Appendix M

Vibration Assessment

WI #19-046

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Subject: Sandpoint Junction Connection
Assessment of Vibration on Northern Pacific Depot

Dear Mr. Smith,

This letter presents our assessment of the likelihood of physical damage to the historic, recently-restored Northern Pacific Depot (the Depot) in Sandpoint, Idaho from the operation of a proposed mainline track between the existing track and the building. Our assessment is based on vibration data provided by McMillen Jacobs Associates. In our opinion, the probability that operations on the proposed mainline track would cause any physical damage to the Depot structure is very low. We develop the technical basis for this assessment below.

1 Measured Vibration Data

Daniel Dreyfus, P.E., of McMillen Jacobs Associates collected vibration data from three trains operating on the existing mainline on January 26, 2015. Locomotives and cars with severe wheel flats typically generate the highest vibration associated with freight and passenger trains, and the collected data exhibits clear evidence of cars with wheel flats, so these data are taken to be characteristic of operations for the proposed project.

Mr. Dreyfus used two Instantel MiniMate Plus portable seismographs for the measurements. Wilson Ihrig owns several of these instruments, and I am personally familiar with them and their operation. These are appropriate instruments for the purpose at hand because they are intended to measure vibration for assessing the propensity for damage from ground vibration. The seismographs measure peak particle vibration velocity (PPV) directly, the vibration measure which is most commonly used to assess physical damage from vibration.

As will be discussed below in the criteria section, the standard in the United States for assessing the propensity for damage from ground vibration is the PPV of the ground surface *outside the structure*, not the floor vibration level inside the structure as is the standard for assessing human annoyance. Peak particle velocity data is widely used to assess physical damage to structures because it is proportional to strain, and strain is what causes brittle materials in structures to crack. Additionally, the relevant measure to assess is the highest peak particle velocity in any one of the three orthogonal directions, not the vector sum of all three orthogonal directions.[1]

The two MiniMate Plus units used by Mr. Dreyfus were serial numbers BE13019 and BE13020. Both had been calibrated by the factory in August 2014, within one year of the Sandpoint measurements which is the industry standard for proper calibration. In addition, MiniMate Plus units perform an electro-magnetically actuated sensor check after every triggering event which confirms that the triaxial vibration sensors (geophones) are functioning properly, and all were for the measurements provided.

Mr. Dreyfus deployed one MiniMate Plus 19 feet from the existing mainline track centerline and the other 29 feet from the centerline. Both instruments were places in shallow, smooth-bottomed holes (1 to 2 inches deep) and covered with 50-pound sandbags (see Figure 1). This is a standard way of mounting these instruments and provides good coupling to the ground for the purpose vibration measurements.

FIGURE 1 VIBRATION MEASUREMENT 19 FT FROM TRACK CENTERLINE

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1 I believe the reason for this is that the standards were developed prior to the advent of digital signal processing when computing the vector sum in real time was difficult.

The seismographs were programmed to digitally record 10 seconds of data whenever the vibration exceeded 0.100 in/s PPV. Each recording is called an "event", and for the closer seismograph there are either four or five events for each of the three trains (so, 40 to 50 seconds of data). However, the trains themselves were on the order of 90 to 120 seconds long (estimated by looking at the first and last event for each train), indicating that there were periods during each train in which the vibration did not exceed 0.100 in/s PPV. This assessment is based on the highest peak particle velocity measured during each recorded seismograph event, so four or five data points per train. These are presumed to be due to the locomotive and wheel flats.

Table I summarizes the vibration data provided by McMillen Jacobs Associates. All the data was collected on 26 January 2015. Table I shows the times that each MiniMate Plus event was triggered, and the various triggers are grouped to indicate the three different trains. Also shown are distance to the track centerline, the highest measured peak particle velocity during the event, the associated frequency of that velocity, and the direction of the velocity. As is typical, vibration in the vertical direction was dominant.

