New Hampshire DOT

Research Record

Ground Vibrations Emanating from Construction Equipment

Final Report

Prepared by New Hampshire Department of Transportation, in cooperation with the U.S. Department of Transportation, Federal Highway Administration

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16. Abstract

The recent trend in highway construction within New Hampshire has been toward reconstruction and rehabilitation projects in congested urban areas. This has resulted in a greater concern for vibrations generated by non-blasting construction activities, a greater potential for complaints, increased potential for damage, and increased need to monitor vibrations during the construction phase of projects.

A procedure for assessing the potential impact of non-blasting construction-induced vibrations at a project site has been modeled after the "Rock Fall Hazard Rating System" as published in the Federal Highway Administration's "Rock Slopes Reference Manual" (FHWA HI-99-007). An impact assessment of construction vibrations can consider each type of vibration producing activity and the potential impact that activity would have on man-made structures and/or vibration sensitive equipment that is in relevant proximity to the project site. A "Construction Vibration Impact Assessment Table" was developed, providing a means of rating the potential impact of a specific construction activity at a given site. This rating will allow comparison of a specific construction activity at different sites, or different construction activities at the same site.

The "Construction Vibration Database" was created as part of this research project, with the intent of providing a means of recording information on various types of non-blasting construction vibration activities. It is intended that this database will be continually updated with data submitted by both in-house resources and by vibration consultant subcontractors working on NHDOT projects. This database will provide designers with a means of accessing empirical data to be used for forecasting expected vibration impacts on upcoming construction projects.

The "Construction Vibration Assessment Procedure" and "Construction Vibration Database" can be used to develop a preliminary cost estimate for vibration monitoring services and as a resource for decision-making during the design and construction phases of NHDOT projects. Information was collected on a variety of non-blasting construction activities to include vibratory compaction, excavation, splitting of rock with a hoe-ram, sheet pile driving, pavement breaking, demolition, track mounted vehicles and heavy construction traffic at various project sites throughout the state.

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Ground Vibrations Emanating from Construction Equipment

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EXECUTIVE SUMMARY

The recent trend in highway construction within New Hampshire has been toward reconstruction and rehabilitation projects in congested urban areas. This has resulted in a greater concern for vibrations generated by non-blasting construction activities, a greater potential for complaints, increased potential for damage, and increased need to monitor vibrations during the construction phase of projects.

A procedure for assessing the potential impact of construction-induced vibrations at a project site has been modeled after the "Rock Fall Hazard Rating System" (RHRS), as published in the Federal Highway Administration's "Rock Slopes Reference Manual" (FHWA HI-99-007). The RHRS, developed by Pierson et al. (1990), has a rating criteria and scores for various categories of existing conditions with scores that increase exponentially from 3 to 81 points. The "Construction Vibration Assessment Process" utilizes a similar formula.

The "Construction Vibration Assessment Process" can be used to consider each type of vibration producing activity and evaluate the impact that activity would have on man-made structures and/or vibration sensitive equipment that is in relevant proximity to the project site. A "Construction Vibration Impact Assessment Table" (Appendix A, Table 1) was also developed, providing a means of rating the potential impact of a specific construction activity at a given site. This rating will allow comparison of a specific construction activity at different sites, or different construction activities at the same site.

In addition, the "Construction Vibration Database" was developed. It is intended that information on various types of non-blasting construction vibration activities will be collected, stored, and tracked in this database. As part of this research project, information has been collected on a variety of non-blasting construction activities including vibratory compaction, excavation and splitting of rock with a hoe-ram, sheet pile driving, pavement breaking, demolition, track mounted vehicles, and heavy construction traffic at various project sites throughout the state. It is intended that this database will provide designers with a means of accessing empirical data to be used in predicting expected vibration impacts on upcoming construction projects.

The "Construction Vibration Assessment Process" and "Construction Vibration Database" can be used to develop a preliminary cost estimate for vibration monitoring services and as a resource for decision-making during the design and construction phases of NHDOT projects.

INTRODUCTION

Energy from construction activities is transmitted into the ground and radiates out from the source of the energy in the form of stress waves. These waves move through the ground similarly to how waves move through a body of water. The potential effects from vibrations produced by the stress waves moving through the ground can include damage to structures, settlement of loose soils, liquefaction of sensitive soils, interference with sensitive equipment/processes, and annoyance of people. Therefore, it is important to accurately measure the ground motion (vibrations), to develop a vibration prediction model for a given site and construction activity, and to develop a site-specific plan for minimizing the construction vibrations. The combined effect of topography and underlying geology results in a unique vibration pattern at every site (Nutting, 1990).

In 1980, the U.S. Bureau of Mines (USBM) established frequency-based limits on blast-induced vibrations for building structures (Siskind, 1980). Although these limits (refer to Figure 1) are known to be conservative, most government agencies have based their regulations and guidelines for other vibration producing construction activities on the USBM blasting study (Oriard, 2002). In general, high explosives transfer greater amounts of energy into the ground than that generated by other types of construction activities. The methods for predicting the vibrations generated by blasting activities are well established and supported by numerous studies. With the exception of variations in the geology and subsurface conditions, vibrations from blasting can often be predicted with reasonable accuracy.

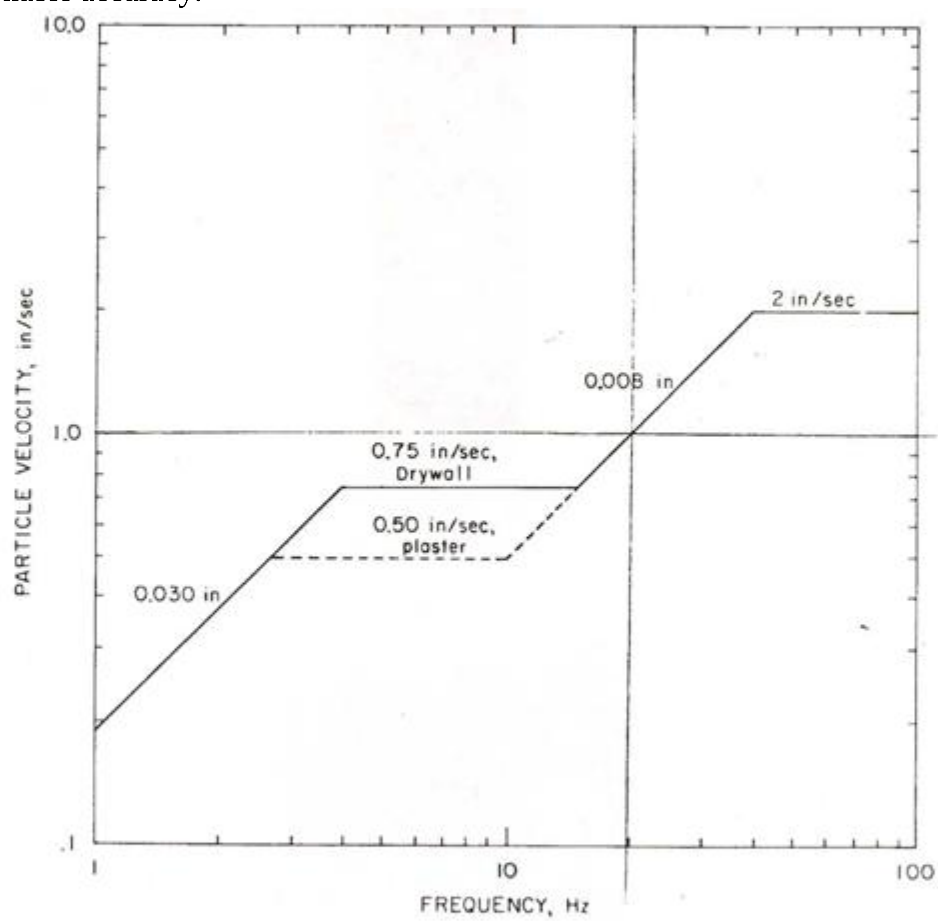


Figure 1 - Vibration Level Blasting Criteria for Residential Structures from OSM, RI 8507, 1980

At present, there are no methods that can consistently and accurately predict vibrations generated by all types of construction activities. The vibrations produced by construction activities (i.e. vibratory rollers, pile driving, pavement breakers, heavy construction equipment, dynamic compaction, track mounted equipment, etc.) are affected by numerous variables. The variety of construction equipment and procedures make it difficult to group construction activities by the expected intensity of vibrations (Oriard, 2002). A better approach is to group equipment types and activities by the method in which the energy is transferred to the ground. There are four mechanisms for transferring energy (Dowding, 1997) (Oriard, 2002):

Impulse – pavement breaker, blasting with explosives, dynamic compaction, drop ball, impact pile driving, etc.
Reciprocating – vibratory roller, vibratory pile drivers, compressors, etc.
Rotating – trenchers, tunnel boring machines, etc.
Rolling – trucks, trains, off-road haulers, etc.

It is common practice to measure construction vibrations as velocity vs. time or peak particle velocity (PPV). The velocity in the soil at a specified distance and direction away from the vibration producing activity depends on the type of vibration (impact, steady state, pseudo-steady state, etc.), the mechanism for transferring the energy, the type of equipment, the equipment's horsepower, the quantity of energy input, and the underlying geology (Wiss, 1981) (Dowding, 1996). The intensity of the construction vibrations and how those vibrations are transmitted throughout a site will depend on the type of construction activity, the distance from the energy source, and the type of soil medium between the source and receiver. The geology and subsurface conditions can vary significantly within the limits of a construction site. This often results in a variation in the measured vibrations at the same distance, but different direction from an energy source. Studies conducted by Forsbald (1974), and Steinberg and Lukas (1984) show that the difference between a loose and stiff soil can affect particle velocities by five to seven fold. Groundwater and major structural features in the bedrock (i.e. faults, joints, etc.) can significantly affect the vibration intensity and can cause directional focusing of vibration energy at a site. All of these factors, along with the duration of the construction activity; type, age and condition of nearby manmade structures; sensitivity of equipment and manufacturing processes; and the makeup of the surrounding population must be considered in determining the potential impact of construction vibrations at a site.

Assessing the potential impact of a construction activity at a site by the type of vibration generated may be more appropriate. There are two basic types of vibrations generated by construction activities. The first type is "continuous vibration" generated by equipment or activities that typically transmit lower levels of energy over longer periods of time (Jones, 2004). Examples of this type of vibration are:

- Excavation equipment
- Static compaction equipment
- Track mounted equipment
- Traffic on roads or haul roads
- Vibratory pile drivers
- Pile-extraction equipment
- Vibratory compaction equipment

The second vibration type is "transient vibrations", which are single-impact or low-rate impact vibrations generated by construction activities that often transmit high levels of energy (Jones, 2004). Examples of this type of vibration are:

Impact pile drivers
Dynamic compaction
Blasting (not included in this study)
Drop balls

Some construction equipment and activities, such as pavement breakers, hoe-rams and jackhammers produce a third type of vibration involving "high-rate repeated impact" (Jones 2004).

All three types of vibrations can cause problems and provoke complaints. People are normally more sensitive to continuous vibrations than to transient vibrations. Therefore, in some circumstances they may be more tolerant of higher levels of transient vibrations. There is a greater potential for complaints the longer the duration of the vibration producing activity.

OBJECTIVES

The objectives of this research study are as follows:

1. Provide a method for assessing the potential level of impact from vibrations generated by a proposed construction activity at a specified site.
2. Establish a database of ground vibrations emanating from various construction activities that could serve as a tool for decision making during the design and construction phases of NHDOT projects.
3. Provide guidelines for estimating hours and cost of vibration services, as described in Section 211 of the NHDOT "*Standard Specifications for Road and Bridge Construction",* for proposed construction projects.
4. Identify the types of equipment and construction activities that could cause damaging vibrations or complaints.

The methods developed for assessing potential impact of construction vibrations and for quantifying vibration services should be reviewed periodically and further refined over time.

BACKGROUND

The trend in highway construction work within New Hampshire has been toward a greater percentage of reconstruction and rehabilitation projects in more congested urban areas. This has resulted in a greater concern for vibrations generated by construction activities, a greater potential for complaints, an increased potential for damage and an increased need to monitor vibrations during the construction phase of projects. The large number of variables and unknowns at each site make it difficult to estimate the level of vibration monitoring services needed for a proposed project. There have been no established guidelines for assessing the potential impact of vibrations generated by construction activities on NHDOT projects. There has been no consistency in how specifications have been applied, no analysis of past vibration data and no attempt to determine reasonable limits based on potential risk factors at a site. A more standardized approach could potentially save money and make more effective use of limited resources.

METHODOLOGY

Data utilized in this research study comes from published information, data collected by consultants working on NHDOT construction projects, and vibration monitoring by the Bureau of Materials & Research on a variety of construction activities. The equipment used by the NHDOT for monitoring in-house construction vibrations was a GeoSonics SSU 3000 EZ+ seismograph (Figure 2) and two SSU Micros II seismographs. The SSU 3000 EZ+ unit has a seismic range of 5.120 in/sec, a frequency response range of 2-250Hz (3dB) and 2-1000 Hz (Nyquist), a sampling rate up to 2000/sec/channel, and a record time of 1 to 15 seconds. In histogram mode the recording intervals are 1, 2, 5, 10, 15, 30, and 60 seconds. The seismographs measure the three mutually perpendicular components of particle velocity in directions vertical, radial, and perpendicular to the vibration source. The equipment measures the corresponding frequency of the maximum peak particle velocity for each of the mutually perpendicular components. Seismograph equipment utilized by consultants on NHDOT projects had similar capabilities. NHDOT specifications require that all vibration monitoring instrumentation used on its projects be calibrated within the last 12 months and the calibration must be performed to a standard traceable to the National Institute of Standards and Technology. The NHDOT seismographs were calibrated annually. All vibration monitoring data was analyzed for peak particle ground vibrations (in/sec) and frequency (Hz). Whenever possible the ground vibrations were monitored over a range of distances from the source of the vibrations and subsurface conditions at the site were verified by referencing geotechnical reports.

Figure 2 - GeoSonics SSU 3000 EZ Seismograph

RESULTS AND DISCUSSION

Information was collected on a variety of construction activities including vibratory compaction (Figure 3), excavation, sheet pile driving (Figure 4), pavement breaking (Figures 5 and 6), splitting of rock with a hoe-ram (Figure 7), demolition, heavy construction traffic (Figure 8), and track mounted vehicles (Figure 9) at various project

Figure 4 - Vibratory roller compacting base course material

sites throughout the state. The construction activities that often generate the greatest number of complaints on NHDOT projects are vibratory compaction (continuous vibration) and impact pile driving (transient vibration). This may be due in a large part to the fact that these activities occur regularly on NHDOT projects, while other high level vibration producing construction activities occur less frequently. Although these activities sometimes generated complaints, there were no documented cases where vibrations caused even minor damage to nearby structures. The highest vibrations during pile driving on NHDOT projects were often measured during the start-up and shut down

Figure 3 - Pile driving

of pile driving equipment.   This is consistent with observations and measurements made by others (Woods, 1997). In addition, higher vibrations were sometimes measured during the extraction of piles compared to the driving of piles. The highest vibrations for vibratory compaction were often measured when the vibratory roller quickly changed direction. Pavement breakers and hoe-rams sometimes generated peak particle velocities that exceeded those for vibratory compaction and pile driving. Even though the vibrations from these activities could be higher than other construction induced vibrations they did not occur as frequently on NHDOT projects. Vibrations from traffic and other construction activities were generally lower than the above construction operations. On a few occasions there have been vibration complaints concerning heavy construction trucks. In each case they involved heavily loaded trucks, driving at high speeds on rough surfaces or on roads with potholes. In several instances there were significant vibrations caused by track mounted equipment traveling on paved surfaces.

