



Vibration Monitoring Plan SR520 Montlake to Lake Washington

Contractor



Owner



sixsense



Contacts	Zhangwei NING – Project Manager
	zhangwei.ning@sixsense-group.com 206-588-1691
	Jeremy TURPIN – Acoustic Consultant
	jeremy.turpin@sixsense-group.com 412-398-0976

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1. Introduction

1.1 Purpose of works

The Montlake project is part of the SR 520 Bridge Replacement and HOV Program, enhancing public safety and mobility by replacing the highway's aging, vulnerable bridges and making significant transit and roadway improvements throughout the corridor. The construction program's planned improvements extend from I-5 in Seattle to I-405 in Bellevue.

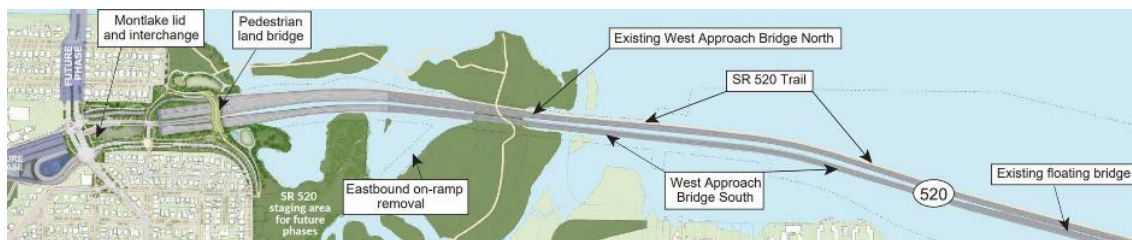
An overview of the project is presented on the picture below.



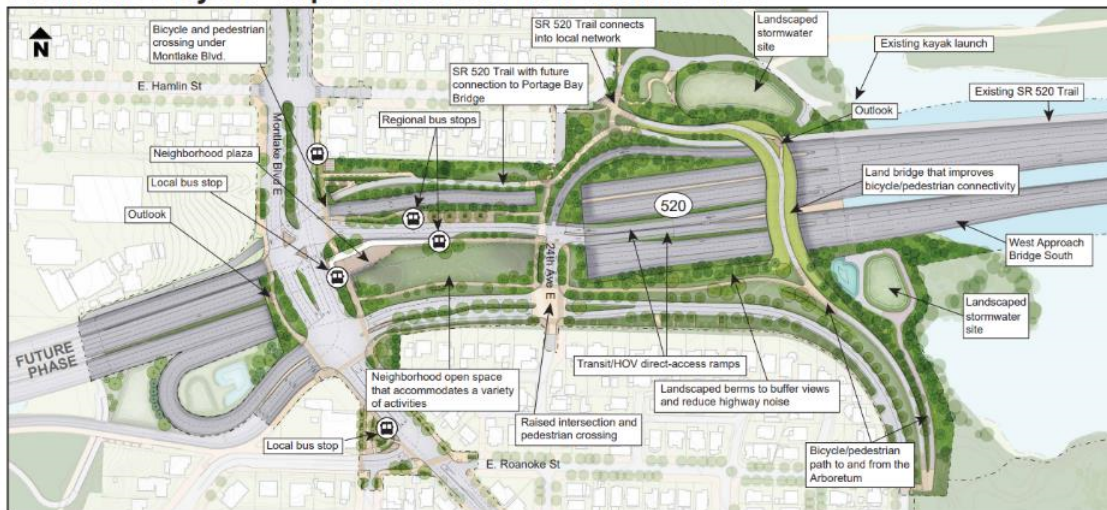
Figure 1: SR 520 improvement overview

Work undertaken by GRAHAM (General Contractor) will consist mainly in the following tasks as shown on the more detailed map below:

- Waterline installation, estimated 5 to 7 months;
- Demolition of existing Montlake Boulevard bridge, estimated 1 month;
- Demolition of existing 24th Avenue Bridge, estimated 1 month;
- Demolition of existing West Approach Bridge, estimated 24 to 36 months;
- Temporary work bridge construction, estimated 9 to 12 months;
- Drilled shafts for WABS, estimated 12 to 16 months;
- Bridge substructure and superstructure construction for WABS, estimated 24 to 28 months;
- Construction of Montlake lid, estimated 48 to 60 months;
- Traffic shifts, estimated 48 to 60 months;
- Utility relocation, estimated 48 to 60 months;
- Temporary shoring wall construction, estimated 48 to 60 months; and



Montlake Project: Improvements in the Montlake area



Note: Graphic depicts SR 520 corridor elements at completion. Major elements of the Montlake Project are labeled above.

Figure 2: SR 520 improvement overview

The work undertaken by GRAHAM will therefore involve mechanical methods and will generate vibrations such as piling (pile driving and installation), foundations, drilling, compaction for paving, excavation, haul routes, use of staging area and demolition activities.

1.2 Vibration monitoring plan

As part of the contract requirements, GRAHAM must control its vibration impact on existing structures. The purpose of the monitoring is to ensure that the vibration triggers are respected for the buildings and structures nearby the working area.

Damage to properties (historic or not) could occur if thresholds are exceeded by any activity.

This plan outlines monitoring methods and procedures to be used on the project, including locations of vibration monitors and details of measurement instrumentation. The exact location of the sensors will be adapted depending on the response of the neighbors.

This vibration monitoring plan is a subsection of the instrumentation plan as per section 2.6.7.5.4 of the Request for Proposal (RFP) specifications.

