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# Memo

**Date:** May 23, 2014

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**Subject:** **Coastal Biology Building and Greenhouse Complex, UC Santa Cruz – Noise and Vibration Levels associated with RAP Construction Methods**

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This memo presents the results of the construction noise and vibration assessment completed for the Coastal Biology Building (CBB) and Greenhouse Complex Project proposed along McAllister Way in Santa Cruz, California. This assessment evaluates the use of Rammed Aggregate Piers (RAP) instead of drilled piers for the foundations of the CBB and the new greenhouses during the worst-case phases of construction that would occur across the site along with the proposed RAP construction activities. Appendix A presents the fundamentals of environmental noise and vibration for those who may not be familiar with acoustical terminology and/or concepts.

**Construction Noise Assessment**

Construction noise impacts evaluated in the UC Santa Cruz MSC Projects EIR[1] were assessed with regard to the following significance thresholds:

- 80 dBA Leq (8-hour) during daytime and evening; and
- 70 dBA Leq (8-hour) during nighttime.

The MSC Projects EIR determined that construction of the proposed MSC Projects could expose nearby sensitive receptors to excessive airborne noise, but not to excessive groundborne vibration or groundborne noise. Previously adopted CLRDP EIR General Mitigation 4.11-1, which is applicable to and included in all of the proposed MSC Projects, requires the use of the best available noise control techniques, the use of hydraulically or electrically powered impact tools wherever feasible, the use of mufflers or external jackets on pneumatically powered tools, and, if feasible, the placement of temporary wooden walls around construction activities that are within 150 feet of sensitive receptors.

[1] Marine Science Campus (MSC) Projects Final Environmental Impact Report, University of California Santa Cruz, Office of Physical Planning & Construction, November 2011.

Noise generated by project-related construction activities would be a function of the noise levels generated by individual pieces of construction equipment, the type and amount of equipment operating at any given time, the timing and duration of construction activities, the proximity of nearby sensitive land uses, and the presence or lack of shielding at these sensitive land uses. Construction noise levels would vary on a day-to-day basis during each phase of construction depending on the specific task being completed. Each construction phase would require a different combination of construction equipment necessary to complete the task and differing usage factors for such equipment. Construction noise would primarily result from the operation of heavy construction equipment and the arrival and departure of heavy-duty trucks.

FHWA's Roadway Construction Noise Model (RCNM) was used to calculate the average noise levels anticipated during the worst-case phases of construction that would occur across the site along with the RAP construction activities. This construction noise model includes representative sound levels for the most common types of construction equipment and the approximate usage factors of such equipment that were developed based on an extensive database of information gathered during the construction of the Central Artery/Tunnel Project in Boston, Massachusetts (CA/T Project or "Big Dig"). The usage factors represent the percentage of time that the equipment would be operating at full power. Vehicles and equipment anticipated during each phase of construction were input into RCNM to calculate noise levels at the nearest residences to the construction activities during each phase. Anticipated construction noise levels, by construction activity and phase, are summarized in Table 1.

**TABLE 1 Calculated Construction Noise Levels at Nearest Receptor**

| Date of Construction | Average Equivalent Noise Level ($L_{eq}$) | | |
|---|---|---|---|
| | **CBB Piers** | **Roadwork Ph. 1** | **Combined Noise Level Received at Nearest Residence** |
| 12/15 to 12/29 | 66 dBA at 550 ft. | 66 dBA at 830 ft. | 69 dBA |
| 12/30 to 1/13 | 67 dBA at 550 ft. | 66 dBA at 830 ft. | 70 dBA |
| 1/14 to 1/22 | 67 dBA at 550 ft. | 66 dBA at 830 ft. | 70 dBA |
| **Date of Construction** | **$L_{eq}$, dBA** | | |
| | **CBB Piers** | **Roadwork Ph. 2** | **Combined Noise Level Received at Nearest Residence** |
| 1/23 to 2/5 | 67 dBA at 550 ft. | 66 dBA at 965 ft. | 70 dBA |
| **Date of Construction** | **$L_{eq}$, dBA** | | |
| | **Greenhouse Piers** | **Roadwork Ph. 2** | **Combined Noise Level Received at Nearest Residence** |
| 2/11 to 2/23 | 63 dBA at 1000 ft. | 66 dBA at 965 ft. | 68 dBA |

The predicted worst-case construction noise levels resulting from overlapping phases of construction at distances ranging from 550 feet to 1,000 feet from the nearest sensitive receptors would not exceed the significance thresholds of 80 dBA Leq (8-hour) during daytime and evening or 70 dBA Leq (8-hour) during nighttime and would result in a less than significant impact.

