REPORT

# VIBRATION STUDY DATA REPORT
# GASCO SILTRONIC CONSTRUCTION

**Prepared for**

NW Natural

**Prepared by**

Anchor QEA, LLC

**In Association with**

Colin Gordon & Associates

Sevenson Environmental Services, Inc.

Siltronic Corporation

**May 2009**

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## LIST OF ACRONYMS AND ABBREVIATIONS

| Abbreviation | Definition |
|---|---|
| CGA | Colin Gordon and Associates |
| CM | Construction Management |
| DEQ | Oregon Department of Environmental Quality |
| DNAPL | dense non-aqueous phase liquid |
| FFA | free field arrays |
| FFS | Focused Feasibility Study |
| GRC | gross reality check |
| IH | Junttan HHK 5A Hydraulic Impact Hammer |
| MGP | Manufactured Gas Plant |
| LLS | Laser Light Scatter |
| LM | Laser Mark |
| PM | Project Manager |
| PPE | personnel protective equipment |
| PPM | Plant Process Monitoring |
| RMS | root mean square |
| SEM | Scanning Electron Microscope |
| Site | Gasco and Siltronic facilities |
| SPC | statistical process control |
| SRP | spreading resistance probe |
| VD | APE 200-6 vibratory driver |
| VM | Vibration Monitoring |
| VMVD | Variable Moment vibratory driver |
| VOC | volatile organic compounds |

# 1 INTRODUCTION

## 1.1 Background

The Oregon Department of Environmental Quality (DEQ) required that NW Natural and Siltronic evaluate source control alternatives, including construction of a vertical barrier wall, to control migration of manufactured gas plant (MGP-) related and volatile organic compounds (VOC) contaminants to the Willamette River from the Gasco and Siltronic facilities (the Site). DEQ has determined that a vertical barrier is necessary to prevent MGP-related dense non-aqueous phase liquids (DNAPL) migration at the Gasco property. In the *Groundwater/DNAPL Source Control Focused Feasibility Study* (FFS; Anchor 2007), it was concluded that a steel sheetpile barrier is the most appropriate barrier for the project. Other source control elements described in the FFS are currently under design to address dissolved phase MGP- and VOC-related sources to the river in Segments 1 and 2 of the Site.

On behalf of NW Natural, Anchor QEA, LLC (Anchor QEA), Colin Gordon and Associates (CGA), Stephen Dickenson, PhD (Dickenson), and Sevenson Environmental Services, Inc. (Sevenson) prepared a Work Plan entitled *Work Plan – Gasco Siltronic Construction Vibration Study* (Appendix A) to evaluate construction induced vibrations at the Siltronic facility that may be caused by construction of a vertical barrier wall. The Work Plan was developed in collaboration with Siltronic and was designed to assess the potential impacts of construction-induced vibrations on Siltronic's facility and accommodate Siltronic's production restrictions, process analysis, and feedback schedule during the testing. The Work Plan was approved by DEQ in a letter dated September 12, 2008; however, following comments made by EPA, DEQ suspended its approval of the study for approximately three months while the EPA issues were resolved. The Site vicinity is shown on Figure 1. General features of the Gasco and Siltronic properties are shown on Figure 2.

Siltronic Corporation (Siltronic) manufactures silicon wafers for the semiconductor industry. Siltronic expressed concerns related to the potential impacts to its operations from vibrations induced by vertical barrier construction activities, including steel sheetpile driving. Siltronic described these concerns, as well as recommended protocols for conducting testing to determine the potential effects of the proposed activities on manufacturing processes, in the *Wafer Test Outline, for Potential Effects from Vibrations (December 6, 2007 revision)* and

the *Wafer Test Results Summary (Sample)* (attached to the Work Plan). Additional details related to Siltronic's specifications for scheduling and sequencing the vibration testing, the "wafer test feedback" schedule, and reporting of results are provided in the correspondence (attached to the Work Plan in Appendix A) to NW Natural regarding wafer process monitoring for vibration impacts.

## 1.2 Objectives

The objective of the study is to evaluate concerns expressed by Siltronic about potential impacts to its operations from construction-induced vibrations during installation of a vertical barrier wall. During field testing, comprehensive vibration monitoring was conducted during all construction activities, including heavy equipment movement, backhoe pre-trenching, sheetpile driving, and pile removal. The primary goals of the construction simulation and ground motion monitoring investigation were two-fold: 1) to develop site-specific relationships for the attenuation of ground motions from the source of vibrations, and 2) to bracket the anticipated range of ground vibrations that would be generated by various construction techniques. Given the number of available alternative types of barrier walls and associated construction methods, it was not considered practicable to evaluate all possible methods at the Site. The monitoring program outlined in the Work Plan was intended to characterize the range of motions that could be expected during construction options being evaluated by Anchor QEA and DEQ. It was anticipated that the ground vibrations generated during the investigation would effectively bracket the range of motions during construction; therefore, the findings from the monitoring would be used to quantitatively interpolate the vibrations that would be expected to result from multiple barrier types. The findings of the study are summarized in this report and provided to the Oregon DEQ to assist in its selection of a groundwater DNAPL source control design for the Site.

# 2 METHODS

The investigation scope included a ground vibration monitoring program for both ambient conditions and construction-induced vibrations associated with trenching, installation equipment operation, and sheetpile installation at the Site. The investigation was performed according to the Work Plan (Appendix A) and the *Communication Plan – Gasco Siltronic Construction Vibration Study*, which is provided as Appendix B.

## 2.1 Project Organization

Anchor QEA managed the project and coordinated the implementation of the study with Siltronic. CGA conducted the vibration monitoring with the assistance of Signalysis. Sevenson coordinated and conducted the construction simulation. Siltronic staff monitored production operations during the study, assisted in coordinating the timing of the construction simulations, and provided feedback related to the effect of the construction simulations on production operations.

## 2.2 Vibration Monitoring during Construction Simulation

The vibration monitoring program was sequenced in the following manner:

- Step 1 – monitoring ambient vibrations in Siltronic buildings.
- Step 2 – evaluation of ground and structural vibrations due to trenching and pile driving at the <u>northwestern</u> (downstream) corner of the Gasco facility
- Step 3 – evaluation of ground and structural vibrations due to trenching and pile driving at the <u>northeastern</u> (upstream) corner of the Gasco facility
- Step 4 – monitoring ambient vibrations in Siltronic buildings

The locations of the trenches where the construction simulations were performed, the locations of the ground vibration monitoring equipment (free field arrays [FFAs]), and the locations where vibration monitoring equipment (accelerometers) were placed within the Siltronic fabrication (FAB) buildings are depicted on Figure 2. The horizontal distances between each of these points are provided in Table 1.

Step 1 ambient monitoring was conducted continuously for 7 days before construction simulations began (February 2, 2009 through February 8, 2009). Step 4 ambient monitoring was conducted continuously for twenty days after all construction simulations were completed, from February 19, 2009 through March 10, 2009

Three types of pile hammers were used to assess ground vibrations induced by driving 90-foot-long steel sheetpiles and to evaluate the effectiveness of these hammers for driving the piles. The hammer models that were used included: the APE 200-6 vibratory driver (VD), APE Model 250V Variable Moment vibratory driver (VMVD), and Junttan HHK 5A Hydraulic Impact Hammer (IH).

Two 2-hour construction simulation tests were performed with each of the three types of pile hammers at both the Step 2 and Step 3 locations. In order to ensure that enough process feedback monitoring data were collected during the testing periods, at least 1½ hours of more or less continuous testing was necessary within each 2-hour testing period. Due to equipment issues and typical construction-related delays, two of the testing periods were repeated to ensure that enough process feedback monitoring data were collected.

Construction simulation testing with the three types of pile hammers occurred at the Step 2 location from February 9, 2009 through February 12, 2009. The specific sequence of testing at the Step 2 location was as follows:

- February 9, 2009 – the VD was used during the morning and afternoon testing periods
- February 10, 2009 – the VD was used during the morning testing period and the VMVD was used in the afternoon testing period
- February 11, 2009 – the VMVD was used during the morning testing period and the VD was used in the afternoon testing period
- February 12, 2009 – the IH was used during the morning and afternoon testing periods

Construction simulation testing occurred at the Step 3 location from February 16, 2009 through February 18, 2009.

- February 17, 2009 – the IH was used during the morning and afternoon testing periods and sheet pile was "toed-in" and extracted as necessary using the VM
- February 18, 2009 – the VMVD was used during the morning testing period and the VD was used in the afternoon testing period
- February 19, 2009 – the VD was used during the morning testing period and the VMVD was used in the afternoon testing period

Construction-induced vibrations associated with trenching were monitored at the Step 2 location on February 9, 2009 and at the Step 3 location on February 13, 2009 when trenching was performed at those locations. Construction-induced vibrations associated with installation equipment operations were monitored throughout the pile driving simulation testing periods at both the Step 2 and Step 3 locations. In addition, construction-induced vibrations associated with installation equipment operations were monitored when the crane was relocated between the Step 2 and Step 3 locations on February 13, 2009, when no pile driving simulations were taking place.

## 2.3 Monitoring Protocols

Each day prior to start of testing, there was a face-to-face meeting between the Project Manager (PM), the Siltronic Plant Process Monitoring (PPM) Leads, the Construction Management (CM) Lead, and the Vibration Monitoring (VM) Lead. During that meeting, the group reviewed the tests planned for that day and the communication protocols to be sure that all parties understood the process. Notes from each meeting were summarized and distributed to the project team to provide documentation of attendees, discussions, and agreements made.

Prior to the start of testing, a communication check between the PM, the PPM Leads, the CM Lead, and the VM Lead was performed. The purpose of this check was to confirm that the communication devices were working reliably between all parties. Two-way radios were utilized as the primary communication device. Cell phones were utilized as the back-up communication device. Repeated communication checks were also made between all parties during pile driving tests to confirm that the communication systems were functional.

During Step 1 (ambient monitoring), "warning" triggers of 20 percent above the maximum root mean square (RMS) velocity levels were established. The setting and magnitude of the initial "warning" triggers were reviewed and established by the VM Lead and the PPM Lead before testing began. The "warning" trigger levels were adjusted by mutual agreement between NW Natural and Siltronic during the course of Steps 2, 3, and 4. If a "warning" trigger was exceeded during the course of a testing simulation:

- The VM Lead notified the PM and the PPM Lead immediately.
- The PM notified the CM Lead and directed the CM Lead to pause construction immediately.
- The CM Lead halted all operations and movement of large equipment until cleared by the PM.
- The PPM Lead checked Siltronic's processes and alerted the PM of any catastrophic failures or other identified issues within 1 hour.
- The PM and PPM Lead adjusted the trigger levels in consultation with the VM Lead.

When exceedances of the "warning" triggers occurred during the course of the testing and the PM was authorized to resume testing by the PPM Lead, the trigger levels were increased by mutual agreement of NW Natural and Siltronic to correspond with the maximum RMS peak velocity measured by each individual accelerometer before testing resumed.

## 2.4 Deviations from the Work Plan

Field activities related to the vibration study were generally completed in accordance with the Work Plan, with the following exceptions:

- If warning levels were exceeded, they were to be increased to 20 percent above the maximum RMS values measured pending approval by Siltronic (pending results of inspections of tools and processes). For reasons explained in Section 3.3, after the first 2-hour testing event, the basis for the warning level increases was changed, with approval by Siltronic, to 100 percent above maximum RMS values measured.
- The 2-hour testing periods were increased to 2.5-hour testing periods at the Step 3 location. During testing at the Step 2 location, there were a number of factors (equipment issues, pile damage, movement of the pile driver from one sheet to another, etc.) that prevented active testing to continue throughout the entire 2-hour

period. In order to ensure that active testing occurred for a long enough duration to allow adequate process feedback data to be collected, the testing periods were increased to 2.5 hours based on agreement between NW Natural and Siltronic.

- FAB 2 was shut down for business reasons during the construction simulations at the Step 3 location. Continuous metrology was performed as planned (these are automated processes), however, yield loss gross reality check (GRC) and process statistical process control (SPC) GRC activities were not performed. The operational shut down was scheduled by Siltronic. Despite the fact that yield loss GRC and process SPC GRC activities were not performed, Siltronic stated that the shutdown would not affect the reliability of the study data and results. While no process feedback data was collected for the activities that were not performed, comparable data were collected in FAB 1, which was in closer proximity to the Step 3 testing location and therefore adequate to allow calibration of a vibration model for the Site.

# 3 RESULTS

Vibration data were collected during Step 1 ambient monitoring, Step 2 construction simulations at the northwestern corner of the Gasco facility, Step 3 construction simulation testing at the northeastern corner of the Gasco facility, and Step 4 ambient monitoring. Siltronic process monitoring feedback data were collected during both construction simulation steps (Step 2 and Step 3).

## 3.1 Vibration Data

Vibration data was obtained with three arrays of accelerometers:

- A ground surface, free-field array of four widely spaced sensors that were positioned relative to the pile driving location at Step 2 to establish the attenuation of vibrations with distance from the construction activities
- A ground surface, free-field array of four widely spaced sensors that were positioned relative to the pile driving location at Step 3 to establish the attenuation of vibrations with distance from the construction activities
- A structural array that included sensors at eight locations within Siltronic's facilities.

The latter array, developed with input from Siltronic's representatives, provided vibration data in close proximity to sensitive equipment as well as requisite data for evaluating the building effects on the induced vibrations. The monitoring locations in the Siltronic buildings are listed on Table 2. Table 1 lists the accelerometers used in the buildings and distances between instruments. The vibration sensors utilized in the buildings were mounted to floor slabs or ceilings (i.e., floor diaphragms), and not to raised floors, equipment pedestals, or countertops supporting process or monitoring equipment. The vibration data from the structural array therefore provides an indication of the vibrations experienced by the Siltronic instruments. Additional factors contribute to the actual vibrations of the individual tools (e.g., human foot-fall, dynamics of raised floors and equipment support, and instrument response characteristics).

At all times during Step 2 and Step 3 pile driving sequences, details on the construction operations, pile configuration, and driving activity (driving, extracting, and hammer setting) were recorded by project team members. This allowed for direct comparison of free-field

and building vibration levels during specific time intervals or due to specific events, and changes in vibration characteristics due to construction activities and hammer operation.

## 3.2 Free-Field Array Data

The vibration sensors used in the FFAs were located relative to the pile driving operations; therefore, the sensors were relocated between Step 2 and Step 3 activities (Figure 2). For both steps, the nearest sensor in the array was about 100 feet from the pile driving locations and the remaining sensors were arranged roughly parallel to the Willamette River. The sensors were placed at spacings of approximately 100, 200, 400, and 800 feet from the pile being driven. Table 1 lists the sensors for each step and separation distances. The data obtained during construction activities were plotted in the form of velocity spectra to demonstrate the frequency and amplitude characteristics of the ground motions at various distances for each aspect of the construction process. Vibration data were recorded and reviewed in three orthogonal directions: vertical component, horizontal component in the radial direction (i.e., in the direction of wave travel), and horizontal component in the transverse direction (i.e., perpendicular to the radial direction).

Figure 3.1 illustrates the vibration spectra of each pile driving method, along with trenching and ambient levels as measured at 100 feet from the northwest pile driver location on the Gasco site. (The data are shown from 2 to 50 Hz in narrowband with a frequency band of 0.625 Hz.) These same data are presented in 1/3 octave bands in Figure 3.2. One third octave represents spectra in proportional bandwidth such that the relative amount of energy increases as a function of frequency. Similar narrowband and one third octave spectra are given in Figures 3.3 and 3.4, respectively, for the Siltronic Site. The relative impacts of the construction activities on the vibrations at this location are evident across the frequency band of interest. Plots such as these were prepared for each hammer and for numerous time intervals during the construction simulations at Step 2 and Step 3. These data were shared with the project team during daily meetings at Siltronic.

In the weeks following the construction simulation program, more refined methods of data processing and analysis, incorporating wave coherence and ratios of the vibration amplitudes measured at each sensor location (i.e., transfer functions), were employed to establish

frequency-dependent attenuation relationships across the northern margin of the Gasco site and along the northwestern portion of the Siltronic site. This calculation is based on a transfer function that correlates the relationship between vibrations at each location, hence minimizing the impact from random noise. The attenuation relationships established for pile driving during Step 2 (Gasco site) and Step 3 (Siltronic site) are presented in Figures 4.1 and 4.2. The attenuation of motion is represented as de-amplification in decibels (dB), a logarithmic relationship. These curves are independent of hammer type as the vibration attenuation is a function of the soil deposits (layering, soil type(s), and damping), site configuration, and, to a lesser extent, the depth to bedrock.

The difference in attenuation characteristics across the Gasco and Siltronic sites are evident in Figures 4.1 and 4.2. The construction-induced vibrations attenuate much more rapidly across the Gasco site. In fact, very little attenuation is noted in certain frequency bands at the Siltronic site. This is possibly due to the cumulative effects of lateral variability of the riverfront soils and the influence of the extensive fill that has been placed at the Siltronic site on the density and stiffness of the foundation soils at that location. Given the complexity of wave propagation through layered soil deposits, it is unlikely that the variability in these attenuation trends would have been predicted analytically without the data from these field tests.

The development of the frequency-dependent attenuation relationships facilitates estimates of free-field ground motions at specified distances from the construction activities. Conversely, safe stand-off distances for each construction method can be specified given the maximum allowable vibration amplitude (peak velocity) in sensitive areas. Figures 5.1 through 5.6 show the computed attenuation for ground motions induced at the dominant frequencies by each of the pile driving methods on the Gasco and Siltronic sites. The measured highest and lowest one third octave velocities for several VH runs were used and the attenuation calculated for the expected upper and lower bounds. This relationship was confirmed for each hammer by comparing the trends in Figures 5.1 through 5.6 with data from several pile-driving intervals.

## 3.3 Structural Building Array Data

The vibration sensors located within Siltonic facilities recorded motions caused by continual construction activities, normal operations at Siltronic, as well as transient peaks due to normal industrial activities (foot-fall, loading dock, equipment moving) or more infrequent occurrences (on-site construction, soil drilling, etc.) at the facility. The data, recorded as spectral velocity in one third octave bands, provided during the construction simulation demonstrated the relative contributions of these various sources to the cumulative, absolute vibrations experienced in selected locations of FAB 1 and FAB 2. The contributions of the motions could also be assessed in terms of frequency bands in order to distinguish construction-related vibrations from normal, background sources. Where available, the data from the structural array facilitate the development of transfer functions (i.e., ratios) of building response to the free-field vibrations at similar source-to-location distances.

Possible building attenuation effects on the pile driving vibration were also investigated. Figures 6.1 through 6.7 show comparisons of vibration velocity spectra between the FFA and a vertical accelerometer located within the SEM room of FAB 1, both at 300-foot distances from the pile driver during Step 3. Each figure represents instances corresponding to impact events identified by Siltronic, as well as situations where no events were identified by Siltronic. These results suggest, at least for the dominant frequencies shown, that there is little if any building attenuation.

On the basis of Siltronic data provided subsequent to process monitoring and the statistical analysis of monitoring metrics performed by Siltronic staff, it is our understanding that no process interruptions were experienced during the Step 2 testing and that five incidents were observed during the Step 3 construction simulation. The structural vibration data obtained at the five time intervals identified by Siltronic personnel are presented in Table 3. These tables list the vibration velocity levels, in 1/3 octave bands, recorded by each of the building monitor accelerometers during the events where impacts were observed. Also included are three “events” where no impacts were evident:

- Event 1 includes vibration data collected during trenching.
- Event 2 includes vibration data collected during an impact hammer induced warning event.

- Event 8 includes vibration data collected during the early morning of March 2, 2009, and is representative of ambient levels.

Vibration levels that exceeded the recent ambient background level at each location during the specific event are indicated in bold red font and are assumed to be associated with the pile-driving activity. (Note that the ambient level for a given accelerometer may vary from day to day depending on the on-site activities occurring at the time.) It was noted that for two of the events identified by Siltronic, no unusual vibration amplitudes were observed (Event 5 and Event 7). Vibration induced by trenching appeared at low frequencies at locations close to this construction activity, such as accelerometers 5, 6, and 7. The IH induced broad vibration spectra at most locations, particularly at accelerometer 5. Although the maximum levels here exceed 1,000 μin/s they are still well below the more tonal vibration induced by the VD of Events 3 and 6 and the VMVD of Event 4. During these events, the vibration tends to be concentrated at certain frequencies such as 16 and 20 Hz for the case of the VD.

The significance of the tabulated vibration levels in Table 3 can be evaluated through review of the warning limits given in Table 4. The velocity limits are shown for each building accelerometer location and were intended to signal a warning if the limit was exceeded during pile-driving. Starting on February 9, 2009, individual limits were applied to each 1/3 octave frequency band for each accelerometer. The original limits were established as 1.2 times the ambient motions, with subsequent increases specified as 1.2 times the maximum velocity level observed barring impacts on process. It was quickly realized, however, that due to the relatively small, frequency-dependent incremental increases in these limits, that they would be exceeded multiple times not just during the tests, but also during non-test periods, so the increase in the warning limits barring impacts on process were set, upon mutual agreement of NW Natural and Siltronic, to 2 times the maximum observed. When warning limits were reached over the course of the tests, the pile driving activity would cease until impacts could be assessed. Then the warning limits would be increased by a suitable amount jointly agreed between NW Natural and Siltronic, and the test would resume. Warning limit changes from the previous day (or time) are indicated in bold red on Table 4. It is important to note that some warning limits were increased because of local vibration sources rather than pile-driving (i.e. some warnings occurred during nighttime.)

These instances are indicated as italic red. As can be seen, large increases in warning limits took place on February 17, 2009 during the initial Step 3 pile driving tests at the northeast corner of the Gasco site.

The final warning limits are shown in the March 10, 2009 table. It should be noted that these warning limits have been established as the 2.0 times the maximum recorded spectral velocity at each location. The final warning limits were defined on the basis of peak motions measured at the specific location, not on a site-wide basis as a function of the maximum velocities recorded at any one of the locations. The significance of this is evident in Table 4, wherein the warning limits for motions of similar orientation generally decrease as a function of the distance from the sensor to the construction activities. The warning limits established after 2 weeks of construction simulation for the most distantly spaced sensor locations were not much greater than ambient levels within specific frequency bands. At these locations, the final warning limits were still subsequently exceeded by ambient motions on March 10, 2009. It is anticipated that warning limits in these portions of the Siltronic facility would continue to be exceeded periodically by ambient motions if monitoring were continued.

## 3.4 Process Feedback Data

Siltronic provided a subset of the process feedback data during Step 2 and Step 3 testing as described in the Work Plan and Communication Plan. The primary real-time process feedback data utilized during the testing program included the particle measurement data that are collected each minute in both FABs and the observations of a catastrophic failure of a tool or process. Process feedback data were reviewed by Siltronic in real-time and at the end of each 2-hour testing period. Authorization to proceed with testing was obtained from Siltronic after each warning level exceedance and before the start of each testing period. Available process feedback data were summarized and reported by Siltronic during the coordination meeting the day after testing before additional tests were conducted.

After construction simulation testing was completed, Siltronic reviewed and analyzed data according to the testing methodology described in the Work Plan and provided a vibration testing summary presentation to NW Natural on March 20, 2009. The Siltronic Corporation

Vibration Testing Summary Presentation is provided in Appendix C. In addition, Siltronic provided a vibration testing summary report on May 7, 2009 (Appendix D).

The Siltronic Vibration Testing Summary Presentation summarizes the test methodology for the process feedback parameters and itemizes the impacts Siltronic observed for both the FAB 1 and FAB 2 facilities. As noted in the Work Plan, Siltronic considers specific information concerning its processes and test procedures to be proprietary and trade secret information. The Siltronic Vibration Testing Summary Report presents non-confidential results, recommendations, and summary conclusions based on the process feedback data.

# 4 CONCLUSIONS

The monitoring program was successfully executed to establish the vibration characteristics from construction activities; including equipment transport, trenching, and pile driving using three different hammers. All work was conducted in coordination with, and with full approval by, Siltronic. In addition, the attenuation characteristics of the soils at the northernmost portion of the Gasco site and the northwestern portion of the Siltronic site have been quantified, including the influence of the Siltronic building on the free-field ground vibrations. Ground vibrations generated during the investigation effectively bracketed the range of motions that could be expected during construction using similar equipment and procedures. Additionally, it is anticipated that the results of this construction simulation program can be used to bracket the likely range of motions that could be expected during construction options that have been evaluated by Anchor QEA and DEQ. The findings from the monitoring can be used to quantitatively estimate the vibrations that would be expected to result from multiple barrier types. In summary, NW Natural concludes that:

- The Gasco site shows a significant attenuation of ground surface vibration due to construction activities. At the Siltronic site, the vibrations were also observed to attenuate with distance from the source, but at a much lower rate.
- The pile driving methods generate peak vibrations at different frequencies. The VD tends to create vibration at a consistent 16 Hz on the Gasco site, while generating more vibration at 20 Hz on the Siltronic site.
- The VMVD changed frequencies throughout its operation but tended to stay between 10 and 20 Hz, particularly at the Siltronic site.
- The IH induced motions across a broader portion of the spectrum, specifically between 5 and 20 Hz. The motions were lower in amplitude than those generated by the vibratory hammers and therefore had much less influence on building vibration levels than the other two methods.
- Vibrations associated with moving heavy equipment and pre-trenching were negligible.
- The processes of sheetpile extraction done with the VMVD and the ramping up and down of the pile drivers tended to create the most vibration within the building structures, although such events were intermittent. However, sheetpile extraction

would be a rare occurrence during actual construction.

- Warning limits were established for each 1/3 octave band at each building accelerometer. As pile-driving activity and non-project related local vibration impacts exceeded warning limits, these limits were adjusted upwards by mutual agreement between NW Natural and Siltronic after it was determined that there were no immediate impacts to the plant processes. The final warning limits have been compiled and can be used to assist in future construction.
- Some warning limits were exceeded during ambient monitoring and during times when construction simulations were not taking place. Consequently, this type of information needs to be factored into design and implementation of future construction activities.

In addition, as stated in the Siltronic Vibration Testing Summary Report:

> "Siltronic concludes a sheet pile barrier wall can be constructed along the GASCO shoreline up to the northwest boundary of the Siltronic property with appropriate selection of construction methods, vibration monitoring and warning alarms. Production was significantly impacted by vibration however solutions appear to be available to modify specific tool mounting or relocation of tools and a few office workers to accommodate the construction activities. Long-term effects of continuous vibration on sensitive measurement tools and connectors could not be evaluated. Construction of a sheet pile barrier wall adjacent to the operating wafering fabs also could not be evaluated. It is likely that additional testing will be necessary should it become necessary to install a barrier wall along the Siltronic shoreline."

# 5 REFERENCES

Anchor 2007. *Groundwater/DNAPL Source Control Focused Feasibility Study*. NW Natural Gasco Site. Prepared for NW Natural. Prepared by Anchor Environmental, L.L.C. November 2007.

# TABLES

**Table 1**
**Horizontal Distances Between Key Points**

| | | FFA 1(step 2) | FFA 2 (step 2) | FFA 3 (step 2) | FFA 4 (step 2) | Trench (step 2) | FFA 1 (step 3) | FFA 2 (step 3) | FFA 3 (step 3) | FFA 4A (step 3) | FFA 4B (step 3) | Trench (step 3) | Loc 1 (ceiling, V) | Loc 2 (ceiling, N-S) | Loc 3 (ceiling, E-W) | Loc 4 (1st floor, V) | Loc 5 (V) | Loc 6 (E-W) | Loc 7 (V) | Loc 8 (V) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Step 2 | FFA 1 (step 2) | 0 | 100 | 290 | 673 | 112 | 1361 | 1455 | 1556 | 1756 | 1348 | 1254 | 2087 | 2087 | 2087 | 2087 | 1517 | 1517 | 1951 | 2039 |
| | FFA 2(step 2) | 100 | 0 | 191 | 573 | 210 | 1262 | 1356 | 1457 | 1657 | 1248 | 1155 | 1991 | 1991 | 1991 | 1991 | 1417 | 1417 | 1851 | 1939 |
| | FFA 3(step 2) | 290 | 191 | 0 | 383 | 401 | 1071 | 1165 | 1266 | 1466 | 1058 | 964 | 1817 | 1817 | 1817 | 1817 | 1229 | 1229 | 1661 | 1751 |
| | FFA 4( step 2) | 673 | 573 | 383 | 0 | 782 | 693 | 787 | 887 | 1086 | 676 | 584 | 1462 | 1462 | 1462 | 1462 | 847 | 847 | 1279 | 1371 |
| | Trench (step 2) | 112 | 210 | 401 | 782 | 0 | 1471 | 1566 | 1667 | 1866 | 1457 | 1364 | 2183 | 2183 | 2183 | 2183 | 1625 | 1625 | 2060 | 2144 |
| Step 3 | FFA 1 (step 3) | 1361 | 1262 | 1071 | 693 | 1471 | 0 | 94 | 197 | 397 | 91 | 111 | 988 | 988 | 988 | 988 | 257 | 257 | 610 | 743 |
| | FFA 2 (step 3) | 1455 | 1356 | 1165 | 787 | 1566 | 94 | 0 | 102 | 303 | 138 | 202 | 932 | 932 | 932 | 932 | 214 | 214 | 519 | 659 |
| | FFA 3 (step 3) | 1556 | 1457 | 1266 | 887 | 1667 | 197 | 102 | 0 | 201 | 223 | 303 | 872 | 872 | 872 | 872 | 202 | 202 | 419 | 568 |
| | FFA 4A (step 3) | 1756 | 1657 | 1466 | 1086 | 1866 | 397 | 303 | 201 | 0 | 413 | 502 | 785 | 785 | 785 | 785 | 305 | 305 | 233 | 409 |
| | FFA 4B (step 3) | 1348 | 1248 | 1058 | 676 | 1457 | 91 | 138 | 223 | 413 | 0 | 110 | 925 | 925 | 925 | 925 | 201 | 201 | 605 | 717 |
| | Trench (step 3) | 1254 | 1155 | 964 | 584 | 1364 | 111 | 202 | 303 | 502 | 110 | 0 | 1030 | 1030 | 1030 | 1030 | 310 | 310 | 706 | 825 |
| Accelerometers | Loc 1 (ceiling, V) | 2087 | 1991 | 1817 | 1462 | 2183 | 988 | 932 | 872 | 785 | 925 | 1030 | 0 | 0 | 0 | 0 | 730 | 730 | 629 | 450 |
| | Loc 2 (ceiling, N-S) | 2087 | 1991 | 1817 | 1462 | 2183 | 988 | 932 | 872 | 785 | 925 | 1030 | 0 | 0 | 0 | 0 | 730 | 730 | 629 | 450 |
| | Loc 3 (ceiling, E-W) | 2087 | 1991 | 1817 | 1462 | 2183 | 988 | 932 | 872 | 785 | 925 | 1030 | 0 | 0 | 0 | 0 | 730 | 730 | 629 | 450 |
| | Loc 4 (1st floor, V) | 2087 | 1991 | 1817 | 1462 | 2183 | 988 | 932 | 872 | 785 | 925 | 1030 | 0 | 0 | 0 | 0 | 730 | 730 | 629 | 450 |
| | Loc 5 (V) | 1517 | 1417 | 1229 | 847 | 1625 | 257 | 214 | 202 | 305 | 201 | 310 | 730 | 730 | 730 | 730 | 0 | 0 | 442 | 526 |
| | Loc 6 (E-W) | 1517 | 1417 | 1229 | 847 | 1625 | 257 | 214 | 202 | 305 | 201 | 310 | 730 | 730 | 730 | 730 | 0 | 0 | 442 | 526 |
| | Loc 7 (V) | 1951 | 1851 | 1661 | 1279 | 2060 | 610 | 519 | 419 | 233 | 605 | 706 | 629 | 629 | 629 | 629 | 442 | 442 | 0 | 196 |
| | Loc 8 (V) | 2039 | 1939 | 1751 | 1371 | 2144 | 743 | 659 | 568 | 409 | 717 | 825 | 450 | 450 | 450 | 450 | 526 | 526 | 196 | 0 |

**Table 2**
**Monitoring Locations and Related Information**

| Location | FAB Facility | Specific Location | Orientation | Activities At Location |
|---|---|---|---|---|
| 1 | 2 | Room 6D113 1st Floor Ceiling | Vertical | FAB 2 Production |
| 2 | 2 | Room 6D113 1st Floor Ceiling | North-South | FAB 2 Production |
| 3 | 2 | Room 6D113 1st Floor Ceiling | East-West | FAB 2 Production |
| 4 | 2 | Room 6D113 Concrete Floor | Vertical | Equipment Maintenance |
| 5 | 1 | Room A120 Concrete Floor | Vertical | Scanning Electron Microscope |
| 6 | 1 | Room A120 Concrete Floor | East-West | Scanning Electron Microscope |
| 7 | 1 | Room E180 Concrete Floor Below Raised Access Floor | Vertical | FAB 1 Final Cleaning |
| 8 | 1 | Room H138 Concrete Floor Below Raised Access Floor | Vertical | FAB 1 Epitaxy |

## Table 3
## Vibration Levels Recorded During Intervals When Impacts Were Observed

**Event 1: Trenching, 13 Feb 09 between 11:10 and 11:18**

| | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1/3 oct Freq | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 4 | 365 | 103 | 114 | 250 | 796 | 174 | 247 | 645 |
| 5 | 296 | 66 | 127 | 255 | 988 | 212 | 520 | 886 |
| 6.3 | 272 | 76 | 111 | 227 | 818 | 154 | 249 | 472 |
| 8 | 139 | 76 | 105 | 86 | 334 | 130 | 191 | 247 |
| 10 | 150 | 51 | 80 | 53 | 197 | 56 | 119 | 229 |
| 12 | 166 | 62 | 79 | 70 | 116 | 38 | 177 | 257 |
| 16 | 187 | 205 | 142 | 59 | 118 | 35 | 288 | 350 |
| 20 | 218 | 107 | 164 | 50 | 247 | 31 | 426 | 309 |
| 25 | 367 | 148 | 223 | 43 | 122 | 13 | 183 | 236 |
| 31.5 | 154 | 244 | 82 | 29 | 157 | 30 | 220 | 477 |
| 40 | 126 | 112 | 89 | 21 | 59 | 11 | 165 | 92 |
| 50 | 113 | 157 | 104 | 25 | 34 | 7 | 134 | 65 |
| 63 | 354 | 226 | 329 | 76 | 103 | 27 | 103 | 523 |
| 80 | 72 | 61 | 54 | 13 | 14 | 4 | 88 | 111 |