To assess the quality of the vibration data, we used the general vibration prediction methodology from the Federal Transit Administration (FTA) *Transit Noise and Vibration Impact Assessment Manual* ("FTA Manual", FTA Report No. 123, September 2018) to estimate vibration from a locomotive. The FTA Manual includes information on locomotive powered passenger or freight trains noting that the maximum vibration levels from both are similar since the suspensions are similar. The FTA Manual provides baseline, ground-surface vibration levels at distances between 10 and 300 ft for a locomotive powered train traveling 50 mph.[2] In keeping with standard FTA analysis procedures, because the trains passing the Depot reportedly travel 25 to 35 mph, a multiplicative speed adjustment factor of 0.7 (35/50) was used to adjust the reference PPV. Also, because the measured data exhibit evidence of some wheel flats, a multiplicative factor of 1.8 was also used to adjust the reference PPV to account for those.[3]

Figure 2 shows the adjusted FTA reference PPV for distances between 10 and 40 feet along with the PPV data collected by Mr. Dreyfus. Although the spread in the recorded data is large, the FTA estimate is consistent with the recorded data, indicating high-quality data sufficient for these analyses. The spread in the recorded data is most likely due to the range in severity of the wheel flats, which can increase the PPV by as much as a factor of 3.2 per the FTA Manual.

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[2] The reference levels in the FTA Manual are stated in terms of root-mean-square (RMS) vibration levels expressed in decibels. These were converted to PPV using the mathematical relation

$$PPV = CF \cdot V_{ref} \cdot 10\text{^}(dB_{RMS}/20)$$

where CF = crest factor, V_{ref} = 1 micro-in/s, and dB_{RMS} = the RMS level in decibels. A crest factor of 4 was used based on an analysis of the data collected by McMillen Jacobs at the project site.

[3] A multiplicative factor of 1.8 corresponds to +5 dB for those more familiar with that notation.

TABLE I SUMMARY OF TRAIN VIBRATION DATA

Train No.	Event Time 26 Jan 2015	Distance to Track CL	PPV	Freq	Direction
			in/s	Hz	
1	2:54:45 PM	19 ft	0.105	41	Vert
	2:55:08 PM	19 ft	0.175	45	Long
	2:55:58 PM	19 ft	0.135	51	Vert
	2:56:10 PM	19 ft	0.185	45	Vert
	2:54:16 PM	29 ft	0.100	49	Vert
	2:54:49 PM	29 ft	0.130	38	Vert
	2:56:02 PM	29 ft	0.140	47	Vert
2	3:10:40 PM	19 ft	0.225	49	Long
	3:10:53 PM	19 ft	0.145	64	Vert
	3:11:20 PM	19 ft	0.120	54	Vert
	3:11:32 PM	19 ft	0.100	57	Vert
	3:12:22 PM	19 ft	0.120	57	Vert
	3:10:45 PM	29 ft	0.185	39	Vert
	3:11:24 PM	29 ft	0.130	41	Vert
	3:12:25 PM	29 ft	0.130	41	Vert
3	4:04:56 PM	19 ft	0.100	68	Vert
	4:05:18 PM	19 ft	0.140	51	Vert
	4:06:37 PM	19 ft	0.105	64	Vert
	4:07:53 PM	19	0.125	47	Vert
	4:06:56 PM	29	0.195	45	Vert

