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Noise measurement and mitigation for urban building foundation excavation

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Abstract

Excavation noise disturbance case studies are presented for two urban locations; i) a large academic building near a hotel-conference centre and ii) a high rise office building adjacent to an owner-occupied residential condominium, respectively. Impact, milling and drilling in hard limestone resulted in noise and vibration disturbance complaints from nearby buildings. In addition to airborne sound intrusion via windows and walls, there were indications of reinforcing re-radiated interior sound from ground borne vibration transmission into building structures. The acoustical design objectives were to a) determine noise levels of excavation machinery, impact and scraping, and b) to mitigate noise intrusion into nearby buildings to meet criteria limits and to reduce occupants’ distraction and annoyance. Permissible property boundary noise limits exist, but noise limits at building façades relating to interior background sound levels were controlling. Noise reductions were essentially limited to existing insulating glass window performance. Excavation noise contains machinery engine noise, repetitive ram-hoe impacts on rock, scraping noises of milling machine and line drills. The impact procedures transmit potentially “feelable” vibration. Dropping excavated soils and debris into trucks for hauling causes audible impacts. Short-term on-site noise monitoring determined noise spectrum levels and variation over time. Measurement results are summarized in graphs, including statistical (Ln) percentile sound pressure levels (dB) in 1/3-octave spectra. Limited interior floor vibration from one building will be included for comparison. Photos will illustrate excavation equipment and other relevant conditions. Noise mitigation recommendations are summarized.

Keywords: noise, environmental noise, vibration, impact, construction excavation
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1 Introduction

Building demolition, foundation excavation and construction environmental noise in urban areas may disturb nearby buildings, including office, conference, residential and other sensitive occupancies. Airborne construction sound radiates in all directions, and is reinforced by reflections. It also adds to other urban sound sources. Some processes may input impacts or vibration into the soils, which propagates by ground borne paths to other building foundations and result in re-radiated interior audible sounds.

Two unrelated new building excavations caused audible disturbances in nearby buildings. The owners and construction companies sought to achieve neighbors’ satisfaction while maintaining work schedule progress. A consultant was retained who provided recommendations for airborne sound containment on the construction site and/or limited intrusion into adjacent buildings. Continuing issues indicated potential ground borne vibration paths. Measurements of sound and vibration were made to determine relative contributions of sound and vibration. Recommendations were confirmed and supplemented, based on measurement findings.

2 Acoustical Design Objectives

Acoustical studies and measurements were requested by Owners for the purpose of determining ambient and disturbed conditions. Acoustical criteria, including municipal code and ordinance standards plus interior acoustical design goals were researched and established for the types of buildings surrounding the excavation sites. Comparisons of actual construction/excavation noise versus ambient interior sound levels were used to estimate noise reduction requirements.

Acoustical design objectives were similar for the two unrelated projects:

i) Determine effective and economic means of temporary excavation noise control, after accounting for outside to inside sound transmission loss of building shells/windows,

ii) Conduct individual measurements of excavation equipment under controlled conditions (quiet Sunday morning), outside on excavation perimeter and inside the building.

iii) Develop practical recommendations for airborne sound containment on the construction site, attenuation at the sources and/or reduction of intrusive noise at the receivers.

iv) Consider possibility/probability of ground borne impact or vibration caused re-radiated sound from floors, walls, and ceilings of interior spaces. Develop alternate excavation processes and/or day/night scheduling for various types of equipment that would cause least disturbance to nearby conference, office, hotel and residential occupancies.
3 Excavation near Conference Centre/Hotel and Residences

3.1 Case Study 1 - Introduction

An urban foundation excavation site covered a full block, separated by city streets from adjacent buildings on each side: i) conference centre and hotel, ii) residential apartment mid-rise building and iii) retail/commercial buildings on the other sides. Daytime and nighttime sound and vibration sensitivities were considered and reflected in separate criteria.