**Event 2: Impact Hammer, Test 10 – 17 Feb 09 between 13:31 and 13:33**

| | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1/3 oct Freq | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 4 | 220 | 74 | 81 | 220 | 382 | 172 | 260 | 309 |
| 5 | 167 | 54 | 95 | 197 | 565 | 155 | 431 | 445 |
| 6.3 | 173 | 73 | 158 | 163 | 573 | 142 | 491 | 546 |
| 8 | 233 | 72 | 124 | 241 | 1000 | 145 | 772 | 607 |
| 10 | 306 | 76 | 98 | 281 | 1277 | 357 | 575 | 735 |
| 12 | 244 | 87 | 128 | 198 | 1361 | 264 | 581 | 1605 |
| 16 | 178 | 171 | 103 | 84 | 1183 | 216 | 911 | 695 |
| 20 | 204 | 160 | 144 | 61 | 781 | 153 | 768 | 452 |
| 25 | 191 | 58 | 66 | 34 | 887 | 106 | 428 | 306 |
| 31.5 | 134 | 54 | 64 | 27 | 625 | 101 | 399 | 452 |
| 40 | 76 | 45 | 55 | 15 | 212 | 47 | 118 | 84 |
| 50 | 80 | 54 | 48 | 10 | 93 | 20 | 90 | 60 |
| 63 | 288 | 178 | 138 | 71 | 78 | 24 | 84 | 567 |
| 80 | 65 | 41 | 35 | 8 | 36 | 9 | 39 | 64 |

## Table 3
## Vibration Levels Recorded During Intervals When Impacts Were Observed

**Event 3: Ramping Up, sheet extraction, 200-6 VD, Test 12 – 18 Feb 09 between 13:36:38 and 13:37:01**

| | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1/3 oct Freq | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 4 | 98 | 45 | 39 | 95 | 54 | 40 | 73 | 179 |
| 5 | 189 | 41 | 49 | 165 | 186 | 43 | 156 | 241 |
| 6.3 | 133 | 58 | 89 | 119 | 751 | 83 | 310 | 340 |
| 8 | 175 | 121 | 108 | 209 | 2349 | 332 | 1109 | 661 |
| 10 | 333 | 174 | 188 | 360 | 4536 | 1199 | 1574 | 1069 |
| 12 | 610 | 163 | 160 | 504 | 2400 | 844 | 1239 | 4712 |
| 16 | 533 | 460 | 226 | 608 | 6292 | 1495 | 7758 | 4814 |
| 20 | 306 | 164 | 117 | 135 | 5215 | 899 | 3006 | 1831 |
| 25 | 120 | 53 | 51 | 27 | 193 | 22 | 193 | 245 |
| 31.5 | 125 | 62 | 66 | 21 | 1217 | 135 | 455 | 419 |
| 40 | 64 | 49 | 45 | 14 | 613 | 49 | 143 | 101 |
| 50 | 77 | 53 | 46 | 11 | 321 | 57 | 92 | 70 |
| 63 | 249 | 180 | 140 | 72 | 92 | 26 | 146 | 530 |
| 80 | 62 | 36 | 34 | 6 | 43 | 10 | 77 | 37 |

**Event 4: Steady Operation, 250 VM at 90 ft, Test 13 – 19 Feb 09 at 12:24:00**

| | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1/3 oct Freq | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 4 | 59 | 34 | 36 | 49 | 114 | 29 | 42 | 212 |
| 5 | 96 | 12 | 41 | 90 | 52 | 26 | 42 | 78 |
| 6.3 | 98 | 55 | 74 | 100 | 88 | 15 | 60 | 119 |
| 8 | 56 | 46 | 74 | 57 | 59 | 14 | 55 | 127 |
| 10 | 42 | 50 | 45 | 25 | 109 | 35 | 68 | 169 |
| 12 | 91 | 51 | 61 | 45 | 80 | 24 | 136 | 214 |
| 16 | 123 | 65 | 64 | 44 | 85 | 19 | 196 | 231 |
| 20 | 297 | 223 | 247 | 126 | 4398 | 894 | 1320 | 1175 |
| 25 | 145 | 67 | 84 | 34 | 1129 | 270 | 464 | 468 |
| 31.5 | 123 | 49 | 48 | 20 | 71 | 16 | 139 | 386 |
| 40 | 77 | 48 | 42 | 11 | 227 | 59 | 76 | 75 |
| 50 | 77 | 50 | 41 | 11 | 54 | 14 | 77 | 52 |
| 63 | 278 | 187 | 145 | 69 | 89 | 6 | 55 | 516 |
| 80 | 71 | 36 | 33 | 6 | 16 | 4 | 32 | 41 |

## Table 3
## Vibration Levels Recorded During Intervals When Impacts Were Observed

**Event 5: No Operation, – 19 Feb 09 at 13:38:00**

| | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1/3 oct Freq | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 4 | 119 | 43 | 48 | 140 | 101 | 28 | 79 | 122 |
| 5 | 199 | 34 | 61 | 195 | 179 | 31 | 196 | 162 |
| 6.3 | 246 | 56 | 76 | 172 | 170 | 45 | 229 | 289 |
| 8 | 82 | 31 | 76 | 57 | 116 | 21 | 78 | 148 |
| 10 | 57 | 33 | 44 | 50 | 65 | 18 | 83 | 196 |
| 12 | 116 | 56 | 68 | 39 | 86 | 17 | 88 | 224 |
| 16 | 199 | 72 | 90 | 61 | 95 | 21 | 122 | 287 |
| 20 | 184 | 68 | 92 | 47 | 145 | 20 | 310 | 277 |
| 25 | 174 | 50 | 49 | 25 | 64 | 14 | 182 | 207 |
| 31.5 | 125 | 49 | 43 | 15 | 82 | 12 | 150 | 339 |
| 40 | 66 | 44 | 45 | 11 | 56 | 10 | 77 | 75 |
| 50 | 77 | 35 | 56 | 9 | 23 | 6 | 80 | 53 |
| 63 | 259 | 170 | 154 | 69 | 47 | 21 | 70 | 391 |
| 80 | 56 | 29 | 28 | 6 | 14 | 3 | 29 | 27 |

**Event 6: 200-6 VD Ramping Down, Test 14 – 19 Feb 09 btn 14:40:01 and 14:40:38**

| | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1/3 oct Freq | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 4 | 220 | 32 | 42 | 89 | 51 | 31 | 56 | 168 |
| 5 | 91 | 21 | 69 | 67 | 58 | 30 | 70 | 90 |
| 6.3 | 137 | 30 | 75 | 82 | 61 | 21 | 80 | 108 |
| 8 | 120 | 35 | 58 | 156 | 650 | 24 | 205 | 169 |
| 10 | 94 | 29 | 47 | 363 | 1651 | 21 | 605 | 214 |
| 12 | 135 | 37 | 70 | 176 | 2237 | 28 | 825 | 507 |
| 16 | 423 | 99 | 71 | 179 | 6106 | 141 | 7509 | 1861 |
| 20 | 497 | 317 | 295 | 298 | 9325 | 1581 | 7917 | 1491 |
| 25 | 155 | 47 | 52 | 27 | 555 | 12 | 278 | 219 |
| 31.5 | 121 | 37 | 31 | 21 | 713 | 21 | 262 | 379 |
| 40 | 71 | 44 | 50 | 14 | 1121 | 128 | 268 | 105 |
| 50 | 92 | 42 | 42 | 9 | 102 | 19 | 87 | 61 |
| 63 | 279 | 154 | 136 | 71 | 88 | 25 | 77 | 559 |
| 80 | 58 | 35 | 32 | 6 | 59 | 9 | 38 | 39 |

## Table 3
## Vibration Levels Recorded During Intervals When Impacts Were Observed

**Event 7: No Activity – 19 Feb 09 at 14:52:00**

| | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **1/3 oct Freq** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| **4** | 51 | 31 | 36 | 89 | 69 | 40 | 35 | 185 |
| **5** | 60 | 18 | 26 | 37 | 64 | 15 | 35 | 123 |
| **6.3** | 64 | 31 | 52 | 56 | 37 | 18 | 49 | 67 |
| **8** | 84 | 42 | 59 | 74 | 76 | 11 | 90 | 167 |
| **10** | 64 | 11 | 28 | 44 | 91 | 14 | 83 | 125 |
| **12** | 116 | 41 | 73 | 40 | 89 | 19 | 137 | 241 |
| **16** | 117 | 68 | 98 | 44 | 85 | 23 | 213 | 246 |
| **20** | 188 | 66 | 79 | 30 | 219 | 25 | 342 | 366 |
| **25** | 162 | 50 | 32 | 19 | 61 | 10 | 226 | 234 |
| **31.5** | 98 | 48 | 40 | 18 | 86 | 14 | 157 | 197 |
| **40** | 87 | 43 | 47 | 12 | 48 | 9 | 58 | 71 |
| **50** | 94 | 42 | 56 | 8 | 34 | 8 | 52 | 51 |
| **63** | 266 | 182 | 124 | 70 | 97 | 26 | 76 | 612 |
| **80** | 54 | 32 | 32 | 6 | 14 | 5 | 34 | 61 |

**Event 8: Nighttime Ambient – 2 Mar 09 between 1:01 & 1:06**

| | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **1/3 oct Freq** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| **4** | 201 | 41 | 42 | 99 | 49 | 63 | 74 | 203 |
| **5** | 202 | 25 | 50 | 171 | 57 | 35 | 68 | 123 |
| **6.3** | 96 | 50 | 74 | 78 | 79 | 27 | 85 | 151 |
| **8** | 76 | 47 | 55 | 73 | 79 | 20 | 90 | 236 |
| **10** | 86 | 43 | 59 | 66 | 75 | 18 | 90 | 213 |
| **12** | 108 | 57 | 93 | 80 | 84 | 21 | 168 | 220 |
| **16** | 166 | 169 | 114 | 68 | 112 | 23 | 180 | 327 |
| **20** | 213 | 121 | 135 | 49 | 163 | 25 | 229 | 260 |
| **25** | 163 | 54 | 54 | 39 | 88 | 15 | 139 | 398 |
| **31.5** | 125 | 52 | 59 | 25 | 83 | 23 | 175 | 398 |
| **40** | 77 | 47 | 58 | 16 | 59 | 9 | 69 | 76 |
| **50** | 82 | 58 | 52 | 12 | 30 | 6 | 71 | 57 |
| **63** | 196 | 95 | 106 | 14 | 87 | 25 | 76 | 523 |
| **80** | 47 | 33 | 35 | 7 | 12 | 3 | 36 | 35 |

Note:
Entries in **bold red** indicate bands where the level exceeded the ambient background
Values in micro-inches per second

**Table 4A**
**Warning Limit Tables Representing Velocity Limit Changes Over Time**
**February 8, 2009**

| Frequency (Hz) | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 4 | 700 | 700 | 700 | 700 | 400 | 400 | 400 | 400 |
| 5 | 400 | 400 | 400 | 400 | 280 | 280 | 280 | 280 |
| 6.3 | 380 | 380 | 380 | 380 | 300 | 300 | 300 | 300 |
| 8 | 180 | 180 | 180 | 180 | 460 | 460 | 460 | 460 |
| 10 | 130 | 130 | 130 | 130 | 330 | 330 | 330 | 330 |
| 12.5 | 160 | 160 | 160 | 160 | 350 | 350 | 350 | 350 |
| 16 | 250 | 250 | 250 | 250 | 800 | 800 | 800 | 800 |
| 20 | 380 | 380 | 380 | 380 | 380 | 380 | 380 | 380 |
| 25 | 450 | 450 | 450 | 450 | 440 | 440 | 440 | 440 |
| 31.5 | 300 | 300 | 300 | 300 | 640 | 640 | 640 | 640 |
| 40 | 180 | 180 | 180 | 180 | 230 | 230 | 230 | 230 |
| 50 | 160 | 160 | 160 | 160 | 500 | 500 | 500 | 500 |
| 63 | 380 | 380 | 380 | 380 | 700 | 700 | 700 | 700 |
| 80 | 140 | 140 | 140 | 140 | 380 | 380 | 380 | 380 |

Notes:

In microinches per second.

Bold red = warning level increase from previous day or time.

Italic red = warning level increase as a result of non-construction related activity.

**Table 4B**
**Warning Limit Tables Representing Velocity Limit Changes Over Time**
**February 9, 2009**

| Frequency (Hz) | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 4 | *676* | *1400* | *1400* | *560* | *800* | *800* | *800* | *404* |
| 5 | *390* | *800* | *800* | *304* | *560* | *560* | *560* | *263* |
| 6.3 | *370* | *760* | *760* | *283* | *600* | *600* | *600* | *302* |
| 8 | *150* | *360* | *360* | *115* | *920* | *920* | *920* | *460* |
| 10 | *105* | *260* | *260* | *81* | *660* | *660* | *660* | *336* |
| 12.5 | *162* | *320* | *320* | *86* | *700* | *700* | *700* | *351* |
| 16 | *256* | *500* | *500* | *126* | *1600* | *1600* | *1600* | *820* |
| 20 | *372* | *760* | *760* | *73* | *1400* | *1400* | *1400* | *376* |
| 25 | *427* | *900* | *900* | *53* | *880* | *880* | *880* | *438* |
| 31.5 | *286* | *600* | *600* | *36* | *1280* | *1280* | *1280* | *641* |
| 40 | *181* | *360* | *360* | *33* | *460* | *460* | *460* | *148* |
| 50 | *160* | *320* | *320* | *20* | *1000* | *1000* | *1000* | *123* |
| 63 | *382* | *760* | *760* | *80* | *1400* | *1400* | *1400* | *666* |
| 80 | *138* | *280* | *280* | *13* | *760* | *760* | *760* | *262* |

Notes:

In microinches per second.

Bold red = warning level increase from previous day or time.

Italic red = warning level increase as a result of non-construction related activity.

**Table 4C**
**Warning Limit Tables Representing Velocity Limit Changes Over Time**
**February 10, 2009**

| Frequency (Hz) | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 4 | *1115* | *207* | *163* | *918* | *405* | *135* | *490* | *660* |
| 5 | *1415* | *287* | *492* | *1101* | *704* | *107* | *728* | *1278* |
| 6.3 | *693* | *261* | *280* | *519* | *626* | *98* | *595* | *870* |
| 8 | *353* | *171* | *269* | *217* | *267* | *95* | *360* | *718* |
| 10 | *242* | *118* | *198* | *133* | *387* | *228* | *440* | *716* |
| 12.5 | *300* | *131* | *169* | *151* | *337* | *98* | *350* | *641* |
| 16 | *602* | *386* | *325* | *190* | *344* | *98* | *507* | *1262* |
| 20 | *1520* | *970* | *422* | *141* | *565* | *63* | *1161* | *854* |
| 25 | *2596* | *1866* | *1193* | *278* | *313* | *65* | *977* | *628* |
| 31.5 | *585* | *1573* | *911* | *100* | *320* | *74* | *1350* | *966* |
| 40 | *471* | *325* | *206* | *75* | *180* | *21* | *1957* | *384* |
| 50 | *587* | *231* | *208* | *59* | *362* | *20* | *3590* | *920* |
| 63 | *643* | *362* | *641* | *94* | *197* | *52* | *2576* | *1256* |
| 80 | *518* | *222* | *225* | *39* | *183* | *16* | *2450* | *2138* |

Notes:
In microinches per second.
Bold red = warning level increase from previous day or time.
Italic red = warning level increase as a result of non-construction related activity.

**Table 4D**
**Warning Limit Tables Representing Velocity Limit Changes Over Time**
**February 11, 2009**

| Frequency (Hz) | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 4 | 1115 | 207 | 163 | 918 | 405 | 135 | 490 | 660 |
| 5 | 1415 | 287 | 492 | 1101 | 704 | 107 | 728 | 1278 |
| 6.3 | 693 | 261 | 280 | **1560** | 626 | 98 | 595 | 870 |
| 8 | 353 | 171 | 269 | 217 | 267 | 95 | 360 | 718 |
| 10 | 242 | **250** | 198 | 133 | 387 | 228 | 440 | 716 |
| 12.5 | 300 | **280** | 169 | 151 | 337 | 98 | 350 | 641 |
| 16 | 602 | 386 | 325 | 190 | **800** | 98 | 507 | 1262 |
| 20 | 1520 | 970 | 422 | 141 | 565 | **170** | 1161 | 854 |
| 25 | 2596 | 1866 | 1193 | 278 | 313 | 65 | 977 | 628 |
| 31.5 | 585 | 1573 | 911 | 100 | 320 | 74 | 1350 | 966 |
| 40 | 471 | 325 | 206 | 75 | 180 | 21 | 1957 | 384 |
| 50 | 587 | 231 | 208 | 59 | 362 | 20 | 3590 | 920 |
| 63 | 643 | 362 | 641 | 94 | 197 | 52 | 2576 | 1256 |
| 80 | 518 | 222 | 225 | 39 | 183 | 16 | 2450 | 2138 |

Notes:
In microinches per second.
Bold red = warning level increase from previous day or time.
Italic red = warning level increase as a result of non-construction related activity.

**Table 4E**
**Warning Limit Tables Representing Velocity Limit Changes Over Time**
**February 12, 2009**

| Frequency (Hz) | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 4 | 1115 | 207 | 163 | 918 | 405 | 135 | 490 | 660 |
| 5 | 1415 | 287 | 492 | 1101 | 704 | 107 | 728 | 1278 |
| 6.3 | 693 | 261 | 280 | 1560 | 626 | 98 | 595 | 870 |
| 8 | 353 | 171 | 269 | 217 | 267 | 95 | 360 | 718 |
| 10 | 242 | 250 | 198 | 133 | 387 | 228 | 440 | 716 |
| 12.5 | 300 | 280 | 169 | 151 | 337 | 98 | 350 | 641 |
| 16 | 602 | 386 | 325 | *400* | 800 | 98 | 507 | 1262 |
| 20 | 1520 | 970 | 422 | 141 | *1000* | 170 | 1161 | 854 |
| 25 | 2596 | 1866 | 1193 | 278 | 313 | 65 | 977 | 628 |
| 31.5 | 585 | 1573 | 911 | 100 | 320 | 74 | 1350 | 966 |
| 40 | 471 | 325 | 206 | 75 | 180 | 21 | 1957 | 384 |
| 50 | 587 | 231 | 208 | 59 | 362 | 20 | 3590 | 920 |
| 63 | 643 | 362 | 641 | 94 | 197 | 52 | 2576 | 1256 |
| 80 | 518 | 222 | 225 | 39 | 183 | 16 | 2450 | 2138 |

Notes:

In microinches per second.

Bold red = warning level increase from previous day or time.

Italic red = warning level increase as a result of non-construction related activity.

**Table 4F**
**Warning Limit Tables Representing Velocity Limit Changes Over Time**
**February 16, 2009**

| Frequency (Hz) | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 4 | 1115 | 207 | 163 | 918 | *2000* | 135 | 490 | 660 |
| 5 | 1415 | 287 | 492 | 1101 | *2320* | 107 | 728 | 1278 |
| 6.3 | 693 | 261 | 280 | 1560 | *2080* | 98 | 595 | 870 |
| 8 | 353 | 171 | 269 | 217 | *2040* | 95 | 360 | 718 |
| 10 | 242 | 250 | 198 | 133 | 387 | 228 | 440 | 716 |
| 12.5 | 300 | 280 | 169 | 151 | 337 | 98 | 350 | 641 |
| 16 | 602 | 386 | 325 | 400 | 800 | 98 | 507 | 1262 |
| 20 | 1520 | 970 | 422 | 141 | 1000 | 170 | 1161 | 854 |
| 25 | 2596 | 1866 | 1193 | 278 | 313 | 65 | 977 | 628 |
| 31.5 | 585 | 1573 | 911 | 100 | 320 | 74 | 1350 | 966 |
| 40 | 471 | 325 | 206 | 75 | 180 | 21 | 1957 | 384 |
| 50 | 587 | 231 | 208 | 59 | 362 | 20 | 3590 | 920 |
| 63 | 643 | 362 | 641 | 94 | 197 | 52 | 2576 | 1256 |
| 80 | 518 | 222 | 225 | 39 | 183 | 16 | 2450 | 2138 |

Notes:
In microinches per second.
Bold red = warning level increase from previous day or time.
Italic red = warning level increase as a result of non-construction related activity.

## Table 4G
## Warning Limit Tables Representing Velocity Limit Changes Over Time
## February 17, 2009 - 1105

| Frequency (Hz) | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 4 | 1115 | 207 | 163 | 918 | 2000 | 135 | 490 | 660 |
| 5 | 1415 | 287 | 492 | 1101 | 2320 | 107 | **1200** | 1278 |
| 6.3 | 693 | 261 | 280 | 1560 | 2080 | 98 | **1200** | 870 |
| 8 | 353 | 171 | 269 | 217 | 2040 | 95 | **900** | 718 |
| 10 | **500** | 250 | 198 | 133 | 387 | 228 | **900** | 716 |
| 12.5 | 300 | 280 | 169 | 151 | 337 | 98 | **1200** | 641 |
| 16 | 602 | 386 | 325 | 400 | 800 | 98 | **1200** | 1262 |
| 20 | 1520 | 970 | 422 | 141 | 1000 | 170 | **2200** | 854 |
| 25 | 2596 | 1866 | 1193 | 278 | 313 | 65 | 977 | 628 |
| 31.5 | 585 | 1573 | 911 | 100 | 320 | 74 | 1350 | 966 |
| 40 | 471 | 325 | 206 | 75 | 180 | 21 | 1957 | 384 |
| 50 | 587 | 231 | 208 | 59 | 362 | 20 | 3590 | 920 |
| 63 | 643 | 362 | 641 | 94 | 197 | 52 | 2576 | 1256 |
| 80 | 518 | 222 | 225 | 39 | 183 | 16 | 2450 | 2138 |

Notes:

In microinches per second.

Bold red = warning level increase from previous day or time.

Italic red = warning level increase as a result of non-construction related activity.

## Table 4H
## Warning Limit Tables Representing Velocity Limit Changes Over Time
## February 17, 2009 - 1224

| Frequency (Hz) | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 4 | 1115 | 207 | 163 | 918 | 2000 | **400** | **1000** | **1000** |
| 5 | 1415 | 287 | 492 | 1101 | 2320 | **400** | 1200 | **1300** |
| 6.3 | 693 | 261 | 280 | 1560 | 2080 | **300** | 1200 | **1300** |
| 8 | 353 | 171 | 269 | 217 | **3000** | **400** | **1000** | **800** |
| 10 | 500 | 250 | 198 | 133 | **3000** | **1200** | **1000** | **800** |
| 12.5 | 300 | 280 | 169 | 151 | **2000** | **800** | 1200 | **800** |
| 16 | 602 | 386 | 325 | 400 | **2000** | **800** | **1500** | **1300** |
| 20 | 1520 | 970 | 422 | 141 | **6000** | **800** | **3000** | **2000** |
| 25 | 2596 | 1866 | 1193 | 278 | **4000** | **1400** | **3000** | **2000** |
| 31.5 | 585 | 1573 | 911 | 100 | **1200** | **100** | 1350 | **1000** |
| 40 | 471 | 325 | 206 | 75 | **800** | **200** | 1957 | **1000** |
| 50 | 587 | 231 | 208 | 59 | **800** | **200** | 3590 | **1000** |
| 63 | 643 | 362 | 641 | 94 | **600** | **150** | 2576 | **3000** |
| 80 | 518 | 222 | 225 | 39 | **600** | **150** | 2450 | **3000** |

Notes:

In microinches per second.

Bold red = warning level increase from previous day or time.

Italic red = warning level increase as a result of non-construction related activity.

**Table 4I**
**Warning Limit Tables Representing Velocity Limit Changes Over Time**
**February 17, 2009 - 1320**

| Frequency (Hz) | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 4 | 1115 | 207 | 163 | 918 | 2000 | 400 | 1000 | 1000 |
| 5 | 1415 | 287 | 492 | 1101 | 2320 | 400 | 1200 | 1300 |
| 6.3 | 693 | 261 | 280 | 1560 | 2080 | 300 | 1200 | 1300 |
| 8 | 353 | 171 | 269 | 217 | 3000 | 400 | 1000 | 800 |
| 10 | 500 | 250 | 198 | 133 | 3000 | 1200 | 1000 | **1500** |
| 12.5 | 300 | 280 | 169 | 151 | 2000 | 800 | 1200 | **1500** |
| 16 | 602 | 386 | 325 | 400 | 2000 | 800 | 1500 | 1300 |
| 20 | 1520 | 970 | 422 | 141 | 6000 | 800 | 3000 | 2000 |
| 25 | 2596 | 1866 | 1193 | 278 | 4000 | 1400 | 3000 | 2000 |
| 31.5 | 585 | 1573 | 911 | 100 | 1200 | 100 | 1350 | 1000 |
| 40 | 471 | 325 | 206 | 75 | 800 | 200 | 1957 | 1000 |
| 50 | 587 | 231 | 208 | 59 | 800 | 200 | 3590 | 1000 |
| 63 | 643 | 362 | 641 | 94 | 600 | 150 | 2576 | 3000 |
| 80 | 518 | 222 | 225 | 39 | 600 | 150 | 2450 | 3000 |

Notes:
In microinches per second.
Bold red = warning level increase from previous day or time.
Italic red = warning level increase as a result of non-construction related activity.

**Table 4J**
**Warning Limit Tables Representing Velocity Limit Changes Over Time**
**February 17, 2009 - 1507**

| Frequency (Hz) | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 4 | 1115 | 207 | 163 | 918 | 2000 | 400 | 1000 | 1000 |
| 5 | 1415 | 287 | 492 | 1101 | 2320 | 400 | 1200 | 1300 |
| 6.3 | **1200** | 261 | 280 | 1560 | 2080 | 300 | 1200 | 1300 |
| 8 | **1200** | 171 | 269 | **1000** | 3000 | 400 | **1500** | 800 |
| 10 | **1200** | 250 | 198 | **1000** | 3000 | 1200 | **1500** | **2000** |
| 12.5 | **1000** | 280 | 169 | **900** | **6000** | **1200** | **4000** | **5000** |
| 16 | **1000** | 386 | 325 | **900** | **7000** | **1200** | **5000** | **4000** |
| 20 | 1520 | 970 | 422 | **900** | 6000 | **1200** | **8000** | 2000 |
| 25 | 2596 | 1866 | 1193 | 278 | 4000 | 1400 | **4000** | 2000 |
| 31.5 | **1000** | 1573 | 911 | 100 | 1200 | **200** | 1350 | 1000 |
| 40 | **900** | 325 | 206 | 75 | 800 | 200 | **3000** | 1000 |
| 50 | 587 | 231 | 208 | 59 | 800 | 200 | 3590 | 1000 |
| 63 | 643 | 362 | 641 | 94 | 600 | 150 | 2576 | 3000 |
| 80 | 518 | 222 | 225 | 39 | 600 | 150 | 2450 | 3000 |

Notes:

In microinches per second.

Bold red = warning level increase from previous day or time.

Italic red = warning level increase as a result of non-construction related activity.

## Table 4K
## Warning Limit Tables Representing Velocity Limit Changes Over Time
## February 18, 2009 - 1015

| Frequency (Hz) | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 4 | 1115 | 207 | 163 | 918 | 2000 | 400 | 1000 | 1000 |
| 5 | 1415 | 287 | 492 | 1101 | 2320 | 400 | 1200 | 1300 |
| 6.3 | 1200 | 261 | 280 | 1560 | 2080 | 300 | 1200 | 1300 |
| 8 | 1200 | 171 | 269 | 1000 | 3000 | 400 | 1500 | 800 |
| 10 | 1200 | 250 | 198 | 1000 | 3000 | 1200 | 1500 | 2000 |
| 12.5 | 1000 | 280 | 169 | 900 | 6000 | 1200 | 4000 | 5000 |
| 16 | 1000 | 386 | 325 | 900 | 7000 | 1200 | 5000 | 4000 |
| 20 | 1520 | 970 | 422 | 900 | 6000 | 1200 | 8000 | 2000 |
| 25 | 2596 | 1866 | 1193 | 278 | 6000 | 1400 | 4000 | 2000 |
| 31.5 | 1000 | 1573 | 911 | 100 | **4000** | **600** | **3000** | 1000 |
| 40 | 900 | 325 | 206 | 75 | 800 | 200 | 3000 | 1000 |
| 50 | 587 | 231 | 208 | 59 | 800 | 200 | 3590 | 1000 |
| 63 | 643 | 362 | 641 | 94 | 600 | 150 | 2576 | 3000 |
| 80 | 518 | 222 | 225 | 39 | 600 | 150 | 2450 | 3000 |

Notes:

In microinches per second.

Bold red = warning level increase from previous day or time.

Italic red = warning level increase as a result of non-construction related activity.

**Table 4L**
**Warning Limit Tables Representing Velocity Limit Changes Over Time**
**February 18, 2009 - 1030**

| Frequency (Hz) | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 4 | 1115 | 207 | 163 | 918 | 2000 | 400 | 1000 | 1000 |
| 5 | 1415 | 287 | 492 | 1101 | 2320 | 400 | 1200 | 1300 |
| 6.3 | 1200 | 261 | 280 | 1560 | 2080 | 300 | 1200 | 1300 |
| 8 | 1200 | 171 | 269 | 1000 | 3000 | 400 | 1500 | 800 |
| 10 | 1200 | 250 | 198 | 1000 | 3000 | 1200 | 1500 | 2000 |
| 12.5 | 1000 | 280 | 169 | 900 | 6000 | 1200 | 4000 | 5000 |
| 16 | 1000 | 386 | 325 | 900 | 7000 | 1200 | 5000 | 4000 |
| 20 | 1520 | 970 | 422 | 900 | 6000 | **3000** | 8000 | **5000** |
| 25 | 2596 | 1866 | 1193 | 278 | 6000 | 1400 | 4000 | 2000 |
| 31.5 | 1000 | 1573 | 911 | 100 | **6000** | 600 | 3000 | 1000 |
| 40 | 900 | 325 | 206 | 75 | 800 | 200 | 3000 | 1000 |
| 50 | 587 | 231 | 208 | 59 | 800 | 200 | 3590 | 1000 |
| 63 | 643 | 362 | 641 | 94 | 600 | 150 | 2576 | 3000 |
| 80 | 518 | 222 | 225 | 39 | 600 | 150 | 2450 | 3000 |

Notes:

In microinches per second.

Bold red = warning level increase from previous day or time.

Italic red = warning level increase as a result of non-construction related activity.

## Table 4M
## Warning Limit Tables Representing Velocity Limit Changes Over Time
## February 18, 2009 - 1107

| Frequency (Hz) | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 4 | 1115 | 207 | 163 | 918 | 2000 | 400 | 1000 | 1000 |
| 5 | 1415 | 287 | 492 | 1101 | 2320 | 400 | 1200 | 1300 |
| 6.3 | 1200 | 261 | 280 | 1560 | 2080 | 300 | 1200 | 1300 |
| 8 | 1200 | 171 | 269 | 1000 | 3000 | 400 | 1500 | 800 |
| 10 | 1200 | 250 | 198 | 1000 | 3000 | 1200 | 1500 | 2000 |
| 12.5 | 1000 | 280 | 169 | 900 | 6000 | 1200 | 4000 | 5000 |
| 16 | 1000 | 386 | 325 | 900 | 7000 | 1200 | 5000 | 4000 |
| 20 | 1520 | 970 | 422 | 900 | 6000 | 3000 | 8000 | 5000 |
| 25 | 2596 | 1866 | 1193 | 278 | **8000** | 1400 | 4000 | 2000 |
| 31.5 | 1000 | 1573 | 911 | 100 | 6000 | 600 | 3000 | 1000 |
| 40 | 900 | 325 | 206 | 75 | 800 | 200 | 3000 | 1000 |
| 50 | 587 | 231 | 208 | 59 | 800 | 200 | 3590 | 1000 |
| 63 | 643 | 362 | 641 | 94 | 600 | 150 | 2576 | 3000 |
| 80 | 518 | 222 | 225 | 39 | 600 | 150 | 2450 | 3000 |

Notes:

In microinches per second.

Bold red = warning level increase from previous day or time.

Italic red = warning level increase as a result of non-construction related activity.

## Table 4N
## Warning Limit Tables Representing Velocity Limit Changes Over Time
## February 18, 2009 - 1240

| Frequency (Hz) | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 4 | 1115 | 207 | 163 | 918 | 2000 | 400 | 1000 | 1000 |
| 5 | 1415 | 287 | 492 | 1101 | 2320 | 400 | 1200 | 1300 |
| 6.3 | 1200 | 261 | 280 | 1560 | 2080 | 300 | 1200 | 1300 |
| 8 | 1200 | 171 | 269 | 1000 | 3000 | 400 | 1500 | 800 |
| 10 | 1200 | 250 | 198 | 1000 | 3000 | 1200 | 1500 | 2000 |
| 12.5 | 1000 | 280 | **500** | 900 | 6000 | 1200 | 4000 | 5000 |
| 16 | 1000 | 386 | 325 | 900 | 7000 | 1200 | 5000 | 4000 |
| 20 | 1520 | 970 | 422 | 900 | 6000 | 3000 | 8000 | 5000 |
| 25 | 2596 | 1866 | 1193 | 278 | 8000 | 1400 | 4000 | 2000 |
| 31.5 | 1000 | 1573 | 911 | 100 | 6000 | 600 | 3000 | 1000 |
| 40 | 900 | 325 | 206 | 75 | 800 | 200 | 3000 | 1000 |
| 50 | 587 | 231 | 208 | 59 | 800 | 200 | 3590 | 1000 |
| 63 | 643 | 362 | 641 | 94 | 600 | 150 | 2576 | 3000 |
| 80 | 518 | 222 | 225 | 39 | 600 | 150 | 2450 | 3000 |

Notes:

In microinches per second.