**Construction Vibration Assessment**

The UC Santa Cruz MSC Projects EIR determined that construction of the proposed project would not expose sensitive receptors to excessive groundborne vibration or groundborne noise because construction techniques having the potential of yielding relatively high vibration levels, such as pile driving or blasting, were not anticipated. The use of RAP construction methods instead of drilled piers for the foundations of the CBB and the new greenhouses introduces a new construction technique involving vibratory compaction methods.

For structural damage, the California Department of Transportation recommends a vibration limit of 0.5 inches/second, peak particle velocity (in/sec, PPV) for buildings structurally sound and designed to modern engineering standards, 0.3 in/sec, PPV for older residential buildings, 0.25 for historic and some old buildings, and a conservative limit of 0.08 in/sec, PPV for ancient buildings or buildings that are documented to be structurally weakened. All buildings in the project vicinity are assumed to be structurally sound, but these buildings may or may not have been designed to modern engineering standards. No ancient buildings or buildings that are documented to be structurally weakened are known to exist in the area.

The only significant source of ground vibration associated with the project would result from the ramming of aggregate into the drilled cavity. Table 2, below, presents typical vibration levels that could be expected from construction equipment at a distance of 25 feet.

**TABLE 2 Vibration Source Levels for Construction Equipment**

| Equipment | | PPV at 25 ft. (in/sec) |
|---|---|---|
| Pile Driver (Impact) | upper range | 1.158 |
| | typical | 0.644 |
| Pile Driver (Sonic) | upper range | 0.734 |
| | typical | 0.170 |
| Clam shovel drop | | 0.202 |
| Hydromill (slurry wall) | in soil | 0.008 |
| | in rock | 0.017 |
| Vibratory Roller | | 0.210 |
| Hoe Ram | | 0.089 |
| Large bulldozer | | 0.089 |
| Caisson drilling | | 0.089 |
| Loaded trucks | | 0.076 |
| Jackhammer | | 0.035 |
| Small bulldozer | | 0.003 |

Source: Transit Noise and Vibration Impact Assessment, United States Department of Transportation, Federal Transit Agency, Office of Planning and Environment, May 2006.

A review of vibration data measured from RAP construction activities[2] indicates that RAP construction activities would produce vibration of approximately 0.060 in/sec PPV at a distance of 25 feet. Such vibration levels would fall between the vibration levels typically generated by

[2] Fiegel, G. and Farrell, T. (2008) "*Measurement of Vibration and Noise During the Installation of Rammed Aggregate Piers.*" 6th International Conference on Case Histories in Geotechnical Engineering, Arlington, VA.

the operation of a jackhammer (0.035 in/sec PPV) or a large bulldozer (0.089 in/sec PPV) at a distance of 25 feet.

Vibration levels are highest close to the source, and then attenuate with increasing distance at the rate (Dref/D)1.1, where D is the distance from the source in feet and Dref is the reference distance of 25 feet. Using the attenuation rate above, RAP construction techniques are calculated to result in vibration levels of 0.002 in/sec, PPV at the nearest residential land uses located approximately 550 feet to the east. At this distance, vibration levels would not approach or exceed the 0.3 in/sec PPV threshold used to assess the potential for cosmetic damage to residences (e.g., minor cracks in plastered walls or the loosening of paint). There would be no impact to buildings due to the distance separating the construction activities from the nearest sensitive land uses. Further, groundborne vibration levels resulting from RAP construction techniques, as well as other construction activities occurring at the CBB or greenhouse complex would be below the human perceptibility threshold resulting in a less-than-significant impact.

## APPENDIX A: FUNDAMENTALS OF NOISE AND VIBRATION

### Fundamentals of Environmental Noise

Noise may be defined as unwanted sound. Noise is usually objectionable because it is disturbing or annoying. The objectionable nature of sound could be caused by its *pitch* or its loudness. *Pitch* is the height or depth of a tone or sound, depending on the relative rapidity (frequency) of the vibrations by which it is produced. Higher pitched signals sound louder to humans than sounds with a lower pitch. *Loudness* is intensity of sound waves combined with the reception characteristics of the ear. Intensity may be compared with the height of an ocean wave in that it is a measure of the amplitude of the sound wave.