An initial theoretical sound control study with conceptual recommendations was produced [1] for construction site noise containment, scheduling and other mitigation measures, using published construction equipment noise levels [2] to estimate potential transient sound levels at property boundaries. Following the initial study, a more detailed on-site acoustical and vibration measurement study was commenced to determine actual excavation noise and interior sound disturbance levels and develop noise control recommendations to reduce disturbances [3].

![Excavation equipment: Line Drill (left), Milling (scraping, center), Ram Hoe (impact, right).](image)

**Figure 1**: Excavation equipment: Line Drill (left), Milling (scraping, center), Ram Hoe (impact, right).

3.2 Acoustical Criteria

3.2.1 **Municipal Code**: limits machine noise from earth handling to 85 dBA from 10 pm to 2 am and does not permit audibility between 2 am and 10 am [4].

3.2.2 **Acoustical Design Goal (Interior Levels)**:

Although more difficult to apply or enforce, interior performance-based criteria were recommended for limit of intrusive noise increase above interior ambient broadband sound level.
a) Daytime: Conference, hotel and residential intrusive noise exceedance above continuous broadband ambient should be ≤ 5 dBA, to minimize distraction and speech interference. Perceptible tonal or information-bearing sound should not exceed the ambient level.

b) Nighttime: Hotel and residential sleeping quarters intrusive transient noise events should not exceed broadband ambient sound level by 10 dB in any octave band, nor more than once per hour to minimize sleep disturbance (inferred from sleep disturbance studies) [5,6].

3.3 On-Site Measurements and Monitoring

On-site controlled measurements were set up on a Sunday morning when individual excavation machines could be operated independently. The conference centre had no scheduled events at that time and urban ambient environmental noise was lower. A site vicinity plan, Fig. 2, shows the excavation measurement locations and relationships to surrounding buildings. Excavation site sound sources could vary from a minimal 20m (65ft) to the conference centre and/or residential buildings to as much as 90m (295ft) distant. Weather was cool, fair and little breeze.

Acoustic and vibration 1/3-octave spectrum analysis measurements were made and data was integrated into statistical percentiles (Ln). Airborne sound measurements were conducted simultaneously outdoors around the excavation perimeter and indoors in select representative rooms, using real time spectrum analyzers and ANSI Type I (+ 1dB) precision 12.5 mm (1/2 in) microphones with windscreens. Floor response to ground borne vibration was measured in an interior room using a real time spectrum analyzer with seismic (10V/g) accelerometers.

3.4 Measurements and Results

Statistical (Ln) spectrum measurements were conducted around the excavation with one type of equipment operating at a time. Results incorporated urban background, direct equipment noise
propagation and reflection/reverberant build-up (Fig 3). Floor vibration was measured within an interior room continuously, with data integrated into statistical (Ln) percentiles (Fig. 3). 63 Hz peaks in airborne and ground borne appear related, but continuous vibration from building electrical equipment may contribute to the vibration spectra.

Figure 3: Exterior equipment airborne noise spectra and interior structure borne floor response. Airborne Transient (L10) Sound Spectra (left) at Site Perimeter Locations 1-4 due to Ram Hoe impacts and Mill scraping. Statistical (Ln) 1/3 octave velocity RMS versus Vibration Criteria (VC).

During individual equipment operations, airborne sound spectra were measured in representative conference and hotel rooms (Fig. 4).

Figure 4: Representative Interior Airborne Noise Spectra (L33) - various room sizes and types. Ambient versus Disturbed Conditions: Impact (Ram Hoe, lt) and Scraping (Milling Machine, rt).
3.5 Measurement Findings

3.5.1 Exterior excavation sound levels were generally conforming to municipal limits, but caused audible disturbance levels within the building.

3.5.2 Impact procedures caused substantial noise increase within adjacent building, but scraping (mill) and grinding (drill) caused very little interior noise increase.

