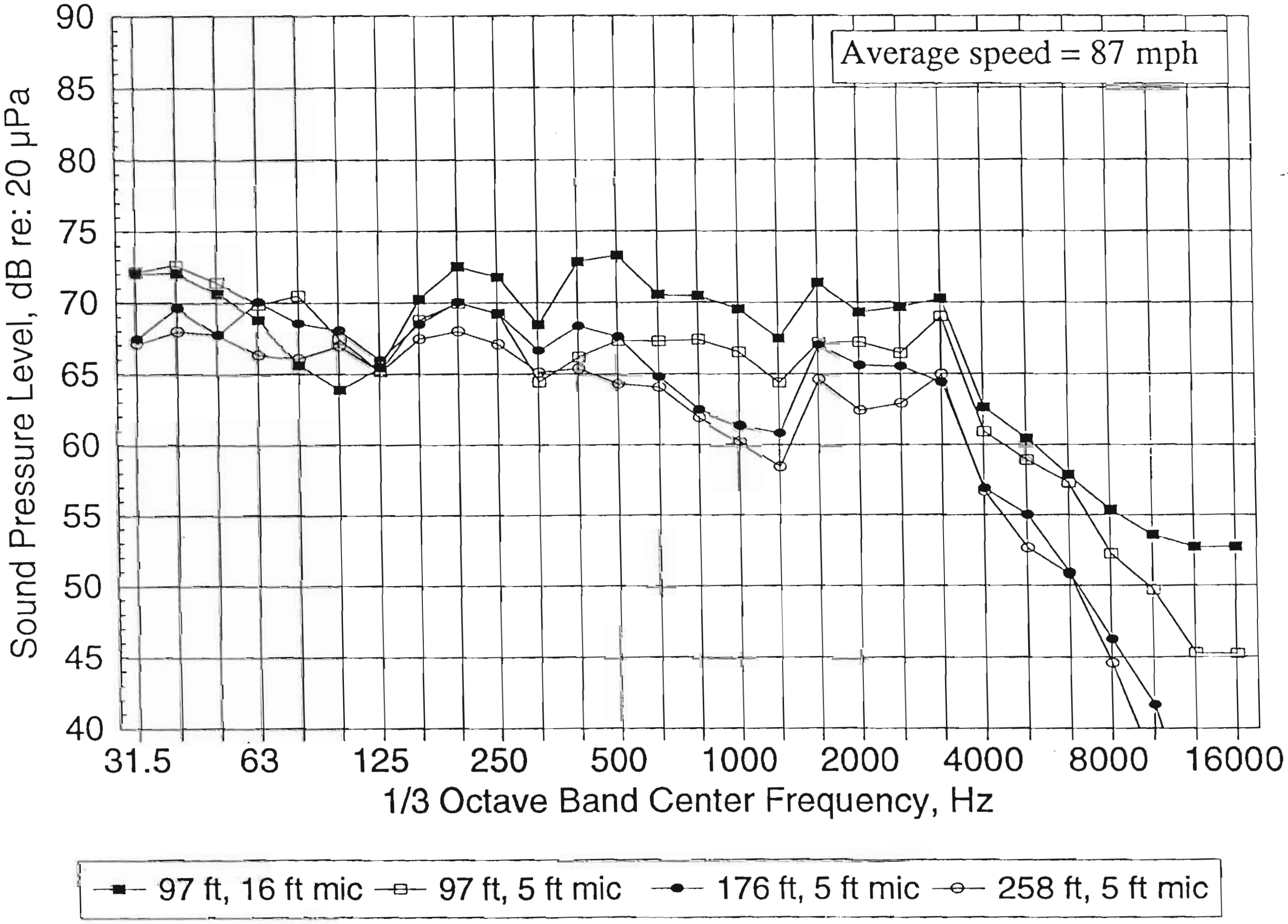
ITALY - SITE 3 (Curve)

Near track Pendolino - Average spectra



ITALY - SITE 3 (Curve)

Far track Pendolino - Average spectra



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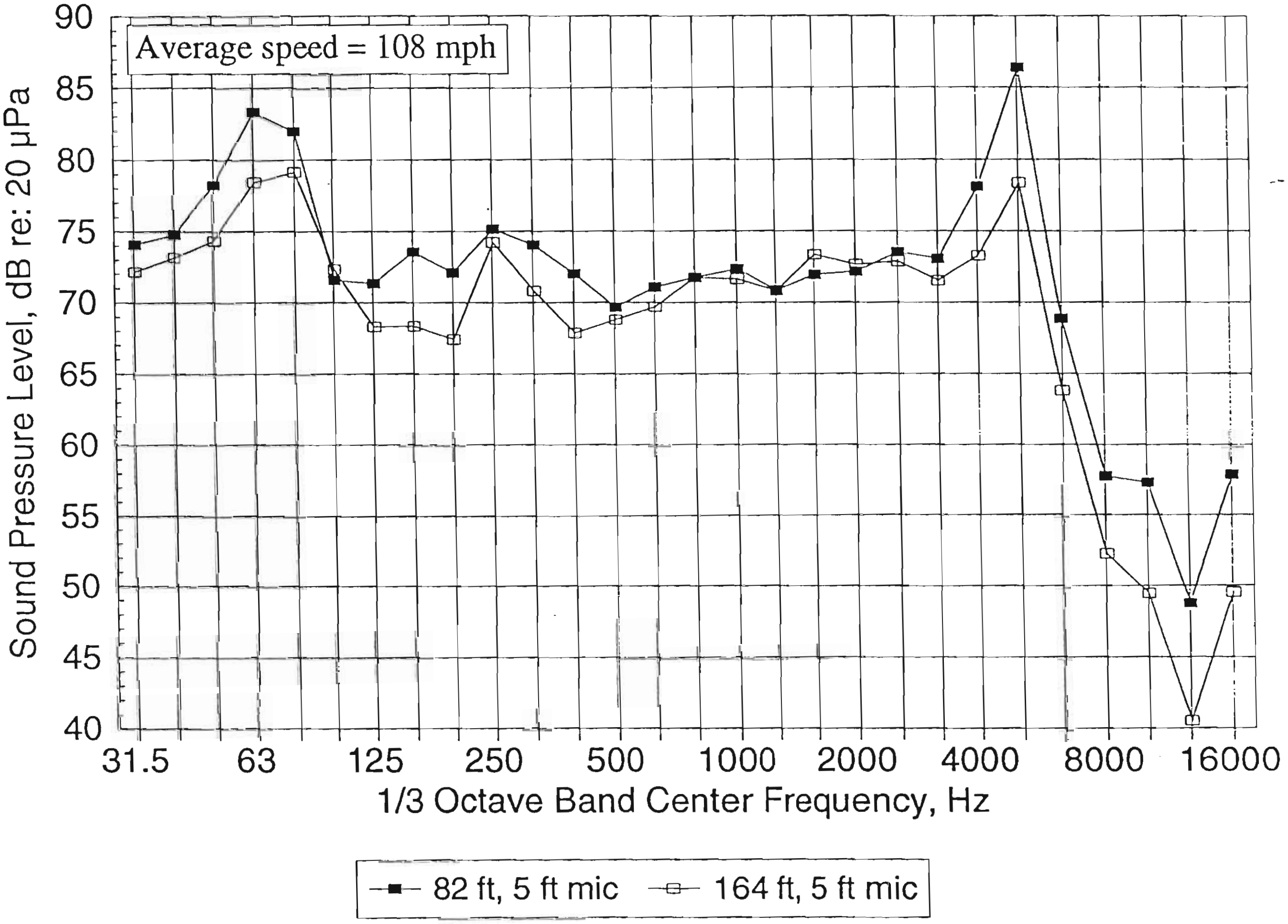
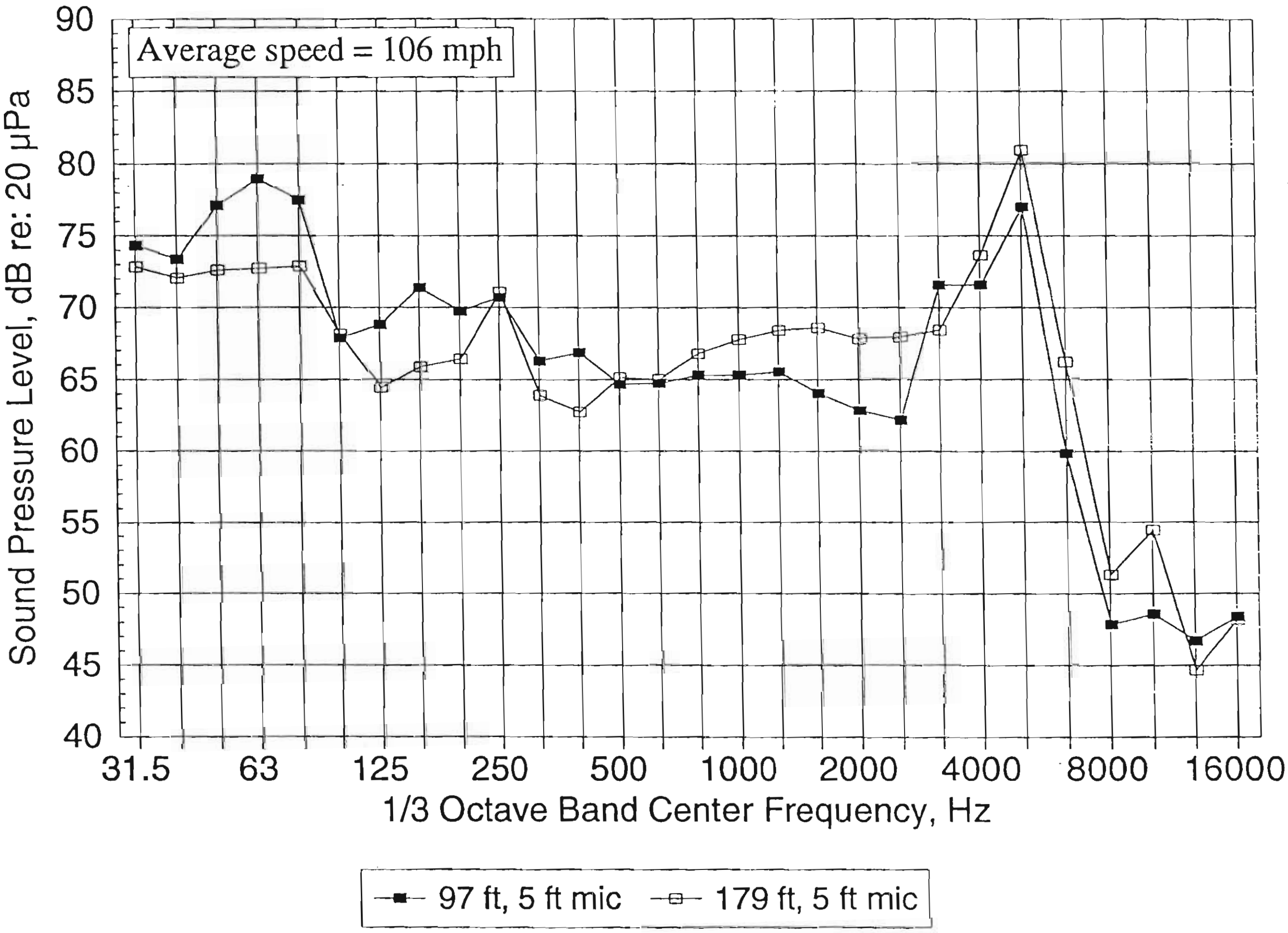
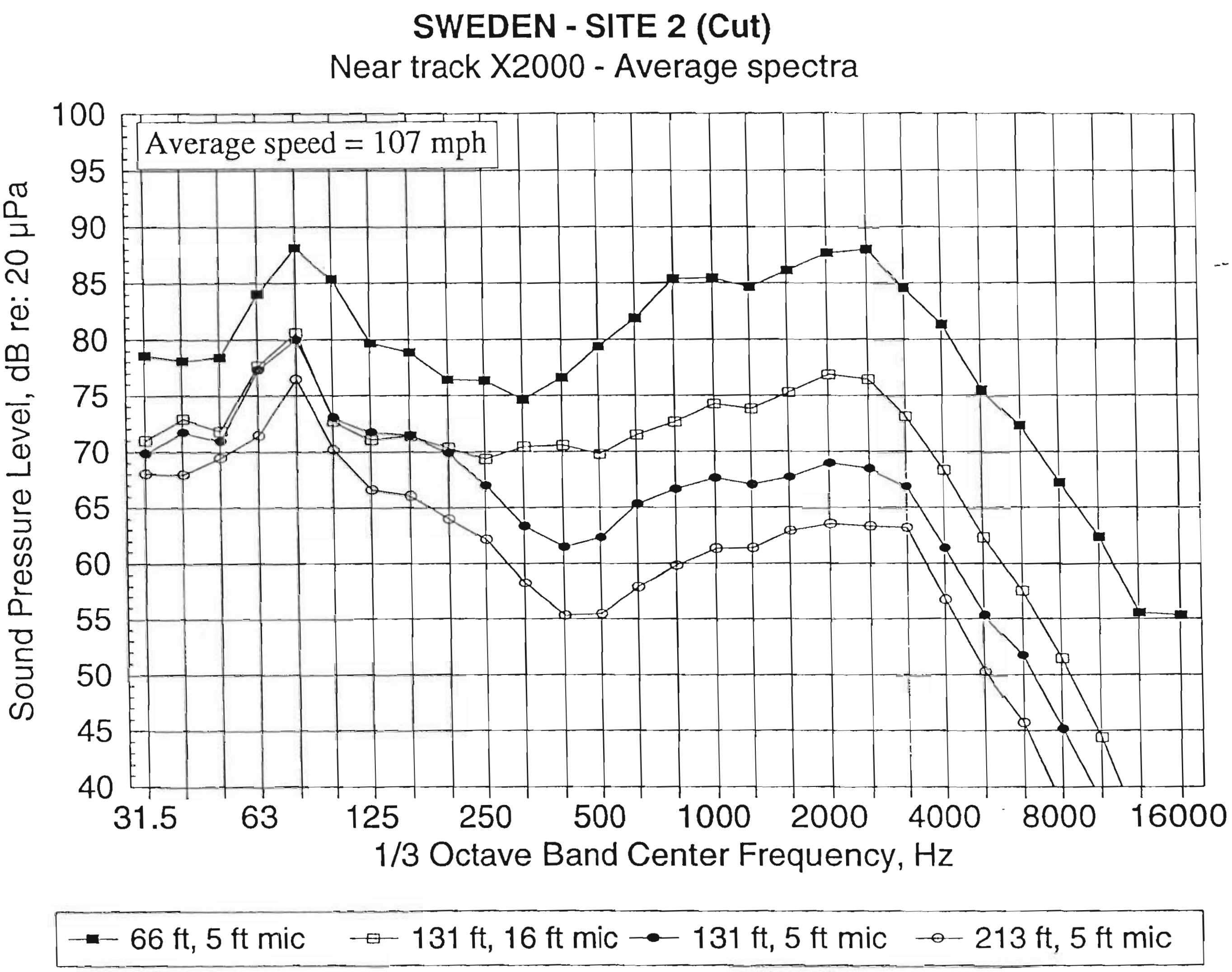
SWEDEN - SITE 1 (Embankment)

