High Speed Rail Ground-Borne Vibration Test Results

Prepared for APTA Track, Noise & Vibration Subcommittee Meeting, Portland, OR
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April 19, 1996

Introduction

In May 1995, noise and vibration tests were performed under contract to the US Federal Railroad Administration along three European high speed rail lines: the X2000 in Sweden, the Pendolino in Italy, and the TGV in France. The purpose of the testing was to obtain data on noise and vibration generated by high speed trains for use in a manual on high speed train noise and vibration assessment prepared under contract to the Federal Railroad Administration.

This is a brief report on the results of the vibration testing. As discussed later, the data dramatically illustrate the effects of local geology on vibration propagation. If vibration propagation tests had not been part of the field testing, it would have been easy to draw incorrect conclusions from the test results.

Test Summary

Detailed vibration testing was performed at one site in each country. The vibration testing included measurements of train vibration at distances of 25 to 200 feet from the near track and vibration propagation tests using the same accelerometer positions. The vibration propagation test, illustrated in Figure 1, consists of dropping a weight onto the ground and measuring the impact force of the dropped weight and the vibration pulses at various distances from the impact. The dropped weight basically represents a calibrated vibration source. Comparing vibration from the calibrated force and the vibration created by a train gives a method of estimating the force generated by the train.

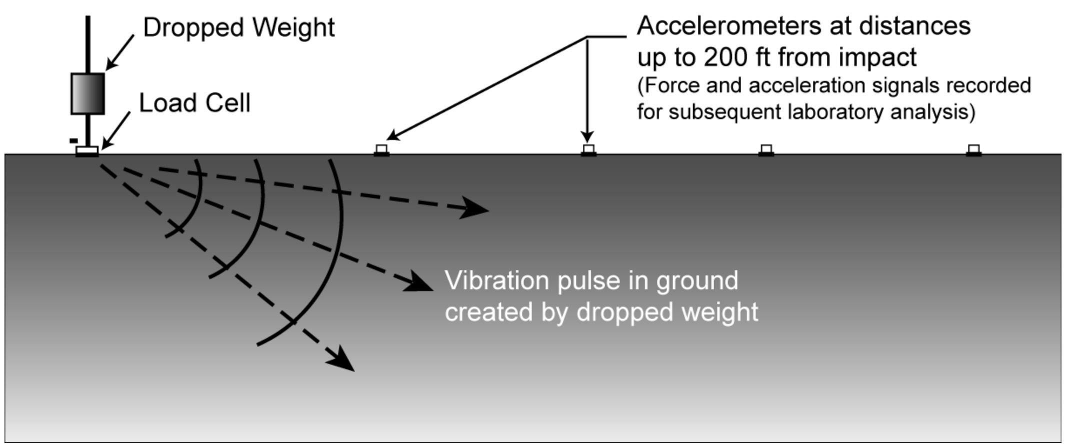

Figure 1: Vibration Propagation Test

The field tape recordings were analyzed to obtain 1/3 octave band spectra of the ground-borne vibration for each train passby and the line-source transfer mobility as a function of distance. In the simplest terms, the transfer mobility (TM), ground-surface vibration velocity (L_v), and vibration force generated by the trains (F_D) are related as follows:

$$L_v = F_D + TM$$

where all quantities are in decibels with consistent reference values. The force is actually a force density since we model the train as a line vibration source. The goal is that transfer mobility represents the vibration propagation at a site, and the force density represents the vibration force exciting the ground independent of local geologic conditions. Given a force density, it is possible to project ground-borne vibration at another location by plugging in a measured transfer mobility.

Overall Vibration Levels

Figure 2 is a plot of average vibration velocity level during passbys of a number of high speed trains. All of the levels are normalized to 150 mph assuming a $20log_{10}$(speed) dependence. Figure 2 includes the measurement results from the May 1995 testing along with previous measurements of TGV trains (labeled "TGV (Atlantique)" in the figure) and measurements of the X2000 while it was being tested on the Northeast Corridor in 1993. There is a wide spread in the data in spite of all of the data points being normalized to 150 mph. The spread is at least partially due to factors such as differences in the train suspension systems, construction of the track and track support system, and wheel and rail condition. What is unclear is how much is due to the local geologic conditions.

