# Blast management- Environmental impact

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Improving Processes. Instilling Expertise.

ORICA VOLVO SANDVIK

# Blasting Management

## Environmental - impact

- Vibrations
- Airblast
- Fly rock

# Blasting Management

## Vibrations

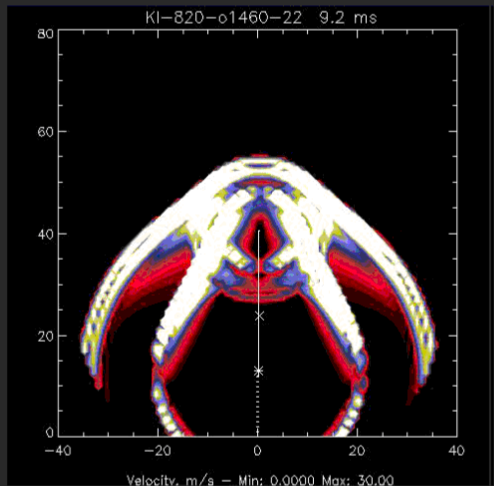
- What is vibrations (seismic waves) and how are they formed
- Why are they monitored
- How do we predict (and if necessary reduce) them
- How are they monitored (and airblast)

# Vibrations

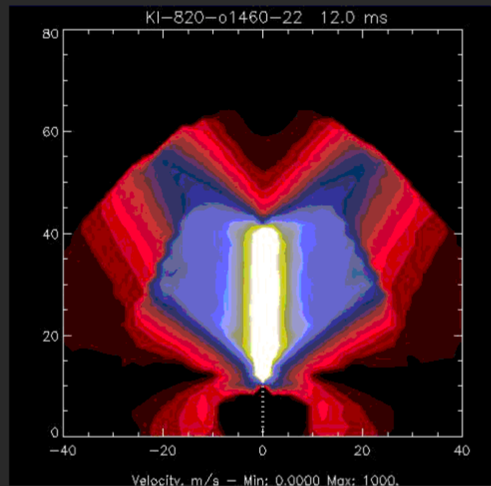
## How are they formed?

## Detonation

1 kg explosive =>
ca  1 $m^3$ gas
5000 m/s VOD




Contours of velocity




Contours of VPPV

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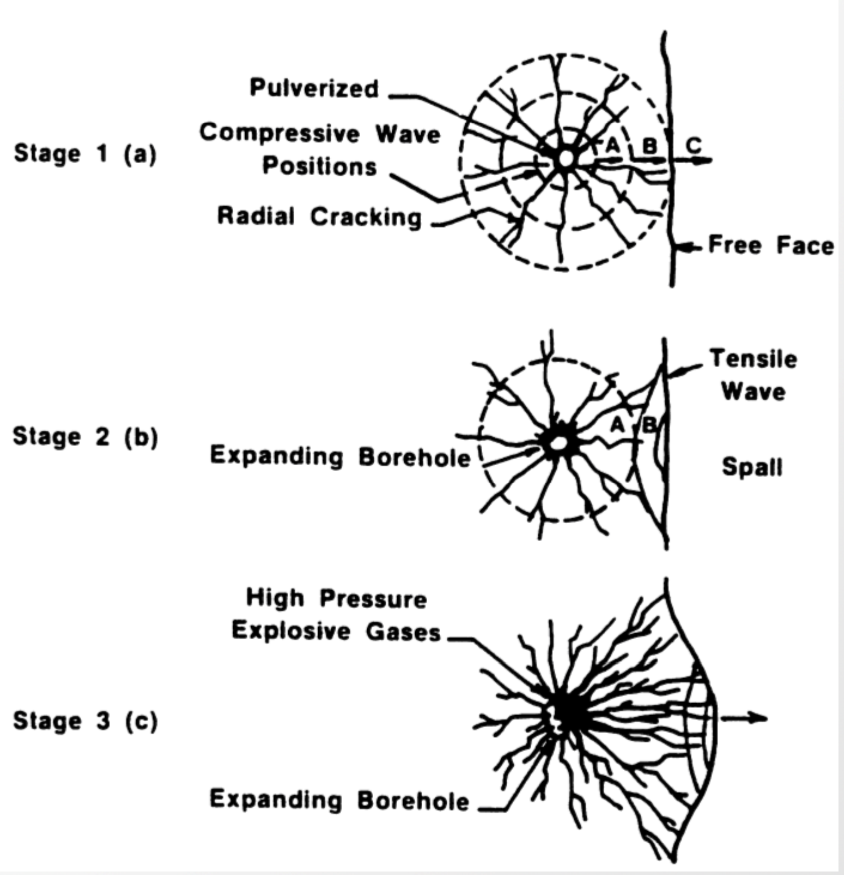
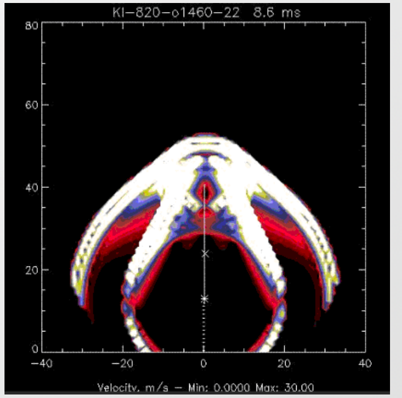
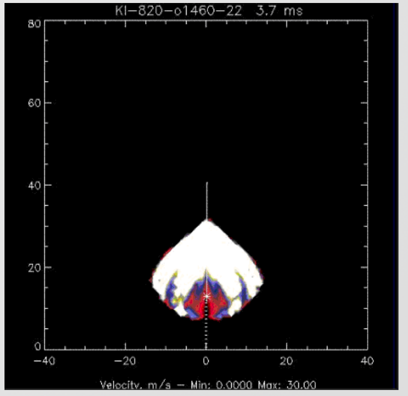
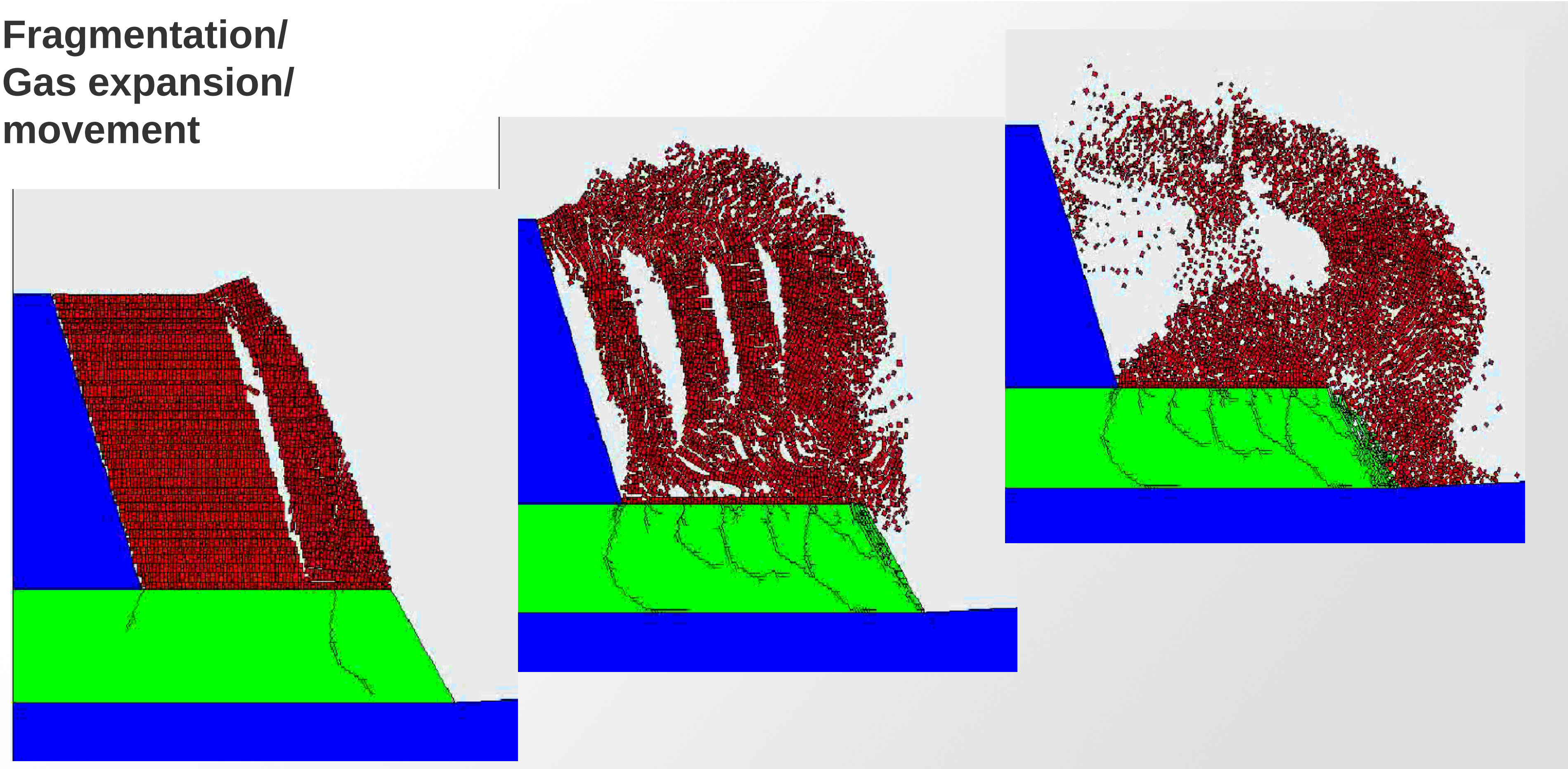
# Blasting


Stage 1 (a)
Pulverized
Compressive Wave Positions
Radial Cracking
A
B
C
Free Face
Stage 2 (b)
Expanding Borehole
Tensile Wave
Spall
A
B
Stage 3 (c)
High Pressure Explosive Gases
Expanding Borehole


