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Vibration Characteristics of the Transrapid TR08 Maglev System

U.S. Department of Transportation
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John A. Volpe National Transportation Systems Center
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13. ABSTRACT (Maximum 200 words)
As part of the Federal Railroad Administration's (FRA) Magnetic Levitation Transportation Technology Deployment Program, this technical report has been prepared to characterize the vibration associated with the operation of the Transrapid International (TRI) TR08 Maglev System. The TRI TR08 Maglev System is an advanced transportation technology in which magnetic forces levitate, propel, and guide a vehicle over a specially-designed guideway. The TR08 Maglev System is the technology that is being considered for deployment in the U.S., and potential vibration impacts of the technology were not known. This document presents vibration data collected during measurements of the TRI TR08 Maglev System in August 2001 at the TRI Test Facility in the Emsland region of Germany. Vibration data presented for the TR08 include generic force spectra for various guideway types, as well as speed- and distance-based vibration relationships.

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PREFACE

As part of the Federal Railroad Administration's (FRA) Magnetic Levitation Transportation Technology Deployment Program, this technical report characterizes the vibration associated with the operation of the Transrapid International TR08 Maglev System, a transportation system employing magnetic levitation (maglev). This report presents measurements of vibration associated with the TR08 Maglev System; these measurements were taken at the Transrapid Test Facility (TVE) in the Emsland region of Germany, in August, 2001. The data presented and analyzed herein can be utilized to support the required environmental planning and deployment activities for any Transrapid Maglev project in the U.S.

This report is the product of a combined international effort. The authors wish to thank the many individuals and organizations whose contributions were instrumental in the coordination, test plan development, field measurements, analysis, documentation, and supporting functions for this report. The participation, cooperation, and forbearance of the operators and staff of TVE during the measurement campaign were especially appreciated. The valuable assistance of Mr. Robert Budell, Mr. Frank Litzmann and Mr. Christian Rausch of Transrapid International, and Mr. Laurence Blow and Mr. Reed Tanger of Transrapid USA, are also acknowledged, as their contributions were critical to the success of this effort. The staff of IABG (Industrieanlagen Betriebsgesellschaft), including Mr. Gerold Snieders and Mr. Hans-Gert Runde, provided important information to the measurement team; special thanks is extended to Dr. Klaus-Peter Schmitz (IABG), who, despite his many other responsibilities at TVE, gave his attention to our needs during the measurement program. In the coordination of the measurement campaign and in the production of this report, we also acknowledge the support of staff at Harris Miller Miller & Hanson, MAGLEV, Inc., and the John A. Volpe National Transportation Systems Center. Particularly, the assistance of Mr. Edd Manges from MAGLEV, Inc., was useful.

EXECUTIVE SUMMARY

INTRODUCTION

In the Transportation Equity Act for the 21st Century (TEA-21), Congress authorized the Magnetic Levitation Transportation Technology Deployment Program (Maglev Deployment Program) to demonstrate the benefits of an operating transportation system employing magnetic levitation (maglev). Maglev is an advanced transportation technology in which magnetic forces lift, propel, and guide a vehicle over a specially designed guideway at variable speeds, including those in excess of 386 kilometers per hour (km/h) (240 miles per hour (mph)). The U.S. Department of Transportation (USDOT) assigned the Maglev Deployment Program to the Federal Railroad Administration (FRA) for implementation.

To satisfy the requirements of the National Environmental Policy Act, and to fulfill the directives of the Programmatic Environmental Impact Statement and associated Record of Decision published in 2001 (FRA), the potential environmental and related impacts associated with the operation of the proposed technology must be analyzed. The maglev technology that is being considered for deployment in the U.S. is the Transrapid International (TRI) TR08 Maglev System. This technical report characterizes the vibration associated with the operation of the TRI TR08 Maglev System based on measurements made at the Transrapid Test Facility (TVE) in Germany in August, 2001. The data presented and analyzed herein can be utilized to support the required environmental planning and deployment activities for any TRI Maglev project in the U.S. that uses the TR08 technology.

The FRA is the lead agency for the Maglev Deployment Program. The project sponsor of the Pennsylvania Project (the Pennsylvania Maglev Alternative), the Port Authority of Allegheny County, and that organization’s private partner MAGLEV, Inc. coordinated, managed, and had technical oversight of the measurement and reporting of the vibration characteristics of the TR08. The actual vibration data were collected, analyzed, and reported by Harris Miller Miller & Hanson, Inc. (HMMH). Technical staff from the John A. Volpe National Transportations Systems Center (Volpe Center) provided active oversight both in the development of the test plans and during the measurements made by HMMH. The Volpe Center also undertook a detailed validation and verification of the final data provided by HMMH and presented herein.

MEASUREMENTS

The environmental measurements described in this report took place at the TVE in the Emsland region of Germany, in August, 2001. The TVE consists of a 31.5

km (19.5 mile) guideway, with two loops at either end of a straight section. Various guideway types (steel, concrete, hybrid, switch) and configurations (at-grade, elevated) exist at the test track.

Vibration measurements were undertaken to obtain wayside ground-borne vibration data during the operation of the TR08 vehicle on the various guideway sections at the test track. Data were obtained for several vehicle speeds and guideway configurations. The results are intended to provide reference levels for use during the environmental impact assessments of the Maglev Deployment Program.

RESULTS

Transrapid TR08 vibration levels measured at 50 feet are summarized in Table ES-1 below.

Table ES-1. TR08 Vibration Levels at 50 feet

SPEED	CONFIGURATION	Level (VdB re 1 microinch/sec)
200 km/h (125 mph)	Concrete Beam	66
	Steel Beam	67
	Hybrid Beam	68
	At-grade Concrete Beam	77
	At-grade Steel Beam	79
	Switch	76
400 km/h (250 mph)	Concrete Beam	77
	Steel Beam	79
	Hybrid Beam	74
	At-grade Concrete Beam	83
	At-grade Steel Beam	84
	Switch	80
Approach and stop	Station	88
Depart	Station	85

In addition to the data presented in Table ES-1, several conclusions may be drawn about the Transrapid TR08 vibration data:

- Force spectra comparisons indicate:
    - Steel beam guideways typically generate greater low-frequency (6.3 Hz – 25 Hz) forces, as compared with the other guideway types, for TR08 operations
    - Hybrid beam guideways typically generate greater high-frequency (25 Hz – 160 Hz) forces, as compared with the other guideway types, for TR08 operations
- TR08 vibration levels generally attenuate at approximately 5 velocity decibels (VdB) per doubling of distance
- TR08 vibration levels generally increase at a rate of 20 to 40 times the logarithm of speed

COMPARISONS OF TR08 VIBRATION LEVELS WITH OTHER RAIL SOURCES

Figure ES-1 presents a comparison of vibration levels of the TR08 traveling at 240 km/h (150 mph) with those of other high-speed rail sources. TR08 vibration levels for both the concrete elevated and concrete at-grade (AG) guideways are compared with those of the French Train à Grande Vitesse (TGV), the Italian Pendolino, the Swedish X2000, and the Acela at 240 km/h (150 mph).

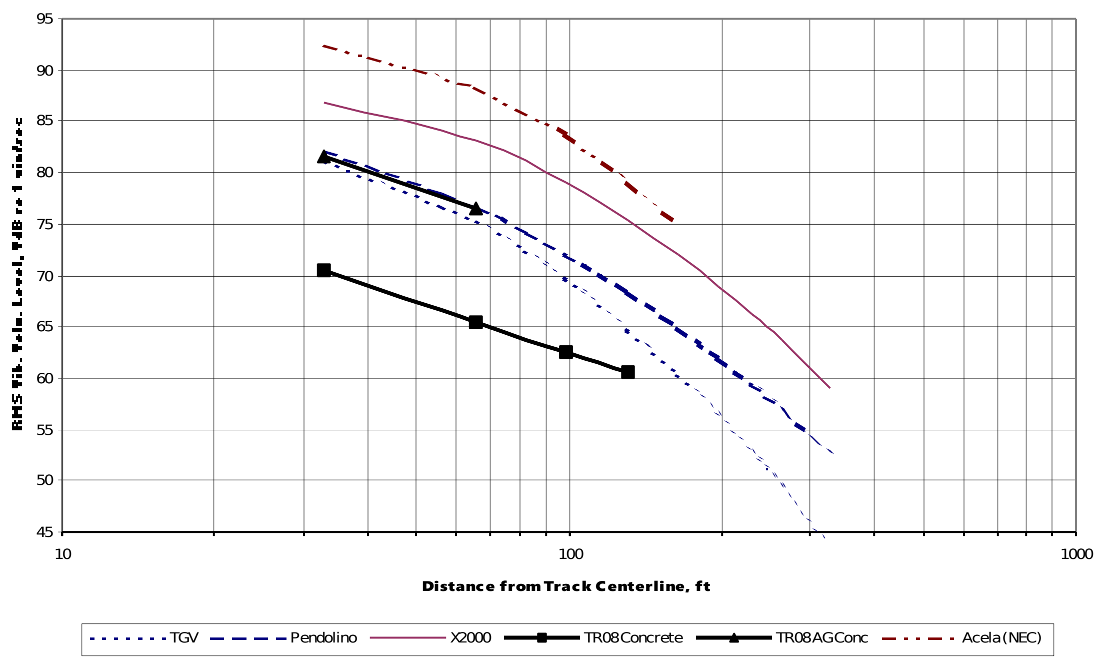


Figure ES-1. TR08 Vibration Level Comparison with Other Rail Sources

As seen in the figure, vibration levels for the TR08 traversing the at-grade guideway structure are comparable to those from high-speed trains measured in Italy and France, whereas the levels for the elevated structure are considerably lower for the distances measured. Vibration levels measured at 50 feet for the TR08 traversing the at-grade guideway at 400 km/h (250 mph) are less than those previously measured at 50 feet for the Acela traveling 240 km/h (150 mph). These comparisons, however, are representative of data collected at various sites and are generally typical of local geological conditions.

Detailed, site-specific vibration analysis may be undertaken using the data contained herein and the methodologies outlined in the FRA's *High-Speed Ground Transportation Noise and Vibration Impact Assessment* (FRA 1998) document.

1.0 INTRODUCTION

1.1 PURPOSE

As part of the Federal Railroad Administration's (FRA) Magnetic Levitation Transportation Technology Deployment Program, this technical report characterizes the vibration associated with the operation of the Transrapid International TR08 Maglev System, a transportation system employing magnetic levitation (maglev). The TR08 Maglev System is the technology that is being considered for deployment in the U.S. (FRA 2001) by maglev programs in Pennsylvania and Maryland. Under the National Environmental Policy Act, potential environmental impacts, including vibration impacts, of a maglev transportation system must be assessed.

The environmental measurements described in this report took place at the Transrapid Test Facility in the Emsland region of Germany, in August, 2001. The data presented and analyzed herein can be utilized to support the required environmental planning and deployment activities for any Transrapid Maglev project in the U.S. This report also includes a limited comparison of the data to similar data from other modes of transportation as well as to current FRA vibration impact criteria.

1.2 BACKGROUND

In the Transportation Equity Act for the 21st Century (TEA-21), Congress authorized the Magnetic Levitation Transportation Technology Deployment Program (Maglev Deployment Program) to demonstrate the transportation, economic, environmental, energy, and other benefits of an operating transportation system employing magnetic levitation (maglev). Maglev is an advanced transportation technology in which magnetic forces lift, propel, and guide a vehicle over a specially designed guideway at variable speeds, including those in excess of 386 kilometers per hour (km/h) (240 miles per hour (mph)). The U.S. Department of Transportation (USDOT) assigned the Maglev Deployment Program to the Federal Railroad Administration (FRA) for implementation.

In order to comply with the TEA-21, FRA conducted a competitive award and selection process to demonstrate maglev in a U.S. transportation application. In May 1999, the Secretary of Transportation selected, from a pool of eleven applicants, seven states (or state-designated authorities) to receive grants for pre-construction planning of their maglev programs. To satisfy the requirements of the National Environmental Policy Act (NEPA), FRA, as the lead agency, determined that the Maglev Deployment Program constituted a major Federal action with the potential to have a significant effect on the environment, and accordingly published a Programmatic Environmental Impact Statement (PEIS) (FRA 2001). The purpose of the PEIS was to describe the Maglev Deployment Program and the potential environmental impacts associated with its possible implementation, as well as to encourage public involvement and to address agency and public concerns (FRA 2001). In developing the PEIS, FRA required each of the seven state participants to prepare environmental assessments, which became the source of baseline data in the Draft PEIS (DPEIS), approved in June 2000. After collecting and incorporating appropriate public and agency comments on the DPEIS, the John A. Volpe National Transportations Systems Center (Volpe Center), on behalf of the FRA, refined the document and prepared the Final PEIS (PEIS), approved in March 2001 (see text at http://www.fra.dot.gov/rdv/maglev/mag_peis.htm). A Record Of Decision (ROD) was executed with the PEIS (FRA 2001).

The PEIS (FRA 2001) analyzed the potential environmental and related impacts associated with the Maglev Deployment Program using the maglev technology available at the time the environmental impacts were being analyzed, and at a level of detail commensurate with the program-level decisions being made at the time of PEIS publication (April 2001). A selection process administered by FRA led to the authorization of further funding for two project-specific environmental impact statements (EIS) for the Maryland and Pennsylvania Maglev Alternatives. Operational parameters of the Transrapid International TR07 Maglev System were used for the PEIS analysis of these two Alternatives, since no direct technical information was available on the proposed vehicle, the TR08 Maglev System. The information about TR07 was based on electromagnetic field measurements made in 1990 and published in 1992 (FRA 1992), and on noise measurements presented in a 1993 publication (FRA 1993). However, the ROD executed with the PEIS (FRA 2001) specified that in order to fully address environmental impacts of the maglev technology, the (1) electromagnetic fields (EMF) and electromagnetic radiation (EMR), (2) noise impacts, and (3) vibration impacts associated with the proposed vehicle, the Transrapid International TR08 Maglev System (see Section 1.4), needed to be identified.

To fulfill the directives of the ROD and its requirements in its grant agreement with FRA, the Port Authority of Allegheny County (the project sponsor of the Pennsylvania Maglev Alternative) contracted with MAGLEV, Inc., to measure and report the vibration characteristics of the TR08 Maglev System and co-author this report. The research on vibration impacts associated with the TR08 vehicle reported in this technical characterization report will be included by reference in the project-specific EISs, which tier from the PEIS (FRA 2001).

1.3 ROLES AND RESPONSIBILITIES

The Maglev Deployment Program constitutes a major Federal action with the potential to have a significant effect on the environment and therefore requires compliance with NEPA. The FRA is the lead agency for the Maglev Deployment Program and is responsible for the NEPA compliance process.

The sponsor of the Pennsylvania Project (the Pennsylvania Maglev Alternative) is the Port Authority of Allegheny County. The Port Authority of Allegheny County's private partner, MAGLEV, Inc., coordinated, managed, and had technical oversight of the measurement and reporting of the vibration characteristics of the TR08 Maglev System. The actual vibration data were collected, analyzed, and reported by Harris Miller Miller & Hanson, Inc. (HMMH).

Technical staff from the Volpe Center provided active oversight and validation both in the development of the test plans and during the measurements made by the contractors. Volpe Center activities included examining techniques and test protocol, reviewing all data and analyses, and documenting these findings.

Assistance to the measurement team, both prior to testing (during development, review, and approval of test plans) and during the measurements at the test facility in the Emsland region of Germany, was also provided by technical staff of the FRA, the Volpe Center, MAGLEV, Inc., Transrapid International, and IABG (Industrieanlagen Betriebsgesellschaft, a European scientific/technical services company). The Test Plans (Appendix A) were reviewed and the measurements were observed by representatives of the Baltimore-Washington Maglev Project (the Maryland Maglev Alternative), including an environmental planning staff person from the Maryland Transit Administration and a representative from Parsons-Engineering Science, a noise and vibration consultant for the Baltimore-Washington Maglev Project.

The Volpe Center has, on behalf of the FRA and the Port Authority of Allegheny County, assembled and co-authored this TR08 vibration characterization report along with MAGLEV, Inc., and HMMH.

1.4 TR08 MAGLEV SYSTEM TECHNOLOGY INFORMATION

Maglev is a transportation technology that uses non-contact electromagnetic systems to lift, guide, and propel the vehicle over a specially-designed guideway. Without wheels or other mechanical parts to cause resistance, cruising speeds of 320 to 480 km/h (200-300 mph) can be reached (TRI 2001).

Maglev technology has been researched since the 1960s, and development programs have been conducted by several countries, most notably Japan and Germany. Both these countries have test tracks on which they have conducted extensive testing and refinement of their maglev concepts and of different prototype vehicles. The German technology, the Transrapid International (TRI) Maglev System, has a design based on a long stator linear synchronous motor with conventional electromagnets in an attractive magnetic force configuration. The Japanese technology, the Railway Technical Research Institute's (RTRI) MLU-series system, has a design based on superconducting magnets in an electrodynamic repulsive system (RTRI 2001). The German TRI TR08 Maglev System is the technology that has been selected for deployment in both the Pennsylvania and Maryland maglev projects (FRA 2001).

TRI has been investigating high-speed rail systems utilizing electromagnetic levitation systems since 1969, and commissioned the TR02 in 1971. The eighth generation vehicle, the TR08 (Figure 1-1), and some of its precursor prototype vehicles, the TR07 and TR06, have been demonstrated and tested at the Transrapid Test Facility (Transrapid Versuchsanlage Emsland (TVE)), in the Emsland region of Germany, for more than 15 years (TRI 2001). A significant number of tests and simulated revenue-service operations were conducted with the TR07 from 1989-1999. The TR08 was delivered to the TVE in August 1999. Although significant differences in measured information/data between the TR07 and TR08 are not expected, some design upgrades and changes (e.g., power rail DC segments near stations for battery charging) necessitated new measurements so that the most recent technical and operational environmental performance data may be used for site-specific EIS work for the planned U.S. projects.

Source: Transrapid International (TRI)

Figure 1-1. The TRI TR08 Maglev System

According to the manufacturer, the TR08 is more aerodynamic and more economical than its predecessor, the TR07 (TRI 2001). A hybrid design, using aluminum hollow profiles and aluminum-clad foam sandwich panels, provides a light and stiff structure for the carriage body. A TR08 vehicle consist is made up of two end sections and zero to eight middle sections (Table 1-1). The consist would not be separated in normal operations. The TR08 used at the TVE is a three-section, pre-production consist that is 79.70 m (261.5 ft) long, weighs 188.50 metric tons (t) (415,571 lbs), has seating for 190+ passengers (Figure 1-2), and is designed for peak 550 km/h (342 mph) operation. The TR08 at TVE is operated as a shuttle on a single guideway with one station. (TRI 2001)

Table 1-1. Specifications* of the Transrapid TR08 Maglev System

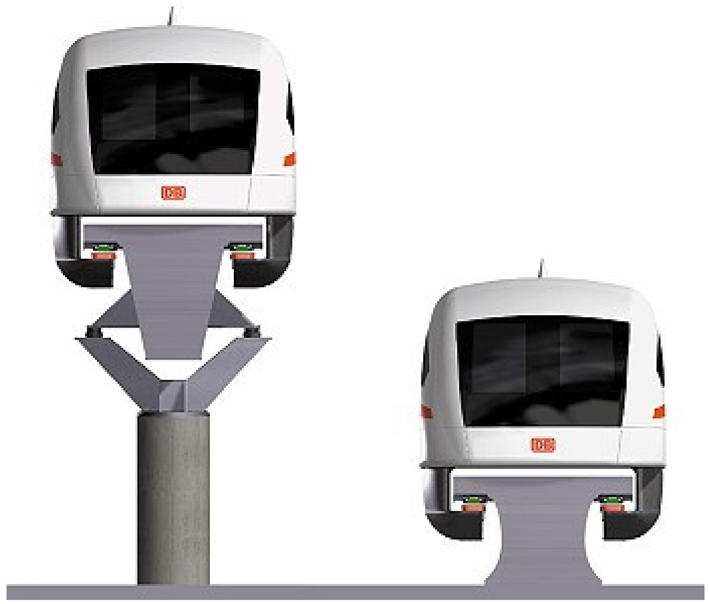
System Features	End Section	Middle Section
Vehicle Size:	2	0-8
Section Length	26.99 m (88.6 ft)	24.77 m (81.27 ft)
Section Width	3.70 m (12.14 ft)	3.70 m (12.14 ft)
Section Height	4.16 m (13.65 ft)	4.16 m (13.65 ft)
Payload per Section:		
Passenger Vehicle	10.3 t (22,708 lbs)	13.9 t (30,644 lbs)
Cargo Vehicle	14.0 t (30,865 lbs)	17.5 t (38,581 lbs)
Seats per Section	62-92	84-126
Floor Space per Section	70 m^2 (754 ft^2)	77 m^2 (818 ft^2)

Source: Transrapid International (TRI)
*TRI offers clients multiple configuration options, thus certain specifications may vary slightly among vehicles.

Source: Adapted from image provided by Transrapid International (TRI)

Figure 1-2. Typical TRI TR08 Interior Plans for (a) medium-density intercity seating, (b) high-density commuter type seating, and (c) first-class intercity seating.

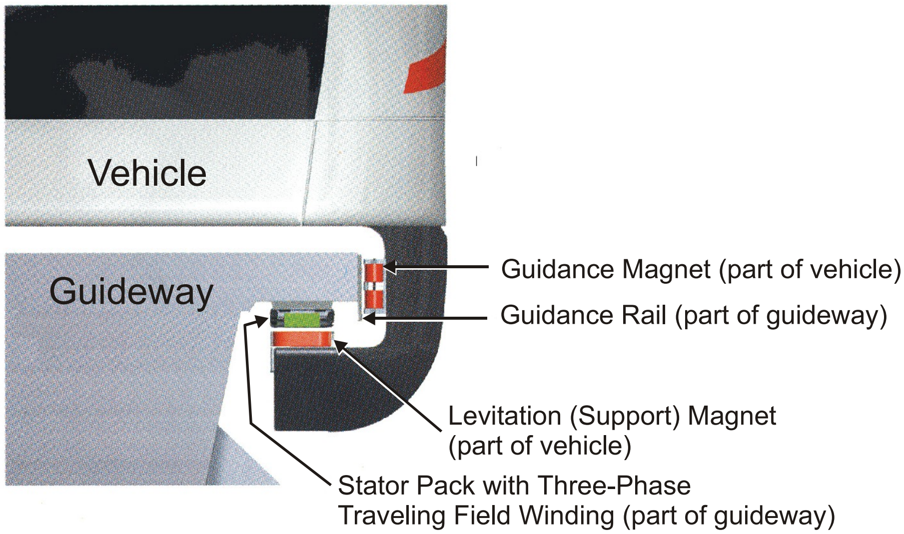
The guideway is the physical structure along which the maglev vehicles are levitated, guided, and propelled. The guideway can be elevated on bridge-style columns, be mounted at grade on a continuous foundation, or can use other configurations (Figure 1-3). The guideway beam structure can be fabricated from steel, concrete, or in a hybrid of steel and concrete; a flexible steel guideway crossover switch section is used for switching.



Source: Transrapid International (TRI)

Figure 1-3. TRI TR08 Guideway (can be either elevated on columns or mounted at grade)

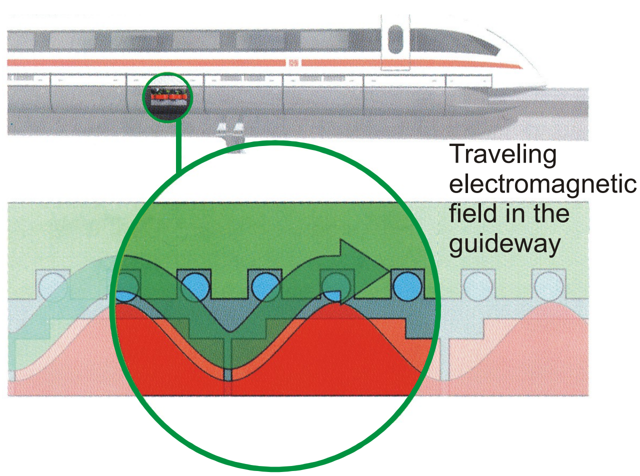
The TRI Maglev vehicle levitation frame wraps around the "T-shaped" guideway to securely hold and guide the vehicle. Attractive forces between the electromagnets located in the vehicle levitation frame that surrounds the guideway, and the stator packs installed on the underside of the guideway allow the vehicle to levitate. The guidance magnets located on the interior sides of the vehicle frame hold the vehicle laterally in place (Figure 1-4). The levitation and guidance magnets are separated from the guideway by a gap of about 1 cm (0.4 in) to allow for levitation and minor vertical and lateral movement.



Source: Adapted from image provided by Transrapid International (TRI)

Figure 1-4. TRI TR08 Support and Guidance Systems

The power to propel maglev vehicles is provided via the powered guideway (Figure 1-5). An electric current through the guideway windings generates a traveling electromagnetic field along the guideway. The interaction between the traveling electromagnetic field in the guideway and electromagnetic fields in the vehicle pulls the vehicle along. Adjusting the frequency (0 Hz to approximately 300 Hz) of the alternating electric current can accelerate or decelerate the vehicle – the higher the frequency of the current, the higher the vehicle's speed.



Source: adapted from image provided by Transrapid International (TRI)

Figure 1-5. TRI TR08 Propulsion

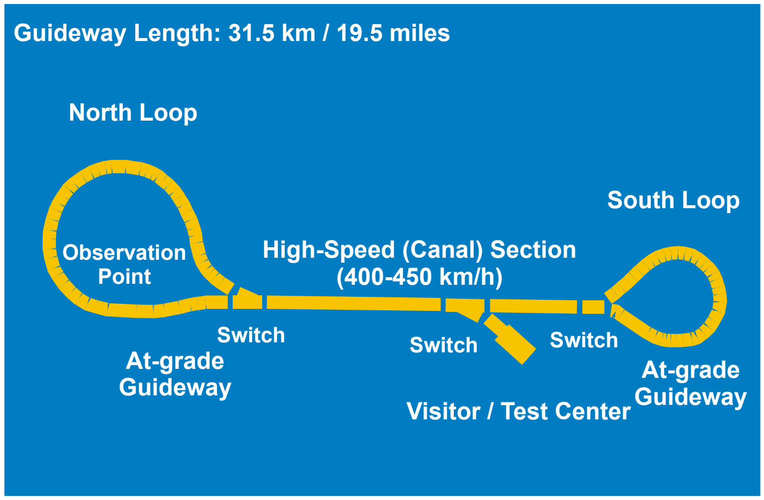
Maglev vehicles are controlled and monitored from a central operations center, and the system runs in automatic mode with pre-programmed speed profiles for revenue operations. Communication between the vehicle and control center is via directional radio data transmission (to date, 38 to 40 gigahertz (GHz) line-of-sight data radio links have been used for the data transmission line).

Power to the maglev system is supplied by electrical power substations that, in turn, supply several individual switching sections. The substations are located at various points along the guideway and are configured to receive their power from the commercial power grid. For reliability, current is fed separately and redundantly into each side of the guideway motor. The long-stator linear synchronous motor installed in the guideway is divided into individual segments (“blocks”); only those segments in which the vehicle is located at that moment are switched on and supplied with current.

1.5 TEST FACILITY

The TVE was completed in 1984 with the purpose of simulating long-term operation of vehicles under conditions similar to actual applications. The Versuchs- und Planungsgesellschaft für Magnetbahnsysteme (MVP), a consortium of German companies, is the owner and operator of the TVE, with management sub-contracted to IABG. Revenue operations began at the TVE in 1995, and more than 70,000 visitors have ridden in the Transrapid maglev vehicles (TRI 2001).

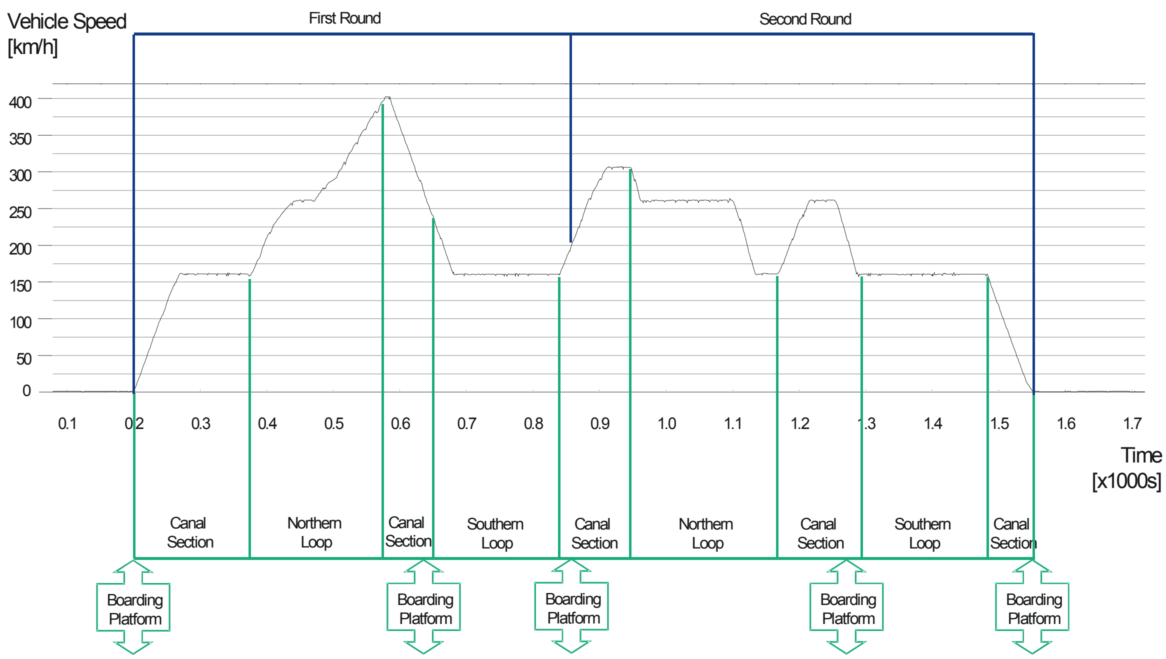
The TVE test facility, located in a generally flat, agricultural, lowland landscape in the Emsland region of Germany, consists of a 31.5 km (19.5 mile) guideway, with two loops (one with constant radius and one without a constant radius) at either end of a straight section (Figure 1-6). Various guideway types (steel, concrete, hybrid) and configurations (at-grade, elevated) exist at the test track. The concrete, steel, and hybrid beam sections are elevated on concrete columns. A flexible steel high-speed switch diverts the northbound maglev vehicle on a turnout to the north loop, then moves back to accommodate the through movement onto the high-speed straight section. The switch consists of a continuous steel beam, anchored at the end adjoining the straight section and moveable at the other end with an electro-mechanical actuated drive system. The at-grade section is an embankment of soil built up to the level of the guideway in the high-speed section of the north loop. Two different at-grade guideway types are placed on the embankment, steel beams and concrete beams. Each type is represented by four 6.2 m (20.3 ft) beams for a total of 25 m (82 ft) of concrete at-grade beams and 25 m of steel at-grade beams.



Source: Adapted from image provided by Transrapid International (TRI)

Figure 1-6. Transrapid Test Facility (TVE)

Vibration measurements were taken for representative guideway types. The test facility typically operates 3-5 days a week and undergoes maintenance at least 1-2 days a week. Normally, the vehicle runs 5-7 times a day depending on weather and guideway conditions. Each trip consists of two complete runs of the entire test track length. The normal operating sequence provides speeds of 150 km/h, 400 km/h, 200 km/h, and 300 km/h on the straight section (Figure1-7).



Source: Transrapid International (TRI)

Figure 1-7. Typical speed profile of TR08 at the Transrapid Test Facility

1.6 VIBRATION MEASUREMENTS

1.6.1 General

During the PEIS analysis, limited technical information was available for the TR08 Maglev System. Thus, TR07 operational parameters were used to derive potential vibration effects for the Transrapid Maglev System. In order to assure that technical concerns are addressed accurately, in 2001 the FRA sponsored a vibration measurement program carried out at the TVE on the TR08 vehicle as part of pre-construction, site-specific environmental impact analysis. Test plans are presented in Appendix A, and briefly summarized here. Conditions and events at the time of actual measurement resulted in some deviations from the original test plan; such deviations were considered minor and did not affect the overall results. Measurement and analytical procedures actually employed are described in detail in Chapter Two.

The moving TR08 vehicle interacts with the stationary guideway structure, creating vibrations. These vibrations propagate out some distance until they dissipate. The extent to which vibration energy propagates depends on the characteristics of 1) the vehicle and guideway, and 2) the ground itself. The vibration tests were performed according to the testing procedure described in FRA's guidance manual, *High Speed Ground Transportation Noise and Vibration Impact Assessment* (FRA 1998). This procedure allows the effect of ground characteristics on vibration propagation to be separated from information about the vehicle as a source of wayside ground-borne vibration. In order to characterize the vibration propagation at a given location, transfer-mobility testing was conducted by impacting the ground with a known force and recording the resulting vibration pulses at various distances from the impact point. The relationship between the input force and the ground surface vibration at a particular distance characterizes a variable called the transfer mobility. Vibrations from the multiple passbys of a TR08 vehicle at varying speeds were measured in the ground near the guideway using high-sensitivity accelerometers. The Test Plan (Appendix A) called for vibration measurements at six different locations along the TVE track (see Figure 2-1).

1.6.2 Applicability of Data

The measurements, data analyses, and conclusions presented in this report are representative of the TR08 Maglev System as constructed in Germany and tested at the TVE in August 2001. Any specific operational applications, such as the construction of a maglev system elsewhere outside of TVE, would probably modify both guideway and vehicle consist specifications (e.g., by modifying the beam design and support structures or by employing different speed profiles) to suit the site-specific operational needs as well as any environmental and/or financial constraints. Such modifications could produce somewhat different vibration levels which would therefore require further analysis during the site-specific EIS process and, possibly, also require characterization during acceptance and safety qualification testing of the TR08 Maglev System. The information in this report will be helpful in any such future endeavor.

