TRANSPORTATION RESEARCH SYNTHESIS

Minnesota Department of Transportation
Office of Policy Analysis, Research & Innovation
Research Services Section
(651) 366-3780
www.research.dot.state.mn.us

TRS 1201
Published July 2012

Impact of Vibratory Equipment to Surrounding Environments during Construction

Introduction

Minimizing vibration induced impact or damage to people and structures adjacent to construction is a major challenge faced by DOTs. Various offices within MnDOT have experienced complaints, claims and concerns resulting from construction using vibration equipment.

MnDOT is interested in the conflict resolution process surrounding the impact of vibratory equipment, including impact or damage to property, best practices for public engagement during large projects, educating the public about the potential for damage during construction, and construction in areas susceptible to damage.

A survey of MnDOT personnel, a survey of state DOTs, and a literature search were performed, focusing on MnDOT current practices, and other state DOT practices that address the conflict resolution process for vibration-producing activities such as compaction, pile driving, blasting or pavement breaking.

Summary

This TRS involved the following tasks:

1. MnDOT interviews

   Four MnDOT personnel were identified by the Department as best suited to describe current practices and procedures used by MnDOT. (The results of these interviews are included on page 4 of this report.)

   The four MnDOT personnel interviewed included:
   - a resident engineer from District 1,
   - an area manager from the Metro District,
   - a resident engineer from the Metro District,
   - **a** project manager/resident engineer from the Metro District.

   All MnDOT personnel indicate that precondition surveys and vibration monitoring are typically only performed during blasting or pile driving projects. There have been instances where precondition surveys and vibration monitoring were performed for compaction equipment, but generally only because of issues that arise during construction or during an environmental assessment.

The common theme from the MnDOT personnel is that 1) the decision of whether or not precondition surveys and vibration monitoring are performed should be part of the design process, and 2) more public education is needed for projects that are identified as being sensitive to construction vibration.

2. Survey of other States' DOT's

Eleven states responded to the State DOT Best Practices survey. (Survey Results begin on page 7 of this report.) Seven of these states have policies, standards or practices regarding impacts related to vibratory construction equipment to area residences and surrounding infrastructure. These agencies are:

- **Florida**, which has a recommended practice for estimating the effect of vibratory compaction of hot mix asphalt pavement in terms of human perception/annoyance, and structural damage using Falling Weight Deflectometer test results.
- **Louisiana**, which was in the process of completing a research study looking at its practice at the time of this survey.
- **Michigan**, which addresses blasting, pile driving, soil compaction, pavement breaking, and demolition and has plans to document its policies.
- **Montana**, which has procedures for assessing vibration impacts during design.
- **New Hampshire**, which is preparing a comprehensive guideline for assessing construction vibration impact during design.
- **New Jersey**, which prepares project specific specifications and has plans to document its practices.
- **Utah**, which considers performing preconstruction surveys and vibration monitoring within about a half-mile radius of the construction site.

MnDOT typically performs precondition surveys and vibration monitoring during pile driving or blasting activities. Of the seven states that responded to the survey and have standards regarding impacts related to vibratory construction equipment, five states consider the impact of vibratory compaction, pavement breaking, and demolition activities prior to construction activities in addition to blasting and pile driving. Of the construction methods used on MnDOT projects, blasting and pile driving are the methods that have historically produced the largest ground vibrations having the potential to cause damage. However, there are other construction activities that can cause damage or annoyance when in close proximity structures and people. By considering the impact of these other construction methods, states realize that the potential for claims and complaints is increased in environments were there may be a large number of structures in close proximity to construction activities and are taking proactive steps to minimize conflicts.

3. Related Literature

A literature search confirms that there are several publications that address the issue of Impact of Vibratory Equipment to Surrounding Environments during construction. Several sources were identified and reviewed in preparation of this document Most of the literature considers vibration impact on structures and people regardless of the construction method being used. The overriding theme is that in addition to ground and structure type, the velocity amplitude of the ground vibration is a critical component in assessing potential for damage and annoyance. Dynamic compaction, pile driving and blasting are examples of methods that can produce large velocity amplitudes at great distances; however, there are many other methods of construction that can produce large velocity amplitudes at small distances. The results of the literature search are included on page 12 of this report.

4. Characterize vibrations produced by vibratory compactors

Part of the scope of this TRS was to characterize vibrations produced by vibratory compactors. Vibrations produced by vibratory compactors can be characterized by a continuous harmonic waveform with a frequency between 22 and 30 Hz. Compactors that are large and/or operating close to adjacent structures can produce ground vibrations with the potential to cause damage. Assessments of the impact of vibratory compactors can be made prior to construction. If the assessment indicates a concern relating to the potential for damage or annoyance then steps can be taken during design to mitigate these concerns. Many states having vibration impact policies currently address the impact of vibratory compaction prior to construction. The full characterization is included in appendix A.