KI–820–o1460–22 8.6 ms
Velocity, m/s – Min: 0.0000 Max: 30.00


KI–820–o1460–22 3.7 ms
Velocity, m/s – Min: 0.0000 Max: 30.00

# Fragmentation/ Gas expansion/ movement

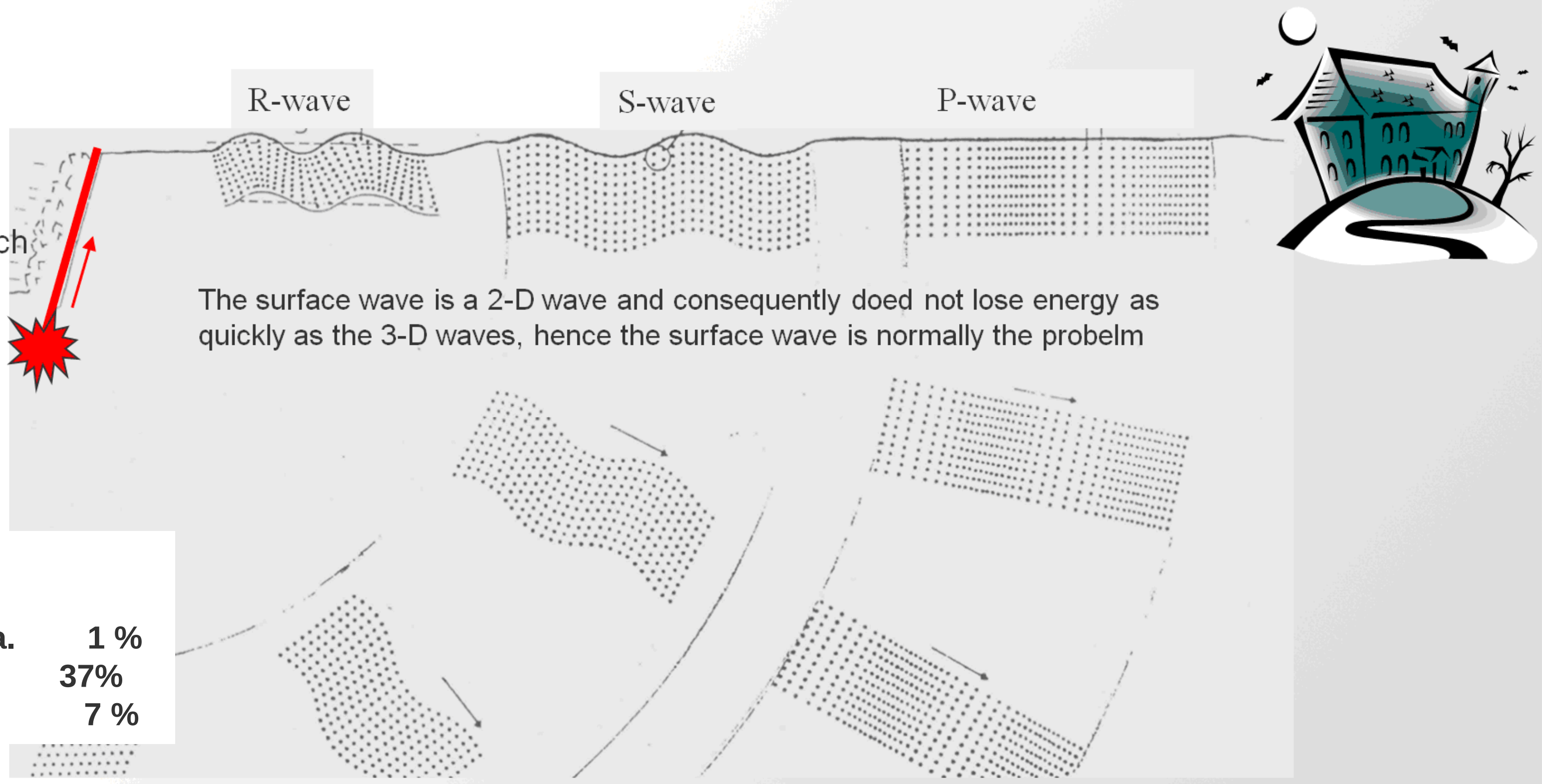


# What is a seismic wave?

- Wave types in soil/rock:
  - Body waves
  - Surface waves
  - Others

- Requires a medium
- Involves particle motion
- Transports energy !

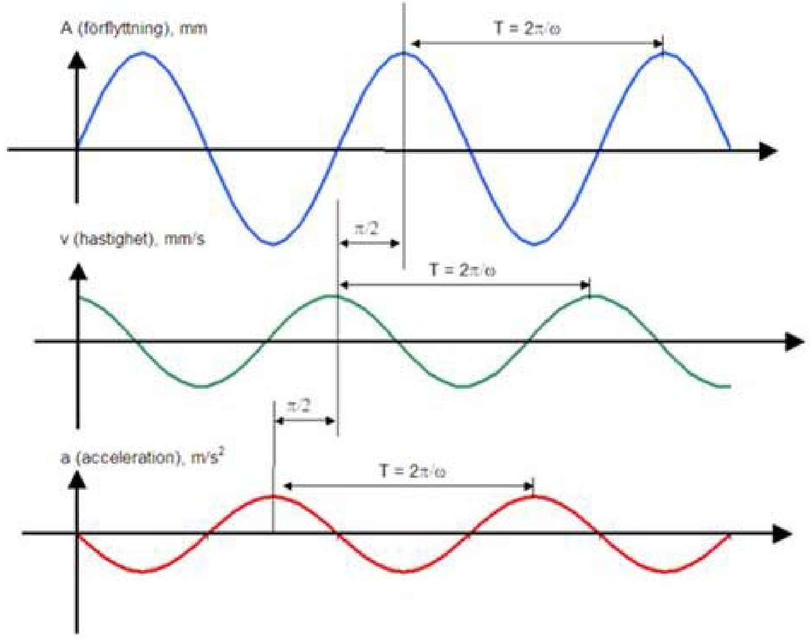
# Vibrations




**Energy:**

| | |
|---|---|
| **Fragmentation ca.** | **1 %** |
| **Movement ca.** | **37%** |
| **Vibrations ca.** | **7 %** |

# Monitoring of vibrations




$$A = \int_0^t v(t)\,dt$$

*Movement (the most intuitive parameter)*

$$v = v(t)$$

*Normally monitored (mm/s), Constructions are sensitive to velocity => strain*

$$a = \frac{dv}{dt}$$

*The human is sensitive to acceleration (m/s²).*

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# What decides size, frequency, ”shape”?

- Source influence
- measurement location influence
- P, S and R waves
- Geology:
  - mode conversions
  - Scattering
  - attenuation - geometric/intrinsic

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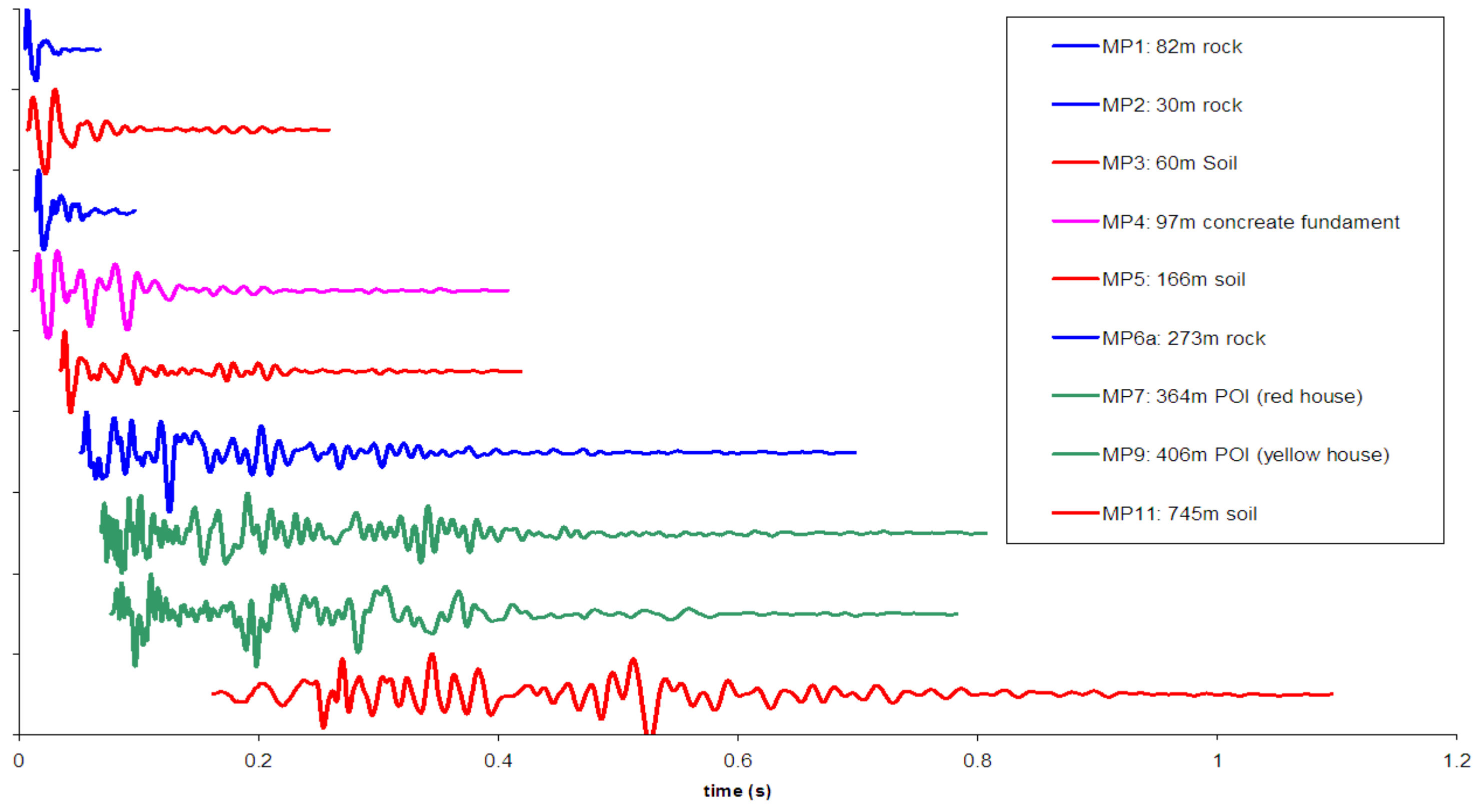
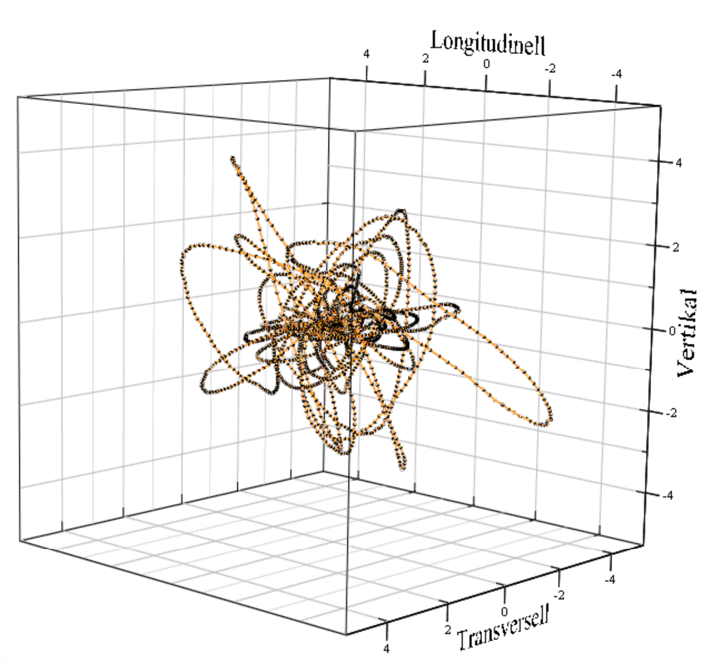
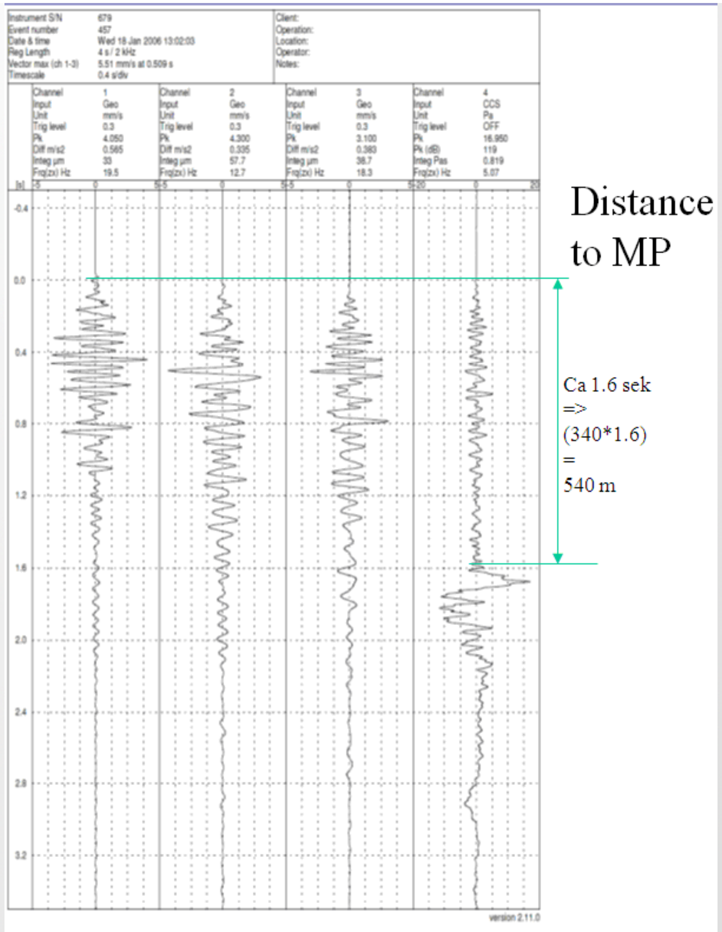
# Single hole shot, monitored at 9 different loations