In addition to the concepts of pitch and loudness, there are several noise measurement scales which are used to describe noise in a particular location. A decibel (dB) is a unit of measurement which indicates the relative amplitude of a sound. The zero on the decibel scale is based on the lowest sound level that the healthy, unimpaired human ear can detect. Sound levels in decibels are calculated on a logarithmic basis. An increase of 10 decibels represents a ten-fold increase in acoustic energy, while 20 decibels is 100 times more intense, 30 decibels is 1,000 times more intense, etc. There is a relationship between the subjective noisiness or loudness of a sound and its intensity. Each 10 decibel increase in sound level is perceived as approximately a doubling of loudness over a fairly wide range of intensities. Technical terms are defined in Table A-1.

There are several methods of characterizing sound. The most common in California is the A-weighted sound level or dBA. This scale gives greater weight to the frequencies of sound to which the human ear is most sensitive. Representative outdoor and indoor noise levels in units of dBA are shown in Table A-2. Because sound levels can vary markedly over a short period of time, a method for describing either the average character of the sound or the statistical behavior of the variations must be utilized. Most commonly, environmental sounds are described in terms of an average level that has the same acoustical energy as the summation of all the time-varying events. This energy-equivalent sound/noise descriptor is called $L_{eq}$. The most common averaging period is hourly, but $L_{eq}$ can describe any series of noise events of arbitrary duration.
The scientific instrument used to measure noise is the sound level meter. Sound level meters can accurately measure environmental noise levels to within about plus or minus 1 dBA. Various computer models are used to predict environmental noise levels from sources, such as roadways and airports. The accuracy of the predicted models depends upon the distance the receptor is from the noise source. Close to the noise source, the models are accurate to within about plus or minus 1 to 2 dBA.

### Fundamentals of Groundborne Vibration

Ground vibration consists of rapidly fluctuating motions or waves with an average motion of zero. Several different methods are typically used to quantify vibration amplitude. One method is the Peak Particle Velocity (PPV). The PPV is defined as the maximum instantaneous positive or negative peak of the vibration wave. In this report, a PPV descriptor with units of mm/sec or in/sec is used to evaluate construction generated vibration for building damage and human complaints. Table A-3 displays the reactions of people and the effects on buildings that continuous vibration levels produce.

The annoyance levels shown in Table A-3 should be interpreted with care since vibration may be found to be annoying at much lower levels than those shown, depending on the level of activity or the sensitivity of the individual. To sensitive individuals, vibrations approaching the threshold of perception can be annoying. Low-level vibrations frequently cause irritating secondary vibration, such as a slight rattling of windows, doors or stacked dishes. The rattling sound can give rise to exaggerated vibration complaints, even though there is very little risk of actual structural damage.

Construction activities can cause vibration that varies in intensity depending on several factors. The use of pile driving and vibratory compaction equipment typically generates the highest construction related ground-borne vibration levels. Because of the impulsive nature of such activities, the use of the PPV descriptor has been routinely used to measure and assess ground-borne vibration and almost exclusively to assess the potential of vibration to induce structural damage and the degree of annoyance for humans.

The two primary concerns with construction-induced vibration, the potential to damage a structure and the potential to interfere with the enjoyment of life are evaluated against different vibration limits. Studies have shown that the threshold of perception for average persons is in the range of 0.008 to 0.012 in/sec PPV. Human perception to vibration varies with the individual and is a function of physical setting and the type of vibration. Persons exposed to elevated ambient vibration levels, such as people in an urban environment, may tolerate a higher vibration level.

Structural damage can be classified as cosmetic only, such as minor cracking of building elements, or may threaten the integrity of the building. Safe vibration limits that can be applied to assess the potential for damaging a structure vary by researcher and there is no general consensus as to what amount of vibration may pose a threat for structural damage to the building. Construction-induced vibration that can be detrimental to the building is very rare and has only been observed in instances where the structure is at a high state of disrepair and the construction activity occurs immediately adjacent to the structure.