3.5.3 Ground borne impact and vibration transmission into foundation was not perceptible, but structure borne vibration in lightweight partitions and ceilings caused radiated audible sound. This effect varied with room type and size due to acoustic room losses and range of potential occupant distances from radiating surfaces.

3.6 Recommendations

3.6.1 Schedule impact procedures (ram hoe) during non-sensitive times of day (or when conference centre events are not scheduled). Do not permit impact operations at night. Maximize use of drilling and milling operations (even though they are less productive).

3.6.2 Provide temporary sound barrier around excavation site approximately 2.5 m (8ft) high to reduce laterally radiated noise (benefits ground level building occupancies only).

3.6.3 Provide temporary sound barrier retrofit glazing or solid material covers over windows of most sensitive conference centre windows (conference/lecture spaces). Check existing entry doorframe seals for acoustical performance. Replace or supplement, if needed.

3.6.4 Stage excavation equipment and support equipment, such as compressors and idling trucks on side of excavation closer to retail/commercial properties and farther from conference centre and residential buildings.

3.6.5 Move earth and rubble, and fill removal truck beds only during non-sensitive daytimes.

4 Excavation near Residential and Commercial Buildings

4.1 Case Study 2 - Introduction

A foundation excavation site was adjacent to a midrise residential condominium and garage, separated only by a 6m (20ft) alley. The building had retail and service occupancies in basement and first (ground) floors. Residential units occupied second and higher levels. Only units on one side of the building overlooked the excavation and construction site. Three other sides of the site faced retail/commercial buildings of various heights across city streets. Direct sound propagation from excavation was reinforced by reflections and added to urban noise.

Sound monitoring and excavation noise investigation was commissioned and conducted, with results and recommendations reported in two documents. [7,8]

4.2 Criteria

4.2.1 Acoustical Design Goal (Interior Levels):

   a) Daytime: Broadband intrusive noise ≤ continuous broadband ambient noise + 5 dBA.

   b) Nighttime: Broadband intrusive transient noise events ≤ broadband ambient level + 5 dB, ≤ 1 loud event per hour (sleep disturbance). Tonal noise ≤ broadband ambient level.
4.2.2 Municipal code: Earth-handling noise < 85 dBA, 10 pm-2 am. No audibility, 2 am-10 am.

Figure 5: Excavation Site Plan (left) with measurement locations (outside monitors in photo, right) plus direct and reflected airborne sound paths and ground borne vibration.

Figure 6: Site Excavation pit viewed from residential tower, Level 10.

4.3 Sound Monitoring

Monitors were stationed i) at the edge of the excavation nearest residential building, ii) on Garage Level 4 (top) corner near residential building and inside the building near windows of units on Levels 4 and 10. Three instruments monitored A-weighted (dBA) sound with 1 minute logging intervals and integrated data to obtain statistical (Ln) percentiles. The Level 10 residential monitor recorded continuous level versus time (not logging) C- and A-weighted levels. Results shown in Fig. 7 are annotated to indicate day (7 am-10 pm) and night (10 pm-7 am), based on federal definitions (the municipal noise limit time periods are inconsistent with federal).
4.4 Monitoring Results

Instantaneous and short duration transients occur at all hours of day and night. Some of those are due to other urban sources in the vicinity, but many are from excavation operations. Comparison of A- versus C-weighted time histories shows much greater variation of A-weighted levels, indicating probability that many transients have significant higher frequency content.

