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**Project Name:**
Chambers Reservior Reconstructionl

**Project ref:**
60606415

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**Date:**
July 24, 2019

# Memo

**Subject:** Chambers Reservoir Reconstruction, Construction Vibration Analysis and Assessment

## Introduction

AECOM is involved with a reconstruction project for the Chambers terminal water supply reservoir near Parker, CO. Due to the proximity of the construction activity to nearby homes, AECOM was requested to conduct a screening level analysis to determine if construction-related ground vibration could result in possible damage to nearby structures or result in annoyance to area residents. This technical memo summarizes the construction vibration analysis and results.

## Project Description and Understanding

The Chambers Reservoir project is located just to the West of Parker, CO, about 1200 feet south of the E-470/Chambers Road interchange. It is a terminal water supply reservoir that experienced a slope failure. To remedy the slope failure, the reservoir is being reshaped with material being importing to raise the bottom of the reservoir above groundwater level. In all approximately 300,000 cubic yard of material is being added. A requirement for local permitting was to conduct a vibration analysis because some construction equipment is expected to be operating within 15 feet of the property line of adjacent residential structures.

As part of the construction project, several pieces of heavy equipment are planned to be used, both working on the reservoir slope sections, and traveling on the service road along the edges of the reservoir.

A list of the construction equipment to be used for the project includes the following:

- CAT 627F or 627G scrapers
- CAT 825C sheep foot compactor
- Cat D9T Dozer
- CAT AWT 740 water tanker truck (holds 7,500 gallons)
- CAT 330 excavator

- John Deere 9520 farm tractor (pulls the disc)

The Extents of the reservoir and several nearby analysis locations are shown in Figure 1.