Figure 3 shows best-fit lines for each of the European measurements of May 1995. This figure makes it easier to discern the differences among the four measurement sets. The TGV and Eurostar are virtually identical, which is expected since they were measured at the same location and are of similar design. The Pendolino shows a different attenuation rate, but has levels comparable to the TGV and Eurostar. Particularly notable is that the X2000 vibration is much higher than the TGV or Pendolino vibration. Based solely on this data, one would be tempted to conclude that the X2000 causes substantially higher levels of ground-borne vibration than the other trains. As discussed below, this conclusion is not supported by the propagation test results.

Note that all vibration levels in this report are root mean square (RMS) vibration velocity in decibels using a reference of 1 µin/sec. The abbreviation VdB is used to avoid confusion with noise decibels.

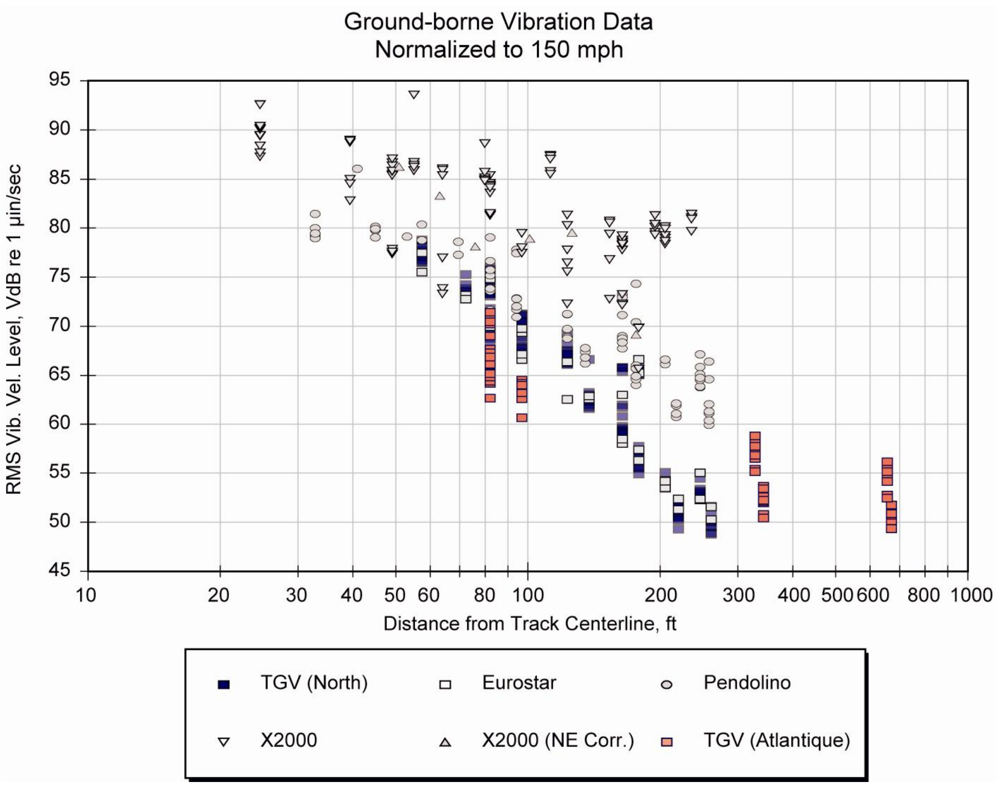

Figure 2: High Speed Train Vibration Levels

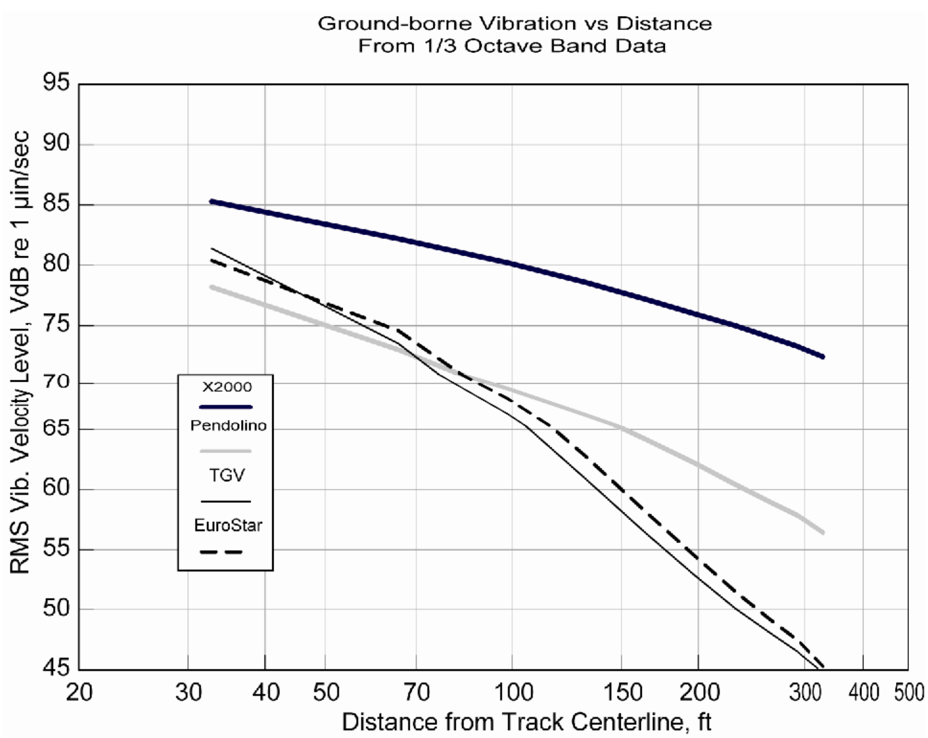

Figure 3: Best Fit Lines of Train Vibration

1/3 Octave Band Spectra