# Example


Longitudinell
Vertikal
Transversell
4
2
0
-2
-4

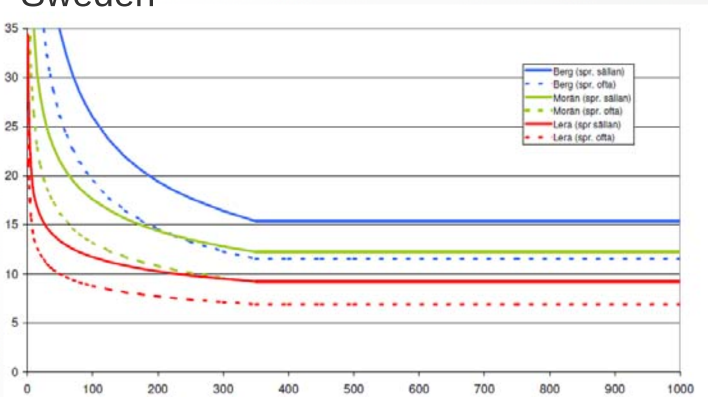

Instrument S/N 679
Event number 457
Date & time Wed 18 Jan 2006 13:02:03
Reg Length 4 s / 2 kHz
Vector max (ch 1-3) 5.51 mm/s at 0.509 s
Timescale 0.4 s/div
Client:
Operation:
Location:
Operator:
Notes:
Channel 1 Input Geo Unit mm/s Trig level 0.3 Pk 4.050 Diff m/s2 0.565 Integ µm 33 Frq(zx) Hz 19.5
Channel 2 Input Geo Unit mm/s Trig level 0.3 Pk 4.300 Diff m/s2 0.335 Integ µm 57.7 Frq(zx) Hz 12.7
Channel 3 Input Geo Unit mm/s Trig level 0.3 Pk 3.100 Diff m/s2 0.383 Integ µm 38.7 Frq(zx) Hz 18.3
Channel 4 Input CCS Unit Pa Trig level OFF Pk 16.950 Pk (dB) 119 Integ Pas 0.819 Frq(zx) Hz 5.07
[s]
-0.4
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
version 2.11.0
Distance to MP
Ca 1.6 sek
=>
(340*1.6)
=
540 m

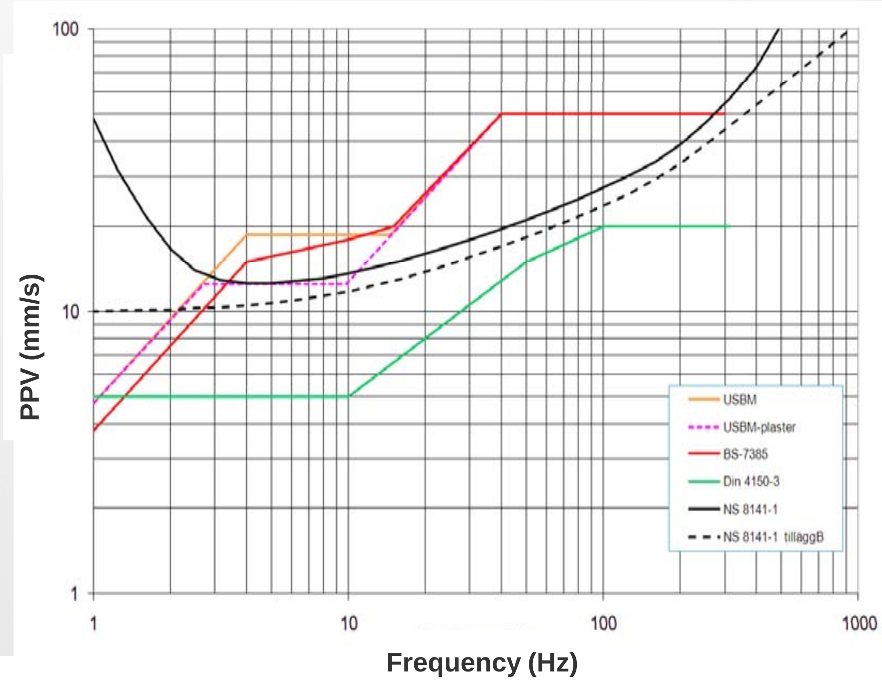
# Why are they monitored (damage, comfort)?

## Authorities, complaints, regulations, STANDARDS

*Standards: residential houses*

Sweden



# Damage – structures

*(background standards)*

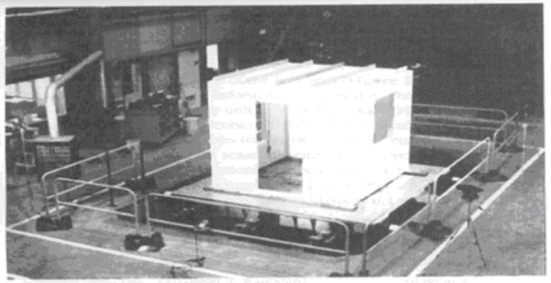
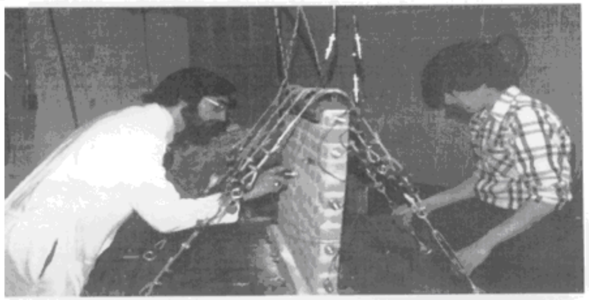
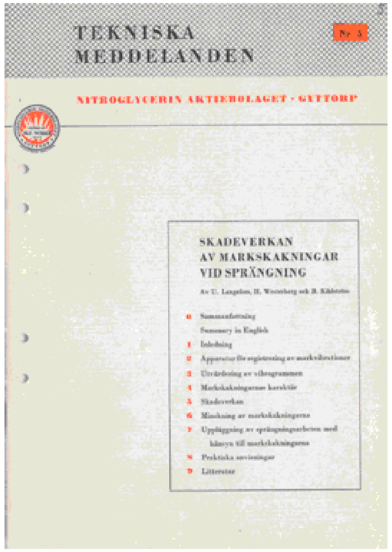


FIGURE 22. Eight-foot cube test "room" on Army Corps of Engineers 12-ft biaxial shake table, CERL, Champaign, IL. Tests done for and with USBM. From Wendler et al., 1975.



IGURE 23. Model CMU wall under shear-load fatigue test at Drexel University Civil ngineering Department. From Koerner and Rosenfarb, 1980.