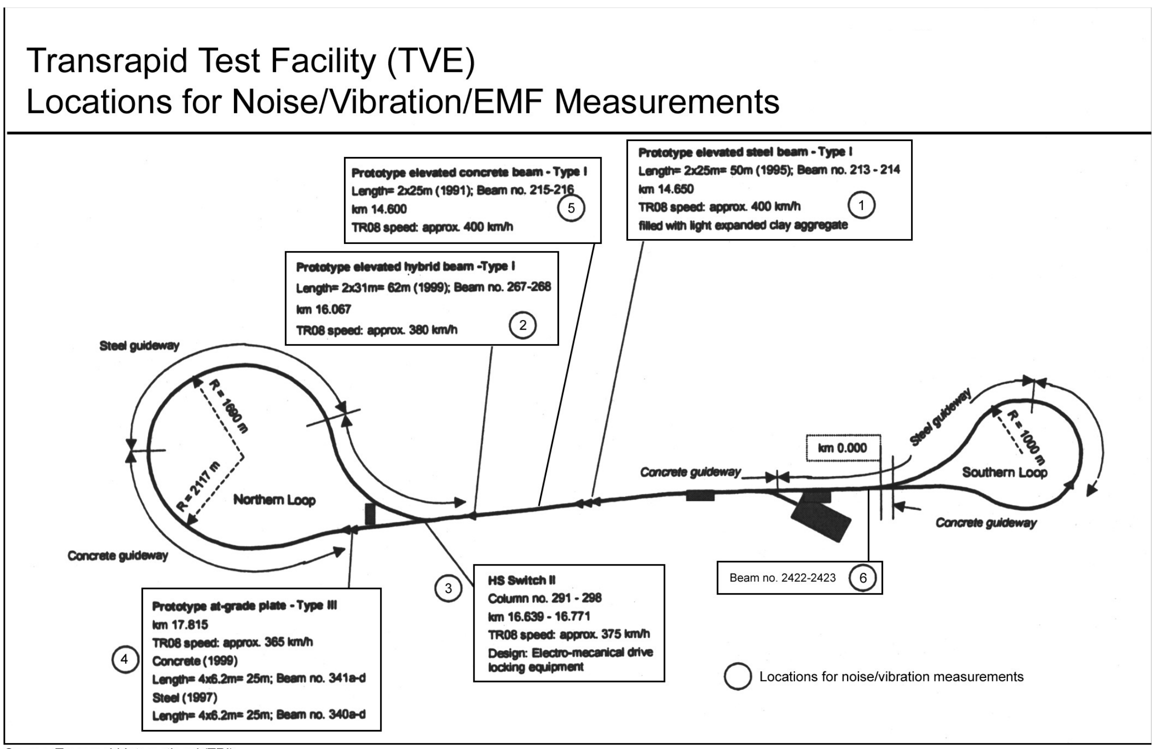
1.7 REPORT ORGANIZATION

This report is organized into an Executive Summary and seven chapters. The Executive Summary presents an overview of the effort to characterize the vibration associated with the TR08, and a summary of the data and major findings. Chapter 1 provides background information on the Maglev Deployment Program, states the objectives and approach of the field measurement effort, describes the TR08 technology, and presents the roles and responsibilities of the various co-authors as well as other people involved in the measurement effort. Chapters 2 and 3 present the vibration measurements, analyses, and results; results are summarized in Chapter 4. Chapter 5 describes the validation and verification process and results. The data are compared with similar data from other high-speed rail systems and set in a regulatory context in Chapter 6. References are listed in Chapter 7.

2.0 VIBRATION MEASUREMENTS

2.1 SITE DESCRIPTION

The vibration measurements were performed at the Transrapid Test Facility (Transrapid Versuchsanlage Emsland (TVE)) in the Emsland region of Germany. The TVE test facility includes 31.5 km (19.6 mi) of guideway as shown in Figure 2-1. The test track is made up of various guideway types and configurations. The general areas where vibration measurements were performed are indicated in Figure 2-1, although the concrete beam site was moved to Beam no. 231 for better terrain (an enlarged version of Figure 2-1 is reproduced in Appendix A, page A-27).



Source: Transrapid International (TRI)

Figure 2-1. General Location of Vibration Measurement Sites

The test track is located in a generally flat agricultural area with rich, tillable soil. On the west side of the test track is a large tree-lined canal, and on the east side is farmland. The ground conditions in the vicinity of each measured guideway segment can generally be characterized by the following observations:

The *concrete, steel, and hybrid beam sections* are elevated on concrete columns. An asphalt- paved access road runs along the east side of the guideway, separated from the farm fields by a drainage ditch. The soil appears to be rich, dark, and tillable, with no evidence of rocks or ledge. The field adjacent to the concrete and steel beams was a recently harvested potato field, newly planted with a cover crop. The field adjacent to the hybrid beam appeared to have been a recently harvested grain field. Figure 2-2 shows the general field conditions where the vibration transducers were mounted for these beams.

The *high-speed switch* is a flexible steel switch that diverts the northbound maglev vehicle on a turnout to the north loop, then moves back to accommodate the through movement onto the high-speed straight section. The switch consists of a continuous steel beam, anchored at the end adjoining the straight section and moveable at the other end with an electro-mechanical actuated drive system. Adjacent to the switch is the paved access road. Between the road and the farm field is a water-filled drainage ditch. The crop in the field was potato plants about waist-high and ready for harvest. Again the soil appeared to be rich, dark, and well-tilled, with no evidence of surface rock or ledge. The site of the high-speed switch is shown in Figure 2-3.

Figure 2-2. Beam 231 (Concrete) Site

Figure 2-3. High-speed Switch Site

The *at-grade section* is actually an embankment of soil built up to the level of the guideway in the high-speed section of the north loop. Two guideway types are placed on the embankment, a steel beam and a concrete beam, each 25 meters (82.0 feet) long. Measurements of ground-borne vibrations near the two at-grade beams were limited by the size of the embankment leading from ground level to the base of the beam supports (see Figure 2-4). The area around these two beams was fenced, making access difficult. The soil on the embankment appears to be a sandy clay, not the same as the ground in the nearby farm fields. Adjacent to the embankment is the paved access road. Beyond the road is a drainage ditch separating the road from the fields.

Figure 2-4. “At-grade” Guideway Site

2.2 LOCATIONS AND TESTS

Vibration measurements during passbys of the TR08 were carried out in open areas adjacent to the following TVE track locations: Beam 231 (Concrete), Beam 213 (Steel), Beam 267 (Hybrid), Column 291-298 (North Switch), Beam 340/341 (At Grade), Beam 2422/2423 (Station). These locations are shown in Figure 2-1. During the testing period, the vehicle carried passengers besides the on-board test personnel. The actual loading for each run is unknown, but the typical passenger load was 130 people. Vibration propagation measurements were also performed at these sites in order to characterize the transfer mobility of the ground. The measurements that were performed at each site are documented in this section.

Beam 231 (Concrete Reference Beam): Measurements of TR08 vibration and vibration propagation were performed at Beam 231 on August 16, 2001. The vehicle speed varied from 148 to 400 km/h (93 to 250 mph) at this site. Accelerometers were placed in a line perpendicular to the guideway at distances of 3.0, 7.6, 15.2, 22.9, 30.5, and 38.1 meters (10, 25, 50, 75, 100, and 125 feet) from the centerline of the guideway. For the vibration propagation measurement described in Section 2.3, impact locations were located at Beams 230, 231, and 232.

Beam 213 (Steel): Measurements of vehicle vibration and vibration propagation were performed at Beam 213 on August 14, 2001. The vehicle speed varied from 145 to 400 km/h (90 to 250 mph) at this site. Accelerometers were placed in a line perpendicular to the guideway at distances of 3.0, 7.6, 15.2, 22.9, 30.5, and 38.1 meters (10, 25, 50, 75, 100, and 125 feet) from the centerline of the guideway. For the vibration propagation measurement, the impacts were located at Beams 212, 213, and 214.

Beam 267 (Hybrid): Measurements of vehicle vibration and vibration propagation were performed at Beam 267 on August 15, 2001. The vehicle speed varied from 145 to 350 km/h (90 to 220 mph) at this site. Accelerometers were placed in a line perpendicular to the guideway at distances of 3.0, 7.6, 15.2, 22.9, 30.5, and 38.1 meters (10, 25, 53, 75, 100, and 125 feet) from the guideway. For the vibration propagation measurement, the impacts were located close to Beams 266, 267, and 268, although a fenced section prevented access to the supports.

Column 291-298 (North Switch): Measurements of vehicle vibration and vibration propagation were performed at Column 291-298 on August 15, 2001. Supplemental vehicle vibration measurements were performed on August 17, 2001. The vehicle speed varied from 147 to 400 km/h (92 to 250 mph) at this site. Accelerometers were placed in a line perpendicular to the guideway at distances of 7.0, 15.2, 22.9, 30.5, and 38.1 meters (23, 50, 75, 100, and 125 feet) from the guideway. Vibration propagation measurements were conducted outside the fence in the vicinity of Beams 297, 298, 299. Vibration propagation measurements were conducted in the vicinity of the switch, but not directly adjacent to the guideway beams due to the large fenced off security area.

Beam 340/341 (At Grade): Measurements of vehicle vibration and vibration propagation were performed at Beam 340 (Steel) and Beam 341 (Concrete) on August 16, 2001. The term "at-grade" is used loosely with respect to the guideway at beams 340 and 341. As can be seen in Figure 2-4 (Section 2.1), rather than truly being "at-grade" in the traditional sense of the term, the guideway is rather the typical (elevated) construction with land back-filled in around it to create an "at-grade" section of the guideway. As such, vibration characteristics of a true at-grade guideway may vary from those measured at beams 340 and 341. This portion of the guideway, however, is the only area considered somewhat representative of at-grade conditions, as they may be built in the U.S. The vehicle speed varied from 150 to 400 km/h (93 to 250 mph) at this site. Three accelerometers were placed in a line perpendicular to the guideway at distances of 7.6, 15.2 and 22.9 meters (25, 50, and 72 feet) from the guideway in the area supported by steel beams (Beam 240). North of those accelerometers, three more accelerometers were placed in a line perpendicular to the guideway at distances of 7.6, 15.2, and 22.9 meters (25, 50, and 72 feet) from the guideway in the area supported by concrete beams (Beam 341). Measurements of vehicle vibration were performed simultaneously with all six accelerometers at this site.

Beam 2422/2423 (Station): Measurements of vehicle vibration and vibration propagation were performed at Beams 2422/2423 (Steel) on August 17, 2001. The beams are not installed in a specially-designed station; they are similar to other steel beams in this section of the guideway. However, the vehicle regularly stops and starts on these beams, thereby adding a different kind of loading from that experienced on other sections of the guideway. The vehicle speed varied from 8 to 277 km/h (5 to 173 mph) at this site. Accelerometers were placed at distances of 3.0, 7.6, and 15.2 meters (10, 25, and 50 feet) from the guideway at Beam 2422 and at distances of 3.0, 7.6, and 15.2 meters (10, 25, and 50 feet) from the guideway at Beam 2423.

2.3 INSTRUMENTATION AND PROCEDURES

Vibration energy in the guideway structure from the moving TR08 vehicle is transmitted through the supporting columns into the ground where it propagates out to some distance and becomes dissipated. The extent to which vibrations propagate depends on the characteristics of both the vehicle on the guideway and the ground. The FRA guidance manual describes a method to separate the ground effect from the vehicle source information (FRA 1998). Using this method allows the information about the vehicle to be used in other locations where the ground may be different from that at the test track in Germany, but other factors are similar (e.g. guideway design, guideway anchoring, etc.). There are two parts to the method: measurements of vibrations during vehicle passbys on various guideway configurations, and measurements of the propagation characteristics in the ground at the same locations.

2.3.1 Ground-borne Vibration Measurements

To determine the characteristics, as well as the extent, of ground-borne vibrations from the passby of a TR08 vehicle, measurements were conducted in the ground near the guideway. The vibration measurements were made with high-sensitivity accelerometers (PCB 393C) attached to the paved surface of the adjacent roadway or on top of steel stakes driven into soil as shown in Figure 2-2. Locations of accelerometers with respect to the guideway are described in Section 2.2. The acceleration signals were amplified and recorded on a TEAC Model RD-135T 8-channel digital audio tape (DAT) recorder and subsequently analyzed in the HMMH laboratory.

System calibration was performed before and after each set of runs at a site. Calibration of both field and laboratory instrumentation is based on the internal calibration signal of the DAT recorder, which records a known signal on the tape. The internal calibration of the recorder is set by the factory and is periodically confirmed in the laboratory. Calibration of the field equipment is supplemented by a PCB Model 492B Transducer Simulator connected in turn to each transducer string. The simulator substitutes for the accelerometer and generates a known signal recorded on tape. The PCB accelerometers are extremely stable devices and hold their calibrations for long periods. All PCB equipment used in the test was returned to the factory for calibration within one year of the test program and found to be in compliance with specifications.

Vehicle speeds up to 320 km/h (200 mph) were measured using a Custom Signals "Falcon" Radar Speed Detector. Speeds over 320 km/h (200 mph), the upper limit of the instrument's capability, were obtained from the test track control room after each day's runs. Radar speeds were confirmed with the test track run documentation and found to be in agreement.

A summary of the measurements is shown in Table 2-1 below.

Table 2-1. Summary of Measurements

SITE	DATE	SPEED Km/h (mph)	NUMBER OF RUNS	TRANSDUCER LOCATIONS, DISTANCE FROM CENTERLINE
Steel Beam #213	2001-8-14	150 (94)	8	3, 7.6, 15.2, 22.9, 30.5, 38.1 meters (10, 25, 50, 75, 100, 125 feet)
		200(125)	8	
		250 (155)	2	
		300 (188)	4	
		400 (250)	7	
Hybrid Beam #267	2001-8-15	150 (94)	4	3, 7.6, 16.2, 22.9, 30.5, 38.1 meters (10, 25, 53, 75, 100, 125 feet)
		175 (110)	3	
		200 (3)	3	
		300 (188)	3	
		400 (250)	1	
North Switch #291-298	2001-8-15	150 (94)	3	7, 15.2, 22.9, 30.5, 38.1 meters (23, 50, 75, 100, 125 feet)
		230 (143)	1	
		400 (250)	1	
At-Grade #340 (Steel)	2001-08-16	166 (104)	1	7.6, 15.2, 22.9 meters (25, 50, 72 feet)
		265 (165)	1	
		280 (175)	1	
		300 (188)	2	
		366 (230)	4	
At-Grade #341 (Concrete)	2001-08-16	166 (104)	1	7.6, 15.2, 22.9 meters (25, 50, 72 feet)
		265 (165)	1	
		280 (175)	1	

SITE	DATE	SPEED Km/h (mph)	NUMBER OF RUNS	TRANSDUCER LOCATIONS, DISTANCE FROM CENTERLINE
		300 (188)	2	
		376 (235)	4	
Concrete #231	2001-08-16	150 (94)	2	3, 7.6, 15.2, 22.9, 30.5, 38.1 meters (10, 25, 50, 75, 100, 125 feet)
		200 (125)	2	
		300 (188)	2	
		400 (250)	2	
North Switch #291-298	2001-08-17	160 (100)	4	7, 15.2, 22.9, 30.5, 38.1 meters (23, 50, 75, 100, 125 feet)
		260 (162)	1	
		383 (240)	3	
Station #2422 - 2423	2001-08-17	Departing	3	3, 7.6, 15.2 meters (10, 25, 50 feet) from each column in line with guideway
		Arriving	4	
		160 (100)	4	
		280 (175)	3	

Figure 2-5. Ground-mounted Accelerometer

Figure 2-6. Vibration Propagation Impact Device

2.3.2 Vibration Propagation Measurements

The vibration propagation test procedure involves impacting the ground with a dropped weight and measuring the response of the nearby ground. The impact device is shown in Figure 2-6. A 27.2 kg (60 lb) weight falls along a track from a height of 1 m (3 ft) onto a load cell on the ground. The load cell measures the force of the impact. Accelerometers mounted to steel stakes driven into the ground measure the resulting vibration pulses at various distances on the ground as shown schematically in Figure 2-7 in the cross section view at the top. The relationship between the input force and the ground surface vibration, called the *transfer mobility*, characterizes vibration propagation at a given location.

The bottom sketch in Figure 2-7 shows how the dropped weight point source is used to simulate a vibration source such as the TR08 on an elevated structure supported by columns. Impact tests are usually made at regular intervals in a line along a rail alignment at-grade. However, an elevated structure is supported at discrete points on the ground. Consequently, the source of ground-borne vibrations from these structures acts like a series of point sources. For these tests, impacts were done at three points, spaced adjacently to three beams in a line perpendicular to the line of accelerometers. Impact testing was performed at each location described in Section 2.2 in conjunction with the passby tests.

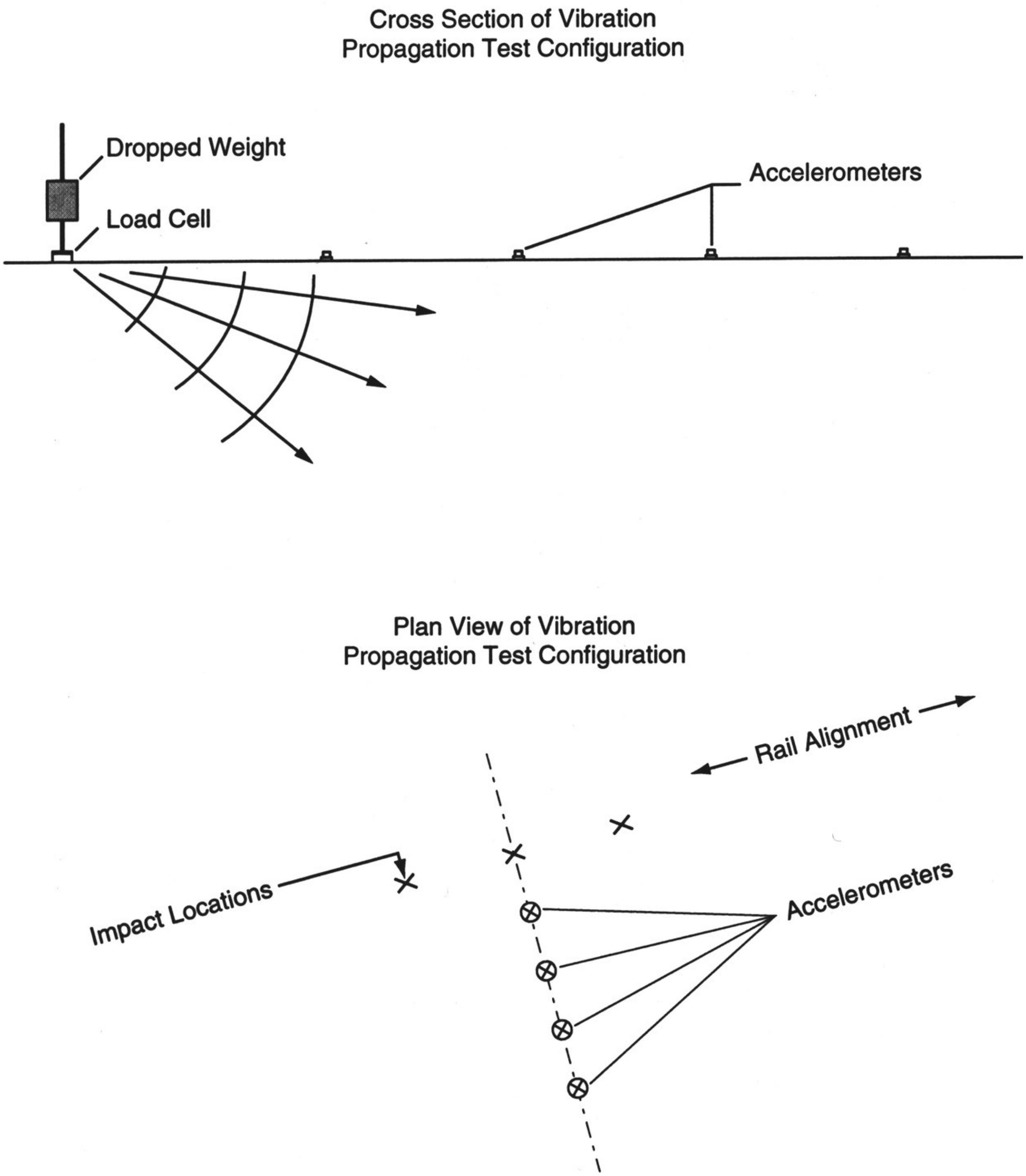


Figure 2-7. Vibration Propagation Test Procedure

3.0 ANALYSIS AND RESULTS

Vibrations from the Transrapid TR08 Maglev System propagate away from the guideways in a manner that depends on specific characteristics of the source and the path. The characteristics of each can be determined through a measurement method described in Chapter 9 of the FRA guidance manual (FRA 1998). Although the FRA method was originally developed for trains on conventional tracks, the same approach can be used for a vehicle on an elevated guideway on columns. The source includes the TR08 and guideway system, all characterized by the force (L_F) transmitted to the ground by the nearest columns. The path includes a special measured property of the ground, called Transfer Mobility (TM). These components are related by an equation as follows:

$$L_V = L_F + TM$$

where, assuming all quantities are in decibels with consistent reference quantities:

L_V = Root Mean Square (RMS) vibration velocity level in 1/3 octave bands

L_F = force of the TR08 transmitted through the guideway support column

TM = point source transfer mobility from the guideway to the measurement site

The force of the TR08 under three guideway configurations, concrete, steel and hybrid beams, was determined using the equation discussed above. The TM and overall TR08 vibration (L_V) were measured at each site. Subtraction of the transfer mobility from the vibration level resulted in the force.

3.1 OVERALL TR08 VIBRATION FROM ELEVATED BEAM SITES

Vibration levels at each beam site were analyzed in terms of overall vibration levels as a function of speed and as a function of distance from the guideway.

3.1.1 Level vs. Speed.

The results of plotting overall vibration level vs. speed are shown in Figures 3-1 through 3-3. The apparent anomalies in the speed relationships are a direct result of resonant behavior during vehicle interaction with the structure. When the TR08 passes the stator magnets, it applies a force to the structure at the pole passing frequency. The plates and girders to which the stators are attached respond to the force input. If a system resonance is near the driving frequency, the response of the structure is great and the transmission of vibration will be enhanced. This phenomenon is illustrated by the spectral plots in Appendix E, where both fixed and speed-dependent peaks are evident. Unfortunately, the vibration spectra measured at a given distance do not reveal the cause of the peaks in the spectra. Although a full diagnosis of the structural response of the TVE guideways is well beyond the scope of this study, more information can be gleaned from the transfer mobility and force spectra discussed later in this section.

By considering only the increase in vibration levels from lowest speed to highest speed, the general trend is that vibration levels tend to increase at a rate between 20 to 40 times the logarithm of speed. At high speeds, the vibration levels from the steel beam guideway are higher than those from the concrete and hybrid beams.

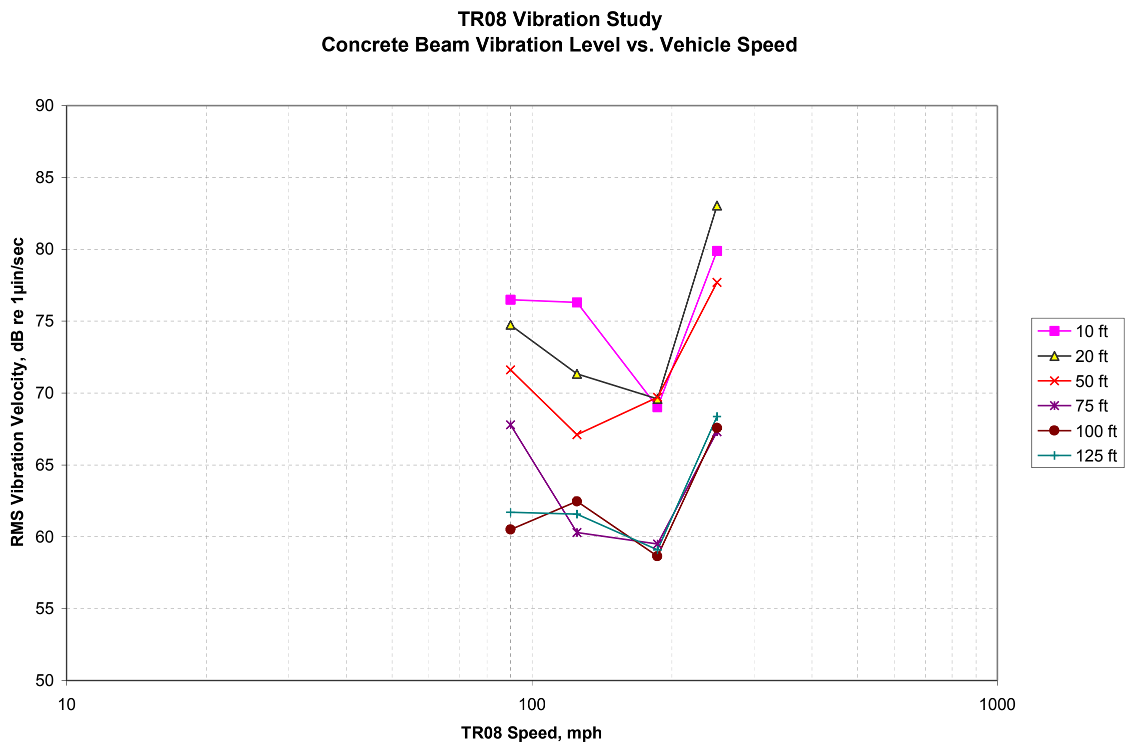


Figure 3-8. Level vs. Speed from Concrete Beam

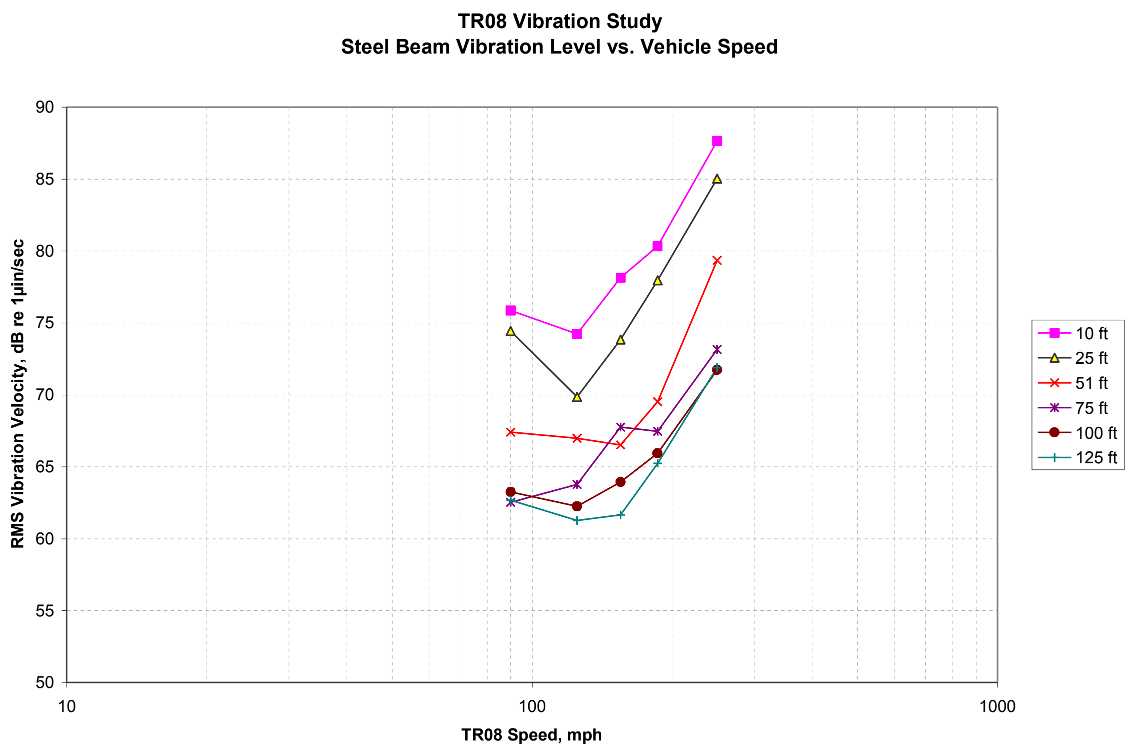


Figure 3-9. Level vs. Speed from Steel Beam

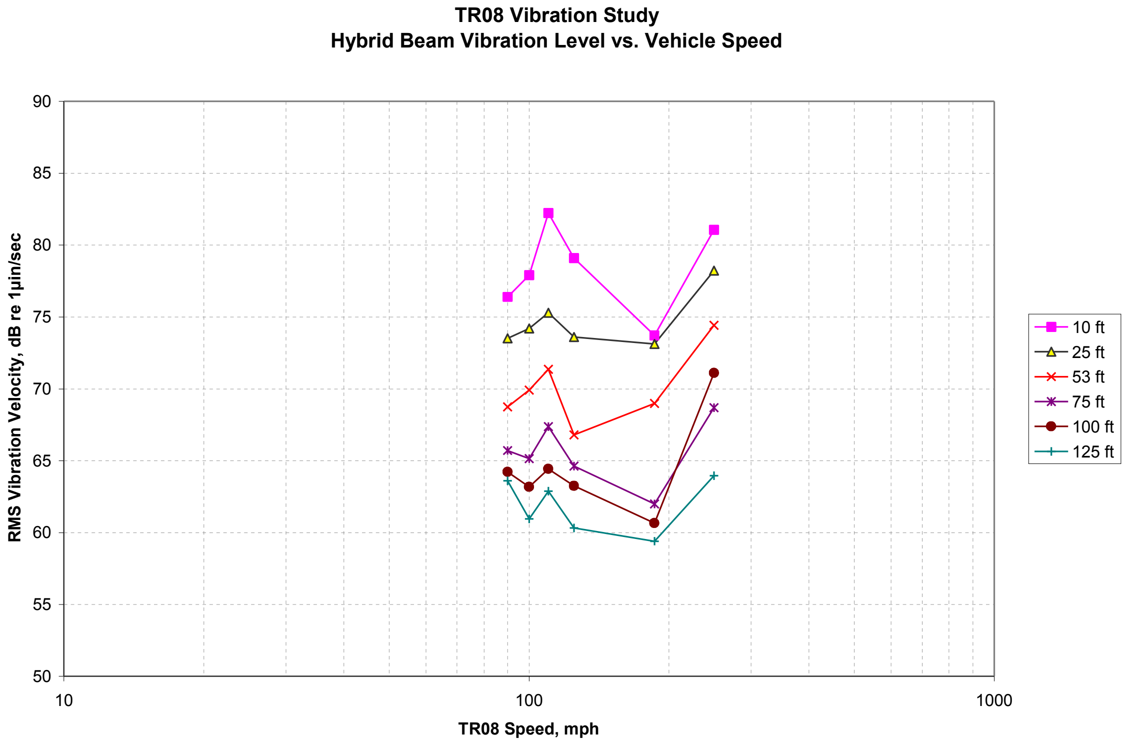


Figure 3-10. Level vs. Speed from Hybrid Beam

3.1.2 Level vs. Distance

Vibration levels are attenuated in the ground as shown at a representative speed of 200 km/h (125 mph) in Figure 3-4. The attenuation rate is approximately 4 to 5 velocity decibels (VdB) per distance doubling for the soil conditions found at the test track in Germany. This attenuation rate is highly dependent on local conditions and may vary considerably from location to location.

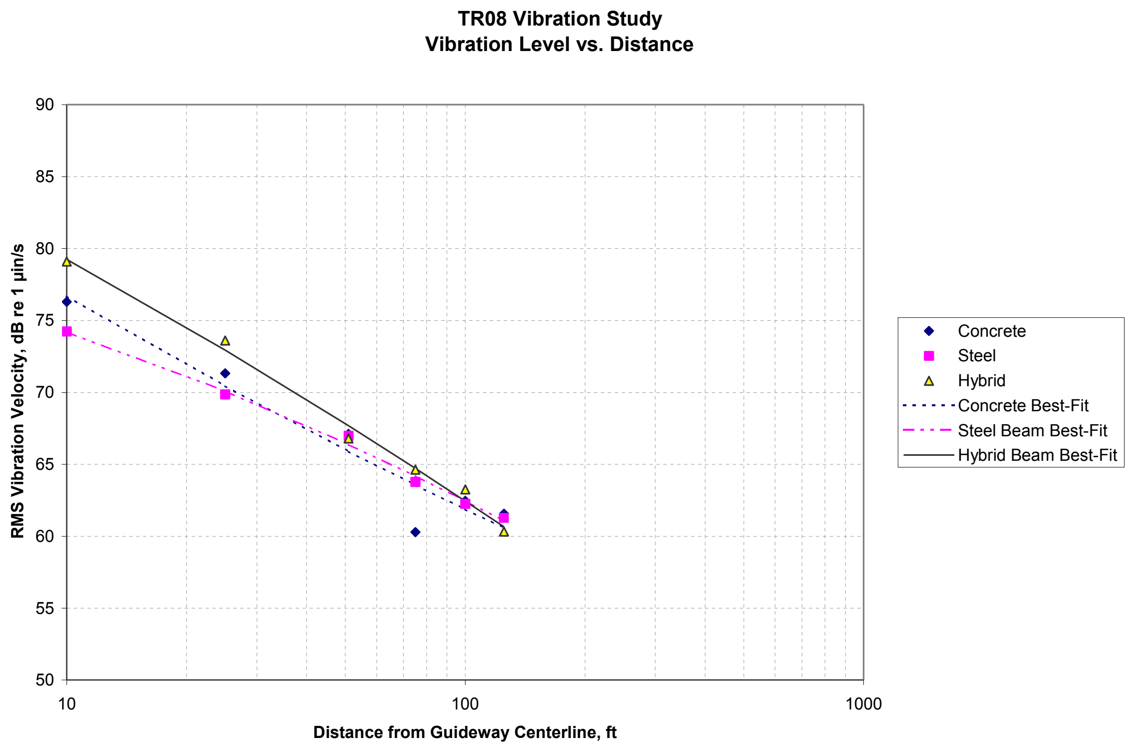


Figure 3-11. Ground-borne Vibration near Elevated Beams at 200 km/h (125 mph)

3.2 TRANSFER MOBILITY

The transfer mobilities measured in the ground near the three beam types show similar behavior with respect to frequency. This result is not surprising considering the proximity of the sites to each other. All show increased mobility over a broad range of frequencies from 25 Hz to 200 Hz, with a maximum at 63 Hz. Thus any vibrations from a source with significant energy around 63 Hz will propagate readily in the ground at the test track. The vibration velocity spectra in Appendix E show enhanced vibration in the ground in that frequency band.

- Transfer mobility of the ground near the *reference concrete beam* is shown in Figure 3-5. The spectra are characterized by a broad peak from

40 to 200 Hz, with a peak at 63 Hz. The transfer mobility drops off rapidly at the higher frequencies.

- The transfer mobility near the *steel beam* is shown in Figure 3-6. The spectra are characterized by a narrower peak from 63 to 80 Hz and have slightly less drop off at the higher frequencies than that of the ground near the concrete beam.
- The transfer mobility near the *hybrid beam* is shown in Figure 3-7. Again, the same frequency range has enhanced mobility, with a maximum at 63 Hz, but the maximum is lower than at the other areas.