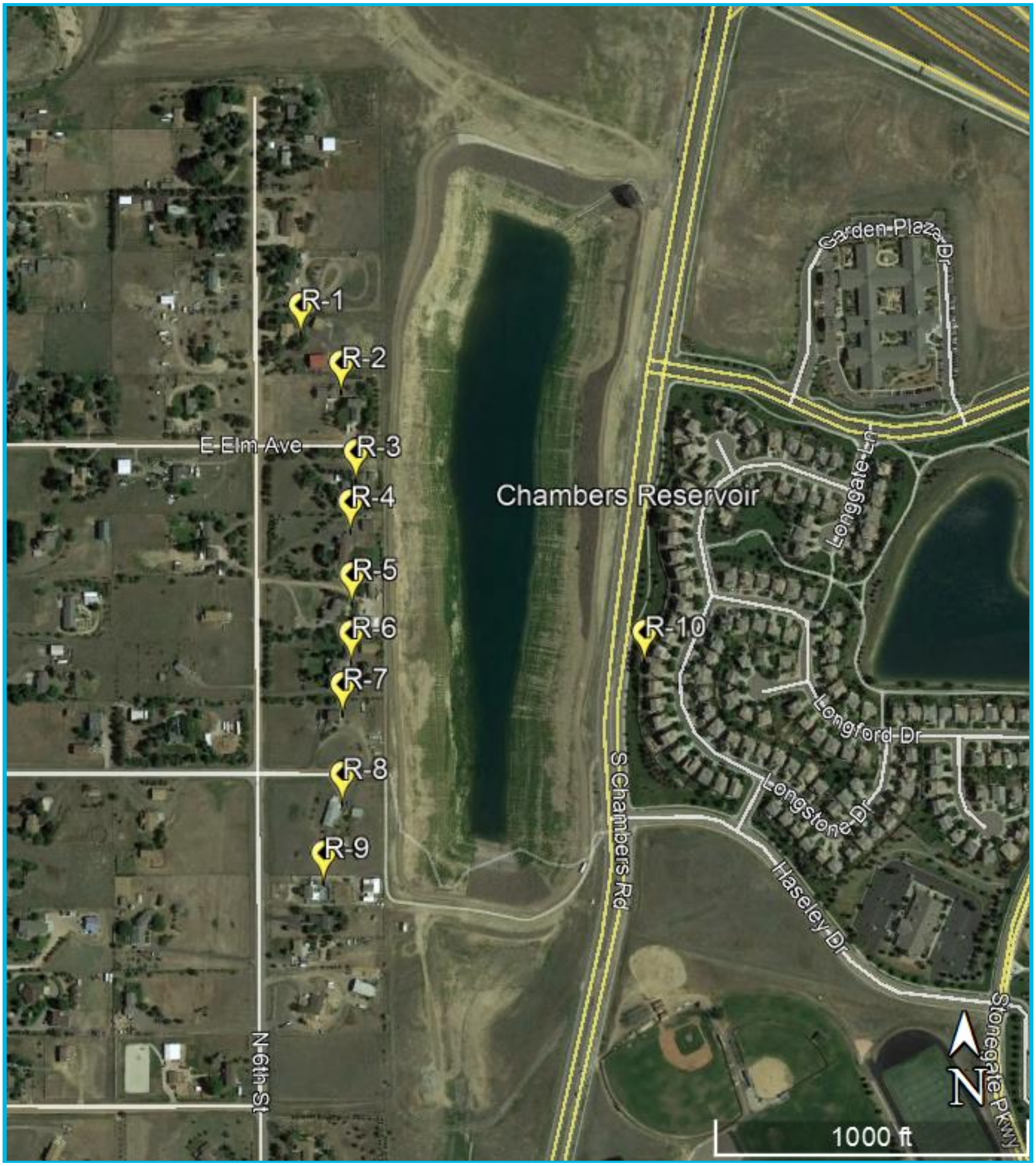


**Figure 1. Project Area**

# Construction Vibration Analysis Methodology

The methodology for describing, predicting and assessing potential impacts from ground-borne vibration from construction activity for this analysis follows the technical procedures and reference material provided in the Federal Transit Administration's Transit Noise and Vibration Impact Assessment Manual (September 2018), primarily from information provided in Section 5 (vibration metrics and annoyance thresholds) and Section 7 (construction vibration prediction and assessment).

## Ground-Borne Vibration Metrics

**Peak particle velocity (PPV)** – PPV is the maximum instantaneous positive or negative peak of the vibration signal. PPV is often used in monitoring of construction vibration (such as blasting) since it is related to the stresses that are experienced by buildings and is not used to evaluate human response.

**Root mean square (rms) velocity** – Because the net average of a vibration signal is zero, the rms amplitude is used to describe smoothed vibration amplitude. The rms of a signal is the square root of the average of the squared amplitude of the signal. The average is typically calculated over a one-second period. The rms amplitude is always less than the PPV and is always positive. The rms amplitude is used to convey the magnitude of the vibration signal felt by the human body, in inches/second.

**Vibration Velocity Level (VdB or $L_v$)** – $L_v$ is a logarithmic quantity expressing the amplitude of the vibration velocity, calculated by the following expression:

$$L_v = 20Log(v/v_{ref})$$

Where:

$L_v$ = velocity level, VdB
$v$ = rms velocity amplitude
$v_{ref}$ = vibration velocity reference level ($1 \times 10^{-6}$ in/sec in the USA)

The $L_v$ is often used to assess human annoyance from ground-born vibration.

The ratio of PPV to maximum rms amplitude is defined as the crest factor for the signal. The crest factor is typically greater than 1.41, although a crest factor of 8 or more is not unusual for impulsive signals. For ground-borne vibration from construction activity, the crest factor is usually 4 to 5. Therefore, when converting from PPV to Lv the following relationship is used:

$$Lv = 20log((PPV*10^6)/4)$$

Where:

PPV is the predicted peak particle velocity at the receiver location in inch/sec

# Ground Vibration Impact Criteria

There are two separate areas of concern related to ground-borne vibration, annoyance and potential building damage. The impact criteria for these are presented in Tables 1 and 2, respectively

**Table 1. Indoor Ground-Borne Vibration Impact Criteria**

| Land Use Category | GBV Impact Levels (VdB re 1 micro-inch /sec) | | | GBN Impact Levels (dBA re 20 micro Pascals) | | |
|---|---|---|---|---|---|---|
| | Frequent Events | Occasional Events | Infrequent Events | Frequent Events | Occasional Events | Infrequent Events |
| **Category 1**: Buildings where vibration would interfere with interior operations. | 65 VdB* | 65 VdB* | 65 VdB* | N/A** | N/A** | N/A** |
| **Category 2**: Residences and buildings where people normally sleep. | 72 VdB | 75 VdB | 80 VdB | 35 dBA | 38 dBA | 43 dBA |
| **Category 3**: Institutional land uses with primarily daytime use. | 75 VdB | 78 VdB | 83 VdB | 40 dBA | 43 dBA | 48 dBA |

* This criterion limit is based on levels that are acceptable for most moderately sensitive equipment such as optical microscopes. For equipment that is more sensitive, a Detailed Vibration Analysis must be performed.
** Vibration-sensitive equipment is generally not sensitive to ground-borne noise; however, the manufacturer's specifications should be reviewed for acoustic and vibration sensitivity.