# Damage - structures



TEKNISKA MEDDELANDEN

Nr 3

NITROGLYCERIN AKTIEBOLAGET · GYTTORP

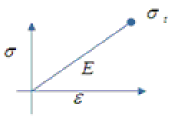
SKADEVERKAN AV MARKSKAKNINGAR VID SPRÄNGNING

Av U. Langefors, H. Westerberg och B. Kihlström

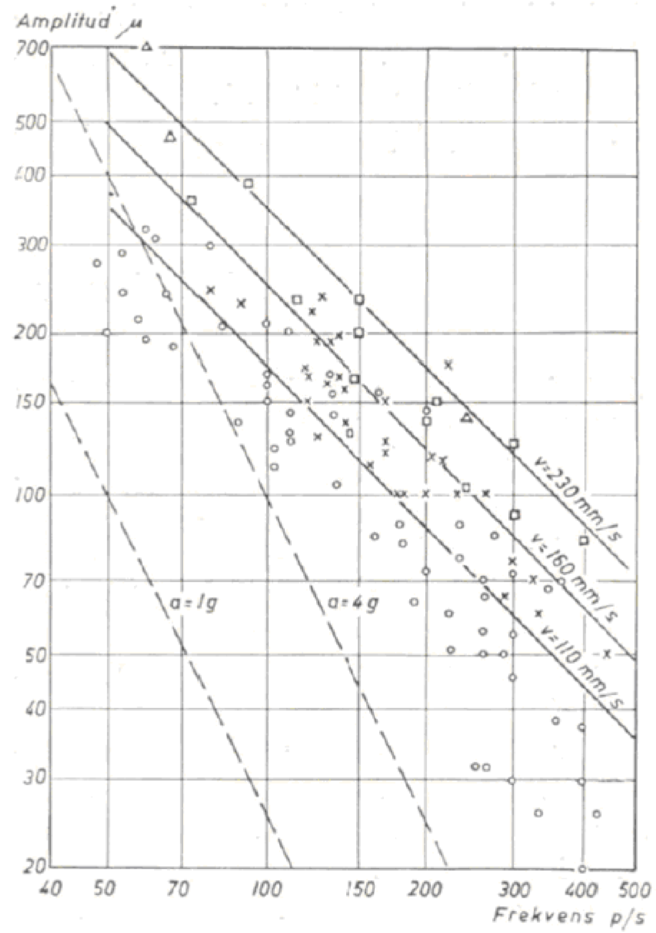
0 Sammanfattning
Summary in English
1 Inledning
2 Apparatur för registrering av markvibrationer
3 Utvärdering av vibrogrammen
4 Markskakningarnas karaktär
5 Skadeverkan
6 Minskning av markskakningarna
7 Uppläggning av sprängningsarbeten med hänsyn till markskakningarna
8 Praktiska anvisningar
9 Litteratur

tests
1946-56

$$\sigma = \varepsilon \cdot E$$




$$\varepsilon = \frac{v_{max}}{v_p}$$




TABELL I. *Gradering av skaderisk i förhållande till svängningshastigheten*

| v | Resultat i normal bostadsbebyggelse |
|---|---|
| 70 mm/s | Ingen märkbar sprickbildning |
| 110 mm/s | Finsprickor och putsfall |
| 160 mm/s | Sprickbildning |
| 230 mm/s | Svår sprickbildning |

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# USBM RI 8507 (1980)

**Damage can be related to Strain (and resonance due to natural frequency)**

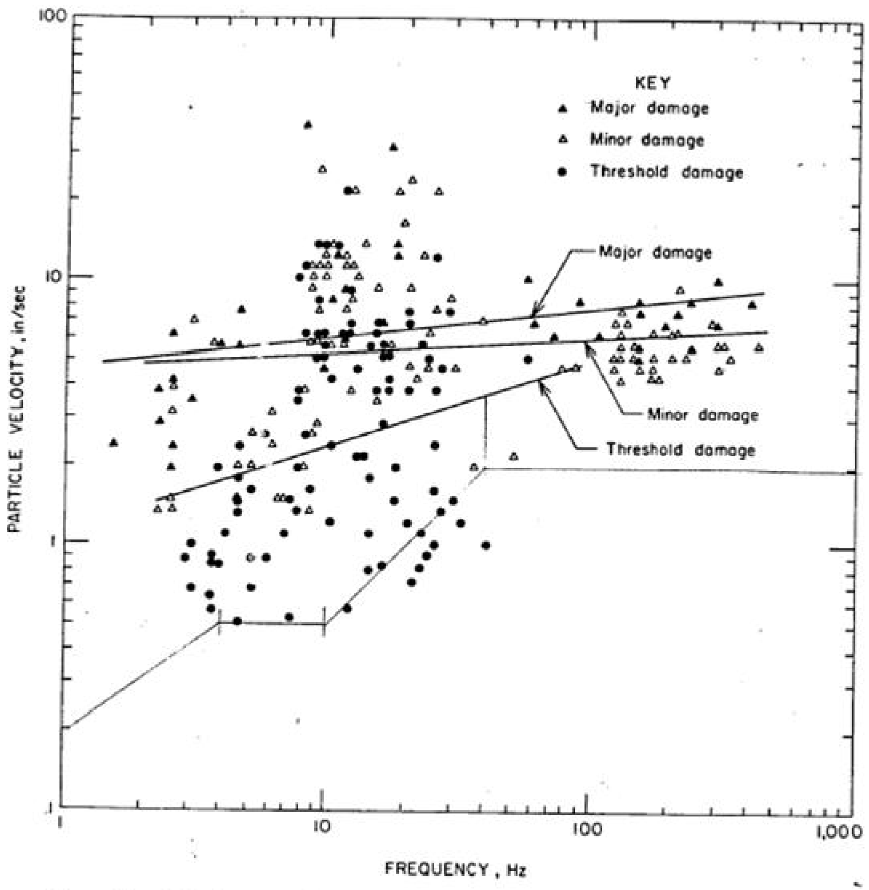



Figure 54.—Velocity versus frequency summary, set 7 mean and variance analysis.

**Unfortunately**: Humans and Buildings are not sensitive for the same kind of vibrations

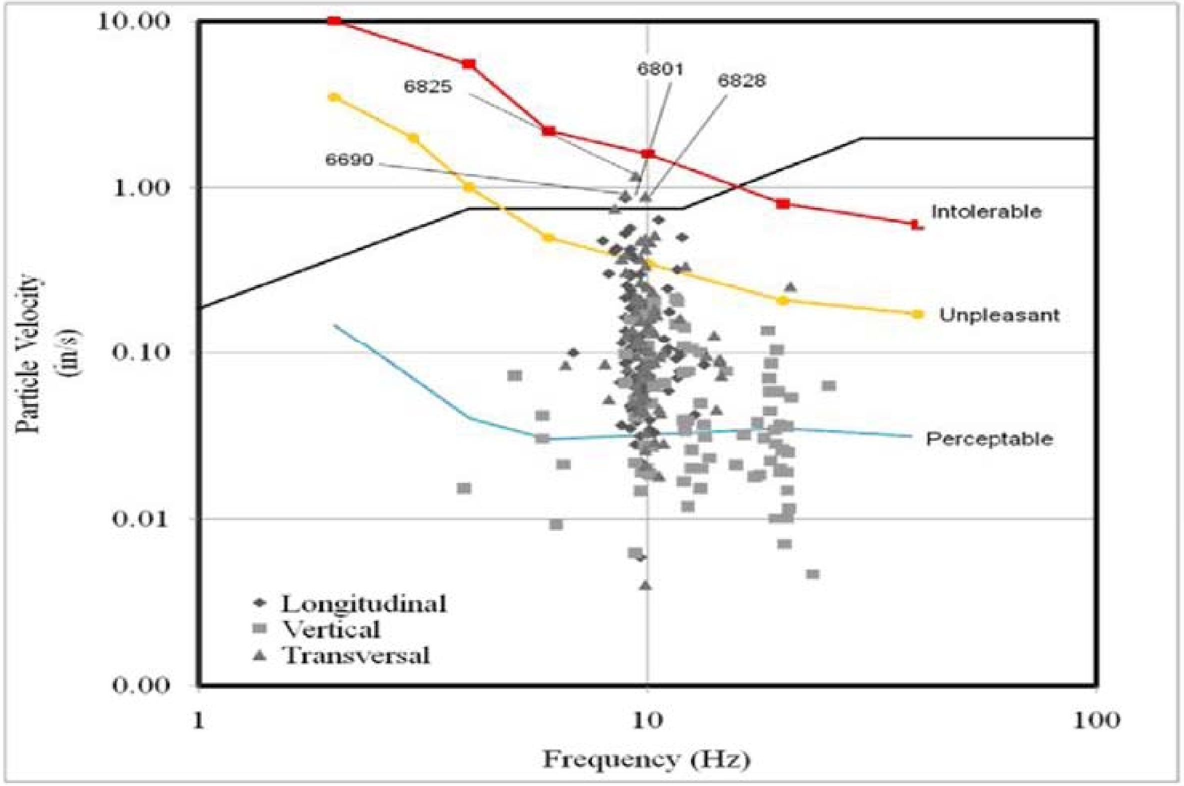


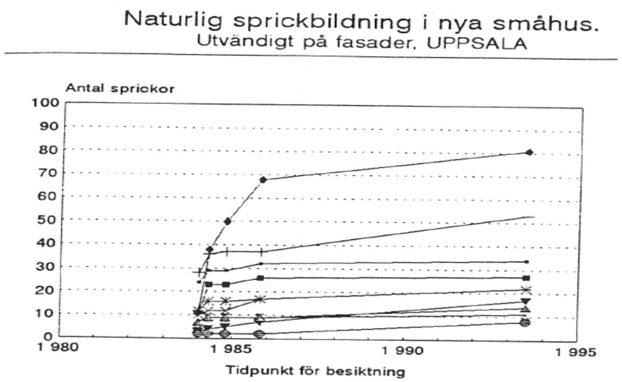

**Figure 1.23** OSM regulation chart, Porch geophone.

## Damage to buildings

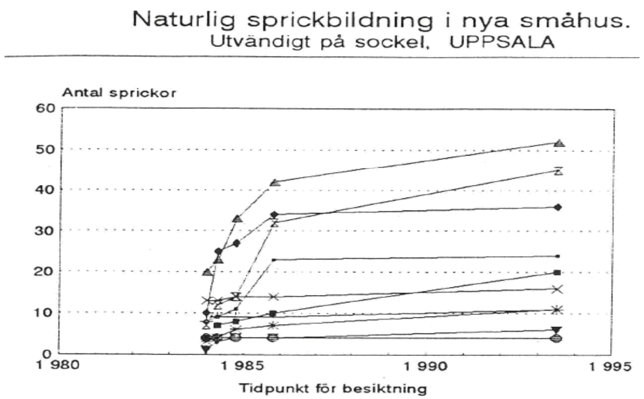
Its important to remember that there are cracks in all houses: inner stress, variations in temperature and humidity. Snow, wind, ground water level all creates strain on the building.