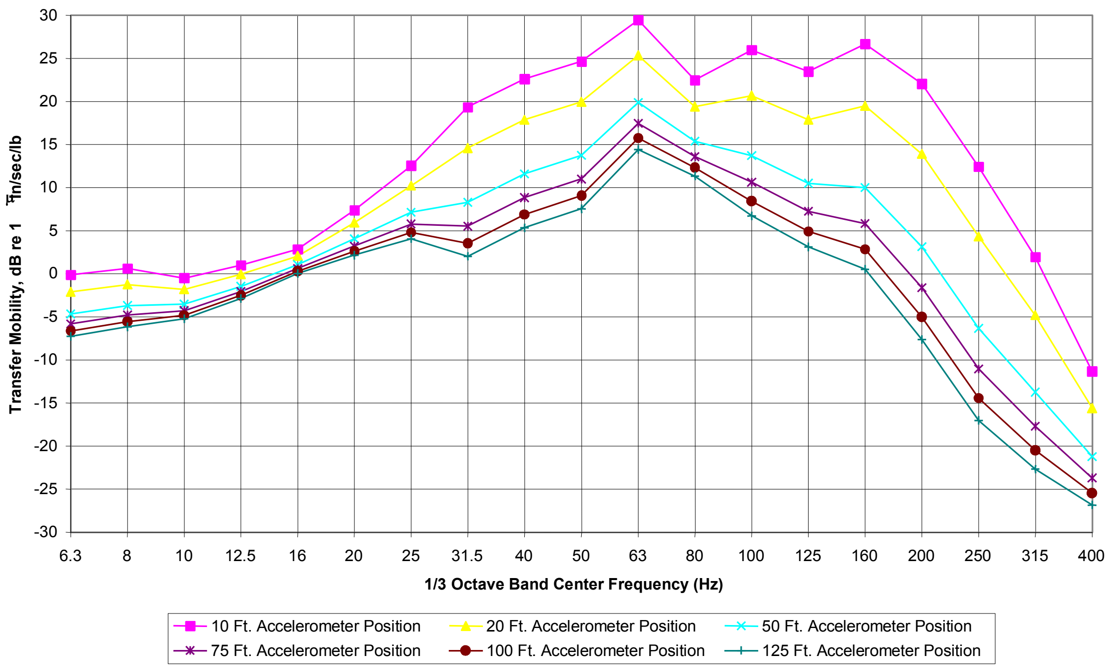


Figure 3-12. Transfer Mobility at Concrete Beam

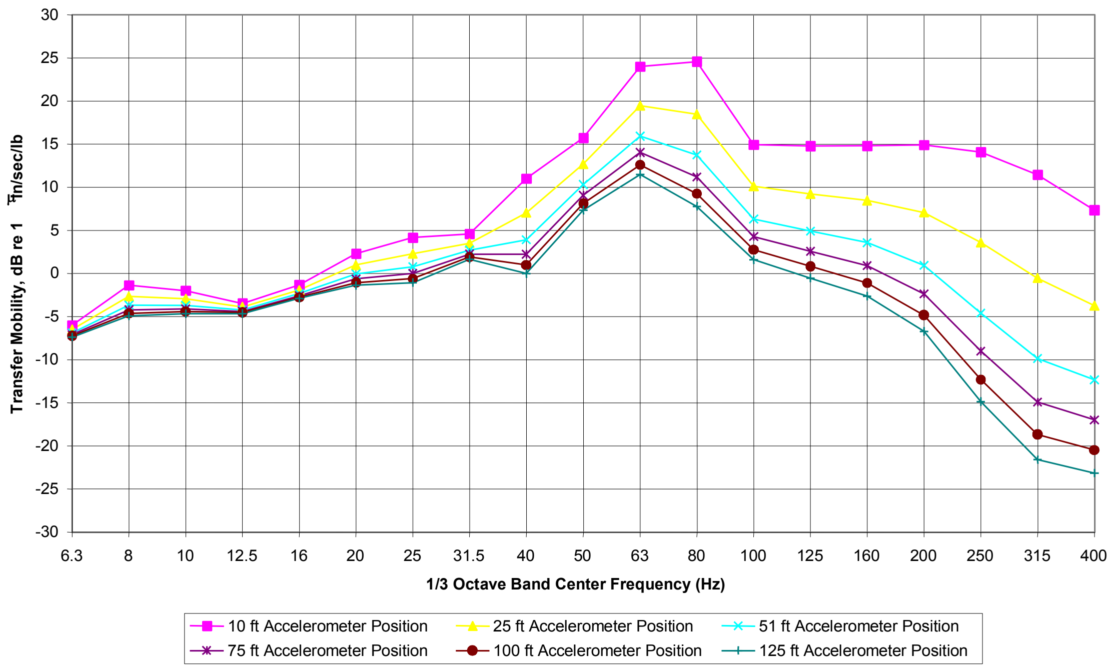


Figure 3-13. Transfer Mobility at Steel Beam

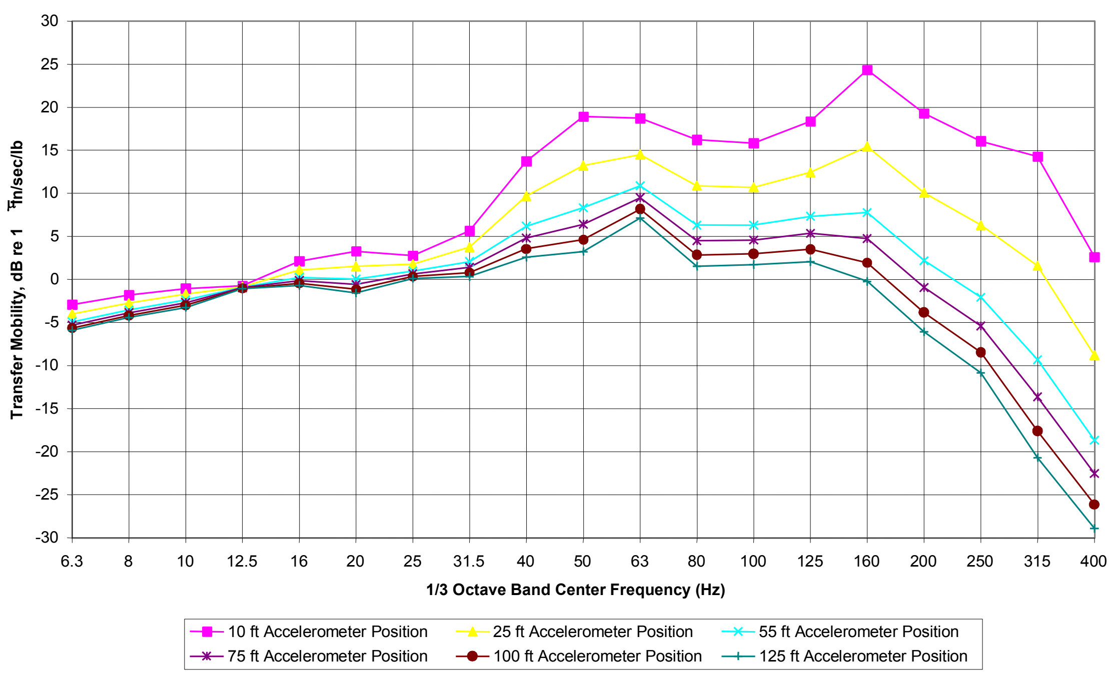


Figure 3-14. Transfer Mobility at Hybrid Beam

3.3 CHARACTERISTIC FORCE OF TR08 ON AERIAL GUIDEWAY

The force transmitted to the ground by the TR08 on various guideways is determined by applying the equations associated with the FRA method described at the beginning of this chapter. Vibration velocity spectra were obtained for each passby. As discussed above, these spectra were the result of both the source characteristics and the ground propagation effects. The ground propagation information in terms of transfer mobility is subtracted from the measured vibration spectra at each accelerometer position to determine the force characteristics of the TR08 vehicle on each beam type. The resulting spectra were averaged arithmetically to derive a representative force spectrum for each measurement position and vehicle speed. The force characteristics are expected to show a dependence on guideway type and on speed, but not on measurement position. Consequently, the spectra at each measurement position were compared. Those sufficiently similar were averaged together to derive a representative force spectrum as a function of vehicle speed. The results are shown in Figures 3-8, 3-9 and 3-10.

Specific characteristics of each guideway structure became evident during the analysis of the measurements: frequency peaks tended to dominate the ground-borne vibration spectra. In some cases these frequency peaks were clearly related to characteristic lengths of elements on the guideway structure. For example, the concrete beam showed one-third octave-band peak frequencies that varied as a function of speed: at 145 km/h (90 mph), the peak is at 40 Hz; at 200 km/h (125 mph), the peak is at 50 Hz; and at 300 km/h (186 mph), the peak is at 80 Hz. Speed-dependent peaks in frequency spectra can be used as clues to estimate the characteristic length of a guideway or vehicle component causing the vibration. Dividing the speed by frequency suggests that these vibrations are generated by the TR08 interacting with a guideway element of about 1 m (3 ft) in length. Consequently, it is possible that these peaks may be vibrations induced in the structure by the vehicle encountering each stator pack (length of 1 m). These peaks are shown in Figure 3-8.

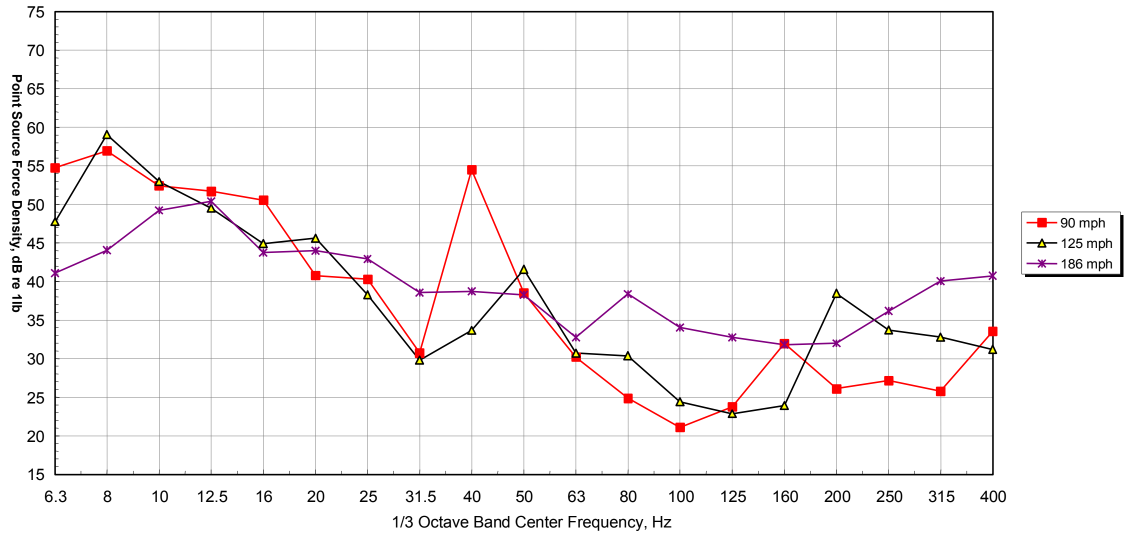


Figure 3-15. Concrete Beam Measured Force Spectrum from TR08

Another example of a speed variable peak is shown in the force spectrum of the hybrid beam in Figure 3-9. Peaks at the one-third octave-bands of 16 Hz, 20 Hz and 31.5 Hz are associated with speeds of 145 km/h (90 mph), 200 km/h (125 mph) and 400 km/h (250 mph), respectively. The characteristic length here turns out to be about 3 m (10 ft), which happens to be the length of the separated deck sections.

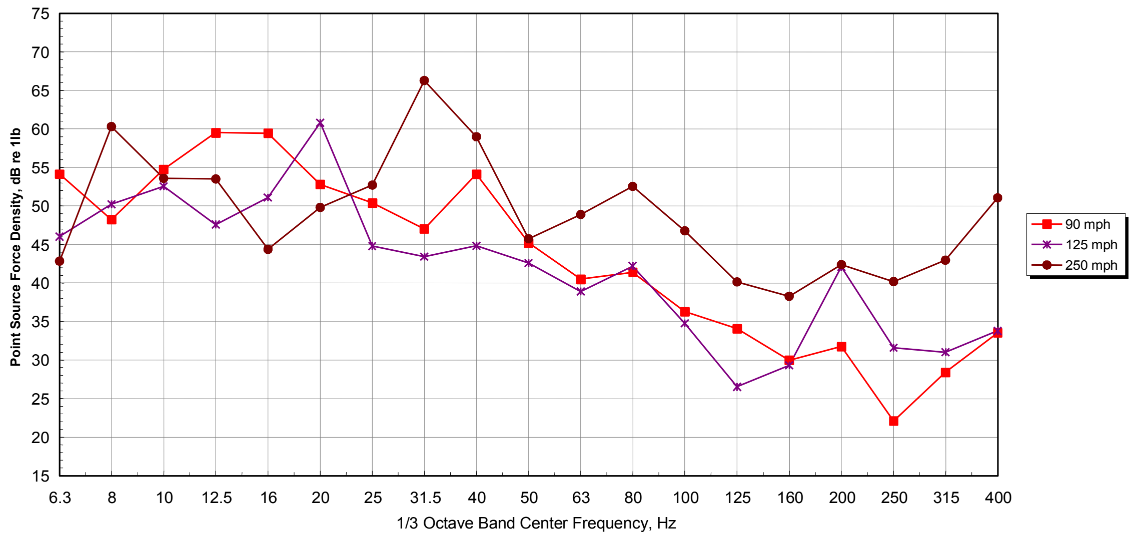


Figure 3-16. Hybrid Beam Measured Force Spectrum from TR08

The force spectra of the steel beam features one-third octave-band peaks at 12.5 Hz, 20 Hz, 25 Hz, and 31.5 Hz associated with speeds of 145 km/h (90 mph), 200 km/h (125 mph), 300 km/h (186 mph), and 400 km/h (250 mph), respectively. Here, again, the characteristic length of a guideway element that would generate those peak frequencies is about 3 m (10 ft). The spectra are shown in Figure 3-10.

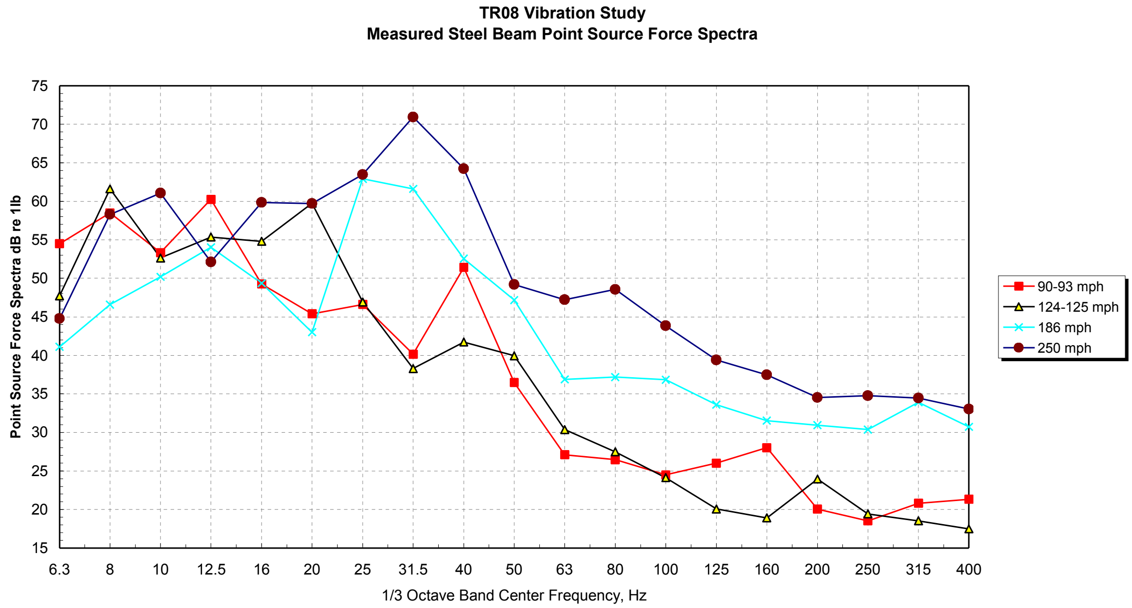


Figure 3-17. Steel Beam Measured Force Spectrum from TR08

As shown in the foregoing figures, the force spectrum associated with each guideway type has somewhat different characteristics. This result is not surprising because each guideway type is of a different design. It is unlikely that future maglev systems will have guideways exactly like those at TVE. Consequently it would be useful to develop a generic force spectrum devoid of the design-specific resonances associated with the TVE guideways. An approximation to the ideal generic force spectrum can be developed by smoothing and normalizing the individual force spectra to reduce the structure- and speed-dependent effects.

Following is the procedure used to develop the “Characteristic Force Spectrum” shown in Figure 3-11:

- Force spectra for each type of beam, Fig. 3-8, 3-9, 3-10, were normalized (adjusted up or down) for speed by subtracting [*K x log (speed/125)*] from each one-third octave-band center frequency level and arithmetically averaging the spectra in each band. The speed relationships from Figures 3-1 through 3-3 have been used to determine K.
- Speed-dependent peaks were reduced in prominence by averaging (arithmetically) the levels of the adjacent frequency bands.

These adjustments result in a collapse of the spectra into basic curves called *characteristic force spectra* for each type of guideway. These curves are the fundamental result of the TR08 vibration measurement program. They can be used at any site to estimate vibrations from the TR08 on generic guideways as long as the transfer mobility spectra obtained using the FRA method are available at that site. A cautionary note: specific resonant peaks cannot be estimated from these curves. The characteristic force spectra are shown in Figure 3-11.

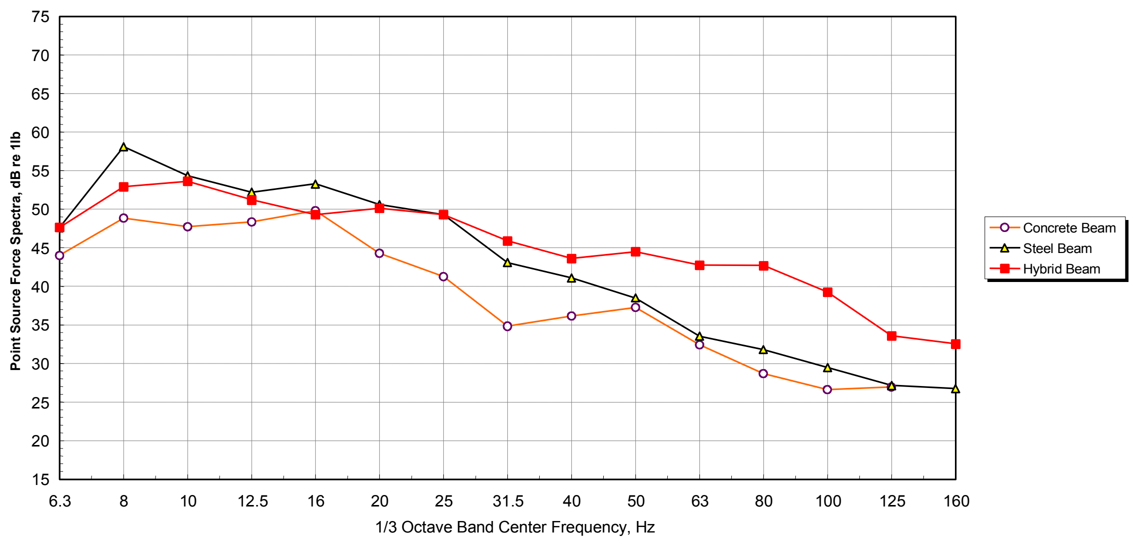


Figure 3-18. Characteristic Force Spectra for the TR08 on Each Type of Guideway

3.4 VIBRATIONS NEAR HIGH SPEED SWITCH

Measurements of vibrations in the ground near the point of switch showed a remarkable speed-dependent peak in the frequency spectrum, shown in Figure 3-12. Peaks in the one-third octave-band frequencies of 12.5 Hz, 16 Hz, 20 Hz, and 31.5 Hz are associated with speeds of 145 km/h (90 mph), 160 km/h (100 mph), 230 km/h (144 mph), and 400 km/h (250 mph), respectively. Again, the characteristic length turns out to be about 3 m (10 ft). The vibration energy at the peak frequency dominates the overall vibration velocity level of 78 VdB at 15.2 m (50 ft) at 400 km/h (250 mph).

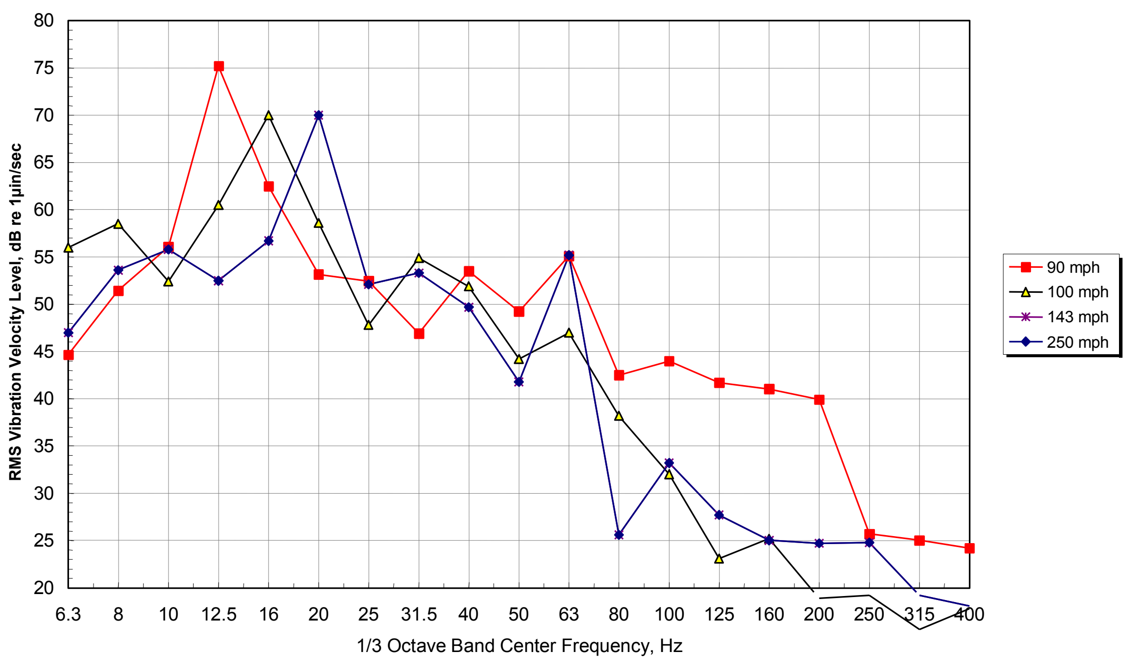


Figure 3-19. Ground-borne Vibration Spectra at High-Speed Switch

3.5 VIBRATIONS NEAR AT-GRADE BEAMS

Measurements at this site were limited to the embankment area, not entirely typical of the ground surrounding the site. However, the results showed attenuation with distance corresponding to that near the elevated beams, about 5 VdB per distance doubling, as shown in Figure 3-13. The concrete beam showed a slightly lower vibration level compared to the steel beam: for example, at a speed of 375 km/h (235 mph), the vibration level at 15 m (50 ft) was 80.5 VdB for concrete and 81.5 VdB for steel. Both at-grade beams gave higher vibration levels than the elevated beams. Transfer mobility measurements of the soil on the embankment were not conducted because of the limited access. Consequently, force density spectra cannot be determined for the at-grade beams.

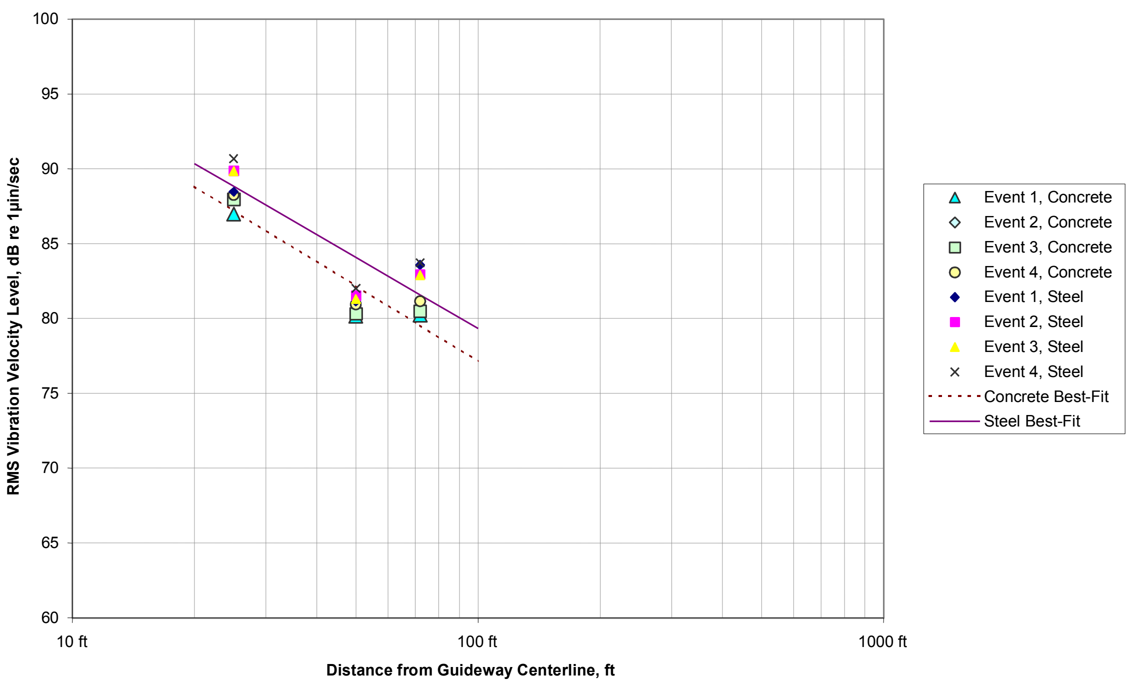


Figure 3-20. Ground-borne Vibration near At-Grade Beams at 375 km/h (235 mph)

3.6 VIBRATIONS NEAR STATION (BEAM 2422.2424)

Vibration measurements in the ground near beams 2422 and 2424 just north of the station were performed for a few vehicle operations to quantify ground vibrations from representative events. The station is an elevated platform adjacent to a section of the guideway configured with steel beams on vertical columns. Vibration levels from three events were recorded and analyzed. These events were a northbound vehicle parking at the station traveling from 16 km/h (10 mph) to a stop, a northbound vehicle departing from the station at 19 to 39 km/h (12 to 24 mph) and a northbound vehicle overshooting the station at 48 km/h (30 mph). The vibration transducers were placed directly beneath the guideway in a line, with the idea of recording vibration levels with changing speed. Unfortunately, due to the limited data collected on site, the results were difficult to interpret in a manner consistent with the previous analyses. Time histories of representative events measured near two different columns are included in Appendix F. The maximum vibration levels during an event are used to characterize worst-case station vibrations. Tables 3-1 through 3-3 provide the maximum vibration levels generated by the vehicle operations at the station. These levels were high enough to be perceptible to observers on site.

Vibration spectra for representative events are included in Appendix E. It is clear from the spectra that the maximum levels are dominated by a few key frequencies, possibly the vehicle passing over individual stator packs or resonances in the guideway structure. It is not clear how well the energy at these frequencies would propagate to the wayside.

Table 3-1. Northbound Vehicle Parking at Station, 16 km/h (10 mph) to stop

Beam	Distance	Vibration Level (VdB)
2422	3.0 m (10 ft)	90
2422	7.6 m (25 ft)	90
2422	15.2 m (50 ft)	88
2423	3.0 m (10 ft)	88
2423	7.6 m (25 ft)	88
2423	15.2 m (50 ft)	84

Table 3-2. Northbound Vehicle Departing from Station, 19-39 km/h (12-24 mph)

Beam	Distance	Vibration Level (VdB)
2422	3.0 m (10 ft)	88
2422	7.6 m (25 ft)	85
2422	15.2 m (50 ft)	84
2423	3.0 m (10 ft)	86
2423	7.6 m (25 ft)	85
2423	15.2 m (50 ft)	85

Table 3-3. Northbound Vehicle Overshooting Station, 48 km/h (30 mph)

Beam	Distance	Vibration Level (VdB)
2422	3.0 m (10 ft)	79
2422	7.6 m (25 ft)	80
2422	15.2 m (50 ft)	76
2423	3.0 m (10 ft)	89
2423	7.6 m (25 ft)	80
2423	15.2 m (50 ft)	80

4.0 SUMMARY OF RESULTS

Measurements of ground-borne vibrations generated by the TR08 on the various guideway configurations at the Transrapid Test Facility (Transrapid Versuchsanlage Emsland (TVE)) test track can be used to characterize vibrations from similar maglev systems. The general results are as follows:

- Force spectra of TR08 on concrete, steel and hybrid guideways are given in Figure 3-11. Steel beams showed highest force at lower frequencies (6.3 Hz–25 Hz), but hybrid beam had highest vibrations in the upper frequency range (25 Hz– 60 Hz). Vehicle interaction with the guideway may generate specific peaks in vibration spectra depending on design details.
- Vibration attenuation with distance was about 5 VdB per distance doubling.
- Vibration levels increased at a rate of 20 to 40 times the logarithm of speed.
- Vibration reference levels at 50 feet can be characterized as in Table 4-1.

Table 4-1. Vibration Reference Levels

SPEED	CONFIGURATION	Lv @ 15 m (50 ft)
200 km/h (125 mph)	Concrete Beam	66 VdB re 1 microinch/sec
	Steel Beam	67 ”
	Hybrid Beam	68 ”
	At-grade Concrete Beam	77 ”
	At-grade Steel Beam	79 ”
	Switch	76 ”
400 km/h (250 mph)	Concrete Beam	77 VdB re 1 microinch/sec
	Steel Beam	79 ”
	Hybrid Beam	74 ”
	At-grade Concrete Beam	83 ”
	At-grade Steel Beam	84 ”
	Switch	80 ”
Approach and stop	Station	88 ”
Depart	Station	85 ”

5.0 VALIDATION AND VERIFICATION

5.1 DESCRIPTION OF EFFORT

Volpe Center personnel provided validation and verification during all phases of the Transrapid TR08 vibration characterization program. Specifically members of the Volpe Center Environmental Measurement and Modeling Division, reviewed and commented on that the test proposal and test protocol, and ultimately recommended to the FRA that it be approved. Verification of contractor measurement techniques was provided during the measurement program at the Transrapid Test Facility (Transrapid Versuchsanlage Emsland (TVE)) in Germany. Finally, validation of contractor data, including analysis techniques and data presentation, was conducted.

Concurrent with this Transrapid TR08 vibration characteristics study, a similar characterization was undertaken for the TR08's noise characteristics (FRA, *in prep*). The Volpe Center's validation and verification efforts for the noise study closely paralleled the efforts documented herein. However, during the noise study, a limited amount of simultaneous acoustic data was collected by the Volpe Center, but it was not considered cost-efficient or necessary to do so for the vibration measurements.

5.2 TEST PROTOCOL

5.2.1 Measurement Proposal

A preliminary measurement proposal was submitted by the contracting team to the Volpe Center in September 2000 (email correspondence, 9/19/2000). Volpe Center staff reviewed the proposal for both reasonableness and completeness. The Transrapid, and magnetic levitation (maglev) technology in general, is a relatively new technology in terms of implementation. As such, there is not a wide body of knowledge on its vibration characteristics. The details outlined in the proposal were considered adequate to characterize the TR08's vibration characteristics and the proposal was subsequently approved by the FRA upon the recommendation of the Volpe Center.

5.2.2 Test Plan

An initial Test Plan was submitted (HMMH 2000b) to the Volpe Center in October 2000. The Test Plan incorporated information from the previous measurement proposals, but also included specifics pertaining to schedule, accelerometer locations relative to the guideway, location of actual measurements along the guideway, as well as data analysis and presentation details.

First, the Test Plan was evaluated to ensure that data collected would fully meet all requirements in appropriate guidance documentation. The FRA's *High-Speed*

Ground Transportation Noise and Vibration Impact Assessment (FRA 1998) provides guidance for the measurement and assessment of potential vibration impacts due to high-speed ground transportation vehicles. The Test Plan was found to be consistent with the Analysis Procedures section of the guidance document.

The Test Plan was also evaluated to ensure that it was reasonable to accomplish in the time allotted for measurements at the Test Facility. Although considered ambitious, the Test Plan schedule was deemed reasonable given (1) favorable weather conditions allowing for completion of all related logistics, and (2) consistent and predictable TVE operations.

The Volpe Center submitted comments to the contracting team requesting that more details be added in several sections and some additional tests be performed. As a result, a revised Test Plan was submitted to the Volpe Center at the end of November 2000. The revised Test Plan (given in Appendix A) was evaluated for completeness and accuracy, and ultimately approved by the FRA upon the recommendation of the Volpe Center.

5.3 FIELD VERIFICATION OF MEASUREMENTS AND PROTOCOL

During the period from August 12 through 18, 2001, Volpe Center staff participated in the field measurements at the TVE in the Emsland region of Germany. Several steps were taken during the measurements to verify contractor measurements and adherence to the approved protocol. Volpe Center staff witnessed the general measurement procedures undertaken daily by the contractor. Placement and alignment of accelerometers were verified and documented using 35 mm photography. Additionally, the set-up and functionality of the entire measurement system, including accelerometers, ground impacter, signal processing and data storage devices, were demonstrated to Volpe Center personnel by the contractor. The general practices of the contractor, including field documentation and protocol were also evaluated.

5.4 VALIDATION OF CONTRACTOR DATA AND ANALYSIS

Contractor data and analyses were first checked for completeness relative to that outlined in the Test Plan. Data and associated analyses were found to be consistent with those described in the final Test Plan. Next, the reasonableness of data trends was investigated. Vibration level presentations as functions of both vehicle speed and distance from the guideway were verified. Some inconsistencies were noted in these relationships, however, the contractor's spectral analysis identifies reasonable contributors to these data anomalies.

The results of the vibration data collected near the station (Section 3.6) should be used with caution for applications in the U.S. Due to TVE operational constraints, data were collected for fewer TR08 events at this location than from other locations along the guideway. Additionally, while TR08 operations near the station during the tests may be representative of those near proposed stations in the U.S., the passenger platform was not purpose-built (as outlined in Section 3.6). Rather, the station is simply a platform constructed alongside the guideway for convenience. A purpose-built station in the U.S. would likely be more massive thereby minimizing vibration propagation more readily than the platform used for measurements at TVE.

5.5 FINDINGS AND CONCLUSIONS

TR08 vibration data measured, analyzed, and presented by the contractor in the preceding sections of this report have been verified and validated. The contractor has demonstrated good technical practices throughout the project, including the design of the general approach and test protocol, measurements, and finally data analysis and presentation.

6.0 COMPARISON WITH OTHER MODES OF TRANSPORTATION AND VIBRATION IMPACT SCREENING DISTANCES

6.1 COMPARISON OF DATA WITH OTHER MODES OF TRANSPORTATION

Ground-borne vibration levels at 240 km/h (150 mph) from the TR08 are compared with those measured from representative high speed trains in Figure 6-1. The French Train à Grande Vitesse (TGV) data were measured on the “TGV Nord” line north of Paris. The Italian Pendolino data were measured along the Milano-Bologna segment of the Italian National Railway’s main line between the cities of Parma and Reggio Emilia. The Swedish X2000 and the Acela data were measured at a test site on the Northeast Corridor near Princeton, NJ. For comparison purposes, vibration levels are shown for the TR08 on the reference concrete beam on an elevated structure and the concrete beam at-grade. The curves for European high-speed trains are taken from the FRA high-speed ground transportation guidance manual (FRA 1998), and for the Acela from measurements conducted by HMMH (FRA 2000).