Source FTA 2018, Table 6-3

**Table 2. Construction Vibration Damage Criteria**

| Building/ Structural Category | PPV, in/sec | Approximate $L_v$* |
|---|---|---|
| I. Reinforced-concrete, steel or timber (no plaster) | 0.5 | 102 |
| II. Engineered concrete and masonry (no plaster) | 0.3 | 98 |
| III. Non-engineered timber and masonry buildings | 0.2 | 94 |
| IV. Buildings extremely susceptible to vibration damage | 0.12 | 90 |

*RMS velocity in decibels, VdB re 1 micro-in/sec

Source: FTA 2018, Table 7-5

Assuming that the structures of concern are primarily single-family residences of wood framed and/or masonry construction, and vibration events would be considered "infrequent" (less than 70 event/day), the impact criteria for this analysis would be 80 VdB vibration velocity level for indoor human annoyance and 0.2 PPV in/sec for potential building damage.

# Ground-Borne Vibration Level Prediction

Section 7.2 of the FTA manual provides the following method for predicting ground-borne vibration levels for construction activity. The basic procedure is to select an appropriate representative type of equipment from the reference equipment list and apply the distance correction formula for the distance of the desired prediction location. Table 3 presents the list of reference vibration levels for common vibration-generating construction equipment.

**Table 3. Reference vibration levels for common construction equipment**

| Equipment | | PPV at 25 ft, in/sec | Approximate Lv* at 25 ft |
|---|---|---|---|
| Pile Driver (impact) | upper range | 1.518 | 112 |
| | typical | 0.644 | 104 |
| Pile Driver (sonic) | upper range | 0.734 | 105 |
| | typical | 0.17 | 93 |
| Clam shovel drop (slurry wall) | | 0.202 | 94 |
| Hydromill (slurry wall) | in soil | 0.008 | 66 |
| | in rock | 0.017 | 75 |
| Vibratory Roller | | 0.21 | 94 |
| Hoe Ram | | 0.089 | 87 |
| Large bulldozer | | 0.089 | 87 |
| Caisson drilling | | 0.089 | 87 |
| Loaded trucks | | 0.076 | 86 |
| Jackhammer | | 0.035 | 79 |
| Small bulldozer | | 0.003 | 58 |

* RMS velocity in decibels, VdB re 1 micro-in/sec

Source: FTA 2018, Table 7-4

The distance correction is applied with the following expression:

$$PPV_{equip} = PPV_{ref} *(25/D)^{1.5}$$

Where:

$PPV_{equip}$ = the peak particle velocity of the equipment adjusted for distance, in/sec
$PPV_{ref}$ = the source reference peak particle velocity at 25 feet in in/sec (from Table 3)
D = distance from the equipment to the receiver, in feet.

The resulting PPV value can then be compared to the appropriate potential damage criterion (from Table 2), and converted to an $L_v$ value and compared to human annoyance impact criterion (from Table 1).

# Vibration Prediction Results and Impact Assessment

For this analysis, two different operations were considered for potential vibration impacts: vibration from heavy equipment traveling along the reservoir's service road (SR) and equipment operating on the reservoir slope. The analysis assumptions used for the construction vibration prediction and impact assessment are presented in Table 4 below.

## Table 4. Construction Vibration Analysis Assumptions

| Activity | Equipment | PPV @ 25 feet | Lv @ 25 feet |
|---|---|---|---|
| Maximum vibration from equipment moving on Service Road | Dozer | 0.089 in/sec | 87 VdB |
| Maximum vibration from equipment operating on slope | Compactor/Roller | 0.21in/sec | 94 VdB |
| **Impact Thresholds** | | | |
| Potential Building Damage (non-engineered timber or masonry) | | 0.20 in/sec, PPV | 94 VdB |
| Potential Human Annoyance (residences, infrequent events) | | 0.04 in/sec, PPV | 80 VdB |

For several adjacent residential properties, there appeared to be primary residential structure and a secondary structure which was generally assumed to be a garage, barn or shop. In these cases, a vibration level was calculated from each. For impact assessment, the potential damage criterion (0.20 in/sec PPV) would be applied to either structure, but the human annoyance impact criterion (80 VdB) would only be applied at the primary residence, not for garages, barns or shops since these are not normally considered to be vibration-sensitive uses for human annoyance. The receiver distances and predicted vibration levels for both residential and secondary structures are presented in Table 5.