In order to be a true problem, from the damage perspective, the effect from the blast have to be large in relation to all these other effects.

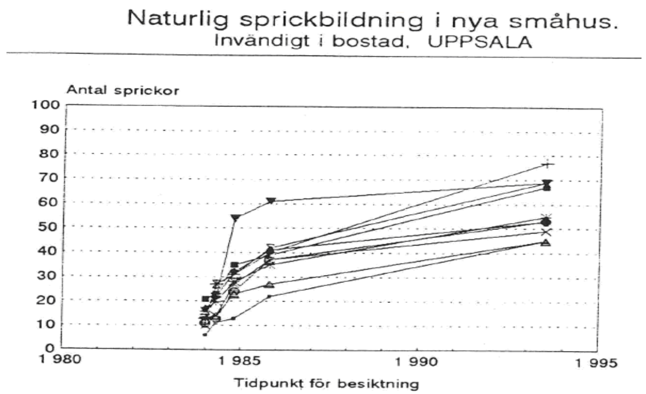
*Inspections of new houses <u>not</u> affected by vibrations:*




Outside of house (walls)




Outside of house (foundation)




Inside of house

# Vibration prediction

- **Charge weight scaling law**

  **Charge and distance only**

- **Superposition models**

  **Includes time**

- **Monte Carlo model**

  **Uncertainties / Scattering**

  **Includes blast plan/ Screening**

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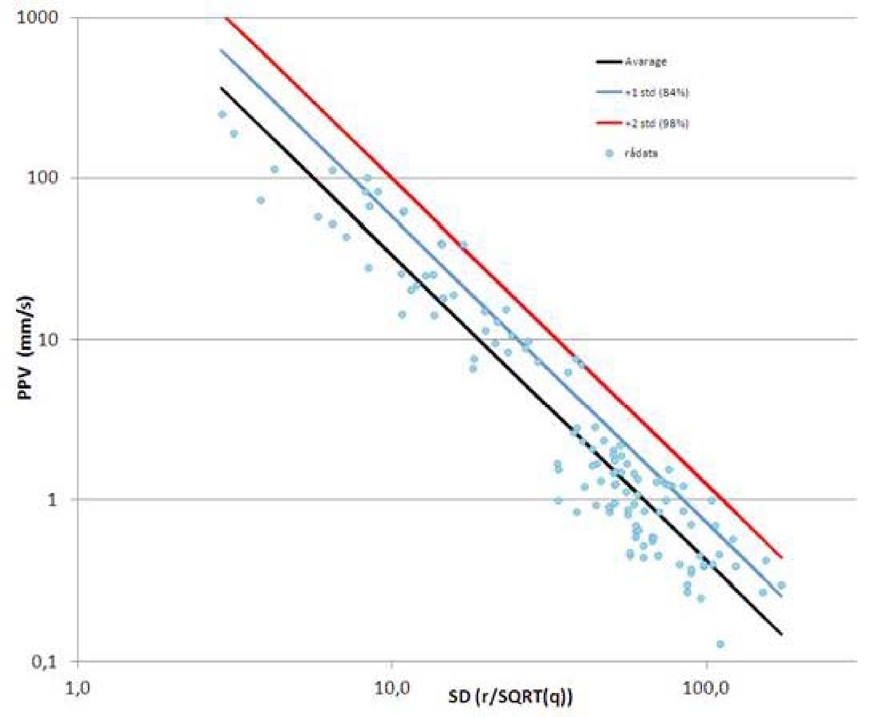
# Vibration prediction

- Charge weight scaling law

$$v_{\max} = A \cdot \left( \frac{r}{\sqrt{q}} \right)^{-B}$$

where
$v_{max}$ = maximum peak particle velocity (mm/s)
r= distance (m)
q= charge weight (kg)
A= site specific constant
B= site specific constant

$$\left( \frac{r}{\sqrt{q}} \right)$$ is often called SD (scaled distance)

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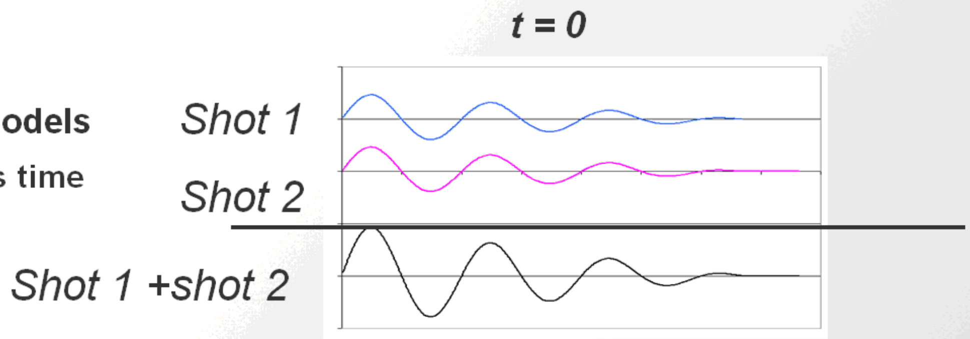
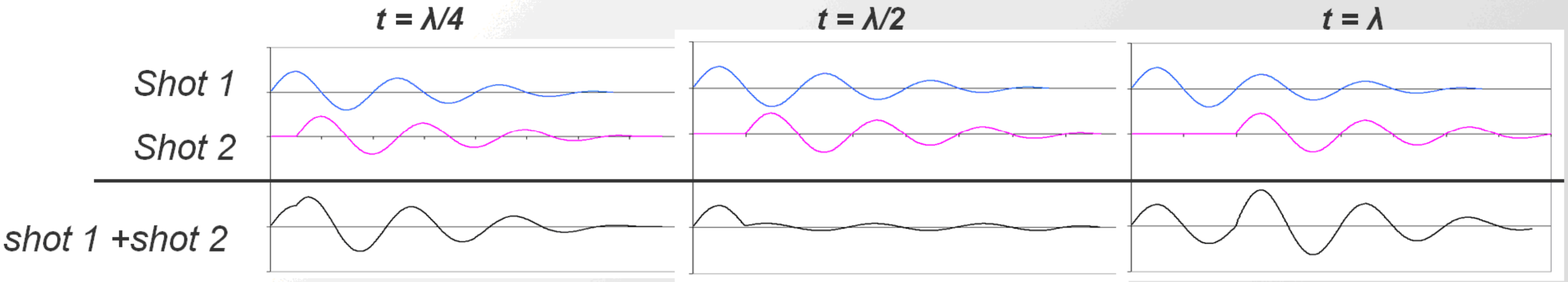
# Vibration prediction

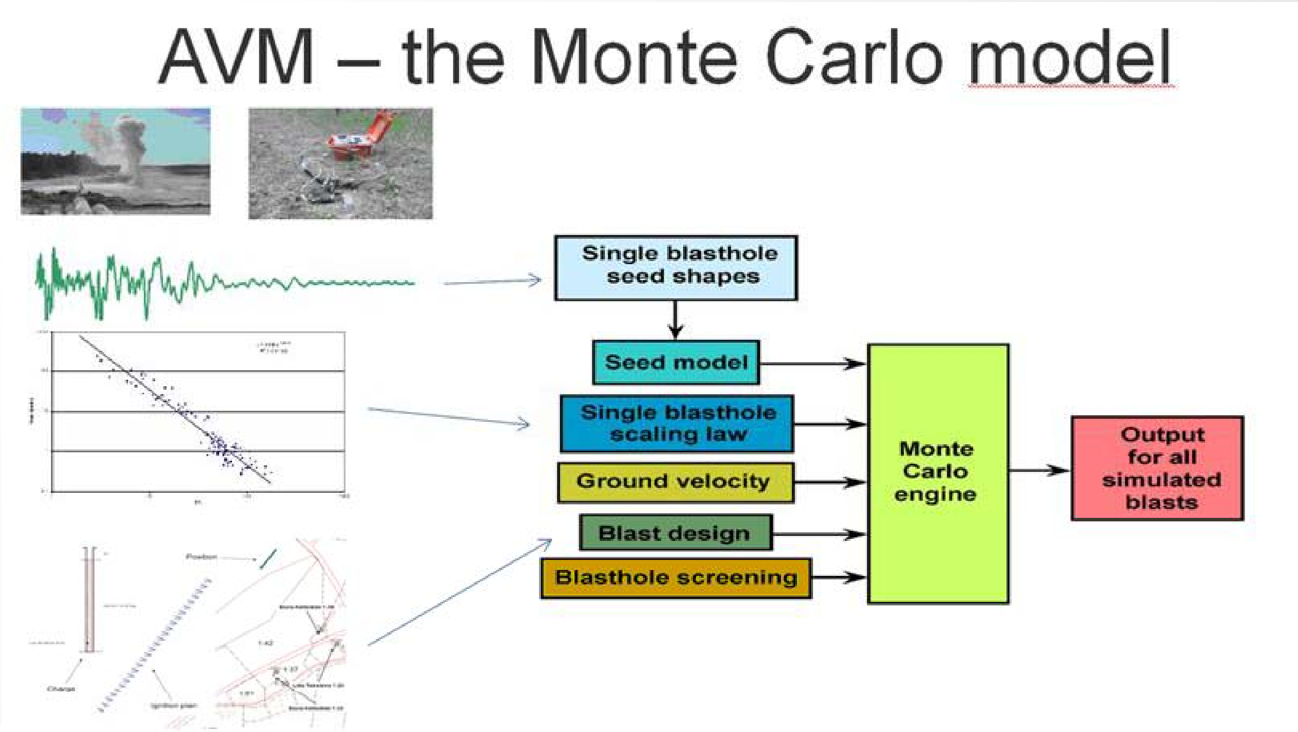
- **Superposition models**

  Includes time



# Vibration prediction

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# Case study: AVM project: Quarry, Gotland, Sweden

