Low frequency noise and induced vibration from air-traffic and military training Processes and new mitigation measures

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Norwegian research on vibration induced by noise from military training – historical overview

1994 – 2001: Full scale investigations, substantial ground interaction with outdoor sound detected

2004-2008: Vibrations in buildings explained due to direct influence of sound – focus on full scale field investigations from blasts and heavy weapons

2009 →: Increased focus on vibration due to military aircrafts and jet fighters, due to reallocation of the Norwegian main air base
Problem setting –
vibration induced by sound in buildings

- Military training, **aircrafts**
- Annoyance
- Delineate mechanisms and develop mitigation measures
Audible sound at and infrasound very low frequency induce these building vibrations
- where most energy from heavy weapons and blast originate
- where buildings respond mostly – main resonances
Pilot study: Full scale field measurements on sound induced building vibration

Rødsmoen Rena, December 6th - 7th 2005

Vibration and air pressure measurements outside and inside test building

Legend:
- Triaxial sensor
- Vertical sensor
- Pressure

C4 blast sources
Conclusions from the pilot study

- The outdoor sound generate wall and ceiling vibration and rattling
- These building vibration set up the indoor sound pressure
- Indoor sound pressure generates floor vibration
- To mitigate the vibration, we must reduce the low frequency sound
Previous studies indicate that aircrafts may induce low frequency noise, vibration, and rattling

- Criteria (Tobita and Nakamura 1981, Hubbard 1982) indicate that perceptible vibration may be induced when the low frequency 1/3 octave values exceed 75-80 dB from 16-64 Hz

- Recent experience of this problem includes among others takeoff at Schiphol Airport and Bodø Airport (Norway)
### Acceptance Criteria for Building Vibration from traffic, Norwegian Standard: NS 8176

<table>
<thead>
<tr>
<th>Vibration Class</th>
<th>Description</th>
<th>Acceptance Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A</strong></td>
<td>Very good vibration conditions, where people will only perceive vibrations as an exception&lt;br&gt;<code>Persons in Class-A dwellings will normally not be expected to notice vibrations</code></td>
<td>0.10 mm/s,w</td>
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<tr>
<td><strong>B</strong></td>
<td>Relatively good vibration conditions&lt;br&gt;<code>Persons in Class-B dwellings can expected to be disturbed by vibrations to some extent</code></td>
<td>0.15 mm/s,w</td>
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<tr>
<td><strong>C</strong></td>
<td>Recommended limit value for vibrations in new residential buildings and in connection with planning and building of new (transport) infrastructure&lt;br&gt;<code>About 15% of the affected persons in Class-C dwellings can be expected to be disturbed by vibrations</code></td>
<td>0.30 mm/s,w</td>
</tr>
<tr>
<td><strong>D</strong></td>
<td>Vibration conditions that ought to be achieved in existing residential buildings&lt;br&gt;<code>About 25% of persons can be expected to be disturbed by vibrations in Class-C dwellings</code></td>
<td>0.60 mm/s,w</td>
</tr>
</tbody>
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F16 sound induced vibration exceeding threshold values in typical Norwegian dwelling close to Bodø airport
Conventional sound proofing for the instrumented building (2004-2005) effective only for the highest frequency.
Research project launched by the Norwegian Defense Estate Agency from 2010-2015

“Low frequency sound and vibration” project, objectives
- Improve our understanding of the underlying mechanisms of building response to low frequency sound
- Quantify the relevance of vibration due to military air traffic
- Develop mitigation measures for typical wooden constructions

Methods
- Novel numerical models for sound and building interaction at low frequency
- Laboratory measurements in SINTEF Sound Lab
- Full scale field measurements
- In add cases, simulations and measurements are conducted for structures before and after countermeasures developed in the project (next slide)
Low frequency countermeasures must

- **Increase the stiffness of the structure**
  - Increased stiffness of components such as walls and roofs
  - Effect: reduced sound transfer for the lowest frequencies

- **Improve the sound reduction for windows**
  - Windows govern the sound transfer in the most critical frequency range (15-25 Hz)
  - Improved damping, stiffer window frame, and mass and stiffness

- **Address cavities and ventilation**
  - Infrasound enters easily through cavities, balanced ventilation may mitigate

- **Work for the higher frequencies**
Suggested mitigation measures for walls

- Designed to reduce both high and low frequency sound
- Increased stiffness of walls and ceilings
- Stiffness increased by adding
  - Steel sections to the wooden columns
  - Plywood to the plasterboard sheets
- Standard wall
  - Used for comparison in simulations and measurements
Some main structures tested in the lab

- Tests conducted from 2013-2014
- Walls before and after countermeasure
- Inclusion of different windows
- Inclusion of vents
- Tests on roof constructions in 2012 (not shown here)
Laboratory measurements - overview

Source room

- Mic 7
- Mic 6
- Mic 5

Receiver room

- Mic 4
- Mic 1
- Mic 2
- Mic 3

Low freq loudspeaker (good signal to noise ratio to ~15Hz)

Instrumented wall
Extensive monitoring of wall vibration

- Accelerometers mirrored on each side
- Located on
  - Stud
  - Free vibrating plate
  - Windows
  - Close to window edges
Novel simulation tool for coupled sound and vibration

- Development of new method in Comsol Multiphysics – two way coupled acoustic and elastic propagation
- May include structures not tested in lab
- Two different degrees of sophistication
  - Modeling the laboratory measurements in full detail, including the wall buildup
  - Modeling the a whole building for a full scale field investigation, less detailed
- Detailed modeling of the walls include
  - Wooden studs, plaster boards and plywood modeled as is
  - Springs located along the joints
  - The modeled walls shown below are seen from above
Model validation towards laboratory measurements for the level difference – remarkable agreement

(sound pressure level relative to corner microphone in source room)
The simulations show that joint properties between the construction elements are crucial for the LF-sound transmission.
Measured and modeled admittance, example

- Admittance defined as: $\beta = v/p$ (velocity/pressure)
- Measures the wall response to acoustic load
- Here: corner microphone and central accelerometer
Comparison between mean measured level difference for standard and improved walls

Unexpected worsening at the lowest frequencies
However, we find that the window behaviour governing the sound reduction for the lowest frequencies:

Below 25 Hz:
- Reduced sound level difference due to the window
- Increased admittance due to the window
A standard wall with standard windows compared with countermeasure on both the wall and window

Sound level difference

Improved sound level reduction in the crucial frequency range 15-25 Hz due to improved window

Admittance

Note of caution— the standard (reference) wall in 2013 and 2014 exhibit considerable differences, and results are therefore only indicative
Improvement in level difference for the full frequency range (10 Hz – 5kHz shown)

5-10 dB improvement
Full scale field measurements at Ørland, Norway

Outdoor mic

Floor vibration

Corner mic

Corner mic

Window vibration
Full scale measurements setup

- F16 and loudspeaker sources
  - Good signal-to-noise-ratio
- Extensive instrumentation
  - Outdoor and indoor microphones
  - Wall, window, and floor accelerometers
- **Next stage** – measurements on building subject to countermeasures – measure the difference
Further work

- We have detected the main mechanisms for sound induced vibration due to aircrafts and other military sound sources.
- An extensive lab program provides unique data on low frequency sound transmission through walls.
- A novel numerical model have been developed and put to use for simulating the sound propagation through walls.
- Countermeasures reducing the low frequency sound transmission and vibration includes stiffer constructions, but more importantly, improved windows.
- The countermeasures will be implemented for the building at Ørland.
- The improvement will be measured in a full scale field test subject to F16 noise this fall.
Acknowledgements

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