Appendix C

Vibration Study

Appendix C:
Vibration Technical Memorandum
Antelope Valley Draft Environmental Impact Statement

1.0 Vibration in Sensitive Buildings

Traffic-induced ground vibration travels through the ground to adjacent receivers in a source-path-receiver scenario. In this scenario, each road vehicle appears physically as a single moving source on the roadway and is modeled as such. The source of vibration is characterized by the following: the type of road vehicle, the nature of the pavement surface, the structure of the pavement/sub-grade, and the alignment of the roadway relative to the receiver.

The assessment of traffic-induced vibration is a very site-specific problem. The vehicle pavement system is the primary vibration source. Other significant parameters are the vehicle speed and weight. Away from the roadway, traffic-induced vibration decreases with increasing distance. Generally, traffic-induced vibration is not an environmental consideration beyond approximately 60 meters (200 feet).

The Amended Draft Single Package roadways would operate close to the Beadle Center, which houses sensitive microscopes. For successful operation of the sensitive equipment located in Beadle Center, vibrations of the facility floor on which the equipment is mounted should satisfy the criterion for maximum acceptable floor vibration for such uses. No other vibration-sensitive land uses were identified within the vibration impact zone.

1.1 Vibration Guidelines

The general literature pertaining to vibration criteria for buildings has developed significantly over the past few years. There are vibration criteria, which extend over a wide range, for defining the acceptability for mechanical vibration in buildings with various types of occupancy or use. The severe requirements of the microelectronics industry have contributed considerably to the development of criteria for vibration-sensitive equipment and activities. However, there are no published standards from national or international agencies establishing minimum vibration levels that would allow successful operation of sensitive electron microscopes. The International Organization for Standardization (ISO) has published vibration criteria in areas such as operating theaters, residential buildings and office buildings.

The ISO vibration criteria can be applied to vibration either originating inside the building or transmitted into the building from outside. External sources of vibration can result in vibration of building floors and walls of sufficient amplitude to interfere with vibration-sensitive activities and be perceptible or annoying to building occupants.

There is much less consensus about the scales and indices used in the measurement of ground-borne vibration. For some fields of interest, the range of vibration intensities is extremely wide and, as in the case of noise, a decibel scale is used. In other fields, vibration levels are usually restricted to direct measurement units (called engineering units). The frequency range of interest may be very small or very large. Further, the desired parameter for assessment purposes could be either displacement, velocity, or acceleration caused by vibration.

Velocity, a measure of the energy carried by vibration, is the preferred unit for assessing any potential risk of damage to buildings. A number of studies have indicated that sensitivity to vibration is relatively independent of frequency above approximately 12 Hz. Because of the general preference for velocity as a measure of both annoyance and building damage, vibration criteria and measured vibration data are presented in terms of overall vibration velocity levels. Common sources of vibration and their maximum velocity levels are shown in Figure C-1.

1.2 Vibration Criteria

In the absence of published national or international vibration criteria for sensitive microscopes, reliable and broadly applicable vibration criteria for sensitive equipment, as summarized by Ungar, are used in this report. In the case of electron microscopes, the image to be observed must not vibrate excessively relative to the eye of the observer, implying a need to limit the instrument's vibrations relative to the observer and to the object being observed. Based on these considerations, vibration velocity criteria that have been found suitable for floors supporting various classes of sensitive equipment are listed in Table C.1. For the sake of comparison, the table also indicates standard values corresponding to several more familiar building spaces including workshops, offices, and residences. It should be noted that the criteria pertaining to sensitive equipment were developed on the basis of limited available data, although these criteria have been found to be conservative and have led to numerous successful facility designs. It is apparent that the most severe criteria are those applied to electron microscopes and laser and optical research equipment.