This monitoring plan is therefore referring to the following key documents:

- Chapter 2 of the Request for Proposal (RFP) specifications
- Transit Noise and Vibration Impact Assessment Manual (Federal Transit Administration) FTA Report No. 0123 (SEPTEMBER 2018), and associated spreadsheet
- German international standard for vibration monitoring DIN (German Institute of Standardization) 45669-1 (ver 2011)
- WABN (West Approach Bridge North) contract Plans reference G101-104

1.3 Perimeter of this document

The following items are excluded from this document:

- The pre-condition, pre-demolition, and post-construction survey (as per defined in section 2.6.7.3 of the Request for Proposal specifications), if any, will be the responsibility of the contractor as per specifications. Monitoring of the ground settlement is not included here either. Underwater vibration monitoring is also excluded from this document.
- The Deformation Analysis Report is not included.
- Vibration levels for freshly placed concrete in conformance with Section 37 6-02.3(6)D of the Standard Specifications (Appendix B2) are not considered here.
- Noise monitoring is described in a separate document.
- Instrumentation monitoring (for displacement/settlement) is described in a separate document.
- Underwater noise impact is not considered here.
- Monitoring of the Sound Transit Tunnel.

1.4 Definitions

The following definitions will be used through this report, as per the Request for Proposal (RFP) specifications:

Action Plan: Design-Builder produced plan for corrective measures to be implemented should maximum vibration or live load levels be reached or exceeded. See section 2.28 of the specifications.

AC: Alternative Current

AMS: Automated Monitoring System

Buildings: Refers to buildings listed in Table B of the specifications.

Cosmetic Damage: shall be defined as vibration levels which will, or have the potential to, cause minor or cosmetic structural damages to buildings, such as cracks in wall or ceiling plaster, misalignment of windows. The criteria limits come from the Federal Transit Administration's Transit Noise and Vibration Impact Assessment Manual, the Acoustical Society of America (American National Standard: Guide to the Evaluation of Human Exposure to Vibration in Buildings, American National Standard Institute ANSI S2.71), and the International Organization for Standardization (Evaluation of Human Exposure to Whole-Body Vibration in Buildings (1-80 Hz), ISO-2361-2, 1989).

DIN: German Institute of Standardization

Frequency: The number of vibration oscillations that occur per second (cycles per second) and shall be expressed in units of Hertz (Hz). Vibration measurements and criteria limits in this section shall include, at a minimum, the frequency range of 1 Hz to 100 Hz.

FTA: Federal Transit Administration.

IT: Information technology

NTP: Network Time Protocol

Peak Particle Velocity (PPV): shall be defined as the maximum vector sum of a particle velocity measured in three mutual perpendicular directions expressed in inches per second as measured using the "peak" response on a vibration meter. Vibration limits and compliance measurements for major and cosmetic structural damages shall be in units of inches per second.

Receptor Location: refers to the location being evaluated for vibration exposure.

RFP: Request for Proposal

WABN: West Approach Bridge North

WABS: West Approach Bridge South

WSDOT: Washington State Department of Transportation



1.5 Contractual requirements

As defined in the section 2.6 of the Request for Proposal (RFP) specifications, the following items are the minimum contractual requirements to be respected at all time:

- Vibration data shall be uploaded to a secure online database the same day the data is collected. The Design-Builder shall provide Washington State Department of Transportation (WSDOT) access to the online database at all times.

Data will be available to WSDOT in near real-time (around 10 min) to use when an alarm notification is sent (delays can occur due to downloads, network, etc.).

- The Design-Builder shall conduct the Work in a manner such that vibrations do not exceed the threshold limits identified in table B of Section 2.6.7.4.
- The Design-Builder shall submit an Allowable Limit Monitoring Exceedance Report for each exceedance occurrence. This report shall describe what vibration and/or deformation measurements values were recorded that exceeded the allowable limits; where the impacted instruments are located; when the exceedances occurred; when work was stopped as a result of the exceedance(s); what demolition and/or construction activities caused the exceedance(s); what actions were taken to limit and reduce vibrations and/or deformations; when demolition and/or construction activities were resumed; and what the ensuing vibration and/or deformation measurements were following Work resumption.

Threshold exceedance will be notified by email immediately.

Allowable Limit Monitoring Exceedance Report will be submitted by GRAHAM within 24 hours based on the data available on GEOSCOPE.

- Corrective Action Plans in accordance with Section 2.28 are measures that can rapidly be implemented by the Design-Builder to decrease or stop detrimental vibrations.
- Instruments that are damaged or fail for any reason of nonperformance shall be replaced and re-baselined within two Calendar Days. If the instrumentation cannot be replaced immediately, vibration causing construction activities within the zone of influence shall cease until the instrumentation is replaced and fully operable.

As per the specifications, this Vibration Monitoring Plan should include at least:

- Frequency of monitoring (for all instruments).
- Identification of the personnel (with their qualifications) who will perform the monitoring.
- Vibration and deformation levels that if exceeded, could be potentially damaging.
- Calibration requirements for the systems that shall be maintained at all times during the monitoring program.