5. Model policy

Part of the scope of this TRS was to provide a model policy based on survey results, best practices in other state DOTs, and technical considerations. Several state DOT written policies were reviewed in order to develop a basis for a model policy. The written policies reviewed included: Florida's research report titled **Use of Nondestructive Techniques to Estimate the Allowable Vibratory Compaction Level during Construction**, (Jackson, Hammons, Walker, & Von Quintus, March 2007); New Hampshire's draft report titled **Ground Vibrations Emanating from Construction Equipment**, (Lane & Pelham, 2011); and California's **Transportation- and Construction-Induced Vibration Guidance Manual** (Jones & Stokes, June 2004). We also reviewed Charles Dowding's book **Construction Vibrations** (Dowding, 2000); and the Federal Transit Administration's manual titled **Transit Noise and Vibration Impact Assessment** (Hanson, Towers, & Meister, May 2006). Based on technical considerations in these documents and the survey results we recommend that a model policy include the following key topics:

- Assessment of construction vibration impacts – To assess the potential for vibration to annoy people and damage structures, a reasonable means must be available for estimating or predicting the PPV from various sources at various distances (Jones & Stokes, June 2004). The vibration levels determined by the assessment can be compared to established construction vibration criteria. More detailed analysis can be performed for specific structures if needed.
- Standards for estimating construction vibration levels – Dowding (2000) states that prediction of particle velocity can be approached from two classical directions: attenuation relations and scaling relations. New Hampshire (Lane & Pelham, 2011), Florida (Jackson, Hammons, Walker, & Von Quintus, March 2007), The Federal Transit Administration (Hanson, Towers, & Meister, May 2006), and California (Jones & Stokes, June 2004) suggest the use of an attenuation relations to estimate and predict vibration levels due to construction. Blasting on the other hand typically relies on scaled relations to estimate vibration levels.
- Basis for establishing project specific construction vibration criteria – Vibration criteria can be established to reduce potential for damage or cosmetic cracking in structures, reduce annoyance to humans, or to reduce the impact to sensitive electronic equipment. Structures with plaster walls will generally experience cosmetic cracking at much lower vibration levels than structures with sheetrock walls. Humans will be more sensitive to vibrations at night than during the day. Sensitive electronic equipment such as MRI scanners or electron microscopes are extremely sensitive to vibrations. Determining the type of construction of adjacent structures, the activities occurring in these structures, and the impact construction will have is useful as a basis for establishing vibration criteria that can reduce impacts to the surrounding environment.
- Methods for reducing construction vibrations – These methods could include any of the following:
    - Limit the size of specific types of equipment.
    - Require the use of non-vibratory pneumatic rubber-tired rollers in lieu of large vibratory soil compaction equipment.
    - Require that alternative low-impact methods are used for demolition activities.
    - Locate haul routes away from sensitive locations.
- Preconstruction surveys – The content and format required for preconstruction surveys should be well defined. Methods for tracking and maintaining the surveys before, during, and after construction should be included to aid in developing data, information, and best practices.
- Guidance for vibration and structure monitoring – This should include recommendations for the use of vibration monitoring equipment, including placement, sampling rate, and reporting procedures. In addition to vibration monitoring, other measures can be taken to monitor critical structures such as crack monitoring, and visual surveys during and after construction.
- Public notification and education. – To be effective, the vibration analysis must be presented to the public in a clear, yet comprehensive manner (Hanson, Towers, & Meister, May 2006). MnDOT personnel suggest that preconditions surveys and vibration monitoring can act as notification to the public. Public meetings can be held prior to construction to address concerns. Social media can be used to notify the public of when vibration impacts will occur. Public demonstrations can be held using vibratory construction equipment and showing the relationship between perceived vibrations and the actual measured ground motion.

In general, the California Department of Transportation's (CALTRANS) guidance manual includes all these topics. We recommend that this document be the model policy used to develop a MnDOT construction vibration impact policy. The CALTRANS guidance manual is included in appendix B.

MnDOT Practices

Summary

We interviewed four MnDOT personnel to describe current practices and procedures used by MnDOT. The interviews were focused on the following questions:

1. How would you describe MnDOT's customs or practices addressing the use of preconstruction surveys and vibration monitoring on construction projects?
2. Are you satisfied with the outcome of MnDOT's customs or practices addressing the use of preconstruction surveys and vibration monitoring on your construction projects? If you are dissatisfied, is the problem related to the number of claims, resolution of those claims and/or the effect on the public image (or something else)?
3. How do you address different sources of construction vibration? Which of the following sources of construction vibrations do you encounter? a) Blasting, b) Pile Driving, c) Soil Compaction, d) Equipment Traffic, e) Pavement Breaking, f) Demolition, g) Other.
4. For which of the following have you conducted precondition surveys or vibration monitoring? a) Blasting, b) Pile Driving, c) Soil Compaction, d) Equipment Traffic, e) Pavement Breaking, f) Demolition, g) Other.
5. Please rank the following sources of construction vibrations with respect to the issues you have encountered (complaints, claims, public image)? a) Blasting, b) Pile Driving, c) Soil Compaction, d) Equipment Traffic, e) Pavement Breaking, f) Demolition, g) Other.
6. How do you decide when to conduct preconstruction surveys or construction-time vibration monitoring? a) Distance. If so what value? b) Predicted vibration levels (i.e. potential for structure damage). If so, what value?, c) Predicted vibration levels (i.e. potential for human nuisance). If so, what value?, d) Soil conditions, e) Number and location of structures. If so, what value?, f) Project size and duration. If so, what value?, g) Public visibility of the project, h) Other.
7. Have you found significantly different responses for different vibration-causing activities? If so, please elaborate.
8. Have preconstruction surveys and/or vibration monitoring impacted the number or size of claims, the number or nature of complaints or the public perception of projects?