Figure 5 - Pavement breaker for rubblizing concrete

Figure 6 - Vibrating foot on pavement breaker

Figure 7 - Hoe-ram breaking up rock

Figure 8 - Construction truck loaded with rock on haul road

Figure 9 - Bulldozer on rock fill

Most vibrations emanating from non-blasting construction activities fall in the low frequency range (5 to 30 Hz) and rarely cause damage to structures (Dowding, 1996). In most cases, the vibrations and frequencies measured on NHDOT projects fell within the ranges commonly published in other studies. As expected there were significant variations from site to site, influenced by geological/subsurface conditions. At some sites changes in the underlying geology was the primary cause for variations in the measured vibrations at the same distance, but in different directions from the vibration source.

Most homeowners believe that if they can feel the vibrations, then it must be causing damage to their home. Numerous studies have shown that humans are very sensitive to vibrations (Figure 10). People will often feel the vibrations and become annoyed long before even minor damage occurs to man-made structures (Hendriks, 2002). Studies have shown that people can feel vibrations in the range of 0.02 in/sec (Konya, 2006). Minor cracking of dry wall joints can occur above 4.00 in/sec. The threshold for structural damage to timber-framed structures is approximately 8.0 in/sec. The threshold for cracking of a concrete slab or driveway is 10.0 in/sec. These limits are significantly higher than the limits specified by the NHDOT and hundreds of times greater than the limits of human perception. Daily environmental changes can exert enormous strains on a structure. A 10 percent change in humidity is equivalent to vibrations in the range of 1.0 to 2.4 in/sec. A 10-degree fluctuation in temperature causes strains equal to vibrations in the range of 1.0 to 3.2 in/sec. A 20 mph wind is equivalent to vibrations in the range of 0.6 to 2.6 in/sec, while a 50 mph wind can exert stresses equal to vibrations ranging from 1.1 to 6.7 in/sec. Everyday occurrences such as slamming the front door of a house can generate vibrations between 0.15 and 1.9 in/sec and the simple act of driving a nail in a wall can result in vibrations ranging from 0.2 to 2.1 in/sec. (Northwestern University, 2010). Structures in the northeast region of the United States are regularly subjected to stresses caused by environmental changes due to rapid changes in temperature and humidity, changes in the moisture content of the underlying soils and freeze/thaw cycles during the spring period. Environmental changes and everyday activities generate stresses on structures that are often greater than those caused by nearby construction activities.

Vibration Level (Peak Particle Velocity)*			
mm/s	**in/sec**	**Human Reaction**	**Effect on Buildings**
0.15-0.30	0.006-0.019	Threshold of perception; possibility of intrusion	Vibrations unlikely to cause damage of any type
2.0	0.08	Vibrations readily perceptible	Recommended upper level of the vibration to which ruins and ancient monuments should be subjected
2.5	0.10	Level at which continuous vibrations begin to annoy people	Virtually no risk of "architectural" damage to normal buildings
5.0	0.20	Vibrations annoying to people in buildings (this agrees with the levels extablished for people standing on bridges and subjected to relative short periods of vibrations)	Threshold at which there is a risk of "architectural" damage to normal dwelling - houses with plastered walls and ceilings Special types of finish such as lining of walls, flexible ceiling treatment, etc., would minimize "architectural" damage
10-15	0.4-0.6	Vibrations considered unpleasant by people subjected to continuous vibrations and unacceptable to some people walking on bridges	Vibrations at a greater level than normally expected from traffic, but would cause "architectural" damage and possibly minor structural damage.

** The vibration levels are based on peak particle velocity in the vertical direction. Where human reactions are concerned, the value is at the point at which the person is situated. For buildings, the value refers to the ground motion. No allowance is included for the amplifying effect, if any, of structural components.*

Source: "A Survey of Traffic-induced Vibrations" by Whiffen and Leonard, Transport and Road Research Laboratory, RRL Report LR418, Crowthorne, Berkshire, England, 1971.

Figure 10 - Human Reaction and Effect on Buildings at Different Levels of Continuous Vibrations (A Survey of Traffic-induced Vibrations, 1971)

The typical levels of ground-borne vibrations for common vibration producing activities compared to human and structural responses at different levels are shown in Figure 11 with a conversion from Velocity Level (VdB) to inches per second.

The 2006 Federal Transit Administration (FTA) manual, "*Transit Noise and Vibration Impact Assessment*, recommends a procedure for estimating vibration impact from construction activities. The procedure utilizes a reference distance of 25 feet (distance from the source of vibration that the original data was collected) and involves the following three steps:

1. Select the type of construction equipment and associated vibration source levels from a table in the FTA manual (reproduced as Table 1 in Appendix D).

2. Use the following formula to make the propagation adjustment (based on point sources with normal propagation):

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

Where:

PPV_{equip} is the peak particle velocity (in/sec) of the equipment adjusted for distance

PPV_{ref} is the reference peak particle velocity (in/sec) at 25 feet from the FTA table (refer to Appendix D, Table 1)

D is the distance from the equipment to the receiver

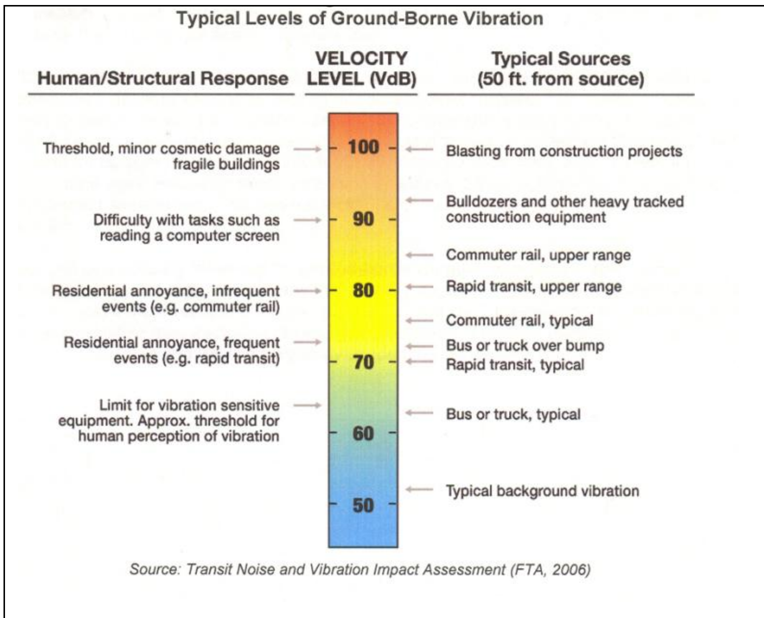
3. Apply the vibration damage threshold criterion of 0.20 in/sec for fragile buildings, 0.12 in/sec for extremely fragile historic buildings.

The FTA manual states that the peak particle velocity (PPV) for each type of construction activity listed in their table is a reasonable estimate for a wide range of soil conditions.

We recommend utilizing the FTA formula with a power of 1.1 for estimating vibrations on NHDOT projects.

$$PPV_{equip} = PPV_{ref}\,(25/D)^{1.1}$$

Solving the equation utilizing a power of 1.1 and a distance (D) greater than 25 feet results in predictions with higher levels of vibrations (more conservative), which are closer in agreement with the data collected in the NHDOT study (See Appendix D, Page 45, NHDOT Vibration Levels for Construction Activities).



Inches/Second = VdB
.056 in/sec = 100 VdB
.018 in/sec = 90 VdB
.0056 in/sec = 80 Vdb
.0018 in/sec = 70 VdB
.0006 in/sec = 60 VdB The VdB is a logarithmic scaling of vibration magnitude

Figure 11 - Typical Levels of Ground-Borne Vibrations from Transit Noise and Vibration (Federal Transit Administration, 2006)

A chart titled “Typical Vibration Sources and Sensitivities” (Figure 12), published by Nugent & Amick in 1992, depicts various vibration sources and peak ground velocity (in/sec) verses effects on structures, people and equipment. The chart is a good overview of how vibrations emanating from typical construction activities relate to vibrations from other sources, and the level of potential impact.

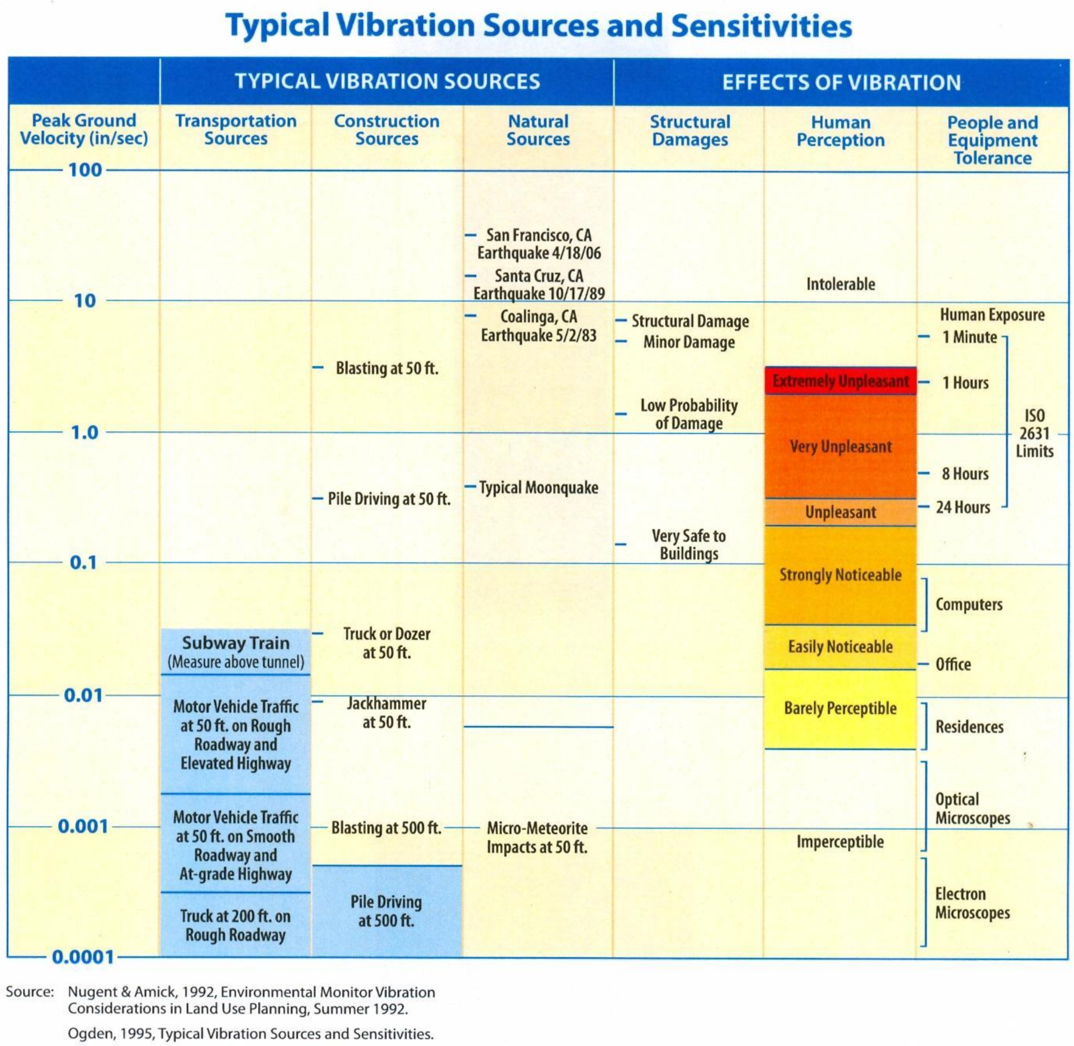


Figure 12 - Typical Vibration Sources and Sensitivities, (Nugent & Amick, 1992)

A series of curves for typical earth vibrations (Figure 13), showing peak particle velocity in mm/s versus distance from source in meters, was developed by Wiss as a comparison of different vibration producing construction activities (Wiss, 1981). Vibration levels for various construction activities taken from several source documents and measurements collected on NHDOT projects are listed in Appendix D. The wide range of vibrations measured for similar activities emphasizes the challenge and difficulty in comparing results from different sites. Although, the NHDOT vibration measurements were sometimes higher for similar activities at approximately the same distances when compared to other published studies, there was good agreement in the overall ranking of vibration levels for different types of construction operations. This information should be used to evaluate the potential level of impact of different activities, not necessarily to predict the actual vibration levels. More accurate predictions can only be made after a site specific study has been conducted.

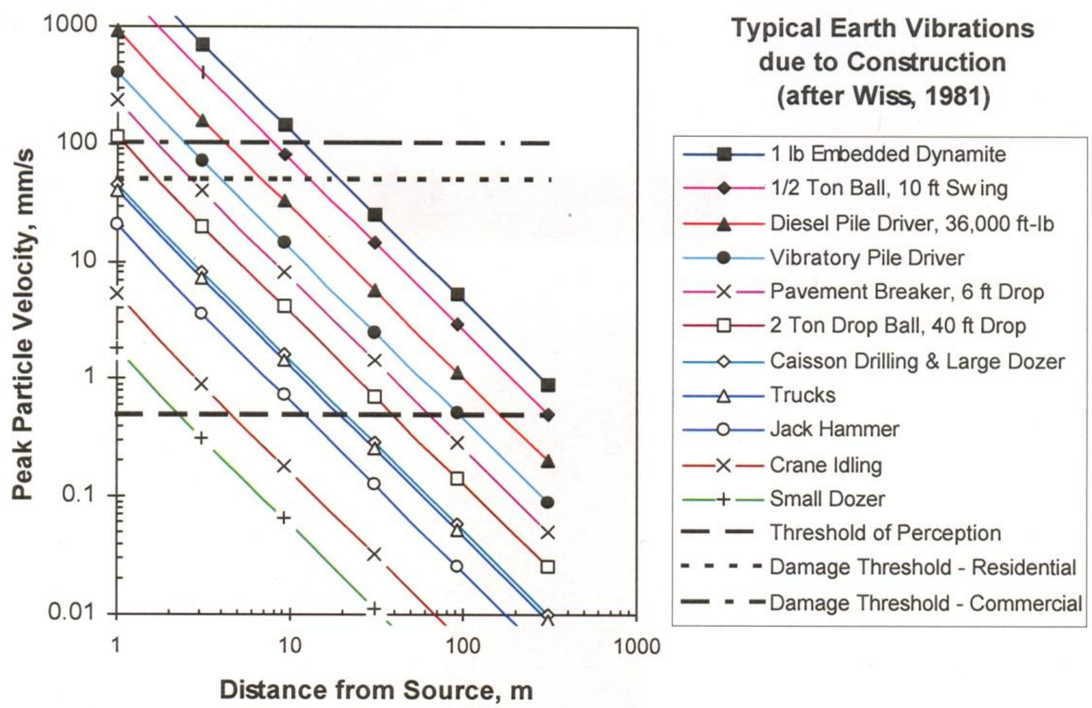


Figure 13 - Construction Vibrations as a Function of Distance, (Wiss, 1981)

DEVELOPMENT OF A "CONSTRUCTION VIBRATION DATABASE"

A standard approach for assessing the potential impact of construction vibrations at a project site and for estimating the level of monitoring services would be helpful to planners, designers and construction personnel. Collecting and tracking vibration data of various construction activities on NHDOT projects could be a valuable resource toward developing and modifying standard specifications, and in making informed decisions during the design and construction phases of projects. A suitable database would track vibration events, evaluate the potential impact, determine the variables involved, and compare different vibration producing activities from site to site. The following categories of data were identified as crucial in developing the framework for a construction vibration database:

Project Information – project number, town, project description, person or company collecting the data

Event Information – vibration activity to include type and model of equipment producing the vibrations, nearby structure type(s) and condition, population sensitivity, type of vibration (continuous, single event, high-rate repeated impact)

Seismograph/Sensor Information – Manufacturer and model, last calibration date, sensor(s) location, distance from vibration source to sensor, monitoring period to include time and date

Subsurface Conditions – Soil type(s), density and thickness of layers, depth to bedrock, groundwater depth

Readings – time, velocity (in/sec), frequency (HZ), type (longitudinal, transverse, vertical)

The “Construction Vibration Database” is a relational database that allows stored information to be sorted based on certain common characteristics. The database serves as a tool to assess the potential impact that various types of construction activities may have at a project site based on the surrounding conditions (i.e. population sensitivity, type and condition of nearby structures), the underlying subsurface materials, and the distance from a vibration producing event. A “User’s Guide” for this database appears in Appendix E.