Table 1: Loudest Transient Intervals for Each Monitoring Location

<table>
<thead>
<tr>
<th>Location</th>
<th>Top 5 L1 transients (dBA)</th>
<th>Day</th>
<th>Approximate Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edge of Construction Site</td>
<td>85-91</td>
<td>5/26/15</td>
<td>2:45-3:55 pm</td>
</tr>
<tr>
<td>Garage, Lvl 4</td>
<td>82-85</td>
<td>5/26/15</td>
<td>3:10 PM-7:55 am (+1)</td>
</tr>
<tr>
<td>Level 4 Daytime Ambient (L90)</td>
<td>38-41</td>
<td>5/26/15</td>
<td>6-7 pm</td>
</tr>
<tr>
<td>Level 4 Disturbance</td>
<td>61-66</td>
<td>5/26/15</td>
<td>2:48-9:17 pm</td>
</tr>
<tr>
<td>Level 10 Daytime Ambient (L90)</td>
<td>42-45</td>
<td>5/26/15</td>
<td>6-7 pm</td>
</tr>
<tr>
<td>Level 10 Disturbance</td>
<td>50*-52*</td>
<td>5/26/15</td>
<td>3:07 PM-8:09 Aam (+1)</td>
</tr>
</tbody>
</table>

*10-H monitored Time History only, exclusive of L(n). Levels shown are max transients from time history.

4.4.1 Interior measurements in Level 4 and Level 10 Residential Units

Variations can be seen in spectral results from residential units on Levels 4 and 10 (Fig. 8). Level 4 has single-pane glass casement windows, versus insulated glass casement windows on Level 10. There are some frequencies showing noise increase in 10 that are not in data from 4,
indicating possibility of interior building sound influence in Level 10 results. Consistent increases in the 125 Hz 1/3-octave and noise in 2k – 4k Hz 1/3-octaves appear to be excavation related.

Figure 8: Level 4 unit single-pane glass (left) and Level 10 unit, insulated glass (right)
24-hr statistical acoustical average Ln(s): L1=1% or < 15 minute aggregate over the measurement period, L5=5% or 72 minutes over 24 hr., L10=2 hr 24 min, L33=8 hr., L50 = 12 hr., L90=21.6 hr.

4.5 Measurement Findings

4.5.1 Exterior excavation sound levels at boundary of site were generally conforming to nighttime municipal limits, but some daytime operations produced levels up to ~ 90 dBA.

4.5.2 Many impacts and machine operations caused audible disturbance levels within the residential building. During set-up, the consultant noted Level 10 intrusions (greater distance and marginally quieter windows) were not as loud as Level 4 interior intrusions.

4.5.3 Impact procedures (ram hoe) caused more perceptible noise increase in the residences building, but scraping (mill) and grinding (drill) caused very little interior noise increase.

4.6 Recommendations

4.6.1 Schedule impact procedures (ram hoe) during non-sensitive times of day (or when conference centre events are not scheduled). Do not permit impact operations at night. Maximize use of drilling and milling operations (even though they are less productive).

4.6.2 Provide temporary and/or mobile sound barriers, located close to excavation machinery and operations to contain operational noise near the source(s).

4.6.3 Consider temporary sound barrier retrofit glazing or solid material covers over more sensitive (sleeping quarters) windows. A limited height sound barrier at excavation perimeter would provide little benefit to residential occupancies.

4.6.4 Stage excavation and support equipment, such as compressors and idling trucks on side of excavation closer to retail/commercial properties and farther from residential building.

4.6.5 Move earth and rubble, and fill removal truck beds only during non-sensitive daytimes.
5 Conclusions

Building foundation excavation created airborne noise and ground borne vibration that became intrusive disturbances in nearby buildings. Impact procedures create loudest airborne sound transmit vibration most likely to be felt as structure borne vibration in buildings. Perceptible instantaneous transient noises and impact vibrations caused distraction, startle and annoyance for occupants. Continuous and transient noises created speech and music listening interference. To some extent, the vibration cues individuals to listen to noise, which aggravates annoyance.

Noise and vibration related to excavation can be mitigated by various means. Recommendations were made to owners and constructors. After consideration and discussion, many of the more practical alternatives were implemented, varying with the different site conditions and schedules.

In both of these case studies, careful implementation of scheduling, staging, containment and noise attenuation did relieve disturbances from the excavation sites in nearby sensitive building occupancies and resulted in decreased complaints from neighbors.

Acknowledgments

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References