Key findings from the interviews are:

- MnDOT sometimes performs preconstruction surveys and/or vibration monitoring for projects involving blasting and pile driving. They generally do not assess the need for surveys and/or monitoring for projects with other vibration sources.
- Vibration impacts resulting from sources other than blasting and pile driving are typically dealt with during construction after an issue arises.
- There is a desire for additional resources for assessing vibration impacts during design. There is also a feeling that the public could be better educated concerning vibration impacts, precondition surveys, and vibration monitoring.
- There is a perceived benefit to performing preconstruction surveys and/or vibration monitoring in terms of reducing complaints, claims and public perception; however, the cost benefit has not been quantified.

Each interview response is provided below. For reference, we have included an abbreviated version of each question before the response; see the first paragraph of this section for the full question text.

District 1 Resident Engineer Interview

1. **Describe MnDOT's customs and practices**: In District 1, vibration impacts were historically mostly on the north shore due to rock blasting, but are now more urban in nature. An example of an urban project is the 2003 and 2004 Piedmont Avenue project which consisted of three phases and included blasting, pile driving, and soil compaction. The specifications were modified for this project to include all vibration activities, and we put monitors out as soon as there was an issue. There were many complaints but no claims. Preconstruction surveys and vibration monitoring were very effective tools. The second phase did not have many vibration impacts, but the third phase was near the Mall and the Target store which were both sensitive. MnDOT didn't really receive any claims on the Mall project either.

   At the last minute, preconstruction surveys were added to the Mega Project, as were specifications for vibration monitoring. The soils were like "jelly". There were a lot of complaints initially. Businesses and the University were having keyboards shaking off tables. The preconstruction surveys were very beneficial, as was the monitoring. He visited and talked to the owners of the most sensitive buildings and also talked to the city building folks. He said that it is critical to be upfront.

   On a project in Grand Rapids, MnDOT had to write a supplemental agreement for preconstruction surveys and monitoring.

2. **Satisfaction with MnDOT's customs or practices**: He would really like this approach to be less of an afterthought and more of a planned approach from the beginning. He would like to have an expert to talk to from time to time. Experience needs to be shared more broadly in the Department. Institutional memory can be lost quickly. He would like to have a best practices document as a resource for everyone's use.
3. **How do you address different sources of vibration**: So far, all sources of vibration have been treated the same. Limits are generally based on a radius and blasting induced vibrations. Vibration monitoring for non-blasting is generally done as a result of an issue, rather than at the start. Blasting projects trigger automatic vibration monitoring.
4. **For what activities have surveys or monitoring been performed**: blasting, pile driving, and soil compaction.
5. **Rank sources of vibration**: All sources of vibration have been treated the about the same, however, non-blasting impacts are not generally treated the same priority as blasting impacts.
6. **Decision process for conducting surveys and/or monitoring**: Every project is different. He has used judgment for distance in the past. He said that there needs to be consideration for special cases, like special structures, older structures, and close structures. He said that there needs to be an understanding of folks that oppose the project and then address their concerns. He feels that District 1 is doing it about right on the projects where they have thought about the problem. He said that one will never know how much will be saved by performing surveys and monitoring, but MnDOT needs to be proactive regardless.
7. **Responses to vibration sources**: Education is a major part of the process. He mentioned that one should take out the seismograph, and show the owners what the limits are like compared to jumping around on the floor.
8. **Impact from surveys and/or monitoring**: Basically he has had no claims on projects where pre-construction surveys and blast monitoring were done. However, on an early bridge project related to the Mega Project, there was an old hotel that was in relatively poor condition that was not surveyed. This was a blasting/rock breakage project where the specifications limited the vibrations to low velocities. The blasting was performed in a controlled manner and the vibrations were kept below the specified limit. Regardless, the owner of the hotel felt some vibrations during blasting and so a survey was performed. Monitoring equipment was then used for the duration of the project.