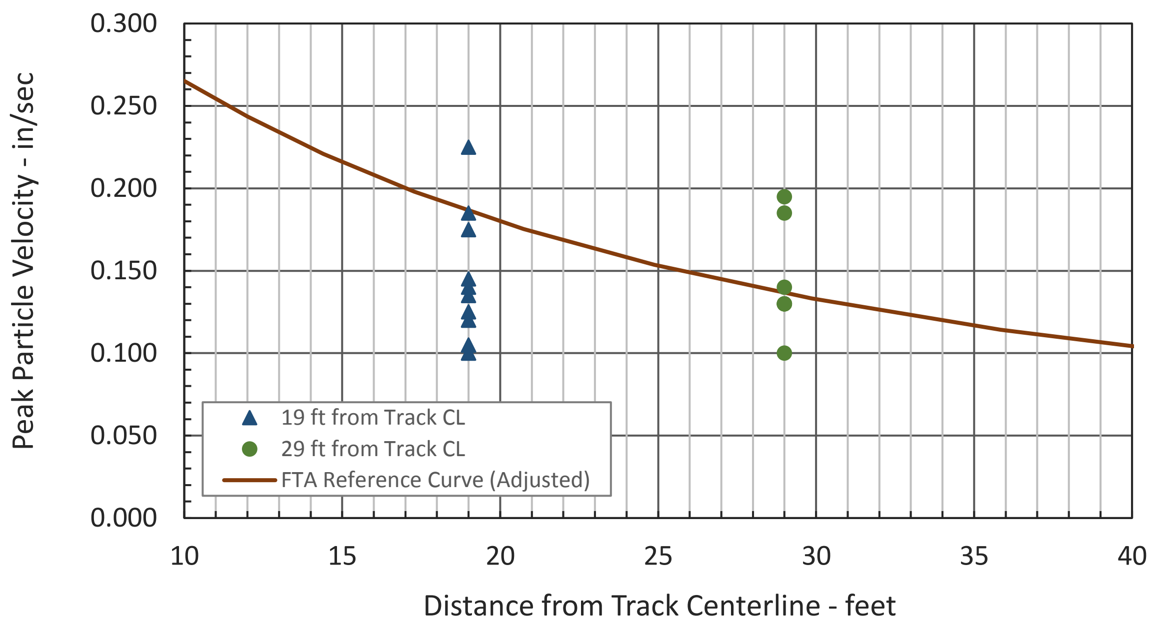

FIGURE 2 COMPARISON OF MEASURED DATA WITH ADJUSTED FTA REFERENCE

2 Vibration Assessment Criteria

The FTA Manual states, "It is extremely rare for vibration from train operations to cause substantial or even minor cosmetic building damage. However, damage to fragile historic buildings located near the ROW may be of concern. Even in these cases, damage is unlikely except when the track is located very close to the structure." [FTA Manual at p. 126] In addition to being over 100 years old, the Depot has a plaster finish on the ceilings and walls, a terrazzo floor, and brick walls, gables, and embattlements. According to press releases, all these elements were repaired, restored, and renovated with work being completed 2015.[4]

It is important to note at the outset that the type of damage that may occur – however rarely – from train vibration is only cosmetic in nature, e.g., minor cracks in plaster. The structural integrity of the Depot would only be threatened if the vibration peak particle velocities were on the order of several inches per second.

Because it is extremely rare for train operations to cause any sort of damage, we turn to construction vibration damage criteria for guidance on PPV that may cause damage. Much of this research in this area has been conducted by the United States Bureau of Mines (USBM) which was concerned about vibration from quarry blasting. The result of one USBM study indicated that building damage from vibration typically results from exposure to high vibration level during a single event, not from repeated exposure to lower vibrations from repeated events.[5] Therefore, the application of construction vibration damage criteria to train vibration is reasonable.

The FTA Manual presents damage criterion for various types of buildings for assessing construction vibration damage. The two categories that are most appropriate for this situation are:

Engineered concrete and masonry (no plaster)	0.300 in/s PPV
Non-engineered timber and masonry	0.200 in/s PPV

These are very conservative limits intended to preclude even the most minor damage, usually taken to be the propagation of existing cracks in plaster. This is sometimes referred to as "cosmetic architectural damage". Because the Depot is known to have plaster finishes, the non-engineered masonry building limit would seem to be more appropriate, though the building was likely engineered.

One main issue with the FTA criteria is that it does not take the frequency of the vibration into account. The magnitude of ground displacement and velocity are related at any given frequency by the relation:

$$\text{Velocity} = 2\pi f \times \text{Displacement}$$

where f = the frequency in Hertz (Hz, cycles/second).

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4 Rasmusson, Cameron. " Back on Track – Amtrak Officials Detail Depot Restoration " *The Coeur d'Alene Press*, 23 January 2014. *Google* Web. 2 June 2019.

5 Stagg, M. S., D. E. Siskind, M. G. Stevens, and C. H. Dowding, *Effects of Repeated Blasting on a Wood Frame House*, United States Bureau of Mines Report of Investigations 8896 (USBM RI 8896), 1984.

So, for a given displacement, the allowable velocity should be lower for low frequency vibration than for higher frequency vibration.

The effect of frequency[6] on vibration was studied extensively by the USBM in the 1970s, resulting in the seminal *Structure Response and Damage Produced by Ground Vibration from Surface Mine Blasting*.[7] Based on ground vibration measured from hundreds of blasting events while inspecting nearby structures for signs of physical damage, the USBM researchers developed "safe levels of blasting vibration" that incorporated both vibration velocity and frequency. The so-called USBM RI 8507 criteria will be presented in Figure 3.