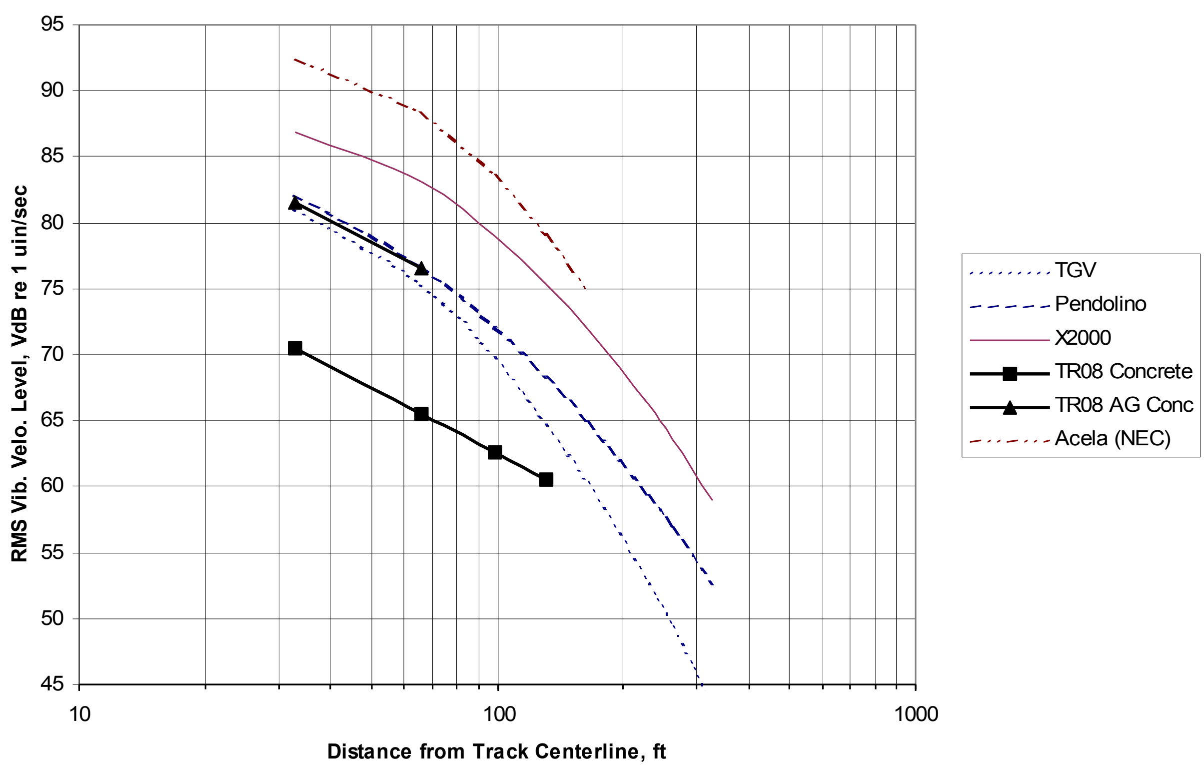


Figure 6-21. Vibrations from High-speed Trains at 240 km/h (150 mph)

The vibration levels from the TVE at-grade beam are comparable to those from high-speed trains measured in Italy (Pendolino) and France (TGV). At 240 km/h

(150 mph), vibrations from the TR08 on elevated structure are considerably lower. Given the derived relationship— that TR08 vibration levels increase at approximately 20 to 40 times the logarithm of speed— elevated guideway vibrations due to TR08 operations at approximately 480 km/h (300 mph) would be comparable to or slightly greater than those of traditional high-speed trains operating at 240 km/h (150 mph). Direct comparisons are made with caution, however, because these data are measured values at the various sites, each with its own geological characteristics, and at only one reference speed. The variations in propagation rates for the various sites are indicative of different soil conditions. The higher levels shown for the Swedish X2000 and the American Acela may be a result of track conditions on the Northeast Corridor. In general, however, ground-borne vibration levels from trains on elevated structures tend to be lower than those from at-grade operations due to two causes: (1) structural damping (vibrations are dissipated in the many components and bearings in a structure); and (2) point source spreading from the discrete contact points with the ground as a result of column spacing.

Structural damping, the dissipation of vibration energy before transmission to the ground, depends on the type and design details of the guideway structure. Structural analyses leading to the factors involved in estimation of damping are beyond the scope of this study.

Point source spreading is taken into account in this study, however. Normally the site characteristics are removed from consideration by employing the force density concept for line sources like trains at-grade. But in the case of trains on elevated structures, the excitation force is applied to the ground as a series of point sources spread quite far apart relative to the wayside distances where vibration has a measured effect. For example, the columns for the concrete beam section are spaced 25 meters (82 feet) apart. Vibrations from the nearest column dominate the overall vibration level for approximately 30 meters (100 feet). Consequently, the point source force spectrum, not the force density spectrum, is used for the TR08 on an elevated structure. The two different parameters are not directly comparable.

6.2 COMPARISON OF DATA TO VIBRATION IMPACT SCREENING DISTANCES

The FRA guidance manual (FRA 1998) includes vibration impact criteria for high-speed ground transportation systems based on the maximum levels that are expected to be achieved on a consistent basis. The criteria account for variation in land use as well as the frequency of events, as indicated in Table 6-1.

Table 6-1. Summary of FRA's Vibration Impact Criteria (FRA 1998)

Land Use Category	Ground-borne Vibration Impact Levels (VdB re 1 microinch/sec)	
	Frequent Events[1]	**Infrequent Events[2]**
Category 1: Buildings where vibration would interfere with interior operations.	65 VdB[3]	65 VdB[3]
Category 2: Residences and buildings where people normally sleep.	72 VdB	80 VdB
Category 3: Institutional land uses with primarily daytime uses.	75 VdB	83 VdB

Notes:

1. *Frequent Events* is defined as more than 70 vibration events per day (e.g., train passbys).
2. *Infrequent Events* is defined as fewer than 70 vibration events per day.
3. Criterion for vibration-sensitive equipment such as optical microscopes.

Application of the FRA criteria to the vibration environment in the vicinity of the TVE test track provides an estimate of the how the TR08 might be assessed for the various test track guideway configurations. An example for two speeds and worst-case station operations is shown in Table 6-2 for the case of infrequent operations (fewer than 70 passbys per day). The distances to FRA's impact criteria are determined using the reference vibration levels in Section 4-1 together with the typical vibration propagation characteristics of the soil in the vicinity of the test track. It is important to understand that the "station" at TVE is not a purpose-built structure. Rather it is one of the normal steel beam guideway sections with a platform built to the side.

Table 6-3. Ground-borne Vibration Screening Distances for Infrequent Operations of TR08*

TVE Guideway Configuration	Distances to FRA's Vibration Impact Criteria					
	Category 1: High Sensitivity		Category 2: Residential		Category 3: Institutional	
	200 km/h (125 mph)	*400 km/h (250 mph)*	*200 km/h (125 mph)*	*400 km/h (250 mph)*	*200 km/h (125 mph)*	*400 km/h (250 mph)*
Concrete	17m (57 ft)	79m (264 ft)	2.2m (7 ft)	10m (33 ft)	1.4m (5 ft)	6.5m (22 ft)
Steel	19.8m (66 ft)	104.6m (349 ft)	2.5m (8 ft)	13m (44 ft)	1.6m (5 ft)	8.6m (29 ft)
Hybrid	22.7m (66 ft)	52.3m (174 ft)	2.8m (9 ft)	6.5m (22 ft)	1.9m (6 ft)	4.3m (14 ft)
At-grade concrete	79.2m (264 ft)	182m (607 ft)	9.9m (33 ft)	22.7m (76 ft)	6.5m (22 ft)	15m (50 ft)
At-grade steel	104.6m (349 ft)	209m (698 ft)	13m (44 ft)	26.1m (87 ft)	8.6m (29 ft)	17m (57 ft)
Switch	69m (230 ft)	120m (400 ft)	8.6m (29 ft)	15m (50 ft)	5.7m (19 ft)	9.9m (33 ft)
Station – approach and stop	364m (1214 ft)		45.5m (152 ft)		30m (100 ft)	

* *Infrequent operations are defined as fewer than 70 per day.*

7.0 REFERENCES

FRA 1992. Safety of High Speed Magnetic Levitation Transportation Systems, Magnetic Field Testing of the TR07 Maglev Vehicle and System, Vol. I-Analysis and Vol.II-Appendices. Federal Railroad Administration, U.S. Department of Transportation. April 1992. DOT/FRA/ORD-92/09.I and/09.II, NTIS#s: PB92-224666-HDM and PB92-224674-HDM.

FRA 1993. Noise from High Speed Maglev Systems. Federal Railroad Administration. January 1993.

FRA 1998. High Speed Ground Transportation Noise and Vibration Impact Assessment (Report No. 293630-1; Contract: DTFR53-94-A-00056). Federal Railroad Administration, U.S. Department of Transportation. December 1998.

FRA 2000. Acela Trainset Noise and Vibration Measurements on the Northeast Corridor (Report No. 295450-3; Contract: DTFR53-94-A-00060). Office of Railroad Development, Federal Railroad Administration, U.S. Department of Transportation. October 2000.

FRA 2001. Final Programmatic Environmental Impact Statement and Record of Decision; Maglev Deployment Program. Federal Railroad Administration, U.S. Department of Transportation. April 2001. DOT/FRA/RDV-00/02, DOT-VNTSC-FRA-00-04.

HMMH 2000a. Personal electronic communication from Carl Hanson, Harris Miller Miller & Hanson, to Christopher Roof, Volpe Center, regarding “Noise and Vibration Measurements of TransRapid Maglev Vehicle TR08 HMMH Proposal No. P00-20115.” September 19, 2000.

HMMH 2000b. Personal electronic communication from Carl Hanson, Harris Miller Miller & Hanson, to Christopher Roof, Volpe Center, regarding “Noise and Vibration Measurements of TransRapid Maglev Vehicle TR08 HMMH Proposal No. P00-20115B” October 6, 2000.

HMMH 2000c. Personal electronic communication from Carl Hanson, Harris Miller Miller & Hanson, to Christopher Roof, Volpe Center, regarding “Proposed Test Plan for Noise and Vibration Measurements of TransRapid TR08” October 23, 2000.

RTRI 2001. Railway Technical Research Institute Home Page. http://www.rtri.or.jp/rd/maglev/html/english/maglev_frame_E.html December 2001.

TRI 2001. Transrapid International Home Page. http://www.transrapid.de/en/index.html November 2001.

APPENDIX A Vibration Test Plan

This appendix contains the text of the Final Test Plans for measurement of vibration as well as noise and electromagnetic fields (EMF) associated with the Transrapid TR08 Maglev System. Details of the EMF measurements have been omitted, as they are not relevant to this report; details about noise measurements are included because they are integrated with the details about vibration measurements.

The Final Test Plans were completed in June 2001. Harris Miller Miller & Hanson (HMMH) authored these plans, with input and additional material from technical staff of the Federal Railroad Administration (FRA), the John A. Volpe National Transportation Systems Center (Volpe Center), MAGLEV, Inc., Transrapid International (TRI), and IABG (Industrieanlagen Betriebsgesellschaft, a European scientific-technical services company). The Test Plans were also reviewed by representatives of the Baltimore-Washington Maglev Project, including an environmental planning staff person from the Maryland Transit Administration and a representative from Parsons-Engineering Science, a noise and vibration consultant for the Baltimore-Washington Maglev Project.

Magnetic Levitation Transportation Technology Deployment Program

Section XIV, Pre-Environmental Impact Statement (EIS) Activities

Field Measurement of the EMF, Noise and Vibration Characteristics of the TR08

Final Test Plans

SECTION XIV
Pre-Environmental Impact Statement (EIS) Activities
Part B and C Final Test Plans

Field Measurement of the EMF, Noise and Vibration Characteristics of the TR08

Disclaimer

Section 1: Introduction

This report documents the final test plans for conducting the field measurements of the electromagnetic fields (EMF), noise and vibration characteristics of the TR08. This document is being submitted to the FRA for approval of the test plans prior to implementation.

The purpose of these tests in part is to repeat previous EMF and noise measurements that were made on the TR07 in the early 1990's. The test plans are also supplemented to include vibration measurements that were not part of the original 1990 FRA test program. The completion of the test plans, data evaluation, and data analysis will result in detailed documentation of the electrical emissions, noise emissions and vibration characteristics of the Transrapid Maglev System and TR08 vehicle. This measurement data will be utilized to support the required environmental planning and deployment activities for any Transrapid Maglev Project in the United States. This work is being accomplished as part of the Federal Railroad Administration's (FRA) Scope of Work Amendment No. 2, Section XIV Pre-Environmental Impact Statement (EIS) Activities, part B and Part C.

Section XIV part B and C is restated here for reference.

B. Field Measurement EMI, EMF and EMR Characteristics of TR08

In cooperation with assigned staff from the Volpe National Transportation Systems Center (VNTSC), the Grantee shall develop a plan to measure and analyze the electromagnetic interference (EMI), electromagnetic fields (EMF), and the electromagnetic radiation (EMR) caused by the operation of the TR08 vehicle in service at the Transrapid Maglev Test Track in Emsland, Germany. With the approval of the FRA, the plan will be implemented.

C. Field Measurement of Noise and Vibration Characteristics of TR08

In cooperation with assigned staff from the Volpe National Transportation Systems Center (VNTSC), the Grantee shall develop a plan to measure and analyze the noise and vibration caused by the operation of the TR08 vehicle in service at the Transrapid Maglev Test Track in Emsland, Germany. With the approval of the FRA, the plan will be implemented.

MAGLEV, Inc. is performing the role of coordinating the diverse technical requirements and logistics associated with the planned test campaign as it relates to US maglev projects.

Section 2: Test Plan Development and Finalization

Under the direction of the FRA, MAGLEV, Inc. contracted the vendor Electric Research Management (ERM) for the electrical emissions testing and the vendor Harris, Miller, Miller and Hanson (HMM&H) for the noise and vibration testing of the TR08. The test plans contained in appendix A and B of this report are the collective efforts of the vendors, staff at Volpe and MAGLEV, Inc. These plans were developed in cooperation with and with the approval of Transrapid International and the TVE test center staff.

Numerous technical interchanges and discussions were held with Volpe personnel, Electric Research Management (EMF test vendor), Harris, Miller, Miller and Hanson (noise and vibration test vendor) and Transrapid in finalizing the plans for the environmental testing of the TR08. As part of this effort, Transrapid recommended and supported a pre-meeting with the vendors and MAGLEV, Inc at the test facility. The purpose of this meeting was to discuss and finalize the details of the draft test plans, familiarize the vendors with the test facility and to select the actual guideway and vehicle locations for measurements.

On February 15-16, 2001, the vendors and MAGLEV, Inc. traveled to the test facility in Emsland, Germany for a meeting with Transrapid and the TVE test facility personnel. As a result of this meeting, agreement was reached on a consolidated test matrix for the noise, vibration and EMF testing. The consolidated test matrix and the measurement locations are documented in appendix C of this report. The noise testing requires the most preparation and time to conduct and therefore drives the test matrix activities. The EMF and vibration measurement activities have been developed to permit all work to be done concurrently with the noise measurements.

Pending approval of the test plans by the FRA, the actual field measurements are scheduled to begin during the week of April 2, 2001 at the test facility.

Section 3: TVE Test Facility Layout and Operational Considerations

The TVE test facility layout and daily operating parameters were considered in developing the final plans. The TVE test facility consists of a 31.5 km track as shown in Illustration 1 below. Various guideway types and configurations (steel, concrete, hybrid, at grade and elevated) exist at the test track. The final plan includes measurements at each representative guideway type.

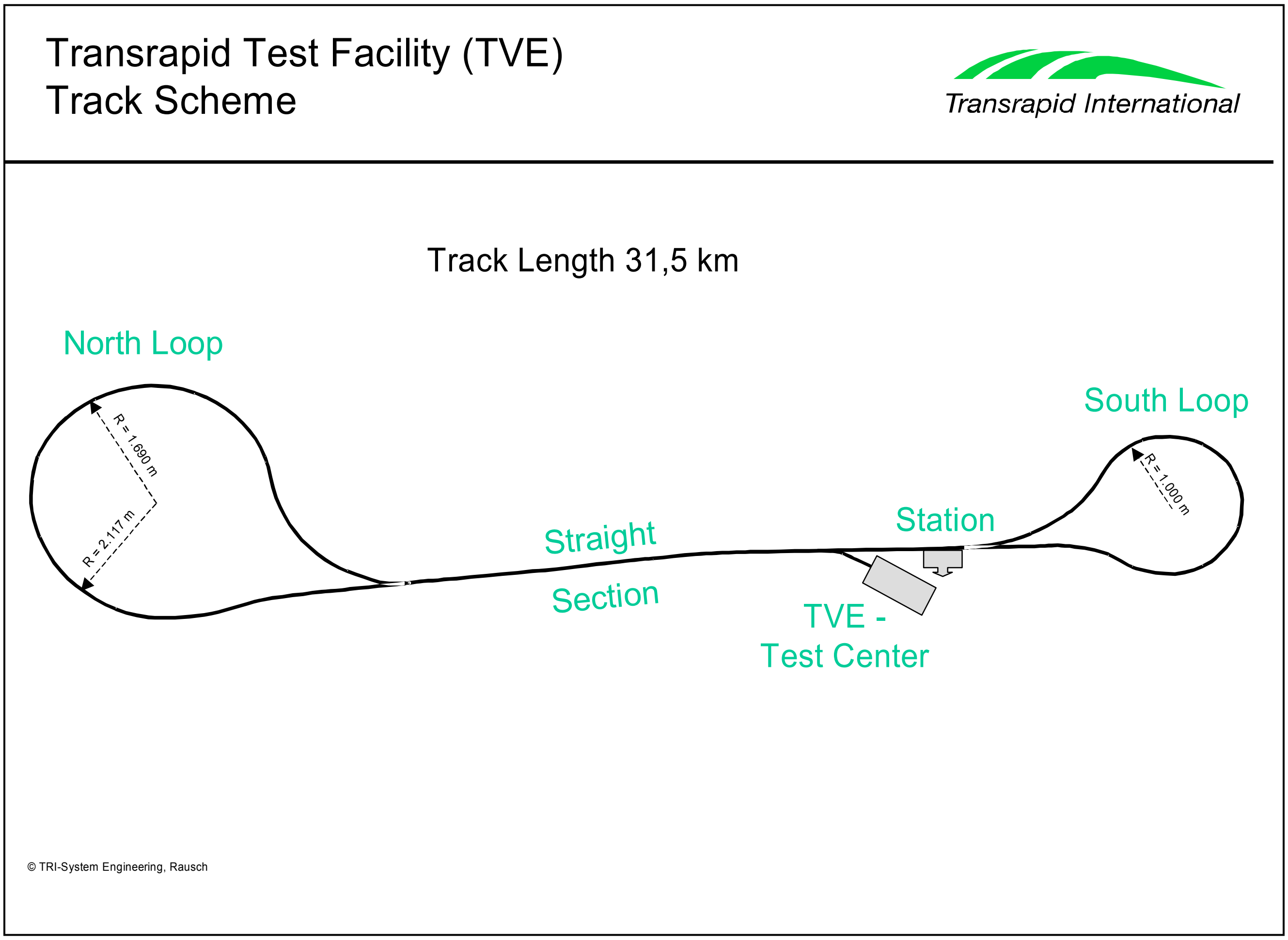


Illustration 1 Transrapid TVE Test Facility Track Scheme

The test facility normally operates from approximately 8:30 AM until 2:30 PM on Tuesday through Friday of each week. The train operates approximately every 30 minutes in the morning hours and every 45 minutes during the afternoon hours. Monday is reserved for facility maintenance and other test activities therefore no measurements requiring vehicle movements have been scheduled on Mondays. Based on the required measurements to fully characterize the noise, vibration and EMF of the system, a period of six days is required to conduct the field measurements.

Table 1: TVE Normal Operating Schedule

Trip Number[1)]	Time of Departure [2)]	Speed Profile [3)]
N1	08:30 am	First Trip of the day, guideway inspection with low speed
N2	09:30 am	Demonstration speed profile
N3	10:00 am	Demonstration speed profile
N4	10:30 am	Demonstration speed profile
N5	11:00 am	Demonstration speed profile
N6	00:15 pm	Demonstration speed profile
N7	01:00 pm	Demonstration speed profile
N8	01:45 pm	Demonstration speed profile
	02:30 pm	Transfer into the Test Center

1) Each trip encompasses two rounds with a total trip length of 80 km
2) Departing at the TVE-Station
3) Speed profile can be adjusted according to the test requirements

Excluding the first inspection trip of the day, each trip consists of two complete runs of the entire test track length. This provides for a total of twenty-eight pass-bys (2 rounds x 2 pass-bys x 7 trips per day = 28 pass-bys) at each of the guideway locations in the straight sections of the track. Table 2 provides a summary of the trips and number of pass-bys.

Table 2, Pass-by Events along the Straight Section of the Guideway

Trip Number	Time of Departure At Station	No. Of Event Pass-by	Direction Towards	Vehicle Speed [1)]
N2	09:30 am	1.	North, 1. Round	up to local max. Speed [2)]
		2.	South, 1. Round	up to local max. Speed [2)]
		3.	North, 2. Round	up to local max. Speed [2)]
		4.	South, 2. Round	up to local max. Speed [2)]
N3	10:00 am	5.	North, 1. Round	up to local max. Speed [2)]
		6.	South, 1. Round	up to local max. Speed [2)]
		7.	North, 2. Round	up to local max. Speed [2)]
		8.	South, 2. Round	up to local max. Speed [2)]
...	...	.		
...	...	.		
N8	01:45 pm	25.	North, 1. Round	up to local max. Speed [2)]
		26.	South, 1. Round	up to local max. Speed [2)]
		27.	North, 2. Round	up to local max. Speed [2)]
		28.	South, 2. Round	up to local max. Speed [2)]

1) Speed can be adjusted according to the test requirements
2) Local maximum speed depends on location

The speed profile for the normal operating sequence permits runs of up to 400 km/h in the straight section of the test track. Referring to Illustration 2, the normal operating sequence will provide a run of 150 km/h, 400 km/h, 200 km/h and 300 km/h in the straight section of the test track for each complete trip (two rounds). Trip time to complete the two rounds is approximately 22.5 minutes. Accounting for time necessary to download measurement data, approximately two trips will be made each hour. Additional trips can be added to the daily schedule in the event of delays in completing the measurements. The normal daily operating speed profile is shown in Illustration 2.

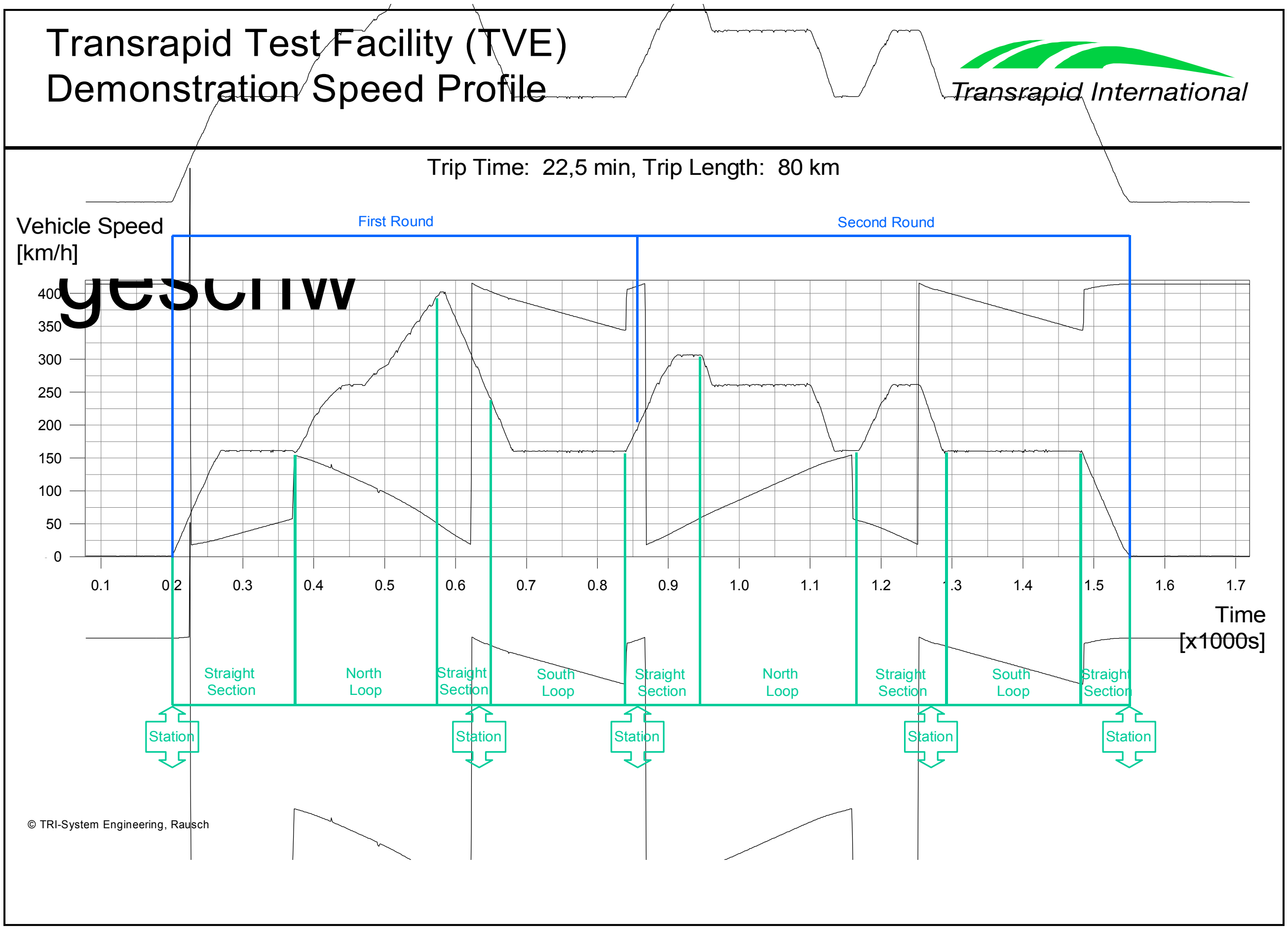


Illustration 2, Transrapid Test Facility (TVE) Demonstration Speed Profile

Guideway Measurement Locations and Local Speeds.

As part of the pre-meeting with Transrapid and the TVE facility personnel, the vendors conducted a survey of the facility and guideway locations. The purpose of this survey was to finalize the test locations for measuring the various guideway types (steel, concrete, hybrid, at grade and elevated) for guideway design and installations that represent the configurations that could be utilized for a US application. The survey also included a review of the local terrain conditions to determine the suitability of the site for measurement purposes. Based on the survey and Transrapid's description of the various guideway types and configurations, specific measurement sites were selected as shown in Illustration 3. The associated maximum speeds at each location are also identified in this Illustration.

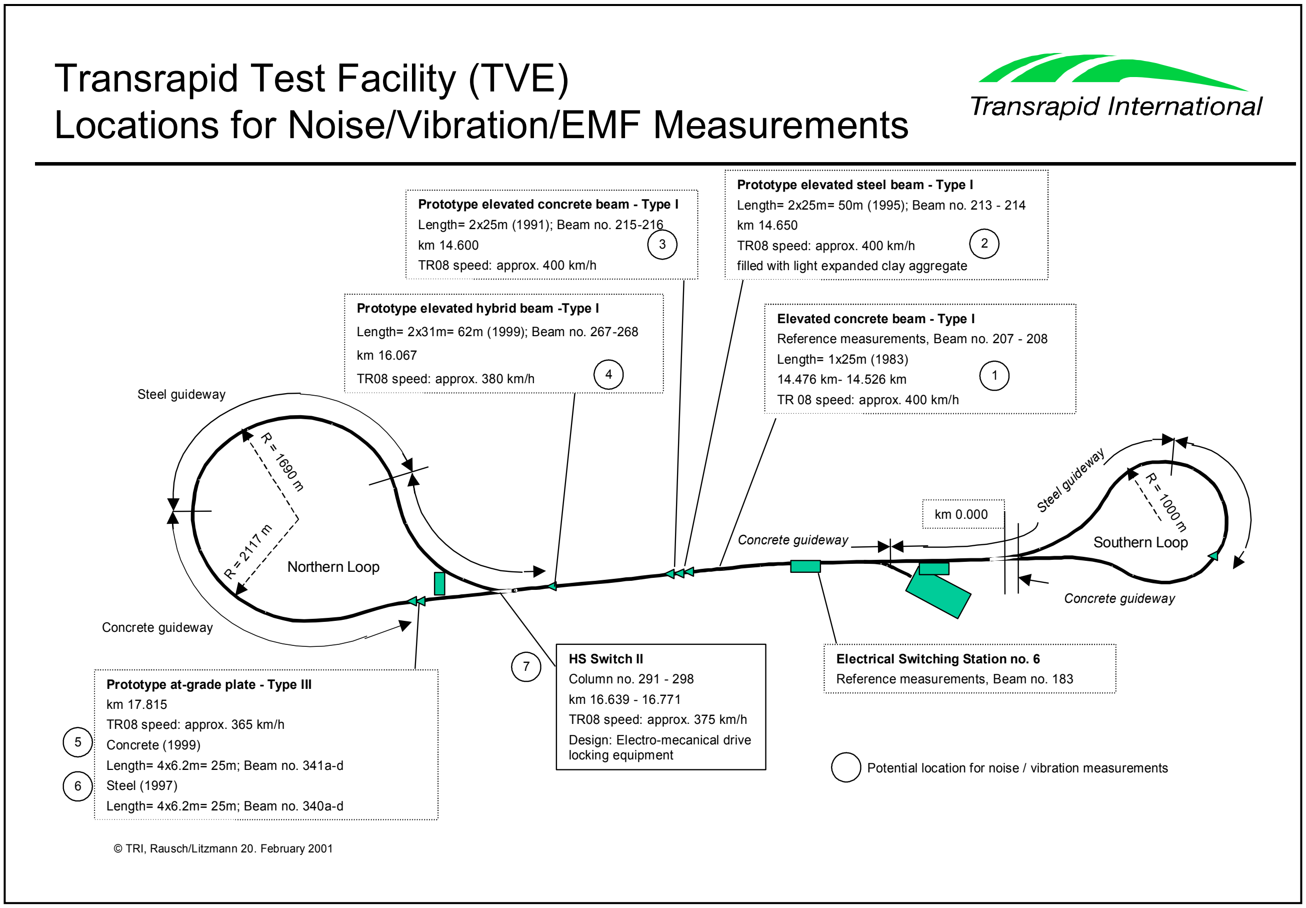


Illustration 3, Location of Measurement Sites and Associated Maximum Speeds

The numbered circles on Illustration 3 identify the basic order that the noise measurements will be conducted. As previously identified, the vibration and wayside EMF measurement teams will coordinate their activities with the noise measurement team. This way each vendor will have unrestricted access to each measurement location during the testing time.

Vehicle Measurement Locations

EMF measurements begin at several locations on the vehicles. These vehicle measurements will be made concurrently with the runs for the noise and vibration testing. Specific locations for measurements on the vehicle will be identified based on the location of propulsion, HVAC, communications and other onboard equipment. Measurements will be made at sixteen locations within the vehicle plus the attendant's compartment. This will result in a complete mapping of the spatial distribution of the electrical fields onboard the vehicle.

Section 4: Summary

MAGLEV, Inc. has worked with Electric Research Management, Harris, Miller, Miller and Hanson, Volpe, Transrapid International and the TVE test facility personnel to develop the final test plan presented in this document. The plan incorporates all comments from the participants and represents a well-structured methodology to obtain, analyze and document the EMF, noise and vibration characteristics of the Transrapid Maglev System and TR08 vehicle.

The measurement location diagram and corresponding consolidated test matrix in Appendix C of this report summarizes each of the daily testing activities. The type of measurement (EMF, noise or vibration), trip number (N2 – N8), guideway measurement location, measurement equipment configurations and pass-by speeds for each series of measurements is identified in the matrix.

The testing is scheduled to commence during the week of April 2, 2001 and will be completed the following week. An additional day for making measurements has also been built into the plan to account for potential equipment failures or weather related delays.

Following completion of the testing in April, all data will be reduced, cataloged and evaluated by the vendors. The vendors are scheduled to complete the data evaluation and analysis and document the testing in a final report approximately two months following completion of the field measurements.

Section 5: Reporting of Results

Subsequent to preparation of Appendices A and B of this document, it was agreed that a collaborative effort as outlined in this Section will be used to prepare and publish final reports that provide documentation and results of the environmental tests.

Background. It is anticipated that the measurement results will be used in the development of maglev project environmental impact statements required under the National Environmental Policy Act (NEPA). The results should be presented in a manner that is acceptable from a technical and objective standpoint, and will minimize questioning of their validity. This information will also become a part of the permanent public record and will be posted by the FRA on a website for general access.

Report Format. The information will be documented in two separate FRA/Volpe Center official reports, one for EMF/EMR and the other for noise and vibration.

These reports will be produced as a collaborative effort among the contractors, MAGLEV, Inc. and the federal staff of the Volpe Center. The "Authors" Box # 6 of the Report Documentation Page will list contributing staff members from contractors, MAGLEV, Inc. and the Volpe Center. The "Performing Organization" Box # 7 will identify their respective organizations. Box # 9 will show the FRA and the Port Authority as "Sponsors".

The Volpe Center staff will write an introductory chapter that describes the maglev deployment program, addresses the administrative process under which the tests were done, describes the MAGLEV, Inc. and FRA/Volpe Center validation, verification and quality assurance efforts, and gives a general summary, interpretation, and perspective of the results. The contractors will prepare the remainder of each report including appendices. Descriptive summary statistics of the EMF/EMR, noise (including spectral time histories), and vibration levels measured on or near the TR08 will be reported in tabular form and summarized graphically. These data will be event-based, i.e., provided for the specific locations and speeds of the vehicle at the time of the measurements. All documentation will be provided in hardcopy and electronic form. Electronic information will use Microsoft office products (WORD for text/ tables, Excel for spreadsheet and graphs) as well as portable document format (.pdf).

Test Plan for
EMF Testing of the TR08

(Appendix A in original Test Plans)

APPENDIX A
NOT INCLUDED IN THIS REPORT

Test Plan for Noise and Vibration Testing of the TR08

(Appendix B in original Test Plans)

TEST PLAN FOR NOISE AND VIBRATION MEASUREMENTS OF TRANSRAPID TR08

INTRODUCTION

Noise and vibration measurements are proposed for the TR08 to be conducted at Transrapid Versuchanlage Emsland (TVE) in Germany. The noise tests are intended to replicate, where possible, previous testing programs on the TR07 vehicle. The testing program is requested by Federal Railroad Administration (FRA) as part of pre-environmental impact statement activities.[1]

The test plan calls for measurement of the TR 08 under specific operating conditions and on a limited number of sites. The plan is proposed to be performed over a three-week period with preparation and installation of microphone array equipment the week before the beginning of measurements and a testing period of up to two weeks. The noise measurement program is planned for six days, but it may have to be extended for additional days under conditions of unfavorable weather, test track operational problems, or last minute requests for additional information other than proposed. Of the foregoing causes for delay, weather is likely to be an important variable. Vibration measurements can, however, be performed with minimal limitations imposed by weather conditions.

The noise test plan has been prepared by Bernd Barsikow of akustik-data Engineering Office in Berlin, Germany. He is familiar with the test track having made similar measurements at that facility in the past. Akustik-data will be responsible for all the noise measurements.

Harris Miller Miller & Hanson Inc. (HMMH) will conduct the vibration measurements. The method will be performed according to the testing procedure described in FRA's guidance manual, *High Speed Ground Transportation Noise and Vibration Impact Assessment*.

Following sections describe the two test plans in general. Details are provided in the consolidated test plan matrix. Other tasks, including data analysis and reporting, are described in the Attachment : Scope of Work.