Metro District Area Manager Interview

1. **Describe MnDOTs customs and practices**: The department generally does not do monitoring or precondition surveys for projects involving only soil compaction although the responsibility for vibration impacts still resides with the Owner, specifically MnDOT. Crosstown was the first major project that had precondition surveys or vibration monitoring done. The Hwy 100 project also had precondition surveys done. Precondition surveys and vibration monitoring were also done on the 169-494 project and on a Hwy 100 project with some bridges.
2. **Satisfaction with MnDOTs customs or practices**: There needs to be some education because the public does not really understand why precondition surveys and vibration monitoring are being done. Even more education is necessary than Crosstown.
   On Crosstown, claims went first to the PR firm. Contractor follow-up should be required under a specified schedule in the Special Provisions.
3. **How do you address different sources of vibration**: Typically he would not do precondition surveys or vibration monitoring for a reconstruction project unless there was pile driving.
4. **For what activities have surveys or monitoring been performed**: Typically only pile driving.
5. **Rank sources of vibration**:
   - Blasting—little to no blasting is done on his projects
   - Pile driving—have had issues, but public awareness helps with the complaints
   - Soil compaction—issues arise because of the closeness to residences (compaction on city streets)
   - Equipment—does occur, and is sometimes just from idling
   - Pavement breaking—has had issues
   - Demolition—has had issues due to a hoe ram, but the issue could have been noise
6. **Decision process for conducting surveys and/or monitoring**: Decisions are made on a case by case basis. He suggested the following considerations: 1) size of the project, 2) pubic visibility, 3) proximity to homes, 4) number of people impacted, and 5) public perception of the project. He believes vibration monitoring is not done to protect MnDOT's interest. He sees vibration monitoring as a PR and education tool, and also a protection for the public.
7. **Responses to vibration sources**: See question 5.
8. **Impact from surveys and/or monitoring**: The MnDOT-sponsored precondition surveys and vibration monitoring have helped the contractor by eliminating uncertainty.

Metro District Resident Engineer Interview

1. **Describe MnDOT's customs and practices**: Typically preconstruction surveys are not performed unless there is pile driving or rock blasting. Older architecture would also trigger a survey. She often talks to the foundations people and the geology folks about the project and potential vibration impacts.
2. **Satisfaction with MnDOT's customs or practices**: Doing a preconstruction survey or vibration monitoring should be on a design checklist. If there is no survey or monitoring performed by MnDOT, then it should be the contractor's responsibility.
3. **How do you address different sources of vibration**: Typically would not do preconstruction surveys unless there is pile driving or rock blasting. Older architecture would also trigger a survey. She does not think that it is appropriate to do preconstruction surveys and vibration monitoring for soil compaction because the contractor can change means and methods. Pile driving is different.
4. **For what activities have surveys or monitoring been performed**: Preconstruction surveys were done on a parking ramps project, Hwy 100 from I-394 to France Avenue, and blasting on Hwy 10 from Hwy 61 to Prescott, WI.
5. **Rank sources of vibration**: She has had a number of complaints on projects using blasting, pile driving and soil compaction. Blasting is infrequent, pile driving is continuous, and soil compaction is like a continuous wave. She has also had complaints due to pavement breaking. Soil compaction and pavement breaking typically produce nuisance complaints. Preconstruction surveys and vibration monitoring are too costly for soil compaction and pavement breaking. It is a struggle to get the contractors to turn down their equipment. Other sources of vibration have not caused complaints. Concrete crushing has created noise complaints.
6. **Decision process for conducting surveys and/or monitoring**: Size, age, and number of structures are the most common trigger. The distance is job specific. A rule of thumb is 200 feet, but the actual value comes from the design people. For example, 200 ft. was acceptable for Hwy 100, but a larger distance was used for the parking ramps project. The depth of pile and kind of strata affect the distance.
7. **Responses to vibration sources**: A lot of the claims have been related to pavement placement, using more and more vibratory compaction due to changes in equipment. However, typically preconstruction surveys and vibration monitoring is not done for pavement work and soil compaction. Preconstruction surveys are very beneficial to the State if there are older buildings or if the project is in a neighborhood. Hwy 100 had a large number of preconstruction surveys and her perception was that people were, in general, very open to having them done. In general she thinks people understand why they are done and believes that there are beneficial aspects to having them done.
8. **Impact from surveys and/or monitoring**: It is a beneficial thing to do because of the public perception. Doing the preconstruction surveys and vibration monitoring likely does reduce the claims and improve public perception, but the cost benefit is difficult to measure and depends upon the nature of the structures, nature of the neighborhood, and trying to show people that their homes are important to the department. Maybe there should be special provisions covering soil compaction near buildings and homes.

Metro District Project Manager/Resident Engineer Interview

1. **Describe MnDOT's customs and practices**: Currently the Resident Engineer on a bridge project in Hastings, which is subject to Section 106 of the National Historic Preservation Act (NHPA) requirements due to the Federal funding. Potential vibration issues arose during predesign. Also involved in the project are MnDOT Cultural Affairs Office and the State Historical Preservation Office (SHPO). Concern about vibrations arose due to the environmental process, more than from some intuition by MnDOT that the project would have issues.
2. **Satisfaction with MnDOT's customs or practices**: There is an inconsistent policy about the need for preconstruction surveys and vibration monitoring.
3. **How do you address different sources of vibration**: The Hastings Bridge documents require preconstruction surveys, the first on any project in his 27 years; however there may have been one other project that required surveys. He noted that a previous bituminous overlay did not require preconditions surveys.
4. **For what activities have surveys or monitoring been performed**: Compaction of the subgrade and pavement.
5. **Rank sources of vibration**: He has only had experience with vibrations due to compaction on the Hastings Bridge project.
6. **Decision process for conducting surveys and/or monitoring**: As mentioned previously concern about vibrations related to the Hastings Bridge project arose due to the environmental process.
7. **Responses to vibration sources**: He has only had experience with vibrations due to compaction on the Hastings Bridge project.
8. **Impact from surveys and/or monitoring**: Hastings bridge project has limits near historic buildings of 0.12 in/s. Recent compaction of subgrade and base near historic buildings produced actual velocities of 0.3 to 0.5 in/s. The contractor switched to static compaction for the bituminous, which did not take much more time than vibratory

compaction would have taken. He expressed concern that it may be difficult to bring the material up to specification using static compaction.