Bold red = warning level increase from previous day or time.

Italic red = warning level increase as a result of non-construction related activity.

## Table 4O
## Warning Limit Tables Representing Velocity Limit Changes Over Time
## February 18, 2009 - 1255

| Frequency (Hz) | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 4 | 1115 | 207 | 163 | 918 | 2000 | 400 | 1000 | 1000 |
| 5 | 1415 | 287 | 492 | 1101 | 2320 | 400 | 1200 | 1300 |
| 6.3 | 1200 | 261 | 280 | 1560 | 2080 | 300 | 1200 | 1300 |
| 8 | 1200 | 171 | 269 | 1000 | 3000 | 400 | 1500 | 800 |
| 10 | 1200 | 250 | 198 | 1000 | 3000 | 1200 | 1500 | 2000 |
| 12.5 | 1000 | 280 | 500 | 900 | 6000 | 1200 | 4000 | 5000 |
| 16 | 1000 | 386 | 325 | 900 | 7000 | 1200 | 5000 | 4000 |
| 20 | 1520 | 970 | 422 | 900 | **8000** | 3000 | 8000 | 5000 |
| 25 | 2596 | 1866 | 1193 | 278 | 8000 | 1400 | 4000 | 2000 |
| 31.5 | 1000 | 1573 | 911 | 100 | 6000 | 600 | 3000 | 1000 |
| 40 | 900 | 325 | 206 | 75 | 800 | 200 | 3000 | 1000 |
| 50 | 587 | 231 | 208 | 59 | 800 | 200 | 3590 | 1000 |
| 63 | 643 | 362 | 641 | 94 | 600 | 150 | 2576 | 3000 |
| 80 | 518 | 222 | 225 | 39 | 600 | 150 | 2450 | 3000 |

Notes:

In microinches per second.

Bold red = warning level increase from previous day or time.

Italic red = warning level increase as a result of non-construction related activity.

## Table 4P
## Warning Limit Tables Representing Velocity Limit Changes Over Time
## February 18, 2009 - 1340

| Frequency (Hz) | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 4 | 1115 | 207 | 163 | 918 | 2000 | 400 | 1000 | 1000 |
| 5 | 1415 | 287 | 492 | 1101 | 2320 | 400 | 1200 | 1300 |
| 6.3 | 1200 | 261 | 280 | 1560 | 2080 | 300 | 1200 | 1300 |
| 8 | 1200 | **250** | 269 | 1000 | 3000 | 400 | 1500 | 800 |
| 10 | 1200 | 250 | 198 | 1000 | 3000 | 1200 | 1500 | 2000 |
| 12.5 | 1000 | 280 | 500 | 900 | 6000 | 1200 | 4000 | **8000** |
| 16 | 1000 | 386 | 325 | 900 | 7000 | 1200 | **9000** | **8000** |
| 20 | 1520 | 970 | 422 | 900 | 8000 | 3000 | **9000** | 5000 |
| 25 | 2596 | 1866 | 1193 | 278 | 8000 | 1400 | 4000 | 2000 |
| 31.5 | 1000 | 1573 | 911 | 100 | 6000 | 600 | 3000 | 1000 |
| 40 | 900 | 325 | 206 | 75 | 800 | 200 | 3000 | 1000 |
| 50 | 587 | 231 | 208 | 59 | 800 | 200 | 3590 | 1000 |
| 63 | 643 | 362 | 641 | 94 | 600 | 150 | 2576 | 3000 |
| 80 | 518 | 222 | 225 | 39 | 600 | 150 | 2450 | 3000 |

Notes:

In microinches per second.

Bold red = warning level increase from previous day or time.

Italic red = warning level increase as a result of non-construction related activity.

## Table 4Q
## Warning Limit Tables Representing Velocity Limit Changes Over Time
## February 18, 2009 - 1515

| Frequency (Hz) | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 4 | 1115 | 207 | 163 | 918 | 2000 | 400 | 1000 | 1000 |
| 5 | 1415 | 287 | 492 | 1101 | 2320 | 400 | 1200 | 1300 |
| 6.3 | 1200 | 261 | **400** | 1560 | 2080 | 300 | 1200 | 1300 |
| 8 | 1200 | 250 | 269 | 1000 | 3000 | 400 | 1500 | 800 |
| 10 | 1200 | 250 | 198 | 1000 | 3000 | 1200 | **2000** | 2000 |
| 12.5 | 1000 | 280 | 500 | 900 | 6000 | 1200 | 4000 | 8000 |
| 16 | 1000 | **800** | **600** | 900 | 7000 | 1200 | 9000 | 8000 |
| 20 | 1520 | 970 | 422 | 900 | 8000 | 3000 | 9000 | 5000 |
| 25 | 2596 | 1866 | 1193 | 278 | 8000 | 1400 | 4000 | 2000 |
| 31.5 | 1000 | 1573 | 911 | 100 | 6000 | 600 | 3000 | 1000 |
| 40 | 900 | 325 | 206 | 75 | 800 | 200 | 3000 | 1000 |
| 50 | 587 | 231 | 208 | 59 | 800 | 200 | 3590 | 1000 |
| 63 | 643 | 362 | 641 | 94 | 600 | 150 | 2576 | 3000 |
| 80 | 518 | 222 | 225 | 39 | 600 | 150 | 2450 | 3000 |

Notes:

In microinches per second.

Bold red = warning level increase from previous day or time.

Italic red = warning level increase as a result of non-construction related activity.

**Table 4R**
**Warning Limit Tables Representing Velocity Limit Changes Over Time**
**February 18, 2009 - 1530**

| Frequency (Hz) | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 4 | 1115 | 207 | 163 | 918 | 2000 | 400 | 1000 | 1000 |
| 5 | 1415 | 287 | 492 | 1101 | 2320 | 400 | 1200 | 1300 |
| 6.3 | 1200 | 261 | 400 | 1560 | 2080 | 300 | 1200 | 1300 |
| 8 | 1200 | 250 | 269 | 1000 | 3000 | 400 | 1500 | 800 |
| 10 | 1200 | **500** | **700** | 1000 | **5000** | 1200 | **4000** | **4000** |
| 12.5 | 1000 | 280 | 500 | 900 | 6000 | 1200 | 4000 | 8000 |
| 16 | 1000 | 800 | 600 | 900 | 7000 | 1200 | 9000 | 8000 |
| 20 | 1520 | 970 | 422 | 900 | 8000 | 3000 | 9000 | 5000 |
| 25 | 2596 | 1866 | 1193 | 278 | 8000 | 1400 | 4000 | 2000 |
| 31.5 | 1000 | 1573 | 911 | 100 | 6000 | 600 | 3000 | 1000 |
| 40 | 900 | 325 | 206 | 75 | 800 | 200 | 3000 | 1000 |
| 50 | 587 | 231 | 208 | 59 | 800 | 200 | 3590 | 1000 |
| 63 | 643 | 362 | 641 | 94 | 600 | 150 | 2576 | 3000 |
| 80 | 518 | 222 | 225 | 39 | 600 | 150 | 2450 | 3000 |

Notes:

In microinches per second.

Bold red = warning level increase from previous day or time.

Italic red = warning level increase as a result of non-construction related activity.

**Table 4S**
**Warning Limit Tables Representing Velocity Limit Changes Over Time**
**February 19, 2009 - 1048**

| Frequency (Hz) | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 4 | 1115 | 207 | 163 | 918 | 2000 | 400 | 1000 | 1000 |
| 5 | 1415 | 287 | 492 | 1101 | 2320 | 400 | 1200 | 1300 |
| 6.3 | 1200 | 261 | 400 | 1560 | 2080 | 300 | 1200 | 1300 |
| 8 | 1200 | 250 | 269 | 1000 | 3000 | 400 | 1500 | 800 |
| 10 | 1200 | 500 | 700 | 1000 | 5000 | 1200 | 4000 | 4000 |
| 12.5 | 1000 | 280 | 500 | 900 | 6000 | 1200 | 4000 | 8000 |
| 16 | 1000 | 800 | 600 | 900 | 7000 | 1200 | 9000 | 8000 |
| 20 | 1520 | 970 | 422 | 900 | 8000 | 3000 | 9000 | 5000 |
| 25 | 2596 | 1866 | 1193 | 278 | 8000 | 1400 | 4000 | **4000** |
| 31.5 | 1000 | 1573 | 911 | 100 | 6000 | 600 | 3000 | 1000 |
| 40 | 900 | 325 | 206 | 75 | 800 | 200 | 3000 | 1000 |
| 50 | 587 | 231 | 208 | 59 | 800 | 200 | 3590 | 1000 |
| 63 | 643 | 362 | 641 | 94 | 600 | 150 | 2576 | 3000 |
| 80 | 518 | 222 | 225 | 39 | 600 | 150 | 2450 | 3000 |

Notes:

In microinches per second.

Bold red = warning level increase from previous day or time.

Italic red = warning level increase as a result of non-construction related activity.

**Table 4T**
**Warning Limit Tables Representing Velocity Limit Changes Over Time**
**February 19, 2009 - 1114**

| Frequency (Hz) | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 4 | 1115 | 207 | 163 | 918 | 2000 | 400 | 1000 | 1000 |
| 5 | 1415 | 287 | 492 | 1101 | 2320 | 400 | 1200 | 1300 |
| 6.3 | 1200 | 261 | 400 | 1560 | 2080 | 300 | 1200 | 1300 |
| 8 | 1200 | 250 | 269 | 1000 | 3000 | 400 | 1500 | 800 |
| 10 | 1200 | 500 | 700 | 1000 | 5000 | 1200 | 4000 | 4000 |
| 12.5 | 1000 | 280 | 500 | 900 | 6000 | 1200 | 4000 | 8000 |
| 16 | 1000 | 800 | 600 | 900 | 7000 | 1200 | 9000 | 8000 |
| 20 | 1520 | 970 | 422 | 900 | 8000 | 3000 | 9000 | 5000 |
| 25 | 2596 | 1866 | 1193 | 278 | 8000 | 1400 | **9000** | 4000 |
| 31.5 | 1000 | 1573 | 911 | 100 | 6000 | 600 | 3000 | 1000 |
| 40 | 900 | 325 | 206 | 75 | 800 | 200 | 3000 | 1000 |
| 50 | 587 | 231 | 208 | 59 | 800 | 200 | 3590 | 1000 |
| 63 | 643 | 362 | 641 | 94 | 600 | 150 | 2576 | 3000 |
| 80 | 518 | 222 | 225 | 39 | 600 | 150 | 2450 | 3000 |

Notes:

In microinches per second.

Bold red = warning level increase from previous day or time.

Italic red = warning level increase as a result of non-construction related activity.

## Table 4U
## Warning Limit Tables Representing Velocity Limit Changes Over Time
## February 19, 2009 - 1121

| Frequency (Hz) | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 4 | 1115 | *400* | *400* | 918 | 2000 | 400 | 1000 | 1000 |
| 5 | 1415 | *400* | 492 | 1101 | 2320 | 400 | 1200 | 1300 |
| 6.3 | 1200 | *400* | 400 | 1560 | 2080 | 300 | 1200 | 1300 |
| 8 | 1200 | *400* | *400* | 1000 | 3000 | 400 | 1500 | 800 |
| 10 | 1200 | 500 | 700 | 1000 | 5000 | 1200 | 4000 | 4000 |
| 12.5 | 1000 | 280 | 500 | 900 | 6000 | 1200 | 4000 | 8000 |
| 16 | 1000 | 800 | 600 | 900 | 7000 | 1200 | 9000 | 8000 |
| 20 | 1520 | 970 | 422 | 900 | 8000 | 3000 | 9000 | 5000 |
| 25 | 2596 | 1866 | 1193 | 278 | 8000 | 1400 | 9000 | 4000 |
| 31.5 | 1000 | 1573 | 911 | 100 | 6000 | 600 | 3000 | 1000 |
| 40 | 900 | 325 | 206 | 75 | 800 | 200 | 3000 | 1000 |
| 50 | 587 | 231 | 208 | 59 | 800 | 200 | 3590 | 1000 |
| 63 | 643 | 362 | 641 | 94 | 600 | 150 | 2576 | 3000 |
| 80 | 518 | 222 | 225 | 39 | 600 | 150 | 2450 | 3000 |

Notes:

In microinches per second.

Bold red = warning level increase from previous day or time.

Italic red = warning level increase as a result of non-construction related activity.

## Table 4V
## Warning Limit Tables Representing Velocity Limit Changes Over Time
## February 19, 2009 - 1352

| Frequency (Hz) | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 4 | 1115 | 400 | 400 | 918 | 2000 | 400 | 1000 | 1000 |
| 5 | 1415 | 400 | 492 | 1101 | 2320 | 400 | 1200 | 1300 |
| 6.3 | 1200 | 400 | 400 | 1560 | 2080 | 300 | 1200 | 1300 |
| 8 | 1200 | 400 | 400 | 1000 | 3000 | 400 | 1500 | **1500** |
| 10 | 1200 | 500 | 700 | 1000 | 5000 | 1200 | 4000 | 4000 |
| 12.5 | 1000 | 280 | 500 | 900 | 6000 | 1200 | 4000 | 8000 |
| 16 | 1000 | 800 | 600 | 900 | 7000 | 1200 | 9000 | 8000 |
| 20 | 1520 | 970 | 422 | 900 | 8000 | 3000 | 9000 | 5000 |
| 25 | 2596 | 1866 | 1193 | 278 | 8000 | 1400 | 9000 | 4000 |
| 31.5 | 1000 | 1573 | 911 | 100 | 6000 | 600 | 3000 | 1000 |
| 40 | 900 | 325 | 206 | 75 | 800 | 200 | 3000 | 1000 |
| 50 | 587 | 231 | 208 | 59 | 800 | 200 | 3590 | 1000 |
| 63 | 643 | 362 | 641 | 94 | 600 | 150 | 2576 | 3000 |
| 80 | 518 | 222 | 225 | 39 | 600 | 150 | 2450 | 3000 |

Notes:

In microinches per second.

Bold red = warning level increase from previous day or time.

Italic red = warning level increase as a result of non-construction related activity.

## Table 4W
## Warning Limit Tables Representing Velocity Limit Changes Over Time
## February 19, 2009 - 1404

| Frequency (Hz) | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 4 | 1115 | 400 | 400 | 918 | 2000 | 400 | 1000 | 1000 |
| 5 | 1415 | 400 | 492 | 1101 | 2320 | 400 | **2000** | **2000** |
| 6.3 | 1200 | 400 | 400 | 1560 | 2080 | 300 | **2000** | **2000** |
| 8 | 1200 | 400 | 400 | 1000 | 3000 | 400 | **2000** | **2000** |
| 10 | 1200 | 500 | 700 | 1000 | 5000 | 1200 | 4000 | 4000 |
| 12.5 | 1000 | 280 | 500 | 900 | 6000 | 1200 | 4000 | 8000 |
| 16 | 1000 | 800 | 600 | 900 | 7000 | 1200 | 9000 | 8000 |
| 20 | 1520 | 970 | 422 | 900 | 8000 | 3000 | 9000 | 5000 |
| 25 | 2596 | 1866 | 1193 | 278 | 8000 | 1400 | 9000 | 4000 |
| 31.5 | 1000 | 1573 | 911 | 100 | 6000 | 600 | 3000 | 1000 |
| 40 | 900 | 325 | 206 | 75 | 800 | 200 | 3000 | 1000 |
| 50 | 587 | 231 | 208 | 59 | 800 | 200 | 3590 | 1000 |
| 63 | 643 | 362 | 641 | 94 | 600 | 150 | 2576 | 3000 |
| 80 | 518 | 222 | 225 | 39 | 600 | 150 | 2450 | 3000 |

Notes:

In microinches per second.

Bold red = warning level increase from previous day or time.

Italic red = warning level increase as a result of non-construction related activity.

**Table 4X**
**Warning Limit Tables Representing Velocity Limit Changes Over Time**
**February 20, 2009**

| Frequency (Hz) | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 4 | 1115 | 400 | 400 | 918 | 2000 | 400 | 1000 | 1000 |
| 5 | 1415 | 400 | 492 | 1101 | 2320 | 400 | 2000 | 2000 |
| 6.3 | 1200 | 400 | 400 | 1560 | 2080 | 300 | 2000 | 2000 |
| 8 | 1200 | 400 | 400 | 1000 | 3000 | 400 | 2000 | 2000 |
| 10 | 1200 | 500 | 700 | 1000 | 5000 | 1200 | 4000 | 4000 |
| 12.5 | 1000 | 280 | 500 | 900 | 6000 | 1200 | 4000 | 8000 |
| 16 | 1000 | 800 | 600 | 900 | 7000 | 1200 | 9000 | 8000 |
| 20 | 1520 | 970 | 422 | 900 | 8000 | 3000 | 9000 | 5000 |
| 25 | 2596 | 1866 | 1193 | 278 | 8000 | 1400 | 9000 | 4000 |
| 31.5 | 1000 | 1573 | 911 | 100 | 6000 | 600 | 3000 | 1000 |
| 40 | 900 | 325 | 206 | 75 | 800 | 200 | 3000 | 1000 |
| 50 | 587 | 231 | 208 | 59 | 800 | 200 | 3590 | 1000 |
| 63 | 643 | 362 | 641 | *240* | 600 | 150 | 2576 | 3000 |
| 80 | 518 | 222 | 225 | 39 | 600 | 150 | 2450 | 3000 |

Notes:
In microinches per second.
Bold red = warning level increase from previous day or time.
Italic red = warning level increase as a result of non-construction related activity.

## Table 4Y
## Warning Limit Tables Representing Velocity Limit Changes Over Time
## February 24, 2009 - 1449

| Frequency (Hz) | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 4 | 1115 | 400 | 400 | 918 | 2000 | 400 | 1000 | 1000 |
| 5 | 1415 | 400 | 492 | 1101 | 2320 | 400 | 2000 | 2000 |
| 6.3 | 1200 | 400 | 400 | 1560 | 2080 | 300 | 2000 | 2000 |
| 8 | 1200 | 400 | 400 | 1000 | 3000 | 400 | 2000 | 2000 |
| 10 | 1200 | 500 | 700 | 1000 | 5000 | 1200 | 4000 | 4000 |
| 12.5 | 1000 | 280 | 500 | 900 | 6000 | 1200 | 4000 | 8000 |
| 16 | 1000 | 800 | 600 | 900 | 7000 | 1200 | 9000 | 8000 |
| 20 | 1520 | 970 | 422 | 900 | 8000 | 3000 | 9000 | 5000 |
| 25 | 2596 | 1866 | 1193 | 278 | 8000 | 1400 | 9000 | 4000 |
| 31.5 | 1000 | 1573 | 911 | 100 | 6000 | 600 | 3000 | 1000 |
| 40 | 900 | 325 | 206 | 75 | *10000* | *3000* | 3000 | 1000 |
| 50 | 587 | 231 | 208 | 59 | *10000* | *3000* | 3590 | 1000 |
| 63 | 643 | 362 | 641 | 240 | *10000* | *3000* | 2576 | 3000 |
| 80 | 518 | 222 | 225 | 39 | *10000* | *3000* | 2450 | 3000 |

Notes:

In microinches per second.

Bold red = warning level increase from previous day or time.

Italic red = warning level increase as a result of non-construction related activity.

**Table 4Z**
**Warning Limit Tables Representing Velocity Limit Changes Over Time**
**March 10, 2009**

| Frequency (Hz) | Accelerometer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 4 | 1115 | 400 | 400 | 918 | 2000 | 400 | 1000 | 1000 |
| 5 | 1415 | 400 | 492 | 1101 | 2320 | 400 | 2000 | 2000 |
| 6.3 | 1200 | 400 | 400 | 1560 | 2080 | 300 | 2000 | 2000 |
| 8 | 1200 | 400 | 400 | 1000 | 3000 | 400 | 2000 | 2000 |
| 10 | 1200 | 500 | 700 | 1000 | 5000 | 1200 | 4000 | 4000 |
| 12.5 | 1000 | 280 | 500 | 900 | 6000 | 1200 | 4000 | 8000 |
| 16 | 1000 | 800 | 600 | 900 | 7000 | 1200 | 9000 | 8000 |
| 20 | 1520 | 970 | *600* | 900 | 8000 | 3000 | 9000 | 5000 |
| 25 | 2596 | 1866 | 1193 | 278 | 8000 | 1400 | 9000 | 4000 |
| 31.5 | 1000 | 1573 | 911 | 100 | 6000 | 600 | 3000 | 1000 |
| 40 | 900 | *500* | *400* | 75 | 10000 | 3000 | 3000 | 1000 |
| 50 | *643* | *500* | *800* | 59 | 10000 | 3000 | 3590 | 1000 |
| 63 | 643 | 362 | 641 | 240 | 10000 | 3000 | 2576 | 3000 |
| 80 | 518 | *362* | 225 | 39 | 10000 | 3000 | 2450 | 3000 |

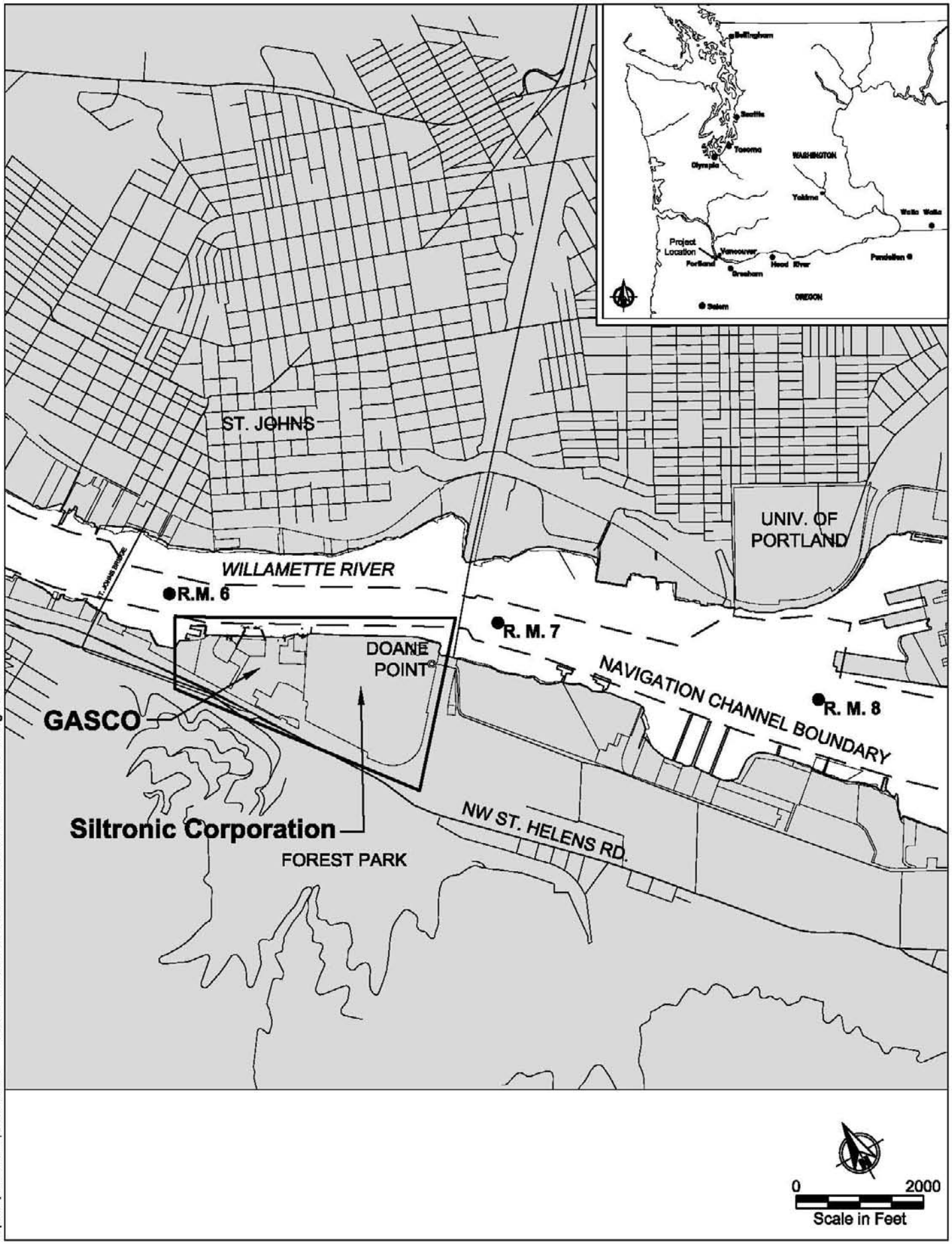
Notes:

In microinches per second.

Bold red = warning level increase from previous day or time.

Italic red = warning level increase as a result of non-construction related activity.

# FIGURES




Apr 23, 2009 3:23pm hariksen K:\Jobs\000029-GASCO\00002902\00002902-RP-028.dwg FIG 1.1

ANCHOR QEA

**Figure 1**
Vicinity Map - Gasco and Siltronic Site
Vibration Study Data Report
Gasco Siltronic Construction

Q:\Jobs\000029-02_Gasco\Maps\2009_Q2\GPS_points_and_siltronic_fab1_fab2_points.mxd ckiblinger 04/23/2009 5:49 PM

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**Figure 2**
Testing and Monitoring Locations
Vibration Study Data Report
Gasco Siltronic Construction

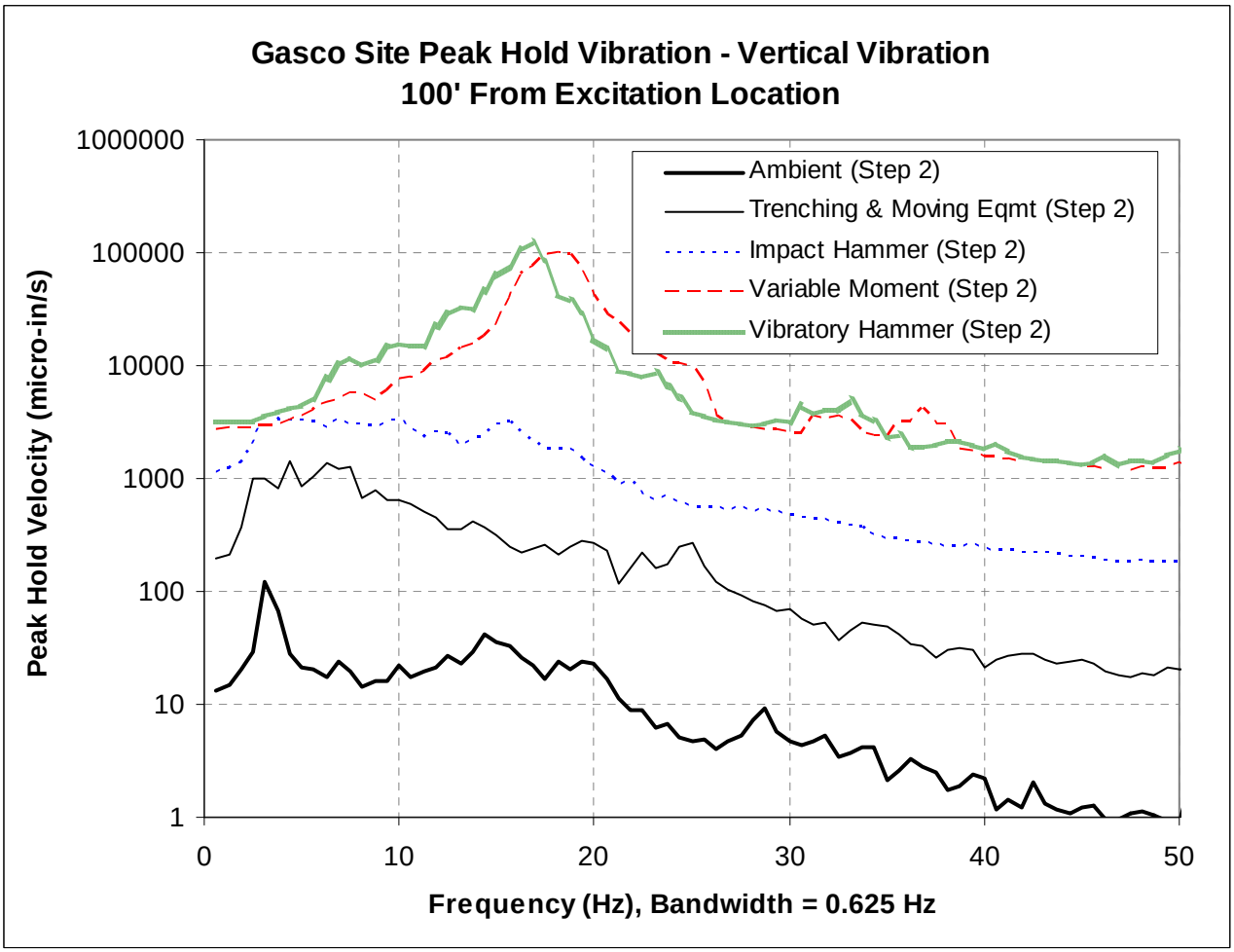



**Figure 3.1**
Typical Peak Hold Narrowband Vibration Spectra
for Construction Activities at Gasco Site
Vibration Study Data Report

ANCHOR QEA

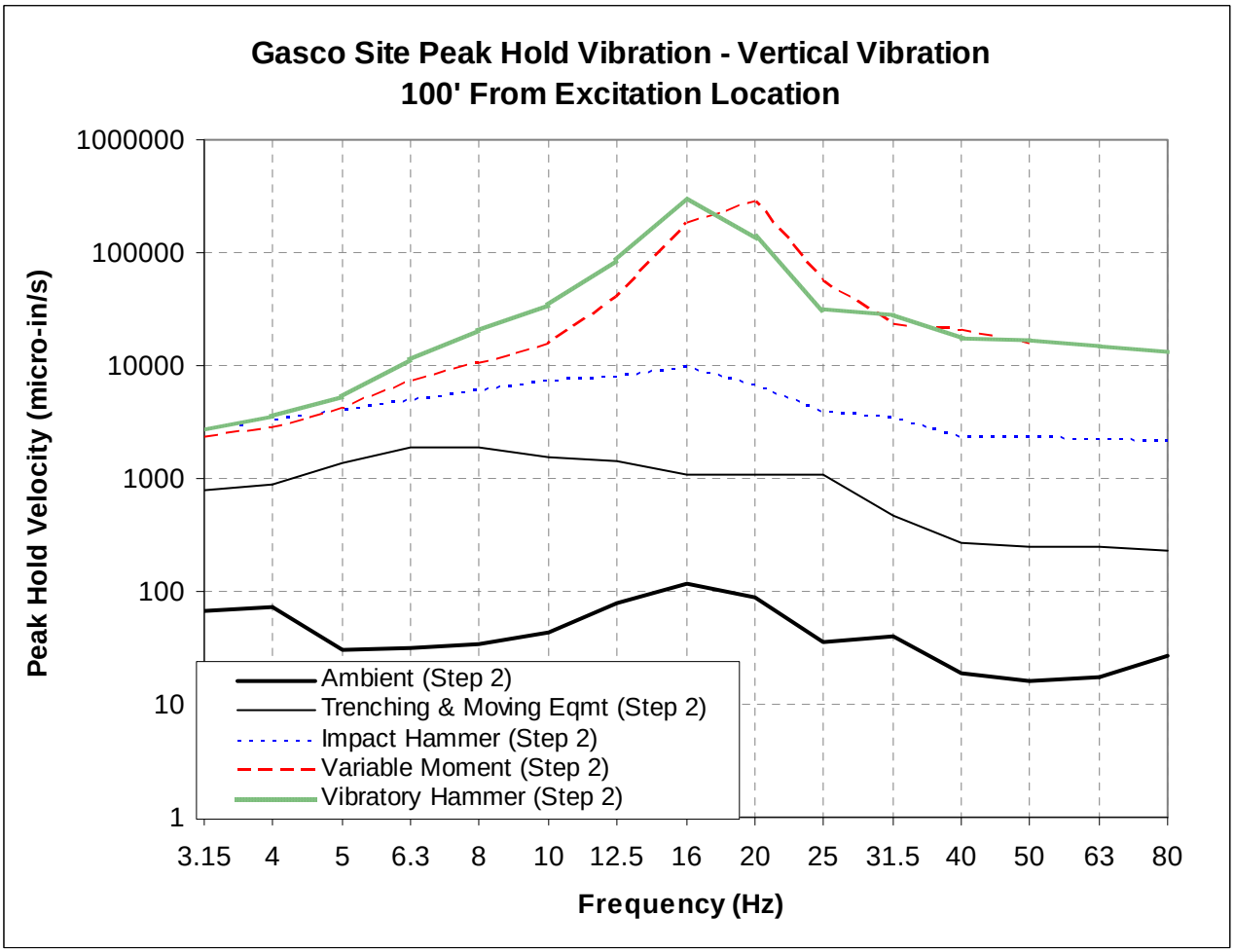



**Figure 3.2**
Typical Peak Hold One-Third Octave Vibration Spectra
for Construction Activities at Gasco Site
Vibration Study Data Report