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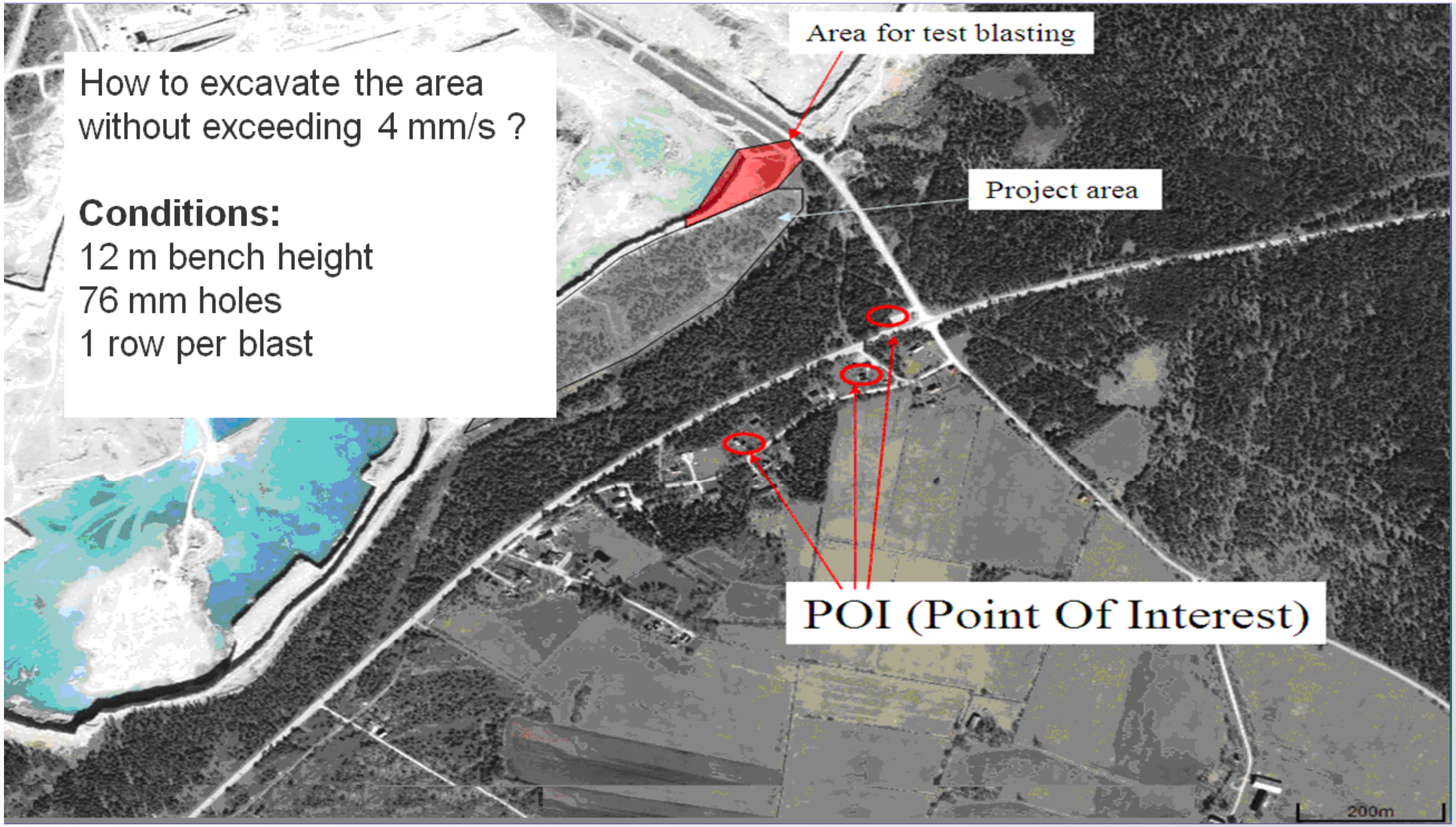
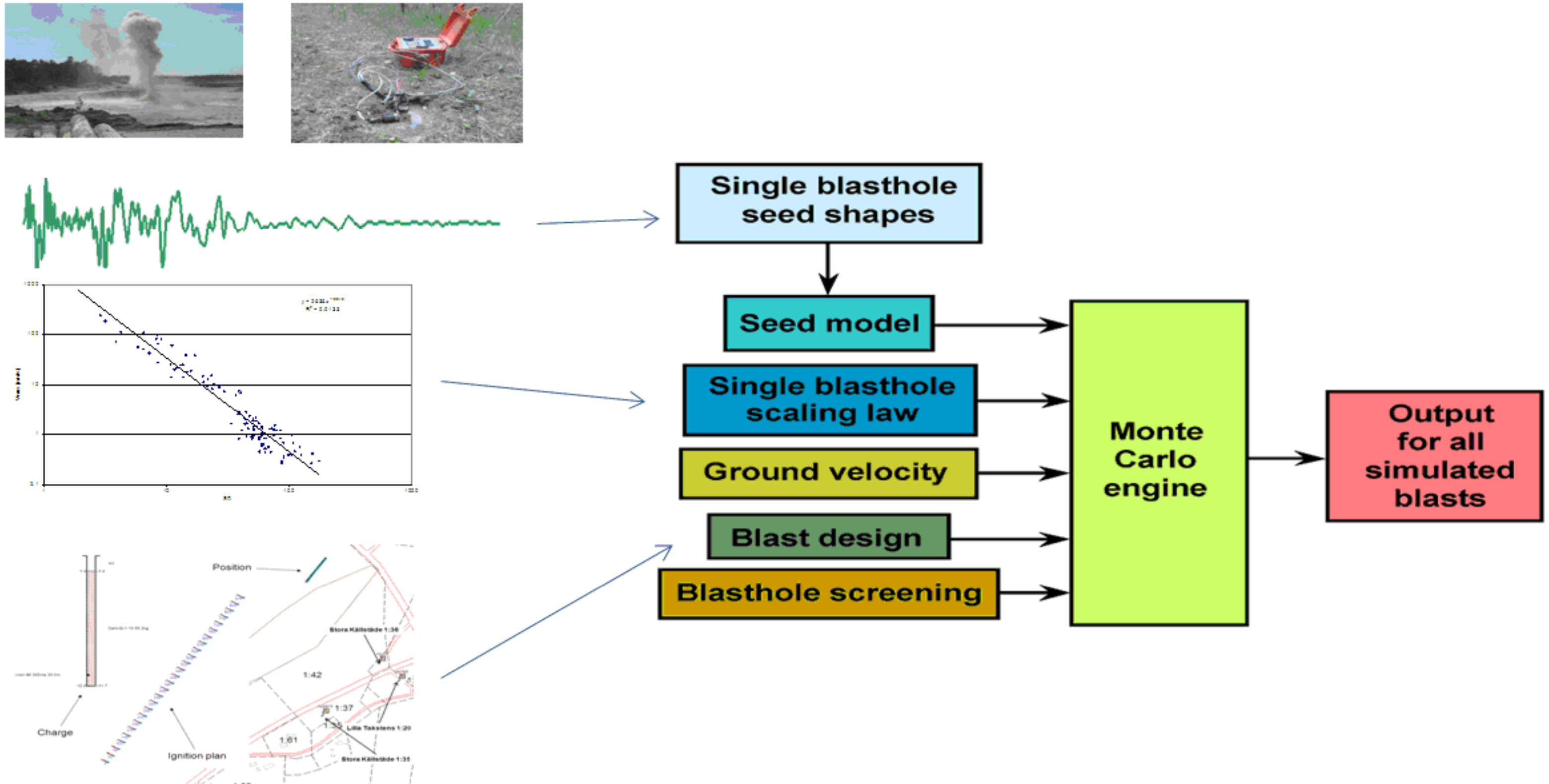
How to excavate the area without exceeding 4 mm/s ?