2. Automated Monitoring System - AMS

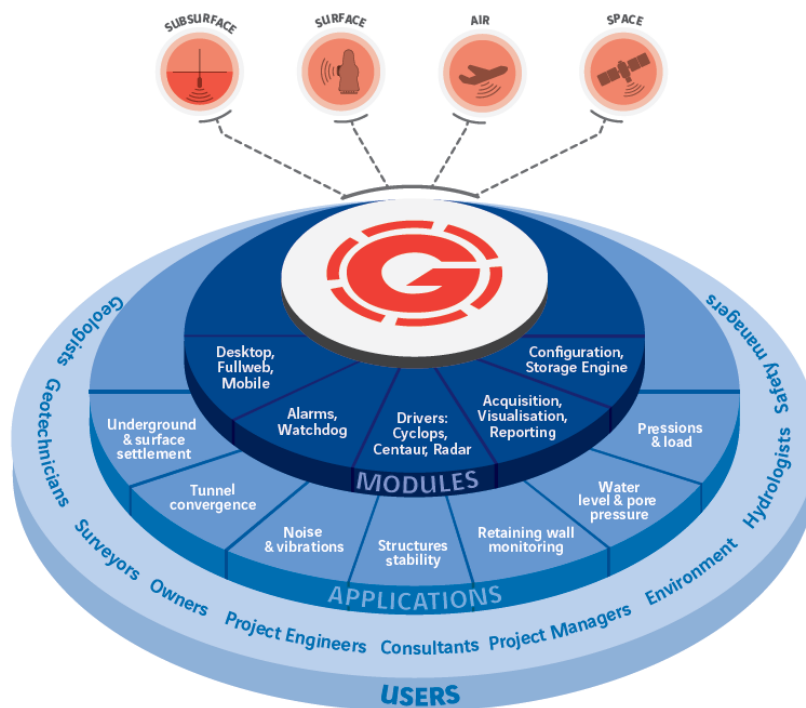
2.1 General

The Automated Monitoring System is an integrated system that automatically collects data from the monitoring instrumentation in the field and places the data into a secure database that can be remotely operated, analyzed, maintained, and accessed.

Thus, the AMS will be comprised of the two following general parts:

- Data acquisition modules located in the field and gathering data directly from the instrumentation
- The data processing system located on our servers and feeding the database

The AMS will operate 24 hours a day, 7 days a week, for the duration of when the monitoring is required and will provide immediate access for all stored data for all authorized users.



The AMS will have the following capabilities:

- Immediately generates email or text alerts of instrument readings outside the set tolerances.
- Logs all alerts in the database for subsequent reporting.
- Able to display current readings in engineering units for any sensor and the entire history of readings for that sensor via a secured web-based database system.
- Messaging to administrators when aspects of the AMS are not functioning or updating correctly.
- Alert message will include the identifier of the instrument exceeding the response level, the data and time of the reading, the value of the reading in engineering units.



- Provide capability for person receiving alert to acknowledge it and to disarm subsequent alert from that sensor.
- Export any data selected by the user into a comma-delineated and XML format for import into other software applications.
- Data for sensors shall be logged at time intervals established and reviewed with the owner: we suggest here that the appropriate time resolution is 1min. This will enable us to track the events with an appropriate resolution.
- The synchronization between the sensors is based on a NTP (Network Time Protocol) synchronization (1 sec difference at the maximum).
- Data and alarms will be pushed by the system with a responsiveness of maximum 10min time frame.
- More details on the AMS capabilities are described in the following sections and Appendices.

2.2 Monitoring System Field Hardware

2.2.1 Assemblies

An assembly is composed of an enclosure containing the different components of the field acquisition system along with the sensors connected to it. Enclosures will be provided to house all the acquisition components and keep them away from dust, moisture. The enclosures are non-corrosive and UV stabilized for hardware protection. Back-plates within the enclosure allow for easy hardware mounting and removal. Padlocks allow for locking and easy opening.

These enclosures will house the following peripheral hardware:

- Power connection and surge protection for the 110V AC source, battery or solar powering (we recommend 110V AC source).
- Back-up battery power
- Data acquisition equipment including dataloggers and field computers
- Data transmission equipment including cellular modems and antennas
- Any necessary interface or connection cables between components

Depending on the location, enclosures will be mounted on existing structures, or a separate pedestal will be provided by the contractor for mounting. All enclosures will be labeled with identification tags listing project number, contact person and phone number. These assemblies should be clearly marked on site and identified, not to create any trip hazard.

2.2.2 Power Supply

Different types of power supply will be used depending on the following parameters

- Duration of monitoring
- Permanent power availability
- Solar effectiveness
- Access to the instrumentation

Due to the conditions on site (experienced on earlier phases of the project), SIXENSE is asking for permanent 110V power source for a more reliable system. Solar can be studied as an option.

2.2.3 Communications

Cellular modems type RV50 from Sierra Wireless will be used for this project and will be connected to the data acquisition equipment. Powered by ALEOS technology, those Sierra Wireless modems are powerful, robust wireless networking and communications platform providing real-time, two-way data exchange.

The antenna type for the modem will depend on the signal strength, which will be determined in the field at the time of installation. Higher gain antennas will be used where signal strength is poor.

2.3 Monitoring System Server and Software

2.3.1 Server

The data transmitted from the on-site instruments will be processed and stored on our server located in a fully secured datacenter facility in the Seattle area. The IT infrastructure is operated and maintained by our IT specialist and data managers with daily checks carried out. The server includes backup power supply and unlimited data storage and is programmed for daily backups. The setup is passive, and after the initial monitoring system programming, no additional manual data management is needed (unless manual data is collected or configuration changes).

Daily data backup will be performed, and a backup server will be operational within 24 hours if the main server is deemed inoperable.

All software applications described below are hosted on the server. The licenses and software keys will be maintained and updated for the duration of the project.

2.3.2 Data Storage and Web-Based Monitoring Software

GEOSCOPE software will be used to manage, format and present the monitoring data. GEOSCOPE applies engineering units and presents graphically the acquired data files from the field. The embedded alarm module scans incoming data for alarm conditions, provides an Alert Notification System with email alerts, and stores the data in a dedicated project database. GEOSCOPE processes and makes the results immediately available via the web or the desktop version.

GEOSCOPE will have the capability to export any data selected by the user into a comma delineated format for import into other software applications.