Near track X2000 - Average spectra

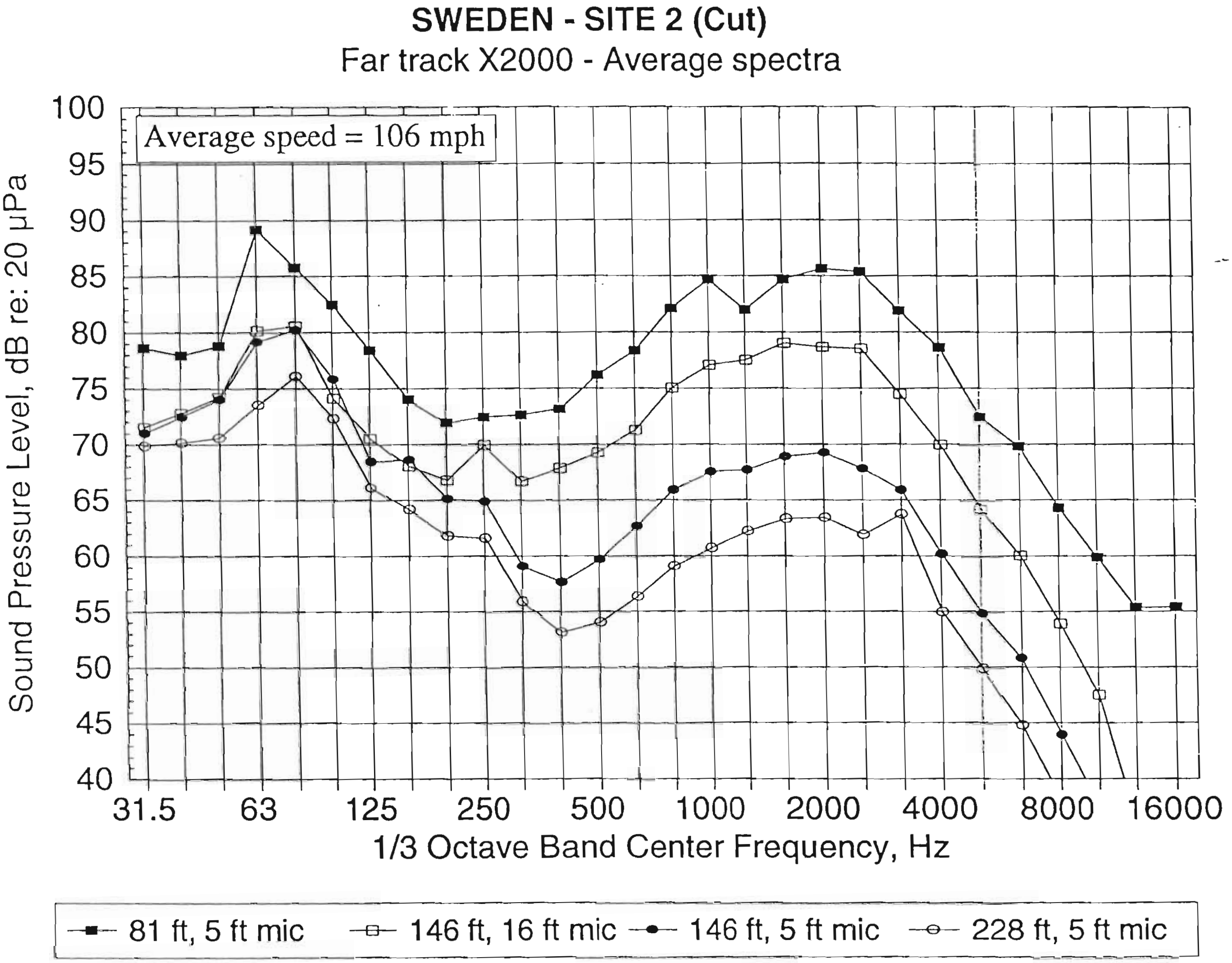


SWEDEN - SITE 1 (Embankment)
Far track X2000 - Average spectra

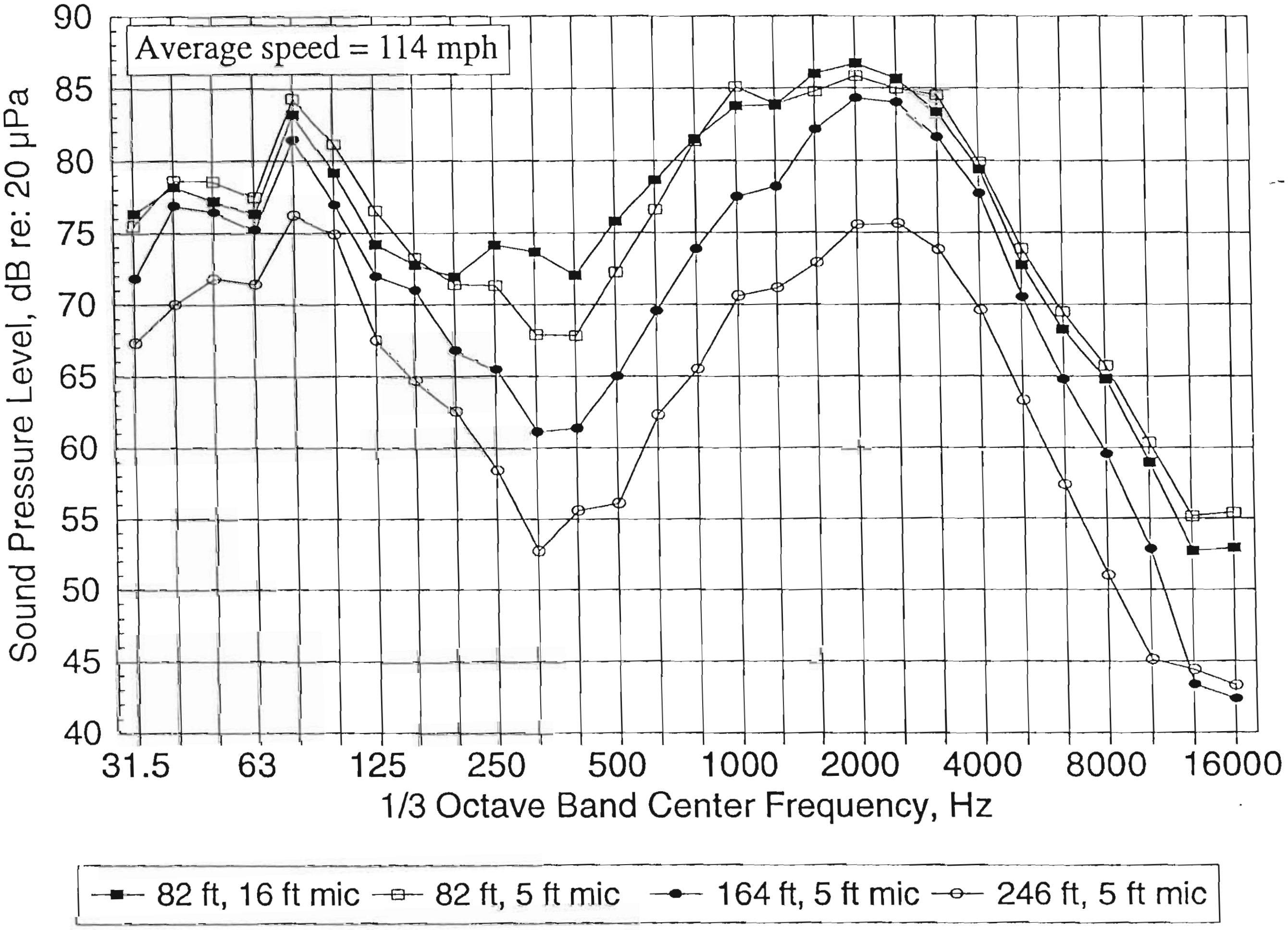


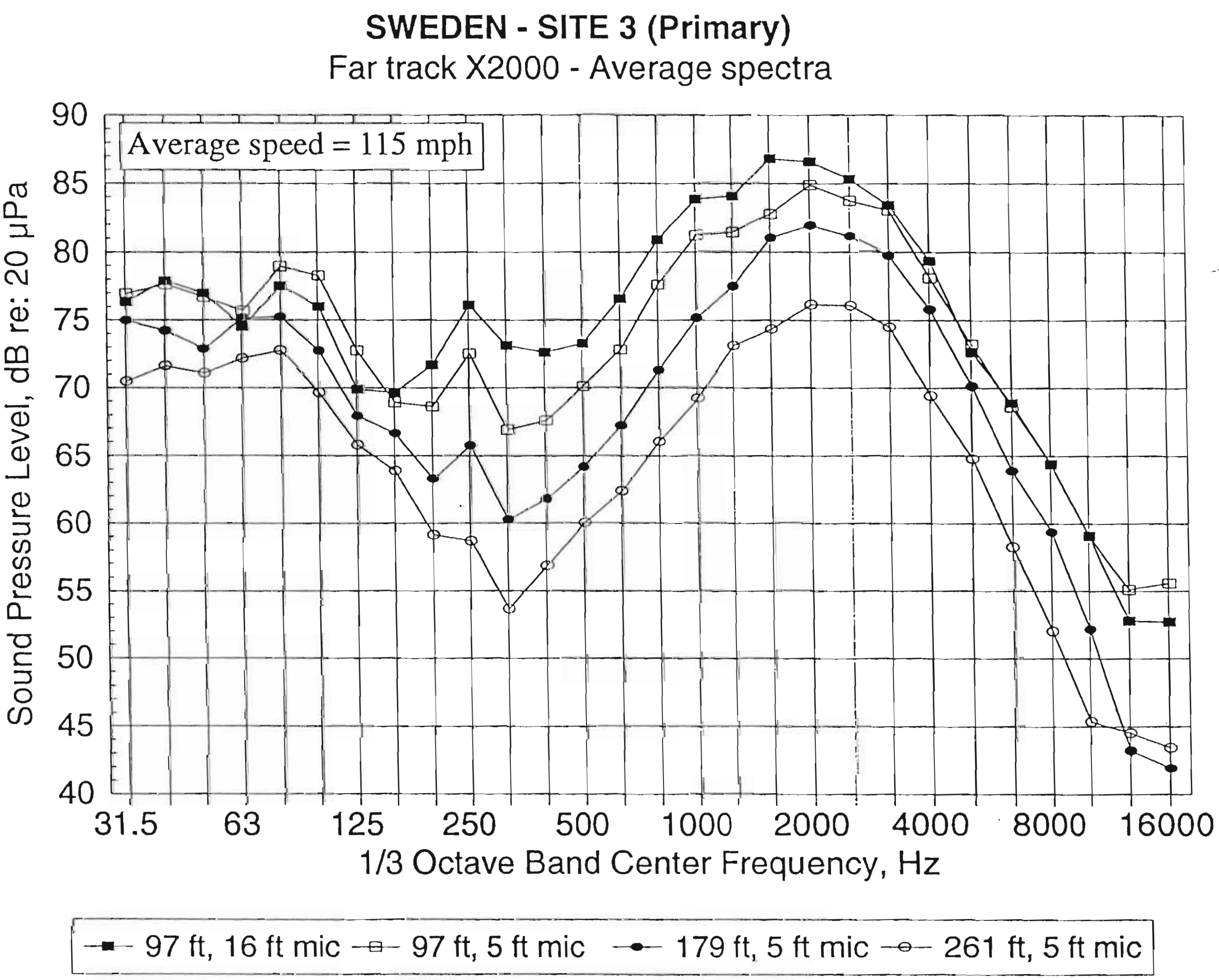


SWEDEN - SITE 2 (Cut)
Near track X2000 - Average spectra
Average speed = 107 mph
Sound Pressure Level, dB re: 20 μPa
100
95
90
85
80
75
70
65
60
55
50
45
40
31.5
63
125
250
500
1000
2000
4000
8000
16000
1/3 Octave Band Center Frequency, Hz
66 ft, 5 ft mic
131 ft, 16 ft mic
131 ft, 5 ft mic
213 ft, 5 ft mic

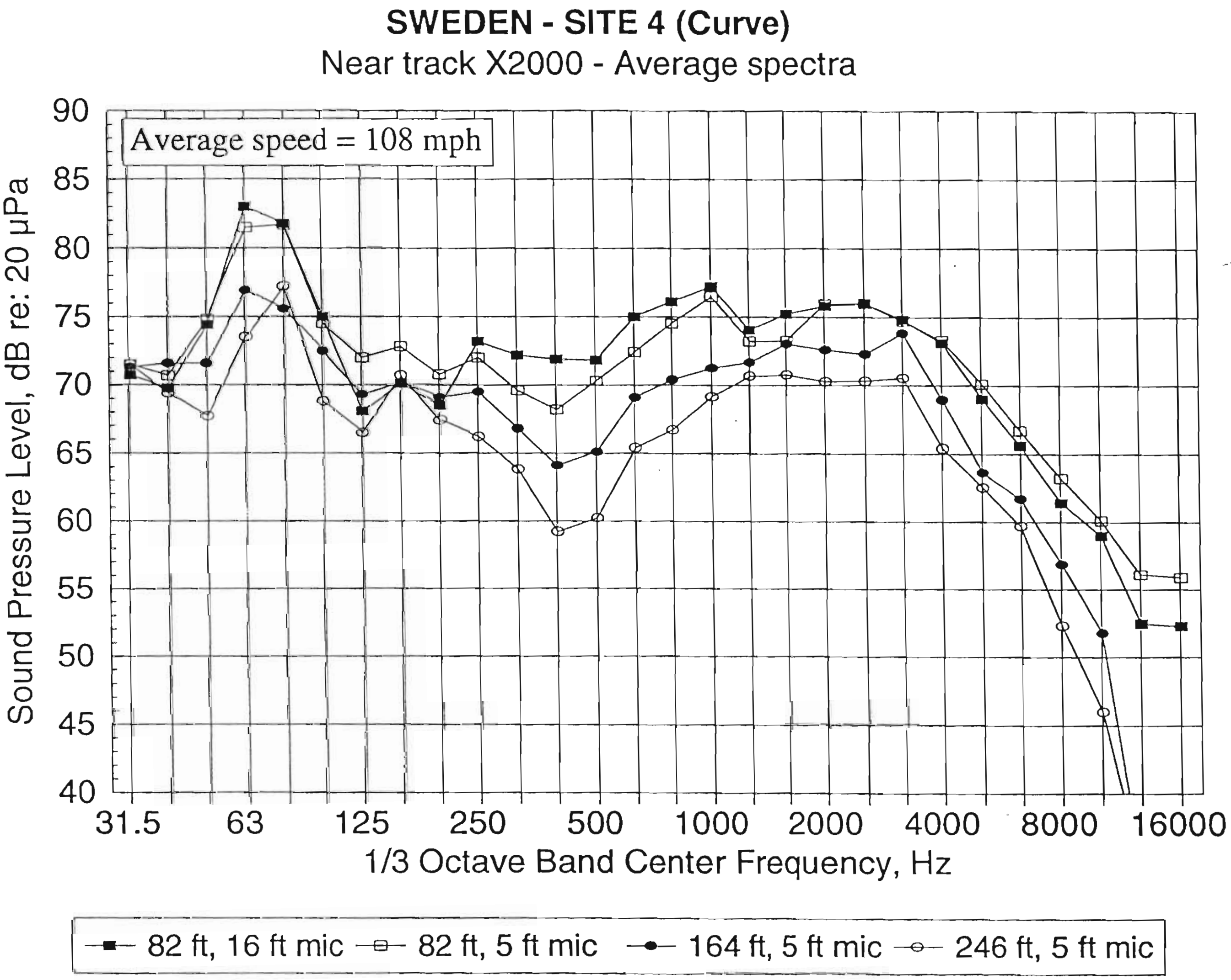

SWEDEN - SITE 2 (Cut)
Far track X2000 - Average spectra
Average speed = 106 mph
Sound Pressure Level, dB re: 20 µPa
100
95
90
85
80
75
70
65
60
55
50
45
40
31.5
63
125
250
500
1000
2000
4000
8000
16000
1/3 Octave Band Center Frequency, Hz
81 ft, 5 ft mic
146 ft, 16 ft mic
146 ft, 5 ft mic
228 ft, 5 ft mic

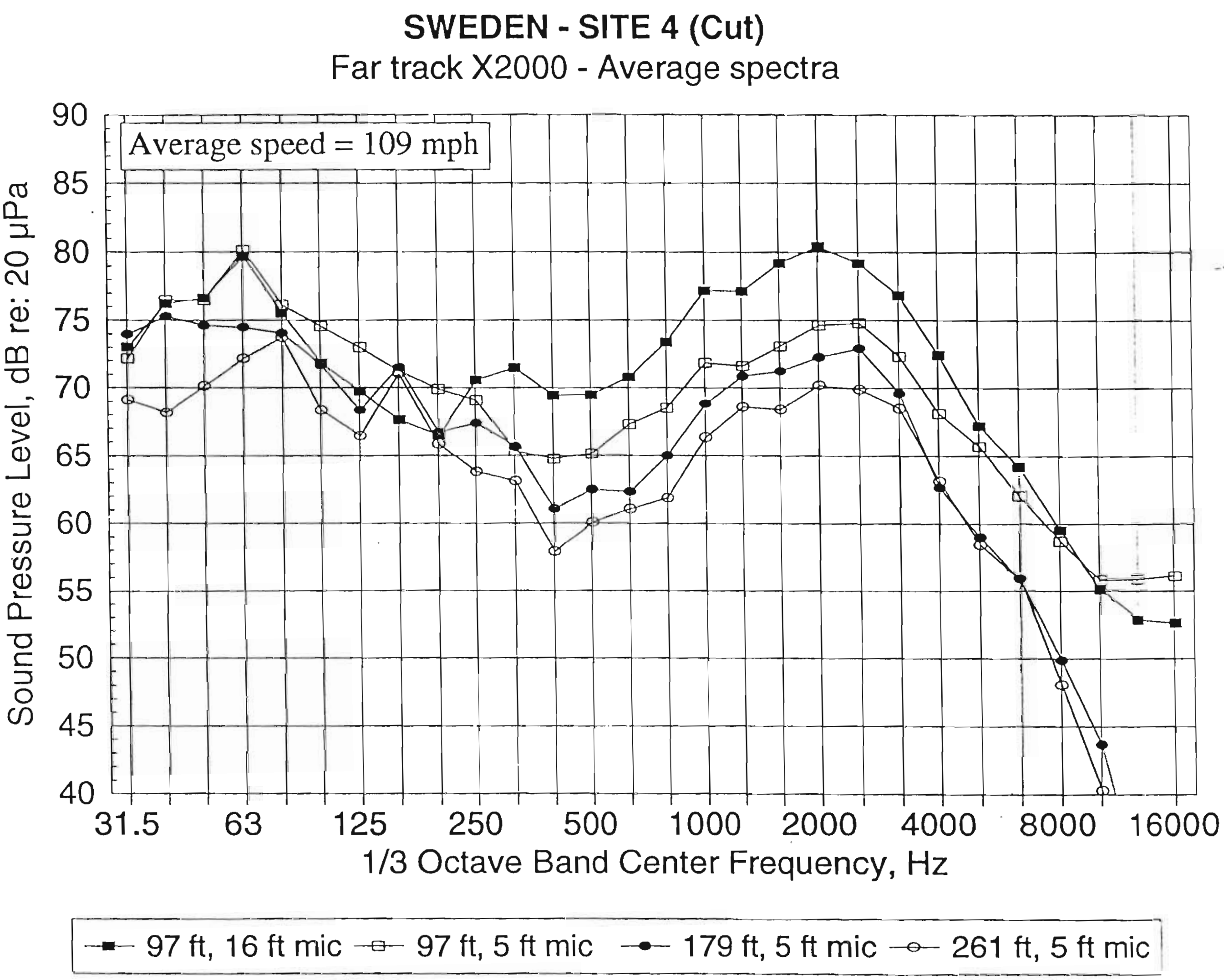
SWEDEN - SITE 3 (Primary)
Near track X2000 - Average spectra