ANCHOR QEA

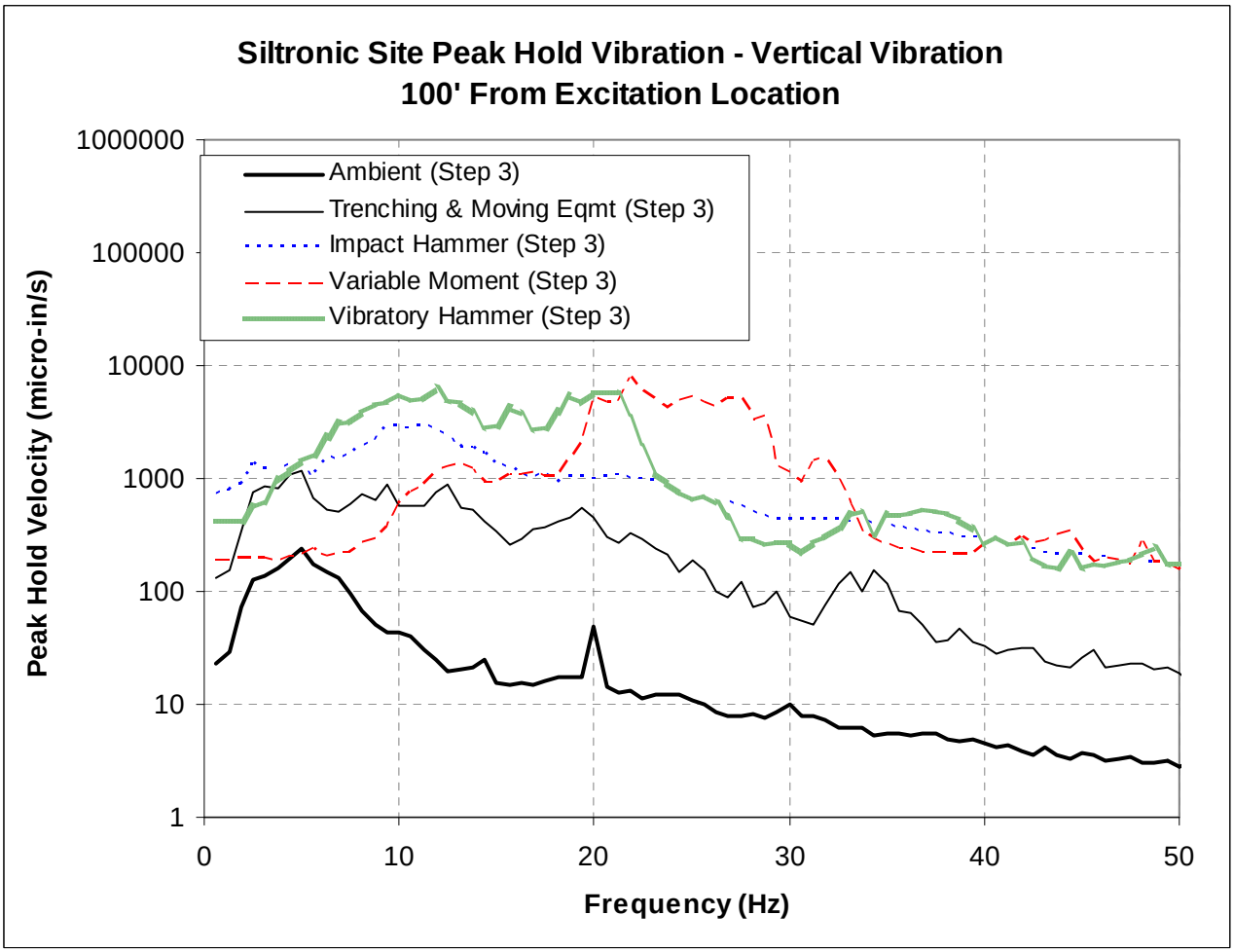



**Figure 3.3**
Typical Peak Hold Narrowband Vibration Spectra
for Construction Activities at Siltronic Site
Vibration Study Data Report

ANCHOR QEA

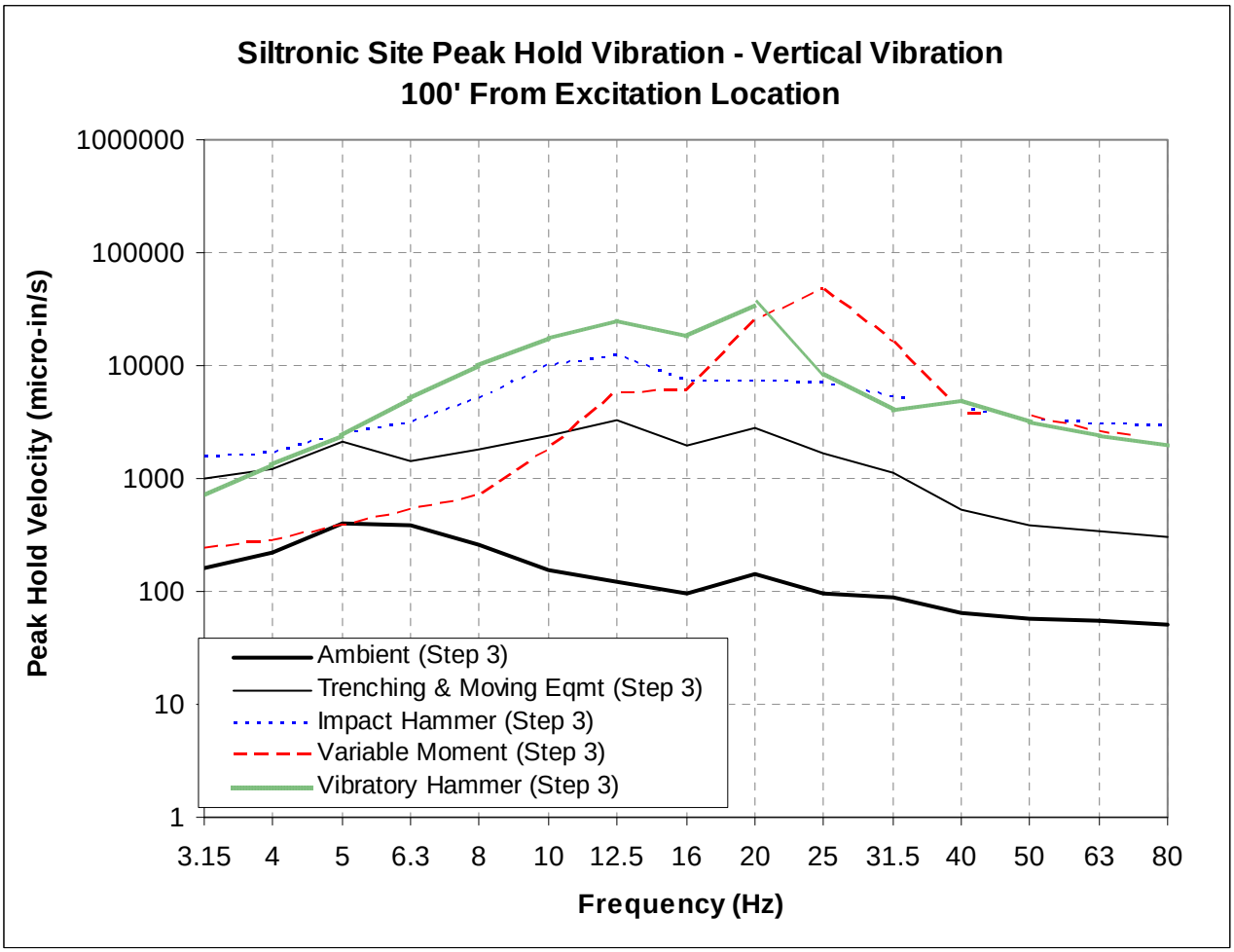
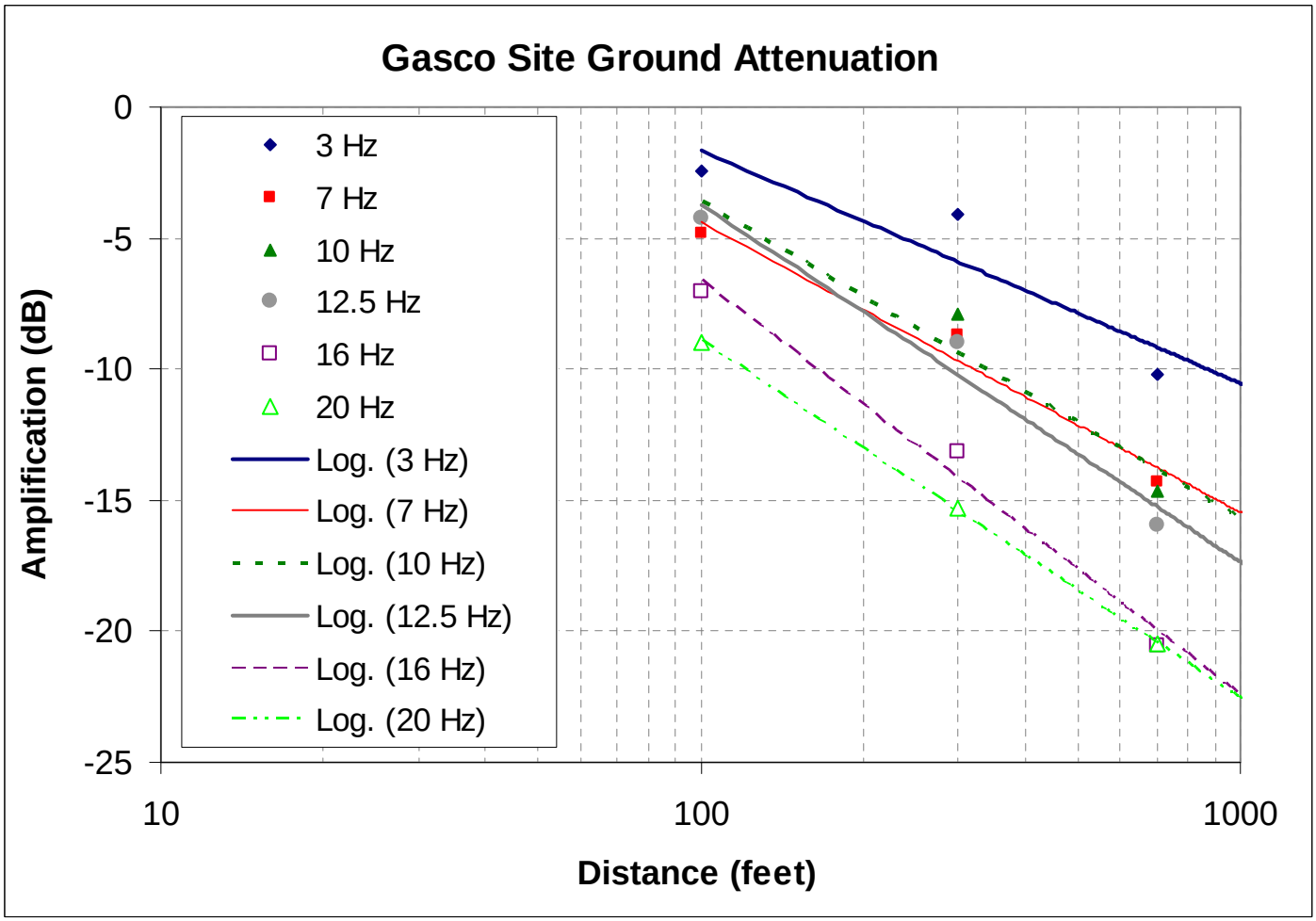



**Figure 3.4**
Typical Peak Hold One-Third Octave Vibration Spectra
for Construction Activities at Siltronic Site
Vibration Study Data Report

ANCHOR QEA




ANCHOR QEA

**Figure 4.1**
Site Attenuation Curves for Gasco Site
Vibration Study Data Report

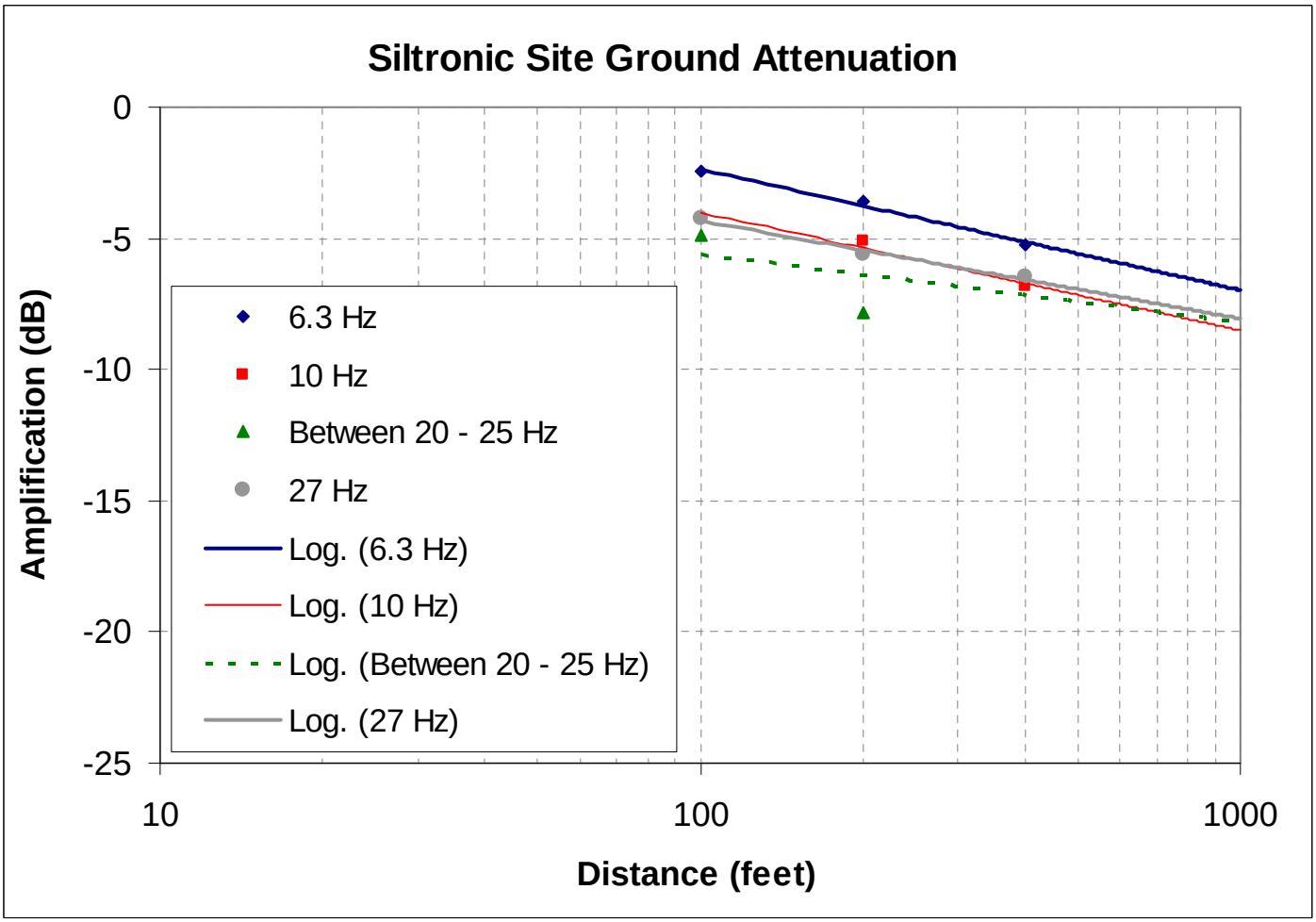



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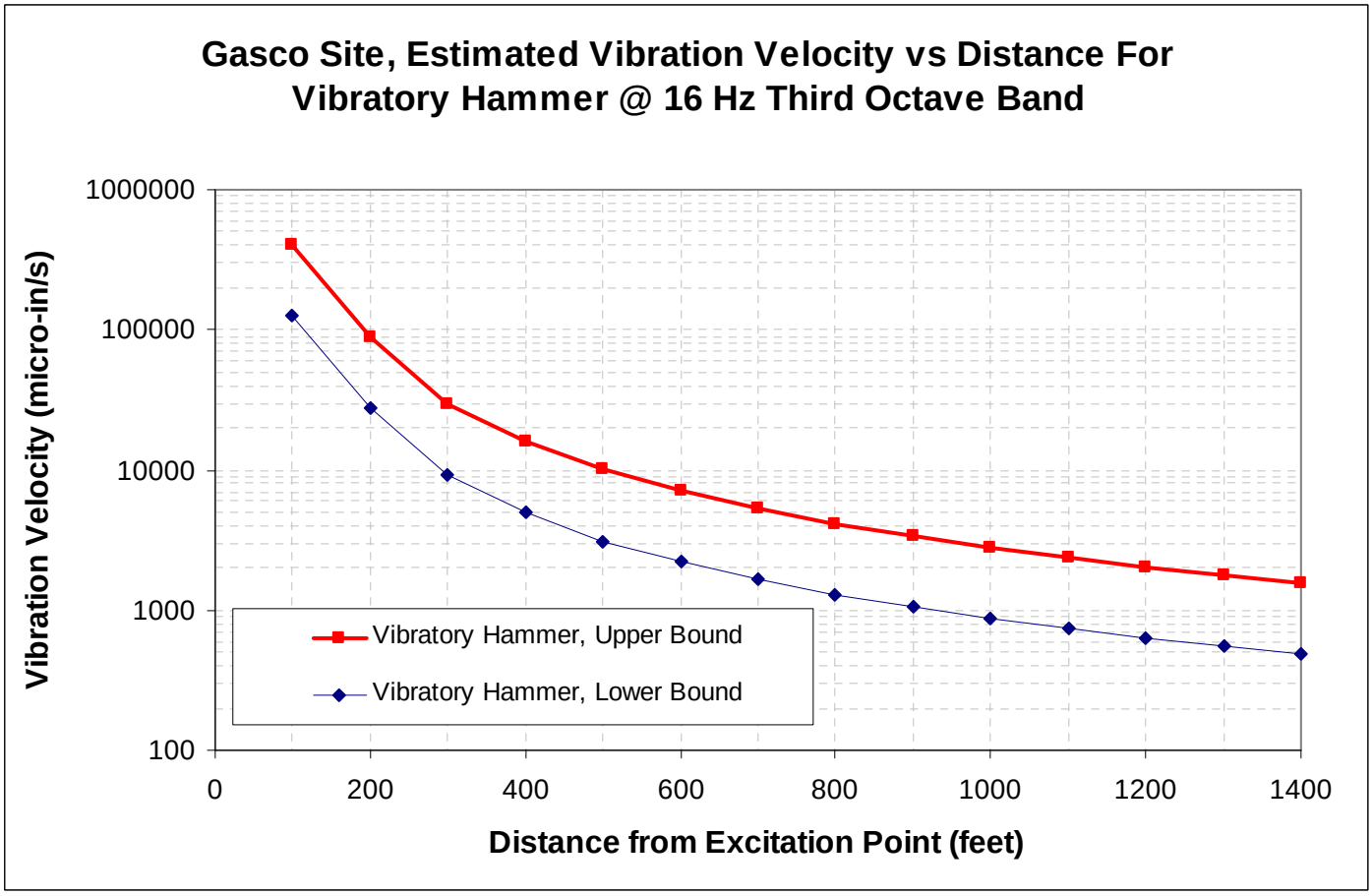
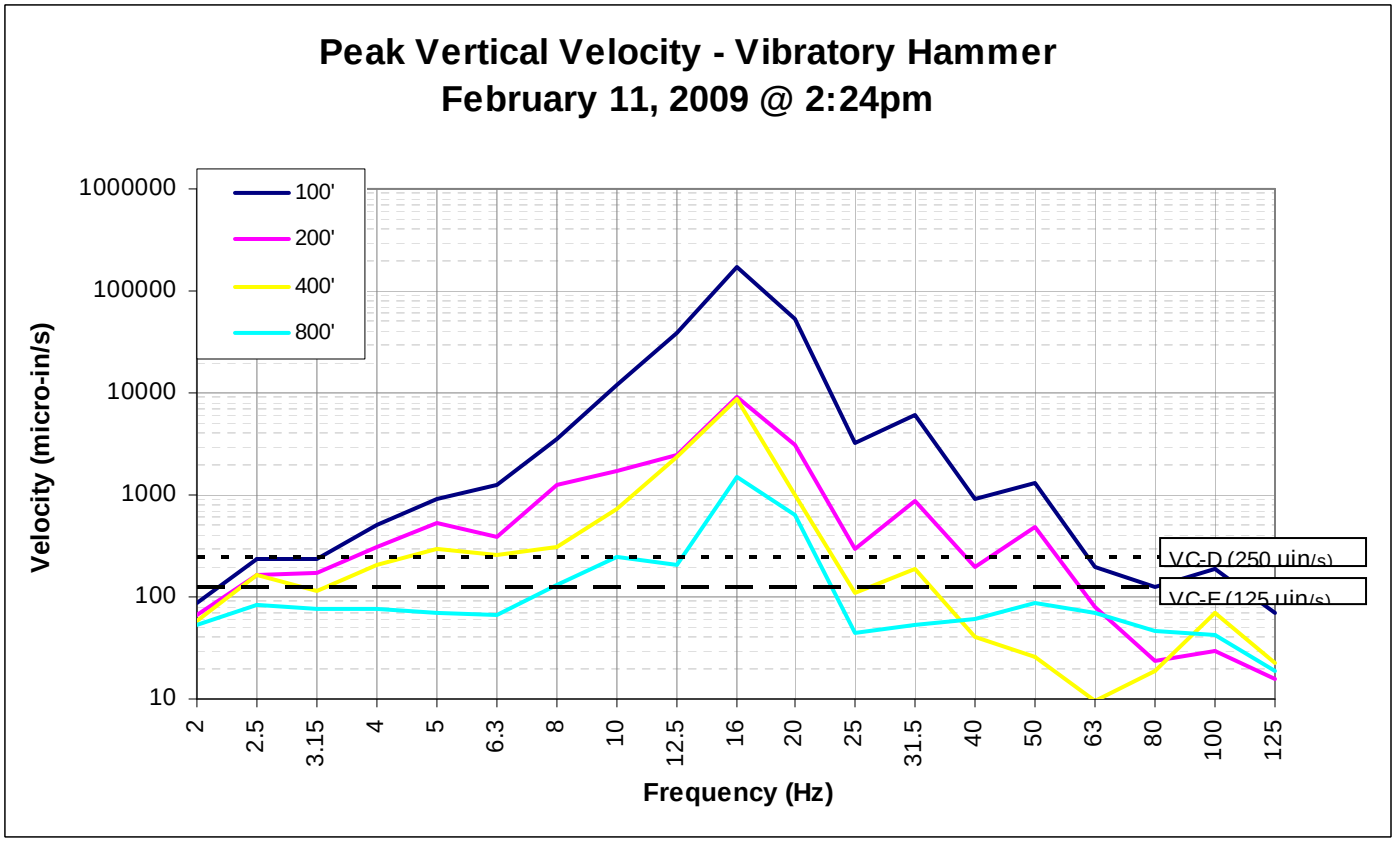
**Figure 4.2**
Site Attenuation Curves for Siltronic Site
Vibration Study Data Report




ANCHOR QEA

**Figure 5.1**
Vibration Velocity vs Distance for Vibratory Hammer, Gasco Site
Vibration Study Data Report

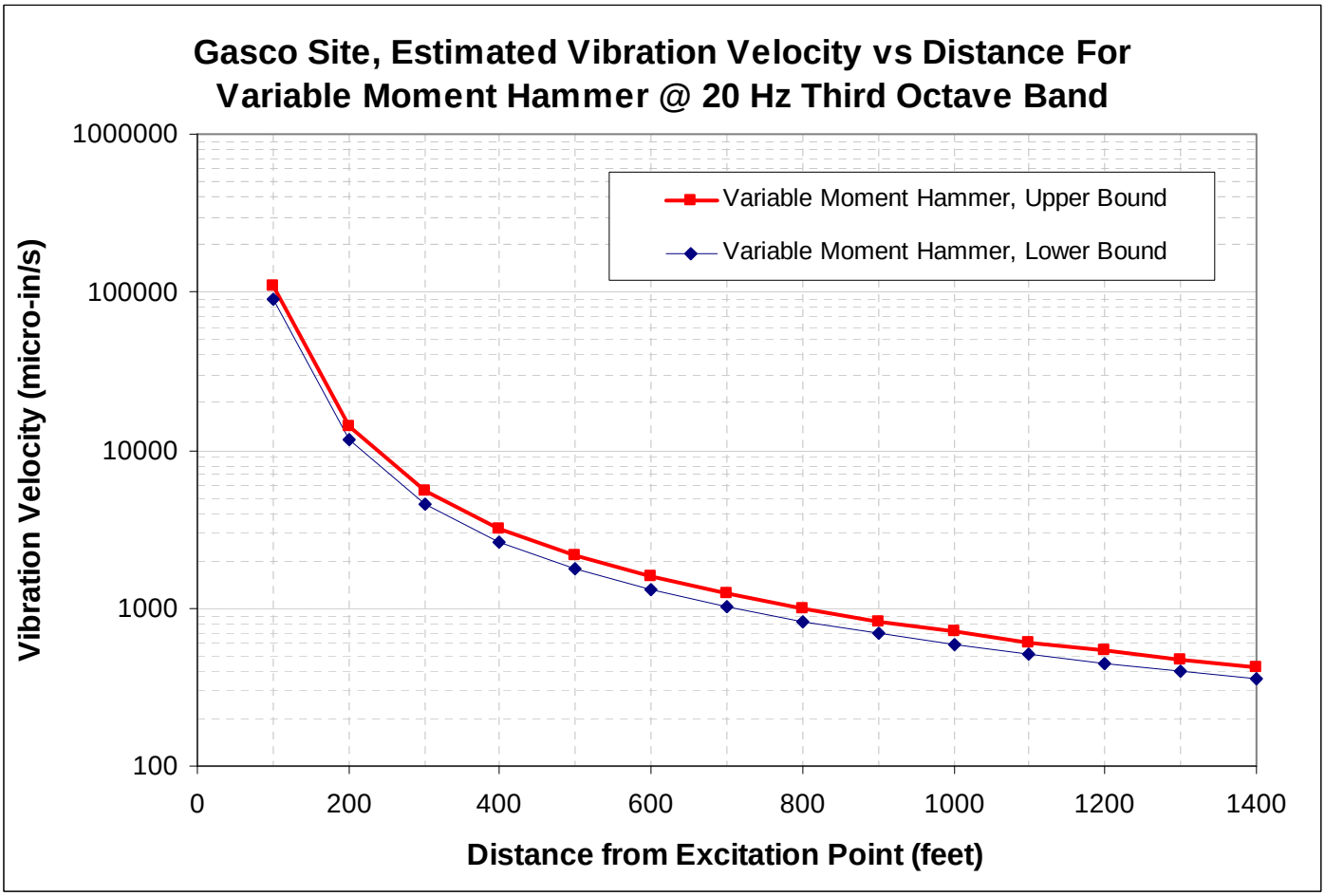



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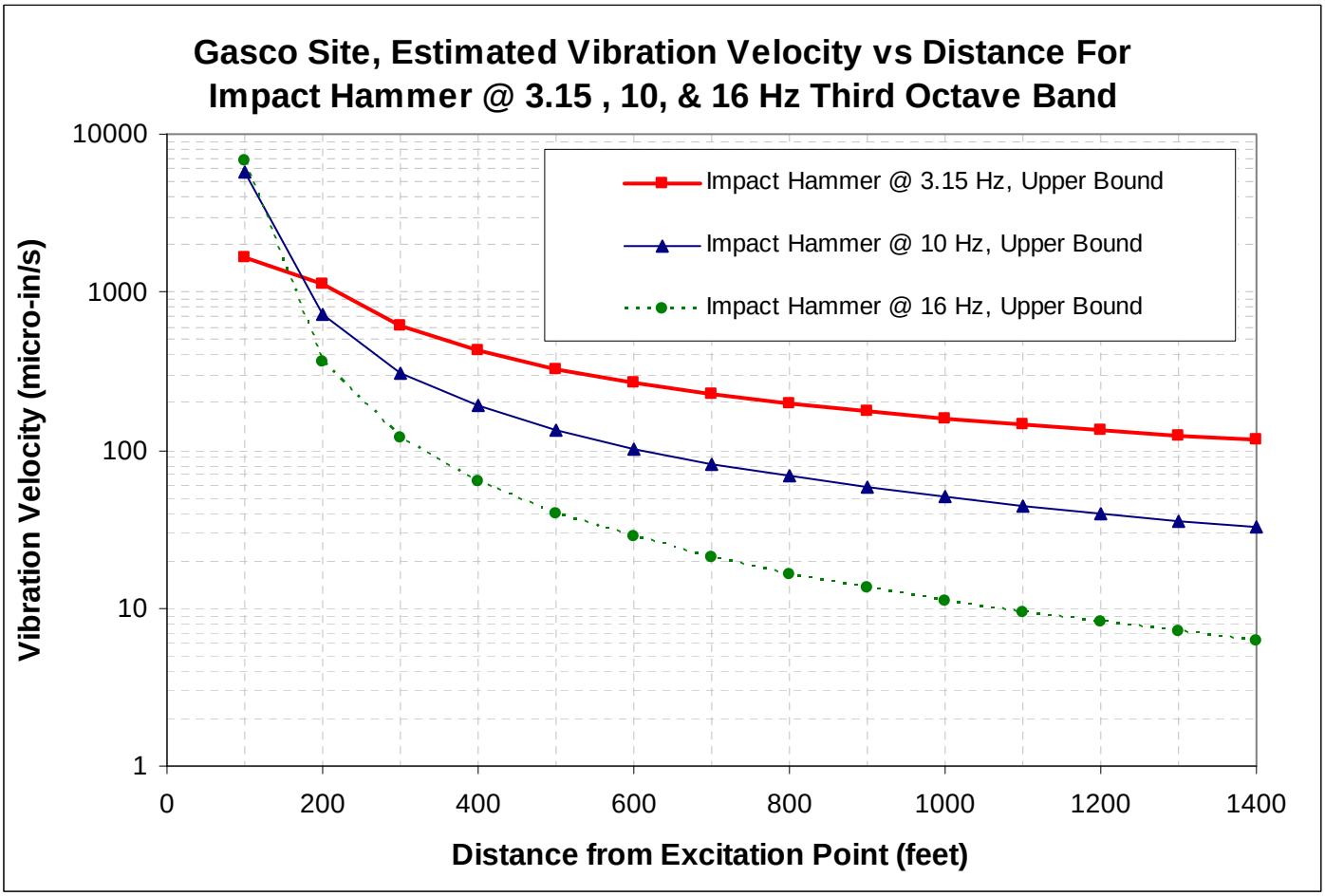
**Figure 5.2**
Vibration Velocity vs Distance for Variable Moment Hammer, Gasco Site
Vibration Study Data Report




ANCHOR QEA

**Figure 5.3**
Vibration Velocity vs Distance for Impact Hammer, Gasco Site
Vibration Study Data Report

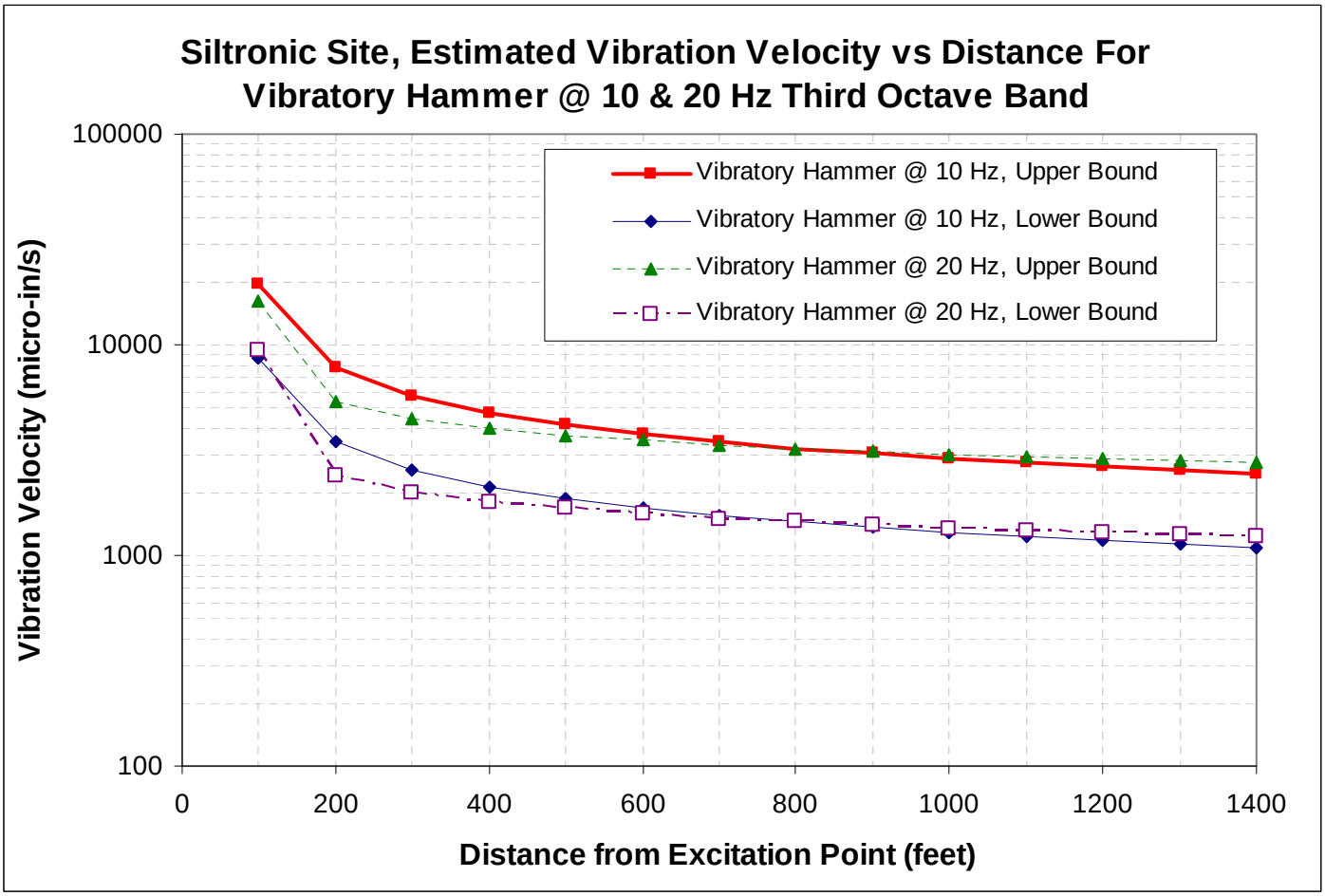



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**Figure 5.4**
Vibration Velocity vs Distance for Vibratory Hammer, Siltronic Site
Vibration Study Data Report