**Conditions:**
12 m bench height
76 mm holes
1 row per blast



# AVM – the Monte Carlo model

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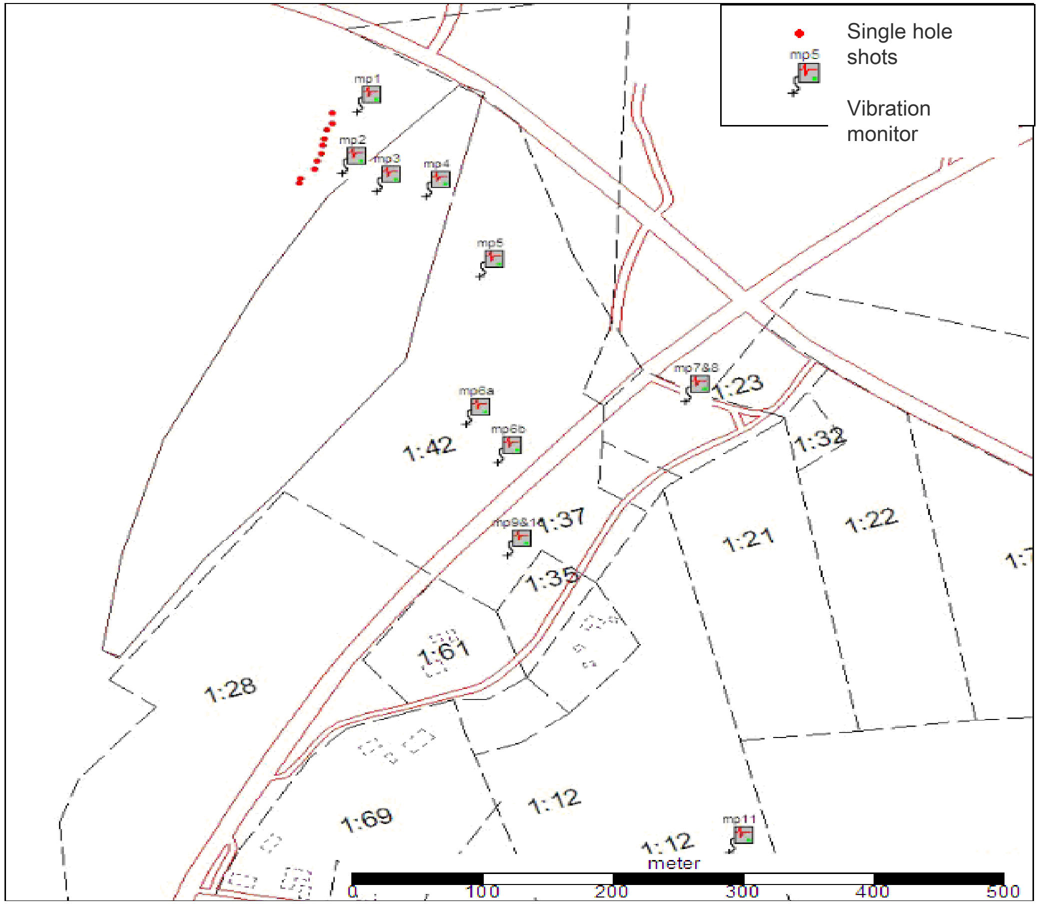
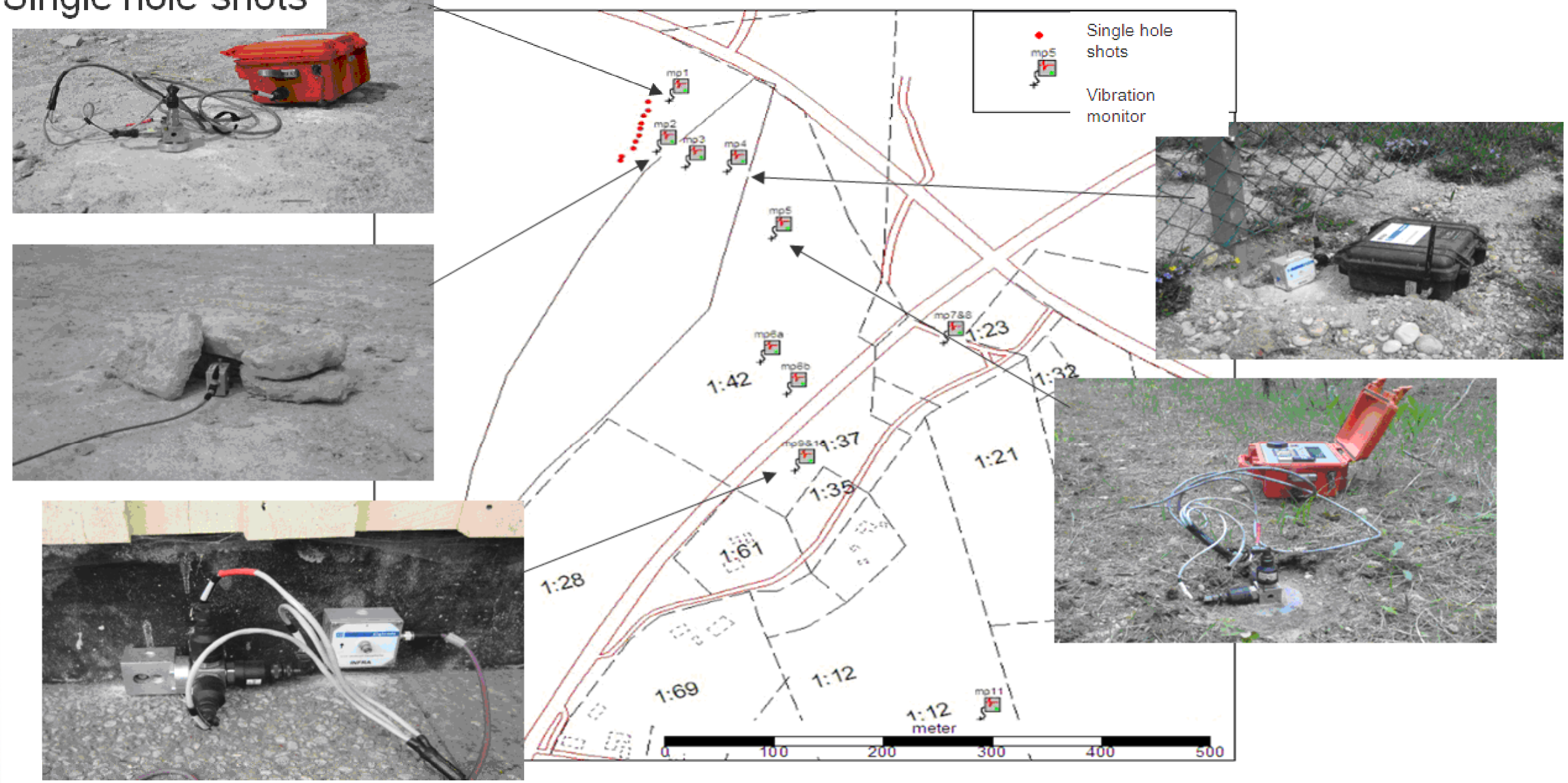
# Single hole shots

Table 1.

| Shot | Charge(kg) | Explosive |
|---|---|---|
| 1 | 52 | SME+2 kg boost |
| 2 | 52 | SME+2 kg boost |
| 3 | 45 | Fordyn |
| 4 | 39,5 | SME+2 kg boost |
| 5 | 52 | SME+2 kg boost |
| 6 | 12,5 | Fordyn |
| 7 | 39,5 | SME+2 kg boost |
| 8 | 27 | SME+2 kg boost |
| 9 | 52 | SME+2 kg boost |
| 10 | 27 | SME+2 kg boost |