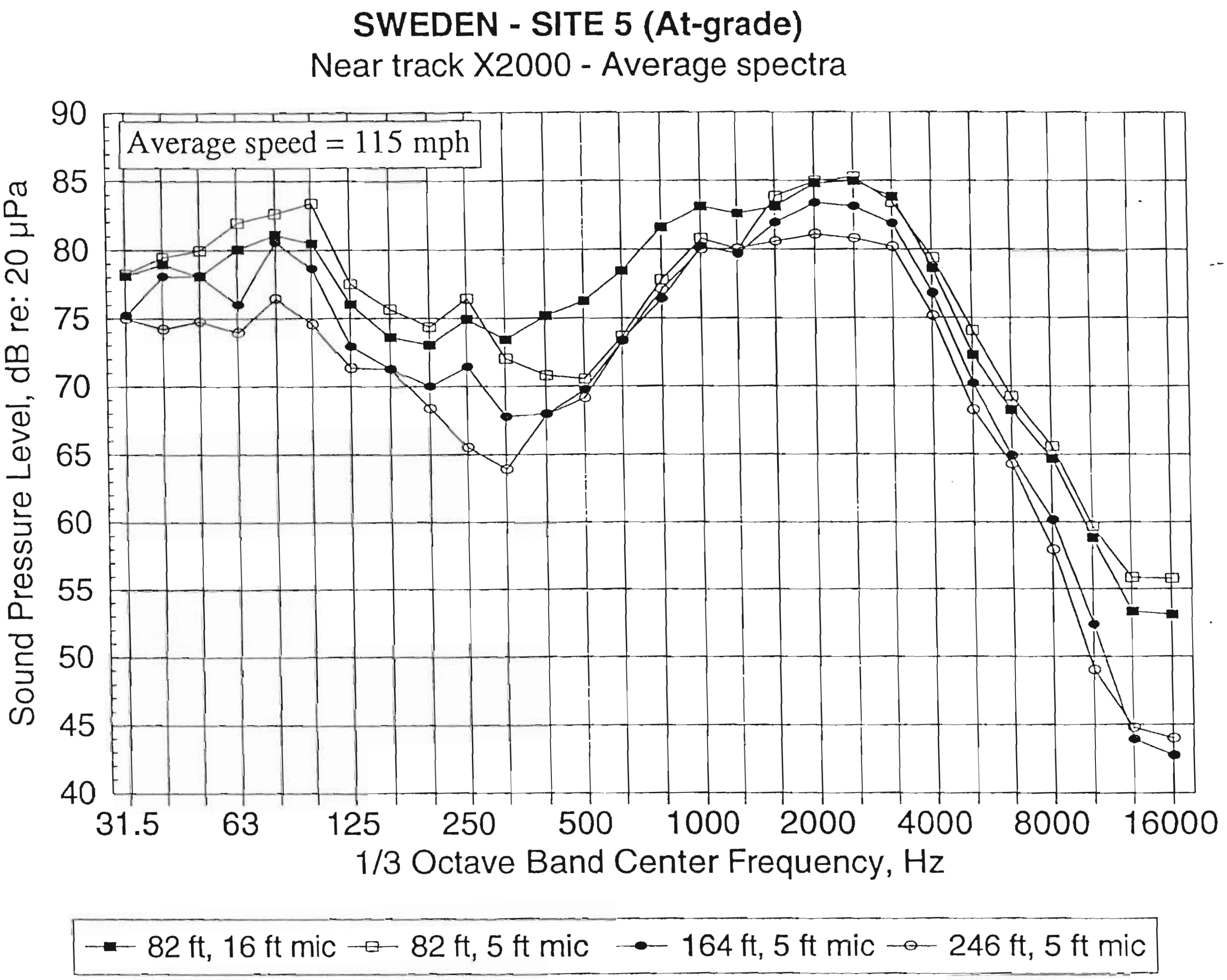




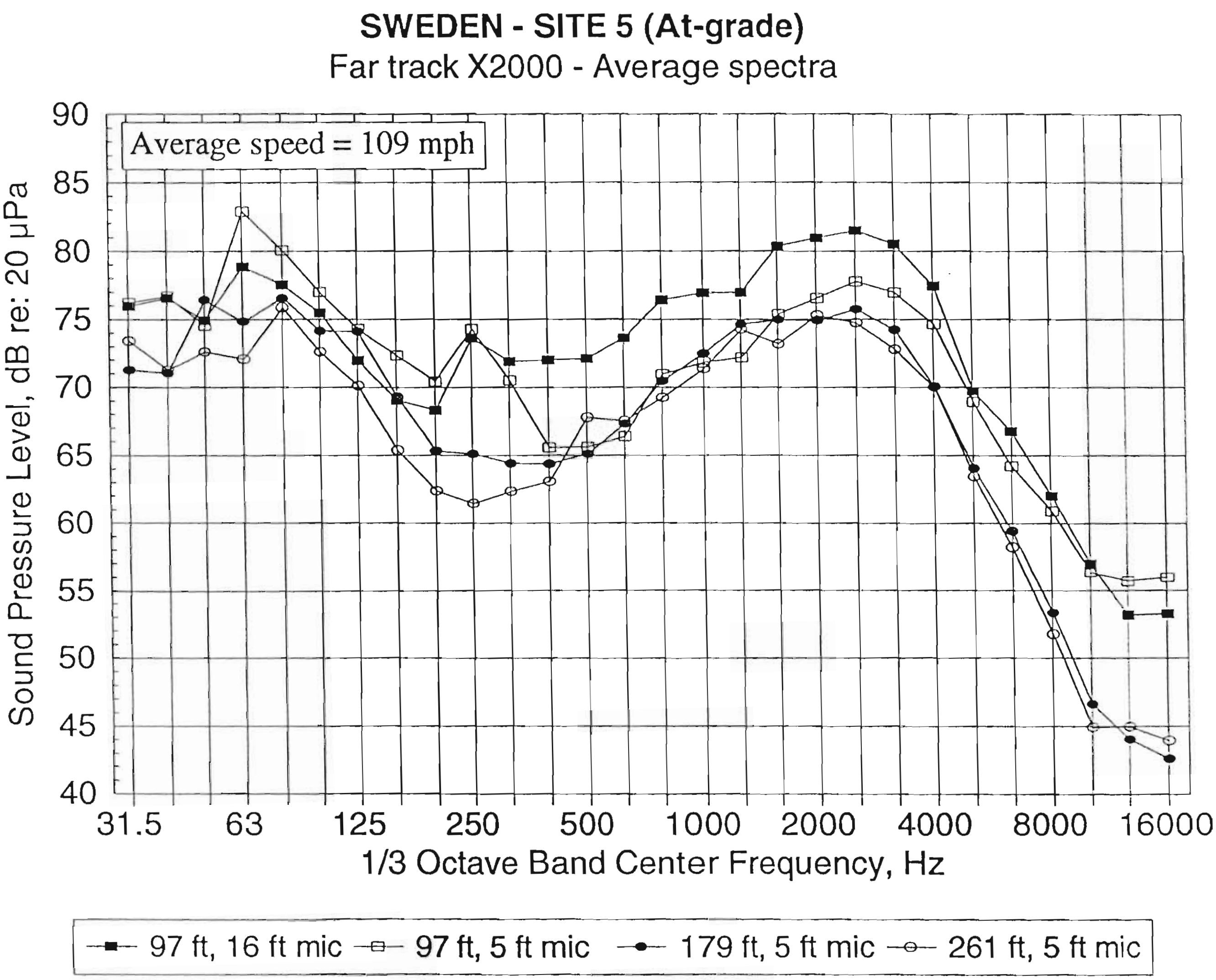
SWEDEN - SITE 3 (Primary)
Far track X2000 - Average spectra
Average speed = 115 mph
Sound Pressure Level, dB re: 20 μPa
90
85
80
75
70
65
60
55
50
45
40
31.5
63
125
250
500
1000
2000
4000
8000
16000
1/3 Octave Band Center Frequency, Hz
97 ft, 16 ft mic
97 ft, 5 ft mic
179 ft, 5 ft mic
261 ft, 5 ft mic


SWEDEN - SITE 4 (Curve)
Near track X2000 - Average spectra
Average speed = 108 mph
Sound Pressure Level, dB re: 20 µPa
90
85
80
75
70
65
60
55
50
45
40
31.5
63
125
250
500
1000
2000
4000
8000
16000
1/3 Octave Band Center Frequency, Hz
82 ft, 16 ft mic
82 ft, 5 ft mic
164 ft, 5 ft mic
246 ft, 5 ft mic


SWEDEN - SITE 4 (Cut)
Far track X2000 - Average spectra
Average speed = 109 mph
Sound Pressure Level, dB re: 20 µPa
90
85
80
75
70
65
60
55
50
45
40
31.5
63
125
250
500
1000
2000
4000
8000
16000
1/3 Octave Band Center Frequency, Hz
97 ft, 16 ft mic
97 ft, 5 ft mic
179 ft, 5 ft mic
261 ft, 5 ft mic



SWEDEN - SITE 5 (At-grade)
Near track X2000 - Average spectra
Average speed = 115 mph
Sound Pressure Level, dB re: 20 µPa
90
85
80
75
70
65
60
55
50
45
40
31.5
63
125
250
500
1000
2000
4000
8000
16000
1/3 Octave Band Center Frequency, Hz
82 ft, 16 ft mic
82 ft, 5 ft mic
164 ft, 5 ft mic
246 ft, 5 ft mic



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APPENDIX C: GROUND-BORNE VIBRATION LEVELS FOR TRAIN EVENTS

HIGH-SPEED TRAIN VIBRATION DATA: FRANCE - SITE D (PRIMARY SITE) - MAY 10, 1995

EVEN	TIME	TRAIN DESCRIPTION				MEASURED MAXIMUM VERTICAL VIBRATION VELOCITY LEVEL (VdB)											
NO.	OF DA	Type	Dir.	Length	Speed	Ch1(17.5mSB/22mNB)		Ch2(25mSB/29.5mNB)		Ch3(37.5mSB/42mNB)		Ch4(50mSB/54.5mNB)		Ch5(62.5mSB/67mNB)		Ch6(75mSB/79.5mNB)	
				(m)	(kph)	RMSV	PPV	RMSV	PPV	RMSV	PPV	RMSV	PPV	RMSV	PPV	RMSV	PPV
2	12:18	TGV	NB	237.5	290	74.5	84.3	72.1	83.7	64.0	74.8	57.1	67.4	52.2	65.0	51.2	63.8
3	12:32	Eurostar	NB	393.7	290	74.8	84.2	71.0	83.2	64.2	75.5	59.0	70.0	54.0	66.2	53.2	63.1
4	12:54	TGV-2	NB	475.0	294	76.0	85.6	72.3	83.0	64.2	75.5	59.5	71.3	53.8	67.4	53.4	66.2
5	12:58	TGV	SB	237.5	290	78.1	89.8	75.0	89.2	68.8	80.3	60.8	71.7	55.3	67.9	54.8	65.8
6	13:10	TGV	SB	237.5	293	79.1	91.2	76.0	89.6	68.6	80.9	61.5	72.6	56.0	68.8	54.8	67.1
7	13:15	TGV	SB	237.5	296	78.8	90.1	75.1	91.0	68.0	78.4	61.0	72.7	55.3	70.5	54.1	67.0
8	13:17	TGV	NB	237.5	293	77.0	88.1	73.0	86.1	65.0	75.8	59.0	71.2	53.5	66.8	52.5	66.8
21	16:25	TGV	SB	237.5	296	80.0	93.7	77.1	90.5	70.0	81.0	61.2	73.1	55.8	68.0	54.5	66.1
22	16:33	Eurostar	SB	393.7	269	76.5	88.3	72.8	89.8	63.5	77.8	59.0	70.0	54.5	67.0	56.0	66.3
23	16:40	TGV	NB	237.5	294	74.8	84.5	71.5	84.0	63.5	75.2	58.0	70.4	52.3	71.4	52.0	64.8
24	16:44	TGV	SB	237.5	290	—	—	76.2	88.9	69.2	80.1	60.8	71.1	55.8	66.4	55.0	64.8
25	16:51	TGV-2	SB	475.0	293	80.5	89.5	77.5	90.2	71.0	81.6	62.5	72.3	56.8	69.5	56.2	67.3
27-1	17:30	Eurostar	NB	393.7	293	74.5	90.4	71.5	82.3	64.6	75.3	58.0	68.0	53.0	65.2	52.0	64.9
27-2	17:31	Eurostar	SB	393.7	296	79.3	91.5	75.5	93.1	68.2	81.1	60.3	73.3	56.0	68.2	54.2	65.4
28	17:35	TGV	NB	237.5	286	75.0	87.9	72.7	85.1	63.8	77.0	57.2	69.7	53.0	66.8	51.0	63.6
29	17:39	TGV	NB	237.5	266	73.8	85.6	70.5	81.7	67.5	74.4	55.8	67.1	50.2	62.8	49.8	62.6
30	17:43	TGV	SB	237.5	294	79.5	90.6	77.8	89.4	69.2	80.5	61.3	71.5	55.7	69.7	54.1	65.8
31	17:52	TGV	NB	237.5	296	75.1	86.0	72.0	83.0	64.3	76.4	58.5	69.4	52.8	65.4	52.0	63.6
32	18:06	TGV	NB	237.5	283	75.0	86.2	72.5	89.4	63.0	76.8	57.0	74.1	51.8	68.8	50.2	68.5
33	18:07	TGV	SB	237.5	293	78.5	91.2	75.2	89.5	68.8	79.5	61.0	71.7	55.2	68.1	54.6	65.9
34	18:10	TGV	NB	237.5	294	75.6	88.9	72.2	87.5	64.8	77.1	59.0	71.8	53.8	67.9	51.8	65.0
35	18:13	TGV	SB	237.5	296	80.0	92.4	76.5	89.1	69.0	80.4	60.3	73.3	55.6	68.5	54.1	64.6
38	18:30	TGV	SB	237.5	293	78.3	90.2	74.8	89.7	68.0	78.6	60.8	71.1	55.4	68.2	54.0	65.8
39	18:42	TGV	NB	237.5	296	74.6	84.3	71.5	83.4	63.8	74.3	58.5	69.4	52.0	65.4	52.1	65.2
40	18:44	TGV	SB	237.5	296	79.0	91.1	75.1	96.1	67.9	79.3	60.8	72.1	55.9	69.0	54.2	65.6
AVG		TGV	SB	237.5	294	79.0	91.1	75.9	90.3	68.8	79.9	61.0	72.1	55.6	68.5	54.4	65.9
			NB	237.5	289	75.0	86.2	72.0	84.9	64.4	75.8	57.8	70.1	52.4	66.7	51.4	64.9
AVG		Eurostar	SB	393.7	283	77.9	89.9	74.2	91.5	65.9	79.5	59.7	71.7	55.3	67.6	55.1	65.9
			NB	393.7	292	74.7	87.3	71.3	82.8	64.4	75.4	58.5	69.0	53.5	65.7	52.6	64.0

HIGH-SPEED TRAIN VIBRATION DATA: FRANCE - SITE K (LOW-SPEED SITE) - MAY 11, 1995

EVE NO.	TIME OF D	TRAIN DESCRIPTION Type	Dir.	Lengt (m)	Speed (kph)	MAX. VIBRATION VELOCITY LEVEL (VdB) Ch1(25mNB/29.5mS RMSV	PPV	Ch2(50mNB/54.5mSB) RMSV	PPV
41	16:30	TGV	SB	237.5	193	67.0	76.2	63.6	72.1
42	16:35	TGV	NB	237.5	198	67.1	76.9	64.1	73.7
43	16:40	Eurostar	SB	393.7	206	65.3	73.9	65.3	73.8
44	16:49	TGV	SB	237.5	201	65.8	74.3	64.0	71.8
45	16:52	TGV-2	SB	475.0	185	66.3	74.8	63.2	71.3
46	17:25	Eurostar	NB	393.7	145	65.6	74.2	58.6	67.2
48	17:33	Eurostar	SB	393.7	169	64.1	73.3	62.2	69.5
49	17:36	TGV	NB	237.5	193	69.9	78.7	63.9	72.9
50	17:45	TGV	NB	237.5	198	67.7	75.4	63.7	72.1
51	17:50	TGV	SB	237.5	201	66.4	75.3	64.4	72.0
52	18:02	TGV	NB	237.5	196	66.5	74.6	64.0	73.0
53	18:12	TGV	SB	237.5	182	65.3	74.1	62.7	70.8
55	18:35	TGV	NB	237.5	216	66.2	75.1	61.0	73.5
56	18:49	TGV	SB	237.5	196	66.0	75.1	63.3	72.3
57	19:00	TGV	NB	237.5	166	66.0	75.1	58.5	67.9
AVG		TGV	NB	237.5	195	67.2	76.0	62.5	72.2
			SB	237.5	195	66.1	75.0	63.6	71.8
AVG		Eurostar	NB	393.7	145	65.6	74.2	58.6	67.2
			SB	393.7	188	64.7	73.6	63.8	71.7

HIGH-SPEED TRAIN VIBRATION DATA: ITALY - SITE 2 (AT-GRADE SITE) - MAY 15, 1995

EVE	TIME	TRAIN DESCRIPTION				MEASURED MAXIMUM VERTICAL VIBRATION VELOCITY LEVEL (VdB)							
NO.	OF D	Type	Dir.	Lengt (m)	Speed (kph)	Ch1(12.5mNB/16.2mS RMSV	PPV	Ch2(25mNB/28.7mS RMSV	PPV	Ch3(50mNB/53.7mS RMSV	PPV	Ch4(75mNB/78.7mS RMSV	PPV
67	20:19	Pendolino	NB	236.6	194	84.2	94.2	77.2	84.7	69.3	77.7	65.3	75.0
68-2	20:34	Pendolino	SB	236.6	---	76.6	86.5	69.0	76.5	64.0	70.3	60.8	68.3
71	20:49	Pendolino	SB	236.6	190	77.1	87.0	68.9	77.7	64.0	72.2	60.0	67.5

HIGH-SPEED TRAIN VIBRATION DATA: ITALY - SITE 3 (CURVE SITE) - MAY 17, 1995

EVE NO.	TIME OF D	TRAIN DESCRIPTION Type	Dir.	Lengt (m)	Speed (kph)	MEASURED MAXIMUM VERTICAL VIBRATION VELOCITY LEVEL (VdB) Ch1(17.5mNB/21.2mS RMSV	PPV	Ch2(25mNB/28.7mS RMSV	PPV	Ch3(50mNB/53.7mS RMSV	PPV	Ch4(75mNB/78.7mS RMSV	PPV
36	20:03	Pendolino	NB	236.6	132	73.6	84.5	70.0	77.3	68.1	75.2	58.6	66.1
40	20:36	Pendolino	SB	236.6	148	73.1	79.3	73.6	77.0	66.2	71.1	60.4	66.3
43	20:48	Pendolino	SB	236.6	130	73.3	82.4	72.1	77.8	69.0	73.8	61.1	66.9
45	20:54	Pendolino	NB	236.6	154	76.5	84.7	72.8	80.3	69.1	75.2	60.0	65.6