1.3 Potential Damage to Beadle Center

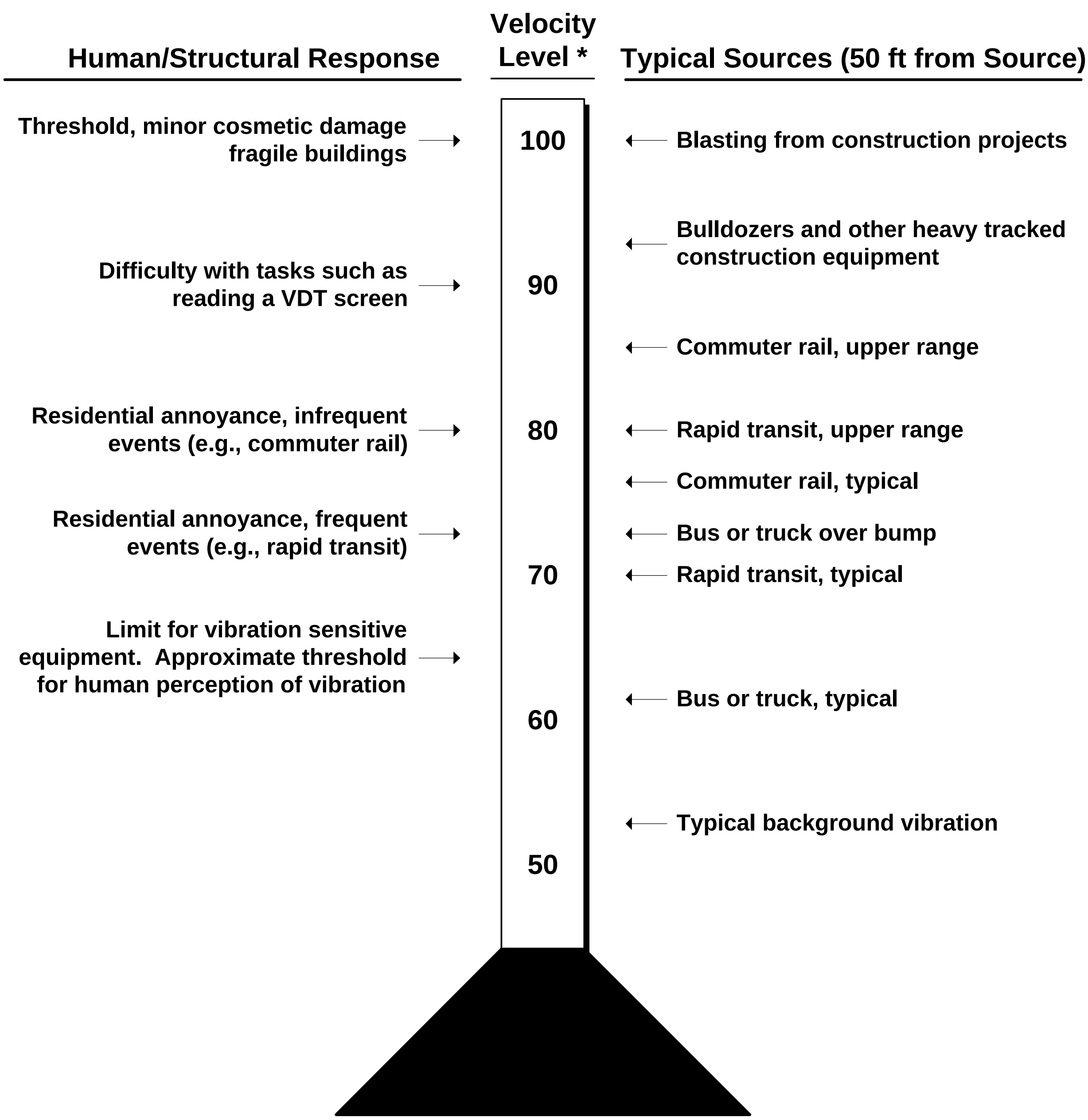
Vibration levels that would cause minor architectural damage are approximately three millimeters per second for historic structures and five millimeters per second for non-historic structures. Typically, at a distance of 15 meters (50 feet), a heavy truck passing by creates a velocity level of 0.08 to 0.10 millimeter per second, considerably lower than the damage criterion of three millimeters per second. As a result, traffic vibration would not cause any damage even to structures that are much closer than 15 meters (50 feet) like the Beadle Center in the study area.

1.4 Potential Annoyance to Beadle Center Occupants

Traffic-induced vibration and its annoyance to people inside the Beadle Center was considered. Vibration effects are assessed based on the maximum amplitude of vibrations caused by a single vehicle rather than on traffic volume. Typically at distances greater than 15 meters (50 feet), road vehicles generate velocities less than the threshold perception. This assumes continuous soil, and therefore overestimates impacts. These levels are lower than the acceptability criteria and, therefore, would not cause annoyance to people inside the building.