The web-based portion of GEOSCOPE will be accessible using a standard web browser. When authorized users log on, plan views, trend plots, profile plots, correlation plots, logs, and reports are obtained simply. The website will have the following capabilities:

- Password protection access and different user levels
- Shows graphically the monitoring points and locations in relation to relevant project features (i.e. new construction, existing buildings and services)
- Gives users the ability to choose which project features and monitoring points are displayed
- Displays all data collected since the beginning of the project for any/all instruments for the time period indicated by the user
- Provides the user with ability to view data in either raw or engineering units
- Displays a summary report of the current active alerts from all active instruments with current Response Levels in different colors
- Provides printed reports, either formatted to a printable screen or outputted as a printable version. The reports will include a table with all the monitoring points and their associated status. The table can be inserted as a cover for the general monitoring report.



- Supports exports of reports to comma-delineated formats for import into other applications

Once the correct user name and password are entered, a site map shows instrument locations. This will be customized throughout the life of the project. Multiple plan views, profile views, or any other image will be used for the site map.



3. Quality/Safety

3.1.1 Intent

The monitoring program will be performed in general accordance with the specifications program to ensure that:

- All instruments meet the intent of the specifications
- All instruments are installed in accordance with this submittal
- All instruments maintain functionality and accuracy at all times during the project
- Instrument records will be completed before, during, and after instrument installation.

3.1.2 Substitutions

Whenever any product is specified by brand name and model number, such specifications are deemed to be used for the purpose of establishing a standard of quality and facilitating the description of the product desired.

The term "acceptable equivalent" is to be understood to indicate that the "acceptable equivalent" product is the same or better than the product named in the specifications in function, performance, reliability, quality, and general configuration.

4. Vibration monitors

SIXENSE has got different options to perform the vibration monitoring (depending on mountings required and site conditions).

All these options will match the contract specifications:



Figure 2: MR3000C from SYSCOM



Figure 3: MICROMATE from INSTANTEL



Figure 4: SWARM from OMNIDOTS



Figure 5: SV958A from SVANTEK

They will be located in the vicinity of the demolition/construction area in order to assess vibrations levels induced by the Contractor's activities in the vicinity of the structures and buildings.

Peak Particle Velocity (PPV) will be recorded on X, Y and Z axis with a high accuracy triaxial sensor. The resultant of the 3 components for frequencies between 1 to 315 Hz will be calculated simultaneously.

The following setup will be entered in the instrument (from the data sheet available in appendix):

- Dynamic range +/- 4.000 inch/sec
- Frequency range from 1 to 315Hz
- PPV recording time period = 1min



4.1 Pre-Installation

4.1.1 General

Instruments will be checked for damage and functionality after they are received and stored in a safe and undisturbed place prior to installation. The following general pre-installation procedures will be followed:

- Examine factory calibrations manufacturers quality check documentation
- Examine manufacturer's final quality assurance inspection checklist to verify completeness
- Check instruments for damage and correct quantities
- Check instrument model, dimensions, and materials
- Verify that all instrument components fit together in their final assembled configuration

Pre-Installation Test Forms will be completed for each instrument (See Appendix).

Any instruments that do not pass pre-acceptance testing will be sent back to the manufacturer for repair or replacement and another pre-installation acceptance test will be performed.

4.1.2 Factory Calibrations

All instruments will be recently factory-calibrated prior to shipment to certify that the instrument used is intended to be installed on the project. The factory calibration will be conducted at the manufacturer's facility. The factory calibration reports will be included as an attachment to the pre-installation forms and included in the project logs available in the AMS. These will be provided within seven (7) workdays of receipt of each instrument at the site.

After installation, Vibration monitors will be sent to the factory for calibration every two (2) years.

4.1.3 Instrument Storage

After receipt, all instrumentation will be stored in an indoor, clean, dry, and secure storage space. Instruments will not be exposed to temperatures outside of the manufacturer's stated working temperature range.

4.2 Installation

4.2.1 General

Vibration monitors will remain fully functional over the required monitoring period. The vibration monitors will be installed in accordance with the detailed step-by-step procedures outlined in this submittal. Work activities will be scheduled such that the monitoring instrumentation is installed prior to vibration causing construction activities.

Different installation will be offered depending on the location (indoor, outdoor, building, structure etc.):



Figure 6: Mounting with rugged enclosure + batteries (options)



Figure 7: Mounting on a rigid structure



Figure 8: Indoors mounting (drilled)



Figure 9: Indoors mounting (sealed)



Figure 10: Mounting on a pier



Figure 11: Mounting on a concrete pad

4.2.2 Sensor Installation Details

The sensors are designed to be mounted horizontally or vertically. The main idea is to have the best coherence with the structure to be monitored. We want to avoid the transfer function to be as close as possible from the receptor. The exact locations will be defined having in mind different factors:

- Safe access and no trip hazard created
- Availability of 110V power
- Representativity of the measurement
- Authorization to install/drill from the owner
- Possible vandalism

We recommend two things (based on past experience):

- Sensors have to be mounted on a concrete structure (concrete pad) instead of just being spiked into the ground (with a sand bag on the top), to avoid external disturbances. We want to avoid having to explain exceedances due to meteorological events or activities of the neighbors for example. This will enable us to focus only on sending representative alerts related to the construction.
- Sensors have to be as close as possible to the foundations of the structure to be monitored (not to be too conservative).

Different configurations are anticipated.

The configuration preferred is this one (if mounting directly on structure is not permitted):



- Mount the sensor onto a concrete block 2ftx2ftx1ft (located directly in the backyard of the houses, facing the construction site, at 5 feet from the façade)
- Drill two 5/16" diameter holes on the surface at the top of the concrete block, solidary to the ground.
- Install 5/16" plastic screws anchor/concrete anchors in the holes.
- Align the sensor with the holes and level it with the dedicated leveling screws.
- Fix it with 4 #14 thread lag stainless steel screw.
- Connect the power supply.
- Test the vibration device.