[1] **FRA Scope of Work Amendment No. 2, Section XIV. Pre-Environmental Impact Statement (EIS) Activities, Part C. Field Measurement of Noise and Vibration Characteristics of TR 08 (12/31/00).** „In cooperation with assigned staff from the Volpe National Transportation Systems Center (VNTSC), the Grantee shall develop a plan to measure and analyze the noise and vibration caused by the operation of the TR 08 vehicle in service at the Transrapid Maglev Test Track in Emsland, Germany. With the approval of the FRA, the plan will be implemented."

1. SUMMARY OF TEST PLAN FOR NOISE MEASUREMENTS

The basis for the following test plan for measurements of airborne noise are the specifications for the various microphone arrays and their measuring stations along the guideway, the single microphones and their locations, and the number of passbys of the TR 08, as given in the consolidated test plan matrix. This measurement program has been cleared with the people who operate TVE and is based on experience gained by the akustik-data Engineering Office during several similar measuring projects carried out at TVE.

In particular, the scheduling of the various passbys on six days is contingent upon the test vehicle being fully operational for this period of time. Another consideration is the weather, which has to be suitable for acoustical measurements during the entire week.[2] Weather during the proposed measurement period is typically problematic in Northern Germany. Although the plan includes some flexibility in the work schedule for the operating crew, it may be necessary to add measurements in the following week as a contingency.

A test-run plan with four passbys of the TR 08 in 30 minutes is the basic assumption according to the standardized speed profile provided by TransRapid International (TRI). The speed ranges will cover 100 km/h to 400 km/h. At slower vehicle speeds (100 to 200 km/h), a complete circuit of the guideway will not be necessary because the vehicle only has to achieve the prescribed speed in the vicinity of the particular measuring station, and, in these cases, the acceleration phase will be relatively short. During the TR 07 measurements at low speed, the vehicle was operated in both directions to save time and energy: we propose to do the same for the TR 08, pending operational constraints imposed by TVE. We have chosen the range of 100 to 400 km/h for all tests (except one switch configuration) so that all guideway configurations will have the same speed ranges. Extrapolation to higher speeds can be performed, but with reduced accuracy. Operating condition of the vehicle will be monitored during test runs. One requirement is that all power sources be switched on during the pass-bys. We do not plan to monitor the passenger load in the vehicles specifically for the noise tests.

At the measuring stations, we have to make sure there will be good access to the elevated arrays (particularly for the IABG tower) as well as to the single microphones positioned at distances from the guideway of 50 and 100 feet and 6.5 and 25 meters. The boundary conditions (i.e., the topological conditions of the land) at these latter stations should also be suitable for acoustical measurements. These conditions should not, however, be a problem when the concrete guideway is mounted on pylons. There are many sections of concrete

[2] For acoustical measurements, wind velocity should be 6 m/s (12 mph) or less, and wind gusts should be no greater than about 9 m/s (20 mph). Tests can be conducted in light rain or drizzle if necessary, but not in heavy rain, sleet or accumulating snow.

guideway where the terrain is satisfactory for acoustical measurements.[3] The reference measuring station will be located at beam No. 208, the site of previous measurements along the high-speed straight section. There are fewer sections of steel guideway. One section of elevated steel guideway will be selected for measurement; beam No. 213 is a section similar to the length and type being proposed for U.S. applications. The hybrid beam No. 267 and the prototype concrete beam No. 215 will also be measured. Final selection was made during a field visit during 15 – 16 February.

In addition to the microphone array sites, locations will be selected for single-microphone measurements near the high-speed switch and along the at-grade guideway where it more or less lies at ground level. In these cases at the TVE, the geometry of the guideway and its immediate surrounds can set a limit to the maximum passby speed on these sections. For the switch, we propose to measure under both conditions straight ahead and turn-out. Speed restrictions apply to the turn-out condition, however, so we will not have as great a range of speeds as is possible for the straight configuration.

Noise test program details are shown in the consolidated test plan matrix.

2. VIBRATION TEST PLAN

The goal of the vibration tests is to obtain the “force density” of the TR08 for use in predictions of ground vibrations near proposed maglev systems at other locations than the test track in Emsland. The key parameters are expressed in the following equation:

$$\mathbf{L_F = L_v - TM_{line}}$$

where, assuming all quantities are in decibels with consistent reference quantities:

L_F	=	force density level for a line source (i.e. maglev on guideway)
L_v	=	rms vibration velocity level of a maglev passby
TM_{line}	=	line source transfer mobility from the guideway to the measurement site evaluated at a specific distance.

The line source transfer mobility (TM_{line}) represents an empirical relationship between a known linear vibration source and the resulting ground vibration. By measuring the TR08 vibration (L_v) at a site and using a special test to measure TM_{line} at the same site, the baseline force density (L_F) for the TR08 can be derived. The force density function is assumed to be independent of the ground characteristics, which means that it can be combined with a measured transfer mobility to predict ground-borne vibration at locations other than the test site.

[3] For example, site conditions satisfying ISO 3095-1975, Section 6 (Acoustical environment, meteorological Conditions, Background Level).

The force density is determined on the ground so the quantity includes the vehicle on its guideway; for example, the force density of the TR 08 on a concrete guideway may be different than that measured for the same vehicle on a steel beam. Analysis of the data will result in a catalog of force densities for TR08 on various guideway configurations.

HMMH test plan covers three days of measurement. Our proposed budget includes only one week of HMMH time at TVE. The test equipment will be shipped to Amsterdam ready for pick-up on Friday morning before the test week. After retrieving the equipment, HMMH will drive to the test track, unpack equipment and check all calibrations. Orientation and meeting with test personnel will take place on Monday morning. Vibration tests will be conducted Monday afternoon through Thursday. Repacking equipment for shipment will take place on Thursday night for return to Amsterdam for shipment back to the US on Friday. Any unforeseen delays in operations of the TR 08 on the test track will, of course, extend the testing period into the following week, as described above regarding the noise tests.

The details of the vibration test program are shown in the consolidated test plan matrix, organized to be almost parallel to the noise measurement program.

ATTACHMENT: SCOPE OF WORK

Noise and Vibration Measurements of TransRapid Maglev Vehicle TR08

Note: This Scope of Work is based on HMMH Proposal No. P00-20115 as modified by subsequent planning discussions. The Scope is included as an attachment to the Proposed Test Plan as an overview of the entire measurement program including data analysis and reporting.

Summary.
MAGLEV, Inc. has requested Harris Miller Miller & Hanson Inc. (HMMH) of Burlington, MA, to prepare a scope of work to measure and report the wayside noise and vibration characteristics of the TransRapid TR08. HMMH will team with akustik-data Engineering Office (a-d) of Berlin, Germany. Measurements will be performed at the TransRapid Test Facility (TVE) in Emsland, Germany. The team of HMMH and akustik-data has completed similar measurement and analyses of Amtrak's new high-speed train, Acela, and is in a good position to compare the noise and vibration characteristics of the different high-speed ground transportation platforms.

Task 1. Planning and Coordination
Dr. Carl Hanson of HMMH and Mr. Bernd Barsikow of a-d will develop a draft test plan for the measurements of noise and vibration of the TR08. The draft plan will be submitted to MAGLEV, Inc. for comments. After both MAGLEV, Inc. and the HMMH/a-d team agree, MAGLEV, Inc. will forward the plan to the Volpe National Transportation Systems Center (VNTSC) for comment and eventual approval. TVE will be consulted during the review process and must approve the test plan as it pertains to their operations. After agreements are reached, Barsikow will travel to the Transrapid Test Facility (TVE) in Emsland for a coordination meeting. Purpose of this meeting is to discuss details for implementing the test plan, select the measurement locations, check out the IABG telescopic tower and associated equipment, and make final plans for the field measurements.

Task 2. Field Testing
Akustik-data will conduct the noise tests and HMMH will conduct the vibration tests. IABG will provide technical support for the noise measurements and will provide information about the operating conditions of the vehicle during the tests.

Task 2A. Noise Measurements. Noise measurements, including preparation, set-up and data collection, will be performed by akustik-data engineering staff. Measurements will be made using akustik-data's microphone arrays placed close to the test track as well as single microphones at the European and FRA standard reference distances. Akustik-data's microphone arrays will be mounted on IABG's telescopic tower to position them appropriately for identifying noise sources on TR08.

Vertical arrays will be positioned to determine noise source heights on both vehicle and guideway. Horizontal and “X-arrays” will be used to pin-point noise source locations on the vehicle. All array configurations will be positioned 3.5 m from the outer wall of the TR 08, or about 5.0 m from the centerline of the track. This distance is close enough to focus on specific noise sources, but far enough away from the boundary layer of the vehicle to avoid gusts of moving air from the vehicle. An example of a microphone array and the TR07 is shown in the attached figure (Figure 1).

Measurements should be made for 3 passbys at each of four speeds ranging from 150 to 400 km/h for each array configuration. The test plan allows for a limited number of passbys at lower speeds of 100, km/h. This plan would result in a total of 178 passbys (11 series of array configurations and two series with single microphones) over a period of 6 days of measurement. Unfavorable weather conditions may extend the period of measurement. The final test plan matrix specifies the exact speeds required for each test, but in general the tests would be run as follows:

Three passbys at each of the following speeds – 150, 200, 300, and 400 km/h (two sets of speed doublings) for the following eleven array configurations (the concrete guideway beam No. 208 will be used as the baseline, as determined during the preliminary site visit):

1. Wayside vertical (WV) nested array in low and high position at the reference site with concrete guideway – for determining source height locations for vehicle;
2. Wayside horizontal (WH) nested array in low position at reference concrete guideway – for determining sources along length of vehicle at magnet locations;
3. Wayside vertical (WV) nested array in low and high position at a site with prototype concrete beam, a site with hybrid beam, and a site with steel beam – for determining source height locations for vehicle on those guideway configurations;
4. X-array with 32 cm microphone spacing (WX32) in mid-position at the reference concrete guideway – for locating low frequency sources; and
5. X-array with 16 cm microphone spacing (WX16) in mid-position at the reference concrete guideway – for locating mid-frequency sources.

Note that four sites would be selected for the array measurements: reference concrete beam, steel beam, prototype concrete beam and hybrid beam guideway locations. The speeds would have to be those on the standard profile at those sites. It is not practical to move the microphone arrays to different sites along the test track to obtain different speeds.

During all these tests, single microphones will be used to measure at three reference locations, 1.5 m above ground level at 50 feet (required by TNM and

FRA noise models), 1.2 meters above ground at 100 feet (required for EPA/FRA noise emission standards), 1.2 meters above ground level at 25 meters and two heights above ground at 6.5 meters (required for German standards). The single microphone set-up will be moved to cover six different guideway configurations: concrete beam, steel beam, prototype concrete beam, hybrid beam, at-grade beam and switch. The single microphone measurements at the concrete, steel and hybrid beams will take place during the array measurements, but a less comprehensive set of measurements (only a few speeds) at the switch will be carried out separately. The single microphone measurements will be used for four purposes: (1) to serve as reference points to sum up and model he sources, (2) to compare with other high-speed trains, (3) to compare with FRA and European standards, and (4) to compare noise characteristics among various guideway configurations.

Data will in all cases be recorded in digital form on magneto-optical disks for later analysis in akustik-data's laboratories. Final storage of data and results will be on CD media.

Task 2B. Vibration Measurements. A full vibration propagation test program will be performed to determine force density of the TR08 vehicle on four guideway configurations. The vibration propagation test procedure is described in Chapter 9 of FRA's guidance manual, *High Speed Ground Transportation Noise and Vibration Impact Assessment*[4]. The test consists of impacting the ground with a measured force and recording the resulting vibration pulses at various distances from the impact point. The relationship between the input force and the ground surface vibration, called the *transfer mobility*, characterizes vibration propagation at a given location.

HMMH will use a purpose-built ground impacter for generating the force. A load cell and amplifier will be used to measure the force of a repeatedly-dropped weight, and ground vibration measurements will be made with high-sensitivity accelerometers mounted in the vertical direction on top of steel stakes driven into the ground. The acceleration signals will be amplified using low-noise amplifiers and recorded on a Teac Model RD-130TE 8-channel digital audio tape (DAT) recorder for subsequent analysis in the HMMH laboratory. Reference signals will be used to calibrate the load cell and accelerometers, based on their rated sensitivities.

Vibration propagation measurements to determine transfer mobility of the ground will be made at four sites with different guideway configurations: concrete beam, steel beam, hybrid beam and a switch. Following the propagation measurements at each site, vibrations from passbys of the TR08 at the exact same positions will be recorded for determination of *Force Density*.

[4] http://www.fra.dot.gov/s/env/guidance.htm

Task 3. Data Analysis

Task 3A. Noise Analysis. Noise data will be analyzed using proprietary computer processing in akustik-data laboratory in Berlin. The microphone array data are analyzed using proprietary software developed by akustik-data. A microphone array is a highly directional sound measuring instrument consisting of several closely-spaced microphones. While a single microphone measures only the total sound generated by all the sound sources on a moving train, a microphone array can be used to locate individual sound sources by properly combining the microphone output signals. When the array is located close to the sound source, where the wavefront can be considered spherical, the total sound pressure from the "focus" of the array is determined during post-processing of the recorded data by summing the individual microphone signals after correcting for the distance from each microphone to the focal point. The focal point can be electronically "steered" simply by the way in which the signals are processed using the time differences among the signals at each microphone. That is, the focus of the array can be thought of as a beam that can be moved to track a moving source with no physical adjustment of the apparatus.

The sound pressure level for each source location is determined for the position of the microphone array. Speed dependence of each source is determined by plotting sound pressure level increases with speed and performing a regression analysis on the data. Projections to source reference distances required for calculation routines are performed using akustik-data's noise model "AD-PRO 2.0." The sound energy from all sound sources measured by the array are combined using this model and compared with the actual measured time histories. The sound exposure level (SEL) of each source is determined using the same model. Time histories of each source are produced and the SEL is calculated. Further, recorded data will be analyzed into narrow band frequency spectra for source diagnostics and one-third octave-band spectra for practical application.

The results will be presented in terms of the reference quantities required for the FRA high speed ground transportation noise and vibration guidance manual detailed noise analysis: SEL, length, and speed coefficient for each relevant source.

Task 3B. Vibration Analysis. Vibration data will be analyzed by HMMH in their laboratory in Massachusetts. Transfer mobility functions are developed from field measurements in 4 steps:

1. Analyze the field data to generate narrowband point source transfer mobilities.
2. Calculate 1/3 octave band transfer mobilities at each measurement point from the narrowband results. Because typical spectrum analyzers are not capable of obtaining 1/3 octave band transfer functions, this processing is performed after transferring the data to a computer.

3. Calculate the transfer mobility as a function of distance for each 1/3 octave band.
4. Compute the line source transfer mobility as a function of distance in each 1/3 octave band.

Force density is derived from the measured vibrations of the TR08 and the transfer mobility at each of the sites. The result will be presented as Force Density spectra in one-third octave-bands

Task 4. Reporting

The results of the noise and vibration testing will be presented in a single report jointly authored by akustik-data and HMMH. It will be similar to the recent report to the FRA on the noise and vibration tests of the Acela at the Transportation Technology Center.[5] Noise data will be interpreted by akustik-data. Results will be accompanied by figures illustrating the location of noise sources and their speed relationships. The attached figure taken from the Acela measurements (Figure 2) is a sample of how the relative sources are depicted. Pictures like this at every speed illustrate the location of noise sources. Source heights and SELs will be documented for use in prediction models. For example, source information will be presented in the appropriate format for the FRA High Speed Ground Transportation Noise and Vibration manual: SEL, effective length, speed coefficient. Differences in noise radiation among guideway types, including concrete, steel, hybrid, and switches will be documented.

The results of the vibration measurements will be presented in a form that can be used with the source levels and propagation curves in the FRA High Speed Ground Transportation Noise and Vibration manual. Force density spectra will be determined as a function of speed and type of guideway.

A summary section will compare the noise and vibration levels from the TR08 with those from other high-speed ground transportation sources.

The report will be prepared jointly by HMMH and akustik-data, with the final combined noise and vibration report edited and printed by HMMH.

KEY STAFFING

The HMMH/akustik-data team will be made up of the same members who measured and analyzed the Acela noise and vibration characteristics at the TTC. Project manager will be Dr. Carl E. Hanson, Senior Vice President and a Founder of HMMH. He will be responsible for coordinating the measurement program among team members and MAGLEV, Inc., as well as providing information as requested by the Volpe Center and the FRA. Dr. Hanson is familiar with TVE and the staff of IABG, having conducted measurements there during FRA's National Maglev Initiative Program. The akustik-data effort will be

[5] Hanson, Carl E. and Bernd Barsikow. *Noise Characteristics of Northeast Corridor High-Speed Trainsets*, Final Report, FRA Task Order No.205, September 2000.

directed by Mr. Bernd Barsikow, principal of the firm. Mr. Barsikow is widely known for pioneering the development of the use of microphone arrays for diagnosing noise sources on high-speed trains. He continues to be a leading acoustical specialist in this field in Europe and is well known by the IABG acoustical specialists at TVE.

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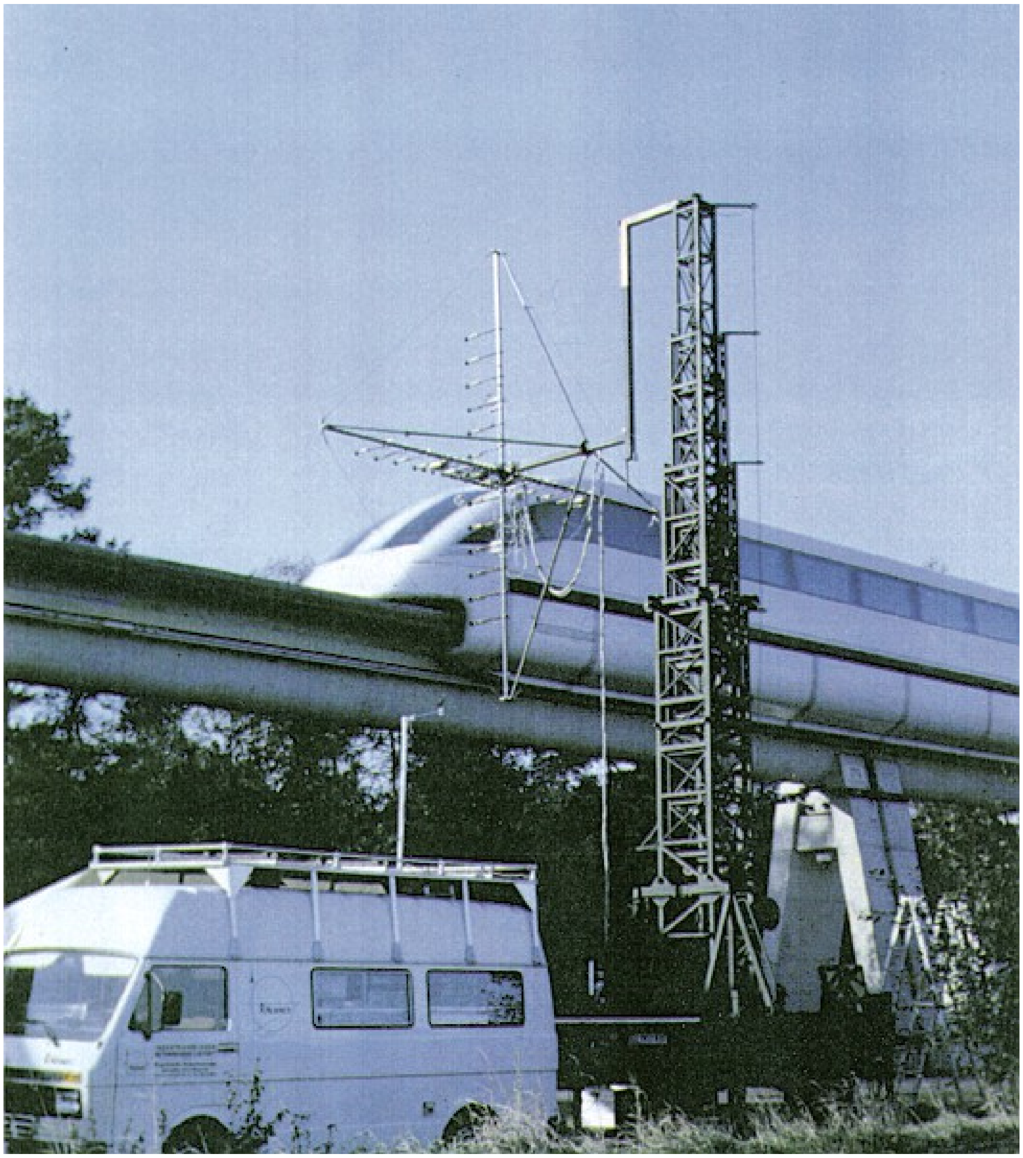


Figure 22. Microphone Array and TR07

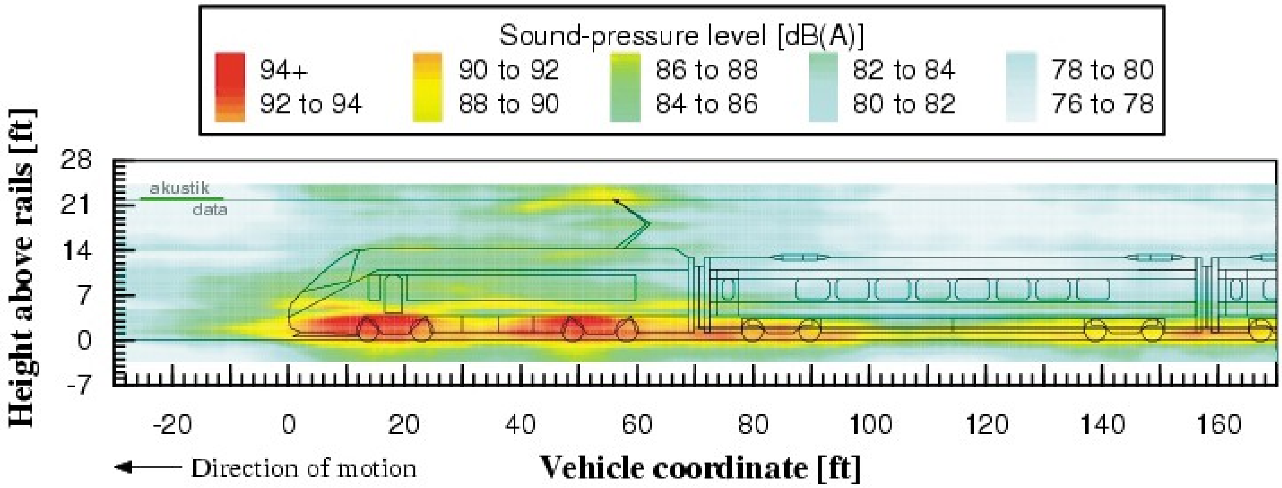


Figure 23. Noise Sources on Acela at 150 mph

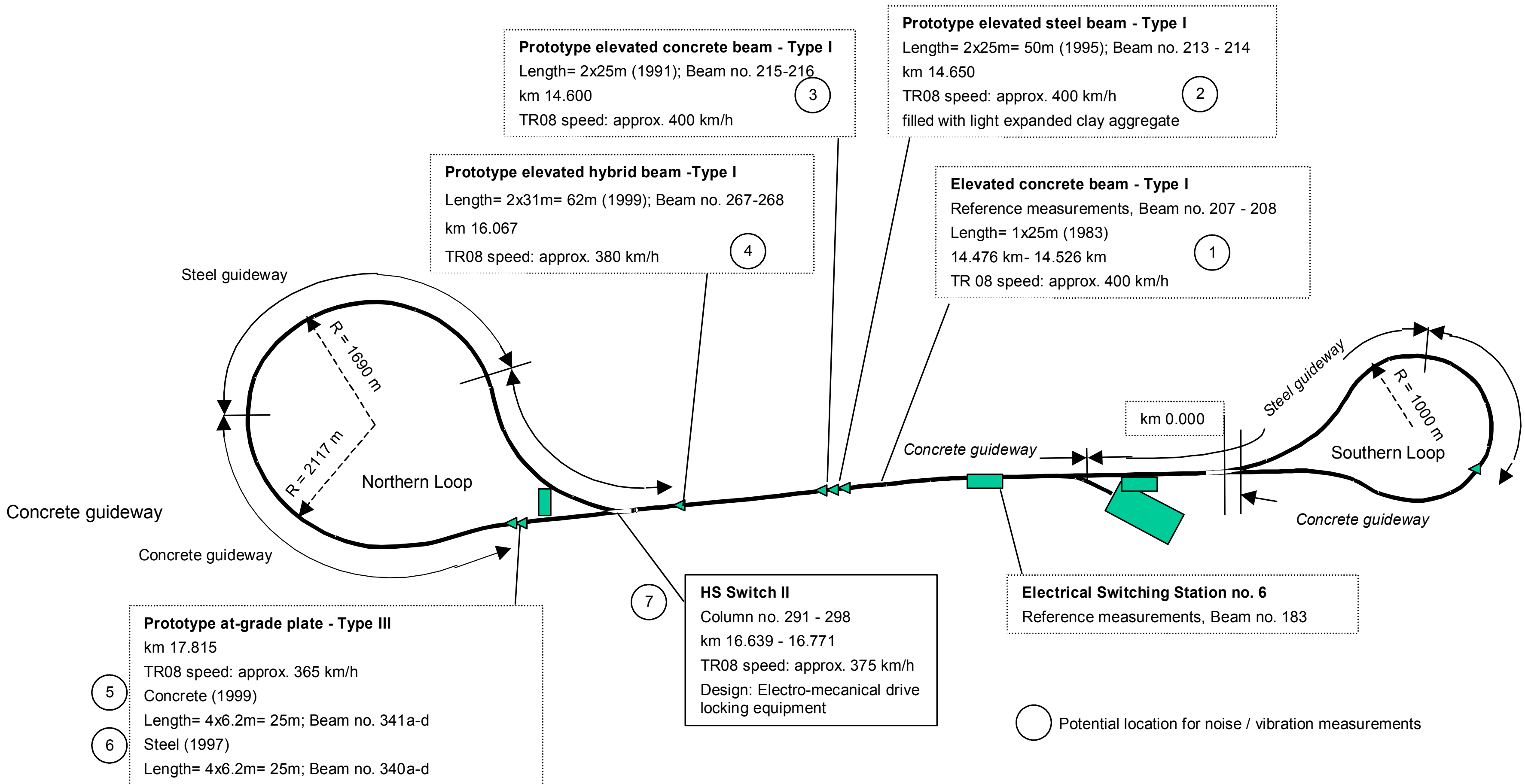
Locations for Noise/Vibration/EMF Measurements and Consolidated Test Matrix

Revised May 24, 2001
To Include Noise Measurements Under the Guideway and Vibration Measurements at the Station Platform

(Appendix C in the original test plans)

Transrapid Test Facility (TVE)
Locations for Noise/Vibration/EMF Measurements

Transrapid International



C-2

Consolidated Test Matrix Schedule of Environmental Noise, Vibration, and EMF Tests at TVE

Date: Monday, 2001-08-13

Noise Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Array configuration	Single microphones	Pass-by vehicle speed [km/h]	Measuring series	Pass-by ID
Inspect equipment, assembly of electronic equipment in measuring van, installation of WX32 microphone array, mount array on IABG telescopic tower.		9:00-18:00							

Date: Monday, 2001-08-13

Vibration Measurement Activities	Trip	Time frame	Measuring location	Beam no.			Pass-by vehicle speed [km/h]	Measuring series	Pass-by ID
Arrive in Amsterdam; clear equipment through customs.		6:00 – 10:00							
Drive to Emsland; orientation at TVE.		10:00-18:00							

Date: Monday, 2001-08-13

EMF Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Sensor array configuration		Vehicle operating speed profile	Measuring series	
Inspect equipment, standardise MultiWave instruments to the time reference of the TVE data acquisition system, select on-board measurement location seat numbers, install sensors on the mannequin, place instruments on charge, and stake sensor locations near the guideway to facilitate rapid relocation of the equipment between tests.		9:00-18:00							

Date: Tuesday, 2001-08-14

Noise Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Array configuration	Single microphones	Pass-by vehicle speed [km/h]	Measuring series	Pass-by ID
Install microphones on WX32 array, calibrate, elevate array to “mid” position, set up single microphones.		7:00-9:30	concrete guideway (reference type) ①	208	setup/ reconstruction	setup/ reconstruction			
Make noise measurements with WX32 array in "mid" position, make noise measurements with single microphones.	N2	09:30-10:00	concrete guideway (reference type) ①	208	WX32	6.5 m (high)	standardized speed profile (150, 200, 300, 400 km/h)	A	A-150-1 A-400-1 A-200-1 A-300-1
	N3	10:00-10:30							A-150-2 A-400-2 A-200-2 A-300-2
	N4	10:30-11:00							A-150-3 A-400-3 A-200-3 A-300-3
Reconfigure array to WX16, elevate array to “mid” position, make noise measurements with single microphones.	N5	11:00-11:30	concrete guideway (reference type) ①	208	setup/ reconstruction	6.5 m (high), 25 m, 50 ft, 100 ft, under guideway	100 km/h	A	A-100-1 A-100-2
						6.5 m (low), 25 m, 50 ft, 100 ft, under guideway	100 km/h	B	B-100-1 B-100-2
Make noise measurements with WX16 array in "mid" position, make noise measurements with single microphones.	N7	13:00-13:30	concrete guideway (reference type) ①	208	WX16	6.5 m (low), 25 m, 50 ft, 100 ft, under guideway	standardized speed profile (150, 200, 300, 400 km/h)	B	B-150-1 B-400-1 B-200-1 B-300-1
	N8	13:45-14:15							B-150-2 B-400-2 B-200-2 B-300-2
	N9 (instead of N6)	14:30-15:00							B-150-3 B-400-3 B-200-3 B-300-3
Retrieve single microphones and reconstruct array to WV08/16/32.		15:00-18:00			setup/ reconstruction	setup/ reconstruction			

Date: Tuesday, 2001-08-14

Vibration Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Activity		Pass-by vehicle speed [km/h]	Measuring series	Pass-by ID
Unpack and check out equipment.		7:00-9:30			setup/ reconstruction				
Set up accelerometer, recording instruments. Calibrate.	N2	09:30-10:00	steel guideway ②	213	setup/ reconstruction		standardized speed profile (150, 200, 300, 400 km/h)	A	A-150-1 A-400-1 A-200-1 A-300-1
	N3	10:00-10:30							A-150-2 A-400-2 A-200-2 A-300-2
	N4	10:30-11:00							A-150-3 A-400-3 A-200-3 A-300-3
Record ground vibrations from TR08 at site.	N5	11:00-11:30	steel guideway ②	213	Measure		100 km/h	A	A-100-1 A-100-2
							100 km/h	B	B-100-1 B-100-2
	N7	13:00-13:30	steel guideway ②	213	Measure		standardized speed profile (150, 200, 300, 400 km/h)	B	B-150-1 B-400-1 B-200-1 B-300-1
	N8	13:45-14:15							B-150-2 B-400-2 B-200-2 B-300-2
	N9	14:30-15:00							B-150-3 B-400-3 B-200-3 B-300-3
Set up ground impacter and conduct transfer mobility test.		15:00-18:00			setup/ reconstruction/ measure				

Date: Tuesday, 2001-08-14

EMF Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Sensor array configuration		Vehicle operating speed profile	Measuring series	
Transport equipment to the lead vehicle, place sensors in the first measurement location, and verify instrument performance.		8:00-9:30	Onboard lead vehicle		Mannequin positions and fixed reference				

EMF Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Sensor array configuration		Vehicle operating speed profile	Measuring series	
Onboard lead vehicle. EMF and RF measurements in three adjacent seats toward the front of the vehicle and away from major on-board equipment to identify center-to-side variation in field levels.	N2	09:30-10:00	Onboard lead vehicle Aisle seat.		„		Standardized speed profile	Onboard	
	N3	10:00-10:30	Onboard lead vehicle Middle seat.		„		Standardized speed profile	Onboard	
	N4	10:30-11:00	Onboard lead vehicle Window seat.		„		Standardized speed profile	Onboard	
Station measurements. EMF and RF measurements in the station as the vehicle departs, passes, and re-enters.	N5	11:00-11:30	Location nearest the vehicle where a passenger might wait.		„		Nonstandard speed profile required for low speed noise measurements	Station	
Onboard lead vehicle. EMF and RF measurements away from major on-board equipment to identify side-to-side variation in field levels.	N7 [1]	13:00-13:30	Onboard lead vehicle Middle seat contra-lateral to seat measured on Trip N3 above.		„		Standardized speed profile	Onboard	
Onboard lead vehicle. EMF and RF measurements away from major on-board equipment to identify front-to-back variation in field levels.	N8 [1]	13:45-14:15	Onboard lead vehicle Middle seat far behind seat measured on Trip N3 above but having similar proximity to onboard equipment.		„		Standardized speed profile	Onboard	
Onboard lead vehicle. EMF and RF measurements away from major on-board equipment to confirm side-to-side and front-to-back variation in field levels.	N9 [1] (instead of N6)	14:30-15:00	Onboard lead vehicle Middle seat contra-lateral to seat measured on Trip N8 above.		„		Standardized speed profile	Onboard	
Remove instruments from the vehicle and place them on charge. Inspect data for integrity and back up.		15:00-16:30			Instruments removed from vehicle				

Note: [1] All trips conforming to the standardized speed profile regardless of their trip number will be used for onboard measurements which will be conducted in the order given in this test plan. If additional trips are made during any given day, they will be used to accelerate the test schedule.