Figure 4 shows representative vibration velocity spectra for the European high speed trains. These show substantial differences between the shape and magnitude of the 1/3 octave band spectra. Again, these curves do not indicate why the spectra are different. However, by combining these 1/3 octave band spectra with the results of the vibration propagation tests, it is possible to derive "force density" functions for each train set that are, at least to a first order approximation, independent of local geology. The derived force densities are shown in Figure 5. Although the force density curves are different, they vary over a much smaller range than the vibration spectra.

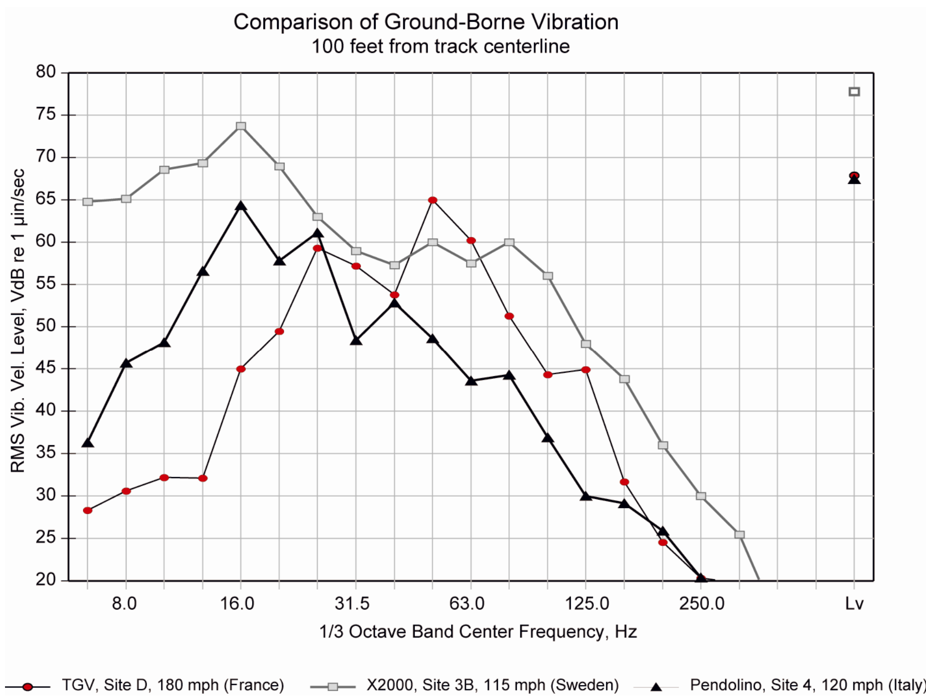

Figure 4: Frequency Spectrum of Train Vibration

Projected Vibration Levels

The force densities shown in Figure 5 can be used to compare the three types of high-speed trains under similar geologic conditions and to look at one train at all three test locations. Figure 6 shows the projected overall vibration velocity level for all four trains at the test site in Sweden. This graph indicates that the four trains generate comparable vibration levels, the exact opposite of what one might conclude from Figure 3. The X2000, TGV and Eurostar curves are within about 3 VdB and the Pendolino is about 3 VdB lower. This strongly suggests that the geology is the primary factor responsible for the differences in overall vibration levels at the different test sites.