4.2.3 Installation Testing

Instruments will be installed in accordance with heavily tested procedures. The installation details will be recorded on an Instrument Installation Record Form (See Appendix). Pictures of the instruments as they are installed in the field will be included with the record. Instrumentation installation record documentation, including installation record sheets, as-built location plans, initial readings, and vandalism prevention methods will be provided for each instrument. Installation record sheets for each instrument will include applicable items from the following list:

- Project name
- Contract name and number
- General installation notes, including problems encountered, delays, unusual features, and details of any events that may have a bearing on future instrument readings
- Instrument type and number, including readout unit
- Planned and as-built orientation
- Personnel involved with the installations
- Date and time of start and completion
- Space for any necessary measurements or readings during installation to ensure that all previous steps have been followed correctly, including instrument readings made during installation

4.2.4 Instrument Protection

General site requirements that will be considered while installing instruments include:

- Running cables to prevent trip hazards
- Electrical interference and noise
- Loosening/dislodging during construction activities
- Conflicts with subsurface utilities
- Possible vandalism
- Nearby traffic, and maintenance operations.

4.3 Post-Installation

4.3.1 Instrument Post-Installation Tests

Once the instruments have been installed in the field, the components will be checked for stability and initial readings will be performed. All installation records, calibration reports, and post-installation reports will be provided in an installation record. Initial readings will be available in GEOSCOPE soon after the installation is complete.

4.3.2 Monitoring System Post-Installation Tests

The monitoring system will be checked after instruments are installed and wired to ensure data transmission to our server. A remote check will confirm that accurate readings are being uploaded to GEOSCOPE. Once the sensor passed all the tests, the acquisition and visualization configurations will start.



4.4 Long-Term

4.4.1 Instrument Repairs and Replacements

All instruments, connections, and other components of instrumentation systems will be protected from damage due to construction operations, weather, traffic, and vandalism. Any instrument deemed damaged or inoperable will be repaired within 48 hours of receiving replacement instruments, subject to availability by the vendor.

4.4.2 Monitoring Assemblies

Built-in functions and characteristics of the geotechnical and Survey assemblies help maintain performance. All the components are rated for outdoor use and embedded in rugged enclosures. Automated email alerts are generated by the monitoring system and distributed internally to the project staff if incoming data from units is not detected within the reading schedule interval. Those alarms are revised during the daily check performed by the data manager.

4.5 Instruments Removal

After completion of the works and agreement from the Contractor and the Owner, all the monitoring equipment will be shut down and no more data will be collected. Instruments, brackets, prisms and associated cables will be removed. The screws and the plastic anchors will be disposed, and the holes filled with liquid cement, caulk or resin to leave a smooth surface.

5. Simplified risk assessment

This section aims to assess and simplify the anticipated vibration levels that the WABN bridge may experience during the trestle installation and bridge construction as a function of distance.

The drilled shafts installation will include installing traditional temporary steel casing (9-10ft diameter) with a APE 600 vibro-hammer which will induce some vibration to the WABN structure. The impact pile driving associated with the trestle installation will be the single greatest potential source of vibration that the WABN structure will be exposed to.

For this study, the FTA analytical/empirical vibration prediction method has been used to estimate the vibration levels that might propagate from the construction equipment to the vibration sensitive locations.

The fundamental equation used in the model is based on propagation relationships of vibration through average soil conditions and distance, as follows:

$$PPV_{equip} = PPV_{ref} \times \left(\frac{25}{D}\right)^{1.5}$$

With:

- PPV_{equip} , the peak particle velocity of the equipment adjusted for distance, in/sec
- PPV_{ref} the source reference vibration level at 25 ft
- D , distance from the equipment to the receiver, ft

The data in the table below (from FTA manual) provide a reasonable estimate for a wide range of soil conditions.

Table 7-4 Vibration Source Levels for Construction Equipment

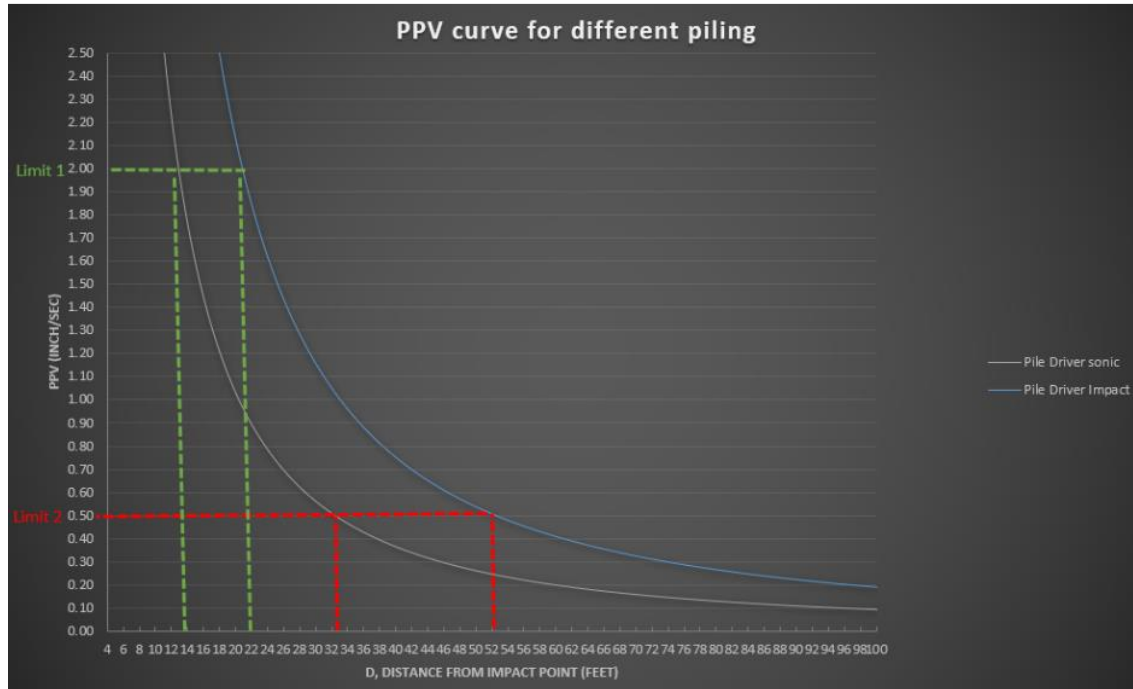
Equipment		PPV at 25 ft, in/sec
Pile Driver (impact)	upper range	1.518
	typical	0.644
Pile Driver (sonic)	upper range	0.734
	typical	0.17
Clam shovel drop (slurry wall)		0.202
Hydromill (slurry wall)	in soil	0.008
	in rock	0.017
Vibratory Roller		0.21
Hoe Ram		0.089
Large bulldozer		0.089
Caisson drilling		0.089
Loaded trucks		0.076
Jackhammer		0.035
Small bulldozer		0.003