3 Vibration Assessment

The vibration data collected in 2015 was either 19 or 29 feet from the existing track centerline. Drawings of the proposed new mainline track and Depot building indicate that the centerline of that track will be as close as 9 feet 6 inches from the Depot footing, specifically, the "bay window" portion that protrudes slightly from the Depot on the track side (east side).[8] To estimate the vibration velocities at this closer distance, the difference in velocity inherent in the FTA reference curve was added to each empirical data point measured by Mr. Dreyfus. For example, at 9.5 feet, the adjusted FTA reference curve indicates a velocity of 0.271 in/s PPV, whereas at 19 feet in indicates 0.186 in/s PPV. The difference, 0.085 in/s PPV, was added to each data point obtained at 19 feet. A similar calculation was made for each data point obtained at 29 feet (0.135 in/s PPV being added to estimate the vibration at 9.5 feet). The estimated vibration velocities at 9.5 feet, along with the measured data on which they are based, are shown in Figure 3. Also shown are the FTA damage criterion and the USBM RI 8507 damage criteria curve.

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[6] *Frequency* in this context refers to the number of cycles/second, not the rate of occurrence. The unit of frequency is Hertz (Hz): 1 Hz = 1 cycle/second. Most people associate frequency in this context with sound, e.g., the frequency of middle C on a piano is 261.6 Hz, but it also applies to vibration.

[7] Siskind, D. E., M . S. Stagg, J. W. Kopp, and C. H. Dowding, *Structure Response and Damage Produced by Ground Vibration From Surface Mine Blasting*, United States Bureau of Mines Report of Investigations 8507 (USBM RI 8507), 1980.

[8] Hanson Professional Services Inc., *BNSF Railway, Kootenai River Subdivision, Sandpoint Junction Connection, Amtrak Depot Clearance Exhibit*, Contract 14R0057, Dwg No. EXH-02, 20 May 2019.
Boden Mountain Architecture, *Sandpoint Amtrak Station-Idaho, Basement Level Floor Plan*, Dwg. No. A.100, Sheet 6, 26 June 2014.