State DOT Practices

Summary

Surveys were sent to all state DOTs. Eleven states responded to our survey. Key findings from the surveys are:

- Several states including Louisiana, Michigan, and New Hampshire are currently conducting or completing studies of construction related vibration impacts. And Florida has a written recommended practice for estimating the effect of vibratory compaction of hot mix asphalt concrete for roadway surfaces.
- Several states including Georgia, Montana, New Hampshire, New Jersey, have general guidelines or standard specifications covering construction related vibration impacts.
- None of the state DOTs address educating the public in their policies, standards, or practices.

The following Table 1 includes the number of responses to each question in the state DOT survey. A total of seven states completed the survey.

Table 1 - Summary of State DOT Responses to Survey

Questions	Responses
1. In your opinion do you find your agency's policy, standards or practices are effective in minimizing impacts due to vibratory construction work?	
Very	5
Somewhat	2
Not very	0
Not at all	0
1.a. If very or somewhat, please provide a copy via PDF, Word or postal mail.	N/A
1.b. Generally speaking, is your agency satisfied with the outcome of the policies, standards or practices addressing the use of preconstruction surveys and vibration monitoring on construction projects?	
Very	5
Somewhat	2
Not very	0
Not at all	0
1.c. If you answered not very or not at all, is the problem related to any of the following?- Mark all that apply.	
Number of Claims	N/A
Resolution of Claims	N/A
Public image of your agency	N/A
All of the above	N/A
2. Which of the following does your policy, standards or practices address?–Mark all that apply.	
Impact or damage to property	6
Best practices for public engagement during large projects	1
Visualization techniques	2
Educating the public about the potential for damage	0
Educating the public about the potential for nuisance	0
Other	1
3. Which vibration activities are addressed in your policy, standards or practices?–Mark all that apply.	
Blasting	6
Pile Driving	6
Soil Compaction	5
Equipment Traffic	2
Pavement Breaking	5
Demolition	5
Other	3

Table 1 Continued

Questions	Responses
4. What changes if any, would you consider helpful related to vibratory guidance when working with affected residences?	4
5. What factors are considered when determining to do preconstruction surveys	
Distance.	5
Predicted vibration levels (i.e. potential for structure damage).	4
Predicted vibration levels (i.e. potential for human nuisance).	2
Soil conditions.	3
Number and location of structures.	3
Project size and duration.	1
Public visibility of the project.	1
Other:	3
6. What factors are considered when determining to do construction-time vibration monitoring	
Distance	4
Predicted vibration levels (i.e. potential for structure damage)	5
Predicted vibration levels (i.e. potential for human nuisance)	3
Soil conditions	3
Number and location of structures	3
Project size and duration	1
Public visibility of the project	1
Other	1
7. Have you assessed the cost-benefit of your policy, standards or practices based on claims, complaints or public perception of your agency?	
Yes	0
No	7
Not Sure	0
8. Do you have any plan to document your practices in written policies or standards?	
Yes	4
No	1
Not Sure	2
8.a. If yes, would you be willing to provide a copy via PDF, Word or postal mail?	
Yes	4
No	0

Each survey response is provided below. For reference, we have included an abbreviated version of each question before the response; for the full question text, see Table 1 of this report.

Arkansas

Contact: Emanual Banks, emanuel.banks@ahtd.ar.gov

Arkansas DOT does not have a policy.

Florida

Contact: Bouzid Choubane, (352) 955-6302, bouzid.choubane@dot.state.fl.us

1. **Is your policy effective**: Florida DOT finds its policy somewhat effective at minimizing impacts and they are somewhat satisfied with the outcome of the policy addressing preconstruction surveys* and vibration monitoring. In lieu of a policy, FDOT has a recommended practice for estimating the effect of construction vibration in terms of human perception/annoyance, and structural damage. The practice is an outcome of a FDOT funded research project which has been implemented in 2008. The research report is attached as a separate file (see appendix C). In essence, this practice uses the load and deflection time histories collected using a Falling Weight Deflectometer during the predesign testing in estimating the effects of ground motion from a vibratory roller. An Excel/VBA based spreadsheet has been implemented for use and is available upon request.
2. **Policy addresses**: Impact or damage to property and impact on human annoyance.
3. **Vibration activities addressed**: Vibratory compaction of hot mix asphalt concrete for roadway surfaces.
4. **Helpful changes**: When vibration is estimated to cause structural damage or excessive human annoyance that may result in public complaint, avoid using vibratory compaction. Instead, use static rolling to minimize the damage and complaints.