The main menu provides access to the “Vibration Event,” “Reports,” and “Maintenance” screens. The “Vibration Event” screen is where data on the vibration producing activity and equipment, nearby structure types and condition, population sensitivity, subsurface conditions, monitoring equipment, sensor location(s), and vibration readings are entered. Multiple readings for each event and site can be input into the database. New information is entered into the database by project, identified by a unique state project number, city/town, route/road, and description. Navigation buttons are provided to facilitate movement between records and to find, add, edit, save, delete, and print records. Drop-down menus are provided for many of the data fields. Many of the drop-down menus can be modified through the “Maintenance” screen.

The NHDOT also maintains a database of subsurface information that is located by GPS coordinates and includes elevations, field classification of soil and rock with remarks, depths of stratum changes, water depth, blows per 0.5 foot of depth, and other supporting information. The “Construction Vibration Database” will indicate if existing subsurface information is available for that specific project and provide access to the database location where it is stored.

The “Reports” screen allows stored data to be sorted by project, vibration activity type, distance from vibration source, measured vibration (in/sec), frequency (Hz), soil type, and density. The activity type (vibration producing activity) must be selected to generate a vibration report. All other fields of information are optional.

The “Maintenance” screen allows for modifications to some of the drop-down menus. Fields of information that can be modified include activity types, equipment types, soil types, vibration types, seismographs and inspectors.

The “Construction Vibration Database” will only be a useful tool if information on a variety of activities over a broad range of conditions is continuously added to the database. This will require the collection of information, in a standardized format, by both in-house resources and by vibration consultant subcontractors working on NHDOT projects. To facilitate this effort, Section 211 of the NHDOT *“Standard Specifications for Road and Bridge Construction”* now requires that vibration consultants complete and submit data for each vibration producing activity, using a standardized form that is available on the Department’s web site. The form can also be found in Appendix C. The completed forms are to be submitted to the Department’s Research Geologist at the Bureau of Materials & Research in Concord, New Hampshire. As the database becomes populated, direct access (view only) to the information will be provided to designers and project administrators in the NHDOT.

DEVELOPMENT OF PROCEDURES FOR CONSTRUCTION VIBRATION ASSESSMENTS AND ESTIMATING VIBRATION MONITORING SERVICES

The "Construction Vibration Assessment Table" (Appendix A, Table 1) can be routinely used by designers for determining if vibration concerns exist and for evaluating the potential impact on a project. In addition, an analysis can be useful in comparing the potential impact of a specific construction activity at different sites, , or as a comparison of different activities at the same site. This information would also be useful in developing a preliminary cost estimate for vibration monitoring services. The "Construction Vibration Assessment Process" can be utilized separately as a tool or in support of developing an estimate for vibration monitoring services.

When estimating the vibration monitoring services required for a project site, all vibration producing activities and potential impacts need to be considered in the calculation. When assessing the overall impact of construction vibrations at a site, the worst-case scenario for each type of construction vibration producing activity should be considered. The closest, oldest, and worst condition of a particular category of structures, and the most vibration sensitive operations should be identified. The worst-case scenario should be the one impacted the most by the construction vibration producing activities. This will help identify when, where and how the greatest impact will be experienced. Ultimately, the controlling factor on the potential for complaints, on the potential for damage to nearby structures, and the effort needed to mitigate vibration impacts should be directly related to the worst-case scenario.

The proposed system for evaluating the potential impact of construction vibrations at a project site developed through this research has been modeled after the FHWA Rock Slope Stability Rating System and the Oregon Department of Transportation Rock Fall Hazard Rating System, which the NHDOT adopted and modified for its rock slope database. The assessment matrix described in Appendix A assigns a point score to ten different categories of data that could potentially influence the impact of construction vibrations on a NHDOT project. The total point score from adding the ten categories is used to determine the level of impact at a site from vibrations emanating from a specific type of construction activity. A construction vibration impact assessment should be conducted for each type of vibration producing activity, evaluating the potential impact of that activity on man-made structures (residential, business, apartment building, industrial, historic structure, etc.) and vibration sensitive equipment within relevant proximity of the project site. This information can then be used to estimate the cost of vibration monitoring services for the project as described under Item 211.11, Vibration Monitoring Services, of the NHDOT Standard Specifications. In addition to the "Construction Vibration Impact Assessment Table", Appendix A provides information on how to conduct a construction vibration impact assessment. Appendix B demonstrates a step-by-step procedure for estimating the total hours for vibration monitoring services. The past utilization of Item 211.11, Construction Vibration Monitoring Services, was reviewed on fifty-three NHDOT projects occurring over a period of ten years. It was determined that the final pay quantity for Item 211.11 was within the range of 125 percent to 75 percent of the estimated bid quantity on only 1 out of 4 roadway projects. On one project, the bid quantity was underestimated by more than 650 percent. This demonstrates the need for implementing a standard and accurate procedure for assessing the potential impact of construction vibrations and for estimating the quantity of vibration monitoring services.

The ten categories of data used to calculate the "Construction Vibration Impact Assessment" are combined with the number and types of potentially impacted structures to calculate the estimated hours of Item 211.11 (Vibration Monitoring Services) required on a project. Refer to Appendix B for a step-by-step method and practical exercise in estimating the hours for Vibration Monitoring Services.

LIMITATIONS

The authors understand the difficulty in trying to assess the potential impact of construction vibrations at a specific site and the nearly impossible challenge of grouping construction activities/equipment by the intensity of potential vibrations. The variables at each construction site make this a daunting task at best. This approach is controversial with the risk of oversimplifying the complexity and variability at a project site. The most reliable method is to take actual measurements at the project location. Until adequate vibration data has been collected on a specific piece of equipment or type of activity at a site, a more accurate assessment is not possible. Therefore, some flexibility is needed in the contract documents and in the preliminary estimate to provide sufficient funding and protection for the public. The monitoring data collected during construction, changes in conditions and the contractor's method of operation should be reviewed on a continuing basis. This provides for informed decisions by the Contract Administrator and the Vibration Consultant.

There was a limited range of equipment and types of vibration producing activities that were available for study on NHDOT projects during the period of the research. The database was initially populated with 268 events from 15 projects involving eight different types of construction vibration producing activities to include vibratory roller, excavator, hoe ram, pavement breaker, sheet pile driving, heavy truck traffic on gravel haul road, movement of tracked equipment on paved surface, and small bulldozer. This necessitated the need to utilize vibration data collected by others or available through published reports. Measured ground vibrations generated by various types of construction activities published by the Federal Transit Administration, the U.S. Department of Transportation, the Port Authority of New York and New Jersey, the City of Calgary, the LeEllen Phelps Mechanical Engineering Group, Kellogg Brown & Root Pty Ltd, Geologic and Geophysical Consulting, Central Federal Lands Highway Division, FHWA, Colorado, and the NHDOT are included in Appendix D. Although conditions and equipment may vary from site to site, these tables give an approximate range of vibration levels that can be expected from different construction activities at different distances on a project.

At present, there is limited information on vibrations from driven piles in the NHDOT database, but there is an existing Microsoft Access™ vibration database for driven piles available online at http://www.piledrivers.org/noise-vibration-database.htm. The database for the installation of driven piles was developed by the Pile Driving Contractor's Association (PDCA), in conjunction with the Citadel, and WPC. The database includes a number of case histories with information on peak particle velocity (PPV) data, vibration frequency, distance to driven pile, pile type, pre-auger information, impact and vibratory hammer data to include rated energy, measured energy based on PDA results, soil data, and pre/post condition survey data. The information in the database can be utilized to develop a preliminary prediction of vibrations from a proposed pile driving operation.

REDUCTION OF CONSTRUCTION VIBRATIONS

Although construction induced vibrations normally do not cause damage to nearby structures, construction activities can generate complaints from people and can affect vibration sensitive operations/equipment. Sometimes the best approach to avoiding or minimizing problems is to schedule the work when people are not in the area or when the sensitive equipment/activity is not in operation (Jones, 2004). Education of the public as to what to expect and good communications are often the most effective way to reduce complaints. The following steps outlined in the CALTRANS Transportation- and Construction-Induced Vibration Guidance Manual (prepared by Jones & Stokes, 2004) can be taken to reduce vibrations from construction activities:

- Impact Pile Driving – Jetting, pre-drilling, auger cast piles, non-displacement piles, using pile cushioning between the driving hammer and the pile, non-impact pile drivers with a vibratory pile driver, use resonance-free vibrator.

- Hydraulic Breakers – use hydraulic crusher, saws, rotary-cutting heads, hydraulic splitters, expansive chemicals to split rock or concrete.

- Vibratory Rollers - shut off vibrator when reversing direction (highest level of vibrations are often generated when quickly stopping and changing direction), utilize a vibrating roller that has the ability to adjust the impulse energy and frequency, compact soil with static method (no vibrations); oscillation compaction in place of conventional vibratory action.

- Track Mounted Equipment – minimize traveling over paved surfaces with steel cleats (Oriard, 2002), rubber pads can reduce vibrations, use rubber tired vehicles in place of tracked vehicles.

- Heavy Trucks – fill in pot-holes and eliminate pavement discontinuities, keep haul roads smooth by periodic grading; pave existing roads to provide a smooth traveling surface, reduce speed of vehicles; weight reduction of vehicles.

Methods for reducing construction vibrations should be considered on a case-by-case basis. Trenches and sheet pile walls have been used as wave barriers to reduce the amplitude of vibrations with limited success. This method of mitigating ground vibrations can be expensive, may not be practical for the site conditions and is often ineffective (Woods, 1997). It is important to monitor vibrations and frequencies during different phases of the construction and during different construction activities at numerous locations on the project. This approach will help identify any vibration patterns and directional focusing caused by a variation in geology and subsurface conditions at a site (Nutting, 1990).

Figure 14 - Track mounted excavator on pavement

CONCLUSIONS AND RECOMMENDATIONS

Although non-blasting construction-induced activities rarely cause damage, they can be a source of annoyance and can generate complaints. The potential impact of vibrations emanating from construction activities should be assessed prior to the start of a project to identify the level of vibration monitoring services required and to develop a plan for minimizing damage and complaints. Through this research, a proposed procedure for assessing the potential impact of construction vibrations and estimating quantities for vibration monitoring services was developed. In addition, a database to document the actual vibrations measured at construction sites in New Hampshire was created and will provide increased value as more data is added. Education of people and good communications are the best and most proactive approach to avoiding problems.

Every construction site is unique with the potential for a wide range of conditions and variables (Svinkin, 2001). Therefore, it is important to follow a standardized process for evaluating the potential impact of construction related vibrations. Collecting, storing and tracking key information in a database on vibrations produced by different non-blasting construction activities can be a resource for decision making during the design and construction phases of projects.

In several instances, steps have been taken on NHDOT construction projects to assess and minimize the impact of vibrations on archaeological sites, on geological features and on wildlife. Examples include a roadway project in close proximity to the remains of an old stone foundation for a historic gristmill, the construction of the Franconia Notch Parkway below the Old Man of the Mountain and road construction through Franconia Notch during the nesting of the Peregrine Falcons. These are unique circumstances requiring special considerations, collection of background data and input from vibration experts.

It is important to periodically review both the method for assessing the potential impact of construction vibrations and the procedure for estimating the level of vibration monitoring services. Data collected from a variety of construction activities with a broad range of site conditions can be used to modify and refine the accuracy of these methods over time.

It is recommended that multiple seismographs be set-up initially at a site at a range of distances and in different directions away from the vibration source. This will help identify patterns in the transmission of vibrations in the project area. Measuring background vibrations prior to the start of construction activities at a project site and conducting pre-construction surveys to determine the condition of surrounding structures are crucial. Sensitive operations/manufacturing processes, historic structures and structures in fragile condition should be identified during the planning phase of the project. Special conditions and other concerns should be stated in the project Prosecution of Work, so that contractors can submit reasonable bids, and modify schedules and activities appropriately. Very sensitive equipment and manufacturing processes often present the greatest challenges. These can potentially have a significant impact on the construction schedule and overall project costs. In many instances, companies do not know the existing background vibrations at their location or the level of vibrations that can be tolerated by their equipment and/or operation. Establishing good public relations through education, communication and coordination with nearby landowners and businesses is the key to minimizing problems during the construction phase.

A distance of 300 feet was arbitrarily chosen as the radius within which pre-construction surveys and monitoring for non-blasting construction-induced vibration activities should occur. A minimum 500-foot radius for blasting induced vibrations is required under Section 203 of the NHDOT Standard Specifications for Road and Bridge Construction. Although, Section 211 of the NHDOT Standard Specification for non-blasting construction activities references the requirements in Section 203, it does allow the Vibration Consultant (with adequate justification and documentation) to set revised limits based on conditions at the project site. Some references recommend distances of up to 1300+ feet or more. The 300-foot distance is reasonable and manageable for most NHDOT projects in urban areas. However, every project site is different and there may be extenuating circumstances, such as liquefiable soils, very sensitive manufacturing processes or very fragile structures that would justify increasing the 300-foot radius. Pile driving can generate low-frequency ground vibrations in the range of 3-12 Hz at distances of 600 feet or greater, which can trigger potentially damaging resonant structural vibrations (Svinkin, 2001). Dynamic vibration sources cause densification of sand at short distances, while settlements can extend out to distances of 1300 ± feet (Woods, 1997). The Vibration Consultant (qualified third party hired by the Contractor) should determine the structures, the vibration sensitive activities, and the types of construction operations that will be surveyed and monitored in the project area. This information along with recommended vibration limits shall be included in a Vibration Monitoring Plan and submitted to the NHDOT for approval (refer to the NHDOT Standard Specifications).