Figure 6 also indicates the importance accounting for local geology through propagation tests or other procedures. Without the vibration propagation data, it would not be possible to make valid comparisons of the ground-borne vibration characteristics of the three types of high-speed trains. With the propagation test data available, it is clear that to a first order approximation, the three types of trains generate similar levels of ground-borne vibration.

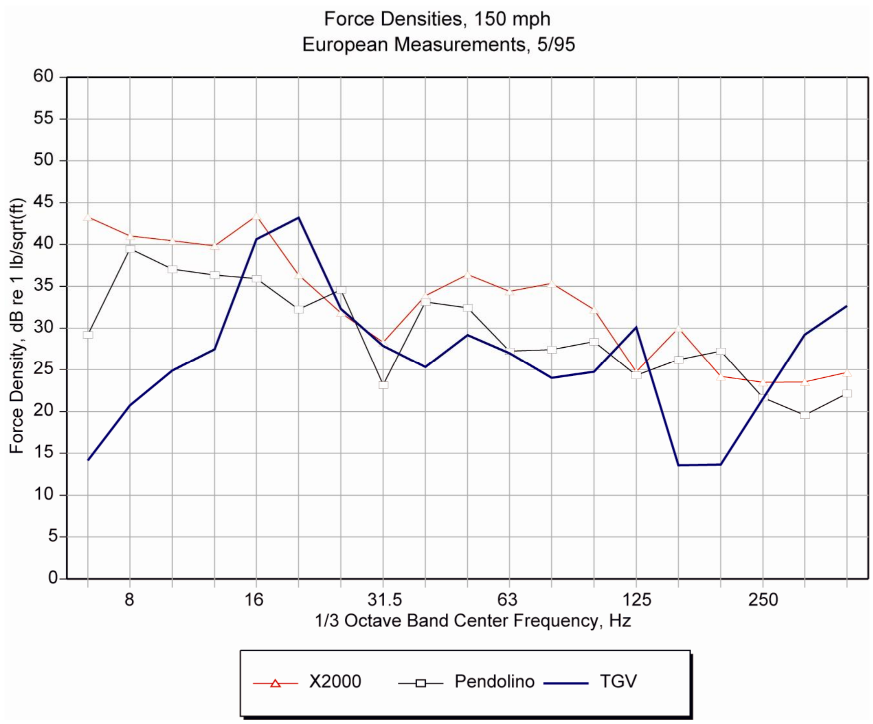

Figure 5: Measured Force Density Curves

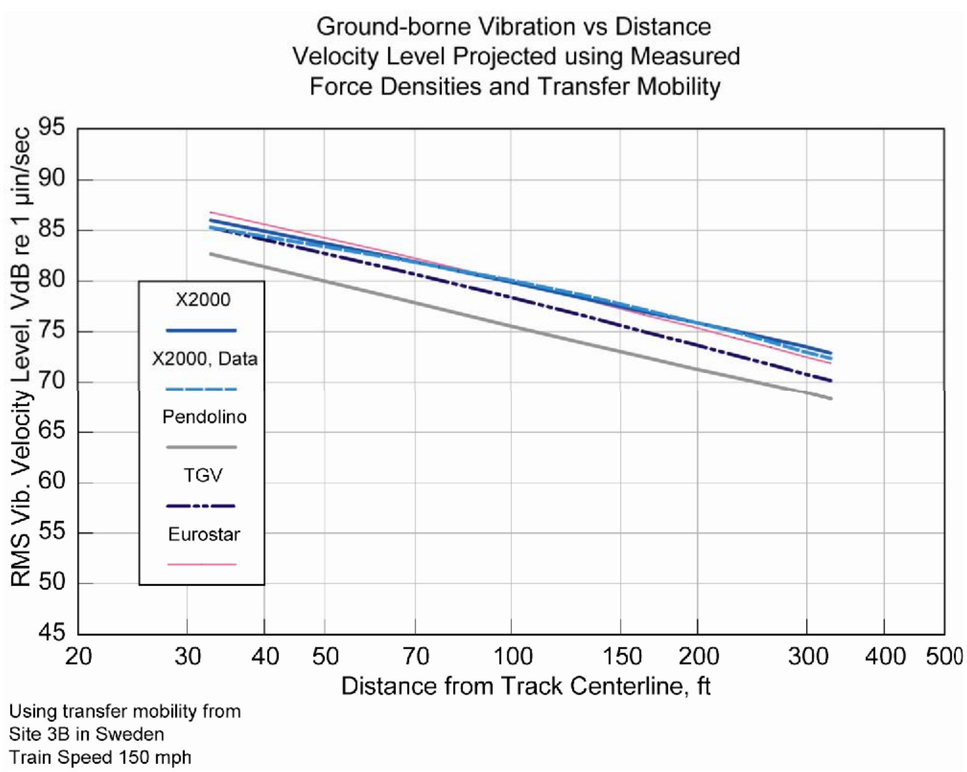

Figure 6: Projected Vibration, Test Site in Sweden

Figure 7 compares the ground-borne vibration levels for the X2000 at the vibration test sites in Sweden, Italy and France. This shows the large difference in ground-borne vibration levels that are possible due solely to geologic conditions. Only limited information is available on the soil conditions at the three test sites, however, they are similar on a superficial basis. All three were in open agricultural areas between cities where trains reached their maximum speeds. Soils maps of Sweden indicate that soils at the test site could have very high clay content. An interesting, perhaps relevant, observation from a recent international conference on rail noise and vibration is that there were a number of papers on prediction and control of ground-borne vibration by consultants and researchers from Scandinavian countries.