5. **Preconstruction survey factors**: Predesign testing is conducted using a Falling Weight Deflectometer which is FDOT's standard protocol for estimating the in-situ soil strength for rehabilitation design of existing pavements. The Falling Weight Deflectometer test is conducted without any of the above factors considered.
6. **Vibration monitoring factors**: Predicted vibration levels (i.e. potential for structure damage): Values depend on the job site. The distance range at which the structural damage is possible is determined based on the predesign testing using a Falling Weight Deflectometer. If there is a structure that is prone to damage within that predetermined distance range, then vibratory compaction is not recommended. Predicted vibration levels (i.e. potential for human nuisance): These values also depend on the job site. The distance range at which human perception or annoyance is possible is determined based on the predesign testing using a Falling Weight Deflectometer. If there are residential or office structures that may results in public complaint within those predetermined distance ranges, then vibratory compaction is not recommended.
7. **Cost-benefit**: Has not been assessed.
8. **Policy documentation**: FDOT's State Materials Office has been advertising the use of this technology to the District offices for the past 3 years and will continue to do so. In addition, this technology is one of the four PaveSuite technologies that were selected by AASHTO's Technology Implementation Group (TIG) as focus technologies. AASHTO TIG is supporting FDOT in marketing and advertising the above mentioned technology.

Georgia
Contact: Thomas Scruggs, (404) 608-4720, tscruggs@dot.ga.gov

1. **Is your policy effective**: Georgia DOT does not have a formal policy regarding vibration & blast monitoring; however, they have general guidelines used to determine whether to perform preconstruction crack surveys and/or perform monitoring during construction activities. The guidelines are somewhat effective in minimizing vibration impacts and we are very satisfied with the outcome of these guidelines.
2. **Policy addresses**: Impact or damage to property, educating the public about the potential for damage and nuisance.
3. **Vibration activities addressed**: Blasting, pile driving, soil compaction, pavement breaking, and demolition.
4. **Helpful changes**: We occasionally hire consultants to perform pre-construction damage surveys and/or monitor vibrations from construction activities if the project is very large; otherwise, we perform these activities ourselves. We determine if these actions are needed on a project by project basis, depending on the type and condition of the structures, the distance from the work, the type of work to be done, predominant soil type in the area, and existence of any pre-construction complaints from property owners. Occasionally, post-construction inspections must be done, although these are more problematic since no pre-construction evidence or monitoring data are available.
5. **Preconstruction survey factors**: Distance: Within approximately 75-100 feet. Predicted vibration levels (i.e. potential for structure damage): > 2.0 in/s. Soil conditions. Condition of structures. Complaints received regarding the project.
6. **Vibration monitoring factors**: Distance: Within approximately 75-100 feet. Predicted vibration levels (i.e. potential for structure damage): > 2.0 in/s. Soil conditions. Condition of structures. Complaints received regarding the project.
7. **Cost-benefit**: Has not been assessed.
8. **Policy documentation**: Not sure if there is a plan to document policies.

Indiana
Contact: Ronald Walker, rwalker@indot.in.gov

Indiana DOT does not have a policy. The response we received is as follows:

> Indiana does not have a formal policy on the use of vibratory compaction equipment that may affect surrounding residences or businesses. If we suspect that we may have problems, we work with the Contractor to assure rolling is only done with static rollers. Since we include compaction in our PWL (Percent Within Limits) acceptance specification, we allow a 100% payment for density when this occurs. Contractors have been using oscillatory rollers in recent years and have not had a problem.

Louisiana
Contact: Harold Paul, harold.paul@la.gov

At the time of this survey, Louisiana had just completed a research study looking at Louisiana's practice. The study was going through editorial review and can be obtained by contacting the Louisiana DOT.

Michigan
Contact: Steven Kahl, (517) 241-4214, kahls@michigan.gov

1. **Is your policy effective**: Michigan DOT finds its policy very effective at minimizing impacts and they are somewhat satisfied with the outcome of the policy addressing preconstruction surveys and vibration monitoring.
2. **Policy addresses**: Impact or damage to property.
3. **Vibration activities addressed**: Blasting, pile driving, soil compaction, pavement breaking, and demolition. Standards focus on limits of vibrations, rather than separating out by equipment or operational category. E.g., "Maximum permissible vibration limit of 0.2 in/sec between 15-30 Hz for operations deemed to cause vibrations per the Engineer".
4. **Helpful changes**: We need to ascertain the settlement risk for structures based on soil conditions and tolerable peak particle velocity limits, e.g., what is the max safe vibration limits/frequency for structures 50' away on sandy soil with water table at 15' below ground?
5. **Preconstruction survey factors**: Distance: generally 100' for residential structures in sound condition. Predicted vibration levels (i.e. potential for structure damage): AASHTO R 8-96. Number and location of structures: determined by the local engineer, usually driven by urban locations. Historical, sensitive, or unique structures, as well as critical underground utilities.
6. **Vibration monitoring factors**: Distance: we measure as close as possible to the structure whether on ROW limit or if grading permit then right at the foundation. Predicted vibration levels (i.e. potential for structure damage): AASHTO R-8 Figure 1 is used as guidance. Soil conditions: saturated sands, silty clays, that have potential for settlement based on past experience. Number and location of structures: we follow moving operations and set up two to four monitors.
7. **Cost-benefit**: Has not been assessed.
8. **Policy documentation**: Michigan DOT has plans to document its practices and will provide a copy. Current research is focused on effects of pile driving on soil settlement; we hope to get a better idea of estimating soil conditions sensitive to vibrations, and the attenuation characteristics.