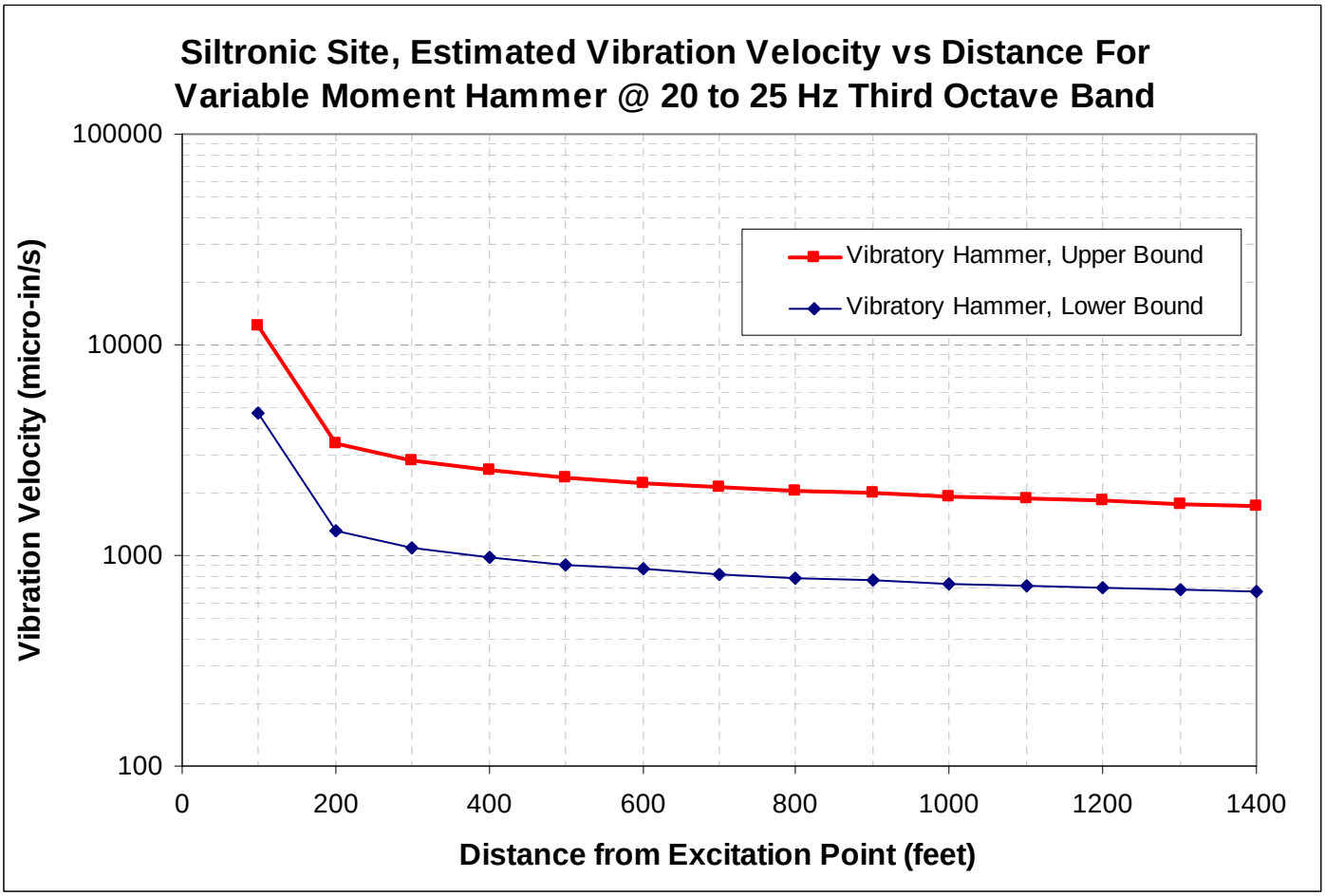


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**Figure 5.5**
Vibration Velocity vs Distance for Variable Moment Hammer, Siltronic Site
Vibration Study Data Report

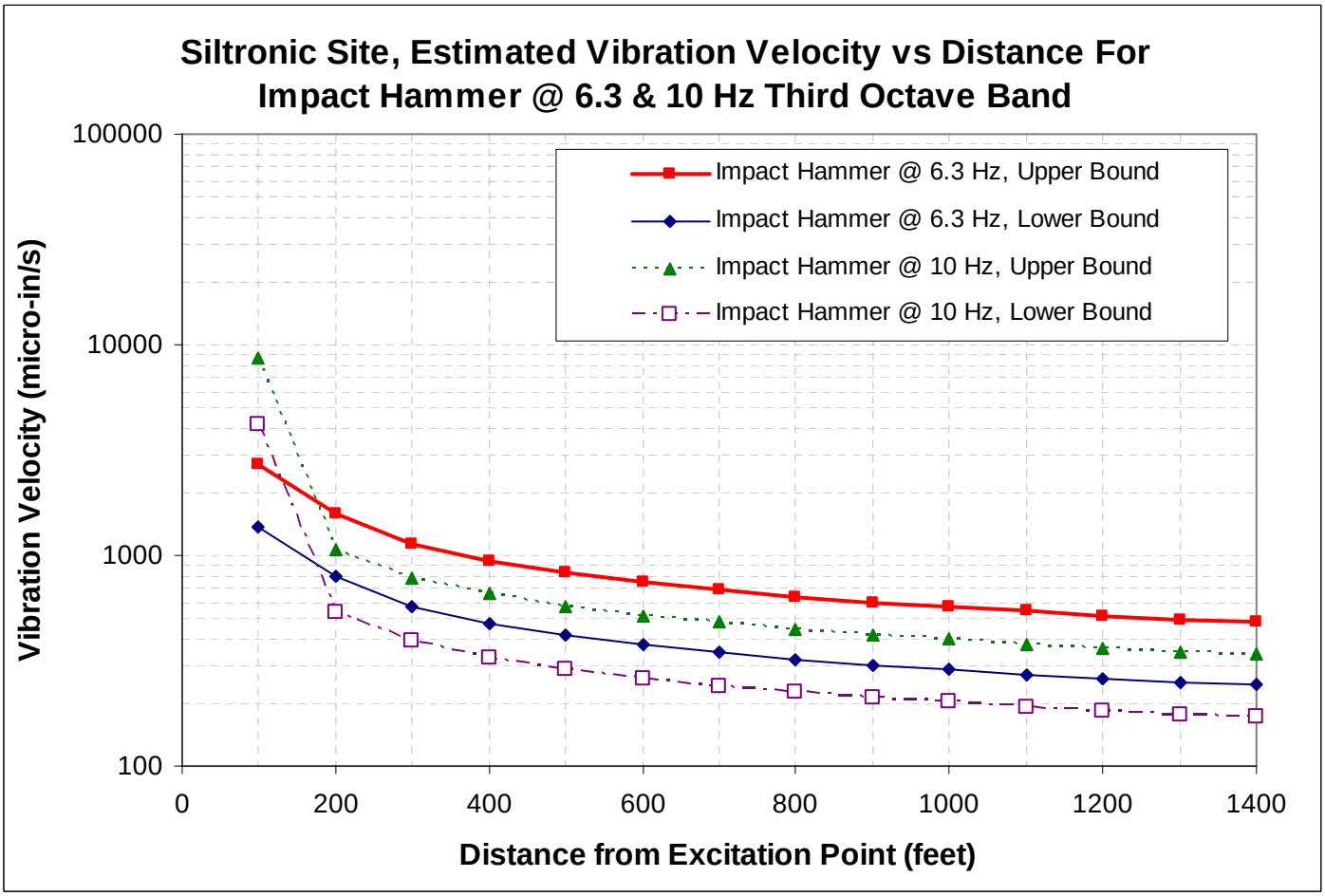


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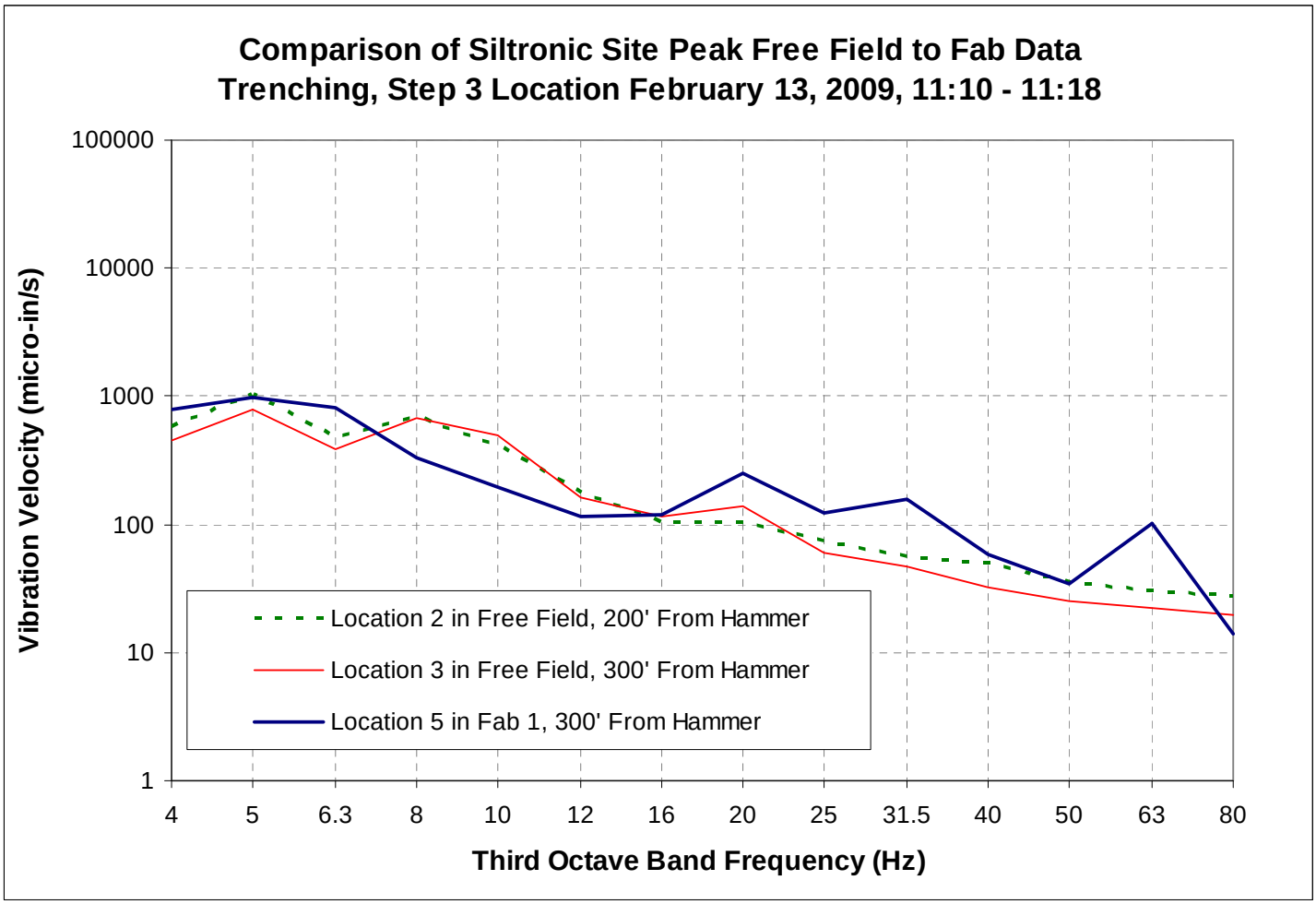
**Figure 5.6**
Vibration Velocity vs Distance for Impact Hammer, Siltronic Site
Vibration Study Data Report




ANCHOR QEA

**Figure 6.1**
Comparison of Siltronic Site Peak Free Field Data vs Fab Data, Event 1
Vibration Study Data Report

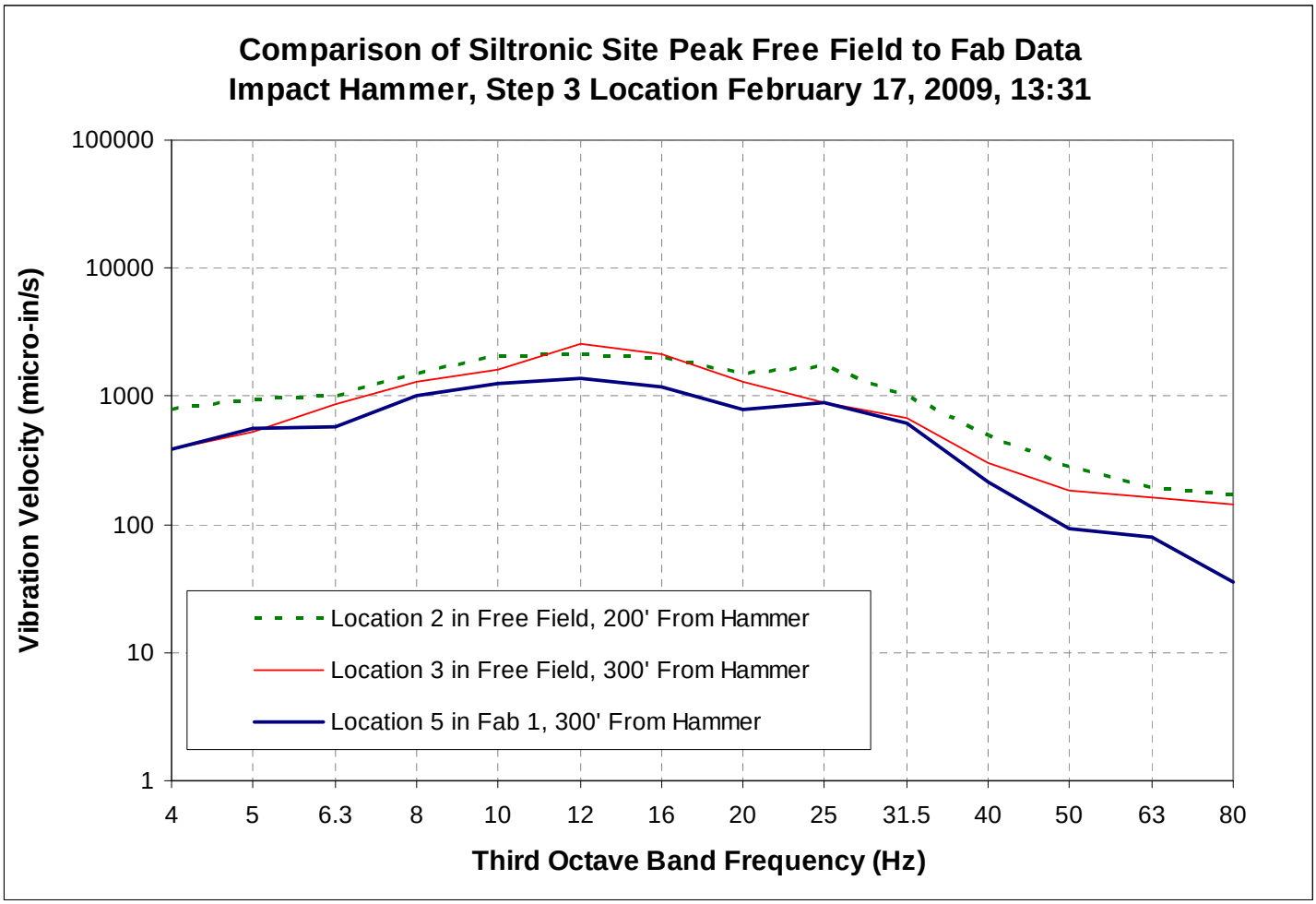



**Figure 6.2**
Comparison of Siltronic Site Peak Free Field Data vs Fab Data, Event 2
Vibration Study Data Report

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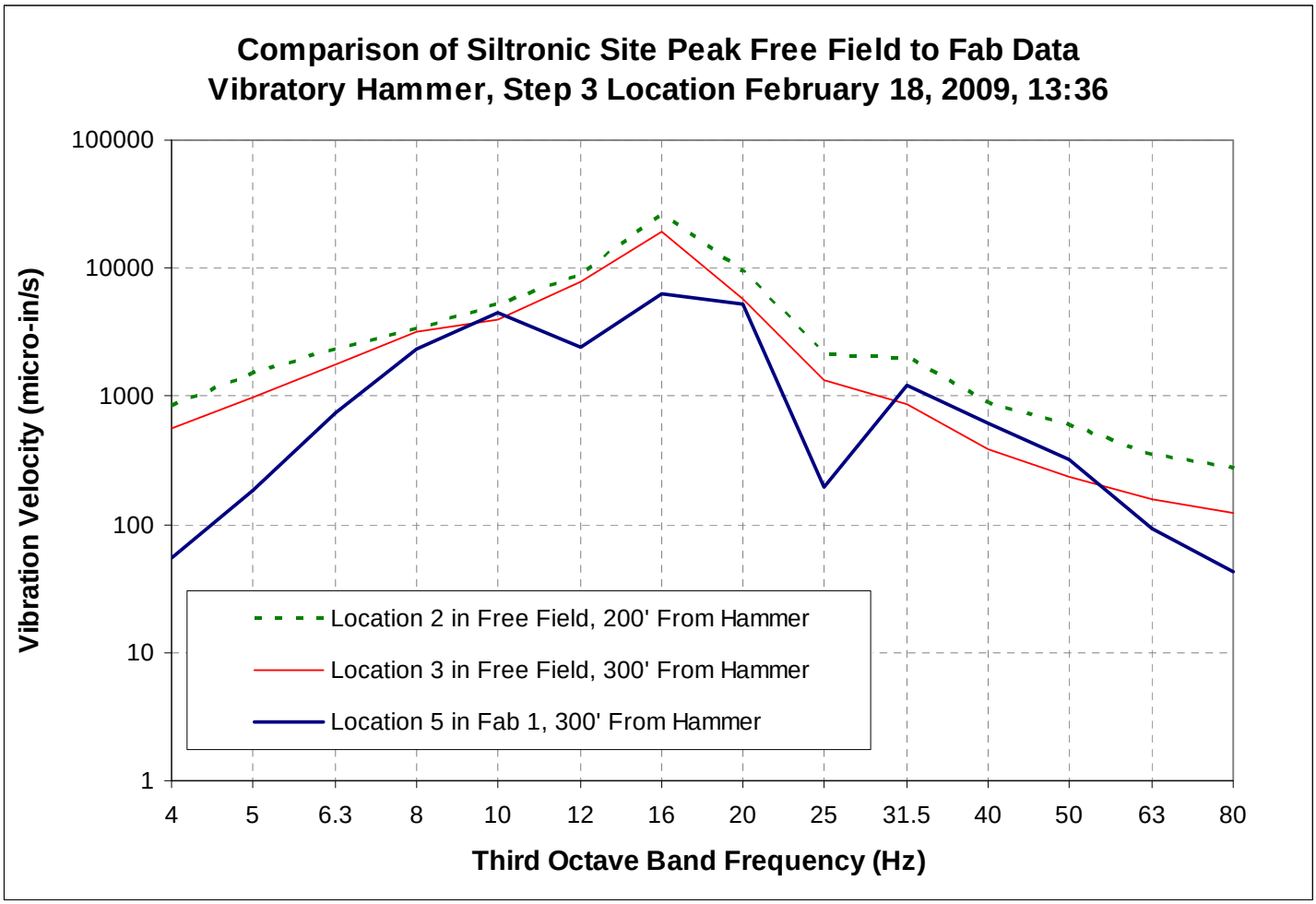


**Figure 6.3**
Comparison of Siltronic Site Peak Free Field Data vs Fab Data, Event 3
Vibration Study Data Report

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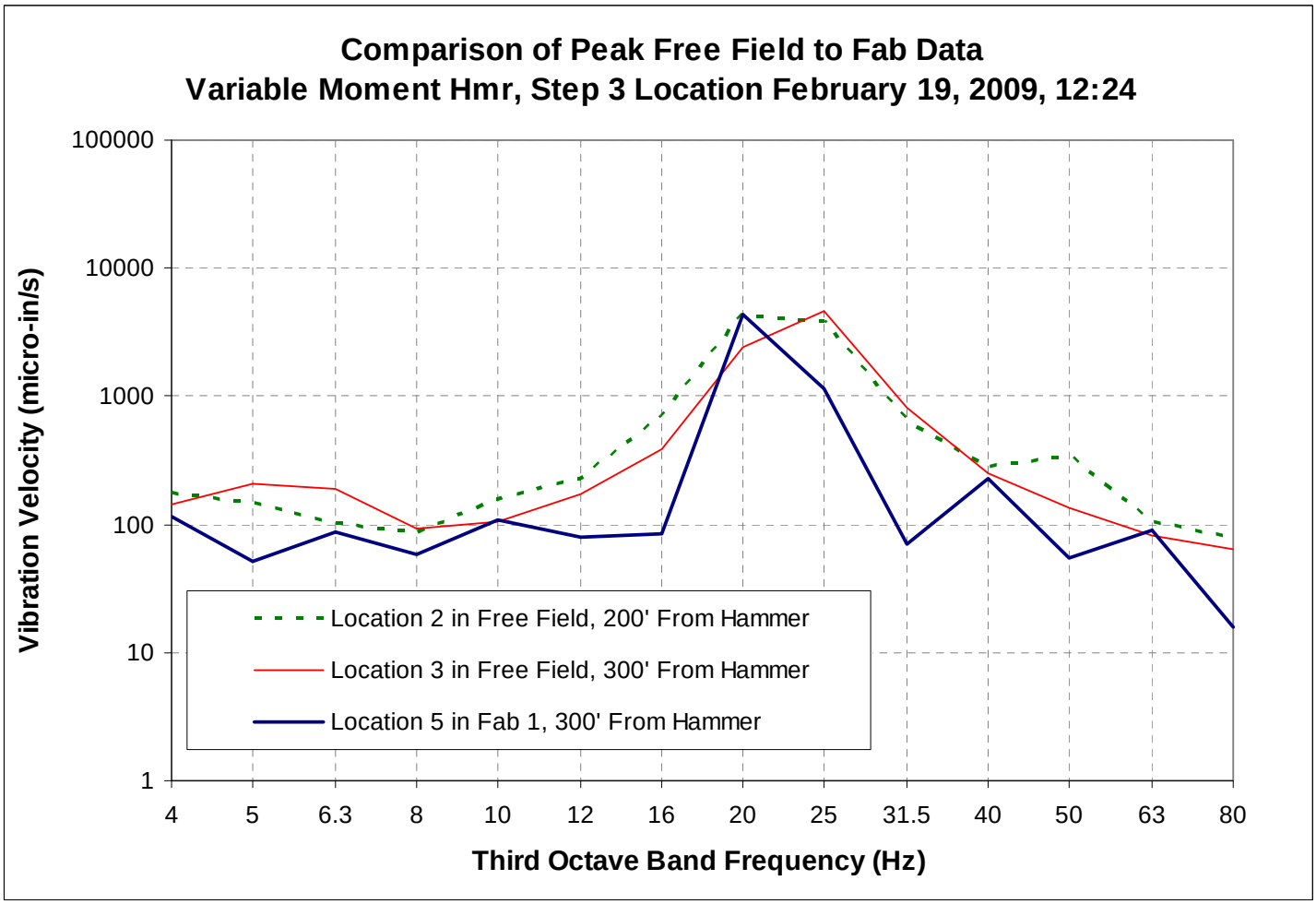


**Figure 6.4**
Comparison of Siltronic Site Peak Free Field Data vs Fab Data, Event 4

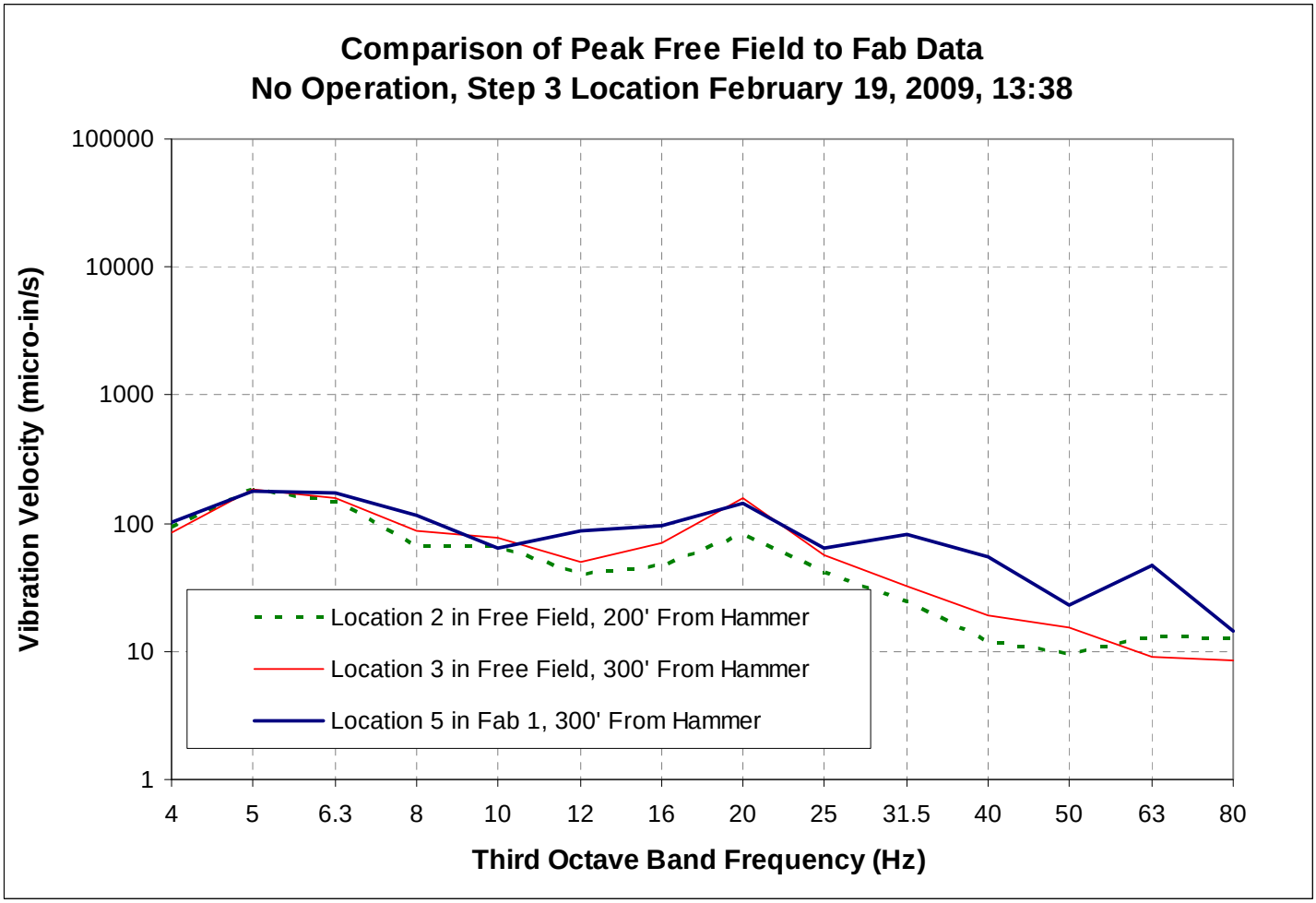


**Figure 6.5**
Comparison of Siltronic Site Peak Free Field Data vs Fab Data, Event 5
Vibration Study Data Report

ANCHOR QEA

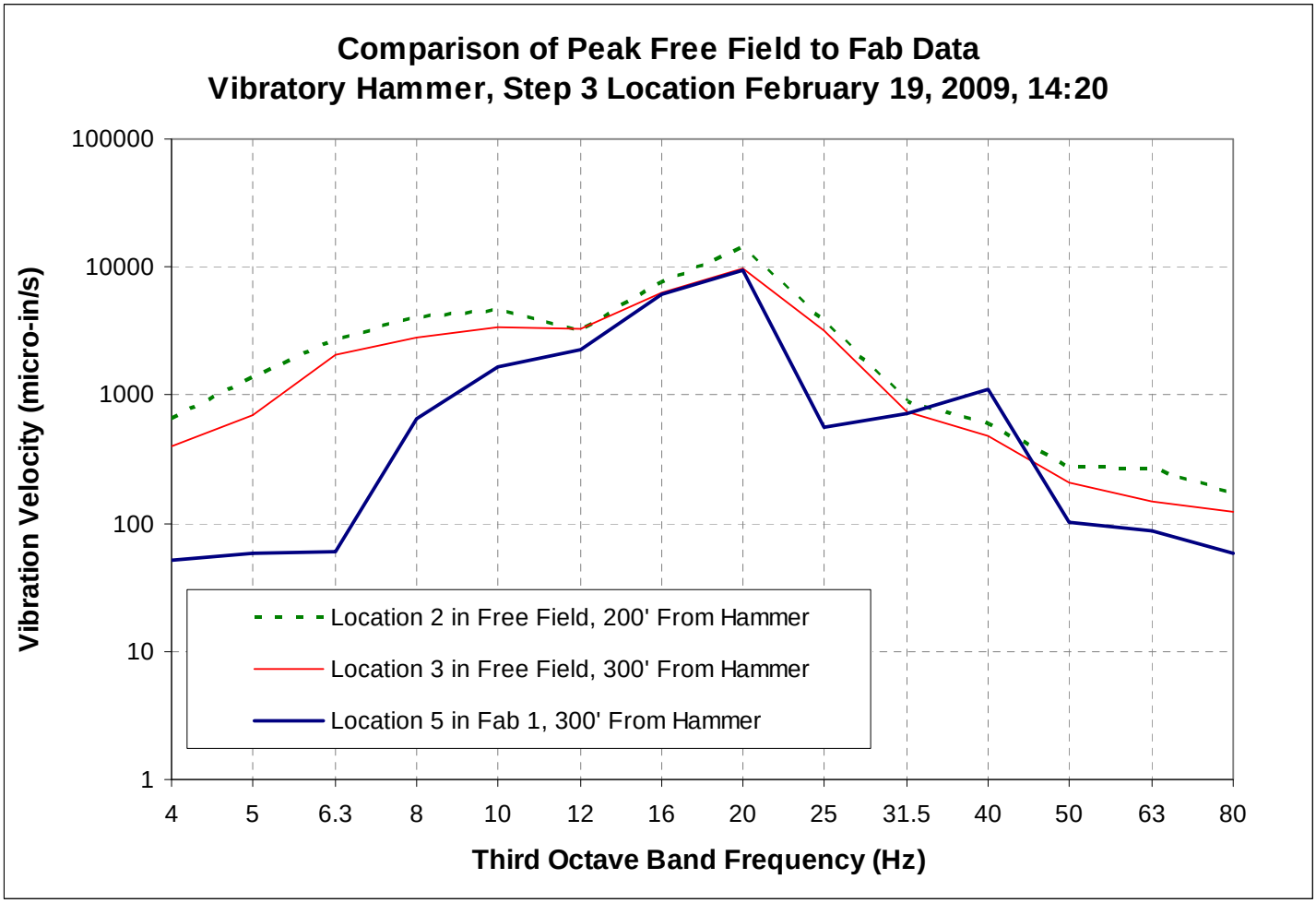


**Figure 6.6**
Comparison of Siltronic Site Peak Free Field Data vs Fab Data, Event 6
Vibration Study Data Report

ANCHOR QEA

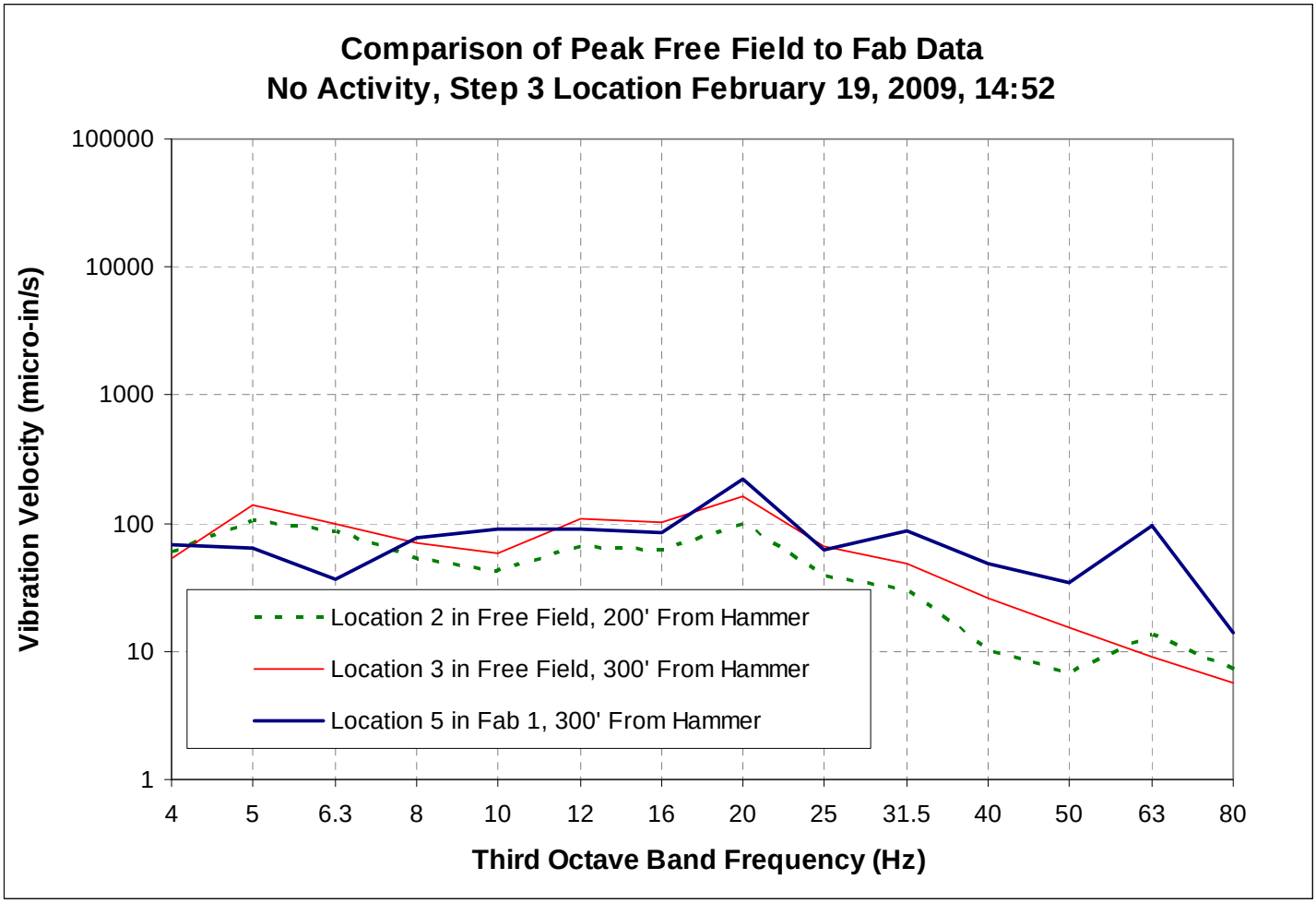


**Figure 6.7**
Comparison of Siltronic Site Peak Free Field Data vs Fab Data, Event 7
Vibration Study Data Report

ANCHOR QEA

# APPENDIX A
# GASCO SILTRONIC CONSTRUCTION VIBRATION STUDY WORK PLAN

# WORK PLAN

# GASCO SILTRONIC CONSTRUCTION VIBRATION STUDY

**Prepared for**

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**Prepared by**

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And

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Niagara Falls, NY 14305

**June 2008**

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**Attachments**

- Figure 1 Vicinity Map
- Figure 2 Vibration Test Location Map
- Siltronic Wafer Test Outline, for Potential Effects from Vibrations (December 6, 2007 revision)
- Siltronic Wafer Test Results Summary (Sample)
- Siltronic Correspondence to NW Natural RE: Wafer Process Monitoring for Vibration Impacts
- Siltronic Test Feedback Schedule
- Construction Equipment Specifications

# 1 INTRODUCTION

## 1.1 Background

The Oregon DEQ has required that NW Natural and Siltronic evaluate alternatives, including construction of a vertical barrier wall, to control migration of MGP-related and VOC contaminants to the Willamette River from the Gasco and Siltronic facilities (the Site). On behalf of NW Natural, Anchor Environmental L.L.C. (Anchor), Colin Gordon and Associates (CGA), Stephen Dickenson, PhD (Dickenson; Oregon State University), and Sevenson Environmental Services, Inc. (Sevenson) prepared this plan to evaluate construction induced vibrations at the Siltronic facility. This plan has been developed in collaboration with Siltronic and has been designed to accommodate Siltronic's production restrictions, process analysis and feedback schedule. The Site Vicinity is shown on Figure 1 (attached). General features of the Gasco and Siltronic properties are shown on Figure 2 (attached).