Date: Wednesday, 2001-08-15

Noise Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Array configuration	Single microphones	Pass-by vehicle speed [km/h]	Measuring series	Pass-by ID
Install microphones on WV08/16/32 wayside vertical array, calibrate, elevate array to "high" position.		7:00-9:30	concrete guideway (reference type) ①	208	setup/ reconstruction				
Set up single microphones at at-		7:30-9:30	at-grade	341a-d		setup/			

Noise Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Array configuration	Single microphones	Pass-by vehicle speed [km/h]	Measuring series	Pass-by ID
grade guideway.			guideway (concrete and steel) ⑤⑥	340a-d		reconstruction			
Make noise measurements with WV08/16/32 array in "high" position.	N2	09:30-10:00	concrete guideway (reference type) ①	208	WV08/16/32 (high)	no	standardized speed profile (150, 200, 300, 400 km/h)	C	C-150-1 C-400-1 C-200-1 C-300-1
	N3	10:00-10:30							C-150-2 C-400-2 C-200-2 C-300-2
	N4	10:30-11:00							C-150-3 C-400-3 C-200-3 C-300-3
Make noise measurements with single microphones at at-grade guideway.	N2	09:30-10:00	at-grade guideway (concrete and steel) ⑤⑥	341a-d 340a-d	no	6.5 m (high and low)	standardized speed profile (300, 400 km/h)	Y	Y-400-1 Y-300-1
	N3	10:00-10:30							Y-400-2 Y-300-2
	N4	10:30-11:00							Y-400-3 Y-300-3
Lower array to "low" position.		11:00	concrete guideway (reference type) ①	208	setup/ reconstruction				
Make noise measurements with WV08/16/32 array in "low" position.	N5	11:00-11:30	concrete guideway (reference type) ①	208	WV08/16/32 (low)	no	standardized speed profile (150, 200, 300, 400 km/h)	D	D-150-1 D-400-1 D-200-1 D-300-1
	N6	12:15-12:45							D-150-2 D-400-2 D-200-2 D-300-2
	N7	13:00-13:30							D-150-3 D-400-3 D-200-3 D-300-3
Make noise measurements with single microphones at at-grade guideway.	N5	11:00-11:30	at-grade guideway (concrete and steel) ⑤⑥	341 a-d 340 a-d	no	6.5 m (high and low)	standardized speed profile (300, 400 km/h)	Y	Y-400-4 Y-300-4
	N6	12:15-12:45							Y-400-5 Y-300-5
	N7	13:00-13:30							Y-400-6 Y-300-6
Make noise measurements with WV08/16/32 array in "low" position.	N8	13:45-14:15	at-grade guideway	341 a-d 340 a-d	WV08/16/32	no	100 km/h	D	D-100-1 D-100-2

Noise Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Array configuration	Single microphones	Pass-by vehicle speed [km/h]	Measuring series	Pass-by ID
			(concrete and steel) ⑤⑥		(low)				D-100-3 D-100-4
Make noise measurements with single microphones at at-grade guideway.	N8	13:45-14:15	at-grade guideway (concrete and steel) ⑤⑥	341 a-d 340 a-d	no	6.5 m (high and low)	100 km/h	Y	Y-100-1 Y-100-2
Retrieve single microphones and reconstruct array to wayside horizontal configuration.		14:30-18:00			setup/ reconstruction	setup/ reconstruction			

Date: Wednesday, 2001-08-15

Vibration Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Pass-by vehicle speed [km/h]	Measuring series	Pass-by ID
Set up accelerometers, recording instrumentation, and ground impacter at site near hybrid guideway and conduct transfer mobility test.		7:00-9:30	hybrid guideway ④	267			
Record ground vibrations from TR08 at site. .	N2	09:30-10:00	hybrid guideway ④	267	standardized speed profile (150, 200, 300, 400 km/h)	C	C-150-1 C-400-1 C-200-1 C-300-1
	N3	10:00-10:30					C-150-2 C-400-2 C-200-2 C-300-2
	N4	10:30-11:00					C-150-3 C-400-3 C-200-3 C-300-3
	N5	11:00-11:30			standardized speed profile (150, 200, 300, 400 km/h)	D	D-150-1 D-400-1 D-200-1 D-300-1
Move accelerometer mounts to high speed switch. Set up accelerometers, recording instrumentation at site near switch		11:30 – 13:00	HS switch II ⑦	291-298			
Record ground vibrations from TR08 at site.	N7	13:00 – 13:30			standardized speed profile (150, 200, 300, 400 km/h)	V	V-150-1 V-400-1 V-200-1 V-300-1
	N8	13:45 – 14:15					V-150-2 V-400-2 V-200-2 V-300-2
	N9	14:30 – 15:00					V-150-3 V-400-3 V-200-3 V-300-3
Set up ground impacter at site near switch and conduct transfer mobility test.		15:00 – 18:00					

Date: Wednesday, 2001-08-15

EMF Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Sensor array configuration		Vehicle operating speed profile	Measuring series	
Transport equipment to the lead vehicle, place sensors in the seventh onboard measurement location, and verify instrument performance.		8:00-9:30	Onboard lead vehicle		Mannequin positions and fixed reference				
Onboard lead vehicle. EMF and RF measurements near onboard equipment.	N2	09:30-10:00	Onboard lead vehicle Middle seat above a battery compartment.		„		Standardized speed profile	Onboard	
	N3	10:00-10:30	Onboard lead vehicle Middle seat above battery charger and control equipment.		„		Standardized speed profile	Onboard	
	N4	10:30-11:00	Onboard lead vehicle Middle seat above an air conditioning compressor.		„		Standardized speed profile	Onboard	
Onboard middle vehicle. EMF and RF measurements at a locations corresponding to the to test locations in the lead car to identify variation in field levels among cars. The measurement locations will correspond to three locations where measurements were made in the lead vehicle.	N5	11:00-11:30	Onboard middle vehicle. Middle seat away from onboard equipment.		„		Standardized speed profile	Onboard	
	N6	12:15-12:45	Onboard middle vehicle . Middle seat above a battery compartment.[2]		„		Standardized speed profile	Onboard	
	N7	13:00-13:30	Onboard middle vehicle. Middle seat above a battery charger and control equipment.[2]		„		Standardized speed profile	Onboard	
Station measurements. EMF and RF measurements in the station as the vehicle departs, passes, and re-enters.	N8	13:45-14:15	Location distant from the vehicle where a passenger might wait.		„		Nonstandard speed profile required for low speed noise measurements	Station	
Remove instruments from the station and place them on charge. Inspect data for integrity and back up.		14:30-16:00			Instruments removed from station				

Note: [2] One of these locations may be changed to above the air conditioning compressor if measurements in the lead vehicle show that piece of equipment to be a significant field source.

Date: Thursday, 2001-08-16

Noise Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Array configuration	Single microphones	Pass-by vehicle speed [km/h]	Measuring series	Pass-by ID
Install microphones on WH08/16/32 wayside horizontal array, calibrate, elevate array to "low" position.		7:00-9:30	concrete guideway (reference type) ①	208	setup/ reconstruction				
Install single microphones at northern switch.		9:00-13:00	HS switch II ⑦	291-298		setup/ reconstruction			
Make noise measurements with WH08/16/32 array in "low" position.	N2	09:30-10:00	concrete guideway (reference type) ①	208	WH08/16/32	no	standardized speed profile (150, 200, 300, 400 km/h)	E	E-150-1 E-400-1 E-200-1 E-300-1
	N3	10:00-10:30							E-150-2 E-400-2 E-200-2 E-300-2
	N4	10:30-11:00							E-150-3 E-400-3 E-200-3 E-300-3
Make measurements with single microphones at switch.	N7	13:00-13:30	HS switch II ⑦	291-298	No	6.5 m (high and low), 25 m, 50 ft, 100 ft, under guideway	standardized speed profile (150, 200, 300, 400 km/h)	Z	Z-150-1 Z-400-1 Z-200-1 Z-300-1
	N8	13:45-14:15					standardized speed profile (150, 200, 300, 400 km/h)		Z-150-2 Z-400-2 Z-200-2 Z-300-2
	N9 (instead of N5/N6)	14:30-15:00					100 km/h		Z-100-1 Z-100-2 Z-100-3 Z-100-4
Retrieve single microphones and detach array from tower.		15:00-16:00			setup/ reconstruction	setup/ reconstruction			
Move tower and equipment to measuring site at steel guideway.		16:00-18:00			setup/ reconstruction				

Date: Thursday, 2001-08-16

Vibration Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Pass-by vehicle speed [km/h]	Measuring series	Pass-by ID
Set up accelerometers, recording instrumentation, and ground impacter at site near concrete guideway and conduct transfer mobility test.		7:00-9:30	concrete guideway (reference type) ①	208			
Record ground vibrations from TR08 at site	N2	09:30-10:00	concrete guideway (reference type) ①		standardized speed profile (150, 200, 300, 400 km/h)	E	E-150-1 E-400-1 E-200-1 E-300-1
	N3	10:00-10:30					E-150-2 E-400-2 E-200-2 E-300-2
	N4	10:30-11:00					E-150-3 E-400-3 E-200-3 E-300-3
Move accelerometer mounts to at-grade guideway. Set up accelerometers, recording instrumentation at site.		11:00 – 13:00	at-grade guideway (concrete and steel) ⑤⑥	341a-d 340a-d			
Record ground vibrations from TR08 at site	N7	13:00-13:30	at-grade guideway (concrete and steel) ⑤⑥	341a-d 340a-d	standardized speed profile (150, 200, 300, 400 km/h)	Z	Z-150-1 Z-400-1 Z-200-1 Z-300-1
	N8	13:45-14:15			standardized speed profile (150, 200, 300, 400 km/h)		Z-150-2 Z-400-2 Z-200-2 Z-300-2
	N9 (instead of N5/N6)	14:30-15:00			100 km/h		Z-100-1 Z-100-2 Z-100-3 Z-100-4
Set up ground impacter at site near at-grade guideway and conduct transfer mobility test.		15:00-17:00					
Move accelerometers to station platform site.		17:00-18:00					

Date: Thursday, 2001-08-16 [3]

EMF Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Sensor array configuration		Pass-by vehicle speed [km/h]	Measuring series	
Transport equipment to beam 213 of the elevated guideway, place sensors beneath the guideway and at distances of 5, 20, and 35m from centerline, and verify instrument performance.		8:00-9:30	Elevated steel guideway	213	Lateral profile 1m above ground.				
Wayside. EMF and RF measurements beneath and near elevated guideway.	N2	09:30-10:00	Elevated steel guideway	213	„		Standardized speed profile (300 and 400 km/h passes recorded)	Guideway	
	N3	10:00-10:30	Elevated concrete guideway	215	„			Guideway	
	N4	10:30-11:00	Elevated hybrid guideway	267-268	„			Guideway	
Wayside. EMF and RF measurements near at-grade guideway.	N7[4]	13:00-13:30	Steel at-grade plate	340 a-d	„		Standardized speed profile (200 and 400 km/h passes recorded)	Guideway	
	N8[4]	13:45-14:15	Concrete at-grade plate	341 a-d	„			Guideway	
Wayside. EMF and RF measurements near wayside electrical switching cabinets.	N9[4] (instead of N5)	14:30-15:00	Standard switch cabinets	183	„		Standardized speed profile (300 and 400 km/h passes recorded)	Wayside equipment	
	N10[4] (instead of N6)	15:00-15:30	Switch building designed for Berlin/Hamberg		„			Wayside equipment	
Remove instruments from the wayside and place them on charge. Inspect data for integrity and back up.		15:30-17:30			Instruments removed from wayside				

Notes: [3] Outdoor measurements described for this day may be moved a day earlier or a day later depending on weather conditions.
[4] All trips conforming to the standardized speed profile regardless of their trip number will be used for guideway measurements. Non-standard trips will be used for the switching cabinet measurements if required

Date: Friday, 2001-08-17

Noise Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Array configuration	Single microphones	Pass-by vehicle speed [km/h]	Measuring series	Pass-by ID
Install microphones on WV08/16/32 wayside vertical array, calibrate, elevate array to "high" position, set up single microphones.		7:00-9:30	steel guideway ②	213	setup/ reconstruction	setup/ reconstruction			
Make noise measurements with WV08/16/32 array in "high" position, make measurements with single microphones.	N2	09:30-10:00	steel guideway ②	213	WV08/16/32 (high)	6.5 m (high)	standardized speed profile (150, 200, 300, 400 km/h)	G	G-150-1 G-400-1 G-200-1 G-300-1
	N3	10:00-10:30							G-150-2 G-400-2 G-200-2 G-300-2
	N4	10:30-11:00							G-150-3 G-400-3 G-200-3 G-300-3
Lower microphone array and 6.5 m single microphone to "low" position.		11:00			setup/ reconstruction	setup/ reconstruction			
Make noise measurements with WV08/16/32 array in "low" position, make noise measurements with single microphones.	N5	11:00-11:30	steel guideway ②	213	WV08/16/32 (low)	6.5 m (low), 25 m, 50 ft, 100 ft, under guideway	standardized speed profile (150, 200, 300, 400 km/h)	H	H-150-1 H-400-1 H-200-1 H-300-1
	N6	12:15-12:45							H-150-2 H-400-2 H-200-2 H-300-2
	N7	13:00-13:30							H-150-3 H-400-3 H-200-3 H-300-3
	N8	13:45-14:15				6.5 m (low), 25 m, 50 ft, 100 ft, under guideway	100 km/h		H-100-1 H-100-2
						6.5 m (high), 25 m, 50 ft, 100 ft, under guideway	100 km/h		H-100-3 H-100-4
Retrieve single microphones and detach array from tower.		14:30-16:30							

Move tower to measuring site at hybrid guideway.		15:30-16:30							
Reconstruct array to WV08/16/32.		16:30-17:30			setup/ reconstructio n				
Pack equipment for weekend storage.		17:30-18:00							

Date: Friday, 2001-08-17

Vibration Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Pass-by vehicle speed [km/h]	Measuring series	Pass-by ID
Set up accelerometers, recording instrumentation, and ground impacter at site near station platform and conduct transfer mobility test.		7:00-9:30	Station Platform				
Record ground vibrations from TR08 at site	N2	09:30-10:00	Station Platform		Low	G	G-1
	N3	10:00 –10:30					G-2
	N4	10:30-11:00					G-3
Pack equipment and depart TVE		11:00 – 15:00					

Date: Friday, 2001-08-17

EMF Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Sensor array configuration		Vehicle operating speed profile	Measuring series	
Transport equipment to the trailing vehicle, place sensors in the seventh onboard measurement location, and verify instrument performance.		8:00-9:30	Onboard trailing vehicle		Mannequin positions and fixed reference				
Onboard trailing vehicle. EMF and RF measurements at a locations corresponding to the to test locations in the lead car to identify variation in field levels among cars. The measurement locations will correspond to three locations where measurements were made in the lead vehicle.	N2	09:30-10:00	Onboard trailing vehicle. Middle seat away from onboard equipment.		„		Standardized speed profile	Onboard	
	N3	10:00-10:30	Onboard middle vehicle . Middle seat above a battery compartment.[2]		„		Standardized speed profile	Onboard	
	N4	10:30-11:00	Onboard middle vehicle. Middle seat above a battery charger and control equipment.[2]		„		Standardized speed profile	Onboard	
Onboard leading vehicle. EMF and RF measurements at the attendant's position in the nose of the vehicle.	N5	11:00-11:30	Onboard leading vehicle. Attendant's position in the nose of the vehicle.		„		Standardized speed profile	Onboard	
Onboard leading vehicle. EMF and RF measurements near onboard equipment.	N6	12:15-12:45	Onboard leading vehicle. Standing near the air handlers at the rear of the vehicle.		„		Standardized speed profile	Onboard	
Contingency This trip will be used to repeat any defective onboard measurement or conduct an additional onboard measurement suggested by a review of data collected in the first two measurement days.	N7	13:00-13:30	As required.		„		Standardized speed profile	Onboard	
Contingency This trip will be used to repeat any defective station measurement or conduct an additional station measurement suggested by a review of data collected in the first two measurement days.	N8	13:45-14:15	As Required.		„		Nonstandard speed profile required for low speed noise measurements	Station	
Remove instruments from the station and pack for shipment. Inspect data for integrity and back up.		14:15-18:00			Instruments removed from station				

Date: Tuesday, 2001-08-21

Noise Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Array configuration	Single microphones	Pass-by vehicle speed [km/h]	Measuring series	Pass-by ID
Install microphones on WV08/16/32 wayside vertical array, calibrate, elevate array to "high" position, set up single microphones.		7:00-9:30	hybrid guideway ④	267	setup/ reconstruction	setup/ reconstruction			
Make noise measurements with WV08/16/32 array in "high" position, make noise measurements with single microphones.	N2	09:30-10:00	hybrid guideway ④	267	WV08/16/32 (high)	6.5 m (high)	standardized speed profile (150, 200, 300, 400 km/h)	I	I-150-1 I-400-1 I-200-1 I-300-1
	N3	10:00-10:30							I-150-2 I-400-2 I-200-2 I-300-2
	N4	10:30-11:00							I-150-3 I-400-3 I-200-3 I-300-3
Lower array and 6.5 m single microphone to "low" position.		11:00			setup/ reconstruction	setup/ reconstruction			
Make noise measurements with WV08/16/32 array in "low" position, make noise measurements with single microphones.	N5	11:00-11:30	hybrid guideway ④	267	WV08/16/32 (low)	6.5 m (low), 25 m, 50 ft, 100 ft, under guideway	standardized speed profile (150, 200, 300, 400 km/h)	J	J-150-1 J-400-1 J-200-1 J-300-1
	N6	12:15-12:45							J-150-2 J-400-2 J-200-2 J-300-2
	N7	13:00-13:30							J-150-3 J-400-3 J-200-3 J-300-3
	N8	13:45-14:15				6.5 m (low), 25 m, 50 ft, 100 ft, under guideway	100 km/h		J-100-1 J-100-2
						6.5 m (high), 25 m, 50 ft, 100 ft, under guideway	100 km/h		J-100-3 J-100-4
Retrieve single microphones and detach array from tower.		14:30-15:30							
Move tower and equipment to measuring site at concrete guideway.		15:30-16:30							

Reconstruct array to WV08/16/32.		16:30-18:00			setup/ reconstruction				

Date: Tuesday, 2001-08-21

Vibration Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Array configuration	Single microphones	Pass-by vehicle speed [km/h]	Measuring series	Pass-by ID
Contingency day for tests if delays.									

Date: Wednesday, 2001-08-22

Noise Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Array configuration	Single microphones	Pass-by vehicle speed [km/h]	Measuring series	Pass-by ID
Install microphones on WV08/16/32 wayside vertical array, calibrate, elevate array to “high” position, set up single microphones.		7:00-9:30	prototype concrete guideway ③	215	setup/ reconstruction	setup/ reconstruction			
Make noise measurements with WV08/16/32 array in "high" position, make noise measurements with single microphones.	N2	09:30-10:00	prototype concrete guideway ③	215	WV08/16/32 (high)	6.5 m (high)	standardized speed profile (150, 200, 300, 400 km/h)	K	K-150-1 K-400-1 K-200-1 K-300-1
	N3	10:00-10:30							K-150-2 K-400-2 K-200-2 K-300-2
	N4	10:30-11:00							K-150-3 K-400-3 K-200-3 K-300-3
Lower array and 6.5 m single microphone to "low" position.		11:00			setup/ reconstruction	setup/ reconstruction			
Make noise measurements with WV08/16/32 array in "low" position, make noise measurements with single microphones.	N5	11:00-11:30	prototype concrete guideway ③	215	WV08/16/32 (low)	6.5 m (low), 25 m, 50 ft, 100 ft, under guideway	standardized speed profile (150, 200, 300, 400 km/h)	L	L-150-1 L-400-1 L-200-1 L-300-1
	N6	12:15-12:45							L-150-2 L-400-2 L-200-2 L-300-2
	N7	13:00-13:30							L-150-3 L-400-3 L-200-3 L-300-3
	N8	13:45-14:15				6.5 m (low), 25 m, 50 ft, 100 ft, under guideway	100 km/h		L-100-1 L-100-2
						6.5 m (high), 25 m, 50 ft, 100 ft, under guideway	100 km/h		L-100-3 L-100-4
Retrieve single microphones and detach array from tower. Pack		14:30-18:00							

equipment.									

Date: Wednesday, 2001-08-22

Vibration Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Array configuration	Single microphones	Pass-by vehicle speed [km/h]	Measuring series	Pass-by ID
Contingency day for tests if delays encountered..									

Date: Thursday, 2001-08-22

Noise Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Array configuration	Single microphones	Pass-by vehicle speed [km/h]	Measuring series	Pass-by ID
Additional contingency day due to weather problems or other unforeseen events.									

APPENDIX B Vibration Instrumentation and Equipment

Mfr	Description	Type	Serial #	Function
PCB	Accelerometer	393C	2481	Vibration Transducer
PCB	Accelerometer	393C	2480	Vibration Transducer
PCB	Accelerometer	393C	2482	Vibration Transducer
PCB	Accelerometer	393C	3179	Vibration Transducer
PCB	Accelerometer	393C	2876	Vibration Transducer
PCB	Accelerometer	393B	162	Vibration Transducer
PCB	Power Unit	480E09	24641	ICP Amplifier for accelerometer
PCB	Power Unit	480C02	2368	ICP Amplifier for accelerometer
PCB	Power Unit	480C02	2367	ICP Amplifier for accelerometer
PCB	Power Unit	480C02	2366	ICP Amplifier for accelerometer
PCB	Power Unit	480C02	18974	ICP Amplifier for accelerometer
PCB	Power Unit	480E09	18975	ICP Amplifier for accelerometer
PCB	Transducer Simulator	492B	574	Calibrator
Custom Signals	Radar Gun	Falcon	10129	Speed Detector
TEAC	8 Chan. Recorder	RD135T	731044	DAT Field Recorder
EPAC	Line Amp	60/10LN	071	Amplifier for vibration signal
EPAC	Line Amp	60/10LN	115	Amplifier for vibration signal
EPAC	Line Amp	60/10LN	22500	Amplifier for vibration signal
EPAC	Line Amp	60/10LN	224	Amplifier for vibration signal
EPAC	Line Amp	60/10LN	068	Amplifier for vibration signal
EPAC	Line Amp	60/10LN	079	Amplifier for vibration signal
EPAC	Line Amp	60/10LN	114	Amplifier for vibration signal
Powerwinch	Elect. Winch	501	N/A	Hoists weight
HMMH	Tripod Set	N/A	N/A	Support structure for winch
HMMH	Weight Set	N/A	N/A	Imparts force to ground
Sensotec	Load Cell	41/574-03	286906	Measures force
Sensotec	In Line Amp.		448380	Amplifier for force signal
Sensotec	In Line Amp.		525226	Backup amplifier

APPENDIX C Site Photographs

Figure C-1. Vibration Transducers in Field at Concrete Reference Beam 231

Figure C-2. Concrete Reference Beam 231

Figure C-3. Ground-borne Vibration Transducers at Steel Beam 213

Figure C-4. Steel Beam 213 and Nearby Vibration Transducers

Figure C-5. Ground-borne Vibration Transducers at Hybrid Beam 267

Figure C-6. North End of Hybrid Beam 267

Figure C-7. Vibration Transducers at North Switch

Figure C-8. North End of At-Grade Concrete Beam 341

Figure C-9. At-Grade Steel Beam 340

Figure C-10. Station Beam 2422 with Vibration Transducers on Ground

APPENDIX D Transfer Mobility Data

Included in this appendix are point source transfer mobility and coherence for each vibration propagation measurement. Point source transfer mobility (TM_{point}) is the ratio of the vibration velocity at one location and an excitation force at another location. TM_{point} is a function frequency that defines the vibration propagation characteristics between the point of application of the force and the location where the resulting vibration velocity is measured. A high value of mobility in a frequency band is an indication that vibration transmits readily at those frequencies.

Coherence is a measure of the linear dependence between the impact signal and the measured vibration signal as a function of frequency. A low coherence would indicate that the output measured was not related to the input.

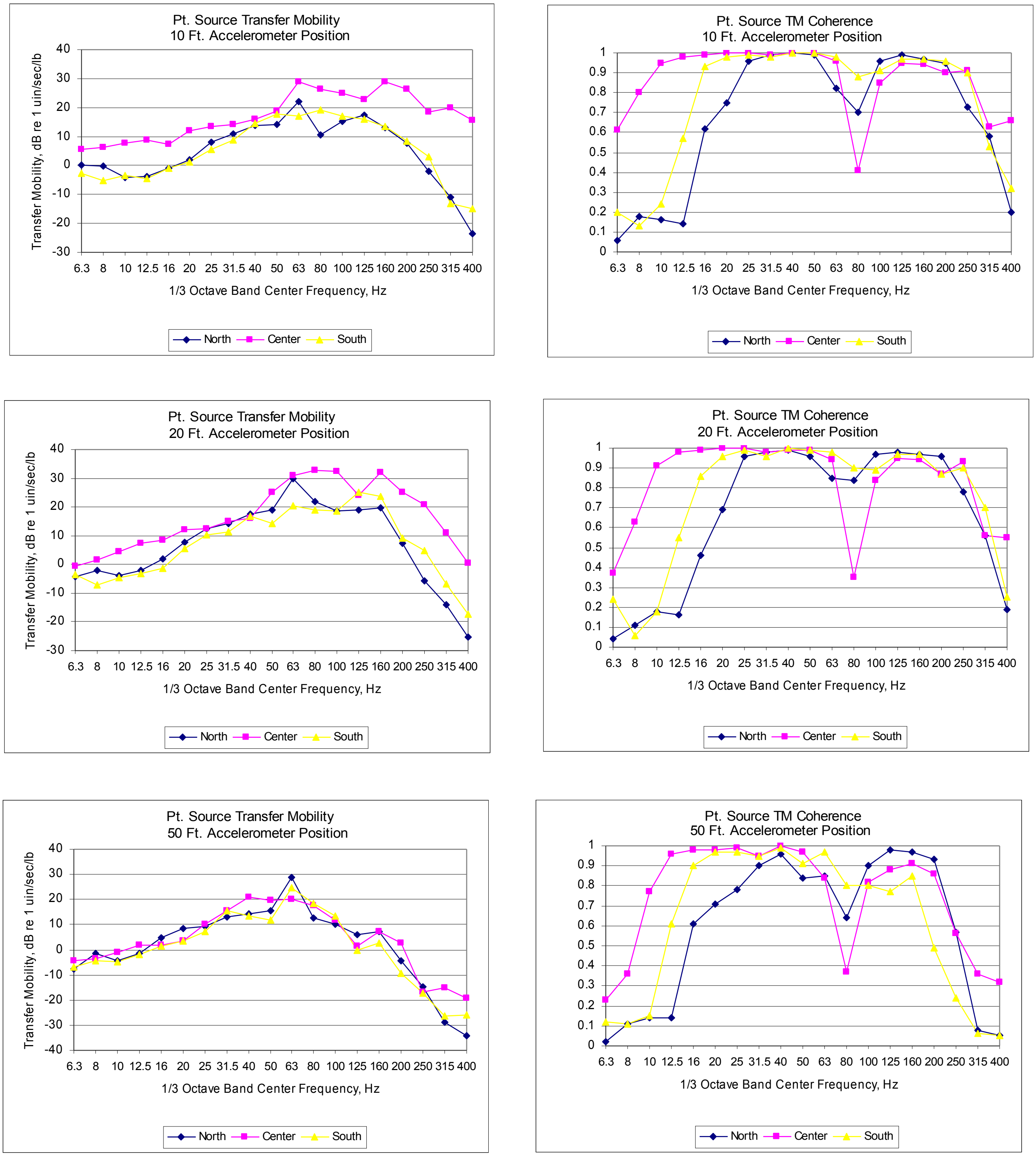


Figure D-1. Point Source Transfer Mobility and Coherence, Concrete Beam (10, 25, 50 ft positions)

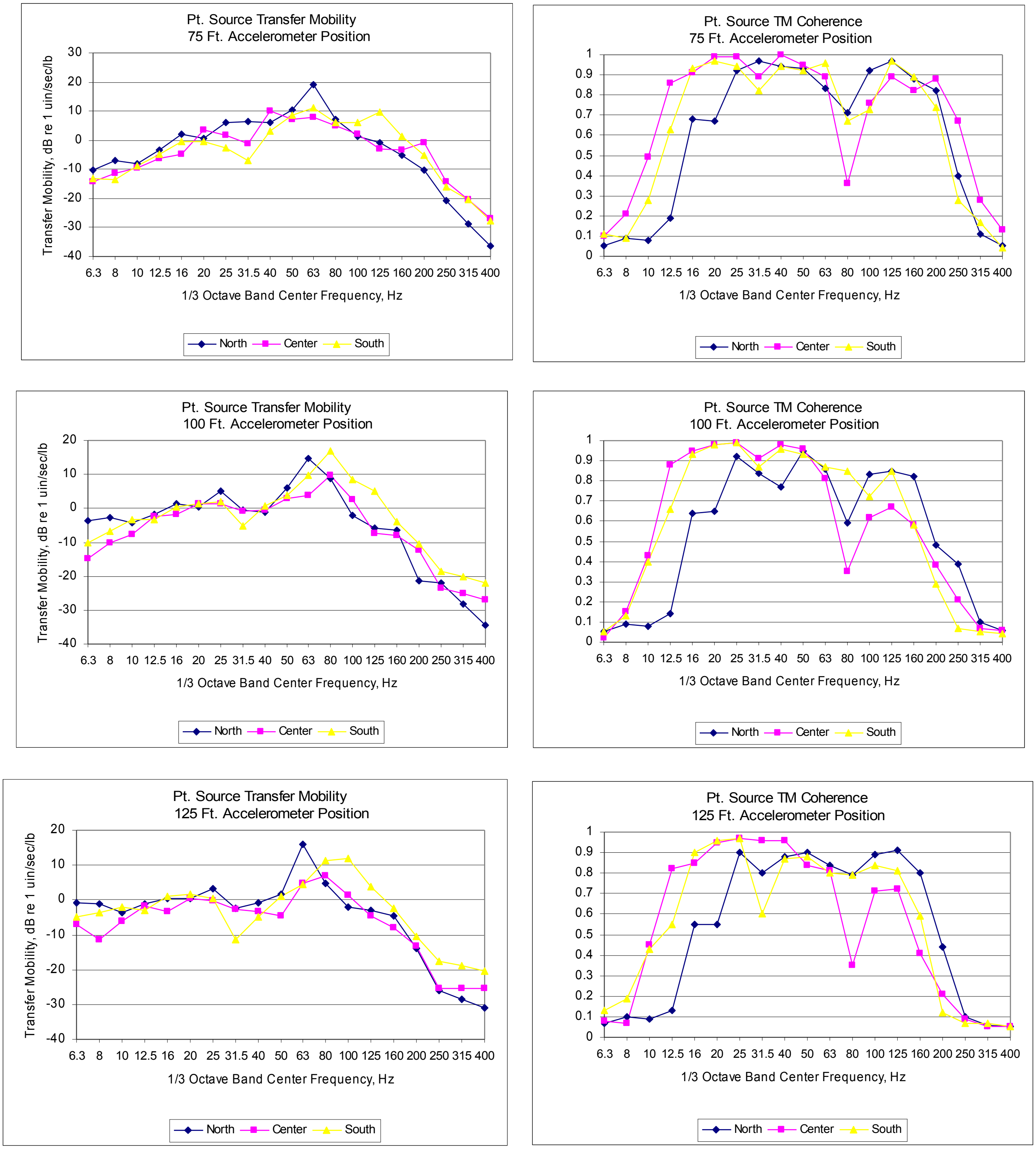
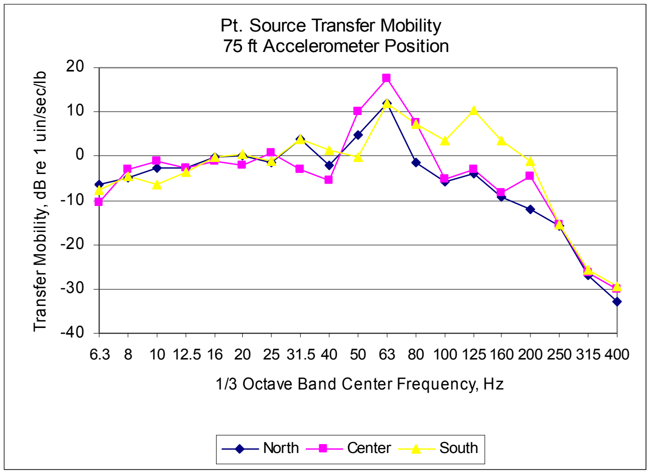
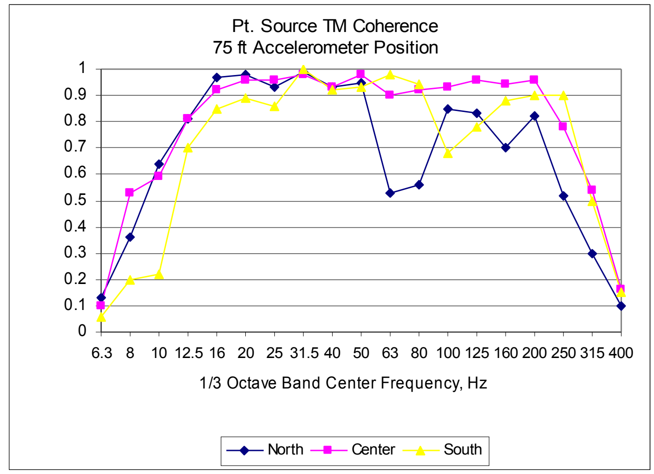
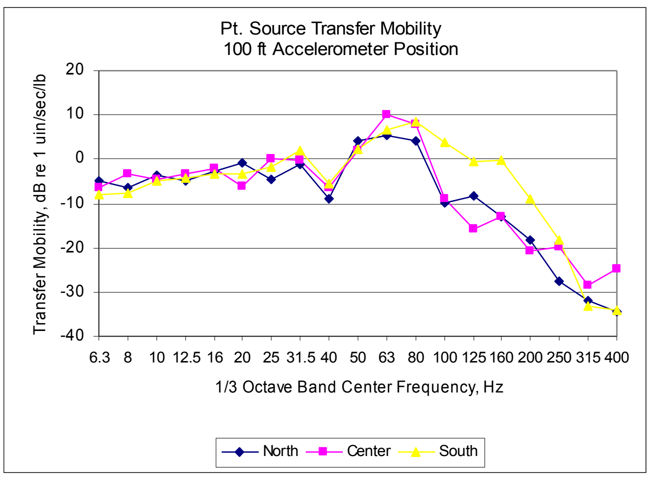


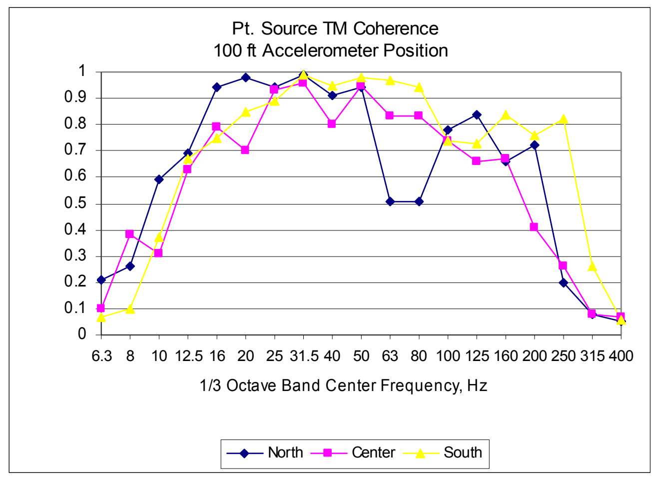
Figure D-2. Point Source Transfer Mobility and Coherence, Concrete Beam (75, 100, 125 ft positions)

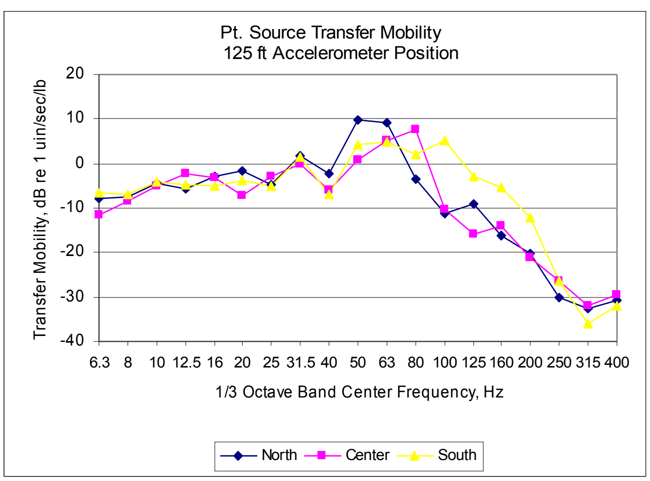
Figure D-3. Point Source Transfer Mobility and Coherence, Steel Beam (10, 25, 51 ft positions)