IMPLEMENTATION PLAN

It is expected that the Bureaus of Design, Construction and Materials & Research will utilize the information in the database and the "Construction Vibration Impact Assessment Table" to assess the potential level of impact from vibrations generated by a proposed construction activity at a specified site, to estimate the cost of vibration monitoring services and as a resource for decision making during the design and construction phases of NHDOT projects. Information will continue to be added to the "Construction Vibration Database" by personnel at the Bureau of Materials & Research. The process for conducting the construction vibration impact assessments and for estimating the vibration monitoring services should be modified and refined as more information becomes available. Equipment purchased under this research study will need to be maintained, upgraded and calibrated periodically (annual).

A change has been made to Section 211 – Vibration Monitoring, NHDOT Standard Specification, requiring the contractor's Vibration Consultant to complete a "Contractor Vibration Report Form" per day, per vibration producing activity. Copies of the completed forms shall be submitted to the Project Contractor Administrator and the Research Geologist at the Bureau of Materials & Research. The form will facilitate the collection and transfer of vibration data into the NHDOT database. The required form can be found at http://www.nh.gov/dot/business/contractors.htm.

A "Guidance Manual for Non-Blasting Construction Vibrations" will be published. This manual is intended to provide a reference source that can help designers determine when it is appropriate to include vibration monitoring, as described in Section 211.11 of the NHDOT *"Standard Specifications for Road and Bridge Construction,"* in a given project. The guideline will provide a systematic method for determining a quantity of hours for that item. The guideline will be a living document, subject to revision from actual experience with the vibration monitoring item.

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APPENDIX A - CONSTRUCTION VIBRATION IMPACT ASSESSMENT TABLE

Figure 15 - Construction Vibration Impact Assessment Table

	Points 1	Points 3	Points 9	Points 27	Points 81
Type of Construction Activity/Equipment/ Energy Input from Activity	Hand tools; small plate compactors; tampers; jack hammer	Excavation with backhoe; heavy wheeled construction vehicles	Vibratory roller; tracked mounted equipment on pavement; hoe ramming	Pile driving; pavement breaker	Dynamic compaction; drop ball
Attenuation (decay) of peak particle velocity	Cohesive Soils Very soft to soft (0 –4 blows/ft) Non-cohesive soils Very loose (0 – 4 blows/ft)	Cohesive Soils Medium Stiff (5 – 8 blows/ft) Non-cohesive soils Loose (5 – 10 blows/ft)	Cohesive Soils Stiff (9 – 15 blows/ft) Non-cohesive soils Medium dense (11 – 24 blows/ft)	Cohesive Soils Very Stiff (16 – 30 blows/ft) Non-cohesive soils Dense (25 – 50 blows/ft)	Cohesive Soils Hard to very hard (30+ blows/ft) Non-cohesive soils Very dense (50+ blows/ft)
Displacement; Densification & Settlement	Very dense soil or bedrock	Dense soil	Medium dense soil	Loose soil	Soft, very loose, saturated soil; cohesionless soils
Distance from Vibration Source	Greater than 400 ft	201 – 400 ft	101 –200 ft	51 – 100 ft	50 ft or less
Type of Vibration	Single isolated event	Intermittent and random impact	Steady state; continuous, harmonic	Numerous multiple impact	Continuous impact
Duration of Construction Activity	5 minutes or less	Longer than 5 minutes to 1 hour	Longer than 1 hour to one day	Longer than one day to one week	Longer than one week
Type of Structure	Reinforced concrete structure (i.e. bridge); structures w/ deep foundation	Concrete w/ shallow foundation	Private residence(s) or commercial structure w/ drywall	Private residence(s) or commercial structure w/ plaster walls	Historic or fragile structures
Condition/Age of Structure	Excellent condition, less than 10 years old, no visible cracks	Good condition; minor hairline cracks; 10 to 20 Years Old	Fair condition; many cracks; structure constructed after 1950	Fair condition; many cracks; structure constructed prior to 1950	Poor condition; over 100 years old
Vibration Sensitive Equipment/Vibration Sensitive Manufacturing Process	No vibration sensitive equipment or processes; private residence	Home office	Small business, bank or store w/ computers	Large business w/ sensitive equipment, dentist or doctor’s office	Medical/ research labs, hospital, computer chip manufacturing, other sensitive manufacturing processes or equipment
Sensitivity of Population	Rural area/single family residence	Urban area w/ multiple single family residences	Urban area w/ apartment house(s)	Business/ store	Hospital/ nursing home

Construction Vibration Impact	**Point Total**
Very High Impact	400 or greater
High Impact	300 to <400
Moderate Impact	200 to <300
Low Impact	100 to <200
Very Low Impact	Less than 100

Explanation of Categories for Construction Vibration Impact Assessment

Notes for Construction Vibration Impact Assessment Matrix: The primary purpose of this table is not to quantify all the variables that contribute to the impact of construction vibrations at a site, but to provide a systematic procedure for vibration assessment during project planning. A vibration assessment can be useful in comparing the potential impact of a specific construction activity at a site versus the same activity at another site or a comparison of different activities at the same site. This information can be useful in developing a preliminary cost estimate for vibration monitoring services. Determining the level of construction vibration impact at a site should be based on the worst-case scenario for each type of construction vibration producing activity. The assessment should identify the closest, the oldest or worst condition of a particular category of structures and/or the most vibration sensitive operation.

1. **Type of construction activity/Equipment/Energy input from activity** - The type of equipment and/or construction activity, the energy output and how that energy is transferred to the ground are all major factors in the intensity of the vibrations. Since there is such a wide range of equipment sizes and construction activities, the order of placement in the table is based on our experience with NHDOT construction projects. Valid arguments can be made for different point rankings of construction equipment/activities.

2. **Attenuation of peak particle velocity -** Attenuation (decay) of peak particle velocity is based on the frequency of the motions, the damping provided by the material through which the stress waves (ground motion) travel and the type of stress wave generated. Higher frequency motions have shorter wavelengths than lower frequency motions. A high frequency wave will have a greater number of cycles of motion to travel the same distance as a low frequency wave (Dowding, 1996). Therefore, higher frequency waves (shorter the wavelength) interact more with the ground material over the same distance, resulting in greater damping (Dowding, 1996). The U.S. Bureau of Mines R.I. 8507 report on surface mine blasting established limits for safe vibration levels for residential structures based on frequency (Siskind, 1980). The recommended safe vibration levels measured in inches/second (Peak Particle Velocity) decreases below a frequency of 40 Hz. This is the most widely used vibration criteria for either blast-induced or construction equipment-induced vibrations. Vibrations emanating from most construction equipment fall in the lower frequency range of 5 to 30 Hz (Dowding, 1996).

   Ground motions with the same initial dominant frequency will have longer wavelengths and higher propagation velocity in stiffer soils. The result is less decay and greater particle velocities in stiffer material as compared to softer material at the same distance from the energy source (Dowding, 1996). The difference between a loose and stiff soil can influence particle velocities by five to seven fold (Forsbald, 1974) (Steinberg and Lukas, 1984). In general, a clay soil will have a higher damping effect than sandy soils, wet sand attenuates less than dry sand, and frozen soil attenuates less than thawed soil (Dowding, 1996).

Vibrations generated by construction equipment produce two types of stress waves, body waves and surface waves. Body waves decay more rapidly due to greater damping and confinement. Surface waves (Rayleigh waves) travel along the ground surface, tend to travel long distances with minimal decay and are often more damaging to nearby structures. Almost two-thirds of the energy applied to the ground surface is transmitted in the form of surface waves (Dowding, 1996).

3. **Displacements; Densification & Settlement** – Construction vibrations could potentially cause displacement, densification and settlement of the material underlying or adjacent to a structure. An impulsive energy source at a particular level is more likely to generate stress waves of lower frequency and larger displacements in softer, looser or more saturated soil (Dowding, 1996) (Oriard, 2002). The greatest densification will occur in loose saturated sands that are low density, low blow count and fully saturated (Oriard, 2002). Steady vibrations of longer duration have a greater potential to cause densification, or even liquefaction if the soils are saturated and subjected to high strains (Oriard, 2002). Lateral displacement can occur when driving piles or compacting soils in close proximity to walls, structures and utilities. This type of direct mechanical damage should not be confused with vibration-induced damage (Oriard, 2002). As a general rule, most damage from pile driving activities occurs within a distance equal to or less than the length of a pile. There have been exceptions. Damage from settlement or liquefaction of soils resulting from vibrations emanating from pile driving have occurred at greater distances.

4. **Distance from Vibration Source -** Distance from the source of energy is an important factor in the intensity of vibrations. Vibrations would theoretically be the same intensity at a given distance in all directions from the energy source, if the transmission medium is uniform and homogenous throughout. In reality, the conditions at a site are variable both laterally and vertically, encountering materials of different composition, density, water content, layering, etc. A general rule is that if the distance is reduced by half, the intensity of vibration should increase approximately by three times (Oriard, 2002). This relationship is very dependent on the conditions at the site. Vibration intensities at the ground surface are higher than those below ground. In general, the vibration intensity would decrease to approximately 50% of the surface value within 10 to 20 feet below the ground (Oriard, 2002). This is important when assessing the potential impact of vibrations on buried utilities. Buried utilities in good condition and properly installed are not only more confined and more resistant to vibration damage, but will likely experience less vibration intensity than that measured at the surface.

5. **Type of Vibration -** The type of vibration can be linked to the energy transfer mechanism or equipment type/construction activity. Impact vibrations (impulsive energy) generated by dynamic compaction, impact pile driving and pavement breakers tend to deliver high levels of energy. Steady-state vibrations (reciprocating energy) such as vibratory rollers tend to generate complaints even when the measured vibration intensity is low. Rotating energy transfer (trencher, tunnel boring machine) and rolling energy transfer (heavy vehicles, railroads) are pseudo-steady vibrations, which can generate a large range of vibration intensities

(Wiss, 1981), but typically have not been a problem on NHDOT projects. Heavily loaded ledge trucks traveling at a high rate of speed on a very rough road could potentially generate high vibrations. Some subjective judgment is required when rating this category.

6. **Duration of Construction Activity** - The duration is the total time period during which the construction-induced vibration activity will occur. A longer duration provides a longer complaint period, a greater potential for annoyance and disturbance, and increased opportunities to generate damaging vibrations. A longer duration would require more vibration monitoring services. Some vibration activities could extend over several years through different seasons resulting in significant changes to site conditions. This increases the exposure to a broader range of environmental changes (temperature, humidity, fluctuation in moisture content of soils, etc.) over time. Settlement and cracking of structures due to environmental factors such as frost action, erosion of soil, natural cyclic changes in expansive soils, drainage problems, decomposition of underlying organic deposits are common (Oriard, 2002). Vibrations generated by construction activities are often blamed for damage, which in reality was caused by natural environmental changes that occurred over time.

7. **Type of Structure** - The amount of reinforcement and bracing in a structure relates directly to its ability to withstand vibrations. Concrete structures and deep foundations are particularly resistant to damage. Plaster on wood lath for interior walls will experience cosmetic cracks at lower vibrations than drywall interior construction. Multi-level structures may experience greater movement in the upper levels than a single story structure. Historic structures and older buildings with shallow stone foundations may be fragile.

8. **Condition/Age of Structure** – A variety of stronger and longer lasting building materials have been developed during the last twenty years. Building construction methods have improved significantly during the last 50 years (Hajduk, 2004). Newer buildings and structures have been subjected to less damage and deterioration caused by natural environmental factors.

9. **Vibration Sensitive Equipment/Vibration Sensitive Manufacturing Process** – Some manufacturers of sensitive equipment provide vibration criteria, but it often covers continuous vibrations not transient vibration sources. Types of sensitive operations may include medical research facilities, hospitals, computerized industries, banks, industrial machinery, computer chip companies, equipment with sensitive switches and other sensitive manufacturing processes. Sensitive equipment could include optical microscopes, magnetic resonance imaging (MRI) machines, scanning electron microscopes, micro-lathes, and precision milling equipment. It is important to determine the background vibrations that typically occur in the vicinity of the sensitive equipment and its support structure.

10. **Sensitivity of Population** – Humans are very sensitive to vibrations. People experience vibrations in their daily life to include riding in an automobile or on commercial transportation (bus, train or airplane), vibrations at home and in the work environment. These types of vibrations are familiar to the individuals and

often go unnoticed. Vibrations generated by construction activities are unfamiliar and often disturbing to people, causing concern, annoyance and fear (Siskind, 1980) (Dowding, 1996). These types of vibrations often trigger an adverse response from people long before they reach a level that could potentially cause even minor cosmetic damage. The response from people is often dependent on the makeup of the nearby population, the type of vibration (transient or continuous), the vibration intensity, frequency and duration. The ability of people to perceive motion and vibrations can vary significantly between individuals. In general, people are more sensitive to continuous vibrations than vibrations of short duration. If the vibration is accompanied by sound it is often perceived to be more annoying (Oriard, 2002).

While ground-borne vibrations emanating from construction activities rarely cause structural damage, annoyance of the occupants and disturbance of vibration sensitive equipment/manufacturing processes can occur. Effects from ground-borne vibrations can include movement of the building floors and walls, rattling of windows, shaking of items on shelves and hanging on the walls, and rumbling sounds. Vibrations from construction activities are transmitted as vibration waves that move through the ground medium into the foundation of a structure. Vibrations in the foundation propagate throughout the structure causing movement of internal floors and walls. Depending on resonance frequencies, vibrations inside the structure may provoke an adverse human reaction. Ground-borne vibrations caused by the same activity may not be perceived as objectionable to people who are outside the building (FTA, 2006). It may be necessary to measure vibrations at different locations from inside a structure to evaluate the actual vibration impact from a construction activity.

APPENDIX B – METHOD FOR ESTIMATING HOURS FOR VIBRATION SERVICES

Method for Estimating the Hours for Vibrations Services

1. Identify the number of structures, the types of structures and man-made features, and the vibration sensitive operations/equipment that could be potentially impacted by vibrations from construction activities. The structures, man-made features and vibration sensitive operations/equipment should include everything within a 300-foot radius and any others (beyond 300 feet) specifically identified as a concern during the planning phase.

2. Assume approximately two (2) hours for pre-construction surveys for residential structures, four (4) hours for small stores/businesses, six (6) hours for apartment buildings, and eight (8) hours for historic structures, vibration sensitive processes and industrial facilities. Estimate sixteen (16) hours for pre-construction surveys when working in close proximity to extremely fragile structures or highly sensitive operations.

3. Estimate the "uncorrected" vibration monitoring time (hours) needed for each type of vibration construction activity identified in step 1. For construction activities where the vibration source (vibratory rollers, pavement breakers, excavation equipment, construction vehicles, etc.) is moving throughout the project, assume four (4) hours of monitoring for each residential structure, six (6) hours for other types of structures and eight (8) hours for historic structures. For construction activities where the vibration source (pile driving, drop ball, demolition, etc.) is stationary or stays in the same general area, assume ten (10) hours of monitoring time at each potentially impacted structure/operation for each type of construction-induced vibration activity. Estimate twenty (20) hours of vibration monitoring time for extremely fragile structures or highly sensitive operations.