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

Comments:

- Conservative values (upper range) will be used, considering the specifications of the equipment being used.

Considering hypothesis (homogeneous propagation of vibrations, average ground conditions, etc), we can therefore have a rough idea of the vibration impact depending on the distance (see below):



The results (based on conservative empirical formulas, according to international standards) show that **the vibration impact of the piling activity may be significant within about 50 feet of distance.**

The calculation method is based on a simplified approach and results may be confirmed by trial tests and vibration continuous monitoring on site for the whole duration of the project.

6. Unattended automatic monitoring

The monitoring layout and points identification, as well as the alarms set up location by location are available in appendix 7.

Structures that will be monitored are as follow. At this stage, the exact location of each instrument on these structures is not defined yet (contact with neighbors being established).

Structures monitored:

- Montlake Bridge (WSDOT Bridge 513/10)
- 24th Ave Bridge (WSDOT Bridge 520/5)
- WABN
- WCB Bridge (WSDOT Bridge 520/7.7S)
- Various Retaining Walls
- Various Homes

6.1 Initial Readings

This section describes the initial reading procedures for determining background behavior for each instrument. Initial reading periods will be obtained and agreed upon with the contractor prior to significant demolition activities.

All initial readings will be available in Geoscope, and the thresholds may be updated depending on these initial readings. We believe that 7 days of initial readings is a minimum before the start of the heavy works on site.

6.2 Reading schedule and frequency

Vibration readings will be obtained by the acquisition units. The data will be automatically transferred to the instrumentation server and posted to the GEOSCOPE website. If reading alerts are detected, notification emails will be sent out to pre-defined personnel within 10 minutes.

The Geoscope acquisition system will be configured so that data will be stored in the database in near real time.

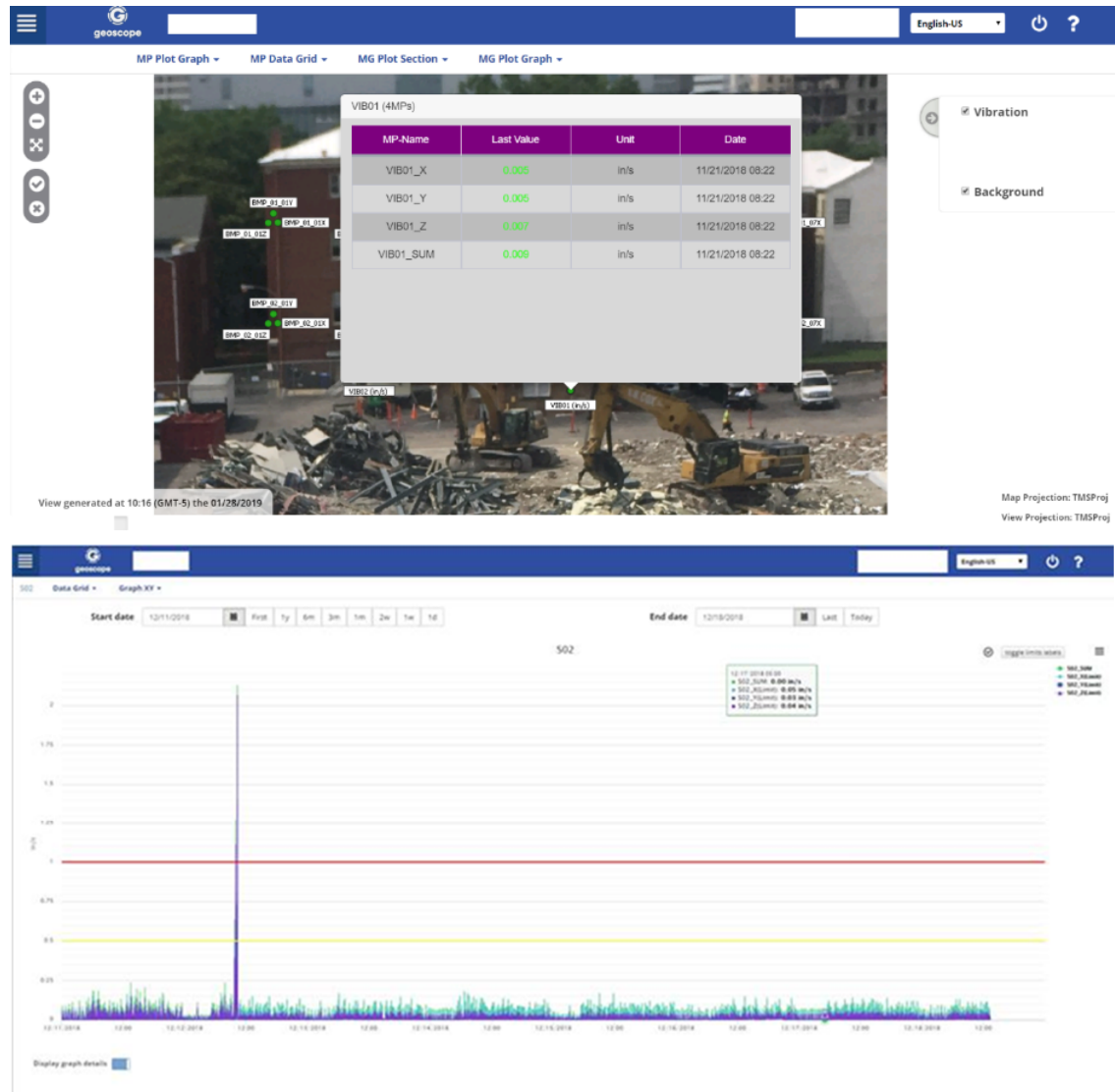
Sensors will be configured to register one measurement per minute.