Figure C-1

Common Vibration Sources and Levels



***** RMS Vibration Velocity Level in VdB relative to 10^{-6} inches/second***

Source: Transit Noise and Vibration Impact Assessment, FTA, DOT-T-95-16, April 1995.

Table C.1
VIBRATION CRITERIA

Equipment or Facility	Vibration Velocity Micrometer/Second	Vibration Velocity Microinch/Second
Workshops	800	32 000
Offices	400	16 000
Residences, Computer Systems	200	8 000
Precision Balance, Coordinate Measuring Machines, Metrology Laboratories, Optical Comparators, MME Class A	50	2 000
Microsurgery, Optical Equipment On Isolation Tables, MME Class B	25	1 000
Electron Microscopes At Up To 30 000 X Magnification, Magnetic Resonance Imagers, MME Class C	**12**	**500**
Electron microscopes At More Than 30 000 X Magnification. Mass Spectrometers, Cell Implant Equipment, MME Class D	**6**	**250**
Unisolated Laser and Optical Research Equipment MME Class E	3	130

Source: Eric E. Ungar "Vibration Criteria for Sensitive Equipment" Proceedings of Inter-Noise '92, p 737.

1.5 Potential Effect on Sensitive Equipment Operations at Beadle Center

The potential vibration impacts at the Beadle Center include interference with sensitive electron microscopes during the temporary construction phase and during the long-term operations phase. The concerns are greater during the construction phase than during the operations phase since the use of such heavy construction equipment is more likely to cause impacts. From an assessment of existing vibration velocities in the

Beadle Center and the criteria presented in Table C.1, a floor vibration criterion of 12.7 micrometer/second or 0.0127 mm/sec (500 micro inch/second) was initially selected as the appropriate criterion for the proposed microscope location at the Beadle Center. That criterion was later refined to 0.006 mm/sec based on input from Beadle Center faculty.

1.6 Measured Existing Vibration Velocities at the Beadle Center

Existing vibration levels in Beadle Center were measured with a calibrated set of Bruel and Kjaer (B&K) vibration measuring equipment which included a B&K Type 2231 sound level meter fitted with a B&K Type 4379 accelerometer and a B&K Type ZR 0020 integrator. Vibration monitoring sites included: a) on the floor of room N 319 where an electron microscope is already located and b) on the floor of room E 119 where a second electron microscope would be located in the future. The analysis of measured floor vibration levels at the two sites (see Figure C.2) shows that the existing vibration velocities are 0.018 mm/sec in room N 319 and 0.015 mm/sec in room E 119. The measured, existing vibration velocities at both of the sites are higher than the criteria of 0.012 and 0.06 mm/sec. Existing vibration velocities at the two sites are caused principally by activities within the building. The existing vibration levels at the two sites are far below perceptible range, which is on the order of 0.045 millimeters per second.

2.0 Vibration Predictions

Since many of the prediction parameters are usually not determined until final design, predicted vibration velocities from the proposed Antelope Valley roadways were conservatively estimated from a generally accepted rate of decrease of vibration velocity with increasing distance from the trucks. No adjustments were made to coupling losses to the building or to its upper floors. Such losses would decrease building vibration velocities even further. It is estimated that maximum vibration levels would be on the order of 0.014 mm/sec at the two microscope sites from heavy trucks traveling at highway speeds on the proposed highway along the Beadle Center. This level is lower than the measured existing levels (0.015-0.018 mm/sec) and is not significantly higher than the criterion levels (0.012 mm/sec). Vibration effects are assessed using the maximum vibration from single events; the levels are not cumulative. More detailed predictions would be performed during final design once parameters including soil conditions (loose soil versus hard rock), type of trucks (weight, speed, etc.), and foundation details at the Beadle Center are obtained.

3.0 Abatement of Traffic-Induced Vibration

The study shows that movement of heavy trucks on the proposed North-South Roadway is not likely to cause unacceptable vibration levels at the proposed microscope locations in the Beadle Center. It is recommended that field measured data be obtained by the construction contractor to verify the vibration predictions that were made in this report. As a result of the field studies, if abatement of traffic-induced vibration is warranted, a number of strategies are available. They are classified as active and defensive strategies.