4. Calculate the "corrected" vibration monitoring hours required by applying a correction factor(s) to the hours estimated in Step 3. The basis for determining the correction factor(s) is the "Construction Vibration Impact Assessment Table" (Figure 15, page 25). The table provides a way of scoring the potential impact of a vibration producing activity on each type of structure or vibration sensitive equipment. The correction factor for a vibration producing activity is based on the point total for all impacted structures and/or vibration sensitive operations. Correction factors to be used are as follows:

    - Factor of 1 for very low to low impact (0 to 199 total points)
    - Factor of 1.5 for moderate to high impact (200 to 399 total points)
    - Factor of 2 for very high impact (400 or greater total points)

5. Add the corrected vibration monitoring hours for each type of activity verses type of man-made structure/vibration sensitive operation to the hours for the pre-construction surveys to determine the hours of vibration monitoring services. To provide a contingency for conducting post-construction surveys, add 10% of the hours for vibration monitoring services to obtain the total hours for the vibration monitoring services.

Example: Practical Exercise for Estimating Vibration Monitoring Service Hours

The proposed project involves widening a 2500-foot long section of state roadway and the replacement of a bridge structure over a stream. The project site is located in an urban area that includes 10 private homes with dry wall construction (most are in fair condition and constructed prior to 1950). In addition, there is a small country store (good condition and built 15 years ago), a historic church (poor condition and over 200 years old) and a two-story apartment house (good condition and 10 years old) within the limits of the proposed construction. Four of the residential structures, the store, the historic church and the apartment house are in close proximity to the proposed bridge construction. The vibration producing construction activities are expected to include vibratory compaction of the base course materials for the roadway widening and pile driving for the bridge replacement. Based on geotechnical borings taken for the project, the underlying soil between the source of the construction vibrations and the surrounding structures is expected to be a very loose sand with a high water table (2 to 3 feet in depth). The only exception is a roadway boring taken in the vicinity of the country store that encountered a medium dense glacial till. A day care center is located in the basement of the church. There is no known vibration sensitive equipment located in any of the surrounding structures. The project is expected to take two construction seasons to complete.

Step 1 – Identify the number and type of structures
Step 2 – Estimate pre-construction survey hours

Type of Structure	Pre-construction survey hours	
10 – Residential structures	10 structures x 2 hrs	20 hrs
1 – Apartment building	1 structure x 6 hrs.	6 hrs.
1 – Business	1 structure x 4 hrs.	4 hrs.
1 – Historic building	1 structure x 8 hrs.	8 hrs.
	Total pre-construction survey hours	38 hrs.

Step 3 – Calculate the estimated uncorrected vibration monitoring hours for each activity

Vibration Producing Activity	Structure Type	Number of Structures	Uncorrected Vibration Monitoring (Hours)
Vibratory Roller	Residential	10	10 X 4 hrs. = 40
Vibratory Roller	Business	1	1 X 6 hrs. = 6
Vibratory Roller	Apartment Building	1	1 X 6 hrs. = 6
Vibratory Roller	Historic Building	1	1 X 8 hrs. = 8
Pile Driving	Residential	4	4 X 10 hrs. = 40
Pile Driving	Business	1	1 X 10 hrs. = 10
Pile Driving	Apartment Building	1	1 X 10 hrs. = 10
Pile Driving	Historic Building	1	1 X 10 hrs. = 10
Total Monitoring Hours			130 hours

Step 4 – Calculate the corrected vibration monitoring hours.
(Refer to Table 15, page 25)

VIBRATORY ROLLER

Category	Residential Structure (points)	Country Store (points)	Apartment Building (points)	Historic Church (points)
Type of Construction	9 (vibratory roller)	9 (vibratory roller)	9 (vibratory roller	9 (vibratory roller
Attenuation	1 (very loose sand/ 4 blows per foot)	9 (medium dense till in area of store/ 15 blows per foot)	1 (very loose sand/ 4 blows per foot)	1 (very loose sand/ 4 blows per foot)
Displacement Densification	81 (Very loose sands with high water table)	9 (medium dense till)	81 (Very loose sands with high water table	81 (Very loose sands with high water table
Distance from Vibration Source	27 (less than 100 ft from roadway to most residential structures)	9 (150 ft from roadway)	3 (210 ft from roadway)	27 (75 feet from roadway)
Type of Vibration	9 (Continuous vibration)	9 (Continuous vibration)	9 (Continuous vibration)	9 (Continuous vibration)
Duration of Construction	81 (longer than one week; two construction seasons)	81 (longer than one week)	81 (longer than one week)	81 (longer than one wee);
Type of Structure	9 (Private residential structures with dry wall)	9 (Commercial with dry wall)	9 (Private residential structures with dry wall	81 (Historic Structure)
Condition/Age	27 (Most of the homes are in fair condition and constructed prior to 1950)	3 (Good condition/ 15 years old)	3 (good condition/10 years old)	81 (poor condition/over 200 years old)
Vibration Sensitive Equipment	1 (Private residence/ no vibration sensitive equipment)	9 (Small store)	1 (No vibration sensitive equipment)	1 (No vibration sensitive equipment)
Sensitivity of Population	3 (Urban area with multiple single family homes)	27 (Small store)	9 (Apartment in urban area)	27 (Day care in basement of church)

Vibratory Roller (Residential Structure) = 248 points
Vibration Roller (Country Store) = 120 points
Vibratory Roller (Apartment Building) = 152 points
Vibratory Roller (Historic Church) = 344 points

Step 4 (continued)

PILE DRIVING FOR BRIDGE STRUCTURE

Category	Residential Structure (points)	Country Store (points)	Apartment Building (points)	Historic Church (points)
Type of Construction	27 (Pile driving)	27 (Pile driving)	27 (Pile driving)	27 (Pile driving)
Attenuation	1 (very loose sand/ 4 blows per foot)	9 (medium dense till in area of store/ 15 blows per foot)	1 (very loose sand/ 4 blows per foot)	1 (very loose sand/ 4 blows per foot)
Displacement Densification	81 (Very loose sands with high water table)	9 (medium dense till)	81 (Very loose sands with high water table	81 (Very loose sands with high water table
Distance from Vibration Source	27 (Closest residential structure is 100 ft from bridge)	81 (50 ft from bridge)	27 (95 ft from bridge)	81 (50 feet from bridge)
Type of Vibration	27 (Multiple impact)	27 (Multiple impact)	27 (Multiple impact)	27 (Multiple impact)
Duration of Construction	81 (longer than one week; two construction seasons)	27 (longer than one day)	27 (longer than one day)	27 (longer than one day)
Type of Structure	9 (Private residential structures with dry wall)	9 (Commercial with dry wall)	9 (Private residential structures with dry wall	81 (Historic Structure)
Condition/Age	27 (Most of the homes are in fair condition and constructed prior to 1950)	3 (Good condition/ 15 years old)	3 (good condition/10 years old)	81 (poor condition/over 200 years old)
Vibration Sensitive Equipment	1 (Private residence/ no vibration sensitive equipment)	9 (Small store)	1 (No vibration sensitive equipment)	1 (No vibration sensitive equipment)
Sensitivity of Population	3 (Urban area with multiple single family homes)	27 (Small store)	9 (Apartment in urban area)	27 (Day care in basement of church)

Pile Driving (Residential Structure) = 284 points
Pile Driving (Country Store) = 228 points
Pile Driving (Apartment Building) = 212 points
Pile Driving (Historic Church) = 434 points

Multiply the total hours for each construction activity and structure type by one of the following correction factors based on the level of construction vibration impact:

- Factor of 1 for very low to low impact (0 to 199)
- Factor of 1.5 for moderate to high impact (200 to 399)
- Factor of 2 for very high impact (400 or greater)

CORRECTION FACTOR FOR EACH COMBINATION OF ACTIVITY AND TYPE OF STRUCTURE

	Residential Structure	Business	Apartment House	Historic Structure
Vibratory Roller	248 points (factor 1.5)	120 points (factor 1.0)	152 points (factor 1.0)	344 points (factor 1.5)
Pile Driving	284 points (factor 1.5)	228 points (factor 1.5)	212 points (factor 1.5)	434 points (factor 2.0)

Multiply the computed uncorrected vibration monitoring hours from Step 3 by the correction factors from Step 4 to determine the corrected vibration monitoring hours.

Vibration Producing Activity	Structure Type	Number of Structures	Uncorrected Vibration Monitoring (Hours)	Corrected Vibration Monitoring Hours (Correction Factor X Monitoring hours)
Vibratory Roller	Residential	10	10 X 4 hrs. = 40	40 X 1.5 = 60 hrs.
Vibratory Roller	Business	1	1 X 6 hrs. = 6	6 X 1.0 = 6 hrs.
Vibratory Roller	Apartment Building	1	1 X 6 hrs. = 6	6 X 1.0 = 6 hrs.
Vibratory Roller	Historic Building	1	1 X 8 hrs. = 8	8 X 2.0 = 16 hrs.
Pile Driving	Residential	4	4 X 10 hrs. = 40	40 X 1.5 = 60 hrs.
Pile Driving	Business	1	1 X 10 hrs. = 10	10 X 1.5 = 15 hrs.
Pile Driving	Apartment Building	1	1 X 10 hrs. = 10	10 X 1.5 = 15 hrs.
Pile Driving	Historic Building	1	1 X 10 hrs. = 10	10 X 2.0 = 20 hrs.
Total Monitoring Hours (corrected)				198 hrs.

Step 5 – Summarize the total estimated hours of vibration monitoring services and add 10% for post-construction surveys.

TOTAL ESTIMATED HOURS FOR VIBRATION MONITORING SERVICES

Vibration Service	**Residential**	**Business (small business)**	**Apartment Building**	**Historic Structure**	**Vibration Services (hours)**
Pre-Construction Survey (hrs.)	2 X 10 = 20 hrs.	1 X 4 = 4 hrs.	1 X 6 = 6 hrs.	1 X 8 = 8 hrs.	20+4+6+8 = 38
Vibration Monitoring (Vibratory Roller)	60 hrs. (corrected)	6 hrs. (corrected)	6 hrs. (corrected)	16 hours (corrected)	60+6+6+16 = 88
Vibration Monitoring (Pile Driving)	60 hrs. (corrected)	15 hrs. (corrected)	15 hrs. (corrected)	20 hours (corrected)	60+15+15+20 =110
Vibration Services (hours)	140 hours	25 hours	27 hours	44 hours	236 hours
10% for Post-construction Surveys	**(.10) X (hours of vibration services) = hours** **(.10) X (140+25+27+44) = 23.6 hours**				
Estimated hours for Item 211.11 Vibration Monitoring Services (140+25+27+44+24) = 260 hours					

APPENDIX C - CONSTRUCTION VIBRATION REPORT FORM

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Contractor Vibration Report Form

State Project #: __________ Federal Project #: ________ Event Date: ___________________
City/Town: __________ Route/Road: _______________________________________
Name & Company Conducting Vibration Monitoring: ______________________________

Event Information

Vibration Producing Activity: (circle one)
Vibratory Roller Excavating Hoe Ram Pavement Breaker Sheet Pile Driving
Traffic Vibratory Compaction
Other (explain): ____

Type and Model of Equipment Producing Vibrations: _______________________________

Structure Type: (circle one or more)
Reinforced concrete structure with deep foundation Concrete structure with shallow foundation
Private residence(s) or commercial structure with drywall
Private residence(s) or commercial structure with plaster walls Historic or fragile structure
Other (explain) ____

Structure Condition: (circle one or more)
Excellent - < 10 years with no visible cracks Good – 10 to 20 years with minor hairline cracks
Fair – built after 1950 with many cracks Poor – over 100 years old
Other (explain): ____

Population Sensitivity: (circle one or more)
No vibration sensitive equipment/or processes Private residence Small business
Bank or store with computers Large business with sensitive equipment
Dentist or doctor's office Medical research labs Hospital or nursing home
Vibration sensitive manufacturing process or equipment
Other (explain) ____

Seismograph/Sensor Information

Seismograph (make & model): ________________ Calibration Date: ________________

Sensor Location (brief description): ____
____

Sensor Distance from Vibration Source (ft): ____

Readings

Reading Date	Reading Time	Max PPV (in/sec)	Corresponding Frequency (HZ)	Type (long., trans. or vert.)

Continuation Sheet - Contractor Vibration Report Form

Reading Date	Reading Time	Max PPV (in/sec)	Corresponding Frequency (HZ)	Type (long., trans. or vert.)

APPENDIX D - VIBRATION LEVELS FOR CONSTRUCTION ACTIVITIES

(NHDOT STUDY AND OTHER PUBLISHED DATA)

Vibration Source Levels for Construction Equipment from the FTA, 2006 Manual on Transit Noise and Vibration Assessment

Equipment		PPV (in/sec.) at 25 feet
Pile driver (impact)	upper range	1.518
	typical	0.644
Pile Driver (sonic)	upper range	0.734
	typical	0.170
Clam shovel drop (slurry wall)		0.202
Hydromill (slurry wall)	in soil	0.008
	in rock	0.017
Vibratory Roller		0.210
Hoe Ram		0.089
Large bulldozer		0.089
Caisson drilling		0.089
Loaded trucks		0.076
Jackhammer		0.035
Small bulldozer		0.003

Source: Information from Vibration Source Levels for Construction Equipment, Federal Transit Administration. 2006, *Transit noise and vibration impact assessment.* FTA-VA-90-1003-06. Office of Planning and Environment, Washington, D.C., Prepared by Harris Miller & Hanson, Inc., Burlington, MA. Vibrations are measured data from the following sources:

D.J. Martin, "Ground Vibrations from Impact Pile Driving during Road Construction," Supplementary Report 544, United Kingdom Department of the Environment, Department of Transport, Transport and Road Research Laboratory, 1980.

J.F. Wiss, "Vibrations During Construction Operations," Journal of Construction Division, Proc. American Society of Civil Engineers, 100, No. CO3, pp. 239 –246, September 1974.

J.F. Wiss, "Damage Effects of Pile Driving Vibrations," Highway Research Record, No. 155, Highway Research Board, 1967.

D.A. Towers, "Ground-borne Vibrations from Slurry Wall Trench Excavation for the Central Artery/Tunnel Project Using Hydromill Technology, "Proceedings of Inter-Noise 95, Newport Beach, CA, July 1995, pp. 227 – 232.

2006 Construction Period Vibration Levels vs. Distance from Source for The Preferred Alternative (in dBA)

Equipment	Peak Particle Velocity (inches per second)					
	5 feet	10 feet	20 feet	30 feet	40 feet	50 feet
Pile driver (typical impact)	7.20	2.55	0.90	0.49	0.32	0.23
Clam shovel drop (slurry wall)	2.26	0.80	0.28	0.15	0.10	0.07
Hydromill slurry wall in soil	0.09	0.03	0.01	0.01	0.00	0.00
Hydromill slurry wall in rock	0.19	0.07	0.02	0.01	0.01	0.01
Large bulldozer	1.00	0.35	0.12	0.07	0.04	0.03
Caisson drilling	1.00	0.35	0.12	0.07	0.04	0.03
Loaded trucks	0.85	0.30	0.11	0.06	0.04	0.03
Jackhammer	0.39	0.14	0.05	0.03	0.02	0.01
Small bulldozer	0.03	0.01	0.00	0.00	0.00	0.00

Source: Final Environmental Impact Statement by the U.S. Department of Transportation, Federal Transit Administration and the Port Authority of New York and New Jersey, Permanent WTC Path Terminal in Borough of Manhattan, New York County, Chapter 10: Noise and Vibration, May 2005.

