TRB ADC40, Summer Meeting 2014, Postsmouth, NH

Issues and Recommendations for Construction Vibration Monitoring*

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*This presentation summarizes the paper of the same name published as part of INCE NoiseCon 2014, Fort Lauderdale, FL., Sept. 8-10, 2014

Original abstract for "*Issues and Recommendations for Construction Vibration Monitoring*"

Sometimes, when building a bridge or a road
Piles are driven under a kinetic load

Or trucks loaded heavy with stone or lumber
pass in proximity to where people slumber

To avoid annoyance, disruption or damage
Construction vibration must be well managed

In monitoring its levels, engineers may find
Construction vibration can be brought into line

Original abstract for "*Issues and Recommendations for Construction Vibration Monitoring*" continued…

By establishing a proper criterion or limit
Monitoring vibration can help stay within it

A change of equipment or reduction of force
May help lower vibrations, as a matter of course

Using proper methods, equipment and technique
Concerns can be dampened, so to speak

- P L Burge

Presentation Outline

- Cheesy Poetry ✓
- Snappy Introduction
- Interesting Technical Background
- Thoughtful Ground Vibration Criteria
- Obvious Construction Activities that Generate Vibration
- Helpful Vibration Monitoring Elements
- Merciful Conclusions and Recommendations

First, some Deep Thoughts:

- We can calculate approximate or reasonable worst case vibration levels from nearby construction activities, but these are, at best, educated guesses.
- Knowing the actual vibrational power of specific equipment and ground propagation characteristics is impossible
- Measuring the actual vibration level at or near the vibration-sensitive activity is the only way to know the truth! And the truth will set us free!
- What if our entire solar system is just a molecule in some giant's fingernail? Huh?

Introduction

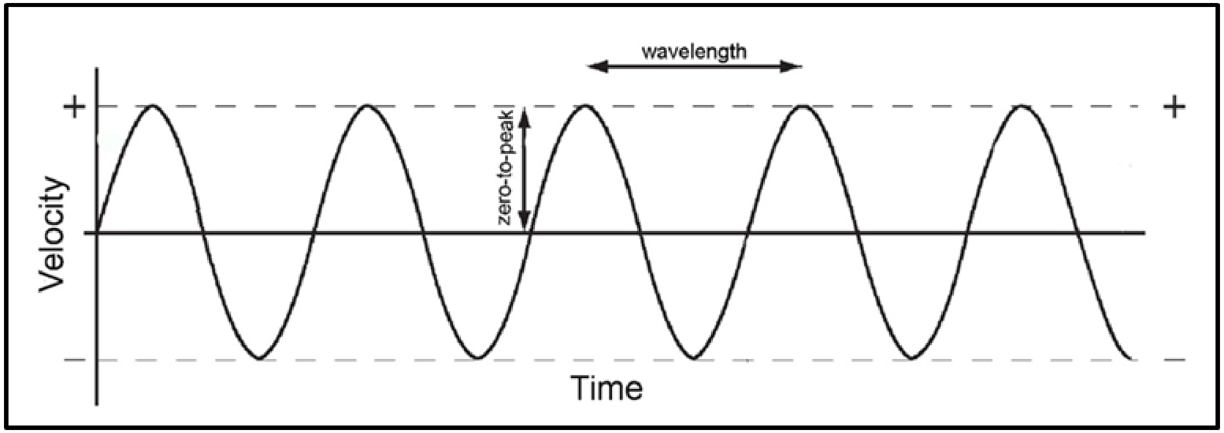
- Many types of construction equipment and processes can generate high levels of vibration that can potentially cause annoyance, activity disruption and even damage at nearby properties.
- A predictive analysis can help to predict if vibration will be a concern or how to reduce vibration to acceptable levels.
- Vibration monitoring can offer empirical documentation of actual construction vibration levels and can be used to stop or control levels that approach or exceed identified thresholds.

Ground Vibration Technical Background

- Common Metrics
- Ground vibration propagation
- Different types of waves
- Influence of soil type and geological conditions

Ground Vibration Technical Background

- Common Metrics
  - Peak Particle Velocity (PPV) in inches/second, indicated as Zero-to-Peak in diagram below, is the most common metric for construction vibration monitoring.
  - Vibration Velocity Level (L_v or VdB) is sometimes used, but not in this presentation