Figure C.2

Active Strategies

Active strategies are related to the engineering parameters characterizing the problem. These parameters include the following: traffic parameters, pavement/sub-grade parameters, propagation parameters, and building parameters. Traffic parameters and pavement/sub-grade parameters are the concern of the highway planner or engineer prior to construction; building parameters cannot be changed for the existing Beadle Center. Altering the source-receiver propagation characteristics either on or off the highway right-of-way does not generally appear practical. Therefore, for this study, active strategies do not appear practical.

3.2 Defensive Strategies

Vehicle speed and weight are primary variables for the traffic-induced vibration problem. Vehicles striking potholes or other bumps induce high impact loading on the pavement. This loading is very dependent upon vehicle speed, weight, and suspension stiffness parameters. More important, however, is the fact that the high pavement loading results in a continuous deterioration of the pavement surface. Hence, a smooth roadway surface may rapidly become very rough and the potential for increased possibility of traffic-induced vibration exists. Decreasing posted speed limits by one-half may abate traffic-induced vibration by approximately half. This change in ground vibration level and the resulting decrease in building vibration levels may be quite significant. Weight regulation of vehicles on the roadway is another potential abatement strategy for traffic-included vibration. A combination of vehicle speed and weight regulation aimed at abating traffic-induced vibration may be possible. The particular combination of vehicle speed and weight regulation can only be assessed on a local basis, but may not be practical for this study.

4.0 Construction Vibration

Blasting is potentially the greatest source of ground vibration during heavy construction. Blasting would not be used during construction of the Amended Draft Single Package. However, limited pile driving is anticipated during some phase of construction. Pile driving is also a source of ground-borne vibration, and vibration levels generated by the pile driver are largely associated with the type of equipment used.

Construction equipment vibration levels indicate that sonic pile drivers may provide a substantial reduction of vibration level compared to conventional impact type pile drivers. However, continuous operation of sonic pile drivers or vibratory pile drivers may be more noticeable even at low vibration levels. Furthermore, with the use of the pile drivers, the steady excitation of the ground may increase the resonance response of building components. Impact pile drivers, on the other hand, produce a high vibration level for a short time with sufficient time between impacts to allow any resonant response to decay. The construction contractor should decide the type of driver to use on this project. The decision would be based on the soil conditions in the area. Occupants of buildings within a radius of approximately 60 meters (200 feet) from the impact pile driver may perceive ground vibration effects during operation of the pile driver. Even minor cosmetic damage is not likely to buildings situated beyond approximately 30 meters (100 feet) from pile-driving equipment.

All other construction equipment would generate much lower vibration levels and would not cause noticeable annoyance to people living in adjacent homes. Vibration from the operation of construction equipment would not exceed the impact threshold for most of activities, except for the operation of electron microscopes in the Beadle Center. Potential vibration effects could be avoided by including vibration specifications in the construction contracts and by occasional vibration monitoring during the construction period. The following table may be used to calculate the vibration levels caused by construction equipment:

Table C.2
VIBRATION LEVELS DUE TO CONSTRUCTION EQUIPMENT AND TRAFFIC AT 30 m (99 ft)

Source	**Peak Particle Velocity (mm/sec)**
Diesel Pile Driver (36 000 ft/1b/49 000 joules)	5.0
Vibratory Pile Driver	3.75
Vibratory compactor	0.75
Pavement Breaker	1.25
Large Bulldozer	0.275
Heavy Trucks	0.25
Jack Hammers	0.075
Vibration Criteria (Old House, Poor Cond.)	
• After CHAE (ASCE 48, pp 77-79, 1978)	12.5
• Swiss Standard, Blasting	7.5
• Swiss Standard for Machines and Traffic	3.0-5.0

For other distances d, the expected level may be determined by the formula:

$$V(d) = \frac{V(30)}{\frac{d}{30}}$$

Where V(d), and V(30) are the particle velocities at d meters and 30 meters, respectively.

Source: Report on the Pre-design Studies of Noise and Ground Vibration For N.W.L.R.S., City of Calgary (Oct. 1986).