HIGH-SPEED TRAIN VIBRATION DATA: ITALY - SITE 4 (PRIMARY SITE) - MAY 16 & 18, 1995

EVEN	TIME	TRAIN DESCRIPTION				MEASURED MAXIMUM VERTICAL VIBRATION VELOCITY LEVEL (VdB)											
NO.	OF DA	Type	Dir.	Length	Speed	Ch2(10mSB/13.7mNB)		Ch3(25mSB/28.7mNB)		Ch4(37.5mSB/41.2mNB)		Ch5(50mSB/53.7mNB)		Ch6(62.5mSB/66.2mNB)		Ch7(75mSB/78.7mNB)	
				(m)	(kph)	VRMS	PPV	VRMS	PPV	VRMS	PPV	VRMS	PPV	VRMS	PPV	VRMS	PPV
MAY 16, 1995																	
1	7:56	Pendolino	SB	236.6	—	78.2	86.9	69.8	79.5	67.8	76.8	67.3	75.2	65.0	70.7	63.6	70.4
5	8:58	Pendolino	SB	236.6	175	78.7	88.2	73.0	82.4	67.0	76.1	65.0	74.2	63.4	71.8	63.1	70.5
6-2	9:59	Pendolino	NB	236.6	190	78.1	85.2	70.8	79.0	64.2	73.0	62.0	69.4	58.7	66.6	57.9	64.8
21	12:59	Pendolino	NB	236.6	193	77.9	86.5	70.9	78.8	65.5	72.9	62.7	69.8	60.0	67.1	59.2	65.2
27	14:02	Pendolino	SB	236.6	195	77.4	85.2	69.8	78.4	67.1	74.1	67.2	74.2	64.8	70.0	63.3	71.0
30-2	16:59	Pendolino	NB	236.6	193	78.0	86.4	69.8	78.4	65.9	73.7	63.8	70.9	60.2	66.9	59.4	66.1
MAY 18, 1995																	
48	7:57	Pendolino	SB	236.6	182	77.6	86.2	71.2	79.6	68.8	76.1	66.3	74.2	—	—	62.2	69.2
51	8:59	Pendolino	SB	236.6	196	77.2	85.4	69.9	78.5	67.0	75.8	67.0	72.9	—	—	62.8	69.4
55	9:18	Pendolino	SB	236.6	185	77.2	85.6	71.6	79.2	69.0	75.9	66.1	73.2	—	—	62.5	69.4
60	10:00	Pendolino	NB	236.6	192	77.1	86.2	70.1	78.1	64.9	73.9	63.0	70.4	59.1	67.4	58.4	65.2
AVG		Pendolino	SB	236.6	187	77.7	86.3	70.9	79.6	67.8	75.8	66.5	74.0	64.4	70.8	62.9	70.0
			NB	236.6	192	77.8	86.1	70.4	78.6	65.1	73.4	62.9	70.1	59.5	67.0	58.7	65.3

HIGH-SPEED TRAIN VIBRATION DATA: SWEDEN - SITE 3B (PRIMARY SITE) - MAY 23, 1995

EVEN	TIME	TRAIN DESCRIPTION				MEASURED MAXIMUM VERTICAL VIBRATION VELOCITY (VdB)											
NO.	OF DA	Type	Dir.	Length	Speed	Ch2(7.5mWB/16.8mEB)		Ch3(15mWB/24.3mEB)		Ch4(25mWB/34.3mEB)		Ch5(37.5mWB/46.8mEB)		Ch6(50mWB/59.3mEB)		Ch7(62.5mWB/71.8mEB)	
				(m)	(kph)	VRMS	PPV	VRMS	PPV	VRMS	PPV	VRMS	PPV	VRMS	PPV	VRMS	PPV
62	9:23	X2000	WB	140.0	183	87.0	99.2	84.3	91.2	83.0	89.6	75.4	82.1	76.2	83.2	77.8	86.0
64	9:47	X2000	WB	140.0	185	85.5	94.7	83.2	90.7	82.3	89.1	73.3	79.8	75.5	81.5	76.7	84.4
67	10:43	X2000	WB	140.0	185	86.1	95.9	83.2	91.6	82.1	89.1	70.0	77.2	76.0	82.3	77.0	84.1
69	11:32	X2000	EB	140.0	159	90.0	99.5	85.0	90.9	82.2	88.0	69.2	74.5	76.0	82.6	77.5	82.8
70	13:31	X2000	EB	140.0	182	84.3	93.6	82.7	90.1	85.0	90.1	74.4	81.2	77.7	84.4	79.0	84.5
73	14:04	X2000	WB	140.0	185	86.1	95.4	83.1	92.5	81.3	89.4	74.2	82.1	76.5	83.3	76.1	83.0
15	16:32	X2000	EB	140.0	185	83.6	92.4	83.4	91.3	83.2	90.1	77.1	82.7	79.0	85.2	77.4	84.9
18	16:54	X2000	WB	140.0	185	85.4	95.3	83.5	91.2	82.0	91.3	78.0	87.6	76.1	81.9	76.4	84.6
20	17:30	X2000	EB	140.0	182	84.0	91.1	82.5	90.2	84.9	90.5	78.3	83.7	78.0	83.8	79.0	84.3
25	18:31	X2000	EB	140.0	180	83.7	92.1	82.3	89.1	84.5	90.2	78.0	84.3	76.8	83.7	78.4	85.3
26	18:49	X2000	WB	140.0	188	87.3	97.9	84.2	93.0	82.0	89.3	79.2	86.8	77.1	83.5	77.8	85.6
AVG		X2000	WB		185	86.2	96.4	83.6	91.7	82.1	89.6	75.0	82.6	76.2	82.6	77.0	84.7
			EB	w/o#69	182	83.9	92.3	82.7	90.2	84.4	90.2	77.0	83.0	77.9	84.3	78.5	84.8

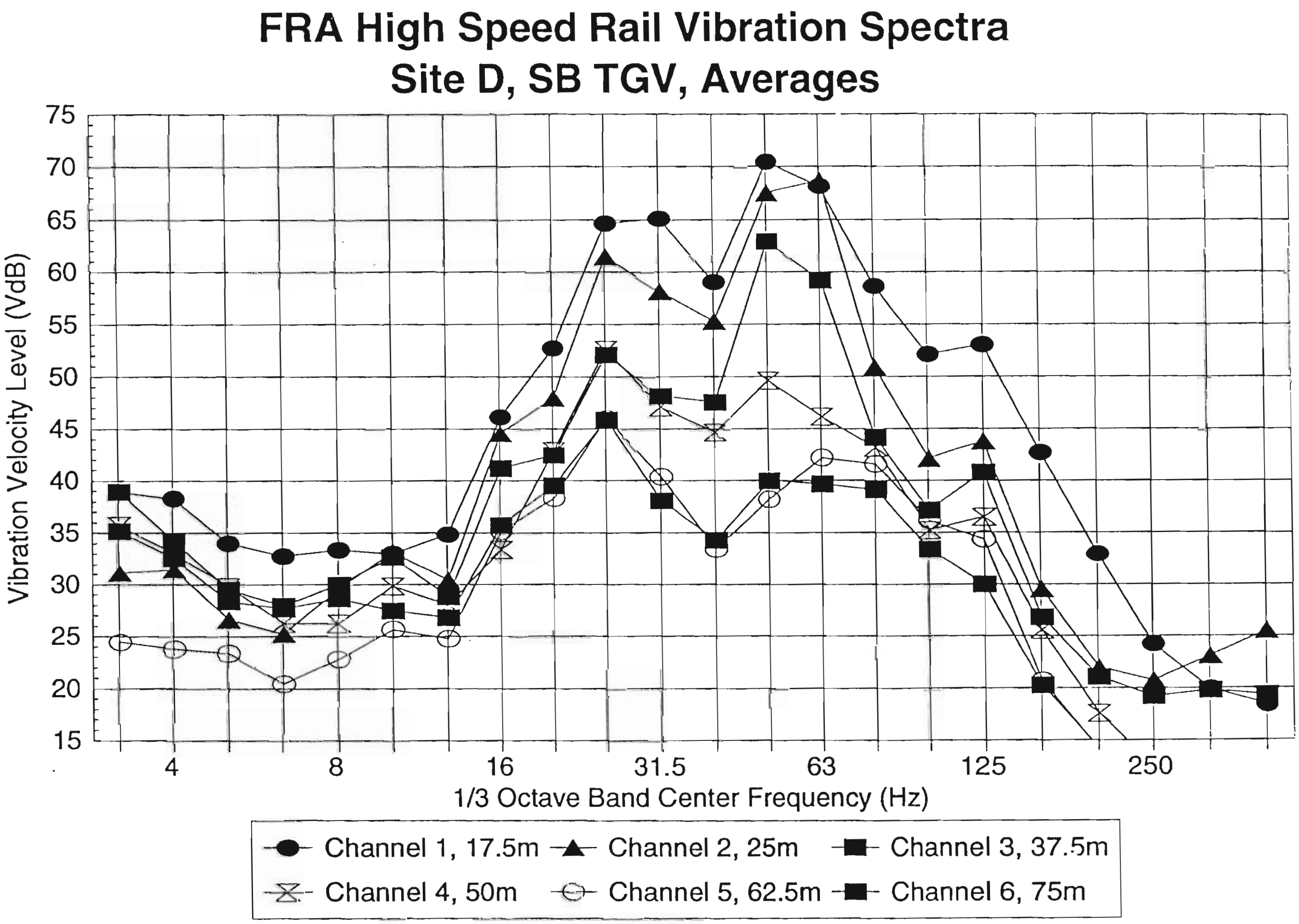
HIGH-SPEED TRAIN VIBRATION DATA: SWEDEN - SITE 4 (CURVE SITE) - MAY 24, 199

EVE NO.	TIME OF D	TRAIN DESCRIPTION Type	Dir.	Lengt (m)	Speed (kph)	MAXIMUM VERTICAL VIB. VELOCITY (V Ch1(7.5mEB/12mW VRMS	PPV	Ch2(15mEB/19.5m VRMS	PPV
30	9:19	X2000	WB	140.0	175	86.2	98.3	83.3	91.7
31	9:42	X2000	WB	140.0	174	85.9	98.6	83.1	90.5
40	11:33	X2000	EB	140.0	174	89.8	99.7	83.0	91.4
41	13:35	X2000	EB	140.0	72	82.1	91.5	76.6	84.1
42	13:51	X2000	WB	140.0	183	86.5	98.2	83.0	92.1
AVG		X2000	WB	140.0	177	86.2	98.4	83.1	91.4

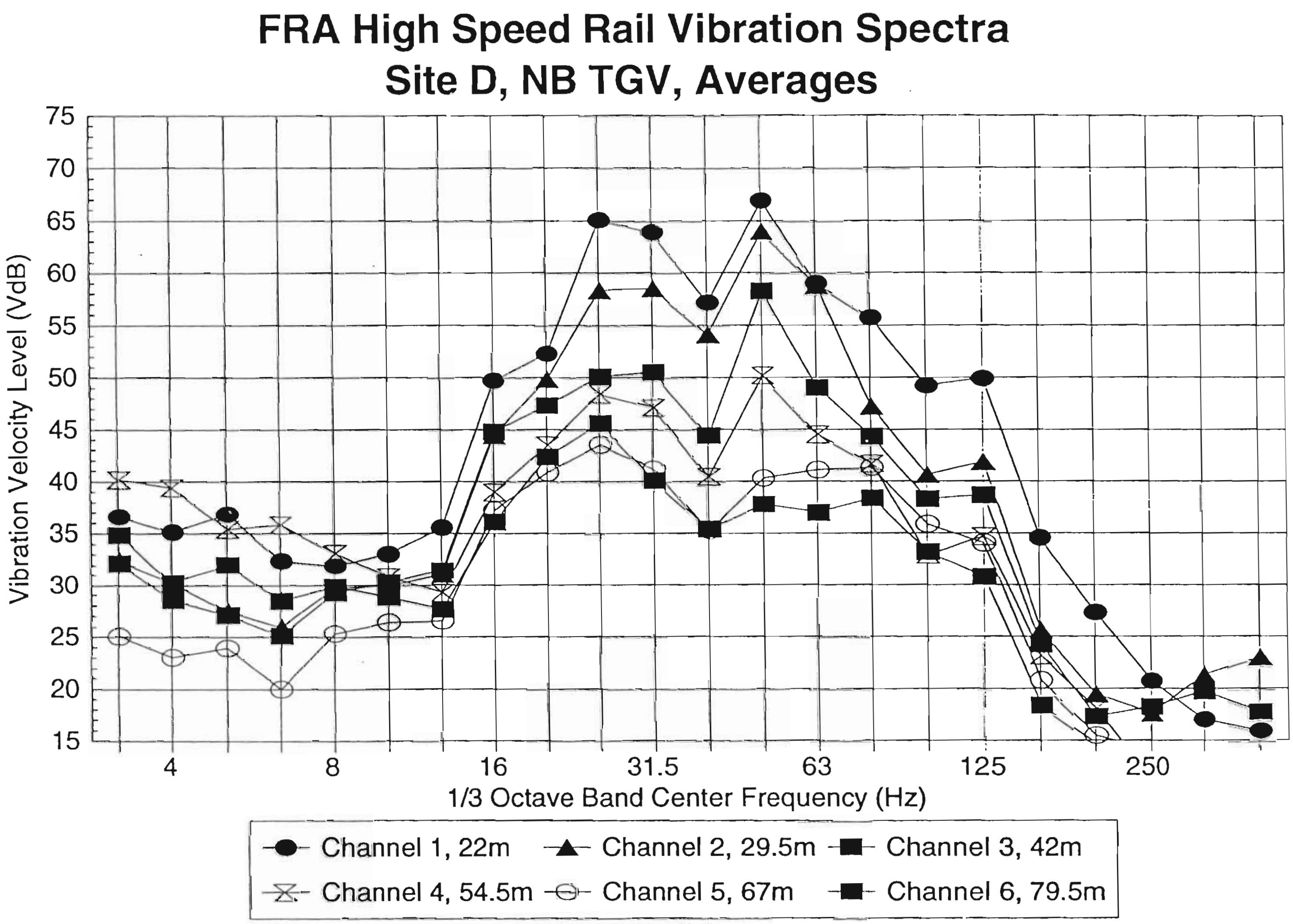
HIGH-SPEED TRAIN VIBRATION DATA: SWEDEN - SITE 5 - MAY 24, 1995

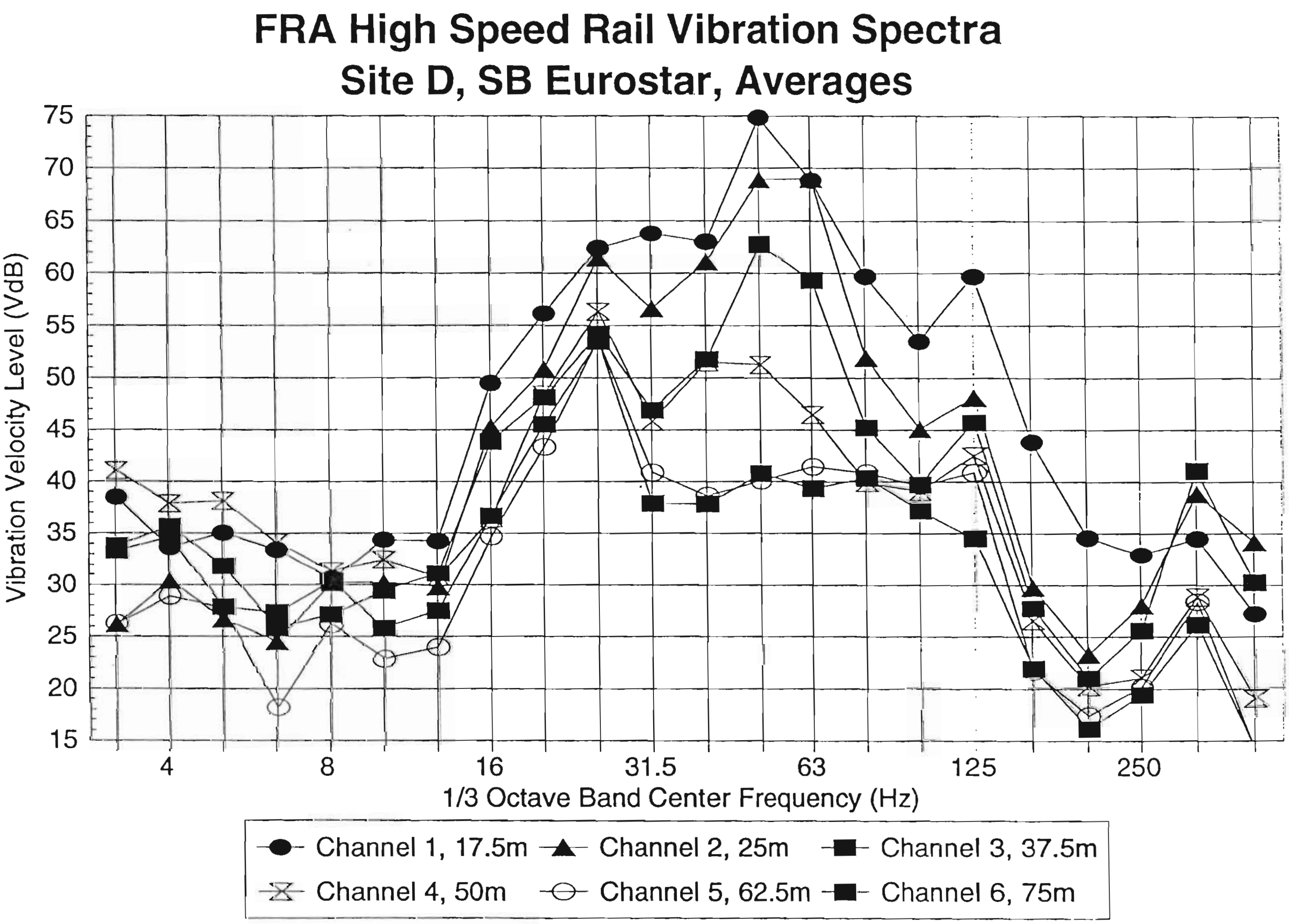
EVE	TIME	TRAIN DESCRIPTION				MEASURED A-WEIGHTED SOUND LEVEL (dBA)							
NO.	OF DA	Type	Dir.	Length	Speed	Ch1(7.5mEB/12mW		Ch2(15mEB/19.5mW		Ch3(25mEB/29.5mW		Ch4(50mEB/54.5mW	
				(m)	(kph)	VRMS	PPV	VRMS	PPV	VRMS	PPV	VRMS	PPV
44	16:38	X2000	EB	140.0	183	87.7	100.4	75.5	84.0	79.0	89.7	70.9	79.1
45	16:44	X2000	WB	140.0	177	82.3	94.0	71.2	79.8	74.8	85.9	67.2	77.3
47	17:38	X2000	EB	140.0	187	88.0	100.8	75.2	84.0	79.1	92.4	70.1	79.1
48	18:37	X2000	EB	140.0	187	88.2	101.0	75.4	83.5	79.3	92.5	70.0	78.2
49	18:42	X2000	WB	140.0	174	81.7	92.9	70.5	80.4	75.2	87.6	67.0	75.6
50	19:38	X2000	WB	140.0	114	76.3	88.2	70.5	79.7	73.0	84.2	59.2	69.0
AVG		X2000	EB	140.0	186	88.0	100.7	75.4	83.8	79.1	91.5	70.3	78.8