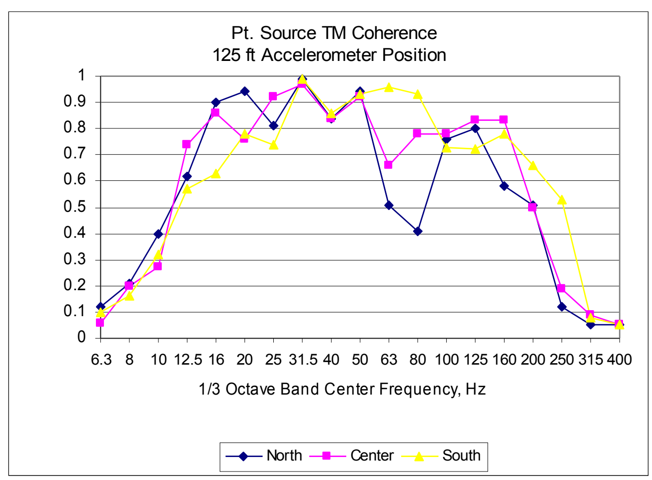


Figure D-4. Point Source Transfer Mobility and Coherence, Steel Beam (75, 100, 125 ft positions)

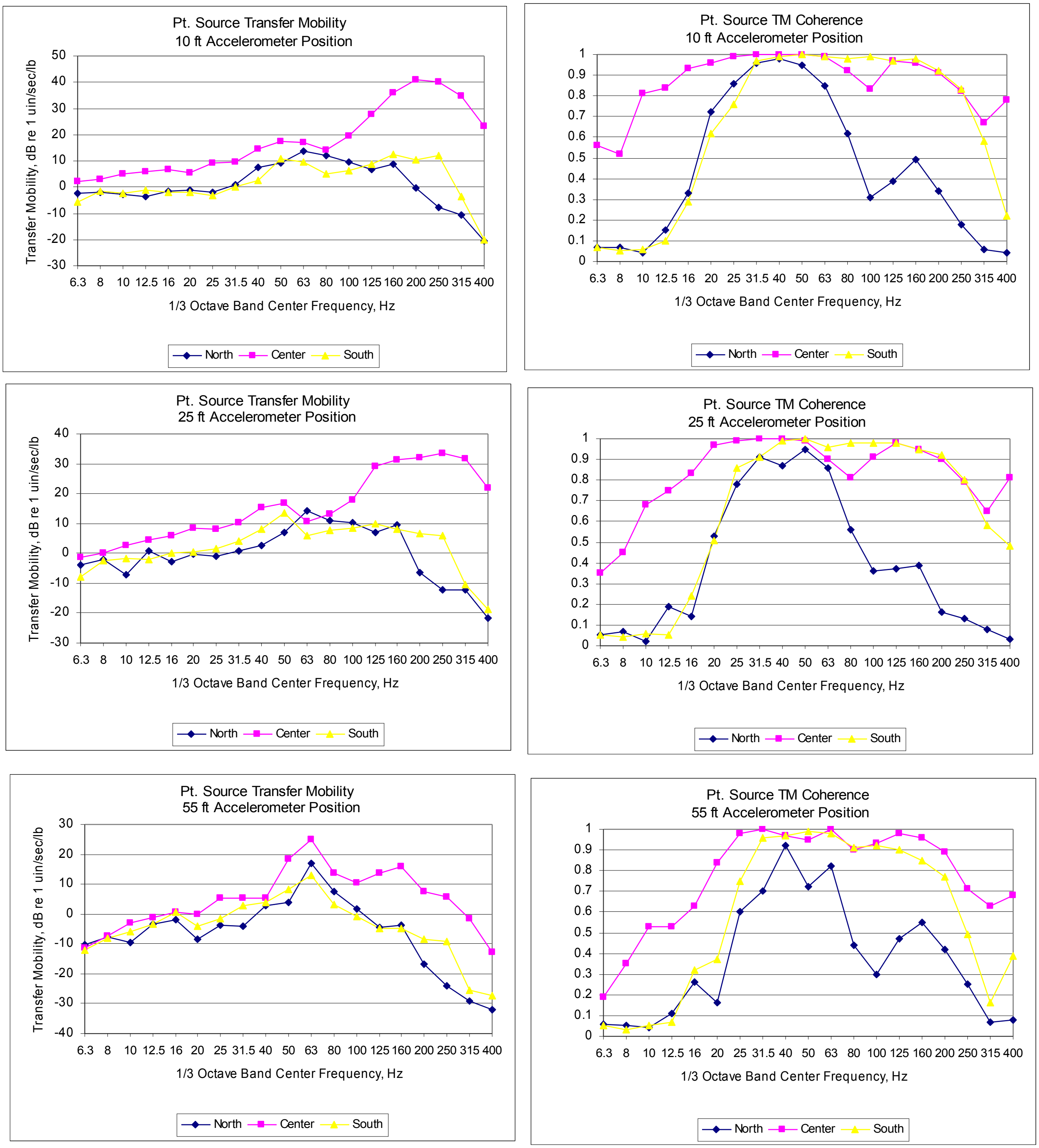


Figure D-5. Point Source Transfer Mobility and Coherence, Hybrid Beam (10, 25, 55 ft positions)

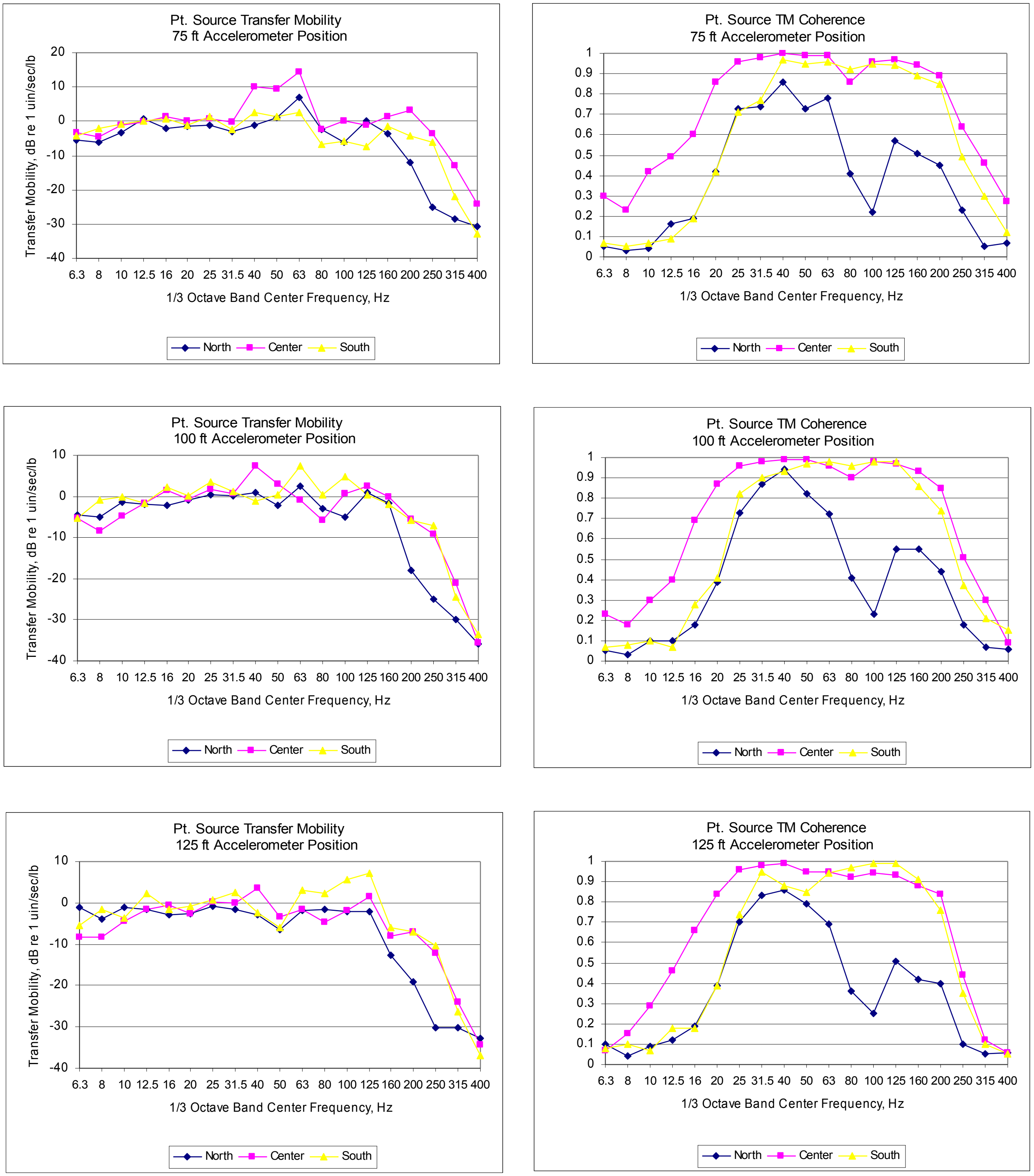


Figure D-6. Point Source Transfer Mobility and Coherence, Hybrid Beam (75, 100, 125 ft positions)