	Pre-demolition initial readings		Construction		Post-construction	
	Duration	Frequency	Duration	Frequency	Duration	Frequency
Vibration	7 days minimum	Every minute	During operations	Every minute	N/A	N/A

6.3 Provided measurements

Vibration sensors will provide peak particle velocity (PPV) on the X, Y and Z axis in inches per second. The vector sum will be calculated as the resultant.

All the measure points will be accessible from a web-based interface where graphs can be plotted by the users.



6.4 Applicable limits

The section 2.6.7.5.4 of the Request for Proposal (RFP) provides the vibration limits

Table B - Peak Particle Velocity Limits for Vibrations of Existing Structures and Facilities caused by Demolition and Construction Activity

Location	Threshold Limit	Allowable Limit
On-Land Facilities and Structures	Peak Particle Velocity (from transient or continuous vibration source)	
Type I - Reinforced-concrete and steel structures (without plaster) such as industrial buildings, masts, retaining walls, unburied pipelines, open channels; underground structures such as caverns, tunnels, galleries, lined and unlined	0.38 inches per second	0.50 inches per second
Type II - Buildings with concrete floors and basement walls, above-grade walls of concrete, brick or ashlar masonry; ashlar retaining walls, buried pipelines; underground structures such as caverns, tunnels, and galleries with masonry lining	0.26 inches per second	0.30 inches per second
Type III - Buildings with concrete floors and basement walls, above-grade masonry walls, timber joist floors and ceilings	0.15 inches per second	0.20 inches per second
Type IV - Structures identified as historic, are particularly vulnerable to vibrations	0.09 inches per second	0.12 inches per second

Threshold limit = amber alert

Allowable limit = red alert

These limits correspond to typical cosmetic structural damage. We suggest considering mainly the type 3 building for housings surrounding the project.

On the top that, the following threshold have been applicable for the WABN bridge vibration in the past.

Cosmetic Structural Damage – WABN Bridge

Location	Threshold limit PPV inch/sec	Allowable limit PPV inch/sec
WABN bridge	1.500	2.000

Threshold limit = amber alert

Allowable limit = red alert

6.5 Corrective Action Plan

According to the contract specifications, the Design-Builder shall take the following actions if any instrument measurement reaches or exceeds the threshold value, but is less than the allowable value, listed (**Amber alert**):

1. The measurement shall be verified by the contractor and the WSDOT will be notified immediately as well as the EOR. Event should be disqualified if corresponding to disturbances on site (stepping on the sensor for instance).
2. Contractor will identify what work operations are contributing to the threshold level alert and determine if they may continue or if work should be stopped immediately.
3. Determine the cause of the vibrations. If they are caused by construction activities, evaluate the activities to determine a practical method to reduce the vibrations. The specific Corrective Action Plan cannot be developed until the cause of the vibrations have been identified.
4. Report vibration measurements to WSDOT until the Design-Builder has verified that the vibrations have been limited or reduced. If it is not already being read continuously, double the monitoring frequency of the affected monument, and monitor the adjacent monuments at the same frequency as the affected monument until the displacements and vibrations have stabilized.
5. Verify that the corrective actions have limited or reduced vibrations to levels at or below the threshold values.
6. If the increasing trends of the vibrations have not been stopped within 48 hours of exceedance, then the Design-Builder shall revise their Corrective Action Plan.
7. The Design-Builder may continue work while the steps specified above are underway.

If measurements reach or exceed the allowable limits (**red alert**), the Design-Builder shall:

