

**California Department of Transportation
 Division of Environmental Analysis
 Office of Noise, Air Quality, and Hazardous Waste Management
 Sacramento, CA**

**TRANSPORTATION RELATED EARTHBORNE
 VIBRATIONS
 (Caltrans Experiences)**

**Technical Advisory, Vibration
 TAV-02-01-R9601**

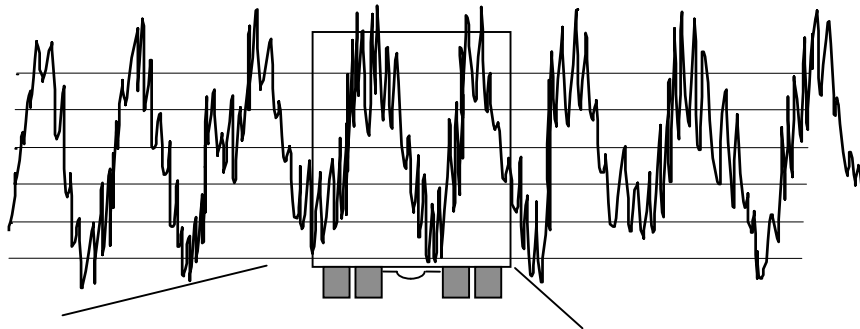
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NOTICE:

This document is a revision of technical advisory TAV-96-01-R9201 with the same title, prepared by the same author, dated June 13, 1996. This revision does not alter the basic information of the earlier version, except for the Rayleigh wave propagation equation (see eq.1 and associated eq.2), which was in error and has been corrected. The text associated with the equation as well as the text in figure 1 has also been changed. The error did not affect the vibration dropoff curve in figure 1. Some other changes were made in formatting and wording.

This document is not an official policy, standard, specification or regulation and should not be used as such. Its contents are for informational purposes only. Any views expressed in this advisory reflect those of the author, who is also responsible for the accuracy of facts and data presented herein. The latter were derived from Caltrans vibration studies from 1958 to 1994, and the author's vibration experiences from 1980 to 1994 at the Caltrans Transportation Laboratory (Translab) in Sacramento, CA.



stationary point the pendulum decelerates in the negative (-) direction which is the same as increasing acceleration in the positive (+) direction.

Vibration amplitudes are usually expressed as either "peak", as in peak particle velocity, or "rms" (root mean square), as in rms acceleration. The relationship between the two is the same as with noise. The rms value is approximately 0.71 x the peak value for a sine wave representing either displacement, velocity, or acceleration.

Finally, the direction in which vibrations are measured, analyzed or reported should be specified (vertical, horizontal longitudinal, horizontal transverse, or the resultant of all three motions). For example, Caltrans most often uses a peak vertical particle velocity descriptor, because vibrations along the ground surface are most often (although not always) greatest in the vertical direction.

Propagation

Propagation of earthborne vibrations is complicated because of the endless variations in the soil through which waves propagate.

The relationship between frequency (**f**), period (**T**), wave length (**λ**), and wave velocity (**c**) is the same as that in noise, that is:

$$f=1/T \text{ and } f=c/\lambda$$

However, the wave velocity (c, sometimes also called the phase velocity) in soils varies much more than the speed of airborne sound does, and is often also frequency dependent (the speed of sound only varies with temperature). As a consequence, wavelength cannot readily be calculated when frequency is known and vice versa, unless the wave velocity happens to be known also.

There are three main wave types of concern in the propagation of earthborne vibrations:

1. **Surface or Rayleigh waves**, which as the name implies, travel along the ground surface. They carry most of their energy along an expanding cylindrical wave front, similar to the ripples produced by throwing a rock into a lake. The particle motion is retrograde elliptical, more or less perpendicular to the direction of propagation.
2. **P-waves, or compression waves**. These are body waves that carry their energy along an expanding spherical wave front. The particle motion in these waves is longitudinal, "push-pull". P-waves are analogous to airborne sound waves.
3. **S-waves, or shear waves**. These are also body waves, carrying their energy along an expanding spherical wave front. Unlike P-waves, however, the particle motion is transverse, or perpendicular to the direction of propagation.

As wave fronts move outward from a vibration source, their energy is spread over an ever increasing area. The more rapidly this area increases, the more quickly the energy intensity (energy per unit area) decreases. The areas of cylindrical Raleigh wave fronts

Other criteria - At times, other criteria may be necessary to address very specific concerns. For example, vibration sensitive manufacturing or calibration processes, such as close tolerance machining, laboratories calibrating sensitive electronic equipment, use of electron microscopes, etc. often require vibration criteria that are much lower than the threshold of perception level.

Determining the specific criterion level for such sites is no easy task, and requires the cooperation of the engineers, technicians, or managers involved with the operations. Frequently, even those experts do not know at what level of vibrations their operations will be disturbed, and tests involving generation of vibrations (such as running a heavy truck over 2"x4" wooden boards outside the plant), vibration monitoring equipment, and a test operation must be performed.

Typical Traffic Vibration Levels

From Figure 1 typical relationships of traffic vibrations vs. distance from a freeway can be developed. For instance, vibration data of truck passbys are characterized by peaks that are considerably higher than those generated by automobiles. These peaks last no more than a few seconds and often only a fraction of a second, indicating a rapid drop-off with distance. Figure 1 showed that at 15 m (50 ft) from the centerline of the nearest lane, truck vibrations are about half of those measured near the edge of shoulder (5 m, or about 15 ft from the centerline of the near lane). At 30 m (100 ft) they are about one fourth, at 60 m (200 ft) about one tenth, and at 90 m (300 ft) less than one twentieth. These rough estimates are supported by years of measurements throughout California.

Because of the rapid dropoffs with distance, even trucks traveling close together often do not increase peak vibration levels substantially. In general, more trucks will show up as more peaks, not necessarily higher peaks. Wavefronts emanating from several trucks closely together may either cancel or partially cancel (**destructive interference**), or reinforce or partially reinforce (**constructive interference**) each other, depending on their phases and frequencies. Since traffic vibrations can be considered random, the probabilities of total destructive or constructive interference are extremely small. Coupled with the fact that two trucks cannot occupy the same space, and the rapid drop-off rates, it is understandable that two or more trucks normally do not contribute significantly to each other's peaks. It is, however, good practice to try and include the worst combinations of truck clusters with heavy loads in traffic passby vibration measurements. This obviously requires a good view of the traffic, or an observer who is in communication with the instrument operator.

Figure 2 is a plot of maximum highway truck traffic vibrations vs. distance from the centerline of the nearest freeway lane. The curve was compiled from the highest measured vibrations available from previous studies. Some of the Table 2 criteria are also plotted, for comparison. The graph indicates that the highest traffic generated vibrations measured on freeway shoulders (5 m from center line of nearest lane) have never exceeded 2.0 mm/s, with worst combinations of heavy trucks. This level coincides with the maximum recommended “safe level” for ruins and ancient monuments (and historical buildings). The graph illustrates the rapid attenuation of vibration levels, which dip below the threshold of perception for most people at about 45 m (150 ft).

Automobile traffic normally generates vibration peaks of one fifth to one tenth of truck vibrations.

Traffic vibrations generally range in frequencies from 10-30 Hz, and tend to center around 15 Hz. However, it is not uncommon to measure lower frequencies, even down to 1-2 Hz. Due to their suspension systems, city buses often generate frequencies around 3 Hz, with high velocities (indicating high displacements). It is more uncommon, but possible, to measure frequencies above 30 Hz.