Vibration Levels Due to Construction Equipment and Traffic at 30M (99 ft)

Table C.2
VIBRATION LEVELS DUE TO CONSTRUCTION EQUIPMENT AND TRAFFIC AT 30 m (99 ft)

Source	Peak Particle Velocity (mm/sec)	Converted to English units: Peak Particle Velocity (in/sec)
Diesel Pile Driver (36 000 ft/1b/49 000 joules)	5.0	0.2 in/sec
Vibratory Pile Driver	3.75	0.148 in/sec
Vibratory compactor	0.75	0.029 in/sec
Pavement Breaker	1.25	0.049 in/sec
Large Bulldozer	0.275	0.011 in/sec
Heavy Trucks	0.25	0.010 in/sec
Jack Hammers	0.075	0.003 in/sec
Vibration Criteria (Old House, Poor Cond.)		
• After CHAE (ASCE 48, pp 77-79, 1978)	12.5	0.49 in/sec
• Swiss Standard, Blasting	7.5	0.295 in/sec
• Swiss Standard for Machines and Traffic	3.0-5.0	0.118 – 0.197 in/sec

Source: Report on the Pre-Design Studies of Noise and Ground Vibration For N.W.L.R.S., City of Calgary (Oct. 1986), Appendix C, Vibration Study, Antelope Valley Roadway Project, University of Nebraska, Lincoln, Nebraska

Readings Compiled from Study of Vibrations due to Construction Activities on Haleakala

Type of Construction Activity	Max. PPV (in/sec) at 25 ft	Max. PPV (in/sec) at 50 ft	Max. PPV (in/sec) at 75 ft	Max. PPV (in/sec) at 100 ft	Max. PPV (in/sec) at 150 ft
Excavator	0.175	0.109	0.0425	0.065	0.0488
Backhoe	0.028	0.015	--------	--------	---------
Loader	0.0263	-------	--------	--------	---------
Vehicle (large semi-truck)	---------	0.010	0.0475	---------	0.010
Backhoe with hammer	0.120	0.0438	---------	0.019	--------
Excavator with hammer	0.325	0.070	0.050	0.0325	--------

Source: Readings compiled from Study of Vibrations due to Construction Activities on Haleakala, LeEllen Phelps, Mechanical Engineering Group, Document TN-0113, Revision A, ATST (Advanced Technology Solar Telescope), Appendix Q: Vibration Study, July 8, 2009.

Approximate Generated Vibration Levels for Various Sources

Note: Equivalent English measurements included

1 mm = 0.03937 inches

1 meter = 3.2808 feet

Activity	Typical levels of ground vibrations
Vibratory rollers	Up to 1.5 mm/s (.059 in/sec) at distances of 25 m (82 ft) Higher levels could occur at closer distances; however, no damage would be expected for any building at distances greater than approximately 12 m (39.4 ft) (for a medium to heavy roller)
Hydraulic rock breakers (levels typical of a large rock breaker operating in hard sandstone)	mm/s (.177 in/sec) at 5 m (16.4 ft) 1.30 mm/s (.051 in/sec) at 10 m (32.8 ft) 0.4 mm/s (.0157 in/sec) at 20 m 65.6 ft) 0.10 mm/s (.0039 in/sec) at 50 m (164 ft)
Compactor	20 mm/s (0.787 in/sec) at distances of approximately 5 m (16.4 ft), 2 mm/s (.0787 in/sec) at distances of 15 m (49.2 ft). At distances greater than 30 m (98.4 ft), vibrations is usually below 0.3 mm/s (.0118 in/sec)
Pile driving/removal	1 mm/s (.0394 in/sec) to 3 mm/s 0.118 in/sec) at distances of 25 m (82 ft) to 50 m (164 ft) depending on soil conditions and the energy of the pile driving hammer Theses levels are well below the threshold of any possibility of damage to structures in the vicinity of these works. At closer distances to the piling operations, some compaction of loose fill would occur due to vibratory effects
Bulldozers	1 mm/s (.0394 in/sec) to 2 mm/s (.0787 in/sec) at distances of approximately 5 m (16.4 ft). At distances greater than 20 m (65.6 ft), vibration is usually below 0.2 mm/s (.00787 in/sec).
Air track drill	4 mm/s (.157 in/sec) to 5 mm/s (.197 in/sec) at a distance of approximately 5 m (16.4 ft) , and 1.5 mm/s (.059 in/sec) at 10 m (32.8 ft). At distances greater than 25 m (82 ft) vibration is usually below 0.6 mm/s (.0236 in/sec), and at 50 m (164 ft) or more, vibration is usually below 0.1 mm/s (.00394 in/sec).
Truck traffic - over normal (smooth) road surfaces	0.01 mm/s (.0039 in/sec) to 0.2 mm/s (.00787 in/sec) at the footings of buildings located 10 (32.8 ft) to 20 m (65.6 ft) from a roadway
Truck traffic (over irregular surfaces)	0.1 mm/s (.00394 in/sec) to 2.0 mm/s (.0787 in/sec) at the footings of buildings located 10 m (32.8 ft) to 20 m (65.6 ft) from a roadway

Source: Northern Expressway Environmental Report, Volume 2, Vibrations, prepared by Kellogg Brown & Root Pty. Ltd., Sinclair Knight Merz Pty. Ltd., QED Pty. Ltd., Department for Transport Energy and Infrastructure, Government of South Australia, March 2007.

Measured Vibration Parameters for Selected Sources

Table 2. *Measured vibration parameters for selected sources. [All amplitudes/frequencies are at the peak amplitude normalized to a 15-m distance and assuming an attenuation of decomposed granite.]*

Vibration Source	Frequency, Hz	Amplitude, mm/sec	in/sec
Hamm Vibratory Compactor	7.2 – 18.7 – 45.5 – 64.3	3.2	.126
CAT Vibratory Compactor	16.8 – 35.9 – 48.6	2.1	.083
Hoe Ram	18.3 – 45.8	0.5	.020
Scraper	46.8	0.1 – 0.2	.0039 - .0079
Haul Truck	28.3 – 47.1	0.1	.0039
Auto Traffic	18.0 – 37.8	0.1	.0039
Blasting – 5.5 kg charge	31.5 – 41.5	18.3	.727
Blasting – Multi-hole	15.5	NA	N/A
Saki Vibra Roller[1]	18	5.2	.205
RT Bomag Roller[1]	14	3.8	.150
Manned Whacker[1]	34	0.2	.0079
Slide Compactor[1]	38	0.1	.0039

[1] Values obtained during a previous project at Chaco Canyon, April, 2001.

15 meters equals 49.2 feet

Source: Impacts of Construction Vibrations on Rock Pinnacles and Natural Bridges, General Hitchcock Highway, Tucson, AZ, Ken W. King of Geologic and Geophysical Consulting, Lakewood, CO and Matthew J. DeMarco of Central Federal Lands Highway Division, FHWA, Denver Federal Center, Denver, CO.

NHDOT Modified Formula

Predicting PPV (in/sec) based on distance from vibration source for NHDOT projects (The Federal Transit Administration equation has been revised based on NHDOT measured vibration levels)

FTA Equation $\quad PPV\ \mathit{equip} = PPV\ \mathit{ref}\ X\ (25/D)^{1.1}$

Note: Solving the Federal Transit Administration (FTA, 2006 Manual on Transit Noise and Vibration Assessment) equation for predicting vibration levels of construction equipment utilizing a power of 1.1 at distances (D) greater than 25 feet results in closer agreement with the data collected in the NHDOT investigation. The FTA utilizes a power of 1.5.

Where: PPV (equip) is the peak particle velocity (in/sec) of the equipment adjusted for distance

PPV (ref) is the reference peak particle velocity (in/sec) at 25 feet from the FTA table (refer to Appendix D)

D is the distance from the equipment to the receiver

NHDOT Vibration Levels for Construction Activities

Measured Range of PPV (in/sec.) on NHDOT Projects at a Distance of 50 feet or less

Equipment	PPV (in/sec.) at 50 feet or less
Sheet Pile Driver (impact)	0.10 to 0.36
Pavement Breaker	0.28 to 0.49
Vibratory Roller	0.11 to 0.78
Hoe Ram	0.07 to 0.49
Excavator	0.02 to 0.06
Loaded Dump Body Trucks on gravel haul road	0.010 to 0.03
Tracked Equipment on pavement	0.095 to 0.328
Small Dozer	0.03 to 0.11

Source: Vibrations measured on NHDOT projects

Note: These limits will change as additional information is collected on a variety of construction activities at numerous sites with a broad range of conditions. A significant variation in ground vibration levels can be measured from construction activities.

Predicted Peak Particle Velocity on NHDOT Projects

Predicted Peak Particle Velocity (PPV) on NHDOT Projects at a distance of 50 ft., 75 ft., 100 ft. *(use average PPV of measured range from table above as the reference peak particle velocity at 25 feet; calculate peak particle velocity utilizing FTA formula at a power of 1.1)*

Equipment	Reference PPV at 25 ft.	Estimated PPV at 50 ft.	Estimated PPV at 75 ft.	Estimated PPV at 100 ft.
Sheet Pile Driver (impact)	.23	.107	.068	.050
Pavement Breaker	.39	.182	.115	.085
Vibratory Roller	.45	.210	.133	.098
Hoe Ram	.28	.131	.083	.061
Excavator	.04	.019	.012	.009
Loaded Dump Body Trucks on gravel haul road	.02	.009	.006	.004
Tracked Equipment on pavement	.21	.016	.062	.046
Small Dozer	.07	.033	.021	.015

APPENDIX E - CONSTRUCTION VIBRATION DATABASE USER'S GUIDE

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VIBRATIONS

USER'S GUIDE

Developed and maintained by DoIT-ASD-SMD
Last changed: 10/27/2008

VIBRATIONS – Table of Contents Page

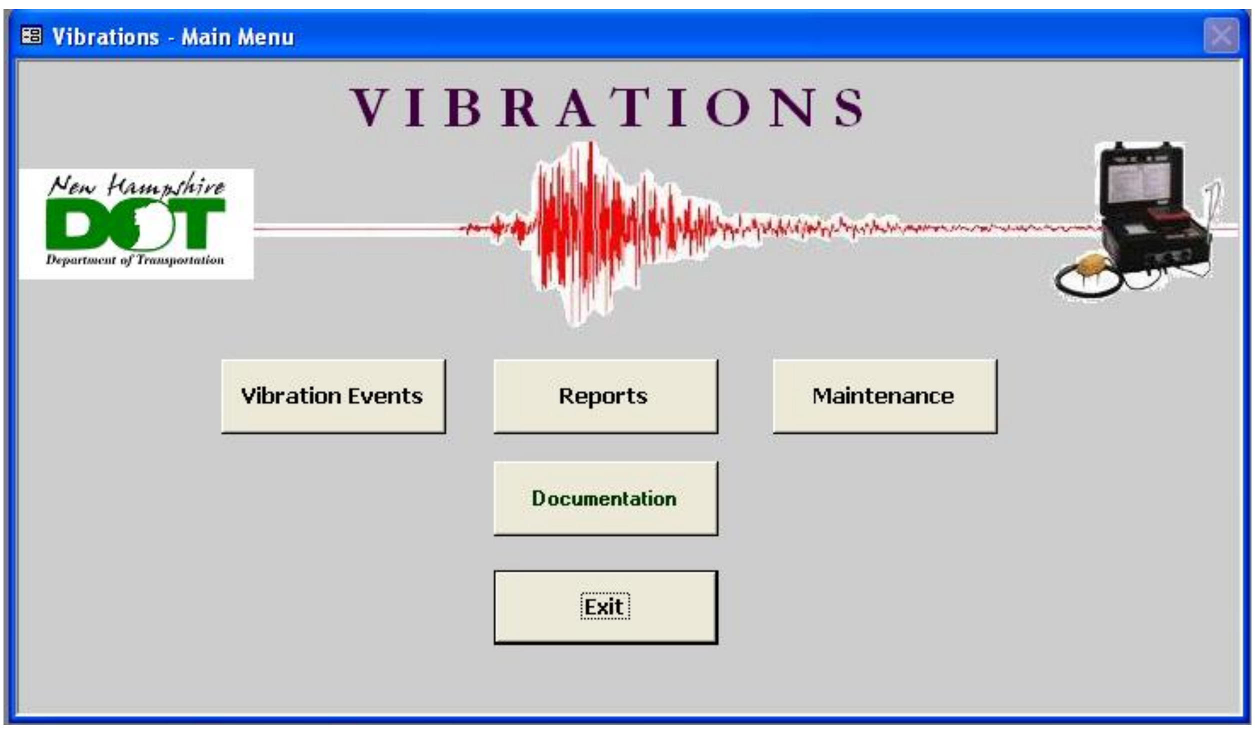
VIBRATIONS APPLICATION

The Vibrations application was developed October 2008 in MS Access 2000 for the NHDOT Bureau of Materials and Research, Geotechnical Section for Krystle Pelham. The application's production location:
\\Hzndotfile1\SB42\Vibrations\SB42\Vibrations.mdb

The daily scheduled job B42ProjectDataWH_Feed.cmd runs on server DBT2 which loads project data from the data warehouse and calls mcrLoadGintData which loads GINT data in to Vibrations database.

note: after 20 minutes of inactivity the Vibrations application will automatically close.

MAIN MENU

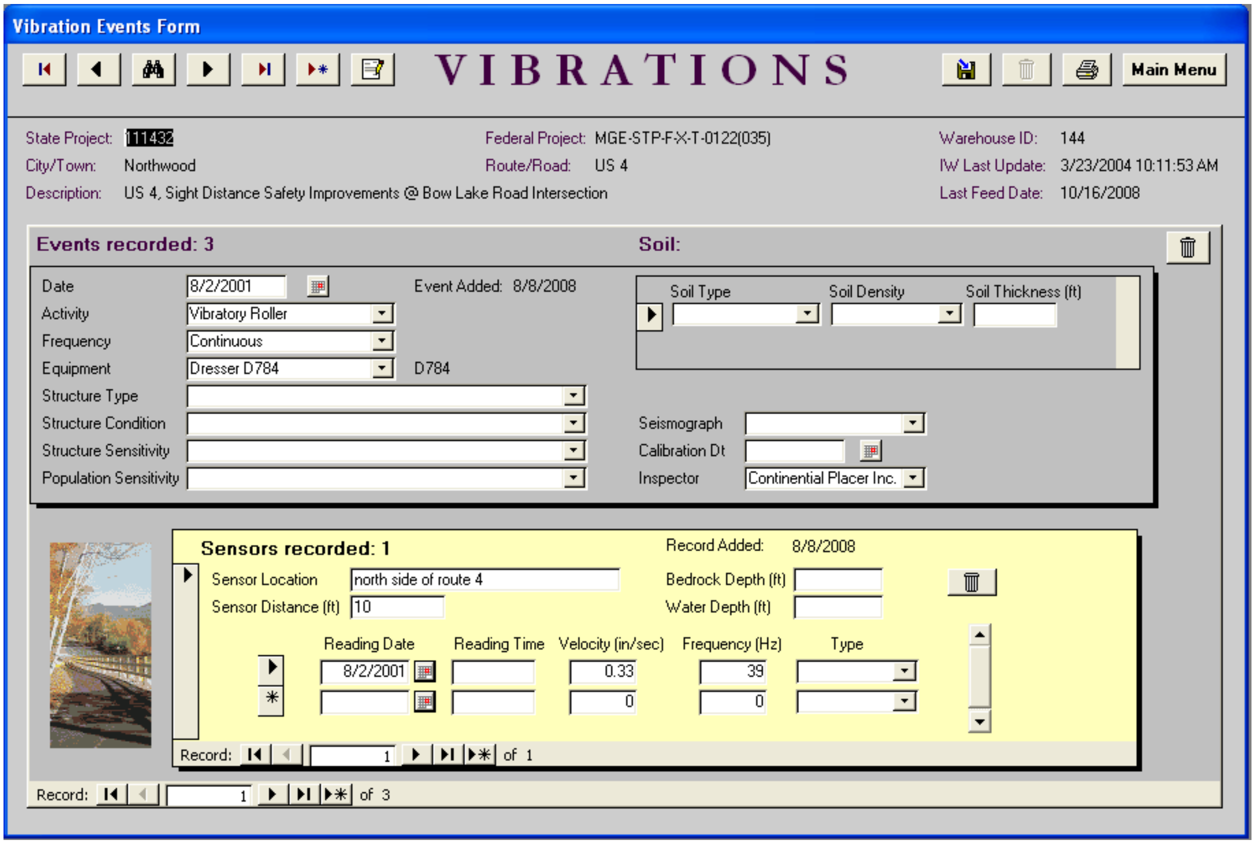


From the Vibrations main menu you can navigate to the Vibration Events screen, Reports or Maintenance screens.