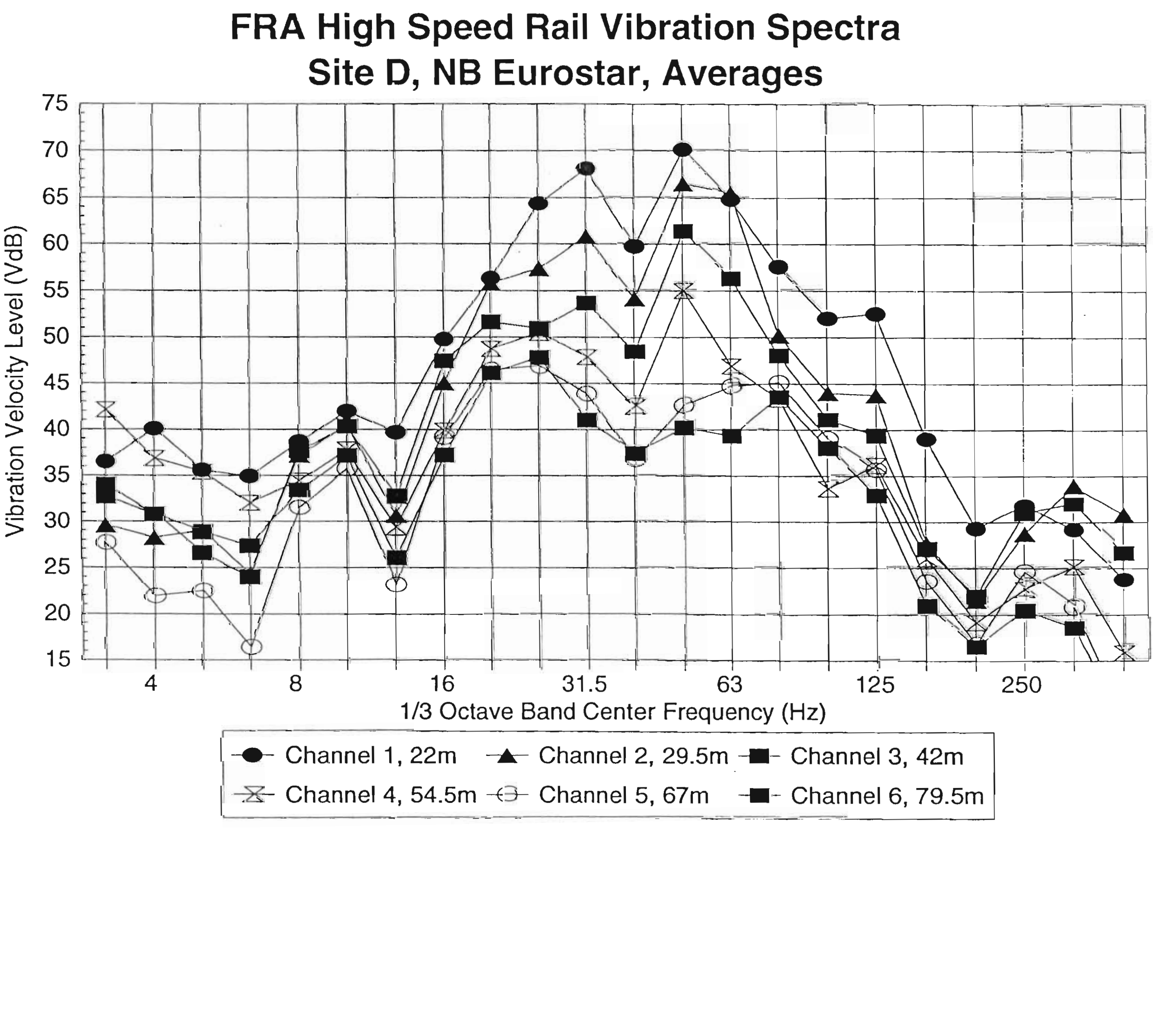
APPENDIX D: GROUND-BORNE VIBRATION SPECTRA FOR TRAIN EVENTS

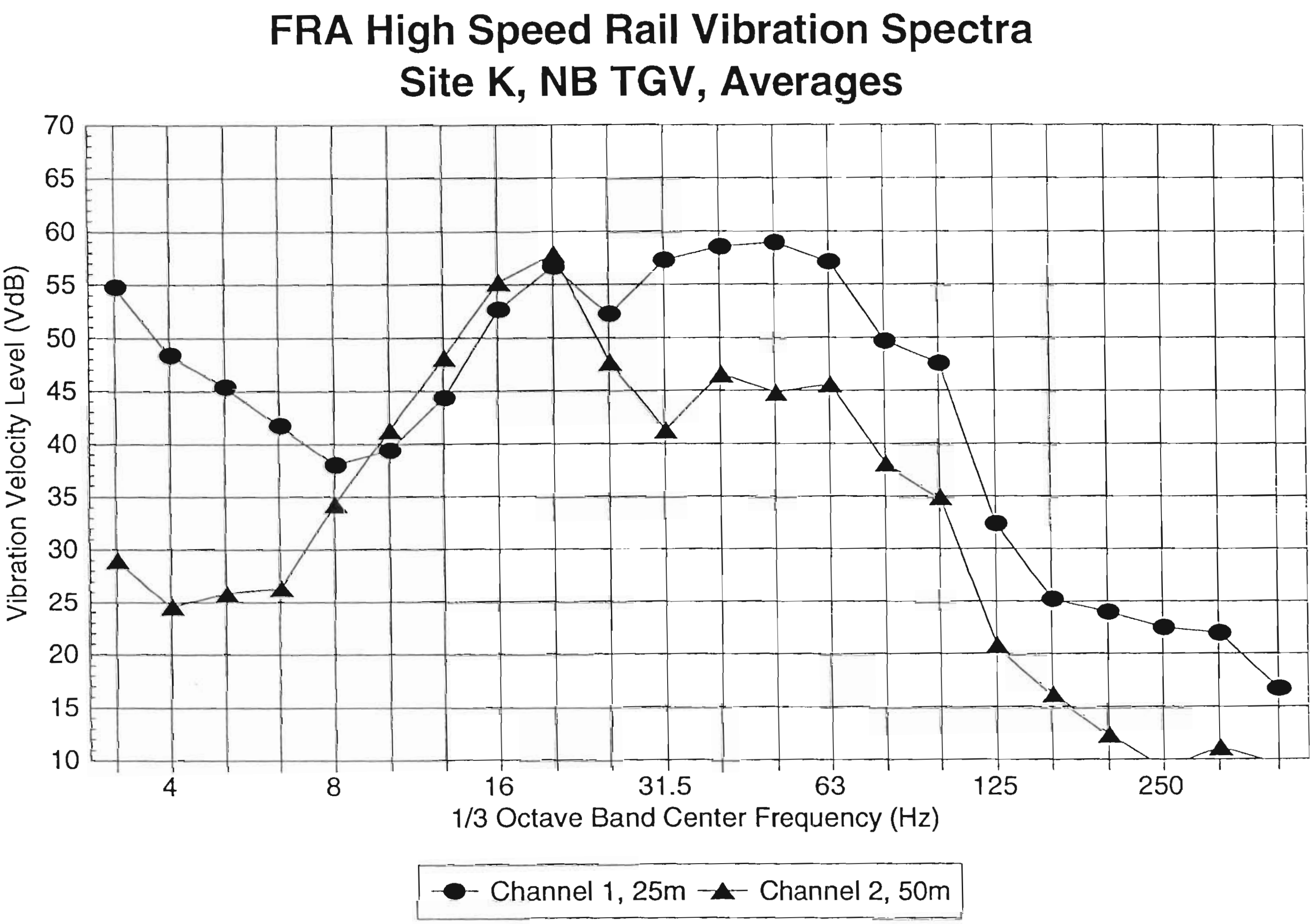


FRA High Speed Rail Vibration Spectra
Site D, SB TGV, Averages
Vibration Velocity Level (VdB)
75
70
65
60
55
50
45
40
35
30
25
20
15
4
8
16
31.5
63
125
250
1/3 Octave Band Center Frequency (Hz)
Channel 1, 17.5m
Channel 2, 25m
Channel 3, 37.5m
Channel 4, 50m
Channel 5, 62.5m
Channel 6, 75m

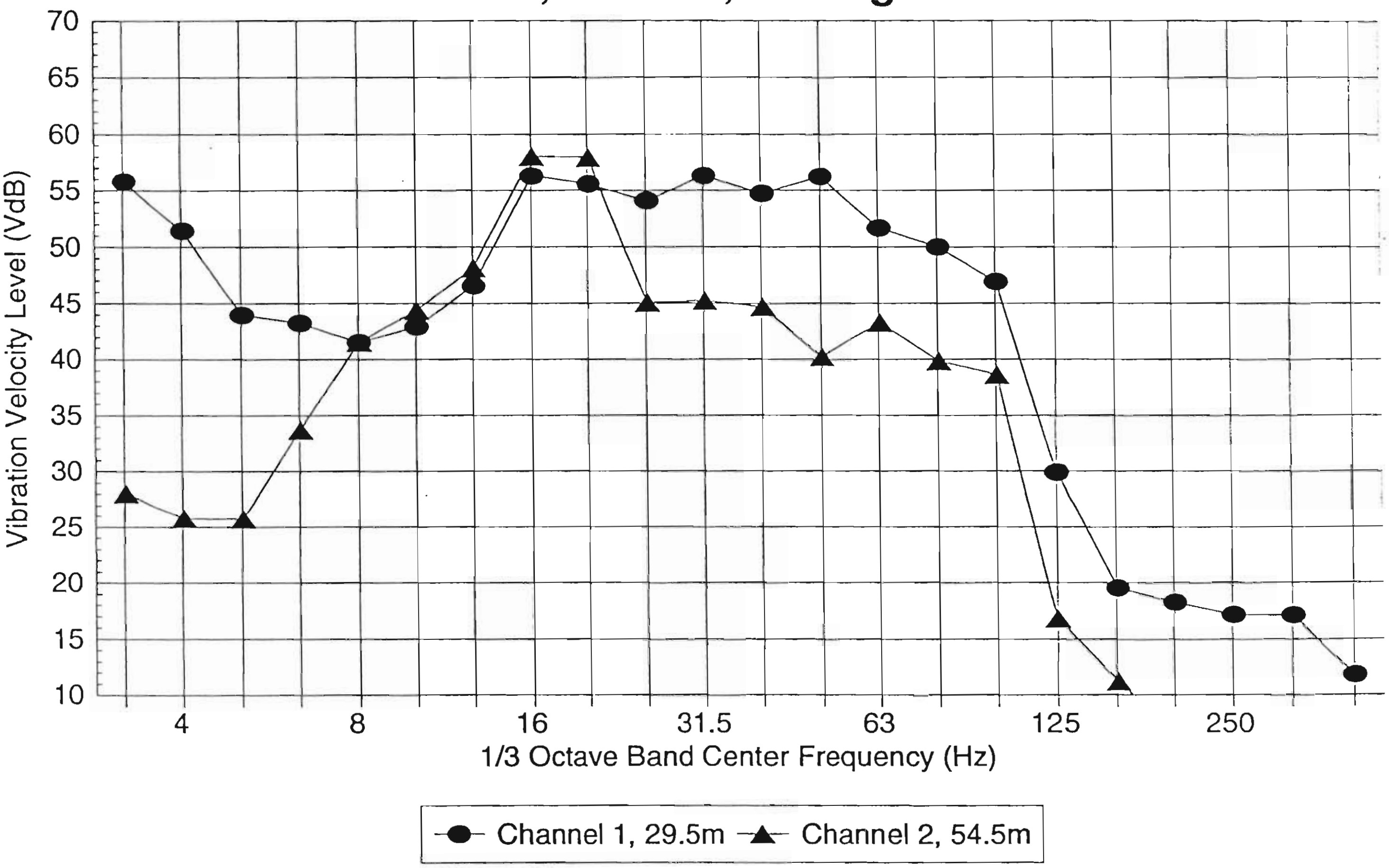

FRA High Speed Rail Vibration Spectra
Site D, NB TGV, Averages
Vibration Velocity Level (VdB)
75
70
65
60
55
50
45
40
35
30
25
20
15
4
8
16
31.5
63
125
250
1/3 Octave Band Center Frequency (Hz)
Channel 1, 22m
Channel 2, 29.5m
Channel 3, 42m
Channel 4, 54.5m
Channel 5, 67m
Channel 6, 79.5m

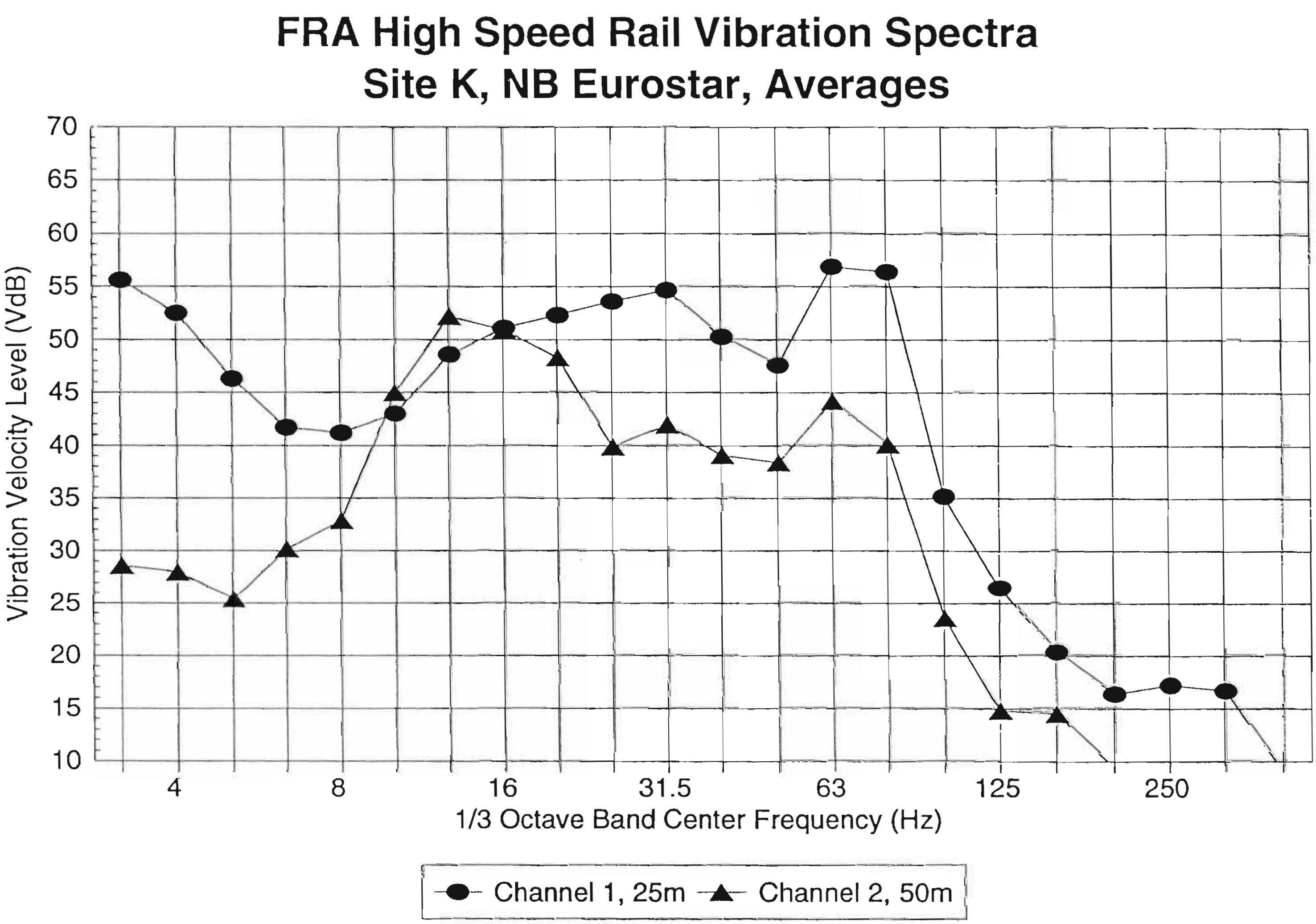

FRA High Speed Rail Vibration Spectra
Site D, SB Eurostar, Averages
Vibration Velocity Level (VdB)
75
70
65
60
55
50
45
40
35
30
25
20
15
4
8
16
31.5
63
125
250
1/3 Octave Band Center Frequency (Hz)
Channel 1, 17.5m
Channel 2, 25m
Channel 3, 37.5m
Channel 4, 50m
Channel 5, 62.5m
Channel 6, 75m