## Table 5. Predicted Vibration Levels at Nearby Homes

| ID | Approximate Address/Location | Structure | Distances (ft) Service Rd | Distances (ft) Reservoir | Vehicles on SR PPV | Vehicles on SR $L_v$ | Work on Slope PPV | Work on Slope $L_v$ |
|---|---|---|---|---|---|---|---|---|
| R-1 | 12870 N 6th Street | Home | 340 | 360 | 0.002 | 52.9 | 0.004 | 59.7 |
| | | Barn/shop | 235 | 255 | 0.003 | 57.8 | 0.006 | 64.1 |
| R-2 | 12830 N 6th | Garage | 170 | 190 | 0.005 | 62.0 | 0.010 | 68.0 |
| | (NE Corner 6th & Elm) | Home | 100 | 120 | 0.011 | 68.9 | 0.020 | 74.0 |
| R-3 | 12790 N 6th | Home | 100 | 120 | 0.011 | 68.9 | 0.020 | 74.0 |
| | (SE Corner 6th & Elm) | Shop | 35 | 55 | 0.054 | 82.6 | 0.064 | 84.1 |
| R-4 | 12750 N 6th | Home | 200 | 220 | 0.004 | 59.9 | 0.008 | 66.1 |
| | | Barn/shop | 45 | 65 | 0.037 | 79.3 | 0.050 | 82.0 |
| R-5 | 12710 N 6th | Home | 145 | 165 | 0.006 | 64.0 | 0.012 | 69.8 |
| | | Shop | 50 | 70 | 0.031 | 77.9 | 0.045 | 81.0 |
| R-6 | 12670 N 6th | Home | 140 | 160 | 0.007 | 64.5 | 0.013 | 70.2 |
| | | Shop | 50 | 75 | 0.031 | 77.9 | 0.040 | 80.1 |
| R-7 | 12630 N 6th (NE Corner of 6th & Dogwood) | Home | 180 | 200 | 0.005 | 61.2 | 0.009 | 67.3 |
| R-8 | 3946 Dogwood (SE corner | Home | 185 | 205 | 0.004 | 60.9 | 0.009 | 67.0 |
| | of 6th & Dogwood) | Shop | 120 | 140 | 0.008 | 66.5 | 0.016 | 72.0 |
| R-9 | 12540 N 6th | Home | 230 | 250 | 0.003 | 58.0 | 0.007 | 64.4 |
| | | Garage/Shop | 60 | 80 | 0.024 | 75.5 | 0.037 | 79.2 |
| R-10 | Homes on Longstone | Min dist. | 167 | 205 | 0.005 | 62.2 | 0.009 | 67.0 |
| | Drive | Max dist. | 245 | 275 | 0.003 | 57.2 | 0.006 | 63.2 |

## Potential Vibration Impacts

Reviewing the results presented in Table 5, it can be seen that at no analyzed location does the predicted PPV value approach or exceed the potential damage threshold of 0.2 inch/sec. The highest predicted PPV value is 0.064 at the rear structure at receiver location R-3 for slope work.

It can also be seen that the predicted vibration velocity level ($L_v$) does not approach or exceed the human annoyance threshold of 80 VdB at any of the analyzed residential structures. The 80 VdB level is exceeded at a few of the closer secondary structures (e.g., 84.1 VdB at the R-3 shop structure), but these structures are not considered vibration-sensitive for human annoyance.

# Conclusions

No potential vibration impacts were found to exist at residential or other structures in the vicinity of the Chambers Reservoir as a result of the proposed construction activity; therefore, no vibration mitigation is recommended.

# References

Federal Transit Administration Noise and Vibration Impact Assessment Manual (2018): https://www.transit.dot.gov/regulations-and-guidance/environmental-programs/noise-and-vibration