Siltronic Corporation (Siltronic) manufactures silicon wafers for the semiconductor industry. Siltronic has expressed concerns related to the potential impacts to its operations from vibrations induced by the construction activities associated with pile driving. Siltronic described these concerns, as well as recommended protocols for conducting testing to determine the potential effects of the proposed activities on manufacturing processes in the *Wafer Test Outline, for Potential Effects from Vibrations* (December 6, 2007 revision) and the *Wafer Test Results Summary (Sample)* (attached). Additional details related to Siltronic's specifications for scheduling and sequencing the vibration testing, the "wafer test feedback" schedule and reporting of results are provided in the attached correspondence to NW Natural regarding *Wafer Process Monitoring for Vibration Impacts.*

## 1.2 Objectives

The primary objective of this study is to evaluate concerns expressed by Siltronic about potential impacts to its operations from construction-induced vibrations during fabrication of a groundwater vertical barrier wall. During the field test comprehensive vibration monitoring will occur during all construction activities, including heavy equipment movement, backhoe pre-trenching, sheet pile driving, and pile removal. The primary goals of the construction simulation and ground motion monitoring investigation are two-fold; (1) to develop site-specific relationships for the attenuation of ground motions from the source

of vibrations, and (2) to bracket the anticipated range of ground vibrations that would be generated by various construction techniques. Given the number of available options for groundwater barrier walls, and associated construction methods, it is not considered practicable to evaluate all methods at the site. The monitoring program outlined herein is intended to characterize the range of motions that could be expected during construction options that have been discussed by Anchor Environmental and DEQ. It is anticipated that the ground vibrations generated during the proposed investigation will effectively bracket the range of motions during construction, therefore the findings from the monitoring will be used to quantitatively interpolate the vibrations that would be expected to result from multiple barrier types. The findings of the study will be provided to the Oregon DEQ to assist in its selection of a groundwater DNAPL source control design for the Site.

# 2 APPROACH

## 2.1 Project Organization

Anchor will manage the project and coordinate the implementation of the study with Siltronic. CGA will conduct the vibration monitoring. Dickenson will provide peer review of the study on behalf of Anchor. Sevenson will coordinate and conduct the construction simulation. Siltronic staff will monitor production operations during the study, assist in coordinating the timing of the construction simulations, and provide feedback related to the effect of the construction simulations on production operations.

## 2.2 Project/Task Descriptions

The investigation scope includes a ground vibration monitoring program for both ambient conditions and construction-induced vibrations associated with trenching, installation equipment operation, and sheet pile installation at the Site.

Anchor's tasks include:

- Working with Siltronic to coordinate access and communication during the study period.
- Preparing a communication plan in advance of the investigation.
- Coordinating the work of CGA and Sevenson during the investigation.
- Coordinating information exchange.
- Reviewing interim project reports.

- Preparing a final project report.

CGA's tasks include:

- Implementing the vibration monitoring program for ambient motions.
- Implementing the vibration monitoring program for construction vibrations.
- Developing curves based on the data that is collected that describe vibration attenuation as a function of distance and frequency.
- Processing data and presenting findings and recommendations in interim project reports.
- Assisting in the preparation of a final project report.

Dickenson's tasks include:

- Reviewing the vibration data obtained during the ambient motion study and the construction vibration program.
- Interpreting and evaluating ground motions, and providing recommendations for modifications of the construction procedures, if any.
- Reviewing CGA interim project reports.
- Assisting in the preparation of a final project report.

Sevenson's tasks include:

- Providing the necessary construction equipment and personnel to operate such equipment.
- Carrying out all of the required construction simulation tests over the course of the study period.
- Coordinating the construction simulation tests with CGA.
- Providing logs of the construction simulation activities.
- Ensuring proper handling of investigative waste, primarily soil from the excavations.

Siltronic's tasks include:

- Providing staff to assist with the implementation of the study.
- Providing access to allow implementation of the study.

- Providing scheduled feedback on plant process monitoring during and between the tests.
- Meeting with NW Natural and DEQ after test results have been submitted to explain findings.

### 2.3 Step 1: Monitoring Ambient Vibrations in Siltronic Buildings

CGA will monitor ambient vibrations at selected locations within Siltronic's Fab buildings. Vibration sensors will be placed on ground floor concrete mat foundations, as well as raised access floors if necessary. The duration of the monitoring should be sufficient to record vibration data due to multiple train passages, loading dock operations, local traffic, and normal daily operations taking place within the building. This study will take place prior to the pile driving investigations and is expected to take a minimum of 48 hours and up to five days. Spot measurements of ambient vibration will also be conducted at various locations within the Fab buildings.

### 2.4 Step 2: Evaluation of Ground and Structural Vibrations due to Trenching and Pile Driving at the Northwestern corner of the NW Natural Gasco Facility

It is currently envisioned that three types of pile hammers will be used to assess the ground vibrations due to driving 90-foot long steel sheet piles and to evaluate the effectiveness of these hammers for driving the piles. The hammer models that have been suggested by Sevenson are; the APE 200-6 vibratory driver, APE Model 7.2mT Hydraulic Impact hammer, and APE Model 250V Variable Moment vibratory driver. Equipment specifications are provided as an attachment. The number and type of hammers may be revised based on: local experience with various hammers on Willamette or Columbia riverfront projects in similar soils; vibration data obtained from the vendors, project reports, or technical literature; and/or availability of the equipment.

Trenching and pile driving will be conducted in the northwestern portion of the Gasco site (at a location where 90-foot piles can be driven to full length) in order to insure minimal vibration at the Siltronic facility. The approximate Step 2 pile driving location is shown on Figure 2, and may vary based on further review of Site soil data and judgments made in the field. Two or more piles will be driven with each of the hammers. This testing will include a quantitative assessment of the influence of construction variables (i.e., movement and

operation of equipment, trenching/excavation, hammer type, driving energy, number of piles driven, etc.) on the measured vibrations.

Construction-induced vibrations during equipment movement, trenching, driving and extraction of the sheet piles will be monitored by CGA in two arrays. The first free-field array will include up to 8 accelerometers and extend from a location in close proximity to the installation equipment to the northeastern extent of the GASCO property. The second free-field array will also include up to 8 accelerometers and extend from a location in close proximity to the Fab 2 building on the Siltronic property to the northwestern extent of the Siltronic property. Structural monitoring will also be conducted inside selected Fab buildings with up to 8 accelerometers set up during the Step 1 ambient monitoring.

A trackhoe will be used to excavate a trench from 20 to 30 feet deep at each pile location. The trench is being constructed to remove potential obstructions in the fill that could affect pile driving. Vibration monitoring to be conducted during trenching operations will provide data that will be used to quantitatively estimate the range of vibrations (as a function of distance from the source) that would result from slurry trench construction and other barrier technologies that involve soil excavation.

Vibration monitoring will be conducted during equipment movement, site preparation, trenching, pile driving, and pile removal to determine the magnitude of vibration during these activities. Anchor, CGA, Dickenson and Sevenson believe that, in general, these activities will encompass the range of vibration magnitudes that would result from the full range of potential barrier technologies that have been considered to date.

CGA and Dickenson will use the vibration monitoring data from the field arrays and building arrays to estimate the vibrations that would be experienced at Siltronic from sheet pile construction activities. Using the range of data from the tests, CGA and Dickenson also will be able to quantitatively bracket the likely range of vibration amplitudes that would result from other barrier installation methods, such as slurry wall, or auger/drill related technologies. While the observed vibration frequencies may differ from the frequencies that might be observed when testing other wall construction technologies, it is not cost effective to field test every possible construction method and alternative procedures. Further, Anchor

believes that sheet piles and slurry walls are the two most likely technologies to be employed based on the findings of the Groundwater/DNAPL Focused Feasibility Study (Anchor, 2007).

The free-field arrays will be oriented roughly parallel to the river. For the structural monitoring, it is recommended that vibration data be recorded on floor slabs and possibly on raised access floors. It may be determined that the vibrations measured on the raised access floors correlate most closely with the wafer scanning and process data. The ground motion attenuation relationships will be developed for each of the pile driving hammers employed.

Siltronic personnel will be informed of the trenching and pile driving sequence and alerted if monitoring devices detect vibrations within the Siltronic fabrication facility exceeding an initial "warning" level of 20% above the maximum RMS value measured in Step 1. If the warning level is exceeded, Siltronic will visually inspect its tools and processes as described in the attached Siltronic plans (December, 2007 Wafer Test Outline and February, 2008 Wafer Process Monitoring) and report any catastrophic tool or process failure to NW Natural immediately. The warning level may be adjusted by NW Natural and Siltronic during the course of Step 2

### 2.5 Step 3: Evaluation of Ground and Structural Vibrations due to Pile Driving at the Northeastern corner of the NW Natural Gasco Facility

On the basis of the Step 2 investigation, the project team will determine the actual number of tests to be done at the northeastern corner of the NW Natural Gasco facility. For example, this may include selection of one pile driving hammer that best satisfies both vibration control and driving efficiency criteria tested at one location, but other permutations are possible based on the results of Step 2. Between one and four two-hour tests will be performed as part of the Step 3 evaluation according to the schedule provided in Section 4. The first test may include trenching and installation of piles using the selected combination of construction equipment and techniques shown to minimize vibration impacts during the quantitative assessment in Step 2. Depending on the results of the first test, the second test may include removal of the same piles installed during the first test.

The pile driving equipment will be mobilized to the northeastern corner of the NW Natural Gasco facility at a location that corresponds to the closest distance from the proposed sheet pile wall to the Fab buildings. Based on recent feedback from DEQ, the wall will potentially extend along the NW Natural Gasco shoreline to the northeastern corner of the NW Natural Gasco property line and will not extend onto the Siltronic property. The approximate Step 3 pile driving location is shown on Figure 2. Construction-induced vibrations will be monitored with the first and second free-field arrays, as well as one structural array. The measured vibration data will be used to establish attenuation relationships across the Siltronic site, and the soil-structure transfer functions (peak motion, rms, and spectral ratios).

Siltronic will observe and test its manufacturing operations, and report the results of those observations and tests as described in the attached Siltronic plans (December, 2007 Wafer Test Outline and February, 2008 Wafer Process Monitoring). Depending upon the results of these operations and tests, the trenching and pile driving sequence may include adjustments in the driving energy, number of sheet piles driven, and/or other construction-related variables. Alternatively, a standoff distance may be estimated using the results of the free-field array data obtained concurrently. The need for additional trenching/pile driving and testing at a third location would constitute Step 4.

### 2.6 Step 4: Evaluation of Ground and Structural Vibrations due to Pile Driving at a Specified Stand-off Distance

If additional testing is required, the stand-off distance will be specified on the basis of the site-specific, free-field attenuation relationships, judgment, and a possible buffer for an additional margin of safety. The trenching and driving sequence performed in Step 3 will be repeated at the new location. The trenching and pile driving location will be located between the Step 2 and Step 3 locations. The final location may be determined by access restrictions, vibration amplitudes and the required stand-off distance, or other project variables. Again, the measured vibration data will be used to establish attenuation relationships across the Siltronic site, and the soil-structure transfer functions (peak motion, rms, and spectral ratios).

## 3 REPORTING

The vibration data obtained from the study will be reviewed by both CGA and Dickenson. The results of the review and evaluation of the project findings will be reported to Anchor in the form of verbal and e-mail correspondence and interim project reports. Siltronic will provide the results of its process monitoring to NW Natural for inclusion in the report. A draft report will be submitted to Siltronic for review. The report will then be submitted to DEQ. The version submitted to DEQ may have some information redacted to remove material designated by Siltronic as confidential business information.

## 4 PROJECT SCHEDULE

The project schedule is dependent on review and approval of the Vibration Study Work Plan by DEQ and negotiation of an access agreement between NW Natural and Siltronic. In addition, the project schedule is highly dependent on the availability of equipment with which to conduct the construction vibration simulations. Because of the uncertainty of equipment availability, the project schedule cannot be tied to a fixed date at this time. For planning purposes, the expected sequence and duration of the project activities is provided below. The actual testing times and days may vary from those described in the following steps, however NW Natural representatives will maintain close communication with Siltronic personnel regarding schedule changes.

**Week 1 (Step 1)**

- CGA will deploy monitoring equipment at the beginning of the week to measure ambient vibrations in Siltronic buildings before construction activities begin. The same equipment will be left in place and used to monitor vibrations during the construction simulations.
- Sevenson will mobilize the pile driving equipment to the Gasco site over the weekend between Week 1 and Week 2.

**Week 2 (Step 2)**

- Monday: Sevenson will prepare the testing site and set up the equipment. CGA will set up a free-field array extending from a location in close proximity to the pile driving equipment toward the Siltronic property and parallel to the river. CGA will also set up a second free-field array extending from a location on the Siltronic property toward the Gasco property and

parallel to the river. The final layout of the monitoring equipment will not be decided until CGA and Siltronic have conferred on access issues.

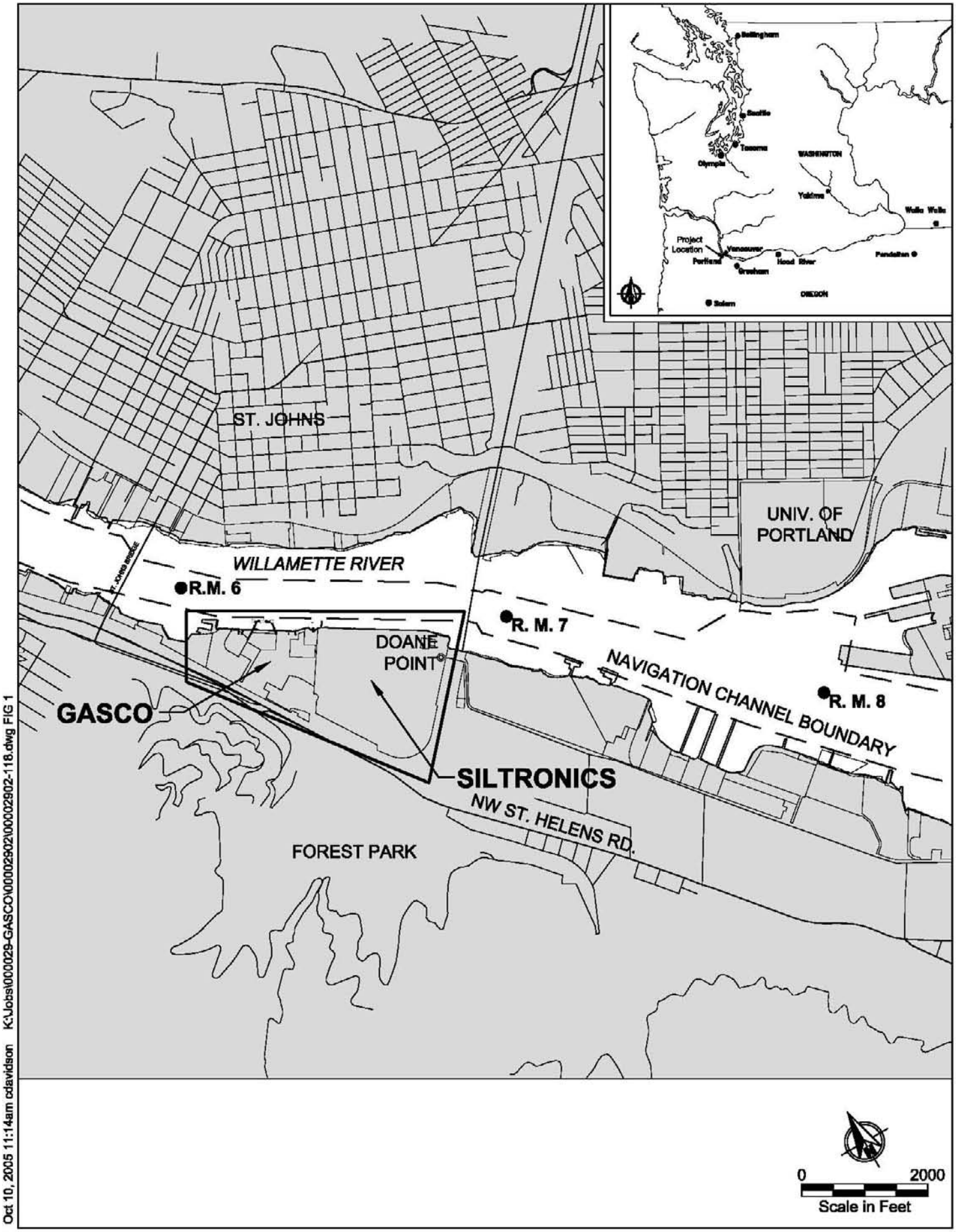
- Tuesday: Sevenson will conduct construction simulations using the first of three types of pile driving equipment. During construction simulations at the Step 2 location, Siltronic staff will provide feedback as described in Section 2.4.
- Wednesday: Sevenson will conduct construction simulations using the second type of pile driving equipment.
- Thursday: Sevenson will conduct construction simulations using the third type of pile driving equipment.
- Friday: Sevenson will break down equipment and prepare to mobilize to the Step 3 location at the northeastern corner of the NW Natural Gasco property.
- Weekend: Sevenson will move equipment to the Step 3 location and begin staging and setting up the equipment.

**Week 3 (Steps 3 and Step 4, all times approximate)**

- Monday Step 3: Sevenson will finish staging and setting up the selected equipment at the Step 3 location.
- Tuesday Step 3: Sevenson will conduct construction simulations from 10:00 AM to 12:00 PM. During construction simulations at the Step 3 location, Siltronic staff will provide feedback during the construction simulations, which will be suspended if requested by Siltronic based upon a catastrophic tool or process failure as described in the attached Siltronic plans (December, 2007 Wafer Test Outline and February, 2008 Wafer Process Monitoring). Depending on the feedback from Siltronic, a second simulation will be conducted from 2:00 PM to 4:00 PM at the same location.
- Wednesday Step 3: Depending on the outcome of the first and second tests, Sevenson will conduct additional construction simulations at the same location from 10:00 AM to 12:00 PM and potentially from 2:00 PM to 4:00 PM. Siltronic will provide feedback during and between the tests. NW Natural and its contractors will confer on the results of the Step 3 tests and then meet with Siltronic to discuss the findings. The need for further testing at a Step 4 location will be discussed.
- Thursday contingency Step 4: Depending upon the findings from Step 3, Sevenson may conduct additional tests at a Step 4 stand-off location. Sevenson will break down and move to the stand-off location and prepare for testing on Friday.

- Friday contingency Step 4: Sevenson will conduct additional construction simulations at the stand-off location from 10 AM to 12 PM. Siltronic would monitor and provide feedback as done during Step 3. A second simulation may be conducted from 2 PM to 4 PM. Sevenson will begin breaking down equipment after the simulation is completed.
- Saturday: Sevenson will continue breaking down construction simulation equipment and demobilize.

# ATTACHMENTS




Oct 10, 2005 11:14am cdavidson K:\Jobs\000029-GASCO\00002902\00002902-118.dwg FIG 1

ANCHOR ENVIRONMENTAL, L.L.C.

**Figure 1**
Vicinity Map
Gasco and Siltronics Site

J:\Jobs\000029-02_Gasco\Maps\2008_04\FIG_2_location_map.mxd pr_l 04/24/2008 7:32 PM

ANCHOR ENVIRONMENTAL, L.L.C.

0 200
Scale in Feet
1 inch equals 200 feet

**Attorney Client Privileged and Confidential**
**Work Product Prepared in Anticipation of Litigation**

**Figure 2**
Location Map
NW Natural - Gasco Site
Portland, Oregon

Dr Larry Buzan
Dir. Engineering and Dir. Technology

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Revised December 6, 2007

# WAFER TEST OUTLINE FOR POTENTIAL EFFECTS FROM VIBRATION

## Overview

Siltronic Corporation manufactures silicon wafers for the semiconductor industry, and must meet our customer's expectations for product capability and quality. Our customers use Siltronic wafers to produce microelectronic devices with line widths as small as 90nm. Wafer geometry and surface contamination are tightly controlled and measured during wafer manufacturing. Our customers require that our wafers are not only within specifications, but also that each lot of wafers produced is not statistically different from previous lots. Siltronic has reached the following conclusions concerning a test for potential effects from vibration caused by the proposed construction activities:

- A two hour test for each pile or boring event is required to achieve a reasonable level of confidence.
- The confidence level that will be applied to the Laser Light Scattering (LLS), Nanotopography data analysis, Epitaxy thickness measurement, and cleanroom particle counts is 95%.
- For other critical yield and capability parameters we will analyze data from lots processed during each testing period to detect any shift from our baseline yield or capability.

## Siltronic's Major Process Concerns

Process tests involving many of the same parameters as proposed herein were conducted in Singapore at a Siltronic facility constructed on similar fill soil, with documented vibration impacts from pile driving activities within 100 meters of an operating FAB. Pile activities within 100 meters required drilling. Concerns about the proposed construction activities along the Siltronic riverfront and adjacent property are therefore well founded. Those construction activities may affect a variety of manufacturing processes that require a stable platform to maintain wafer geometry and metrology.

- The proposed activities may cause an increase in airborne particles in cleanrooms or tool environments.
- The proposed activities may affect inspection equipment that employs Laser Light Scattering to scan wafers for surface nanotopography and surface contamination, causing statistical shifts in the measurements of these parameters.
- The proposed activities may affect Scanning Electron Microscope (SEM) operation in our analytical laboratory.
- Testing to determine potential effects of the proposed activities must include key wafer parameters at potentially sensitive process steps, statistical control of laser inspection equipment, and interference with SEM analytical measurements.

**Summary of Wafer Test Methodology**
Both Fab 1 and Fab 2 have completed an initial assessment of test requirements for vibration testing and are preparing formal Process Test Notices (PTNs) for testing at each Fab. These PTNs and the test methodology proposed below only address the possible effects upon wafers during the proposed testing periods. Additional coordination is required between Siltronic, Northwest Natural, and their consultants to develop a strategy for the actual pile or boring tests to best determine which construction methods are least likely to affect Siltronic processes. This strategy would include the locations and the methods of pile insertion (i.e., driving, vibration, boring, or other). The wafer test data procedures described herein will be repeated for each active test event, as required by the test strategy

Test Duration
Siltronic has determined that a 2 hour test for each pile or boring event is required to achieve a reasonable level of confidence.

Confidence Level
The confidence level that will be applied to the LLS and Nanotopography data analysis (continuous measurement mode) is 95%. The same confidence level will be applied to Epitaxy thickness measurement tools and to particle monitoring in the cleanrooms.

For other critical yield and capability parameters at various process steps listed below a different approach is necessary. For these data the sample size from a 2 hour test is insufficient for 95% statistical confidence in most cases. For these parameters we will analyze data from lots processed during each testing period to detect a shift from our baseline yield or capability, which is defined as the historical yield or capability for each process for the period from June 1 through Aug. 31, 2007. Tolerance levels for baseline shifts during the test will be based on the historical defect rates for 97.7% of lots produced, plus 25% of the difference in defect rates for 97.7% and 99.8% of lots produced. Due to limited sample size during the testing it will not be possible to say with 95% confidence that vibration is the actual cause of a shift from the baseline. However, Siltronic will evaluate any lots with losses above the tolerance levels to determine if other causes may be present.

**Methodology for LLS, Nanotopography, and Epitaxy layer thickness tools**
A statistical analysis will be employed to detect significant changes in means or standard deviations from paired tests. The detectable difference that will be used for statistical testing has been determined by Siltronic in a pilot test of representative measurement tools.

During active testing selected LLS, Nanotopography, and Epitaxy thickness tools will be placed in a continuous measurement mode using standard test wafers. All other measurement equipment will be processing normal production material during the active testing. The selected tools will include

the following:

- FAB 1 Final Cleaning – Two LLS tools, one to monitor Light Point Defects (LPDs) and one to monitor Light Channel Defects (LCDs).
- FAB 1 Epitaxy – One LLS tool to monitor LPDs in the following modes: Dark, Narrow Field, Normal Angle (DNN); Dark, Wide Field, Normal Angle (DWN); and Dark, Composite Field, Normal Angle (DCN).
- Fab 1 Epitaxy – One epitaxy layer thickness measurement tool.
- FAB 2 Final Cleaning - Three LLS tools to monitor LPDs in the following modes: one to monitor in DNN, DWN, and DCN modes; one to monitor in Dark Composite Field, Oblique Angle (DCO) mode, and one to monitor in Bright Field – Differential Field Contrast (DIC) mode.
- Fab 2 Final Cleaning – Two LLS tools, one to monitor LPDs and one to monitor LCDs.
- FAB 2 Final Cleaning – One nano-tool to monitor for Nanotopography
- Fab 2 Epitaxy – Two epitaxy layer thickness measurement tools.

One set of pre-test data will be collected for each selected tool prior to active vibration testing. Additional data sets will be collected from each selected tool during each period of active vibration testing. Differences in the Means of distribution between the pre-test and test data sets will be evaluated using traditional "t-Test" methodology. Differences in the Standard Deviations between the pre-test and test data will be evaluated using traditional "f-Test" methodology. A 95% confidence level will be applied to the analysis

**Methodology for Cleanroom Particle monitoring**

A statistical analysis will be employed to detect significant changes in means or standard deviation from paired tests as follows:

- Airborne particles are continuously sampled in Siltronic cleanrooms. Areas of interest during the test are Fab 1 Final Cleaning, Epitaxy, and Furnace Center; Fab 2 Final Cleaning, Epitaxy, Furnace Center, and Wax Mounting.
- Pre-test data will consist of particle data for the two-hour period prior to active vibration testing.
- Test data will be collected from each of the selected cleanroom monitors during each period of active vibration testing.
- Differences in the Means of distribution between the pre-test and test data sets will be evaluated using traditional "t-Test" methodology. Differences in the Standard Deviations between the pre-test and test data will be evaluated using traditional "f-Test" methodology.
- A 95% confidence level will be applied to the analysis

**GRC Methodology for Yield and Capability analysis at other process steps**
A gross reality check (GRC) is typically used to detect gross problems and is often used if only a very small sample is available, e.g. because of expensive measurements, destructive methods, or measurements that require much time. A GRC is a sample of process performance that is then compared against existing baselines.

Using the GRC method, Siltronic will compare the yield or capability from normal production lots processed during each test period with the baseline yield or capability for similar materials. Tolerance levels for changes in each of the parameters listed below have been selected by analyzing the historical capability for each process for the period from June 1 through Aug. 31, 2007. Tolerance levels have been selected based on the defect rates for 97.7% of lots produced, plus 25% of the difference in defect rates for 97.7% and 99.8% of lots produced. Production lots that exceed the selected tolerance from baseline yield or capability will be evaluated to determine if the cause may be from vibration or from other identifiable causes.

In the proposed test a GRC will be applied to the following yield and capability parameters:

Multi-Wire Sawing
- Potential Effects - Wire movement during slicing or catastrophic wire break
- Parameters – Warp, Total Thickness Variation (TTV), Sawmarks

Edge Grinding
- Potential Effects – Edge quality
- Parameters – Chips, Sparkle

Lapping
- Potential Effects – Loss of slurry film during lapping
- Parameters – Scratches

Backside Deposition (Poly Silicon; LTO: APCVD, LPCVD, PECVD)
- Potential Effects – Particle contamination (airborne or in-tool)
- Parameters – Pinholes, Dimples

Geometry Sorting
- Potential Effects – Measurement Stability
- Parameters – Thickness, Resistivity

Wax Mounting
- Potential Effects – Particle contamination (airborne or in-tool)
- Parameters – Dimples

Polishing
- Potential Effects – Final Polisher cylinder vibration
- Parameters – LLS

Polishing Geometry Measurement
- Potential Effects – Measurement Stability
- Parameters – Thickness, GBIR, GFLR, STIR

Final Cleaning and Inspection
- Potential Effects – Airborne Particles
- Parameters – LLS, airborne particle counters

Automatic Inspection, Laser
- Potential Effects – Measurement Stability (lasers, lenses, & mirrors)
- Parameters – LLS, Nanotopography

Epitaxy
- Potential Effects – Airborne Particles
- Parameters – Spikes, LLS

Laser Marking
- Potential Effects – Stability of laser, lenses, & mirrors
- Parameters – Dot depth, readability of marked wafer

Spreading Resistance Profile (SRP)
- Potential Effects – Measurement stability
- Parameters – Dopant profile of epitaxial layer (concentration and thickness)

Analytical Laboratory
- Potential Effects – SEM stability
- Parameters – Distortion of images

**Vibration monitoring**

Colin Gordon & Associates will place accelerometers near the base mounting of the selected LLS and Nanaotopography tools, plus at least two other locations in Fab 1 and Fab 2. Baseline vibration data will be collected prior to active vibration testing. Baseline vibration data will be compared to the peak and average vibration levels recorded during each active test period, within the range 0 - 100 Hz. The exact level of vibration and frequencies that may affect wafer processes and wafer measurements is unknown. Vibration data may be useful for correlating wafer test data with vibration data and may be useful for establishing warning levels for vibration during the future construction phase.

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December 6, 2007

# WAFER TEST RESULTS SUMMARY (SAMPLE)

This document presents a sample report of wafer test analyses utilizing the protocols described in Siltronic's "Wafer Test Outline For Potential Effects From Vibration," along with sample conclusions and potential business impacts, resulting from a hypothetical vibration test. The intent of this example is to illustrate the general format that will be used in presenting the test results. It does not include all parameters of interest and does not represent actual or expected results or business impacts. Results are expressed as the amount of shift in mean values, standard deviation (sigma), or percent change from historical baseline yield losses or capability. Actual measured test values and Siltronic baseline values are not included in the presentation of test results. Actual measured values and baseline values compiled in Siltronic's Process Test Notices (PTNs) are considered to be *"Trade secrets,"* since they contain production data, which is known only to certain individuals within Siltronic, are used in the design and implementation of Siltronic's production processes, affect the way Siltronic conducts and negotiates its business relationships, and give Siltronic the opportunity to obtain a business advantage over competitors who do not know and therefore cannot use this information.

## Hypothetical Summary of Results and Impacts

Two pile driving tests were conducted on [dates] by Colin Gordon & Associates (CGA) on behalf of NW Natural: one at location "X" and one at location "Y". The methodologies and parameters of those vibration tests are detailed in a separate report prepared by CGA. The test at location "X" had significant impact on Siltronic operations. The test at Location "Y" had no detectable impact. While no significant impacts were detected during the test at location "Y" this test does not rule out the potential for possible impacts during actual construction activities. As explained below, and in Siltronic's Wafer Test Outline, these results are based on statistical analyses that include certain levels of confidence.

The duration of each test was two hours. During each test specific tools for measuring Laser Light Scattering (LLS), Nanotopography, and Epitaxy thickness, were placed in continuous monitoring mode using standard wafers. Particle contamination in cleanrooms was also monitored continuously. These data were analyzed for statistically significant shifts in mean or standard deviation values. A 95% confidence level was applied to the analysis.

Other critical yield and capability parameters were monitored on normal production wafers in process during the test periods. Data from these wafers were analyzed for shifts from baseline yield or capability, which is defined as the historical yield or capability for each process for the period from June 1 through Aug. 31, 2007. Tolerance levels for baseline shifts during the test were based on the historical defect rates for 97.7% of lots produced, plus 25% of the difference in defect rates for 97.7% and 99.8% of lots produced. This analysis is called a gross reality check (GRC), since sample sizes were not large enough to apply a statistical confidence to the results.

Driven Pile Test at Location "X" – Significant changes were detected during this test.

- LLS measurements were significantly affected in two of Siltronic's manufacturing areas located nearest to the pile driving activities. Detected shifts in mean and sigma values for particle measurements indicate, with 95% confidence, that pile driving at this location would produce unreliable LLS measurements. The inability to certify product specifications and production lot uniformity would prevent product shipment to customers and curtail production processes that rely on these measurement tools. Continuous generation of vibrations induced during this test period would result in significant impacts to Siltronic's business, including curtailment of production in these production areas and lost revenue of approximately $10 million per month.
- Defects at the wafer edge grinding process increased by 2.1% over historical baseline. Continuous generation of vibrations induced during this test period would be expected to result in business impacts of approximately $64,000 per month.
- Detailed results from the test at location "X" are shown in tables presented in the following section of this report.