Montana
Contact: Susan Sillick, (406) 444-7693, ssillick@mt.gov

Montana provided a link to their website: http://www.mdt.mt.gov/business/contracting.shtml. The website contains a geotechnical manual which addresses vibration monitoring in chapter 11. Following is a link to this chapter: http://www.mdt.mt.gov/other/materials/external/geotech_manual/chapter11.pdf.

1. **Is your policy effective**: Montana DOT finds its policy very effective at minimizing impacts and they are very satisfied with the outcome of the policy addressing preconstruction surveys and vibration monitoring.
2. **Policy addresses**: Impact or damage to property and visualization techniques.
3. **Vibration activities addressed**: Blasting, pile driving (sometimes), soil compaction, pavement breaking, and demolition.
4. **Helpful changes**: None.
5. **Preconstruction survey factors**: Distance.
6. **Vibration monitoring factors**: None.
7. **Cost-benefit**: Has not been assessed.
8. **Policy documentation**: Not sure. MDT has standard special provisions.

New Hampshire
Contact: Glenn Roberts, (603) 271-3151, groberts@dot.state.nh.us

New Hampshire provided a draft report titled **Ground Vibrations Emanating from Construction Equipment**, by Lane and Pelham, not dated, as well as an implementation manual in draft form. The implementation manual contains guidelines for construction vibration impact assessment, estimating hours for vibration services, estimating vibration levels for construction activities, important lessons learned, and general rules and vibration information. The report and manual are not included in this TRS because they are in draft form.

1. **Is your policy effective**: New Hampshire DOT finds its policy very effective at minimizing impacts and they are very satisfied with the outcome of the policy addressing preconstruction surveys and vibration monitoring.

2. **Policy addresses**: Impact or damage to property.
3. **Vibration activities addressed**: Blasting, pile driving, soil compaction, equipment traffic, pavement breaking, and demolition.
4. **Helpful changes**: NHDOT has established a vibration database to collect information from vibration monitoring conducted on DOT projects.
5. **Preconstruction survey factors**: Distance: 500 feet for blasting. Predicted vibration levels (i.e. potential for structure damage): See specification in appendix D. Predicted vibration levels (i.e. potential for human nuisance). Soil conditions. Number and location of structures. Project size and duration. Public visibility. Note: refer to research report.
6. **Vibration monitoring factors**: Distance: 500 feet for blasting. Predicted vibration levels (i.e. potential for structure damage). Predicted vibration levels (i.e. potential for human nuisance). Soil conditions. Number and location of structures. Project size and duration. Public visibility. Note: refer to research report.
7. **Cost-benefit**: Has not been assessed.
8. **Policy documentation**: NHDOT plans to document their practices. NHDOT intends to market or inform the agency and external stakeholders via the following:
    - Standard specifications
    - Construction Vibrations Implementation Manual
    - Presentation at annual construction school

New Jersey
Contact: Eric Kraehenbuehl, (609) 530-2552 eric.kraehenbuehl@dot.state.nj.us

1. **Is your policy effective**: New Jersey DOT finds its policy very effective at minimizing impacts and they are very satisfied with the outcome of the policy addressing preconstruction surveys and vibration monitoring. They did not provide a written policy.
2. **Policy addresses**: Impact or damage to property, best practices for public engagement during large projects, and visualization techniques.
3. **Vibration activities addressed**: Blasting, pile driving, and sheeting.
4. **Helpful changes**: N/A.
5. **Preconstruction survey factors**: Distance: project specific. Predicted vibration levels (i.e. potential for structure damage): project specific (see project specific specifications in appendix E). Predicted vibration levels (i.e. potential for human nuisance): project specific. Soil conditions. Number and location of structures: project specific.
6. **Vibration monitoring factors**: Distance: project specific. Predicted vibration levels (i.e. potential for structure damage): project specific. Predicted vibration levels (i.e. potential for human nuisance): project specific. Soil conditions. Number and location of structures: project specific.
7. **Cost-benefit**: Has not been assessed.
8. **Policy documentation**: New Jersey DOT plans to document their practices. New Jersey DOT intends to market or inform the agency and external stakeholders via the following: within Standard Specifications & project-specific supplementary specifications.

Oklahoma
Contact: George Raymond, (405) 521-2561, graymond@odot.org

Oklahoma DOT does not have a policy.

Utah
Contact: Jon Bischoff, jonbischoff@utah.gov

1. **Is your policy effective**: Utah DOT finds its policy very effective at minimizing impacts and they are very satisfied with the outcome of the policy addressing preconstruction surveys and vibration monitoring. They did not provide a written policy.
2. **Policy addresses**: Impact or damage to property.
3. **Vibration activities addressed**: Blasting, pile driving, soil compaction, equipment traffic, pavement breaking, and demolition.
4. **Helpful changes**: None.
5. **Preconstruction survey factors**: Distance: about ½ mile. Predicted vibration levels (i.e. potential for structure damage): 2 in/s.