**TABLE A-1 Definition of Acoustical Terms Used in this Report**

| Term | Definition |
|---|---|
| Decibel, dB | A unit describing, the amplitude of sound, equal to 20 times the logarithm to the base 10 of the ratio of the pressure of the sound measured to the reference pressure. The reference pressure for air is 20. |
| Sound Pressure Level | Sound pressure is the sound force per unit area, usually expressed in micro Pascals (or 20 micro Newtons per square meter), where 1 Pascal is the pressure resulting from a force of 1 Newton exerted over an area of 1 square meter. The sound pressure level is expressed in decibels as 20 times the logarithm to the base 10 of the ratio between the pressures exerted by the sound to a reference sound pressure (e. g. , 20 micro Pascals). Sound pressure level is the quantity that is directly measured by a sound level meter. |
| Frequency, Hz | The number of complete pressure fluctuations per second above and below atmospheric pressure. Normal human hearing is between 20 Hz and 20,000 Hz. Infrasonic sound are below 20 Hz and Ultrasonic sounds are above 20,000 Hz. |
| A-Weighted Sound Level, dBA | The sound pressure level in decibels as measured on a sound level meter using the A-weighting filter network. The A-weighting filter de-emphasizes the very low and very high frequency components of the sound in a manner similar to the frequency response of the human ear and correlates well with subjective reactions to noise. |
| Equivalent Noise Level, $L_{eq}$ | The average A-weighted noise level during the measurement period. |
| $L_{max}$, $L_{min}$ | The maximum and minimum A-weighted noise level during the measurement period. |
| $L_{01}$, $L_{10}$, $L_{50}$, $L_{90}$ | The A-weighted noise levels that are exceeded 1%, 10%, 50%, and 90% of the time during the measurement period. |
| Day/Night Noise Level, $L_{dn}$ or DNL | The average A-weighted noise level during a 24-hour day, obtained after addition of 10 decibels to levels measured in the night between 10:00 pm and 7:00 am. |
| Community Noise Equivalent Level, CNEL | The average A-weighted noise level during a 24-hour day, obtained after addition of 5 decibels in the evening from 7:00 pm to 10:00 pm and after addition of 10 decibels to sound levels measured in the night between 10:00 pm and 7:00 am. |
| Ambient Noise Level | The composite of noise from all sources near and far. The normal or existing level of environmental noise at a given location. |
| Intrusive | That noise which intrudes over and above the existing ambient noise at a given location. The relative intrusiveness of a sound depends upon its amplitude, duration, frequency, and time of occurrence and tonal or informational content as well as the prevailing ambient noise level. |

Source: Handbook of Acoustical Measurements and Noise Control, Harris, 1998.

**TABLE A-2 Typical Noise Levels in the Environment**

| Common Outdoor Activities | Noise Level (dBA) | Common Indoor Activities |
|---|---|---|
| | 110 dBA | Rock band |
| Jet fly-over at 1,000 feet | | |
| | 100 dBA | |
| Gas lawn mower at 3 feet | | |
| | 90 dBA | |
| Diesel truck at 50 feet at 50 mph | | Food blender at 3 feet |
| | 80 dBA | Garbage disposal at 3 feet |
| Noisy urban area, daytime | | |
| Gas lawn mower, 100 feet | 70 dBA | Vacuum cleaner at 10 feet |
| Commercial area | | Normal speech at 3 feet |
| Heavy traffic at 300 feet | 60 dBA | |
| | | Large business office |
| Quiet urban daytime | 50 dBA | Dishwasher in next room |
| Quiet urban nighttime | 40 dBA | Theater, large conference room |
| Quiet suburban nighttime | | |
| | 30 dBA | Library |
| Quiet rural nighttime | | Bedroom at night, concert hall (background) |
| | 20 dBA | |
| | | Broadcast/recording studio |
| | 10 dBA | |
| | 0 dBA | |

Source: Technical Noise Supplement (TeNS), Caltrans, November 2009.

**TABLE A-3 Reaction of People and Damage to Buildings From Continuous or Frequent Intermittent Vibration Levels**

| Velocity Level, PPV (in/sec) | Human Reaction | Effect on Buildings |
|---|---|---|
| 0.01 | Barely perceptible | No effect |
| 0.04 | Distinctly perceptible | Vibration unlikely to cause damage of any type to any structure |
| 0.08 | Distinctly perceptible to strongly perceptible | Recommended upper level of the vibration to which ruins and ancient monuments should be subjected |
| 0.1 | Strongly perceptible | Virtually no risk of damage to normal buildings |
| 0.3 | Strongly perceptible to severe | Threshold at which there is a risk of damage to older residential dwellings such as plastered walls or ceilings |
| 0.5 | Severe - Vibrations considered unpleasant | Threshold at which there is a risk of damage to newer residential structures |

Source: Transportation- and Construction-Induced Vibration Guidance Manual, California Department of Transportation, June 2004.