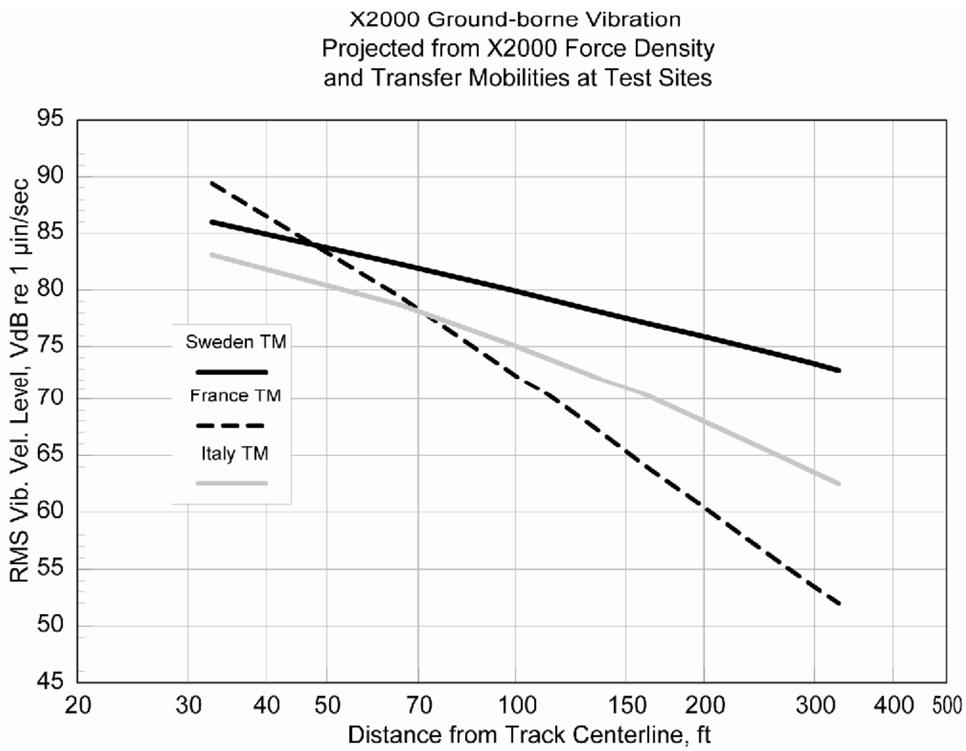

Figure 7: Projected Vibration, X2000 at Various Test Sites

Vibration Prediction Curve

One of the principal goals of the vibration testing was to develop general and detailed procedures for estimating ground-borne vibration from high-speed trains. The detailed method is based on measurements of transfer mobility and force density. The general method is based on a curve that is representative of the high range of ground-borne vibration data. A similar procedure is used in the Federal Transit Administration manual "Transit Noise and Vibration Impact Assessment." To develop the FTA curve, all available ground-borne vibration data from rail transit systems was plotted on one graph, including both light rail and heavy rail systems. The data points were all normalized to 50 mph and data from sites with unusually high levels of ground-borne vibration were excluded. It was assumed that unusually high levels were due to either very efficient vibration propagation or wheels and rails in poor condition. A curve was then drawn through the high end of the data points such that about 90% of the points were below the