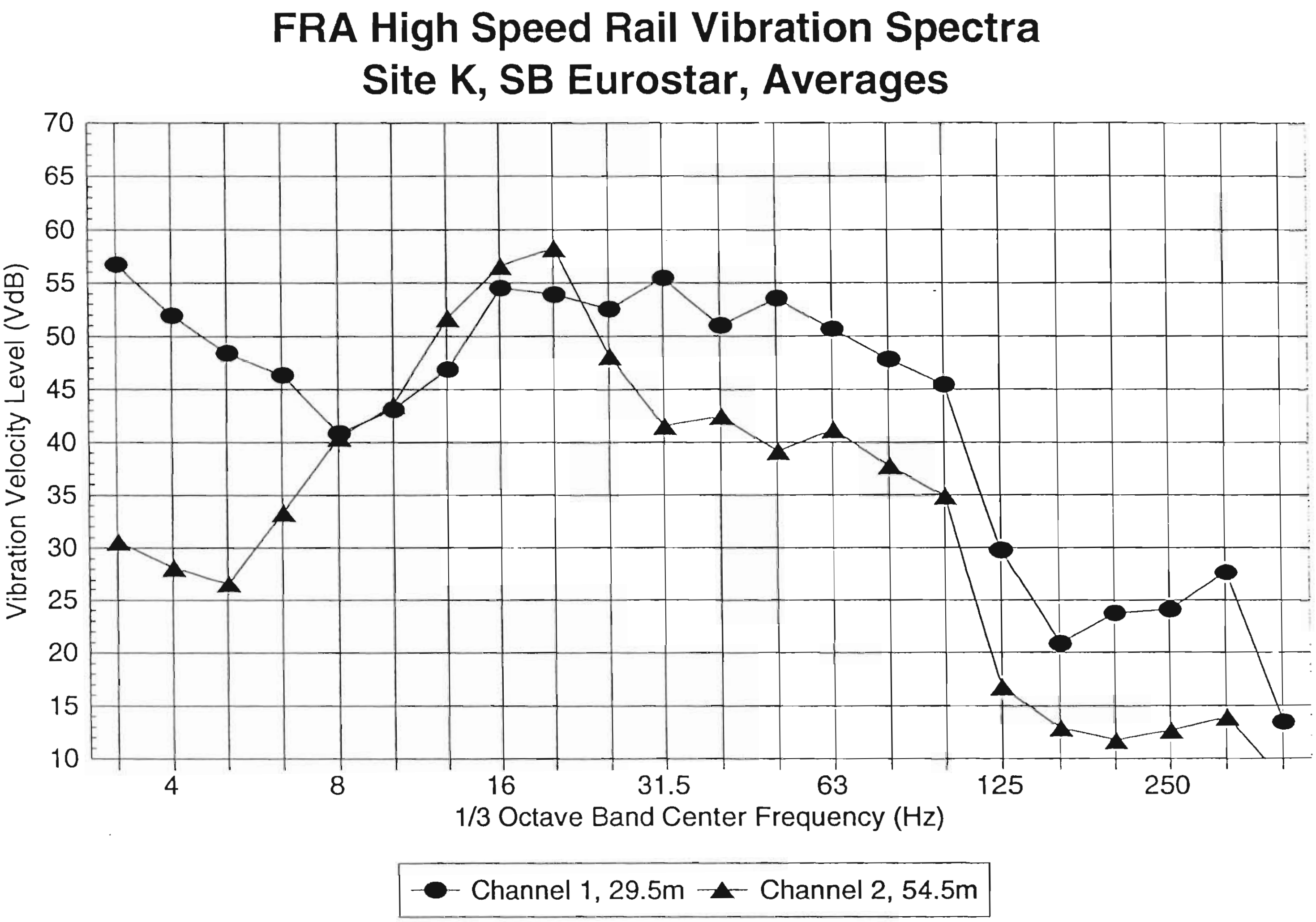

FRA High Speed Rail Vibration Spectra
Site D, NB Eurostar, Averages
Vibration Velocity Level (VdB)
75
70
65
60
55
50
45
40
35
30
25
20
15
4
8
16
31.5
63
125
250
1/3 Octave Band Center Frequency (Hz)
Channel 1, 22m
Channel 2, 29.5m
Channel 3, 42m
Channel 4, 54.5m
Channel 5, 67m
Channel 6, 79.5m


FRA High Speed Rail Vibration Spectra
Site K, NB TGV, Averages
70
65
60
55
50
45
40
35
30
25
20
15
10
Vibration Velocity Level (VdB)
4
8
16
31.5
63
125
250
1/3 Octave Band Center Frequency (Hz)
Channel 1, 25m
Channel 2, 50m

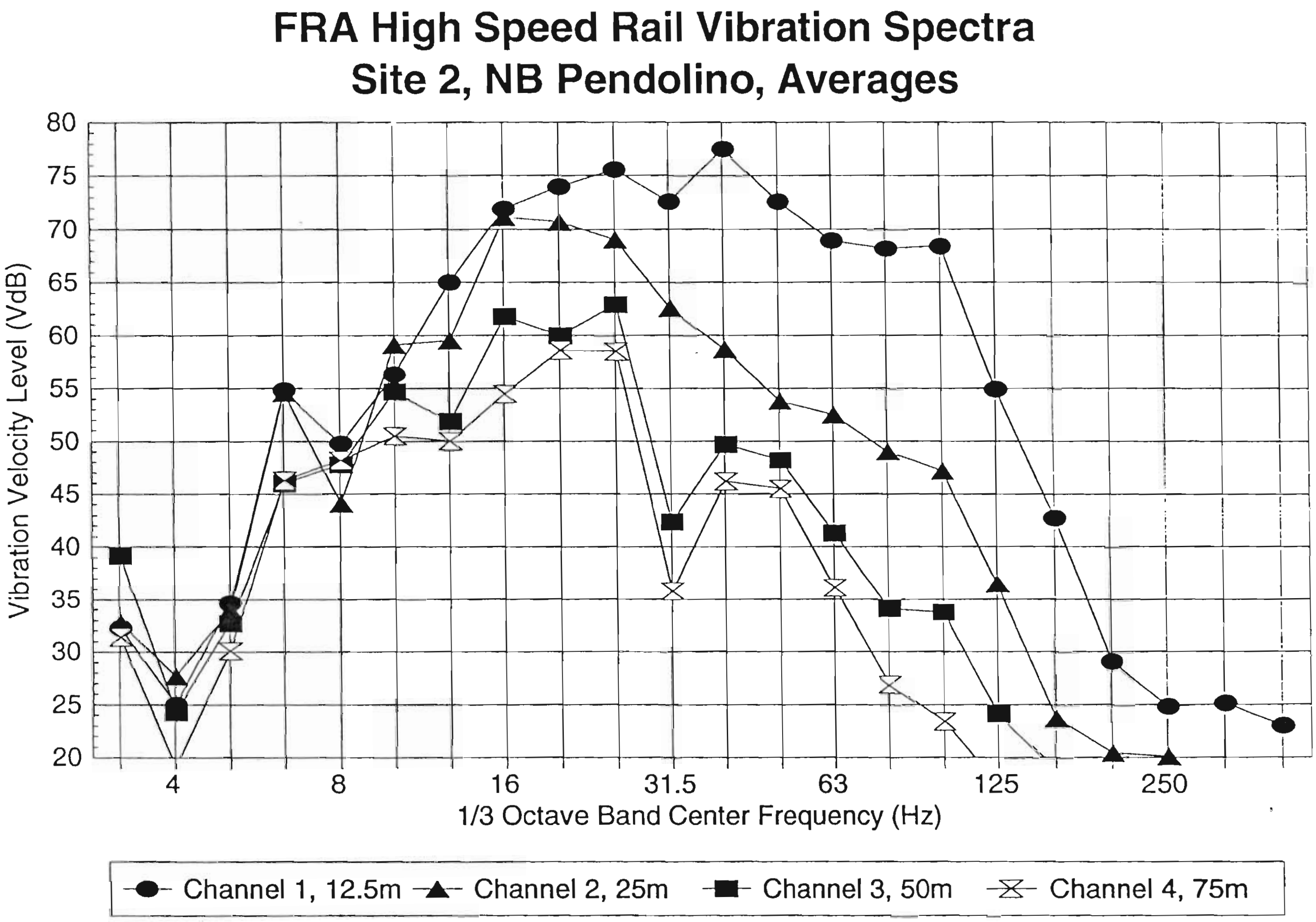
FRA High Speed Rail Vibration Spectra
Site K, SB TGV, Averages

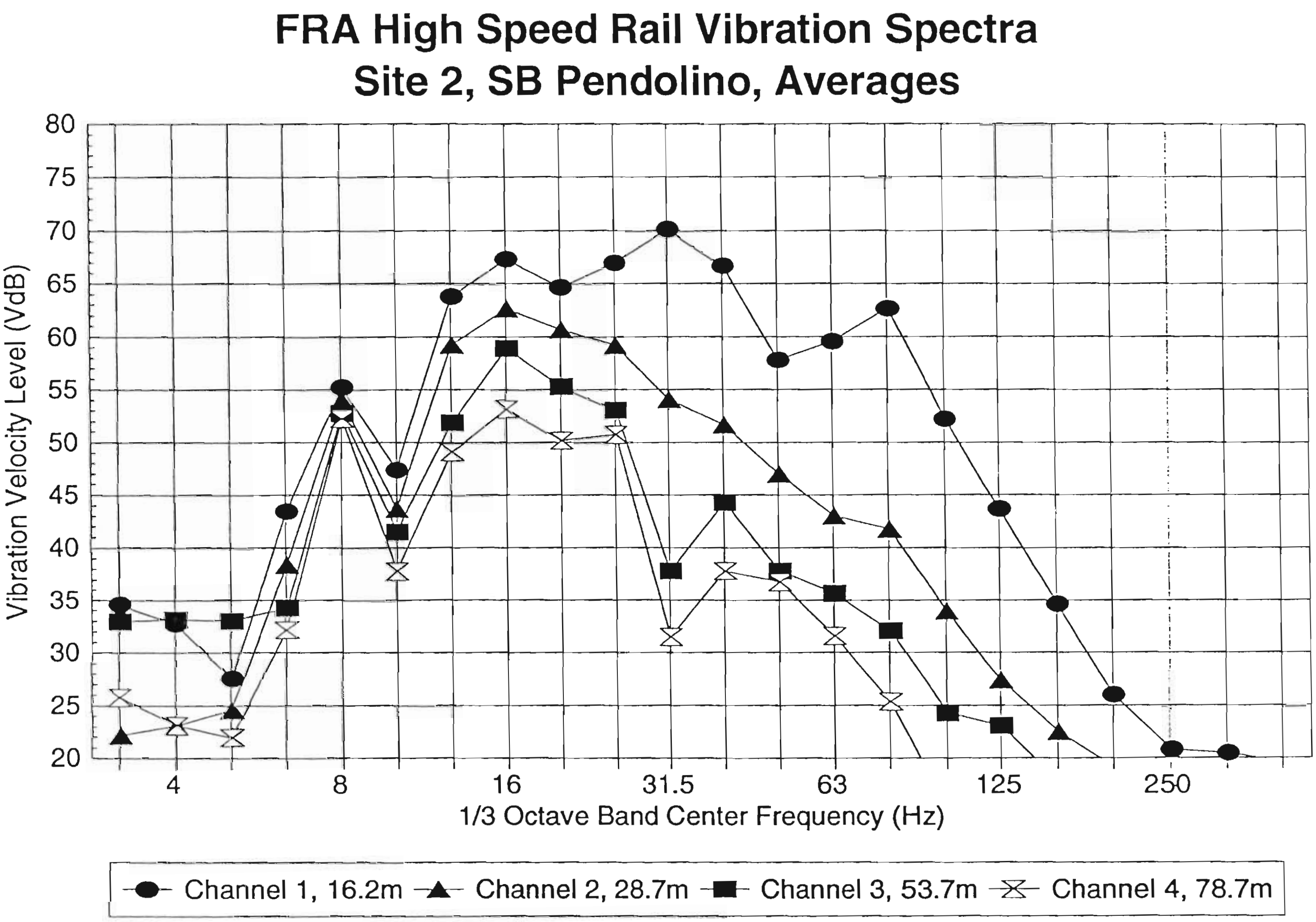



FRA High Speed Rail Vibration Spectra
Site K, NB Eurostar, Averages
Vibration Velocity Level (VdB)
70
65
60
55
50
45
40
35
30
25
20
15
10
4
8
16
31.5
63
125
250
1/3 Octave Band Center Frequency (Hz)
Channel 1, 25m
Channel 2, 50m

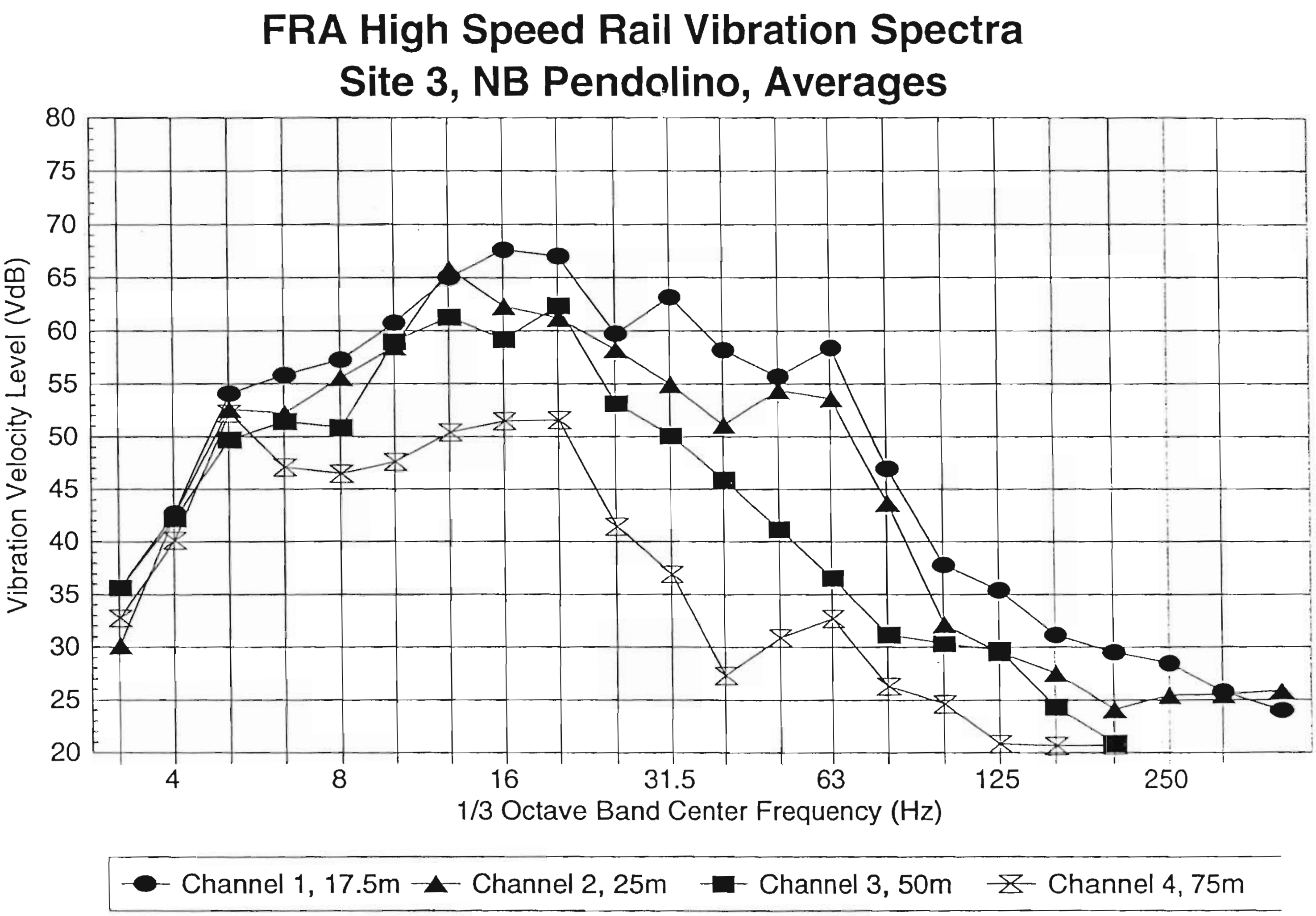


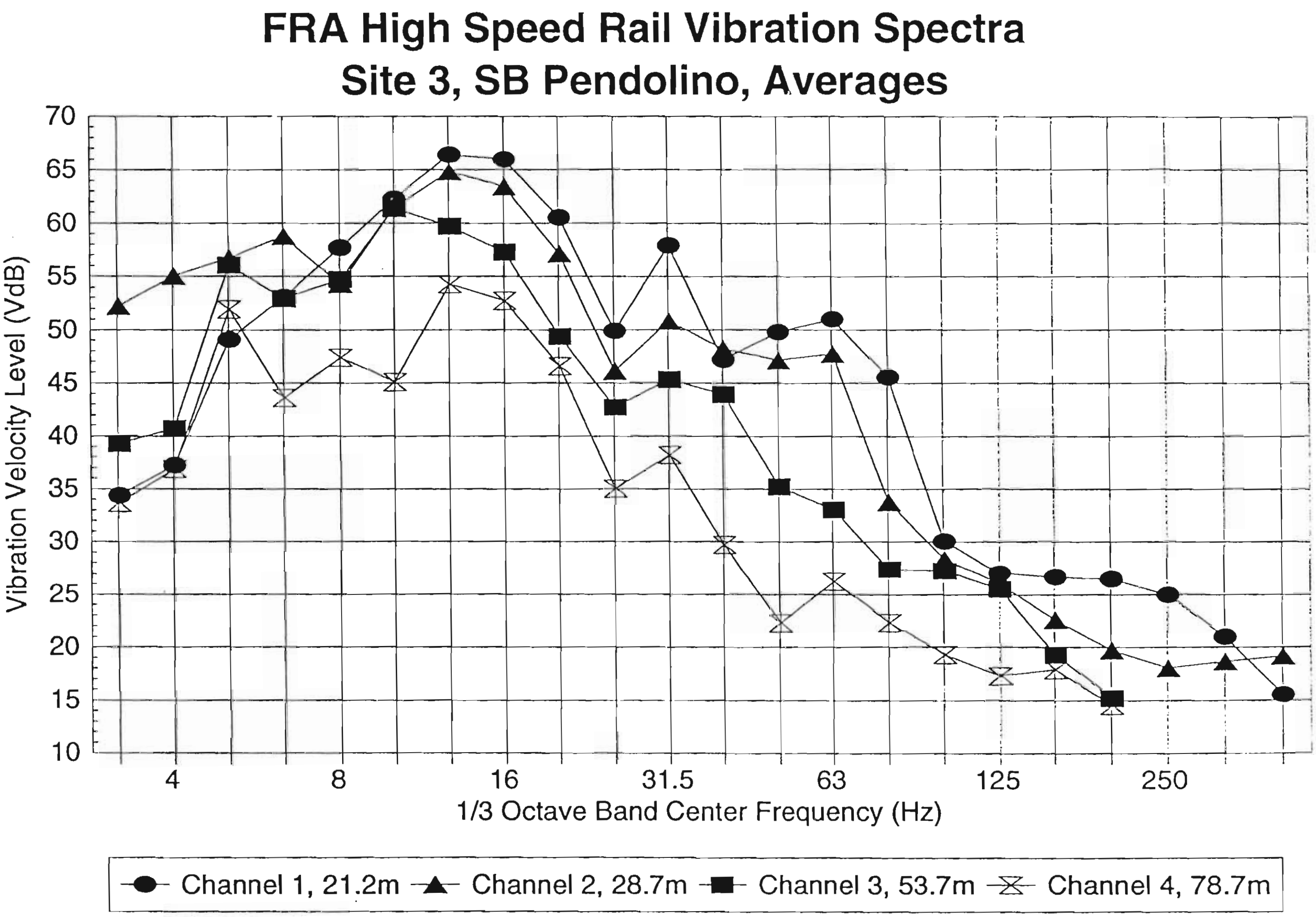
FRA High Speed Rail Vibration Spectra
Site K, SB Eurostar, Averages
Vibration Velocity Level (VdB)
70
65
60
55
50
45
40
35
30
25
20
15
10
4
8
16
31.5
63
125
250
1/3 Octave Band Center Frequency (Hz)
Channel 1, 29.5m
Channel 2, 54.5m