6. **Vibration monitoring factors**: Distance: about ½ mile. Predicted vibration levels (i.e. potential for structure damage): 2 in/s.
7. **Cost-benefit**: Has not been assessed.
8. **Policy documentation**: There is no plan to document policies.

Related Literature

The following literature was reviewed in preparation of this document:

1. American Association of State Highway and Transportation Officials. AASHTO R 8-96 (2009). **Standard Recommended Practice for Evaluation of Transportation-Related Earthborne Vibrations**. Washington, DC.

   This recommended practice is to provide guidance for the assessment of potential or alleged structural damage due to earthborne vibrations related to transportation facility construction, maintenance, or operation.

2. Dowding, C. H. 2000. **Construction Vibrations**. C H Dowding.

   Charles Dowding is a professor at Northwestern University and is a leading expert on the subject of construction vibrations. This book contains more than two decades of research and consulting experience and covers the entire field of construction vibrations including recommended procedures for preconstruction surveys and sample specifications.

3. Hanson, C. E., Towers, D. A., & Meister, L. D. (May 2006). **Transit Noise and Vibration Impact Assessment**. Washington, DC: Prepared for U.S. Department of Transportation, Federal Transit Administration, Office of Planning and Environment.
   http://www.fta.dot.gov/documents/FTA_Noise_and_Vibration_Manual.pdf

   This manual provides procedures for predicting and assessing vibration impacts from construction. Mitigation measures are also described for dealing with adverse vibration impacts.

4. Jones & Stokes. 2004. **Transportation- and Construction-Induced Vibration Guidance Manual**. June. (J&S 02-039.) Sacramento, CA. Prepared for California Department of Transportation, Noise, Vibration, and Hazardous Waste Management Office, Sacramento, CA.
   http://www.dot.ca.gov/hq/env/noise/pub/vibrationmanFINAL.pdf

   This manual provides practical guidance for those who must address vibration issues associated with the construction, operation, and maintenance of DOT projects. Included in the manual is an introduction to the basics of ground vibrations, a summary of various historical vibration criteria, and a simplified procedure for assessing and mitigating groundborne vibration from construction equipment.

5. Siskind, D. E., M. S. Stagg, J. W. Kopp, and C. H. Dowding. 1980. **Structure Response and Damage Produced by Ground Vibration from Surface Mine Blasting**. (Report of Investigations 8507.) Washington, DC: U.S. Bureau of Mines.
   http://arblast.osmre.gov/downloads/USBM/RI%208057%20Blasting%20Vibration%201989.pdf

   The vibration limits published in this report are based on a large set of blasting data. The limits are widely viewed as stringent enough to prevent damage from construction vibrations to most surrounding structures.

6. Wisconsin Department of Transportation. 2003. **Transportation Synthesis Report: Construction Vibration and Historic Buildings**. Bureau of Environment, Division of Transportation Infrastructure Development. Prepared by CTC & Associates LLC.
   http://wisdotresearch.wi.gov/wp-content/uploads/tsrconstructionvibration1.pdf

   This TSR is a good summary of research related to construction vibrations and their impact on historic structures.

7. Literature Search: “Ground Vibration Resulting from Compaction Equipment”

   The literature included in appendix F was found during an independent literature search for “Ground Vibration Resulting from Compaction Equipment” by MnDOT. The abstracts of these documents were reviewed and those found to be applicable to this TRS were included in the appendix. The search was conducted on September 9, 2011 using the following resources: the MnDOT Library Collection, the Web, the Transportation Database, and TRB Research in Progress.

8. Literature Search: “Standards and Guidelines for Preconstruction Survey Use”

   The literature included in appendix G was found during an independent literature search for “Standards and Guidelines for Preconstruction Survey Use” by MnDOT. The abstracts of these documents were reviewed and those found to be applicable to this TRS were included in the appendix. The search was conducted on September 12, 2011 using the following resources: the MnDOT Library Collection, the Web, the Transportation Database, and TRB Research in Progress.

Works Cited

Dowding, C. H. (2000). *Construction Vibrations.* C H Dowding.

Hanson, C. E., Towers, D. A., & Meister, L. D. (May 2006). *Transit Noise and Vibration Impact Assessment.* Washington, DC: Prepared for U.S. Department of Transportation, Federal Transit Administration, Office of Planning and Environment.

Jackson, N. M., Hammons, M. I., Walker, R., & Von Quintus, H. (March 2007). *Use of Nondestructive Techniques to Estimate the Allowable Vibratory Compaction Level during Construction.* Tallahassee, FL: Florida Department of Transportation.

Jones, & Stokes. (June 2004). *Transportation- and construction-induced vibration guidance manual.* (J&S 02-039). Sacramento, CA: Prepared for California Department of Transportation, Noise, Vibration, and Hazardous Waste Management Office, Sacramento, CA.

Lane, & Pelham. (2011). *Ground Vibrations Eminating from Construction Equipment.* Draft Report.