Driven Pile Test at Location "Y" – No significant changes detected during this test.

- Wafer test results from the test at location "Y" are therefore not presented in detail.

**Laser Light Scattering (LLS) Measurement Tools in Continuous Scan of Test Wafers**

The data presented are for two types of LLS tools, and show the shifts in mean values (t-test) and shifts in sigma (f-test) on standard wafers during driven pile test at location "X" on Siltronic property. The sample test results for the second tool type (LLS 3-1 and 3-2) are for Dark-Wide-Normal (DWN) mode only. Actual test results may include other laser measurement modes including Dark-Narrow-Normal (DNN), Dark Composite-Normal (DCN), Dark-Composite-Oblique (DCO), and Bright Field – Differential Contrast where appropriate (DIC).

| LLS Tool | | LPDs (Light Point Defects) Grouped by Particle Size (change in number of counts / wafer) | | | | | | | | | LCD (Light Channel Defects) | Significant at 95% Confidence, P<.05 (Y/N) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | >0.12µm | >0.13µm | >0.15µm | >0.16µm | >0.17µm | >0.18µm | >0.2µm | >0.3µm | >0.7µm | | |
| LLS 1-1 | Mean Shift | 3.2 | 3.4 | 2.9 | 3.9 | 3.5 | 2.0 | 1.9 | 2.0 | 1.1 | NA | Y |
| | Sigma Shift | 8.8 | 9.5 | 7.8 | 8.0 | 9.1 | 7.9 | 7.0 | 7.5 | 4.0 | NA | Y |
| LLS 1-2 | Mean Shift | NA | NA | NA | NA | NA | NA | NA | NA | NA | 1.4 | Y |
| | Sigma Shift | NA | NA | NA | NA | NA | NA | NA | NA | NA | 1.0 | Y |
| LLS 2-2 | Mean Shift | 1.7 | 1.6 | 1.5 | 1.4 | 1.7 | 1.3 | 1.0 | 0.9 | 0.8 | NA | N |
| | Sigma Shift | 1.1 | 1.2 | 0.9 | 1.0 | 1.1 | 1.4 | 1.1 | 0.9 | 0.6 | NA | N |
| LLS 2-2 | Mean Shift | NA | NA | NA | NA | NA | NA | NA | NA | NA | 0.1 | N |
| | Sigma Shift | NA | NA | NA | NA | NA | NA | NA | NA | NA | 0.2 | N |

| LLS Tool | | LPDs (Light Point Defects) Grouped by Particle Size (change in number of counts / wafer) | | | | | | | | Significant at 95% Confidence, P<.05 (Y/N) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | >0.12µm | >0.13µm | >0.15µm | >0.16µm | >0.17µm | >0.18µm | >0.2µm | >0.3µm | |
| LLS 3-1 DWN Mode | Mean Shift | 4.1 | 5.0 | 3.0 | 6.1 | 5.5 | 3.6 | 3.4 | 3.0 | Y |
| | Sigma Shift | 8.5 | 5.4 | 6.6 | 6.7 | 6.9 | 7.5 | 9.0 | 9.9 | Y |
| LLS 3-2 DWN Mode | Mean Shift | 1.1 | 1.3 | 0.6 | 0.6 | 0.6 | 0.8 | 1.2 | 1.3 | N |
| | Sigma Shift | 0.6 | 0.1 | 0.3 | 0.3 | 0.2 | 0.4 | 0.7 | 0.8 | N |

Potential Business Impact from shift in LLS measurements: Approximately $10 million lost revenue per month due to inability to ship wafers from the affected manufacturing facility.

**Nanotopography Measurement Tools in Continuous Scan of Test Wafers**
The data presented are shifts in mean values (t-test) and shifts in sigma (f-test) on standard wafers during driven pile test at location "X" on Siltronic property.

| Measurement Tool | Nanotopography Data (% deviation from target during test) | | | Significant at 95% Confidence, P<.05 (Y/N) |
|---|---|---|---|---|
| | | 2 X 2 sites | 10 X 10 sites | |
| Nano 2-1 | Mean Shift | 0.400 | 2.400 | N |
| | Sigma Shift | 1.500 | 2.250 | N |

**Epitaxy Thickness Measurement Tools in Continuous Scan of Test Wafers**
The data presented are shifts in mean values (t-test) and shifts in sigma (f-test) on standard wafers during driven pile test at location "X" on Siltronic property.

| Measurement Tool | Epitaxy Thickness Measurement Changes in Capability | | Significant at 95% Confidence, P<.05 (Y/N) | Business Impact |
|---|---|---|---|---|
| Thickness Guage 1-1 | Mean shift | 0.000010 | N | None expected |
| | Sigma shift | 0.000005 | N | None expected |
| Thickness Guage 2-1 | Mean shift | No Change | N | |
| | Sigma shift | No Change | N | |
| Thickness Guage 2-2 | Mean shift | No Change | N | |
| | Sigma shift | No Change | N | |

**Cleanroom Particle Monitoring**

The data presented are shifts in mean values (t-test) and shifts in sigma (f-test) for number of airborne particle counts in cleanroom air during driven pile test at location “X” on Siltronic property.

| Cleanroom | Particles per Cu. ft. of Air Changes in Capability | | Significant at 95% Confidence, P<.05 (Y/N) | Business Impact |
|---|---|---|---|---|
| Area 1-1 | Mean shift | No Change | N | |
| Class 10 | Sigma shift | No Change | N | |
| Area 1-2 | Mean shift | No Change | N | |
| Class 10 | Sigma shift | No Change | N | |
| Area 1-3 | Mean shift | No Change | N | |
| Class 1,000 | Sigma shift | No Change | N | |
| Area 2-1 | Mean shift | No Change | N | |
| Class 10 | Sigma shift | No Change | N | |
| Area 2-2 | Mean shift | No Change | N | |
| Class 10 | Sigma shift | No Change | N | |
| Area 2-3 | Mean shift | No Change | N | |
| Class 10 | Sigma shift | No Change | N | |
| Area 2-4 | Mean shift | No Change | N | |
| Class 1,000 | Sigma shift | No Change | N | |

**GRC Test for Process Yield Losses**

The data presented are changes from baseline yield losses for lots processed during driven pile test at location "X" on Siltronic property. Tolerance / significance levels were determined by analyzing defect rates for the period from June 1 through Aug. 31, 2007 for 97.7% to 99.8% of all lots produced.

| Parameter | % Increase From Baseline Yield | Significant (Y/N) | Business Impact |
|---|---|---|---|
| Multi-Wire Sawing | | | |
| Warp | Within Baseline | N | |
| TTV | Within Baseline | N | |
| Sawmarks | 0.50% | N | None. Increase, not related to test |
| Broken | Within Baseline | N | |
| Chips | Within Baseline | N | |
| Wafer Shaping | | | |
| Broken | Within Baseline | N | |
| Chips/Edge Sparkle | 2.10% | Y | $63,518 per month yield loss, plus additional inspection costs to protect customers |
| Sparkle | Within Baseline | N | |
| Scratches | Within Baseline | N | |
| Backside Deposition | | | |
| Pinholes | Within Baseline | N | |
| Dimples | Within Baseline | N | |
| Wax Mounting / Polishing | | | |
| Dimples | Within Baseline | N | |
| LLS | Within Baseline | N | |
| Geometry | Within Baseline | N | |
| Laser Marking | | | |
| Readability | Within Baseline | N | |
| Epitaxy | | | |
| LLS | Within Baseline | N | |
| Spikes | Within Baseline | N | |

**GRC Test for Process Capability Changes**
Changes from baseline capability for lots processed during driven pile test at location "X" on Siltronic property. Tolerance / significance capability levels were determined by analyzing measurements of the listed wafer parameters, by lot, for the period from June 1 through Aug. 31, 2007 for 97.7% to 99.8% of all lots produced.

| Parameter | % Change From Baseline Capability | Significant (Y/N) | Business Impact |
|---|---|---|---|
| **Multi-Wire Sawing** | | | |
| Warp | Within Baseline | N | |
| **Wafer Shaping** | | | |
| Thickness | Within Baseline | N | |
| Warp | Within Baseline | N | |
| **Wax Mounting / Polishing** | | | |
| Thickness | Within Baseline | N | |
| LLS | Within Baseline | N | |
| Geometry (STIR, GBIR) | Within Baseline | N | |
| **Laser Marking** | | | |
| Dot Depth | Within Baseline | N | |
| **Laboratory** | | | |
| SRP (Spreading Resistance Probe) | Within Baseline | N | |
| SEM (Scanning Electron Microscope) | Within Baseline | N | |
| **Epitaxy** | | | |
| Resistivity | Within Baseline | N | |

## Conclusions

During pile driving activities at test location "X" the resulting vibration levels induced by the test resulted in two unacceptable consequences for Siltronic. The most significant consequence was significant shifts in mean and standard deviation values for LLS tools in two of Siltronic's manufacturing areas that measure particles on the surface of the finished wafer. This shift in particle counts was not due to an actual increase in particles, but rather to instability of the measurement tool due to vibration. The resulting inability to certify product specifications and production lot uniformity would prevent product shipment to customers and curtail production processes that rely on these measurement tools. Continuous generation of vibration levels induced during this test period would result in significant impacts to Siltronic's business, including curtailment of production in these production areas and lost revenue of approximately $10 million per month.

A second consequence of the test at location "X" was a 2.1% increase in wafer edge grinding defects over historical baseline. The financial impact from these losses is estimated at $64,000 per month.

During pile driving activities at location “Y” no significant changes were detected in measurement capability, baseline yield losses, or baseline capability of key parameters. While no significant impacts were detected during the test at location “Y” this test does not rule out the potential for possible impacts during actual construction activities. As explained previously, and in Siltronic’s Wafer Test Outline, these results are based on statistical analyses that include certain levels of confidence.

In the event that construction activities are allowed to proceed in the future, Siltronic will require the following:

- Construction activities (of a type to be determined) cannot be conducted closer than location “Y” to Siltronic production facilities.
- Construction methods for pile insertion cannot vary from those used during testing.
- Installation of vibration monitoring instruments near LLS measurement tools in Fab 1 and Fab 2. Continuous monitoring and data collection from these instruments during construction.
- Siltronic engineers and NWN consultants will meet weekly to review vibration monitoring data.
- If vibration levels exceed 80% of those measured during testing at location “Y” Siltronic engineers will notify NWN and their consultants and will evaluate Siltronic processes and products for possible impacts.
- If at any time during construction vibration levels exceed those measured during testing at location “Y” Siltronic engineers will immediately notify NWN and their consultant, who will halt construction activities. Both parties will access the data and determine how best to proceed.

siltronic
perfect silicon solutions

**Thomas C. McCue**
Environmental Affairs Manager

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2008-02-07

Mr. Robert J. Wyatt
NW Natural
220 NW 2nd Avenue
Portland, OR 97068

RE: Wafer Process Monitoring for Vibration Impacts

Dear Bob,

This letter is in response to the questions posed during our February 5, 2008 vibration study coordination meeting. It is intended to outline the requested schedule as to the time needed for Siltronic to analyze wafer test data and provide feedback to NW Natural's consultants and equipment operators about likely impacts to Siltronic's measurement and production processes.

Siltronic will generally employ the methodology outlined in the December 6, 2007, document titled "Wafer Test Outline for Potential Effects From Vibration" to determine whether pile-driving trials have any such adverse impacts and, if need be, to quantify those impacts. However, to ensure our ability to provide immediate feedback regarding catastrophic process disruptions, we will need to deploy several process engineers at various production stations during each vibration test trial. Such active real-time monitoring will occur at a subset of measurement and productions stations that have been pre-selected based on engineering judgment as the most likely areas to be adversely affected by pile-induced vibrations. More subtle impacts will require data analysis as outlined in the schedule presented below.

During the February 5 meeting, NW Natural's consultants provided a general description comprising three stages of vibration tests. It is our understanding that NW Natural's consultants will prepare a detailed vibration test plan that takes into consideration the data analysis and feedback schedule projected by Siltronic in this letter. The three stages that will be described in NW Naturals vibration test plan, as outlined verbally during the meeting, are as follows:

1. Ambient vibration measurements will be collected at mutually-selected locations in Siltronic's wafer process areas during a one week period.
2. At least three types of pile driving equipment will be used to install piles at a point near the north end of GASCO property. Accelerometers will be placed at several locations between the pile driving equipment and Siltronic's manufacturing areas, both inside and outside of the Siltronic facilities, to determine vibration attenuation with distance and to select the best

equipment for further testing as potentially suitable for barrier wall construction. Siltronic will monitor its measurement and production processes for potential impacts. This stage is anticipated to last about a week.

3. The equipment selected during stage 2 will be used to drive piles on the Siltronic site at a location close to the likely alignment of a barrier wall. Testing will include pre-piling excavation to a depth of 20 or more feet, heavy equipment movement near wafer manufacturing buildings, and pile driving activities. Accelerometers will be appropriately placed, both inside and outside of Siltronic's facility, and Siltronic will monitor potential adverse effects using its wafer test methodologies.
4. Potential additional testing will be discussed and implemented, if needed.

Siltronic expects that it will have an opportunity to review and comment on NW Natural's proposed vibration test plan in advance of its submittal to DEQ, and to ensure that any confidential business information included in the draft is removed from the version submitted to DEQ.

Wafer Test Scheduling Requirements

Siltronic will need two hours of setup time before the start of each test trial and a minimum of two hours between each test trial to collect data and evaluate gross impacts on wafer processing. We believe this schedule can accommodate up to two tests in an eight hour period from Monday through Friday under optimum conditions. During the two hours before each test, however, it is essential that there not be measurable vibrations above ambient levels from the outside construction activities. Accordingly, if vibrating a test pile out of the ground after the test trial might exceed ambient vibration levels, then pile removal would serve as a separate trial.

Data Collection

Any catastrophic tool or process failures that could be the result of the vibration test will be reported immediately in real time. A paired T-test and F-test statistical analysis for some of the measurement tools can be prepared within 1 hour of completion of each test trial. This procedure is expected to be our most sensitive measure for vibration impacts. If there is a significant change detected, this information can be relayed immediately after analysis and before the start of the next test trial. The cursory gross reality check ("GRC") of SPC for potentially affected measurement tools can be evaluated during each test trial, and can be reported once it is determined to be the result of the vibration test. The yield loss "GRC" triggers are limited by the cycle time in the fab and can be relayed as they become available. These trigger feedback times can range from 2 hours after the test trial to as much as 7 days. We expect to have 50% of the information within 1 day, 95% of the information within 3 days and 100% within 7 days. An additional one week period will be needed at the completion of tests to compile and summarize all of the available information

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for each test. Siltronic will take production-control measures to ensure that data are not confounded between the tests and will exclude data in the event that confounding may occur.

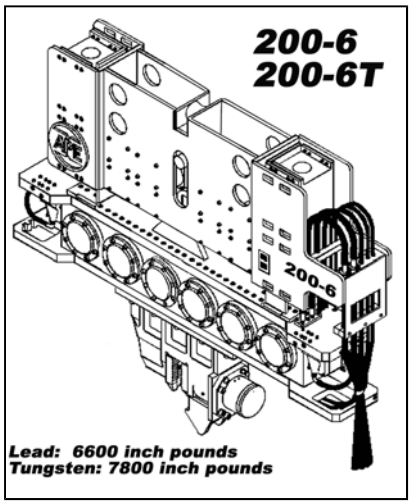
Communication and direct feedback by radio or cell phone during all phases of pile driving tests will reduce the potential for catastrophic impact on wafer manufacturing and will help to improve the confidence in the test process. Further questions related to Siltronic coordination, communications, access, data collection and evaluation, and other emerging issues can be refined within the draft test plan.

Sincerely,

Tom McCue

Cc: Alan Gladstone
Chris Reive

# Model 200-6 Vibratory Driver/Extractor

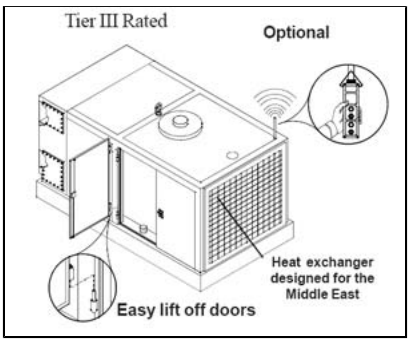



| | |
|---|---|
| Eccentric moment | 7600 kg-cm (6600 in-lbs) |
| Centrifugal force | 2135 kN (240 US tons) |
| Frequency (variable) | 1600 vpm (1800 attainable) |
| Amplitude | 30mm (1.17 in) |
| Pile gripping force (std. clamp) | 2010 kN (226 tons) |
| Maximum line pull | 1335 kN (150 US tons) |
| Suspended weight (w/universal clamp) | 6167 kg (13600 lbs) |
| Length | 318 cm (125 in) |
| Width at throat | 35 cm (14 in) |
| Width at widest point | 43 cm (17 in) |
| Height (with 150 ton short suppressor & 200 clamp) | 238 mm (94 in) |
| Hydraulic hose length (standard) | 46 m (150 ft) |
| Hydraulic hose weight | 680 kg (1,500 lbs) |

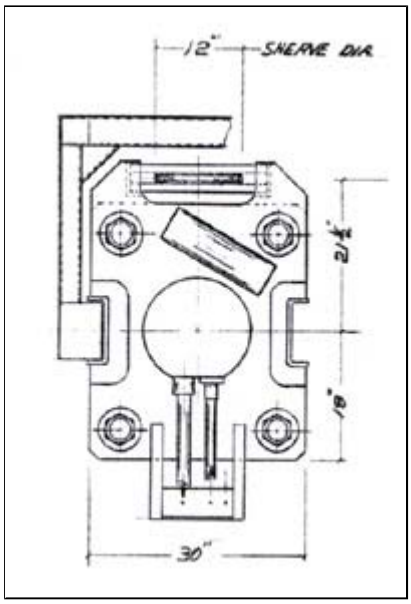
**Power Unit Specifications**

**Model 630 Power Unit**

| | |
|---|---|
| Power Unit Engine | C18 ACERT Tier III Certified |
| Maximum Power | 470 kW (630 hp) |
| Operating Speed | 800 to 2100 rpm |
| Maximum Drive Pressure | 310 bar (4500 psi) |
| Maximum Hyd. Flow-Forward | 0 to 190 gpm (779 lpm) |
| Maximum Hyd. Flow-Reverse | 0-741 lpm (0-196 gpm) |
| Clamp Pressure (sheet clamp) | 310 bar (4500 psi) |
| Clamp Flow | 41 lpm (10 gpm) |
| Weight | 9061 kg (19975 lbs) |
| Length | 401 cm (158 in) |
| Width | 196 cm (77 in) |
| Height | 259 cm (102 in) |
| Fuel Capacity | 145.4 gal (550 L) |
| Hydraulic Tank (main) | 533.4 gal (2019 L) |
| Hydraulic Tank (reserve) | 76.2 gal (288 L) |



# Model 7.2mT Hydraulic Impact Hammer




| | |
|---|---|
| Ram Weight | 16,200 lbs |
| Maximum Stroke | 38 Inches |
| Maximum Rated Energy@Maximum Stroke | 50,000 ft-lbs |
| Blow Rate | 40-75 per minute |
| Minimum Rated Energy@Minimum Stroke | 2,000 ft-lbs |
| Minimum Stroke | 1 inch |
| Weight of Hammer with Drive Cap | 20,500 lbs |
| Complete Operating length with Cap | 9.8 feet |
| Standard Lead size | 8 by 26 inch |
| Hydraulic Hose length | 100 feet |

**Power Unit Specifications**

**Model 260 Power Unit**

| | |
|---|---|
| Engine | Cummins C8.3 |
| Maximum power | 260 hp (194 kW) |
| Maximum drive pressure | 4,500 psi (310 bar) |
| Maximum hyd. flow - forward* | 80 gpm (303 lpm) |
| Maximum hyd. flow - reverse* | 80 gpm (303 lpm) |
| Clamp pressure | 4500 psi (310 bar) |
| Clamp pump flow | 6.5 gpm (27 lpm) |
| Weight | 6,800 lbs (3,090 kg) |
| Length (fits sideways on truck) | 103 in (262 cm) |
| Width | 55 in (140 cm) |
| Height | 64 in (163 cm) |
| Fuel Capacity | 96.5 gal (365 L) |
| Hydraulic Tank (main) | 201 gal (761 L) |
| Hydraulic Tank (reserve) | -- |

# APE Model 250V (Variable Moment) Vibratory Driver/Extractor with Model 630 Power Unit

*Variable amplitude and vibration speed for driving in vibration sensitive areas*

## SPECIFICATIONS: VIBRATOR Model 250V

| | | |
|---|---|---|
| Eccentric moment (variable) | 0 - 4,500 in-lbs | (5,184kg-cm) |
| Centrifugal force | 250 tons | |
| Frequency (variable) | 400-2000 rpm | |
| Vibrating Mass with standard sheet clamp | 9,500 lbs | (4,309 kg) |
| Amplitude with standard clamp | .95 inches | (25.4 mm)** |
| Pile cylinder force | 125 tons | (1,112 kN) |
| Extraction line pull | 122 tons | |
| Suspended weight (without clamp) | 15,600 lbs | (7,076 kg) |
| Suspended weight (with standard sheet clamp) | 17,800 lbs | (8,073 kg) |
| Length | 116 inches | (295 cm) |
| Width at throat | 14 inches | (35.5 cm) |
| Width at widest point | 28 inches | (71 cm) |
| Height without clamp | 83.625 inches | (212.4 cm) |
| Height with standard clamp including guide | 113 inches | (287 cm) |
| Hydraulic hose length (standard) | 150 ft | (381 m) |

***Amplitude equation: Eccentric moment x 2 / Vibrating Mass****

## SPECIFICATIONS: POWER UNIT Model 630

| | | |
|---|---|---|
| Engine | CAT C16 DITA 630hp | |
| Power | 630hp | (469.8Kw) |
| Operating speed | 800-2100 rpm | |
| Max pressure | 5000 psi | (344 bar) |
| Drive flow | 0-190 gpm | (0-779 lpm) |
| Clamp pressure | 5000 psi | (344 bar) |
| Clamp flow | 10 gpm | (38 lpm) |
| Weight | 18,000 lbs | (8,165 kg) |
| Length | 156 inches | (396.24 cm) |
| Height | 101 inches | (257 cm) |
| Width | 70 inches | (179 cm) |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May/03

# APPENDIX B
# GASCO SILTRONIC CONSTRUCTION VIBRATION STUDY COMMUNICATION PLAN

# COMMUNICATION PLAN
# GASCO SILTRONIC CONSTRUCTION VIBRATION STUDY

## 1. INTRODUCTION

On behalf of NW Natural, Anchor Environmental L.L.C. (Anchor) will coordinate subcontractor construction, monitoring, and evaluation during the Gasco Siltronic Vibration Study to be conducted during February 2009. This communication plan will be followed during monitoring and testing and is intended to be used in conjunction with the Gasco Siltronic Construction Vibration Study Work Plan (Work Plan; June 3, 2008).

The communication protocols required for this investigation are described in this plan in terms of four primary roles, which include:

- Project Management
- Construction Management
- Vibration Monitoring
- Plant Process Monitoring

Contact information for key individuals as well as their role in the investigation is provided in Table 1.

**Table 1 – Project Roles and Key Contact Information**

| Name | Role | Cell Phone | Office Phone | e-mail |
|---|---|---|---|---|
| **Project Management** | | | | |
| Ben Hung | Project Management Lead | 971-678-2100 | 503-670-1108 ext 21 | bhung@anchorenv.com |
| Wes MacDonald | Engineer | 615-830-5139 | 206-903-3377 | wmacdonald@anchorenv.com |
| Bob Wyatt | NWN Lead | 503-860-3451 | 503-860-3451 | rjw@nwnatural.com |
| Steve Dickenson | Geotechnical Lead | 541-602-0984 | 541-602-0984 | sdickenson99@gmail.com |
| Doug Laffoon | Construction Monitoring | 503-396-8879 | 503-670-1108 ext 28 | dlaffoon@anchorenv.com |
| **Construction Management** | | | | |
| Joe Burke | Construction Management Lead | 401-486-8204 | 716-284-0431 | BurkeJW111@aol.com |

| Name | Role | Cell Phone | Office Phone | e-mail |
|---|---|---|---|---|
| **Vibration Monitoring** | | | | |
| Steve Jaeger | Vibration Monitoring Lead | 650-464-7924 | 650-358-9577 | stephen.jaeger@colingordon.com |
| Blong Xiong | Vibration Consultant | 415-572-2834 | 650-358-9577 | Blong.xiong@colingordon.com |
| Neil Coleman | Vibration Monitoring | 513-404-3847 | 513-528-6164 ext111 | neil.coleman@signalysis.com |
| Sang Ham | Vibration Monitoring | 513-240-8226 | 513-528-6164 | sang.ham@signalysis.com |
| Gary Lytle | Siltronic Information Technology Lead | 503-219-4601 | | gary.lytle@siltronic.com |
| **Plant Process Monitoring** | | | | |
| Jason VanHorn | Fab 1 Vibration Project Manager | | 503-219-7907 | jason-vanhorn@siltronic.com |
| Michael Sutton | Process Engineer Monitoring Lead (Fab 1) | | 503-219-4572 | Michael.sutton@siltronic.com |
| Craig Lowe | Equipment Engineer Lead (Fab 1) | 503-310-8801 | 503-219-7799 Radio | Craig.lowe@siltronic.com |
| Todd MacClanathan | Fab 2 Vibration Project Manager | | 503-219-7211 | Todd.macclanathan@siltronic.com |
| Mazibur Khan | Process Engineer Monitoring Lead Fab 2 Team 1 | 503-219-7681 | 503-219-4346 Radio | Mazibur.khan@siltronic.com |
| Abebe Kassaye | Process Engineer Monitoring Lead Fab 2 Team 2 | 503-219-7613 | 503-219-7232 Radio | Abebe.kassaye@siltronic.com |
| Tom McCue | Siltronic Project Lead | 503-329-3653 | 503-219-7532 | Tom.McCue@siltronic.com |
| Mohan Khorsandian | Siltronic Lead Electrical Engineer | | 503-219-7997 Radio | moe.khorsandian@siltronic.com |

## 2. VIBRATION STUDY MONITORING SUMMARY

Monitoring will be performed according to the Work Plan, which includes a ground vibration monitoring program for both ambient conditions and construction-induced vibrations associated with trenching, installation equipment operation, and sheet pile installation. The program will be sequenced in the following manner:

- Step 1 – monitoring ambient ground vibrations as well as ambient vibrations in Siltronic buildings;

- Step 2 - evaluation of ground and structural vibrations due to trenching and pile driving at the northwestern (downstream) corner of the NW Natural Gasco Facility;
- Step 3 - evaluation of ground and structural vibrations due to trenching and pile driving at the northeastern (upstream) corner of the NW Natural Gasco Facility;
- Step 4 - monitoring ambient ground vibrations as well as ambient vibrations in Siltronic buildings.

## 3. COMMUNICATION PROTOCOLS

Prior to start of testing there will be a communication check between the Project Manager (PM), the Plant Process Monitoring (PPM) Leads, the Construction Management (CM) Lead, and the Vibration Monitoring (VM) Lead. The purpose of this check is to confirm that the communication devices are working reliably between all parties. Two-way radios will be utilized as the primary communication device. Cell phones will be utilized as the back-up communication device. Repeated communication checks should also be made between all parties at least hourly during pile driving tests to confirm that the communication systems are functional.

Each day prior to start of testing there will be a face to face meeting between the PM, the PPM Leads, the CM Lead, and the VM Lead. During that meeting the group will review the tests planned for that day and the communication protocols to be sure that all parties understand the process. Meeting notes from each meeting will be summarized and distributed to the project team to provide documentation of attendees, discussions, and agreements made.

### 3.1 Warning Level Exceedance

A flow chart for communication protocols for monitoring warning level exceedances is provided in Figure 1.

During Step 1 of the Work Plan, a "warning" trigger of 20% above the maximum root mean square (RMS) velocity level will initially be established. The setting and magnitude of the "warning" trigger will be agreed between the VM Lead and the PPM Lead before testing begins. This warning level may be adjusted by NW Natural and Siltronic during the course of Steps 2, 3, and 4. If this trigger is exceeded:

- The VM Lead will notify the PM and the PPM Lead immediately.

- The PM will notify the CM Lead and direct the CM Lead to pause construction immediately.
- The CM Lead will halt all operations and movement of large equipment until cleared by the PM.
- The PPM Lead will check Siltronic's processes and alert the PM of any catastrophic failures or other identified issues within one hour.
- The PM and PPM Lead may adjust the trigger level in consultation with the VM Lead.

### 3.2 Catastrophic Tool or Process Failure

If a catastrophic tool or process failure occurs during testing operations:

- The PPM Lead will notify the PM immediately.
- The PM will notify the CM Lead to pause construction immediately and VM Lead to note vibration levels when this occurred.
- The CM Lead will halt all operations and large movements until cleared by the PM.

### 3.3 Construction Period Process Monitoring Review

As provided in the study work plan, at the end of each 2 hour construction and vibration monitoring period, the PPM Lead will review process monitoring for LLS, Nanotopography data analysis, Epitaxy thickness measurement, and particle monitoring in the cleanrooms. If the PPM lead determines, with 95% certainty, that any shifts in mean or sigma values for production because of project construction have caused a shift in production quality, the following steps will be taken:

- The PPM Lead will notify the PM.
- The PM will notify the CM Lead to not proceed with the next test period.
- The PPM Lead will work with the VM Lead to correlate wafer test data with vibrations for establishing warning levels for vibrations during future construction phases.

If no shifts in mean or sigma values are determined, the PPM Lead will contact the PM within one hour to allow the next phase of the investigation to be performed. In addition, if the PPM Lead determines, with 95% certainty, that any shifts in mean or sigma values for production because of factors *other than* project construction have caused a shift in

production quality, the PPM Lead will contact the PM within one hour to allow the next phase of the investigation to be performed.

The PPM Lead is solely responsible for evaluating process monitoring data and identifying impacts to production quality.

### 3.4 Post-Construction Communication

After all testing is complete, the following communications steps will be taken:

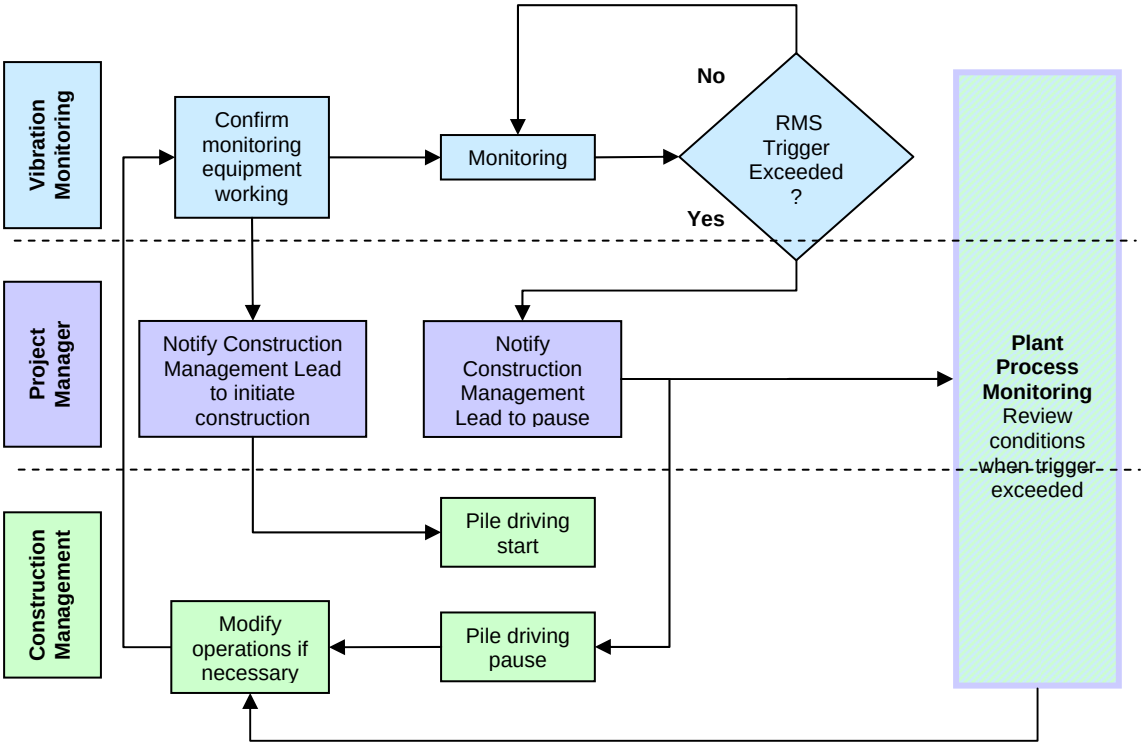
- The PM and the VM Lead will review vibration data from the test and report results to the PPM Lead.
- The PPM Lead will provide the PM and the VM Lead with compiled and summarized process monitoring data within 14 days of completion of the final vibration test trial as described in "Wafer Process Monitoring for Vibration Impacts" (Work Plan Attachment; February 7, 2008).
- NW Natural will submit a draft report to Siltronic for review.
- After Siltronic comment (and discussion as necessary) NW Natural will submit a draft report to DEQ for review.

## 4. TESTING SCHEDULE

The overall schedule for vibration testing is provided as an attachment to this document. Mobilization testing, restaging, and demobilization will occur as depicted on the schedule. During active construction simulation testing scheduled for Monday February 9 through Wednesday February 11, 2009, and Monday February 16 through Wednesday February 18, 2009, the following schedule will be followed:

- 07:00 - Project management, construction management and vibration management representatives will meet at the GASCO site for the daily safety meeting.
- 08:00 – Project management, construction management, vibration management, and plant process monitoring leads will meet at the Siltronic site as described in Section 3.
- 10:00 to 12:00 – Construction and vibration monitoring will be performed.
- 12:00 to 14:00 – Plant process monitoring will be performed.
- 14:00 to 16:00 – Construction and vibration monitoring will be performed.
- 16:00 to 18:00 – Plant process monitoring will be performed.