Click Exit to close and exit the system.

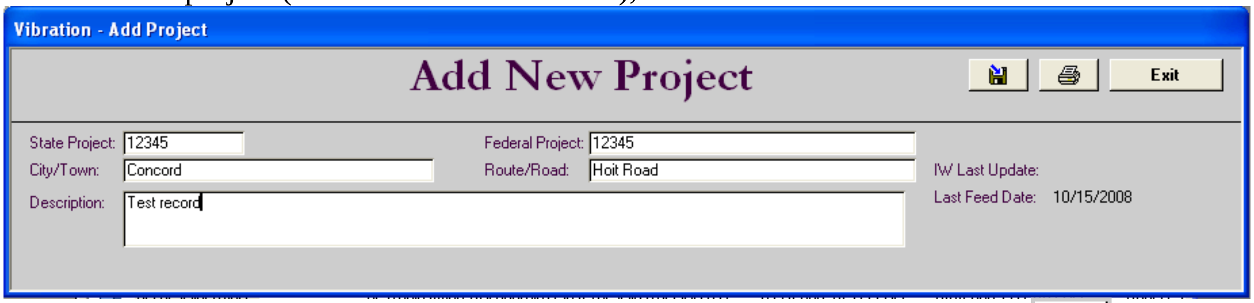
VIBRATION EVENTS SCREEN

Click the Vibration Events button open the vibration events screen.



To enter an event for a project, you must select an activity type. The soil and sensor fields will not be available until the activity is selected.

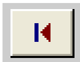
To add a new project (not in the data warehouse), click the add button

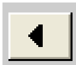


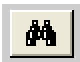
When the add screen opens, enter the project information. Click the save button to save the record. Click [Exit] to return to the Vibration Events screen.

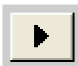
NAVIGATION BUTTONS

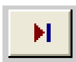
On the top of the Vibration Events form are navigation buttons. Move the mouse pointer over the button to display the button's description.

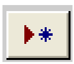
 - go to the First record

 - go to the Previous record

 - Find a record

 - go to the Next record

 - go to the Last record

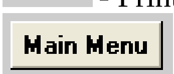
 - Add a new record

 - Edit the project record

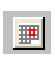
 - Save the record

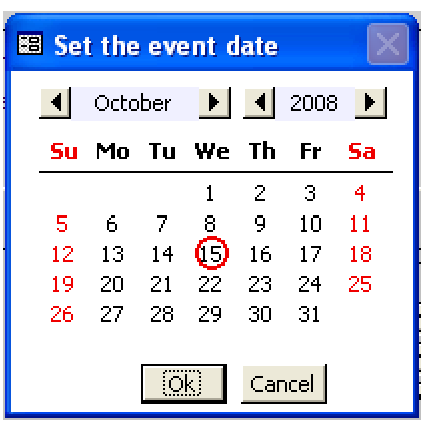
 - Delete the project, event or sensor record.*

 - Print the project record



- return to the Vibration main menu

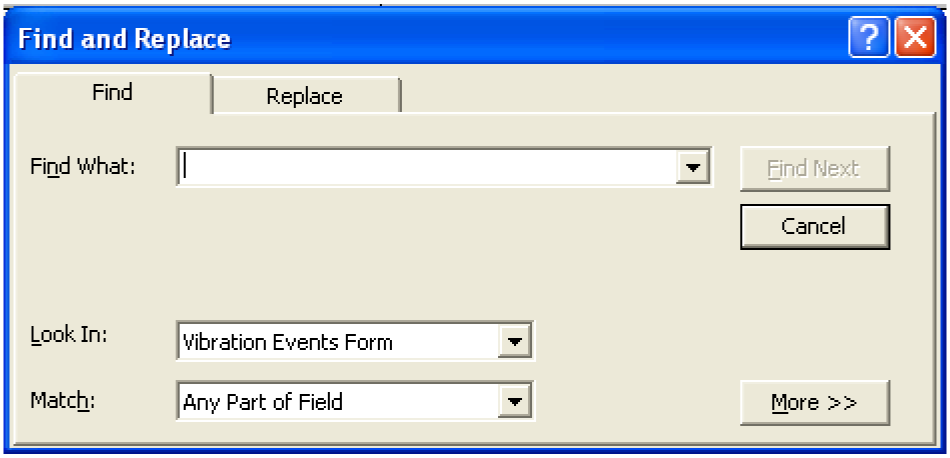
 - open the Calendar window to select an event date, calibration date or sensor reading date.



Click on the date then click the [Ok] button. The date selected will be returned to the appropriate date field.

SEARCHING

To find a record, click the button to open the Find window.



Enter your search criteria in “Find What:”

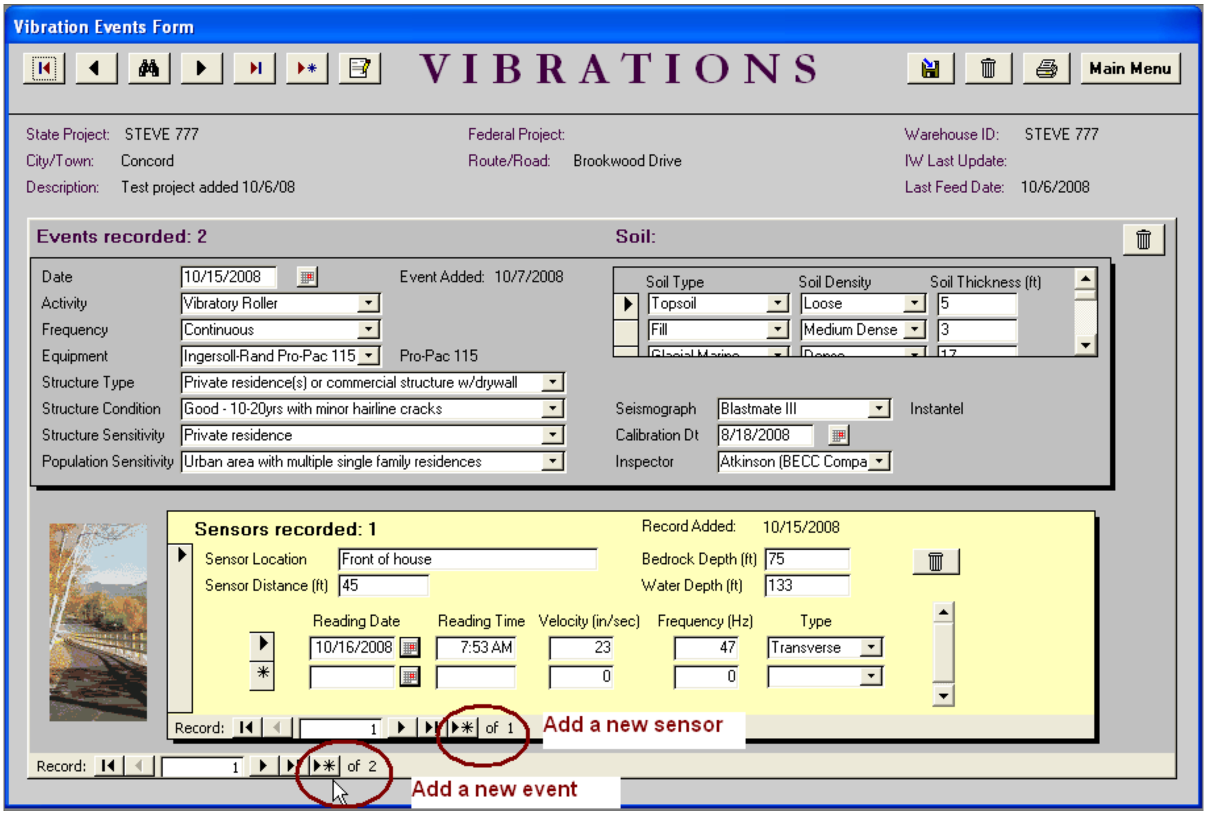
Change “Look In:” to ‘Vibration Events Form” to search in all fields or change to ‘State Project’ to search only in the state project field.

You can change “Match:” to ‘Any Part of Field’, ‘Whole Field’ or , ‘Start of Field’.

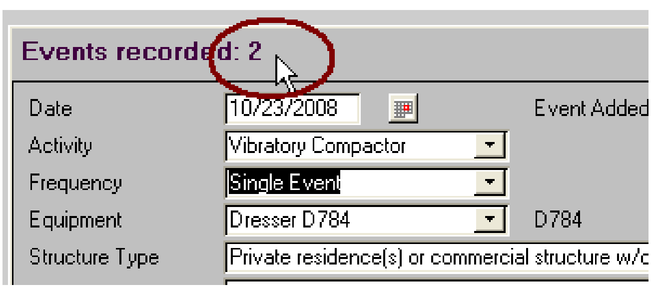
Click 

to find the next criteria match.

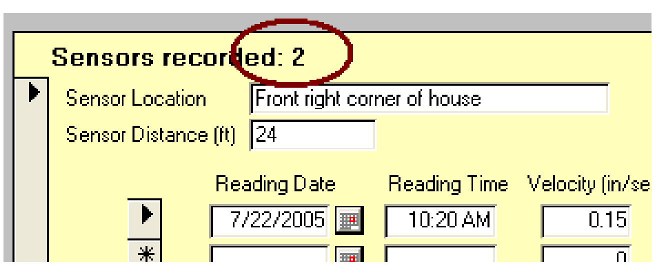
ENTERING EVENT, SOIL and SENSOR INFORMATION



To add a new event or sensor record, click the  button.
You must enter the event activity type; all other event fields are optional.

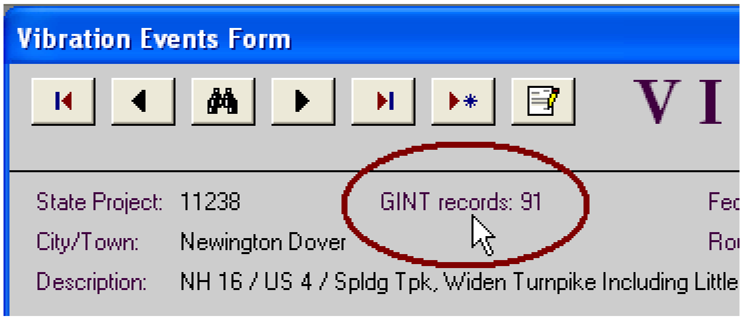


The ‘Events recorded’ will display the number of events for the project.

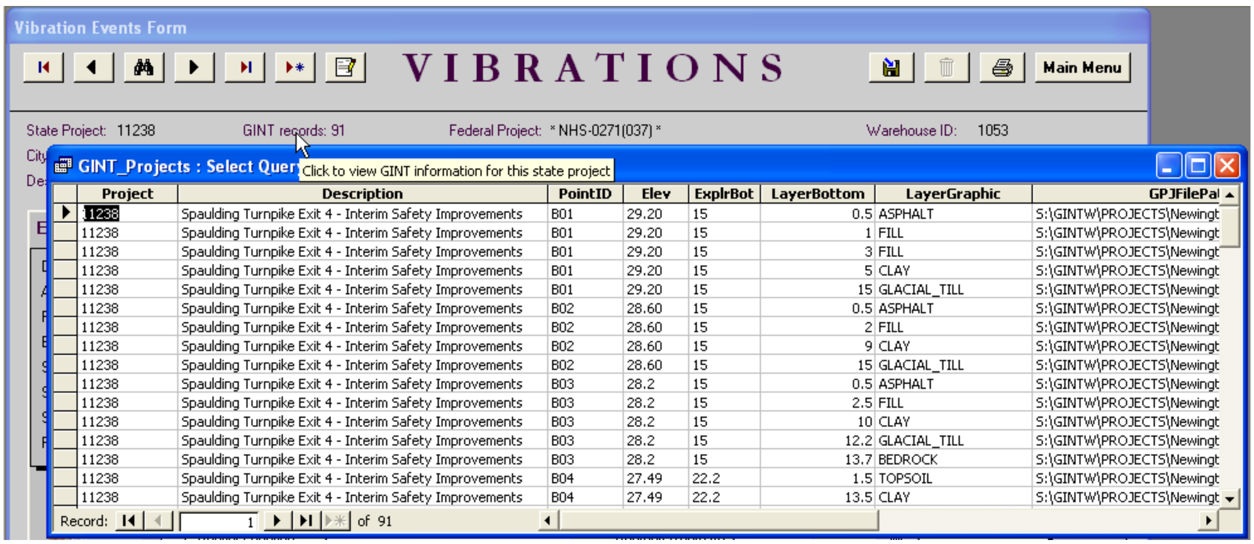


The same count is displayed for the number of sensor records for the project.