FRA High Speed Rail Vibration Spectra
Site 2, NB Pendolino, Averages
Vibration Velocity Level (VdB)
80
75
70
65
60
55
50
45
40
35
30
25
20
4
8
16
31.5
63
125
250
1/3 Octave Band Center Frequency (Hz)
Channel 1, 12.5m
Channel 2, 25m
Channel 3, 50m
Channel 4, 75m



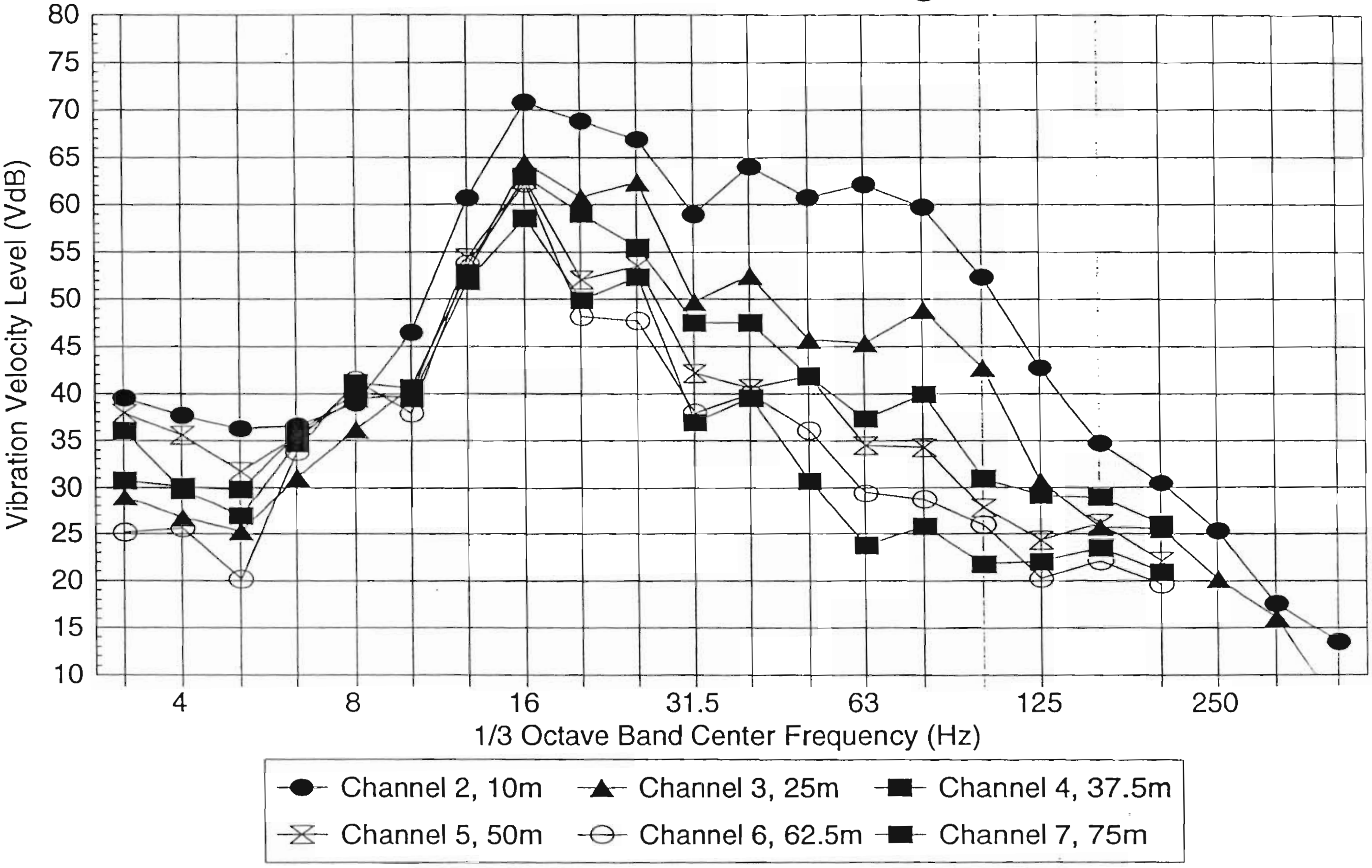
FRA High Speed Rail Vibration Spectra
Site 2, SB Pendolino, Averages
80
75
70
65
60
55
50
45
40
35
30
25
20
Vibration Velocity Level (VdB)
4
8
16
31.5
63
125
250
1/3 Octave Band Center Frequency (Hz)
Channel 1, 16.2m
Channel 2, 28.7m
Channel 3, 53.7m
Channel 4, 78.7m


FRA High Speed Rail Vibration Spectra
Site 3, NB Pendolino, Averages
Vibration Velocity Level (VdB)
80
75
70
65
60
55
50
45
40
35
30
25
20
4
8
16
31.5
63
125
250
1/3 Octave Band Center Frequency (Hz)
Channel 1, 17.5m
Channel 2, 25m
Channel 3, 50m
Channel 4, 75m

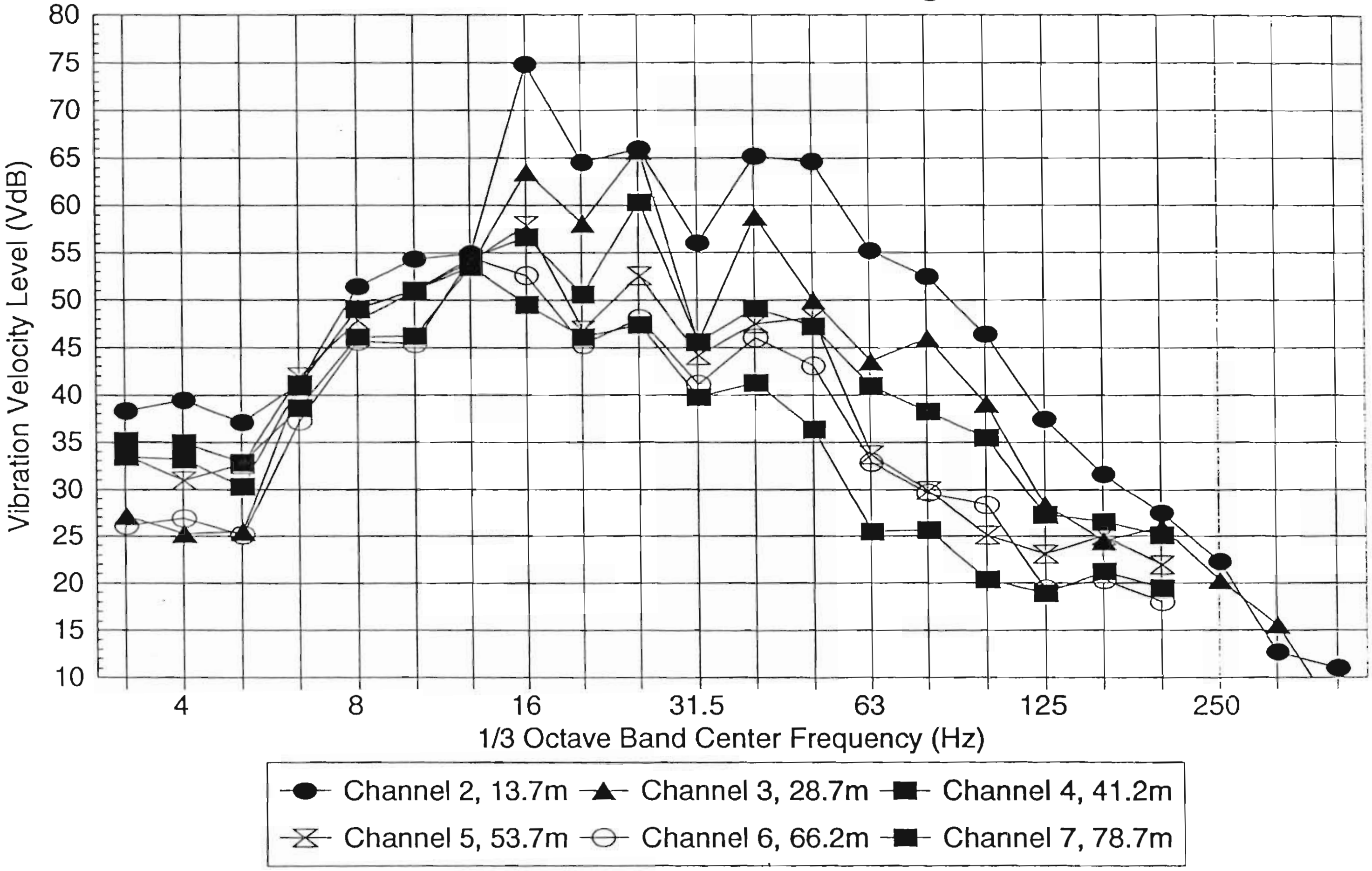


FRA High Speed Rail Vibration Spectra
Site 3, SB Pendolino, Averages
Vibration Velocity Level (VdB)
70
65
60
55
50
45
40
35
30
25
20
15
10
4
8
16
31.5
63
125
250
1/3 Octave Band Center Frequency (Hz)
Channel 1, 21.2m
Channel 2, 28.7m
Channel 3, 53.7m
Channel 4, 78.7m

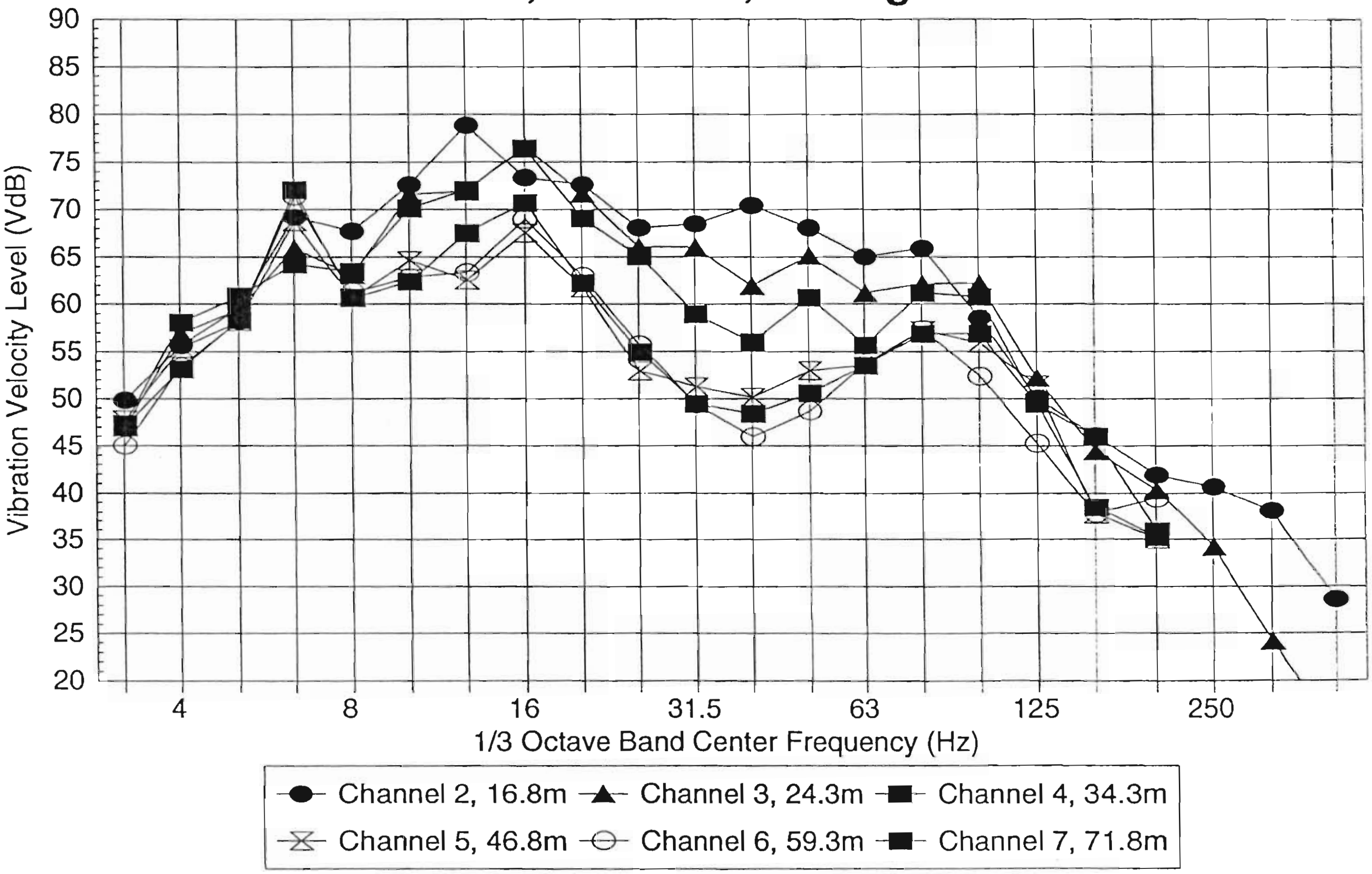
FRA High Speed Rail Vibration Spectra
Site 4, SB Pendolino, Averages