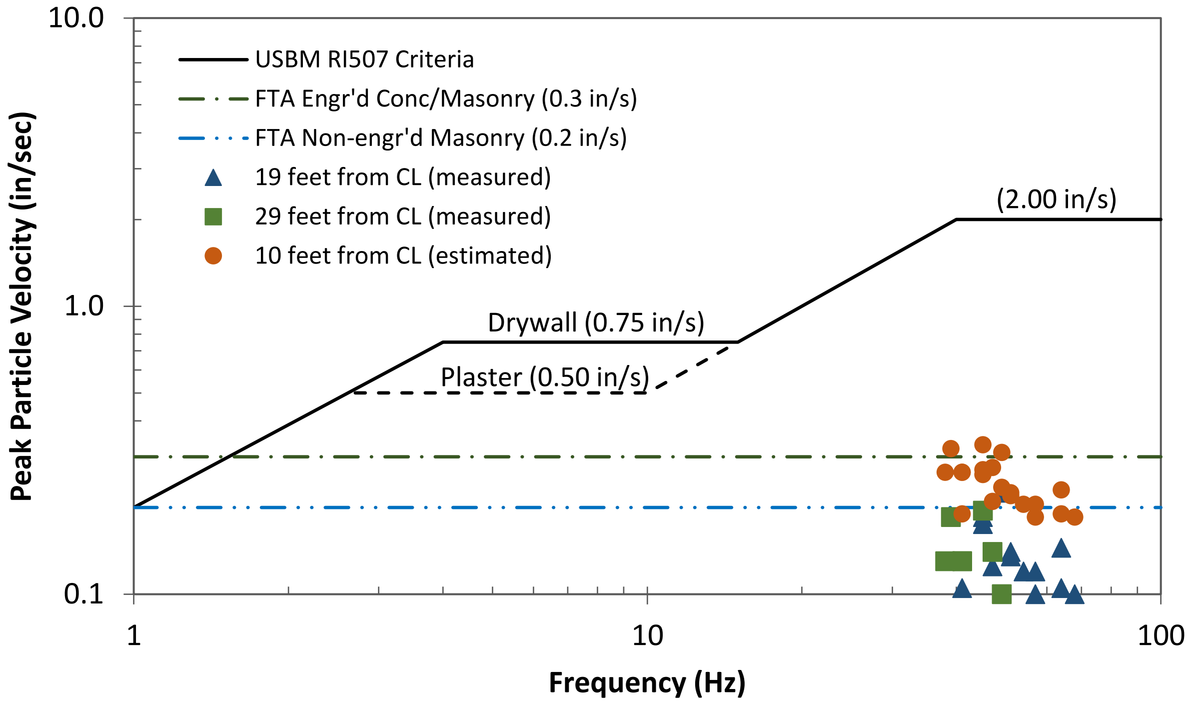

FIGURE 3 ASSESSMENT OF VIBRATION DAMAGE

As can be seen in Figure 3, the peak particle velocities expected at the closest part of the Depot building, about 10 feet from the proposed mainline track centerline, will exceed 0.300 in/s PPV, though not likely 0.400 in/s PPV, and, as is typical of rail vibration, occur at frequencies in the 35 to 70 Hz range (see Table I for the specific frequencies associated with the measured data). While the expected velocities do exceed the conservative FTA criterion of 0.200 in/s PPV for non-engineered masonry buildings and some even exceed the 0.300 in/s PPV FTA criterion for engineered masonry buildings, they are well below the USBM standard which is around 2.00 in/s PPV in the 35 to 70 Hz range. USBM has a separate, lower criteria for buildings with plaster finishes, but these lower criteria indicate that plaster is more susceptible to damage in the 3 to 15 Hz frequency range, well below the measured and expected train frequencies. Additionally, the expected velocities do not exceed the plaster criterion of 0.500 in/s PPV.

4 Discussion

As mentioned above, vibration damage criteria are typically associated with construction, not train vibration. This is because construction vibration damage is more prevalent than train vibration damage, the latter being extremely rare. The application of construction criteria to assess ongoing train operations vibration is reasonable because building damage from vibration is typically associated with a single, high-level event, not repeated, low-level exposure.

Given that the FTA criterion is frequency-independent, it stands to reason that the FTA chose the very conservative damage limit of 0.200 in/s PPV. This limit, which is also used by many public agencies (such as Caltrans) and municipalities (such as San Francisco), is widely regarded as the limit below which no damage whatsoever can occur, not even the most minor cosmetic damage. While it is conservative and convenient if vibration can be limited to this velocity, Wilson Ihrig has worked on many construction projects where achieving this limit simply has not been possible. On most of these projects, an incremental process was used by which the allowable vibration level was increased in small steps that enabled construction while keeping a careful eye to the potential for vibration damage. On some of these projects, the USBM criteria were used as a guide when increasing the allowable limit. To my knowledge, construction vibration, which is often lower in frequency than train vibration, has not been found to have caused any damage even at velocities approaching 0.500 in/s PPV. This experience supports the higher, more detailed criteria suggest by the USBM study than the simple limit adopted by the FTA.

This analysis only considers the amplitude from vibration traveling through the ground and does not anticipate or examine the propensity for train vibration to induce differential or permanent settlement of the ground. Qualified civil and geotechnical engineers should be retained to ensure that the vibration from new proposed mainline would not cause undue settlement at the Sandpoint Depot and that the mainline track is properly founded.

5 Conclusion

Given that the Depot was recently renovated, it is reasonable to assume that both the structure and the finishes are in good, not fragile, condition. That being the case, we believe the frequency-dependent U. S. Bureau of Mines "safe blasting" criteria are suitable for assessing the propensity for damage to the Depot from future vibration caused by locomotive-powered trains operating at speeds up to 35 mph on the proposed new mainline. Using data measured by McMillen Jacobs Associates on the Depot property and information from the FTA *Transit Noise and Vibration Impact Assessment Manual*, we estimate that train vibration will be well below the frequency-dependent USBM vibration criteria and, therefore, very unlikely to cause any physical damage to the Depot structure or finishes.

Please call me if you have any questions or comments about this assessment.

Very truly yours,

WILSON IHRIG

Derek L. Watry
Principal

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