APPENDIX E Vibration Spectra

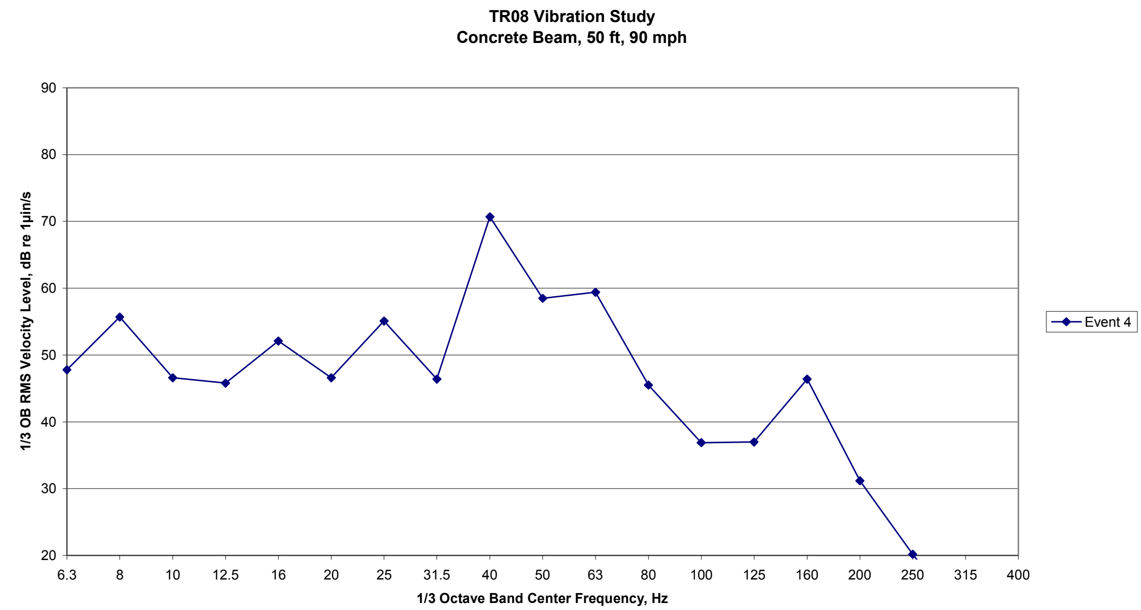


Figure E-1. Vibration Spectra, Concrete Beam, 50 ft, 90 mph

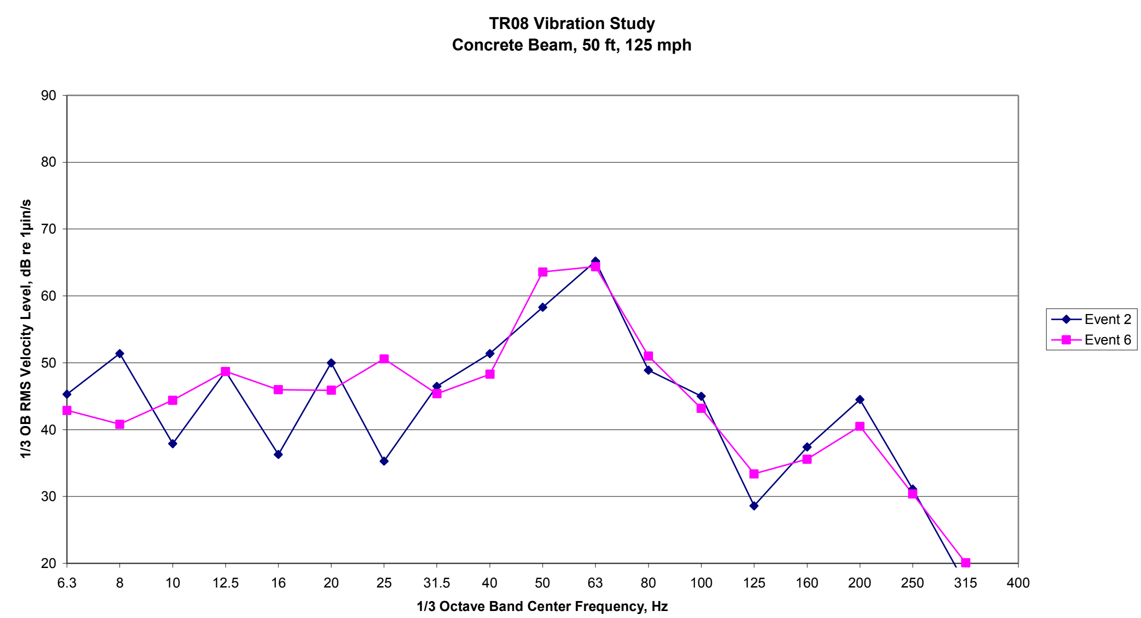


Figure E-2. Vibration Spectra, Concrete Beam, 50 ft, 125 mph

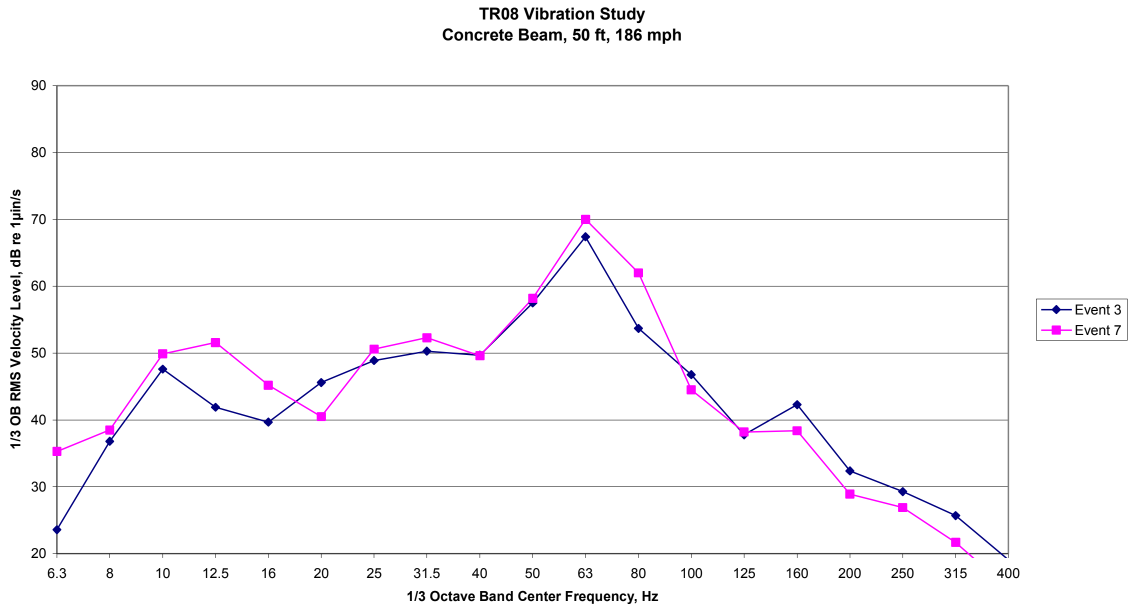


Figure E-3. Vibration Spectra, Concrete Beam, 50 ft, 186 mph

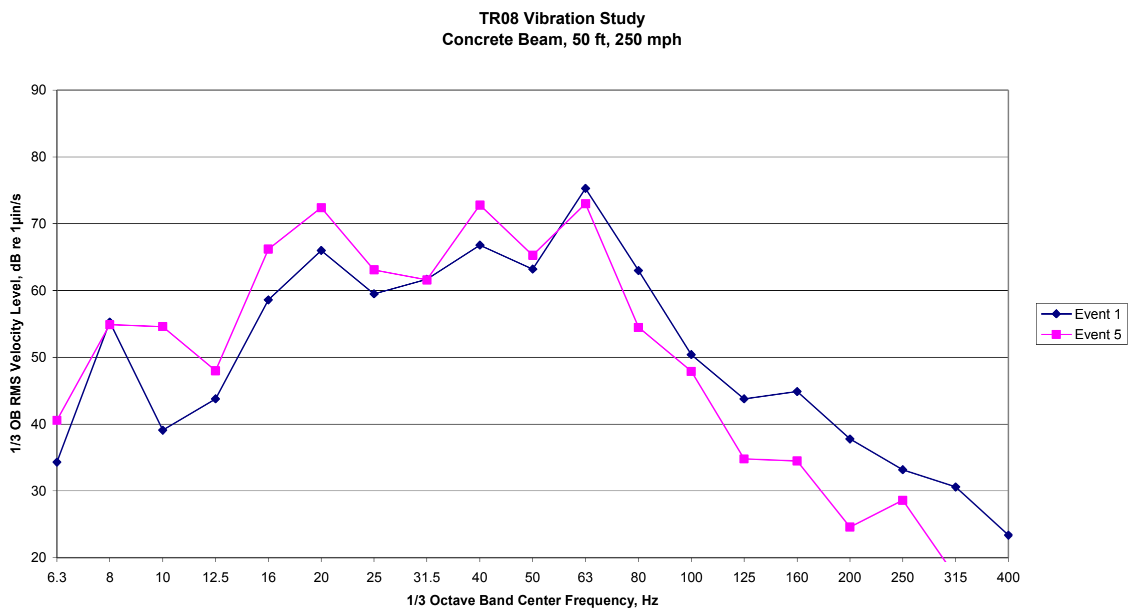


Figure E-4. Vibration Spectra, Concrete Beam, 50 ft, 250 mph

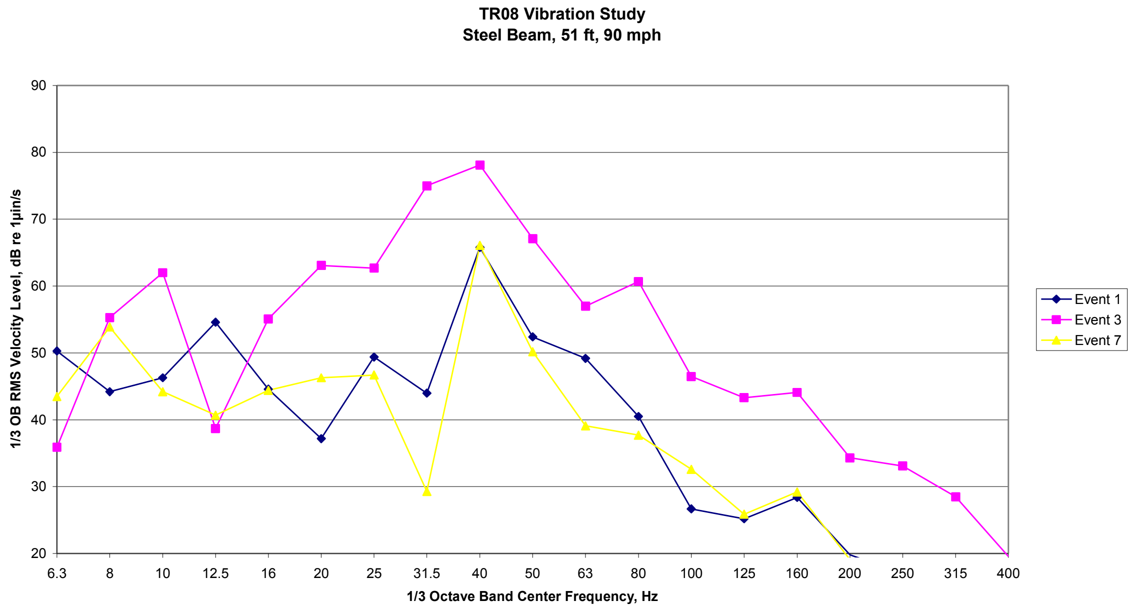


Figure E-5. Vibration Spectra, Steel Beam, 51 ft, 90 mph

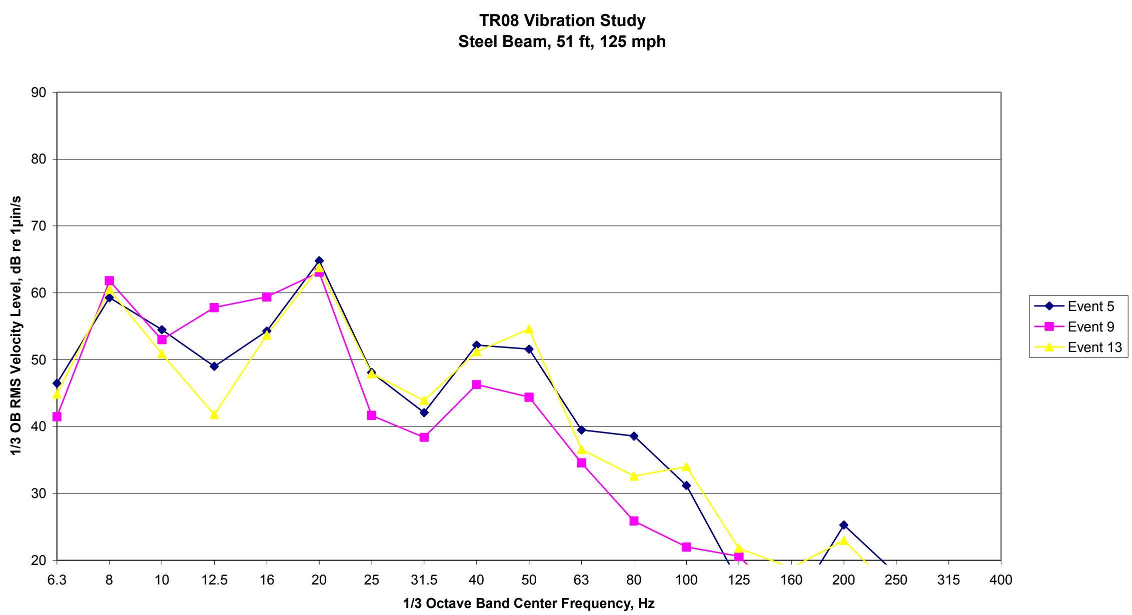


Figure E-6. Vibration Spectra, Steel Beam, 51 ft, 125 mph

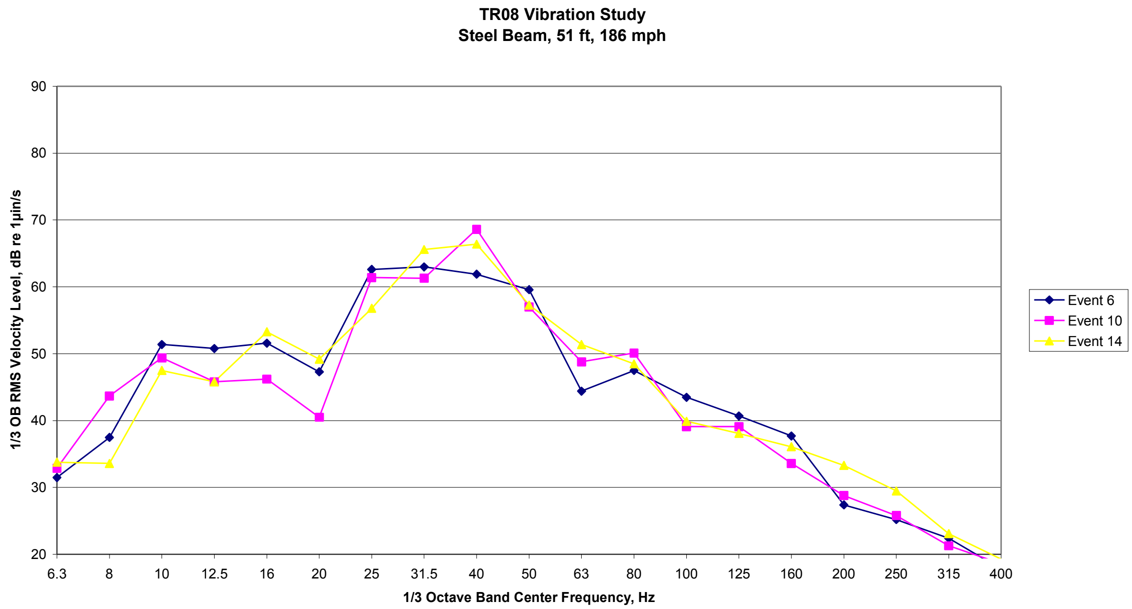


Figure E-7. Vibration Spectra, Steel Beam, 51 ft, 186 mph

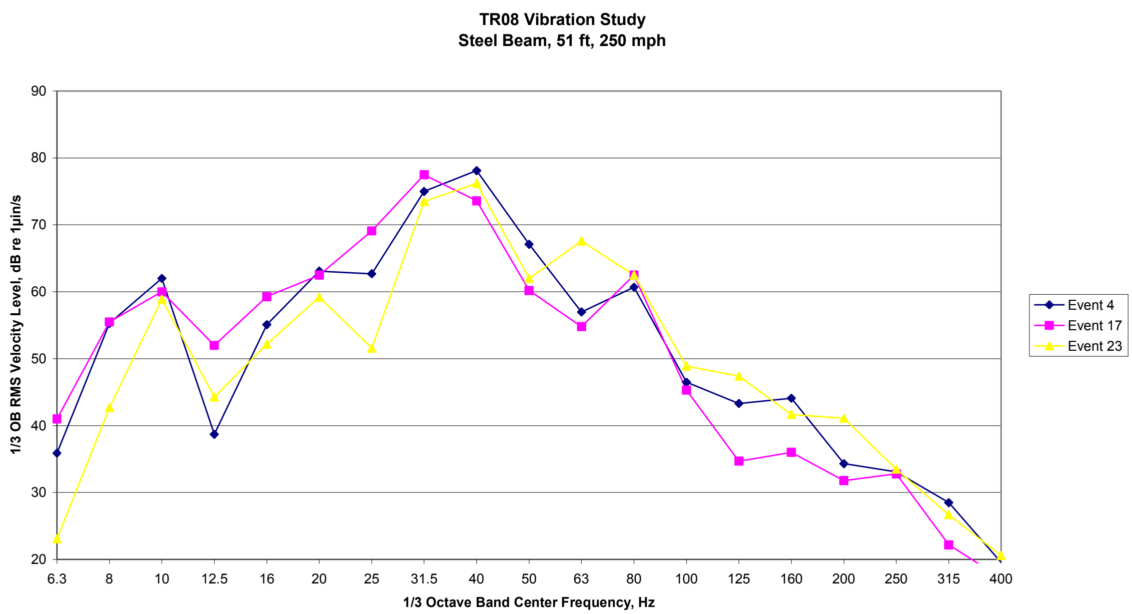


Figure E-8. Vibration Spectra, Steel Beam, 51 ft, 250 mph

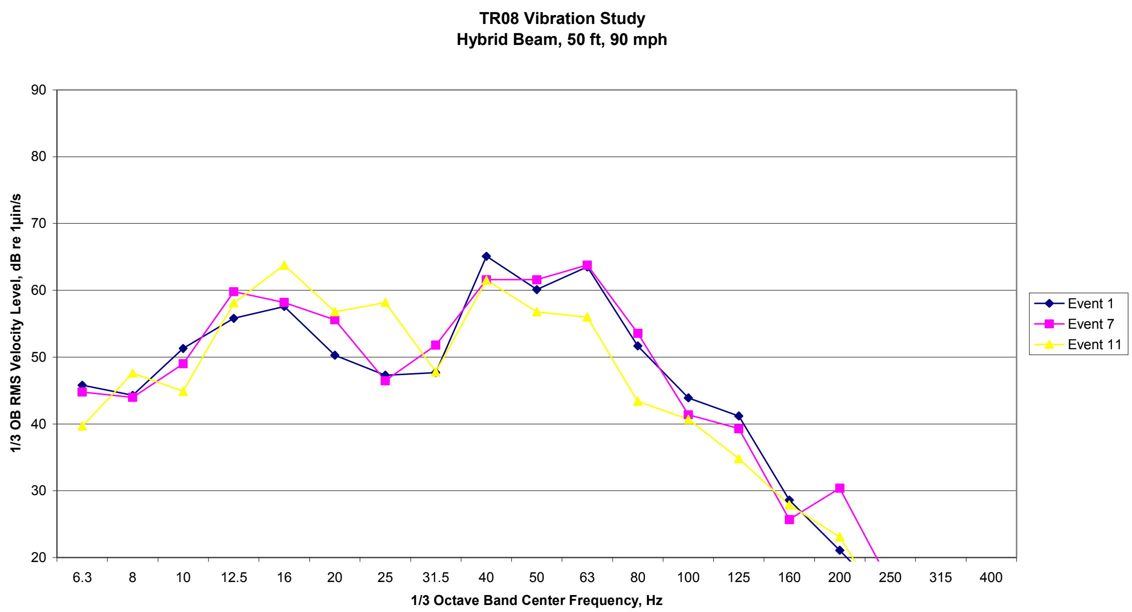


Figure E-9. Vibration Spectra, Hybrid Beam, 50 ft, 90 mph

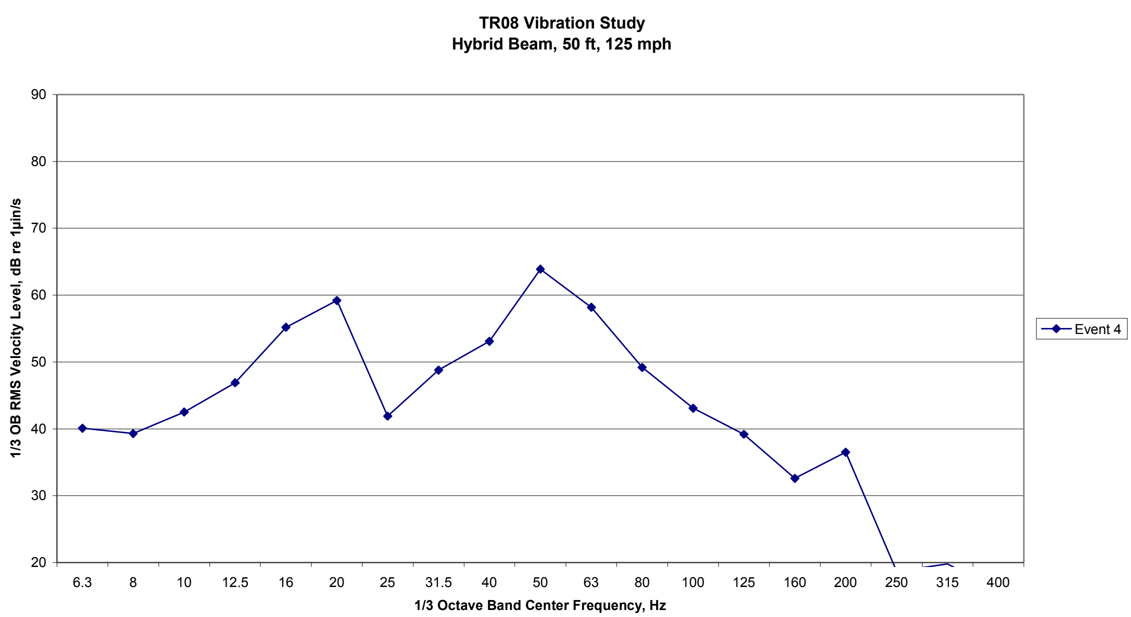


Figure E-10. Vibration Spectrum, Hybrid Beam, 50 ft, 125 mph

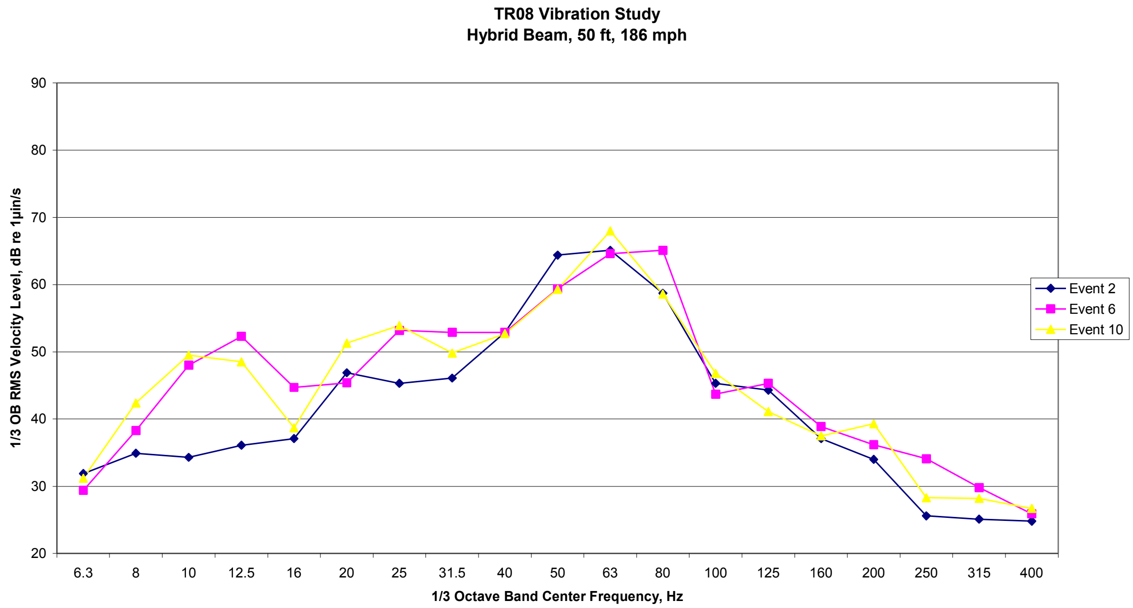


Figure E-11. Vibration Spectra, Hybrid Beam, 50 ft, 186 mph

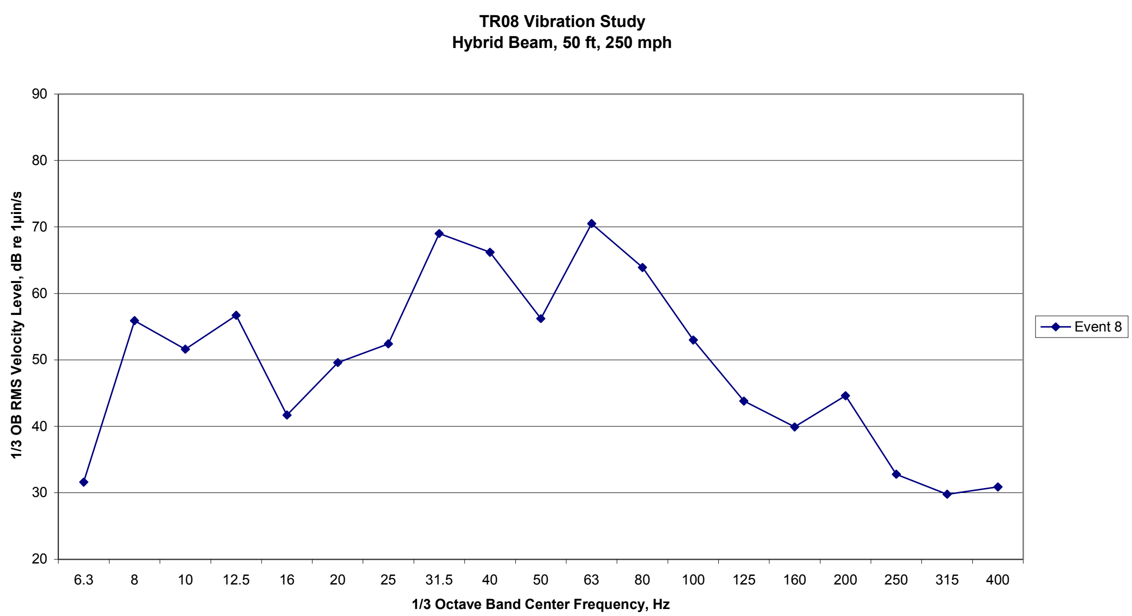


Figure E-12. Vibration Spectrum, Hybrid Beam, 50 ft, 250 mph

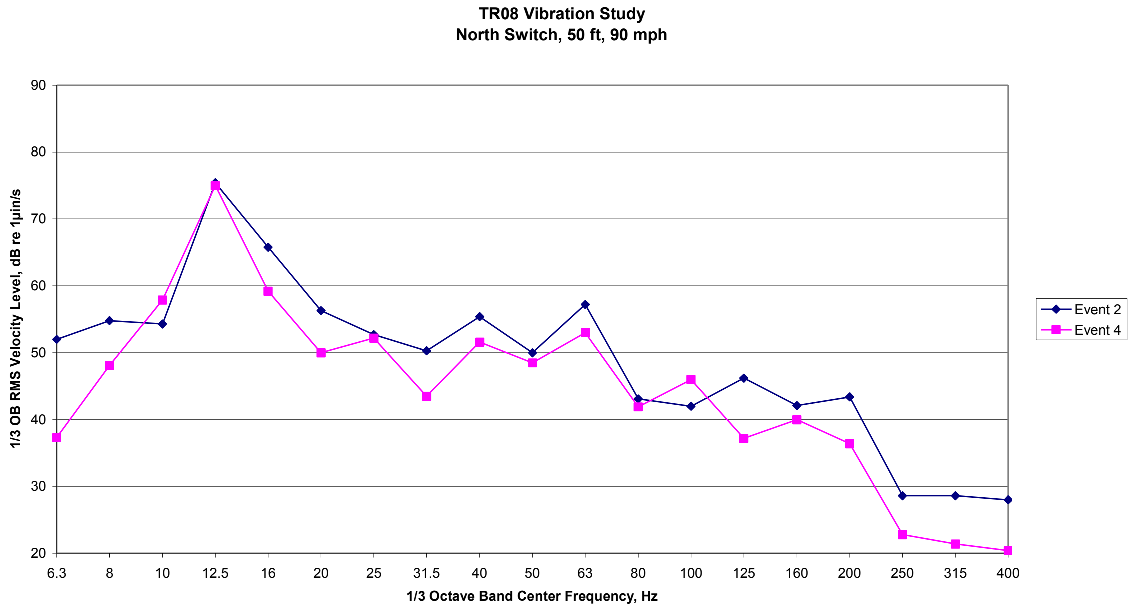


Figure E-13. Vibration Spectra, High Speed Switch, 50 ft, 90 mph

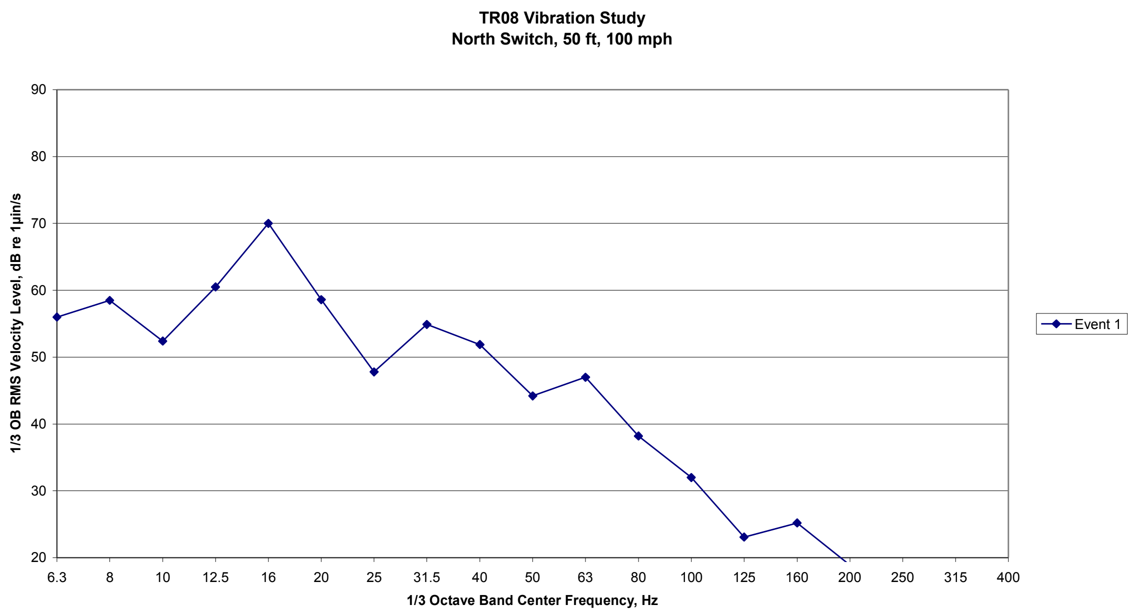


Figure E-14. Vibration Spectrum, High Speed Switch, 50 ft, 100 mph

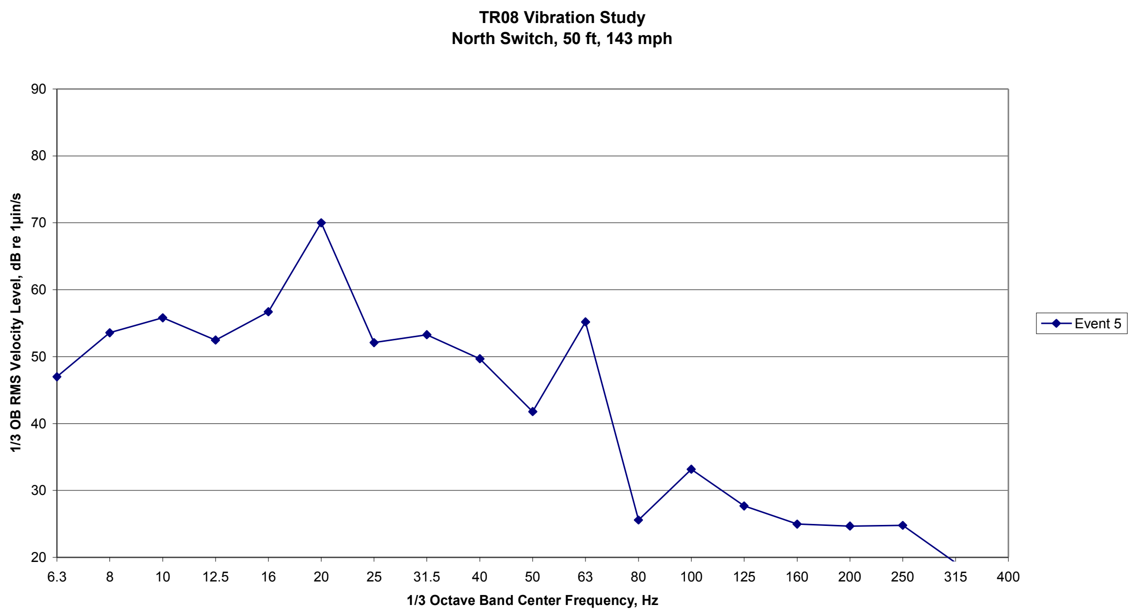


Figure E-15. Vibration Spectrum, High Speed Switch, 50 ft, 143 mph

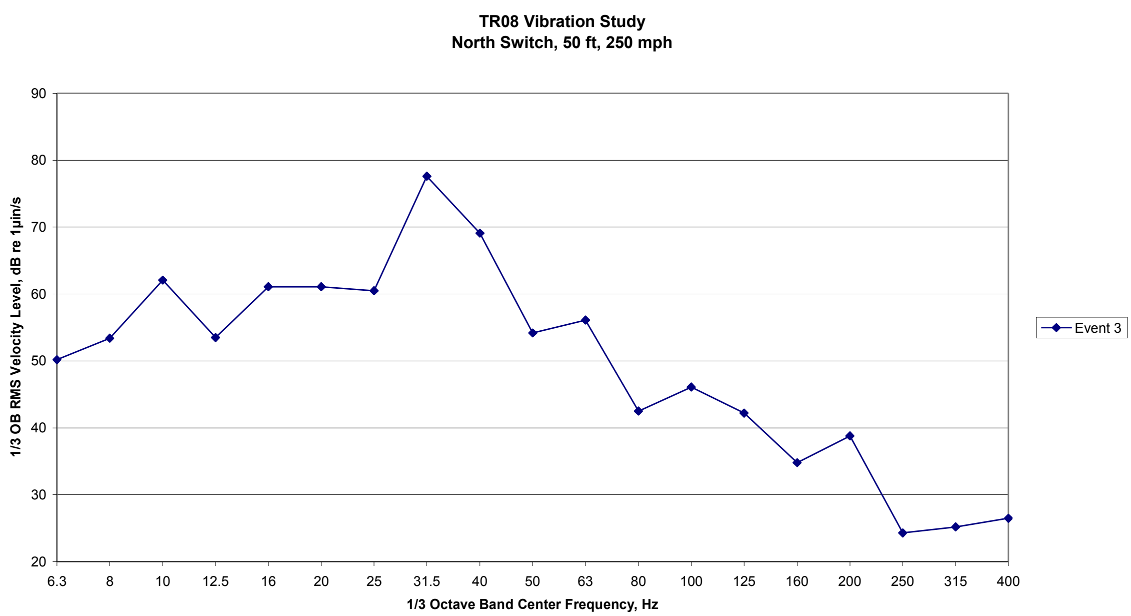


Figure E-16. Vibration Spectrum, High Speed Switch, 50 ft, 250 mph

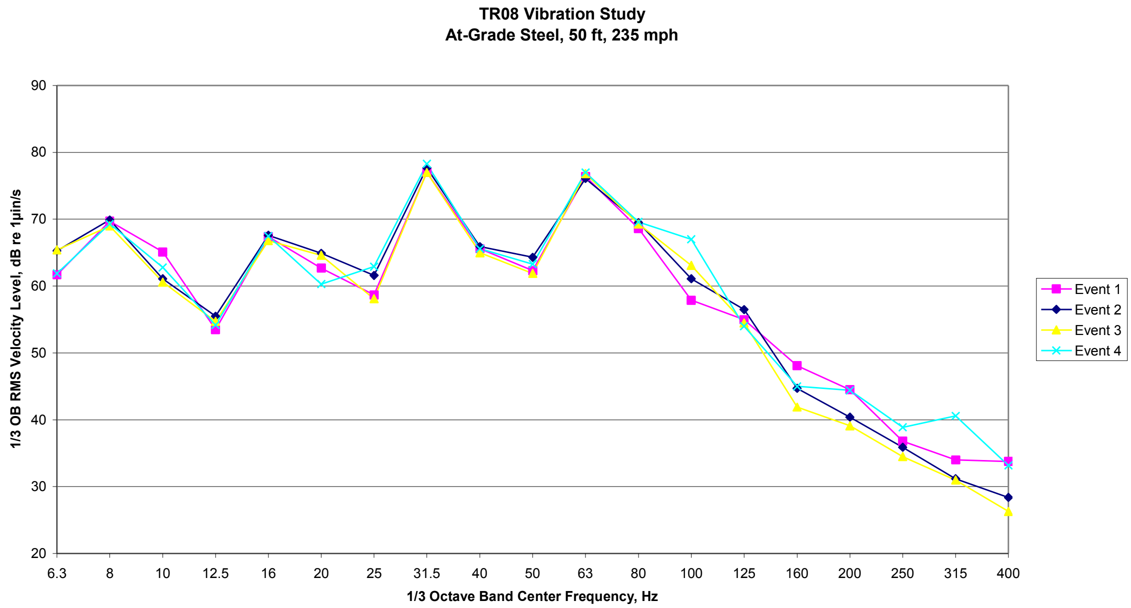


Figure E-17. Vibration Spectra, At-Grade Steel Beam, 50 ft, 235 mph

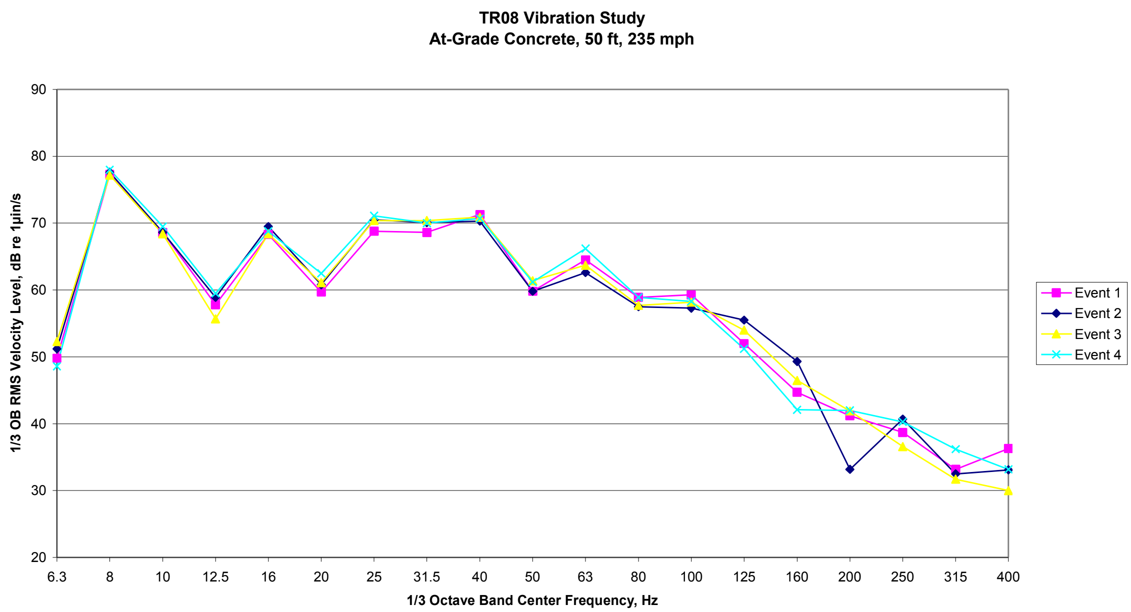


Figure E-18. Vibration Spectra, At-Grade Concrete Beam, 50 ft, 235 mph

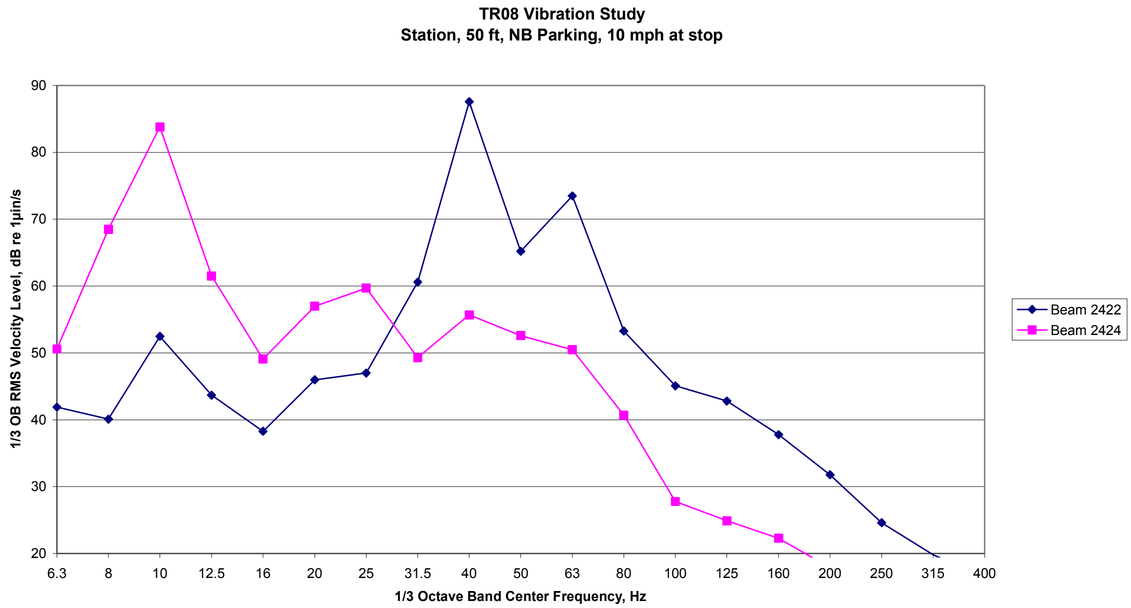


Figure E-19. Vibration Spectra, Station, 50 ft, NB Parking

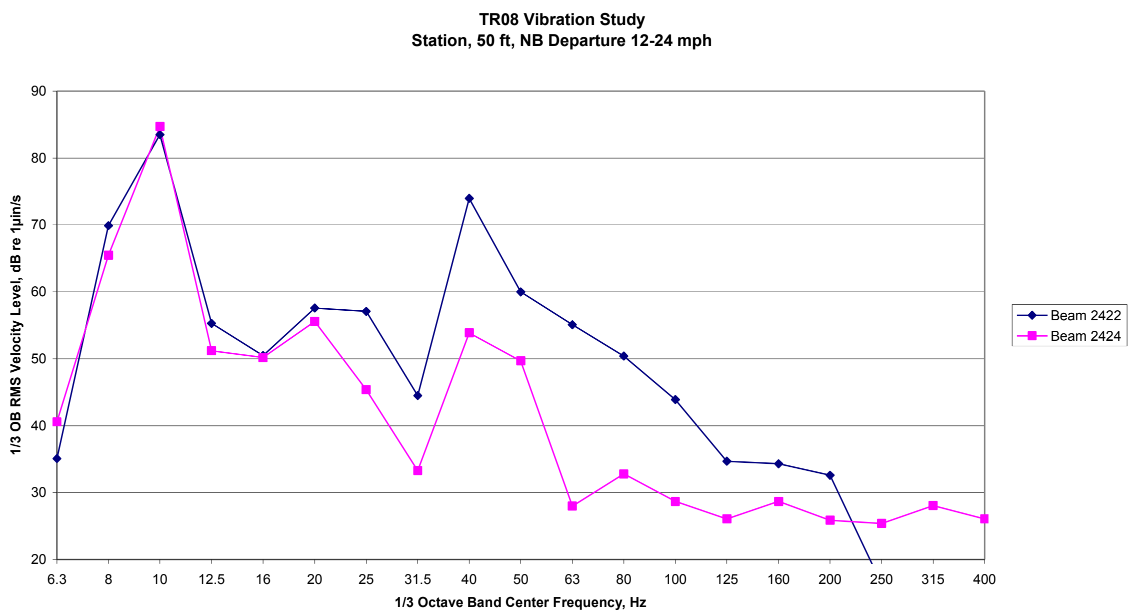


Figure E-20. Vibration Spectra, Station, 50 ft, NB Departure

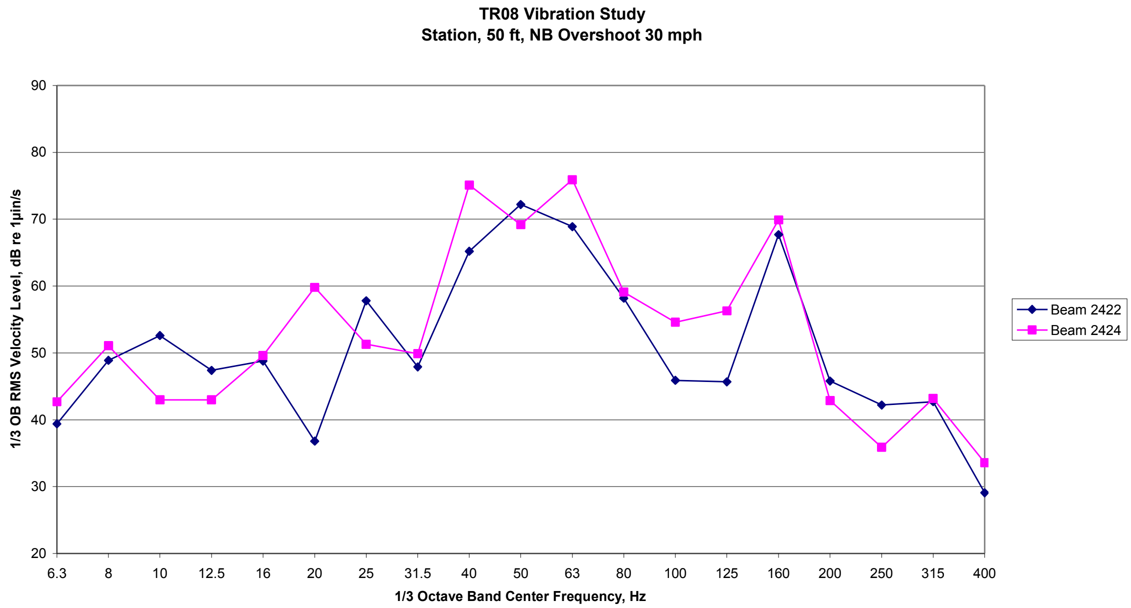


Figure E-21. Vibration Spectra, Station, 50 ft, NB Overshoot

APPENDIX F Time Histories

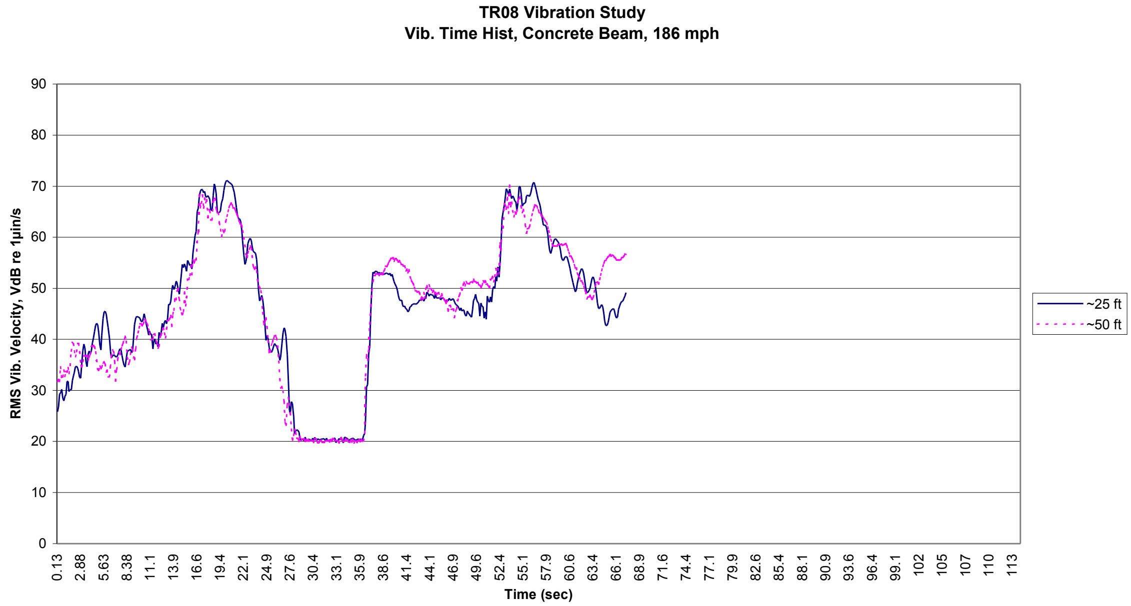


Figure F-1. Vibration Time History, Concrete Beam, 186 mph

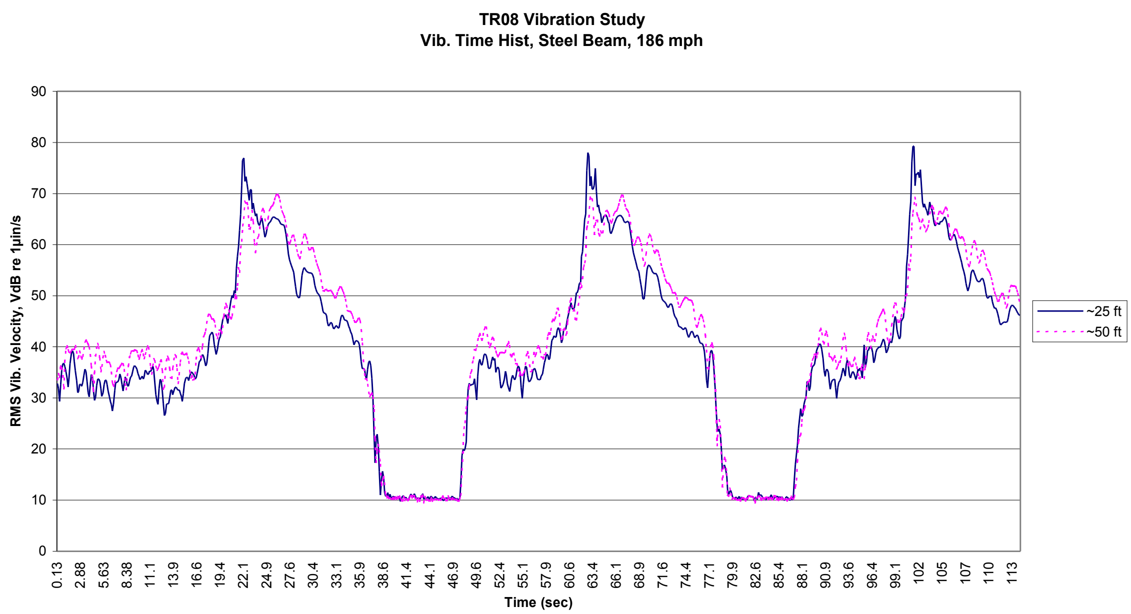


Figure F-2. Vibration Time History, Steel Beam, 186 mph

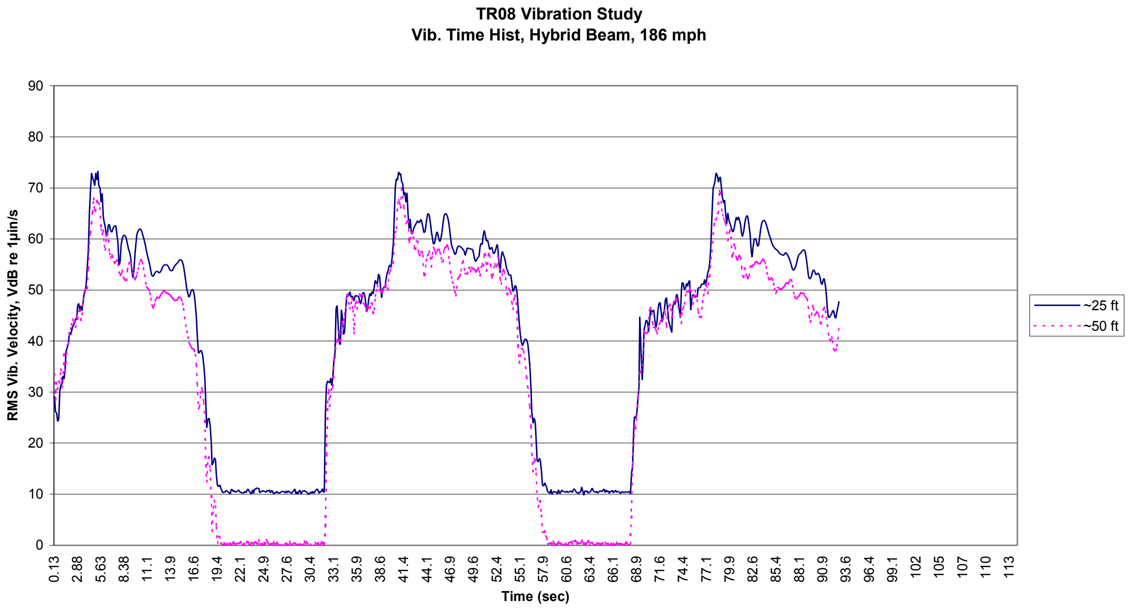


Figure F-3. Vibration Time History, Hybrid Beam, 186 mph

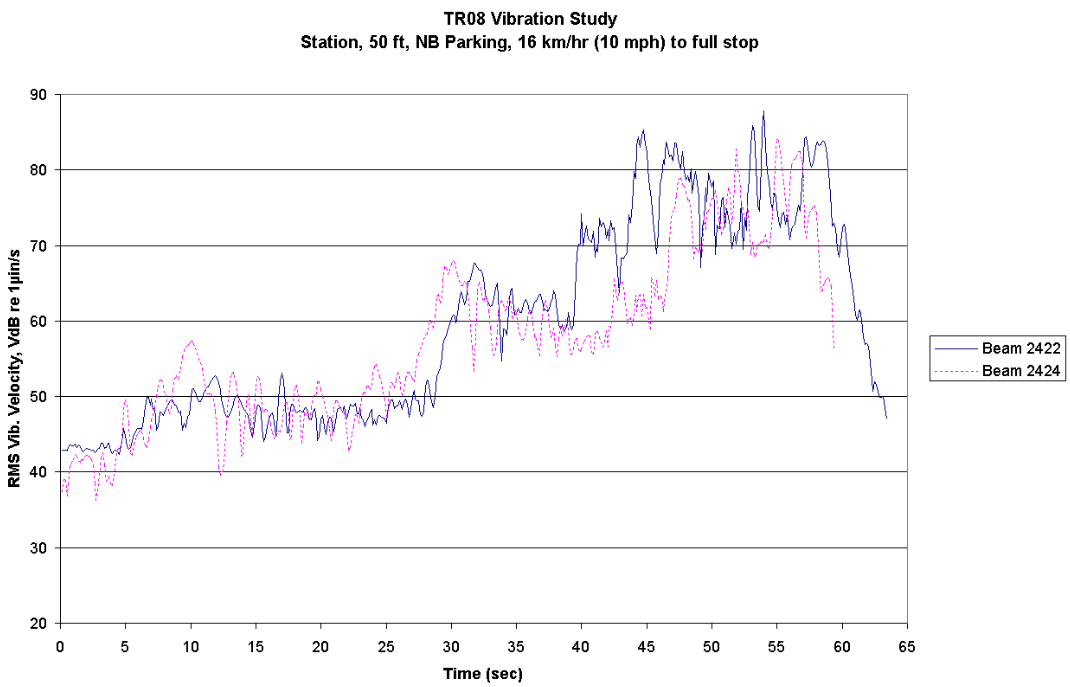


Figure F-4. Vibration Time History, Station, NB Parking

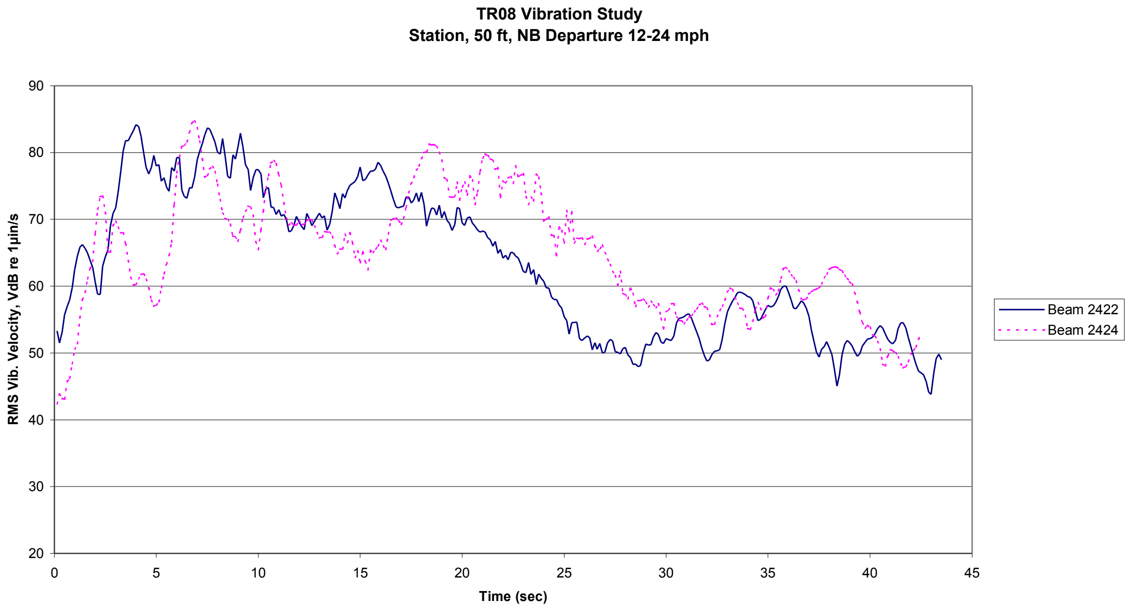


Figure F-5. Vibration Time History, Station, 50 ft, NB Departure

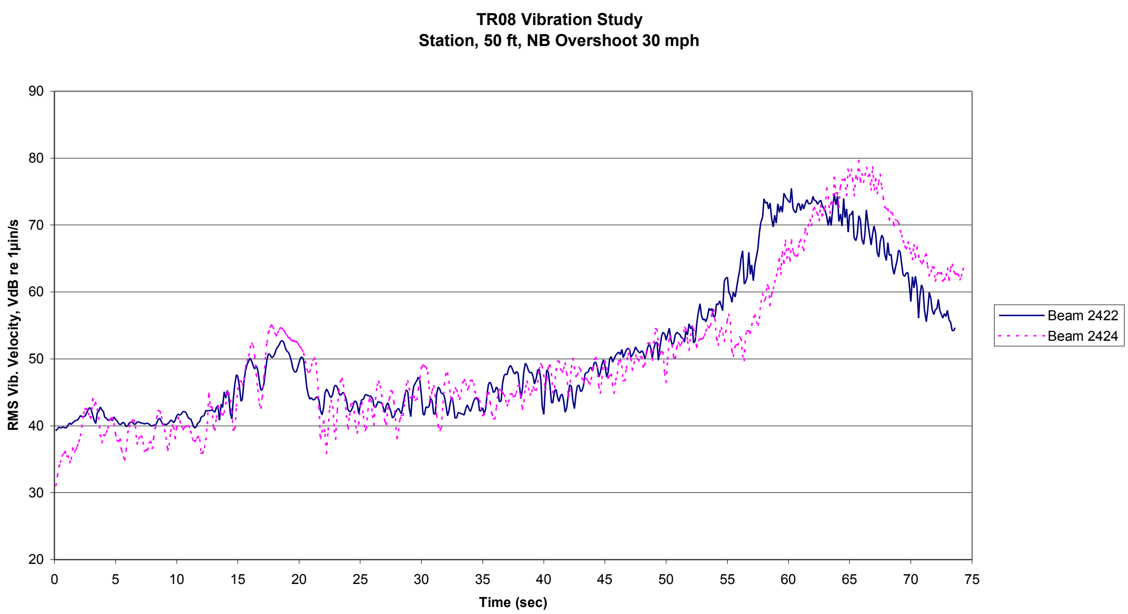


Figure F-6. Vibration Time History, Station, 50 ft, NB Overshoot