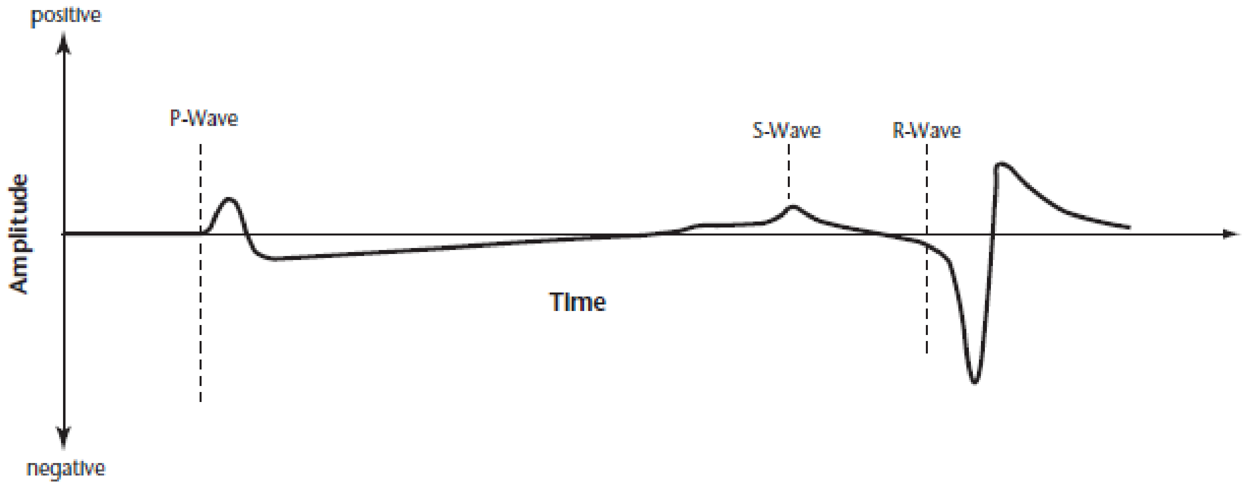


Ground Vibration Technical Background

- Different types of waves
  - "Primary" or "compression" waves (P-waves) with particle motion parallel to wave front
  - "Secondary" or "shear" waves (S-waves) with particle motion transverse to the wave front.
  - "Rayleigh" waves (R-waves) with horizontal and vertical components that travel mostly near the surface.

Ground Vibration Technical Background

- Different types of waves
  - All three waves travel at different speeds, with R-waves most significant along surface.



Source: Caltrans 2013

Ground Vibration Technical Background

➢Ground vibration propagation

The amplitudes of body waves decrease in direct proportion to the distance from the source, except along the surface, where their amplitudes decrease in direct proportion to square of the distance to the source.

- $$v_b = v_a (r_a/r_b)^{\gamma}$$

Where:

- v_a = *vibration amplitude of the source at distance* r_a
- v_b = *vibration amplitude at distance* r_b
- γ = *geometric attenuation coefficient*

Source	Wave Type	Measurement Point	γ
Point on surface	R	Surface	0.5
Point on surface	Body (P or S)	Surface	2
Point at depth	Body (P or S)	Surface	1
Point at depth	Body (P or S)	Depth	1

Ground Vibration Technical Background

➢ Influence of soil type and geological conditions

A simplified model that takes into account both geometric and material damping is given by:

$$V = kD^{-n}$$

Where:

- *V = PPV of the seismic wave*
- *k = value of velocity at one unit of distance*
- *D = distance from the vibration source*
- *n = slope or attenuation rate*

Soil Class	Soil Type	"n" Value for Eq. 2
Class I	*Weak or soft soils:* lose soils, dry or partially saturated peat and muck, mud, loose beach sand, dune sand, recently plowed ground, soft spongy forest or jungle floor, organic soils, topsoil (shovel penetrates easily)	None identified
Class II	*Competent soils:* most sands, sandy clays, silty clays, gravel, silts, weathered rock (can dig with a shovel)	1.5
Class III	*Hard soils:* dense compacted sand, dry consolidated clay, consolidated glacial till, some exposed rock (cannot dig with a shovel, need a pick to break up)	1.1
Class IV	*Hard, competent rock:* bedrock, freshly exposed hard rock (difficult to break with a hammer)	None identified

Caltrans 2013

Ground Vibration Criteria

- Annoyance
- Building Damage
- Vibration sensitive equipment and processes

Ground Vibration Criteria

- Annoyance

Guideline for Vibration Annoyance Criteria

Human Response	Maximum PPV (in/sec)	
	Transient Sources	Continuous/Frequent Intermittent Sources
Barely perceptible	0.04	0.01
Distinctly perceptible	0.25	0.04
Strongly perceptible	0.9	0.10
Severe	2.0	0.4

