Cautious Blasting in Urban Areas
Society for Rock Mechanics & Engineering Geology
Singapore, 07-12-2012
By Sjoerd Spijkerman
Opening Blast by Speaker
About the Company

- Swedish company in the field of tunneling and surface rock works
- Specialized in rock engineering/ cautious blasting in urban areas
- Network of associated companies working together in larger projects
Following Services

- Blasting consultancy (charge calculation, drilling design, vibration monitoring, production sequence design, air-shock wave calculation)
- Blasting services (drilling and blasting, rock and concrete fracturing)
- Engineering geological services (engineering geological design and calculation, rock support)
- Planning, cost estimates/cost control
- Quality checks (analysis and design followups)
- Geological services (mapping bed-rock, tunnel mapping, groundwater studies)
- Construction management
Seminar topics

- General blasting issues
- Bench blasting / Tunnel blasting
- Vibration monitoring
- Alternative methods
- Example: City Link railway project
Cautious & Smooth Blasting

- Cautious blasting: blasting without causing damage to the environment
- Smooth blasting: blasting without causing damage to the remaining rock
“A great difficulty when it comes to determining the limit values for varying degrees of damage is due to the fact that there have been relatively few cases where damages could be proved”

From Modern technique of rock blasting by Langefors and Kihlström, 1963
Common Blasting Projects in Urban Areas
High Priced Ground

- Foundation for building/construction/bridge projects
- Removing roads/railroads subsurface
- Removing cables/pipelines/sewer/drainage into tunnels
- Free surface ground for housing/offices, build below (storage, sporting arenas, parking, shopping)
- Cooling/heating plants

Conclusion: blasting is getting more complicated
Basics on Blasting

- Preparation works (permits, design, calculations, planning, time-cost estimates)
- Drilling
- Charging and detonation design
- Firing and safety control
- Mucking
- Cleaning and scaling
- Rock support
- Analyse of blasting procedure
Most Important: Geology
Considerations for Rock Excavation

Assessment of rock rippability based on field mapping (Franklin et al (1971)).
Bench Blasting
Risk Analyses Before Blasting
Risks in urban area blasting
Factors Influencing Blasting Effects
Differences in P-waves and S-waves
Drilling is the key to successful blasting.
Drilling Design Pattern

Rock excavation on top of tunnel
Results...
Vibration Equipment

All instrument with GSM modem

Automatically transfer data to NCVIB.com
Guide Values (PPV) for Different Types of Buildings

Svängningshastighet, mm/s

- Manniskans känslighetströskel
- Störande
- Villa på lera
- Villa på morän
- Villa på berg
- Kontor på berg

Avstånd:
- 10 m
- 50 m
- 100 m
- 200 m

Graph legend:
- Avstånd, 10 m
- Avstånd, 50 m
- Avstånd, 100 m
- Avstånd, 200 m
Utility tunnels – guide values

<table>
<thead>
<tr>
<th>Type of tunnel</th>
<th>PPV, mm/s</th>
<th>PPD, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metro tunnels in rock (traffic operating)</td>
<td>60 – 92 (30)</td>
<td>-</td>
</tr>
<tr>
<td>Metro tunnels – concrete (traffic operating)</td>
<td>100 (30)</td>
<td>-</td>
</tr>
<tr>
<td>Utility tunnels</td>
<td>70 or 100</td>
<td>-</td>
</tr>
<tr>
<td>District heating pipes</td>
<td>-</td>
<td>300(^1) mm</td>
</tr>
</tbody>
</table>

\(^1\) Replaces rule that no blastings when temperature below -10°C
Electronic Detonators
Unlimited Time Delays


Date/Time: 2010-12-13 10:45+01:00
Calibrated: 2010-04-06
FEM modelling vibrations
Model: VIBDAMP
Deformation = .15E5
LC01: LC01
Step: 160  TIME: .64E-1
Nodal STRESSES S22
Top surface
Max/Min on model set:
Max = .153E6
Min = -.173E6
Analysis of Blasting Results

Formeln brukar kallas

\[ v = A \cdot \left( \frac{R}{Q_{\text{sam}}^{0.5}} \right)^B \]

där

\( v \) = förväntad svängningshastighet [mm/s]
\( R \) = avstånd mellan salvans sprängcentrum och mätpunkten [m]
\( Q_{\text{sam}} \) = max samverkande laddning [kg]

A och B = konstanter som beror på geologi, geometri och sprängtekniska förhållanden.
Choice of Explosives
The Behaviour of an Explosive

- Detonation velocity
- Strength
- Detonation stability
- Flash-over capacity
- Density
- Water sensitivity
- Detonation sensitivity
- Safety characteristics
- Environmental characteristics

Conclusion: the contractor must have a range of Different products in order to perform a successful blast.
Blasting Cord, But Splitting Along Crack
Damage zones of different explosives
Dynotex 17 mm
Alternative Mechanized Methods

- Chipping /Hammering
- Fracturing hydraulic (fracturing tools or chemicals)
- Cutting the rock (Roadheader, diamond wire saw)
Rock Cracking Cartridges