1. Immediately cease all operations contributing to vibrations.
2. The measurement shall be verified by the contractor and the WSDOT will be notified immediately as well as the EOR. If the level was generated by a false alarm from the monitor, the Contractor shall review the measurements and verify that the measurements were false (disturbance). The Contractor will also verify there is no damage to the monitored structures.
3. Exceedance report must be filled only for genuine alarms. False readings (from kicking the sensor from example will be disregarded).
4. Determine the cause of the vibrations. If they are caused by construction activities, evaluate the activities to determine a practical method to reduce the vibrations. The specific Corrective Action Plan cannot be developed until the cause of the vibrations have been identified.
5. If the Corrective Action Plan is already being implemented and the corrective actions have not limited or reduced vibrations as required, revise the Corrective Action Plan.
6. Transmit the Revised Corrective Action Plan to WSDOT for a 48-hour Review and Comment period. The Design-Builder shall not resume the work that caused the vibration allowable limit to be exceeded until receiving and resolving WSDOT's comments on the Revised Corrective Action Plan.
7. Implement the Revised Corrective Action Plan.
8. Under some circumstances, corrective actions may require modification of construction procedures. Further investigations can be done by a consultant during the following days of an event.
9. The Design-Builder shall submit an Allowable Limit Monitoring Exceedance Report for each exceedance occurrence. This report shall describe what vibration measurements values were recorded that exceeded the allowable limits; where the impacted instruments are located; when the exceedances occurred; when work was stopped as a result of the exceedance(s); what demolition and/or construction activities caused the exceedance(s); what actions were taken to limit and reduce vibrations; when demolition and/or construction activities were resumed; and what the ensuing vibration and/or measurements were following Work resumption.



Examples of few hypothetical mitigation measures for exceedances to the vibration limits are presented below:

- ▶ Scenario: Experiencing vibration limit exceedances on the WABN Structure due to impact pile driving of trestle pile.
 - Mitigation Option #1 – Reduce the hammer setting on the impact hammer. This may require additional Pile Driving Analysis to be performed, ideally the initial PDA will provide blow counts for each hammer setting.
 - Mitigation Option #2 – Downsize the impact hammer to be used. This will require additional Pile Driving Analysis to be performed. Proper pile bearing criteria may not be met if the hammer size must be reduced.

- ▶ Scenario: Asphalt paving operations on city streets causing vibration limit exceedances in the nearby historic buildings.
 - Mitigation Option #1 – Vibratory rollers typically impose the greatest vibration during sudden direction changes with the vibration engaged. In order to reduce this, turn off vibrations during direction changes and slow down the rate of direction changes.
 - Mitigation Option #2 – Downsize equipment, this can reduce the effectiveness of compaction, and may prevent sufficient compaction levels from being achieved.

- ▶ Scenario: Select bridge or wall demolition activities are inducing vibration limit exceedances in nearby walls or bridges that are not to be demolished concurrently.
 - Mitigation Option #1 – Completely cut through any wall or pier that is connecting the demolished structure to the not to be demolished structure.
 - Mitigation Option #2 – Evaluate the demolition means and methods and switch to methods that induce less vibration, such as multiple saw cuts to reduce the amount of effort that demolition requires or using hydraulic munchers instead of hydraulic breakers.

6.6 Routine Monitoring procedure

Vibration monitoring will occur in accordance with the international standards and best practices.

These practices include calibration, monitoring requirements for obtaining initial readings vibration levels prior to construction, vibration monitoring during construction and changes to monitoring procedures in the event vibration levels reach the different trigger levels ("Action Levels").

Good communication between the monitoring expert and the contractor is necessary.

The good functioning of the system will be checked daily by an instrumentation engineer.

In case of external event (damages to the equipment), a remote connection check or manual check will be performed to restore the good functioning of the system.

6.7 Instrument Replacement Procedure

If an instrument is found to be not working or not possible to calibrate on the field, it will be replaced by an equivalent one following the procedure:

- Switch off the monitoring data acquisition and alarms.
- Swap the hardware.
- Configure the new data acquisition and alarm (same measure point name for the client = transparent operation).
- Update the monitoring plan with new calibration certificates and serial numbers.

6.8 Email and text messages notifications

The monitoring system will be programmed to recognize Action and maximum levels as defined above. The AMS will have an administrative interface to allow adding and removing recipients all along the project.

Alerts shall initiate automatic messaging by email and text messages to a pre-selected address list as approved by the contractor/owner. The electronic message will contain the sensor identification, date and time of reading, alarm level, and value.

6/23/2019 13:00:00 – Name: MEASURE - Alarm level: Alarm level 1 - Movement: 0.XXX In/s

6/23/2019 13:00:00 = Date and time of the event

MEASURE = Measure point name in alarm

Alarm level 1 = Alarm level of the event which can be High 1 or High 2.

The alarm notification configuration can be modified on request regarding the threshold levels or the measure points. The list of recipients can also be modified.



6.9 Recipients and Content

If a threshold is exceeded, an alarm is sent to a group of email addresses and phone numbers. The list includes personnel from GRAHAM, SIXENSE, WSDOT, SEATTLE and associated engineering firms. Prior to the alarm module configuration, General Contractor needs to provide the complete list of personnel to be inserted in the monitoring system alarms as per the table below.

Name	Company	Email	Cell Phone #	Type of alerts
Jeremy TURPIN	SIXENSE	Jeremy.turpin@sixsense-group.com	412-398-0976	System Amber Red
Zhangwei NING	SIXENSE	Zhangwei.ning@sixsense-group.com	206-276-4485	System Amber Red
John Welch	GRAHAM	johnwe@grahamus.com	206-713-7312	Amber Red
Vaughn Jorgensen	GRAHAM	vaughnj@grahamus.com	425-757-3543	Amber Red
James Gunther	GRAHAM	jamesgu@grahamus.com	425-628-1555	System Amber Red
Wally Chen	GRAHAM	wallyc@grahamus.com	206-228-6269	Amber Red
Dan Raynor	AMERICAN BRIDGE	draynor@americanbridge.net	412-522-6612	Amber Red
Jon Vannoy	WDOT	vannoyj@consultant.wsdot.wa.gov	850-333-0692	Amber Red
Steve Strand	WDOT	strands@wsdot.wa.gov	206-770-3565	Amber Red

General Contractor will call and email the contact(s) listed.

The recipients can be configured by groups to receive only alarms relevant to a structure or a type of instrument.

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