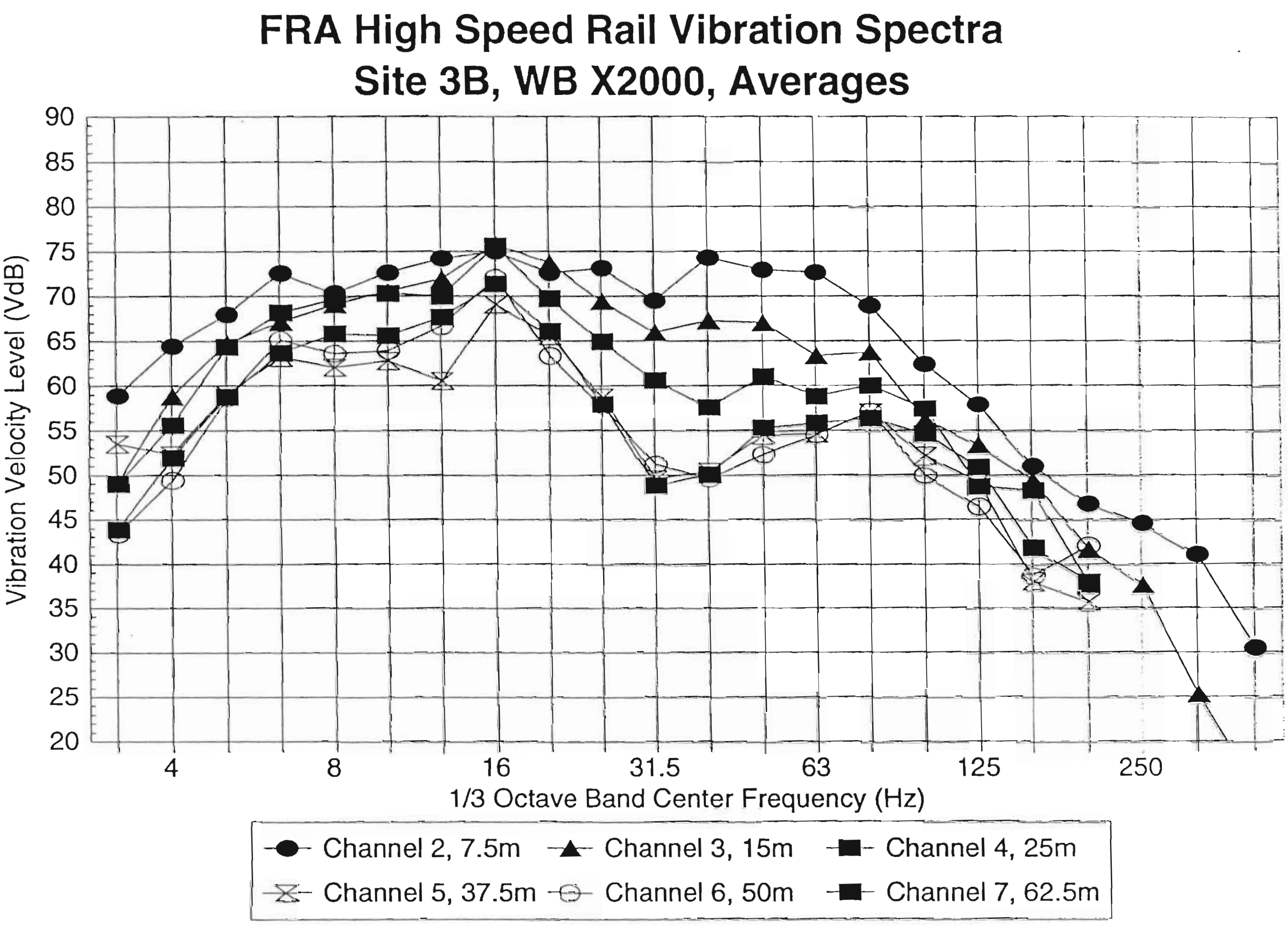


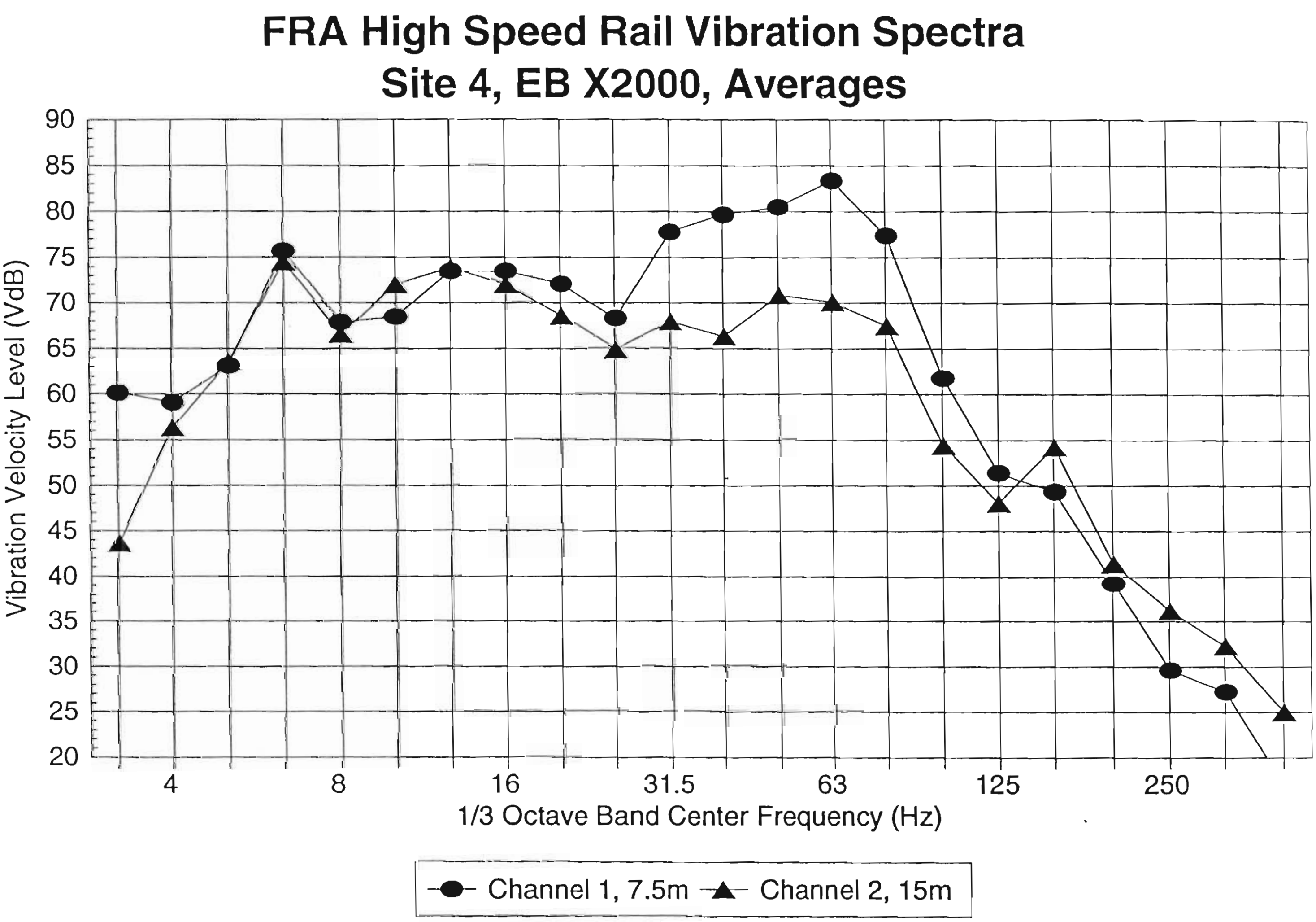
FRA High Speed Rail Vibration Spectra
Site 4, NB Pendolino, Averages



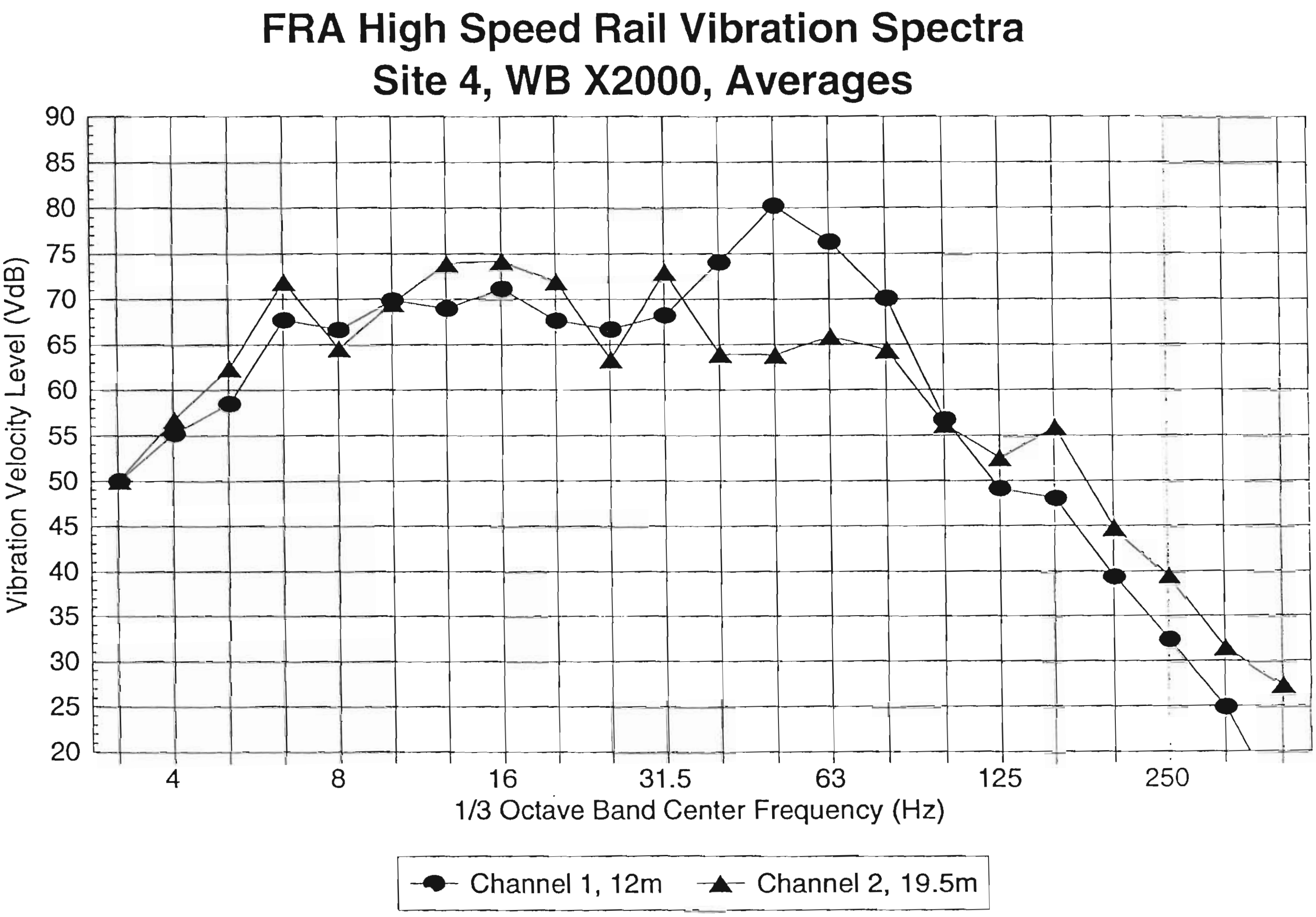
FRA High Speed Rail Vibration Spectra
Site 3B, EB X2000, Averages



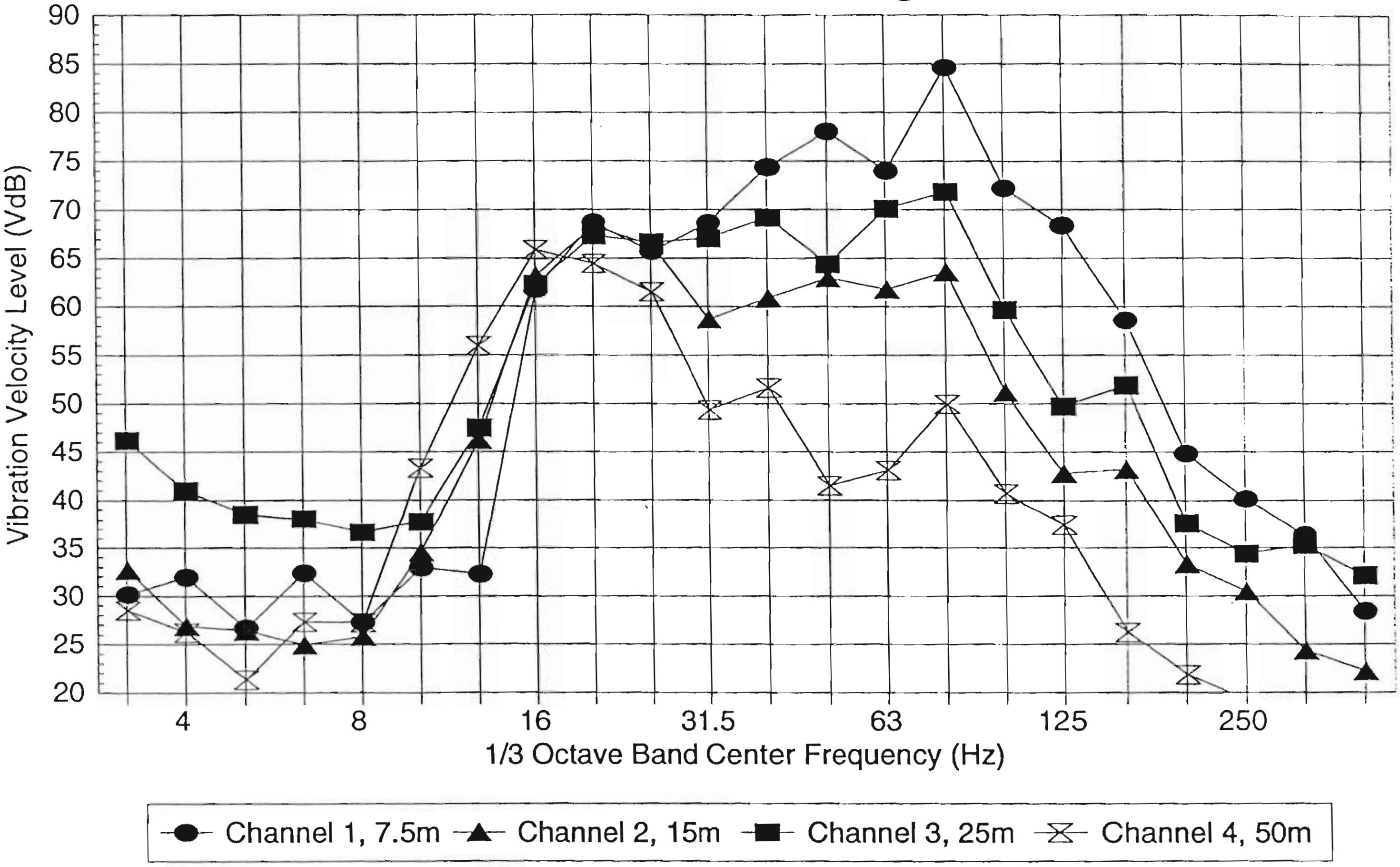

FRA High Speed Rail Vibration Spectra
Site 3B, WB X2000, Averages
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
Vibration Velocity Level (VdB)
4
8
16
31.5
63
125
250
1/3 Octave Band Center Frequency (Hz)
Channel 2, 7.5m
Channel 3, 15m
Channel 4, 25m
Channel 5, 37.5m
Channel 6, 50m
Channel 7, 62.5m

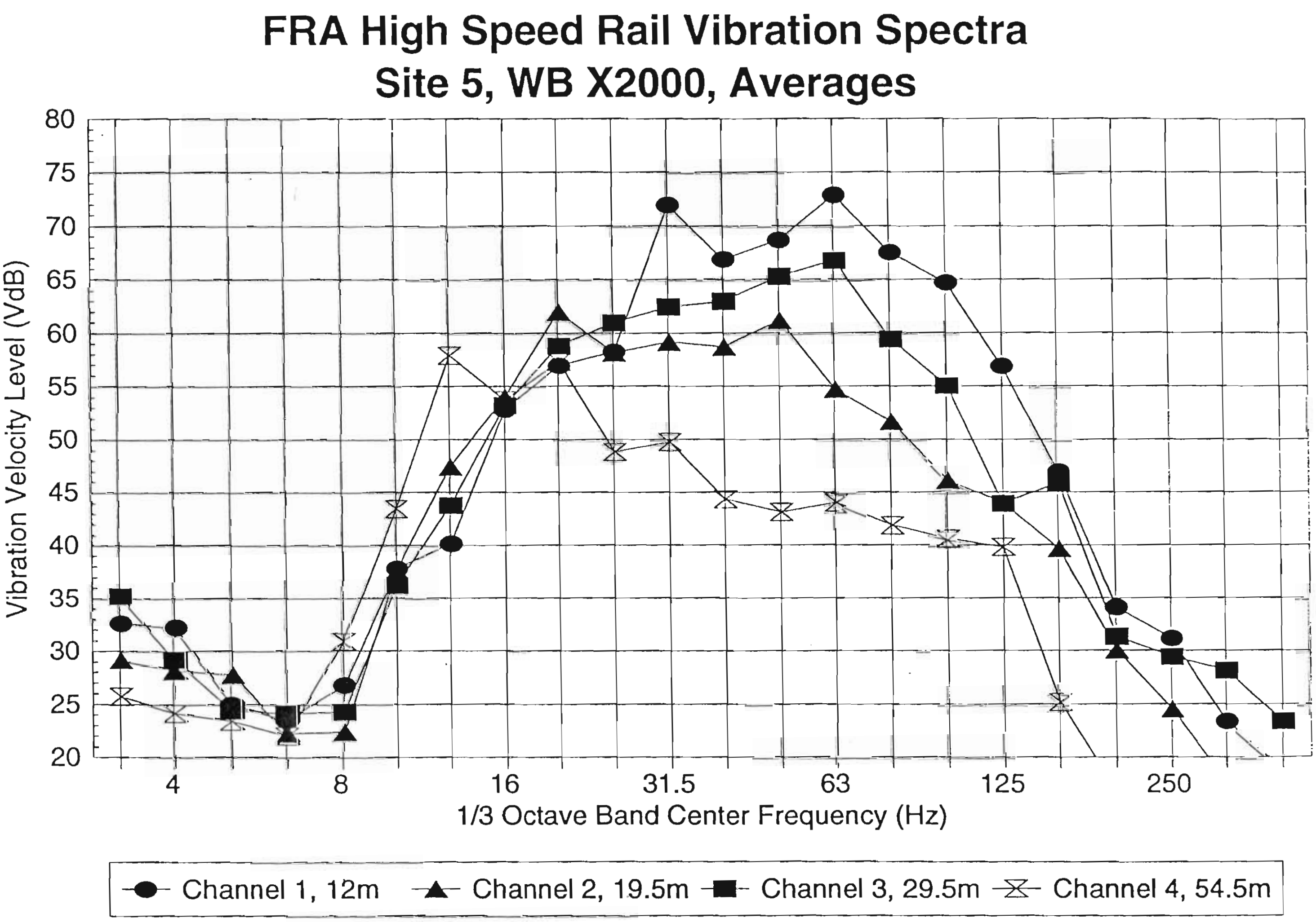


FRA High Speed Rail Vibration Spectra
Site 4, EB X2000, Averages
Vibration Velocity Level (VdB)
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
4
8
16
31.5
63
125
250
1/3 Octave Band Center Frequency (Hz)
Channel 1, 7.5m
Channel 2, 15m


FRA High Speed Rail Vibration Spectra
Site 4, WB X2000, Averages
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
Vibration Velocity Level (VdB)
4
8
16
31.5
63
125
250
1/3 Octave Band Center Frequency (Hz)
Channel 1, 12m
Channel 2, 19.5m

FRA High Speed Rail Vibration Spectra
Site 5, EB X2000, Averages




FRA High Speed Rail Vibration Spectra
Site 5, WB X2000, Averages
80
75
70
65
60
55
50
45
40
35
30
25
20
Vibration Velocity Level (VdB)
4
8
16
31.5
63
125
250
1/3 Octave Band Center Frequency (Hz)
Channel 1, 12m
Channel 2, 19.5m
Channel 3, 29.5m
Channel 4, 54.5m

hmmh

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