GINT INFORMATION



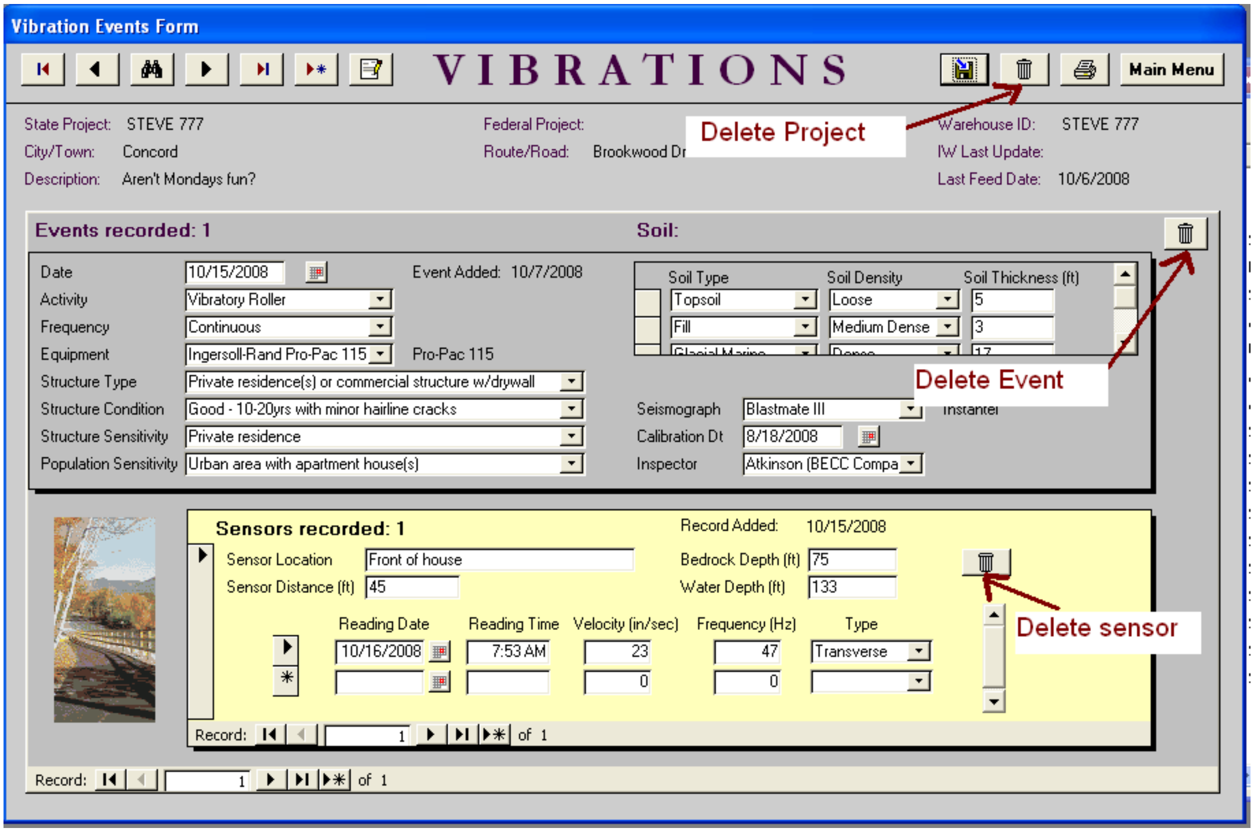
When a project has matching GINT data, the number of records will displayed to the right of the state project number. Click on the “GINT record: ##” to display the GINT detail records.



Project	Description	PointID	Elev	ExplrBot	LayerBottom	LayerGraphic	GPJFilePat
11238	Spaulding Turnpike Exit 4 - Interim Safety Improvements	B01	29.20	15	0.5	ASPHALT	S:\GINTW\PROJECTS\Newingt
11238	Spaulding Turnpike Exit 4 - Interim Safety Improvements	B01	29.20	15	1	FILL	S:\GINTW\PROJECTS\Newingt
11238	Spaulding Turnpike Exit 4 - Interim Safety Improvements	B01	29.20	15	3	FILL	S:\GINTW\PROJECTS\Newingt
11238	Spaulding Turnpike Exit 4 - Interim Safety Improvements	B01	29.20	15	5	CLAY	S:\GINTW\PROJECTS\Newingt
11238	Spaulding Turnpike Exit 4 - Interim Safety Improvements	B01	29.20	15	15	GLACIAL_TILL	S:\GINTW\PROJECTS\Newingt
11238	Spaulding Turnpike Exit 4 - Interim Safety Improvements	B02	28.60	15	0.5	ASPHALT	S:\GINTW\PROJECTS\Newingt
11238	Spaulding Turnpike Exit 4 - Interim Safety Improvements	B02	28.60	15	2	FILL	S:\GINTW\PROJECTS\Newingt
11238	Spaulding Turnpike Exit 4 - Interim Safety Improvements	B02	28.60	15	9	CLAY	S:\GINTW\PROJECTS\Newingt
11238	Spaulding Turnpike Exit 4 - Interim Safety Improvements	B02	28.60	15	15	GLACIAL_TILL	S:\GINTW\PROJECTS\Newingt
11238	Spaulding Turnpike Exit 4 - Interim Safety Improvements	B03	28.2	15	0.5	ASPHALT	S:\GINTW\PROJECTS\Newingt
11238	Spaulding Turnpike Exit 4 - Interim Safety Improvements	B03	28.2	15	2.5	FILL	S:\GINTW\PROJECTS\Newingt
11238	Spaulding Turnpike Exit 4 - Interim Safety Improvements	B03	28.2	15	10	CLAY	S:\GINTW\PROJECTS\Newingt
11238	Spaulding Turnpike Exit 4 - Interim Safety Improvements	B03	28.2	15	12.2	GLACIAL_TILL	S:\GINTW\PROJECTS\Newingt
11238	Spaulding Turnpike Exit 4 - Interim Safety Improvements	B03	28.2	15	13.7	BEDROCK	S:\GINTW\PROJECTS\Newingt
11238	Spaulding Turnpike Exit 4 - Interim Safety Improvements	B04	27.49	22.2	1.5	TOPSOIL	S:\GINTW\PROJECTS\Newingt
11238	Spaulding Turnpike Exit 4 - Interim Safety Improvements	B04	27.49	22.2	13.5	CLAY	S:\GINTW\PROJECTS\Newingt

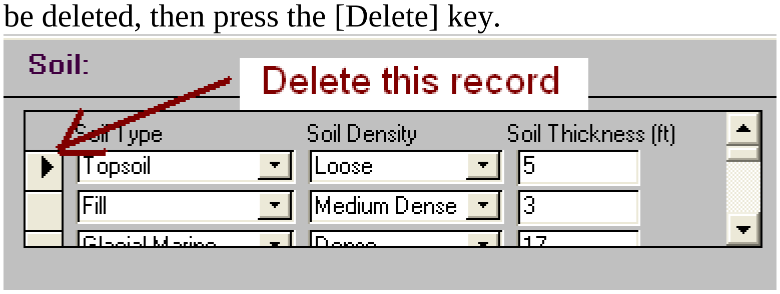
The GINT record detail for the project will be displayed.

DELETING RECORDS



There is a delete button in the project, event and sensor locations on the Vibrations screen. When you delete a project, the related events, soil and sensor information will also be deleted.
note: the project delete button is only available for projects that were manually added.

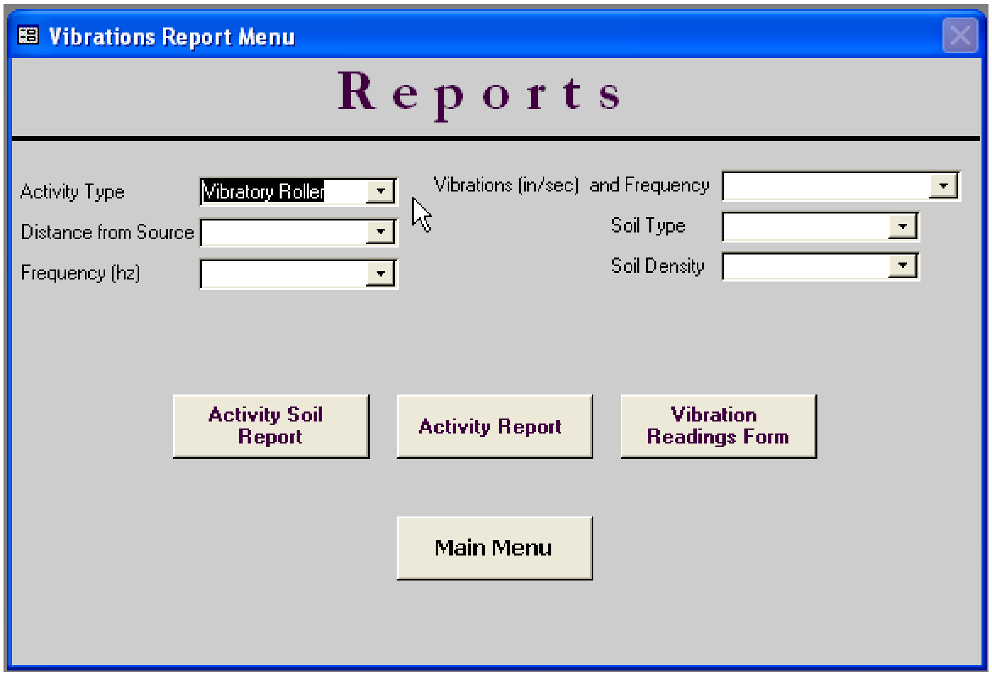
To delete records where there is not a specific delete button, click the  on the row to be deleted, then press the [Delete] key.



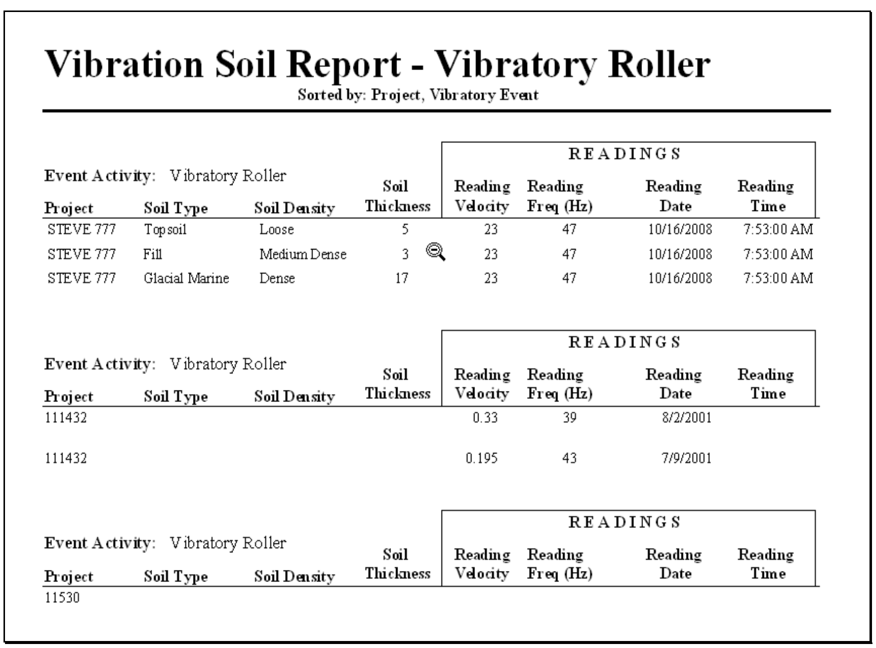
REPORTS

Click the 

button open the vibrations reports screen.



You must select the activity type to run the either activity reports.
All other fields are optional.



Vibration Soil Report - Vibratory Roller

Sorted by: Project, Vibratory Event

Event Activity: Vibratory Roller

Project	Soil Type	Soil Density	Soil Thickness	READINGS Reading Velocity	Reading Freq (Hz)	Reading Date	Reading Time
STEVE 777	Topsoil	Loose	5	23	47	10/16/2008	7:53:00 AM
STEVE 777	Fill	Medium Dense	3	23	47	10/16/2008	7:53:00 AM
STEVE 777	Glacial Marine	Dense	17	23	47	10/16/2008	7:53:00 AM

Event Activity: Vibratory Roller

Project	Soil Type	Soil Density	Soil Thickness	READINGS Reading Velocity	Reading Freq (Hz)	Reading Date	Reading Time
111432				0.33	39	8/2/2001	
111432				0.195	43	7/9/2001	

Event Activity: Vibratory Roller

Project	Soil Type	Soil Density	Soil Thickness	READINGS Reading Velocity	Reading Freq (Hz)	Reading Date	Reading Time
11530							

An example of the Vibration Readings form:

Vibration Readings Form

State Project#: ______ Federal Project#: ______ Today's Date: ______

City/Town: ______ Route/Road: ______ Your Name: ______

Event Information:

Event Date: ______

Event Activity: ______

Frequency: ______

Equipment ______

Structure Type: ______

Structure Condition: ______

Structure Sensitivity: ______

Population Sensitivity: ______

Soil Information:

Soil Type: ______ Soil Density: ______ Soil Thickness (ft): ______

Soil Type: ______ Soil Density: ______ Soil Thickness (ft): ______

Soil Type: ______ Soil Density: ______ Soil Thickness (ft): ______

Soil Type: ______ Soil Density: ______ Soil Thickness (ft): ______

Seismograph: ______

Calibration Dt: ______

Inspector: ______

Sensor Information:

Sensor Location ______ Bedrock Depth (ft) ______

Sensor Distance (ft) ______ Water Depth (ft) ______

Readings:

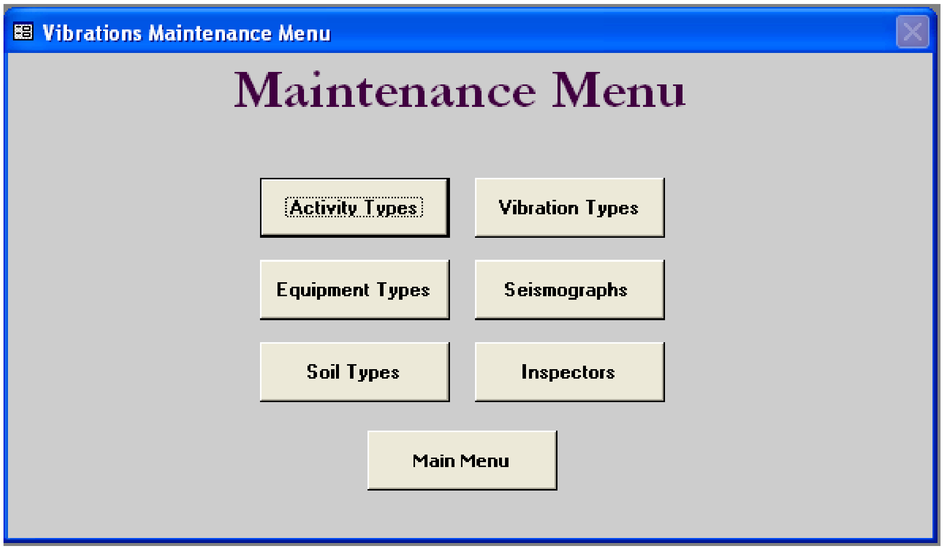
Reading Date	Reading Time	Velocity (in/sec)	Frequency (Hz)	Type

(Long Transv Vert)

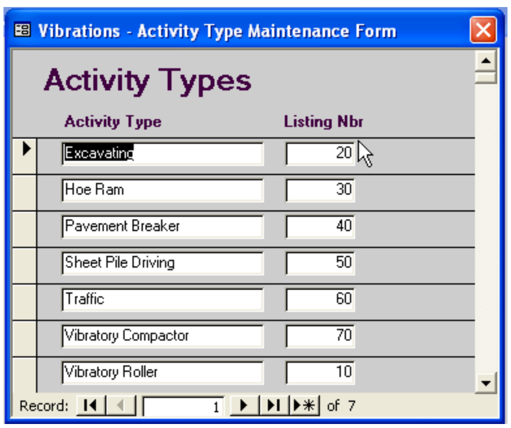
MAINTENANCE MENU

Click the 

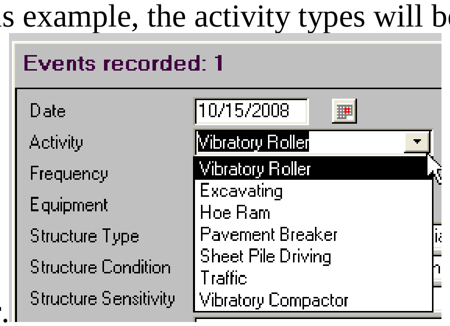
button open the vibrations maintenance menu.



The "Listing Nbr" fields in some maintenance screens is available for you to determine, from lowest to highest, the order in which the items will be displayed in the pull-down fields.



In this example, the activity types will be presented in the pull-down in the listing number order.



EXIT

Press the 

button to exit the Vibrations system.