curve. This means that projections made using this curve will tend to be on the high side. The goal was to limit the potential for missing any vibration impacts during a general assessment. As the design of a project becomes more detailed, it will usually be possible to develop more accurate projections of ground-borne vibration that are lower than the initial projections.

Figure 8 shows the curve from the FTA manual on top of the same data as in Figure 2. The FTA curve has been scaled from 50 mph to 150 mph assuming a 20*log* speed dependence. Ignoring the data from the test site in Sweden, this curve is representative of the high range of the ground-borne vibration data and looks like it was derived from the high-speed rail data. That the transit curve so closely approximates vibration from high-speed rail systems may be an indication that the mechanisms that cause ground-borne vibration do not change with speed and that procedures that are used to control vibration from rail transit systems may be equally applicable to high speed rail systems.

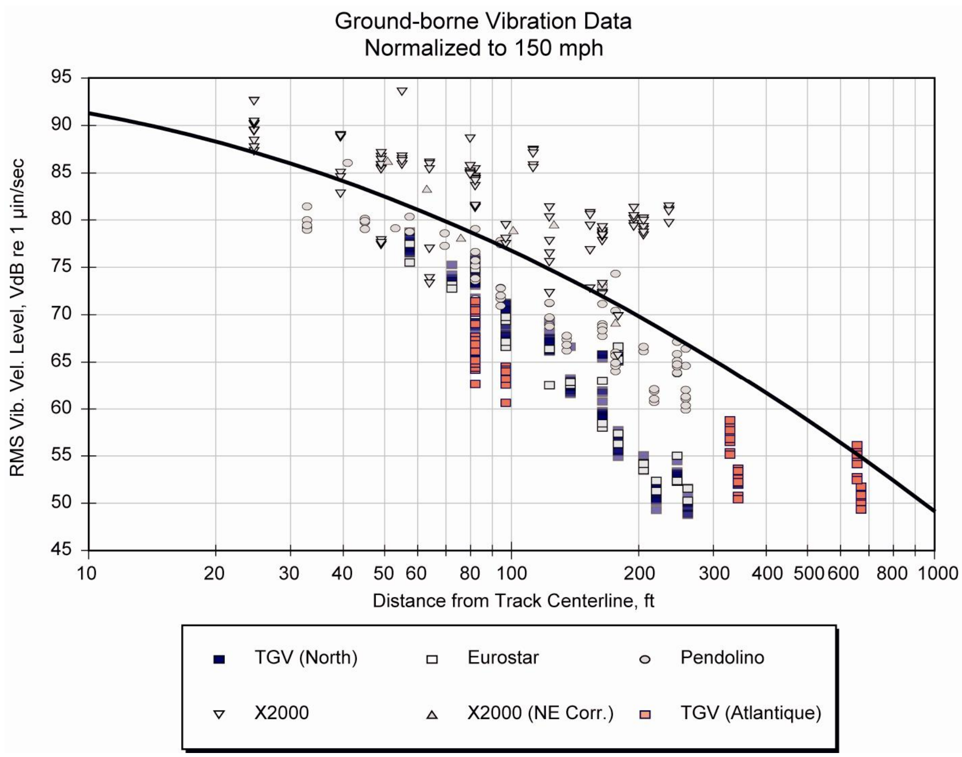

Figure 8: Curve from FTA Manual and High Speed Train Data