- Hög säkerhet
- Låga vibrationer
- Låga tillståndskrav
- Kostnadseffektiv
Wire Cutting All Contours
Wire Cutting
FEM Analysis
Effect of a Slot in the Contour

Model: SCHAKT
VNOLL: vnoll_1m/s
Step: 61  TIME: .122E-1
Nodal VELOC V3
Max/Min on model set:
Max = .519E-1
Min = -.498E-1

Här står Matteus kyrka

09 MAR 2010 15:18:52 fig.cgm
Result of FEM Analysis

<table>
<thead>
<tr>
<th></th>
<th>Dampening degree, PPV vertical direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bench 1</td>
<td>80 %</td>
</tr>
<tr>
<td>Bench 2</td>
<td>84 %</td>
</tr>
<tr>
<td>Bench 3</td>
<td>72 %</td>
</tr>
</tbody>
</table>
Monitoring Points

Matteus kyrka

002  MY007-001

004   Pall 1

006

003

005

Pall 2

Pall 3

Slits

ö.k. berg
## Average Damping Ratio

<table>
<thead>
<tr>
<th>Monitoring Point</th>
<th>Damping ration – bench 1, [%]</th>
<th>Damping ratio – bench 3, [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behind the slot, Vertical direction</td>
<td>72</td>
<td>71</td>
</tr>
<tr>
<td>Behind the slot, Longitudinal</td>
<td>50</td>
<td>61</td>
</tr>
<tr>
<td>Behind the slot, Transversal</td>
<td>42</td>
<td>33</td>
</tr>
<tr>
<td>Church, MS013-003, Vertical</td>
<td>77</td>
<td>75</td>
</tr>
<tr>
<td>Church, MS013-005, Vertical</td>
<td>69</td>
<td>37</td>
</tr>
</tbody>
</table>

Data provided by Nitro Consult
Example of Urban Blasting Project
Stockholm City Link Railway project
6 km railway tunnel + 2 tracks = 3 stations + 1,5 km fly over bridge

Double capacity & easy availability
What is directly above the blasting area?
Risk Investigation Area

- Approx. 2000 Buildings above the rock tunnels
- 13 crossings with utility tunnels – rock cover 0 to 10 meters
- 70 electrical substations
- 60 switching center for Telecommunications
- 4 crossings of metro tunnels & stations
Blasting for a New Metro Station
Potential Damage Risks

Relationship between natural frequency of wall and frequency of imposed vibration. Damages can be caused by:

- Elongation
- Shearing
- Bending

Existing static state of building unknown...

Foundation unknown or transfer mechanism between foundation and building unknown...

Vibration energy...

**Solution:** FEM modelling or conservative attitude
FEM Model of Gustaf Vasa Church

Model: KYRKAN
Analysis: FS2
Analysis Type: Structural
# Results of Analysis

<table>
<thead>
<tr>
<th>Part of the Church</th>
<th>Safe value, PPV mm/s</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foundation and Columns</td>
<td>30</td>
<td>Theoretical limit for new cracks 36 mm/s (tensile strength 200 kPa)</td>
</tr>
<tr>
<td>Columbariet</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Arch vaults (Johannes, Matteus, Lukas)</td>
<td>20</td>
<td>Acceleration 4.8 g</td>
</tr>
<tr>
<td>Arch vault (Marcus)</td>
<td>15</td>
<td>Safety factor set at 5 for avoiding loosening of plaster</td>
</tr>
<tr>
<td>Altar Piece</td>
<td>10</td>
<td>Incoming vibration measured at floor level</td>
</tr>
</tbody>
</table>
## Permitted Vibration Levels in Churches

<table>
<thead>
<tr>
<th>Church</th>
<th>Permitted PPV, mm/s</th>
<th>Alarm value, mm/s</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>S:t Matteus Church</td>
<td>22</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Gustaf Vasa Church</td>
<td>18</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>S:t Clara Church</td>
<td>12</td>
<td>5</td>
<td>Distance &gt;40 m</td>
</tr>
<tr>
<td>Adolf Fredrik Church</td>
<td>7</td>
<td>3</td>
<td>Foundation on sand/gravel.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Distance &gt;130 m</td>
</tr>
<tr>
<td>Maria Magdalena Church</td>
<td>10</td>
<td>7</td>
<td>Foundation on sand/gravel.</td>
</tr>
</tbody>
</table>
Crack Monitoring

Sprickviddsmätning i Markusvalvet
Gustaf Vasa kyrka
Crack Monitoring

Crack width and temperature measurement on the Marcus Vault in Gustav Vasa Church

Crack width, mm

Temperatur, C

Sprickvidd, mm

Temperatur, C
Damages - Natural Causes or Blasting?

Fotodokumentation
Lokalisering av registrerade skador

Tillvarataget material från skadeställe 2 – detaljbild 2a och 2b
Conclusions

• Blasting works are fully possible in urban areas
• Rock blasting opens new possibilities (creating space)
• An accurate planning and execution is a demand
• Modern techniques available
• But... very many prejudices

Very important questions:
- What is a damage?
- Cost of damage vs. Cost of project

Thx to Trafikverket, Nitro Consult, Skanska & Royex
Thank you!

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