**Figure 1 - Communication Flow Chart for Monitoring RMS Triggers**



# ATTACHMENT 1

# VIBRATION TESTING SCHEDULE

Project: Gasco/Siltronic Vibration Study Point of Contact: Ben Hung

## Field Schedule

| Sunday | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday |
|---|---|---|---|---|---|---|
| **1/25** | **1/26** | **1/27** | **1/28** | **1/29**<br>Deploy monitoring equipment | **1/30 Step 1**<br>Deploy monitoring equipment, begin Step 1 monitoring | **1/31 Step 1**<br>Continue Step 1 monitoring |
| **2/1 Step 1**<br>Continue Step 1 monitoring | **2/2 Step 1**<br>Continue Step 1 monitoring | **2/3 Step 1**<br>Continue Step 1 monitoring, crane delivery, misc equip delivery | **2/4 Step 1**<br>Continue Step 1 monitoring, misc equip delivery, steel delivery | **2/5 Step 1**<br>Continue Step 1 monitoring, misc equip delivery | **2/6 Step 1**<br>Continue Step 1 monitoring, hammer delivery, crane setup, misc equip delivery | **2/7**<br>Interim monitoring |
| **2/8**<br>Interim monitoring | **2/9 Step 2**<br>Begin Step 2 monitoring, pre-trenching, 200-6 testing | **2/10 Step 2**<br>Continue Step 2 monitoring, 250 VM testing | **2/11 Step 2**<br>Continue Step 2 monitoring, 7.2 Hyd Impact testing | **2/12**<br>Interim monitoring, restage equipment for Step 3 | **2/13**<br>Interim monitoring, restage equipment for Step 3 | **2/14**<br>Interim monitoring, potential restaging make-up day |
| **2/15 FAB 2 DOWN ALL WEEK**<br>Interim monitoring | **2/16 Step 3**<br>**HOLIDAY** | **2/17 Step 3**<br>Begin Step 3 monitoring, pre-trenching, 200-6 testing | **2/18 Step 3**<br>Continue Step 3 monitoring, 250 VM testing | **2/19**<br>Continue Step 3 monitoring, 7.2 Hyd Impact | **2/20**<br>Interim monitoring, demobilization | **2/21 Contingent Step 4**<br>Begin contingent Step 4 monitoring |
| **2/22 BOTH FABS DOWN ALL WEEK Contingent Step 4**<br>Continue contingent Step 4 monitoring | **2/23 Contingent Step 4**<br>Continue contingent Step 4 monitoring | **2/24 Contingent Step 4**<br>Continue contingent Step 4 monitoring | **2/24 Contingent Step 4**<br>Continue contingent Step 4 monitoring | **2/26 Contingent Step 4**<br>Continue contingent Step 4 monitoring | **2/27 Contingent Step 4**<br>Continue contingent Step 4 monitoring | **2/28 Contingent Step 4**<br>Continue contingent Step 4 monitoring |
| **3/1 Contingent Step 4**<br>Continue contingent Step 4 monitoring | **3/2 Contingent Step 4**<br>Demobilize Monitoring Equipment | **3/3** | **3/4** | **3/5** | **3/6** | **3/7** |

# APPENDIX C
# SILTRONIC VIBRATION TESTING SUMMARY PRESENTATION

# VIBRATION TESTING SUMMARY

2009-05-22

# TABLE OF CONTENTS


- TEST METHODOLOGY
- TEST DATES
- SUMMARY OF TESTS, PARAMETERS AND IMPACTS
- DETAILS OF IMPACTS
  - SRP
  - LM MICROSCOPE
- UNKNOWNS THAT MAY BE IMPACTED
- UNKNOWNS THAT MAY BE EXCLUDED
- PRELIMINARY CONCLUSIONS
- CONTINGENCIES

# TEST METHODOLOGY

- Continuous Monitoring – Looking for outliers, mean and variance shift with a 95% confidence
  - Localized Laser Light Scattering, Light Point Defect, Airborne Particle counts, SRP.

- Yield Loss Trigger Event - “GRC” Gross Reality Check- yield loss outliers significantly outside of the baseline that could be triggered by the construction activities

- Process SPC “GRC” – Look for out of control process variables during test
  - Multi Wire Slicing Warp

- Gauge SPC “GRC” – Look for out of control gauge variables at least one interval during each test
  - Geometry measurement, 4pp, LM Microscope, Nanospec film measurement

- Noise Surveys – Measurement of noise levels and dosimeter readings within the North Office area and outside areas near the northwest property line

# TEST DATES

- These dates and times are extracted from the daily activity logs generated by Anchor Environmental and used to determine the test times and the baseline times.

| Day | Date | Test | Activity | Time start | Time End | Duration | comments |
|---|---|---|---|---|---|---|---|
| Wednesday | 4-Feb | | | 7:15 | 12:45 | 5:30 | Setup and prep |
| Thursday | 5-Feb | | | | | | Deliveries |
| Friday | 6-Feb | | | | | | Deliveries prep |
| Monday | 9-Feb | 1 | | 10:07 | 12:03 | 1:56 | Trenching |
| Monday | 9-Feb | 2 | | 14:30 | 15:50 | 1:20 | Pile driving |
| | | | | | | 2:27 | Duration between tests |
| Tuesday | 10-Feb | 3 | | 10:30 | 12:30 | 2:00 | Pile driving |
| Tuesday | 10-Feb | 4 | | 14:30 | 16:20 | 1:50 | Pile driving |
| | | | | | | 2:00 | Duration between tests |
| Wednesday | 11-Feb | 5 | | 10:00 | 11:55 | 1:55 | Pile driving |
| Wednesday | 11-Feb | 6 | | 14:00 | 15:54 | 1:54 | Pile driving |
| | | | | | | 2:05 | Duration between tests |
| Thursday | 12-Feb | 7 | | 9:53 | 12:25 | 2:32 | Pile driving |
| Thursday | 12-Feb | 8 | | 13:45 | 16:54 | 3:09 | Pile driving |
| | | | | | | 1:20 | Duration between tests |
| Monday | 16-Feb | | | 8:15 | 8:45 | 0:30 | Setup near Siltronic |
| Tuesday | 17-Feb | 9 | | 10:20 | 11:14 | 0:54 | Pile driving |
| Tuesday | 17-Feb | 10 | | 13:00 | 16:00 | 3:00 | Pile driving |
| | | | | | | 1:46 | Duration between tests |
| Wednesday | 18-Feb | 11 | | 10:00 | 12:04 | 2:04 | Pile driving |
| Wednesday | 18-Feb | 12 | | 13:35 | 16:01 | 2:26 | Pile driving |
| | | | | | | 1:31 | Duration between tests |
| Thursday | 19-Feb | 13 | | 10:25 | 12:25 | 2:00 | Pile driving |
| Thursday | 19-Feb | 14 | | 13:46 | 15:56 | 2:10 | Pile driving |

# SUMMARY OF TESTS, PARAMETERS, AND IMPACTS - FAB1 (1/2)

N = No impact
Y = Yes impact
U = Unusable or no data available
M = Maybe an impact, but can not substantiate the results

| Test | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Continuous Metrology** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **Comments** |
| Laser Light Scattering | | | | | | | | | | | | | | | |
| 50(Epitaxy) | N | N | N | N | N | N | N | N | N | N | N | N | N | N | |
| 20(Final Cleaning) | N | N | N | N | N | N | N | N | N | N | N | N | N | N | |
| 156(Final Cleaning) | N | N | N | N | N | N | N | N | N | N | N | N | N | N | |
| | | | | | | | | | | | | | | | |
| Laser Light Scattering DWN | U | U | U | U | U | U | U | U | U | U | U | U | U | U | data unusable |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| EPI Film Thickness | U | U | U | U | U | U | U | U | N | N | N | N | N | N | problems with recipe setup in first week. No impacts in second week |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| Airborne Particle Counts | N | N | N | N | N | N | N | N | N | N | N | N | N | N | Although there were some events, they were equivalent to or within baseline |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| Sheet Resistance | | | | | | | | | | | | | | | |
| Res "Points"Profiling | N | N | N | N | N | N | N | N | M | M | M | M | Y | Y | Tool was unavailable on Test 9, 10, 11, 12 there may have been similar impacts |
| | | | | | | | | | | | | | | | |

# SUMMARY OF TESTS, PARAMETERS, AND IMPACTS - FAB1 (2/2)

| Yield Loss GRC | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Multi Wire Slicing | N | N | N | N | N | N | N | N | N | N | N | N | N | N | |
| Wafershaping | N | N | N | N | N | N | N | N | N | N | N | N | N | N | |
| Backside Deposition | N | N | N | N | N | N | N | N | N | N | N | N | N | N | |
| Polishing/Wax Mount | N | N | N | N | N | N | N | N | N | N | N | N | N | N | |
| Epitaxy | N | N | N | N | N | N | N | N | N | N | N | N | N | N | |
| **Process SPC GRC** | | | | | | | | | | | | | | | |
| Multi Wire Slicing | | | | | | | | | | | | | | | |
| Process Warp | N | N | N | N | N | N | N | N | N | N | N | N | N | N | |
| **Gauge SPC GRC** | | | | | | | | | | | | | | | |
| Tab Removal | | | | | | | | | | | | | | | |
| Thk | N | N | N | N | N | N | N | N | U | N | N | N | N | N | No data available on test 9 |
| Warp | N | N | N | N | N | N | N | N | U | N | N | N | N | N | |
| | | | | | | | | | | | | | | | |
| LM Microscope | | | | | | | | | | | | | | | |
| Dot Depth | N | N | N | N | N | N | N | N | M | M | M | Y | M | M | The sampling frequency may not catch every event. |
| | | | | | | | | | | | | | | | |
| Furnace center | | | | | | | | | | | | | | | |
| Nanospec Poly | U | U | N | U | N | U | N | N | N | N | N | N | N | N | No sample available on some days, but all near filed data |
| LTO | U | U | N | U | N | U | N | N | N | N | N | N | N | N | was collected with no impact |
| | | | | | | | | | | | | | | | |
| CWI | | | | | | | | | | | | | | | |
| Thk | N | N | U | N | N | N | N | N | N | N | N | N | N | N | No sample available on one test |
| Res | N | N | U | N | N | N | N | N | N | N | N | N | N | N | |
| | | | | | | | | | | | | | | | |
| Polish | | | | | | | | | | | | | | | |
| Thk | N | N | N | N | N | N | N | N | N | N | N | N | N | N | |
| warp | N | N | N | N | N | N | N | N | N | N | N | N | N | N | |
| | | | | | | | | | | | | | | | |
| Epitaxy | | | | | | | | | | | | | | | |
| 4pp | N | N | N | N | N | N | N | N | N | N | N | N | N | N | |
| | | | | | | | | | | | | | | | |
| SEM | | | | | | | | | | | | | | | |
| Image Quality | U | U | U | U | U | U | U | U | M | M | M | M | M | M | Tool was unavailable during test |

# SUMMARY OF TESTS, PARAMETERS, AND IMPACTS - FAB 2 (1/1)

N = No impact
Y = Yes impact
U = Unusable or no data available

| Test | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Continuous Metrology** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **Comments** |
| Laser Light Scattering | | | | | | | | | | | | | | | |
| LLS | N | N | N | N | N | N | N | N | N | N | N | N | N | N | |
| Nanotopology | N | N | N | N | N | N | N | N | N | N | N | N | N | N | |
| | | | | | | | | | | | | | | | |
| Oblique BF-DIC | N | N | N | N | N | N | N | N | N | N | N | N | N | N | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| Airborne Particle Counts | N | N | N | N | N | N | N | N | N | N | N | N | N | N | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| **Yield Loss GRC** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | |
| Multi Wire Slicing | N | N | N | N | N | N | N | N | U | U | U | U | U | U | Fab 2 Shut Down 2nd Week of Tests |
| Wafershaping | N | N | N | N | N | N | N | N | U | U | U | U | U | U | Fab 2 Shut Down 2nd Week of Tests |
| Backside Deposition | N | N | N | N | N | N | N | N | U | U | U | U | U | U | Fab 2 Shut Down 2nd Week of Tests |
| Polishing/Wax Mount | N | N | N | N | N | N | N | N | U | U | U | U | U | U | Fab 2 Shut Down 2nd Week of Tests |
| Epitaxy | N | N | N | N | N | N | N | N | U | U | U | U | U | U | Fab 2 Shut Down 2nd Week of Tests |
| **Process SPC GRC** | | | | | | | | | | | | | | | |
| Multi Wire Slicing | N | N | N | N | N | N | N | N | U | U | U | U | U | U | Fab 2 Shut Down 2nd Week of Tests |
| Edge Grinding | N | N | N | N | N | N | N | N | U | U | U | U | U | U | Fab 2 Shut Down 2nd Week of Tests |
| Lapping | N | N | N | N | N | N | N | N | U | U | U | U | U | U | Fab 2 Shut Down 2nd Week of Tests |
| Lasermark | N | N | N | N | N | N | N | N | U | U | U | U | U | U | Fab 2 Shut Down 2nd Week of Tests |
| CWI | N | N | N | N | N | N | N | N | U | U | U | U | U | U | Fab 2 Shut Down 2nd Week of Tests |
| Post Polish Geometry | N | N | N | N | N | N | N | N | U | U | U | U | U | U | Fab 2 Shut Down 2nd Week of Tests |
| Post Polish LLS | N | N | N | N | N | N | N | N | U | U | U | U | U | U | Fab 2 Shut Down 2nd Week of Tests |
| Post Epi Geometry | N | N | N | N | N | N | N | N | U | U | U | U | U | U | Fab 2 Shut Down 2nd Week of Tests |
| Post Epi LLS/Warp | N | N | N | N | N | N | N | N | U | U | U | U | U | U | Fab 2 Shut Down 2nd Week of Tests |

# DETAILS OF IMPACTS – SRP

- SRP: Equipment Description- Spreading resistance profile. Measurement gauge is used to qualitatively control the dopant impurity transition(change in resistance) between the substrate wafer and an epitaxial layer.

- Impact –
  - How was the impact observed?
    - Significant Transient shifts in the measured resistance were observed at various times during the Test 13 and Test 14
    - Each transient spike resulted in a sustained shift in the measured resistance.

  - How the impact affects Siltronic?
    - A transient shift can not be separated from a potential process related issue. The transient shift would require sample remeasurement of the affected material. (Delayed shipment and capacity loss for remeasurement)
    - A sustained shift may require recalibration of the tool due to probe damage. Approximately 6 hours required to recondition probes, and recalibrate.

    (Each event could cause significant Tool capacity loss)

# DETAILS OF IMPACTS – SRP

- No transients or shifts were observed during far field construction . February 9th through Thursday February 12th

- Tool was down and unusable during initial near field tests February 17th and 18th.

- February 19th
  - Test 13 (10:25 to 12:25)
    - transient(1) at approximately 12:26 and a subsequent +4% shift

  - Test 14(13:46 to 15:56)
    - Transient(1) at approximately 13:38 and a subsequent +1% shift
    - Transient(2) at approximately 14:40 and a subsequent +4% shift
    - Transient(3) at approximately 14:52 and a subsequent +1% shift

- We conclude that if the tool was operational on the 17th and 18th there may have been similar issues, but we are unable to substantiate this with actual data collected.

# DETAILS OF IMPACTS – SRP

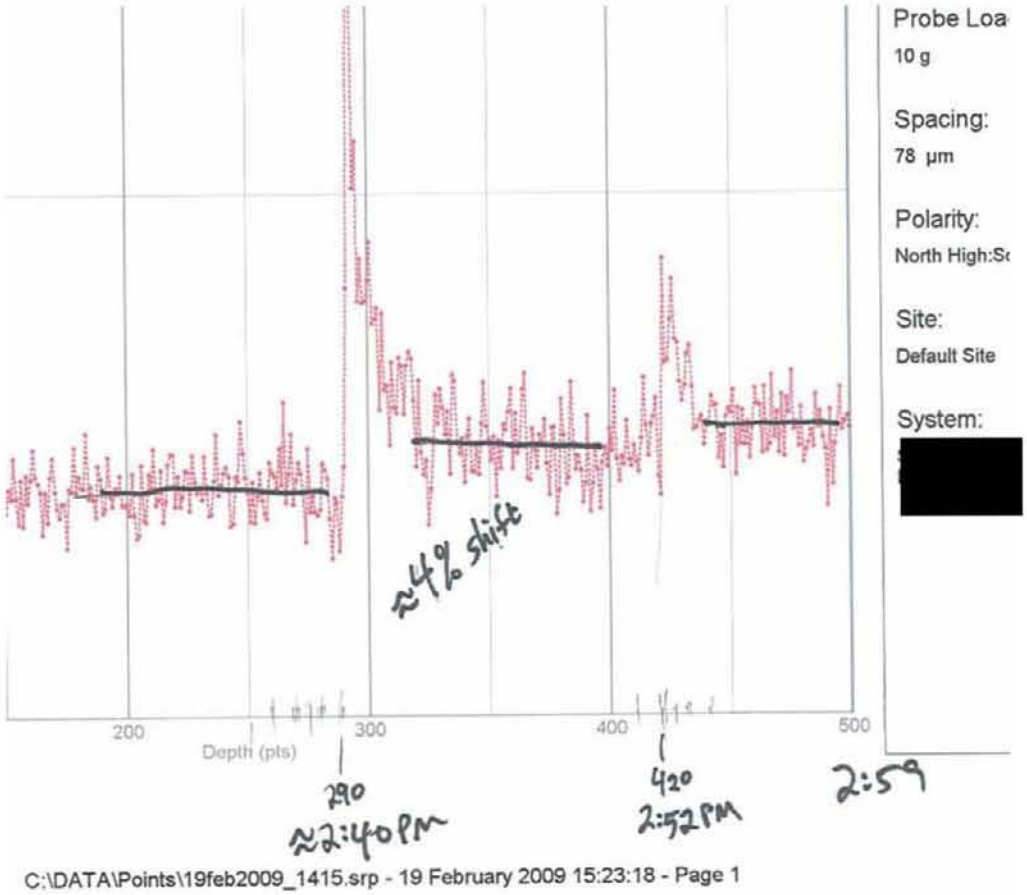
- Summary of actual SRP continuous “points” monitoring during February 19th. One measurement approximately every 5 seconds. Some gaps in monitoring were unavoidable. Tool must be reset after a finite number of measurements.

SRP Monitoring Summary for February 19th

| Time start | Time End | Duration | comments |
|---|---|---|---|
| 10:20 | 11:04 | 0:44 | |
| | | 0:11 | gaps in continuous monitoring |
| 11:15 | 11:59 | 0:44 | |
| | | 0:01 | gaps in continuous monitoring |
| 12:00 | 12:44 | 0:44 | |
| | | 0:36 | gaps in continuous monitoring |
| 13:20 | 14:04 | 0:44 | |
| | | 0:11 | gaps in continuous monitoring |
| 14:15 | 14:59 | 0:44 | |
| | | 0:21 | gaps in continuous monitoring |
| 15:20 | 16:04 | 0:44 | |
| | | | |

# DETAILS OF IMPACTS – SRP

- Example of SRP measurement “transient” events



# DETAILS OF IMPACTS – LM MICROSCOPE

- LM Microscope - Used to determine and control the depth of Lasermarked Si wafers.

- Impact –
  - How was the impact observed?
    - At 13:35 on Wednesday February 18th, significant image quality reduction was observed at the LM microscope. This prevented accurate dot depth measurement.

    - During each test, a single measurement was taken lasting approximately 1 to 1.5 minutes. No other measurements were affected during other tests.

  - How the impact affects Siltronic?
    - The reduction of image quality prevents focus (40x) and accurate assessment of the dot depth. This would result in delayed feedback until image quality returns to normal levels (potential capacity loss for remeasurement)

    - We conclude that it is likely that there were impacts from other similar transient vibration events during the construction, but can not substantiate these due to the inadequate sample frequency of the test.

# DETAILS OF IMPACTS – LM MICROSCOPE

- Summary of actual LM Dot Depth measurements during test conditions

LM Microscope Dot Depth SPC measurement - Data Collection details

| Day | Date | Test | Approx time of measurement at LM | Time start | Time End | comments |
|---|---|---|---|---|---|---|
| Monday | 9-Feb | 1 | 10:10 | 10:07 | 12:03 | No Impact |
| Monday | 9-Feb | 2 | 15:15 | 14:30 | 15:50 | No Impact |
| Tuesday | 10-Feb | 3 | 12:00 | 10:30 | 12:30 | No Impact |
| Tuesday | 10-Feb | 4 | 16:13 | 14:30 | 16:20 | No Impact |
| Wednesday | 11-Feb | 5 | 10:28 | 10:00 | 11:55 | No Impact |
| Wednesday | 11-Feb | 6 | 15:32 | 14:00 | 15:54 | No Impact |
| Thursday | 12-Feb | 7 | | 9:53 | 12:25 | No Impact |
| Thursday | 12-Feb | 8 | | 13:45 | 16:54 | No Impact |
| Tuesday | 17-Feb | 9 | 10:24 | 10:20 | 11:14 | No Impact |
| Tuesday | 17-Feb | 10 | 14:54 | 13:00 | 16:00 | No Impact |
| Wednesday | 18-Feb | 11 | 10:53 | 10:00 | 12:04 | No Impact |
| Wednesday | 18-Feb | 12 | 13:35 &16:21 | 13:35 | 16:01 | Impact at 13:35, No Impact at 16:21 |
| Thursday | 19-Feb | 13 | 11:41 | 10:25 | 12:25 | No Impact |
| Thursday | 19-Feb | 14 | 15:45 | 13:46 | 15:56 | No Impact |

# DETAILS OF IMPACTS – NOISE LEVELS

- Noise surveys were conducted in the North Office area, Warehouse and exterior areas near the northwestern corner of the property during vibration test events 2/17 thru 2/19

- Dosimemetry instruments were provided by and calibrated by Oregon OSHA

- OSHA requires the use of A Scale frequency with slow response

  - L-avg: The average noise level over a period of time that uses an exchange rate of 4, 5 or 6 in the calculation of the final value.
  - L-max: The highest reading with a specified frequency weighting and time response in a sound level meter.
  - L-pk: The absolute highest sound pressure of the noise signal of either the positive or negative part of the sound wave.

# DETAILS OF IMPACTS – NOISE LEVELS

- 8 hour-TWA (L-avg) Noise level exposure remained within a typical office environment range of 45-60 dBA

- Average Maximum (L-max) A scale noise levels in office areas reached 88 dBA and may trigger hearing conservation training and recommendation for PPE during continuous construction

- Average Maximum (L-max) A scale noise levels exterior to the building ranged from 93 dBA – 96 dBA which require employees working or passing through this area to use hearing protection while equipment is operating

How noise impacts affected Siltronic

  - L-max levels range from 25-31 dBA above background and affected productivity within an office environment

  - Peak noise levels (L-pk) within the office area reached 110-115 dB resulting in high level intermittent noise disruption

# SUMMARY NOISE LEVELS

| 17-Feb | | | |
|---|---|---|---|
| Location | A | B | C |
| Time on | 1023 | 1024 | 1026 |
| Time off | 1230 | 1234 | 1238 |
| Lmax | 78.4 | 72.9 | 84.2 |
| Lavg | 48.4 | 48 | 54.2 |
| Lpk | <113.6 | <109.6 | <113.7 |

| 17-Feb | | | |
|---|---|---|---|
| Location | A | B | C |
| Time on | 1305 | 1308 | 1311 |
| Time off | 1532 | 1538 | 1544 |
| Lmax | 81.2 | 74.4 | 84.6 |
| Lavg | 50.7 | 48.3 | 57.9 |
| Lpk | <110.8 | <109.6 | <115.4 |

| 18-Feb | | | |
|---|---|---|---|
| Location | A | B | C |
| Time on | 1021 | 1022 | 1024 |
| Time off | 1216 | 1220 | 1222 |
| Lmax | 88.2 | 79.1 | 81.9 |
| Lavg | 61.1 | 49.2 | 48.5 |
| Lpk | <110.6 | <110.8 | <115.4 |

| 18-Feb | | | |
|---|---|---|---|
| Location | A | B | C |
| Time on | 1341 | 1343 | 1344 |
| Time off | 1520 | 1523 | 1526 |
| Lmax | 81.7 | 77.6 | 77.4 |
| Lavg | 57.1 | 49.4 | 48.6 |
| Lpk | <110.6 | <110.8 | <109.8 |

# SUMMARY NOISE LEVELS

| 19-Feb | | | |
|---|---|---|---|
| Location | A | B | C |
| Time on | 1000 | 1002 | 1004 |
| Time off | 1224 | 1229 | 1232 |
| Lmax | 79.4 | 77.2 | 78.6 |
| Lavg | 58.5 | 50 | 48.8 |
| Lpk | <112.3 | <111.1 | <114.8 |

| 19-Feb | | | |
|---|---|---|---|
| Location | A | B | C |
| Time on | 1328 | 1333 | 1335 |
| Time off | 1503 | 1507 | 1511 |
| Lmax | 77 | 78.8 | 73.8 |
| Lavg | 57 | 51.9 | 48.9 |
| Lpk | <110.6 | <110.8 | <109.8 |

# UNKNOWNS THAT MAY BE IMPACTS

- SEM “SCANNING ELECTRON MICROSCOPE Ultra high resolution microscope for submicron features. Used in assessment of defective wafers and helpful in failure and root cause analysis of quality issues.

- Suspected Impacts
  - Suspect that there would be similar or worse issues with image quality as observed with the LM microscope based on the proximity to the LM microscope and the basic principles of measurement.

  - How the suspected impact affects Siltronic?
    - Reduces and delays Siltonic’s ability to assess and complete root cause analysis in quality issues.

# UNKNOWNS THAT MAY BE EXCLUDED

- Laser Light Scatter DWN metrology tool - due to unforeseen issues the Fab1 information collected during the test was unusable.  We have concluded that the companion Laser Light Scatter information for fab1 will suffice for this tool and any impacts observed.

# CONCLUSIONS

- No indications that transient or acute events due to construction shifted continuous monitoring Airborne Particle Counts in the clean rooms for both factories

- Transient events caused measurement issues with the Spreading Resistance Profiler (SRP) and the Fab1 LM microscope.
    - SRP: Noise in the actual measurement was observed due to vibration. Short-term resolution would be to relocate the tool (minor) or improve vibration resilience. Method to be determined after actual construction begins.

    - LM: Dot focus was observed to be difficult due to vibration. Short-term resolution to install a vibration table. Sample frequency to be increased to ensure no product impacts.

- Although not utilized during the testing phase, the vibration observed in the area of the Scanning Electron Microscope (SEM) shows levels well above the operational criteria.
    - Impacts on the measurements during construction will be required with possible relocation or change in use schedule.

- Although not catastrophic, wafer particle measurement tools (Light Point Defect) did show a statistical difference based on 95% confidence intervals. However, these events were within normal monitoring baselines and are deemed to be minor.

# PRELIMINARY CONCLUSIONS

- No short-term attributable disruptions to production data (losses or capabilities) noted during the test phase for either Fab.
- Long-term effects such as loose connections and board failures could not be determined based on the very short test period.
- Noise levels in office areas were disruptive and reduce productivity. Average Maximum (L-max) Noise levels in office areas were 25-30 dBA above background. L-avg noise levels will increase during continuous construction and longer exposure.

Next Phase

- The last defined alarm limits must be used with slight agreed upon deviations to the alarm durations.
- Due to the fact that there were some noticeable impacts on the LLS, SRP's and LM microscope, the lowest impact method should be used.
- Hearing conservation training and relocation of office workers is likely.

# APPENDIX D
# SILTRONIC VIBRATION TESTING SUMMARY REPORT

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Siltronic Corporation
Vibration Test Results Summary
2009-05-05

## Introduction

A vibration test was conducted by NW Natural and its contractors and consultants in cooperation with Siltronic Corporation to document the potential impacts of significant site construction work as a result of an EPA and DEQ directive to install a barrier wall along the river bank of NW Natural's GASCO property adjoining the Siltronic property line to the west. The test summary outlines methods that will be used to detect a direct change in metrology and lists baselines for process areas that was checked during the test timeframe or when the construction activity begins.

Below is a summary of the test results. Additional data and documentation of full test results are available as confidential business files and will be saved at Siltronic documentation.

### 1.1.1 Vibration Test Conclusions and Recommendations

There were significant metrology impacts from "transient" events during the construction in the near field tests in Spreading Resistance Probe (SRP) and Laser Mark (LM) microscope. However, Siltronic cannot differentiate differences between construction methods (test conditions), and cannot substantiate results for each day of the near field tests. Continuous scan Laser Light Scatter (LLS) confidence interval tests did indicate some statistically significant changes, but these events were concluded to be minor and or inconclusive.

Besides the SRP and LM microscope there were no other significant metrology events reported during any of the tests.

Preliminary conclusion: acute/transient events did impact Siltronic microscopes and SRP, but nominal vibration from construction did not show any short term changes in any processes or metrology.

LM microscope in fab1 was affected by transient(or Peak) vibration from the near site location on Test 12. This tool could not be fully evaluated during the normal construction in the near field location and there may have been similar transient events that were not recorded because of the frequency of statistical process control (SPC) was only once during each test.

Potential improvement would be to add vibration isolation table mounts for this tool.

The SRP was not operational for testing dates 1 through 12, but on Tests 13 and 14 there were 4 single transient (or Peak) events which appeared as spikes in the profile of the continuous monitoring and then manifested in sustained shifts of 1 to 2%. Normal construction did not show differences in measurement capability, however, there may have been similar transient events recorded if the tool had been operational on other days of the test.

Potential improvement would be to relocate tools during construction.

There were no indications that the transient or acute events of the construction caused outliers in production data that was monitored. Continuous Measurements of the Airborne Particle Counts, Epitaxial film thickness measurements did not indicate significant changes outside of our baseline levels.

The scanning electron microscope (SEM) was not available during the test. It is expected that the SEM would be affected based on the effect on the LM microscope. Vibration levels measured at the tool during the test exceeded the ISO construction design standard criterion. Since SEM does not require <8 hour turnaround time, the tool could be used during off hours when construction is not underway.

From Preliminary data supplied by Colin Gordon(Vibration Consultants for NWN), the peak vibration levels observed on the Siltronic property by an array of free field sensors(accelerometers) aligned along the river side of the fab1 building were approximately 10,000 µin/s in both Vertical and Horizontal directions at 100 feet from construction. This translates to a generic Vibration criterion for “Residential construction standards”. At 500 ft from the construction test area, the Peak vibration dropped slightly to ~5000µin/s far exceeding generic Vibration criterion of “VC-D semiconductor fabrication. Construction with Vibratory Moment hammer showed the highest peak events at a Peak frequency of 20-25 Hz. Impact Hammer with a peak frequency of 10Hz showed the greatest attenuation and the lowest impact on the Siltronic Property. This is only to provide a general reference to the vibration levels that were observed during the test in the construction location closest to Siltronic. This is the interpretation of the data provided by Colin Gordon by Siltronic.

In conclusion, the construction of the Barrier wall can proceed with any of the selected methods as long as the vibration levels generated during the test remain within the alarm limits established during the test. However, accommodation is required to reduce or eliminate vibration impacts at the LM, SRP stations. SEM measurements are expected to be possible with a modified schedule during barrier wall construction.

It is recommend that NW Natural start construction of the barrier wall at the farthest point and moving toward Siltronic to minimize long-term vibration impacts to wafer production and measurement tools. It is theorized that starting at the farthest point and moving toward Siltronic would avoid facilitating transmission of vibration along the sheet-pile wall itself during the entire construction process.

### 1.1.2 Noise Dosimeter and Sound Level Measurements

Noise surveys were conducted using calibrated Dosimeters and sound level meter instrumentation provided by Oregon OSHA. Sound level measurements and dosimeters were set up in the north building office area, growing warehouse area. Sound level meter measurements were also taken exterior to the building along the NW corner of the property where workers transport manufacturing supplies daily during the impact/vibration study conducted on February 17th through the 19th of this year. Test results are shown in the following table.

Hearing damage will occur at elevated noise levels. OSHA Action levels are Lmax measurements > 115dB, Lavg measurements >85dB or Lpk measurements > 140dB.

Noise levels in a typical office environment range from 45-60dB. Lavg measurements were typical of an office environment. However, the Lmax measurements during intense pile driving activities were more typical of a heavy manufacturing environment. The wide range of noise level was found to be disruptive to office workers.

Sound level testing was conducted on the exterior of Fab 1 on the road running along the NW corner of the property. Impact noise levels of ~93dB on February 17th, ~96dB on February 18th and ~95dB on February 19$^{th}$ were measured north and west access roads. Because these levels are greater than Lavg measurements >85dB OSHA Action level it will be necessary to post signs along the road requiring that employees working or passing through this area during this project while equipment is in operation use hearing protection. This would likely only impact warehouse and facilities personnel. Construction workers will exceed the Action level and the eight hour exposure limit.

A hearing conservation area will need to be established on the exterior of Fab 1's NW corner requiring hearing protection for any work to be performed in that area. Health & Safety will perform periodic monitoring in the North Building office area during the project to confirm that no overexposures take place.

Alternative work space (with phone and computer access) available in areas outside the North Building office area is recommended for relocation of those employees who are unable to perform critical work during this project due to construction generated noise.

Measurements did not exceed action levels within the building during any of the tests. It can be concluded that there would be no over exposure that would result in hearing damage from any of the construction processes to employees inside the building, however, noise levels were found to be disruptive to workers within the office areas.

**Summary**

Siltronic concludes a sheet pile barrier wall can be constructed along the GASCO shoreline up to the northwest boundary of the Siltronic property with appropriate selection of construction methods, vibration monitoring and warning alarms. Production was significantly impacted by vibration however solutions appear to be available to modify specific tool mounting or relocation of tools and a few office workers to accommodate the construction activities. Long-term effects of continuous vibration on sensitive measurement tools and connectors could not be evaluated. Construction of a sheet pile barrier wall adjacent to the operating wafering fabs also could not be evaluated. It is likely that additional testing will be necessary should it become necessary to install a barrier wall along the Siltronic shoreline.