Note: Transient sources create a single isolated vibration event, such as blasting or drop balls. Continuous/frequent intermittent sources include impact pile drivers, pogo-stick compactors, crack-and-seat equipment, vibratory pile drivers, and vibratory compaction equipment

Source: Caltrans 2013

Ground Vibration Criteria

- Annoyance

Guideline for Vibration Damage Threshold Criteria

Structure and Condition	Maximum PPV (in/sec)	
	Transient Sources	Continuous/Frequent Intermittent Sources
Extremely fragile historic buildings, ruins, ancient monuments	0.12	0.08
Fragile buildings	0.2	0.1
Historic and some old buildings	0.5	0.25
Older residential structures	0.5	0.3
New residential structures	1.0	0.5
Modern industrial/commercial buildings	2.0	0.5

Note: Transient sources create a single isolated vibration event, such as blasting or drop balls. Continuous/frequent intermittent sources include impact pile drivers, pogo-stick compactors, crack-and-seat equipment, vibratory pile drivers, and vibratory compaction equipment.

Source: Caltrans 2013

Ground Vibration Criteria

- Vibration sensitive equipment and processes
  - Allowable operating conditions of different types of vibration sensitivity equipment may range dramatically
  - Much may also depend on internal design of equipment and pedestals
  - Some equipment may include the following:
    - Operating suites, research facilities, micro-electronic manufacturing facilities, MRI suites, etc.
  - Some generalized limits (PPV or VdB) are available, organized by equipment class and detail size
  - Some equipment manufactures may provide vibrational environment limits

Construction Activities that Generate Vibration Issues

- Typical vibration-generating construction equipment and activities
- Some reasonable options and mitigation techniques

Construction Activities that May Generate Vibration Issues

- Typical vibration-generating equipment

Equipment		PPV at 25 ft (in/sec)
Pile Driver (impact)	upper range	1.518
	typical	0.644
Pile Driver (sonic)	upper range	0.734
	typical	0.170
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: FTA, 2006[11]

Construction Activities that May Generate Vibration Issues

- Typical vibration-generating equipment

Hoe Ram

Hydromill

Vibratory Roller

Bulldozer

Construction Activities that May Generate Vibration Issues

- Typical vibration-generating equipment

Construction Activities that May Generate Vibration Issues

- Some reasonable mitigation techniques
  - Select lower level vibration generating equipment, settings, or methods
  - Increase distance between vibrating-generating equipment and sensitive activity
  - Define less obtrusive work schedules
  - Communicate with sensitive receptors
  - Establish a vibration monitoring plan

Vibration Monitoring Element

- When to monitor and why
- Monitoring equipment options
- Monitoring locations and mounting techniques
- Data acquisition options
- Reporting results

Vibration Monitoring Elements

- When to monitor and why
  - Monitor to document actual construction vibrations at or near vibration-sensitive activity
  - Best to monitor whenever actual construction activity is taking place
  - Sometimes only when certain vibration generating equipment is operating (i.e. pile driving)
  - May be helpful to collect some ambient (non-construction) vibration measurements as a baseline, especially if other vibration sources are already present

Vibration Monitoring Elements

- Monitoring equipment options

Several options available:

- Simple seismic accelerometer attached to SLM or frequency analyzer
- Specialized long-term monitor with tri-axial Accelerometer/geophone (allows vector sum)
- Units with cellular and/or WIFI capability
- Remote data upload, threshold alerts and full remote monitoring capabilities

Vibration Monitoring Elements

- Monitoring locations and mounting techniques
  - Always best to monitor as close to the sensitive activity as practical (sleeping space, sensitive equipment)
  - If interior access not available monitor at closest external location to the building with respect to construction activity
  - If exterior, consider coupling loss
  - If possible may wish to consider sample interior/exterior measurement to determine coupling loss
  - Several methods for mounting transducer (mounting plates, sandbags, carpet spikes, mounting putty).

Vibration Monitoring Elements

- Reporting results

Monitoring reporting will generally depend on the needs of the project, client, or other stakeholders, or the capability of the monitoring equipment, but could include any or all of the following:

  - Email or text threshold alerts, to construction foreman or other stakeholders
  - Set up and access controlled use of live monitoring website
  - Periodic summary memo, over life of monitoring
  - Formal report document

Conclusions and Recommendations

- A predictive analysis can identify expected vibration levels given assumptions regarding soil conditions and construction activities
- Established criteria can be used to establish appropriate impact or action thresholds
- Vibration monitoring at sensitive receptor locations can provide an empirical safety switch to help satisfy various stakeholders.

Questions?

Comments?

Opinions?

Please submit in writing!