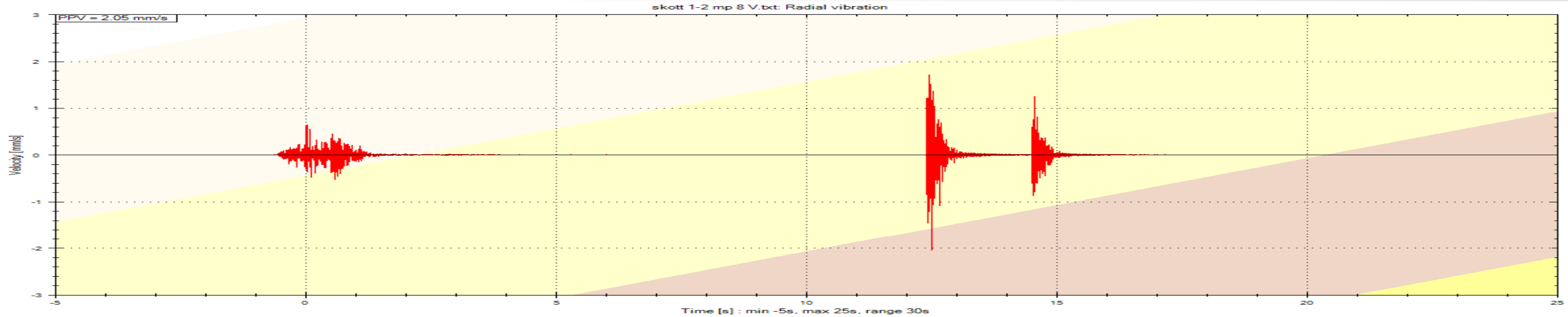
Single hole shots



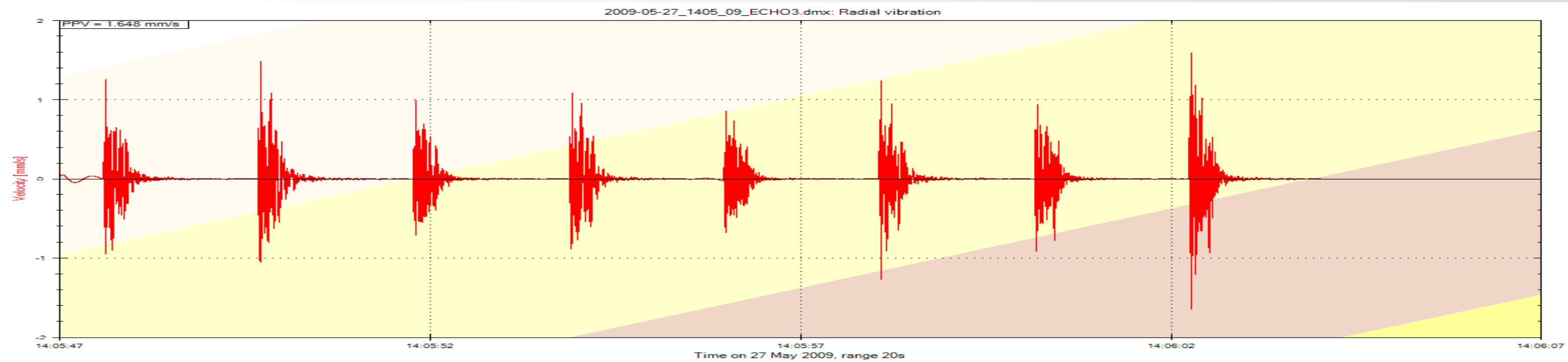
# Single hole shots

# Single hole shots

## Shot 1-2




## Shot 10 - 3

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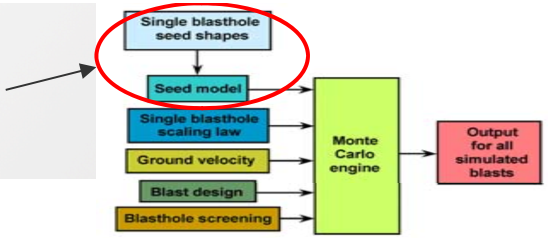
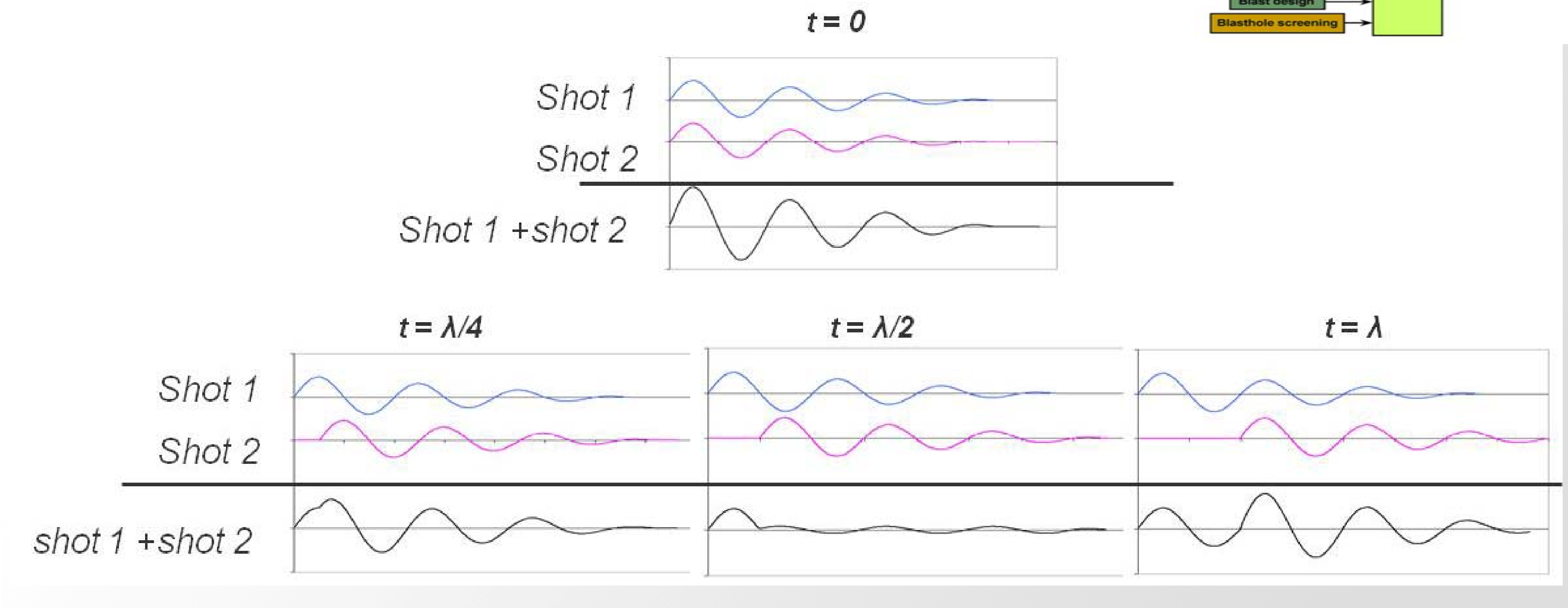
# The seed wave and the superposition model

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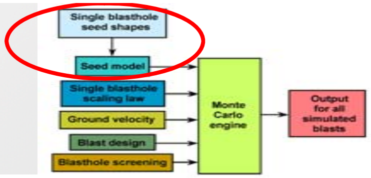
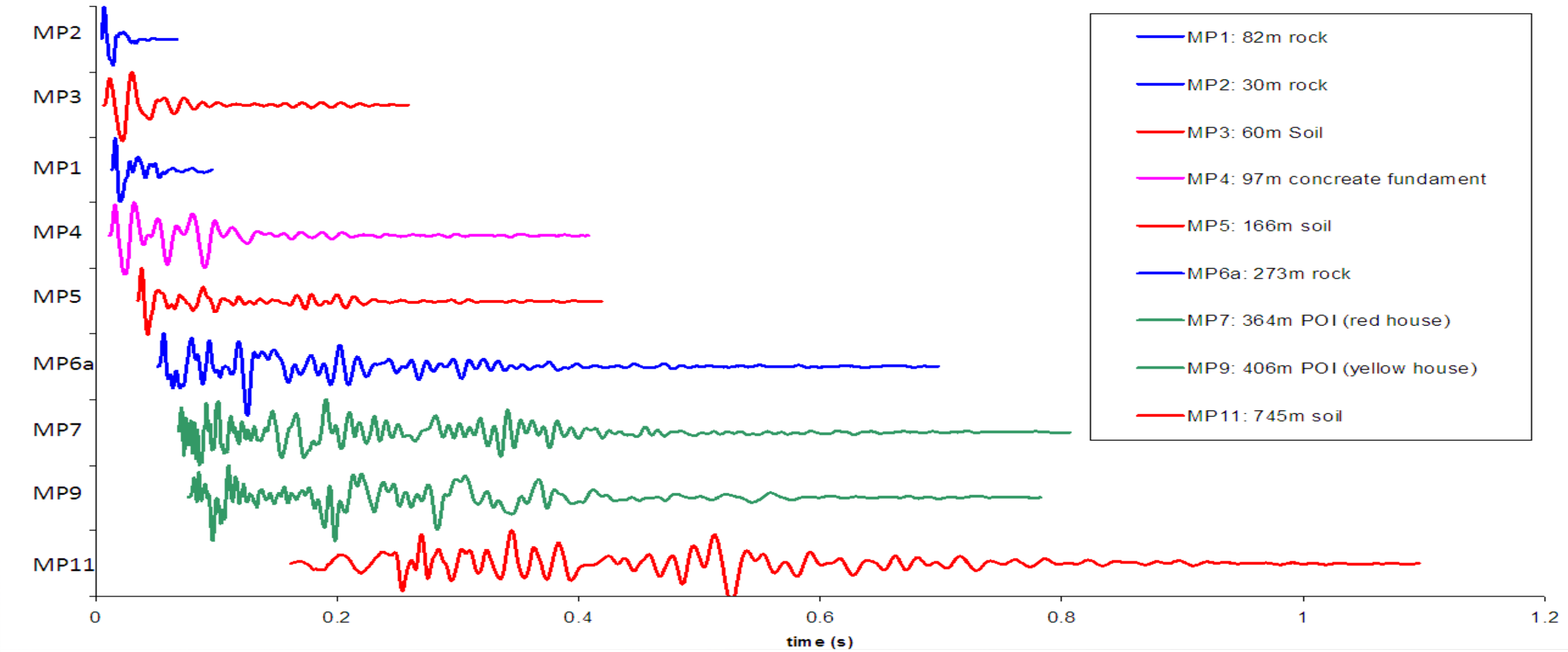
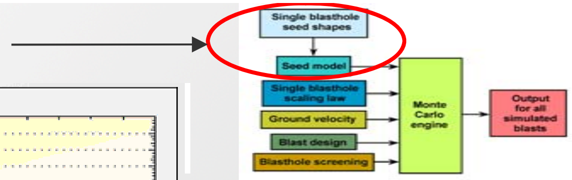
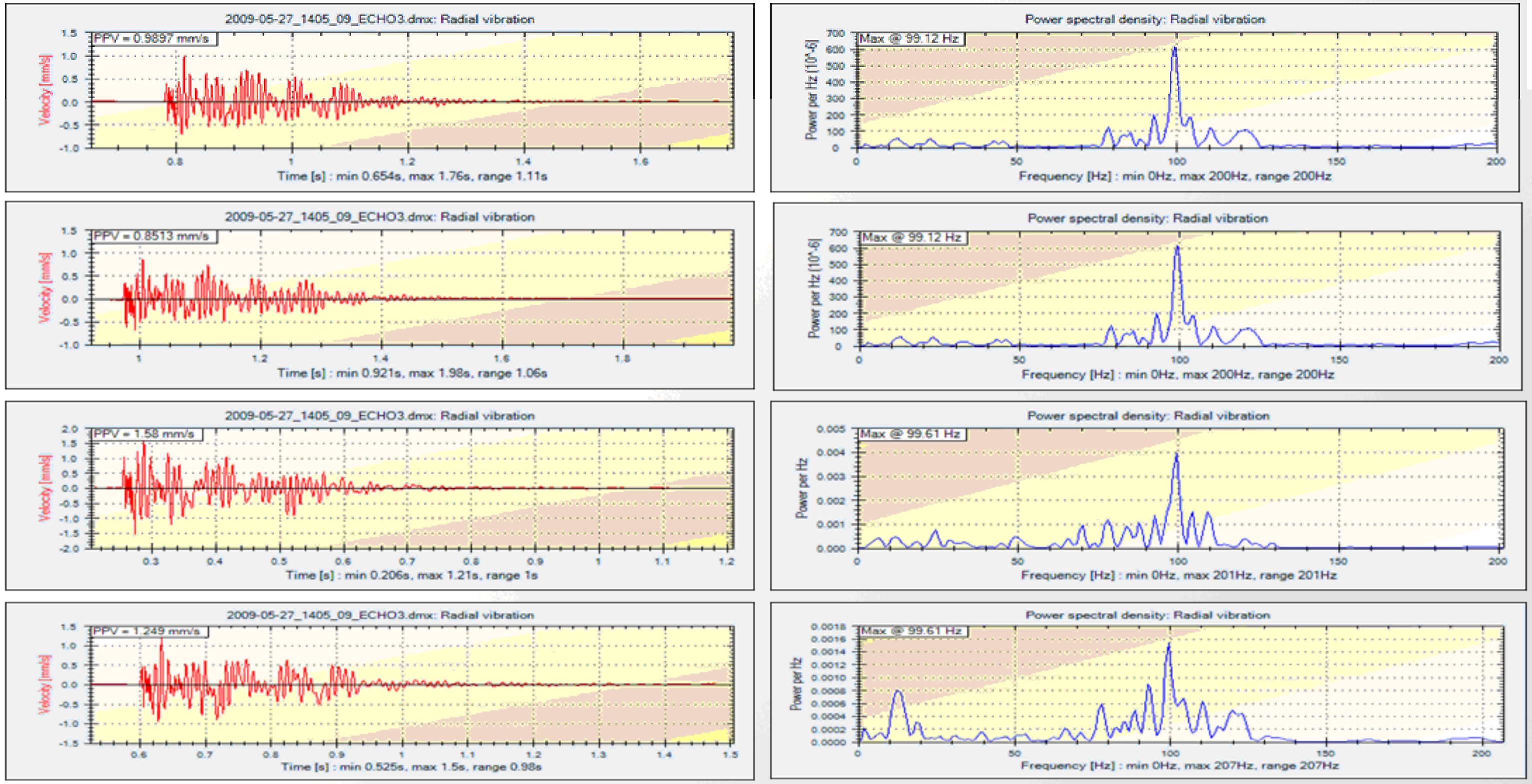
# The seed wave and the superposition model



# The seed wave and the superposition model




Example of four different single hole shots recorded, mp 7

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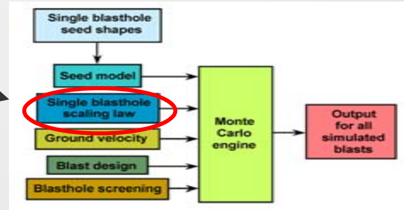
# The charge weight scaling law equation




$$v_{\max} = A \cdot \left( \frac{r}{\sqrt{q}} \right)^{-B}$$

where

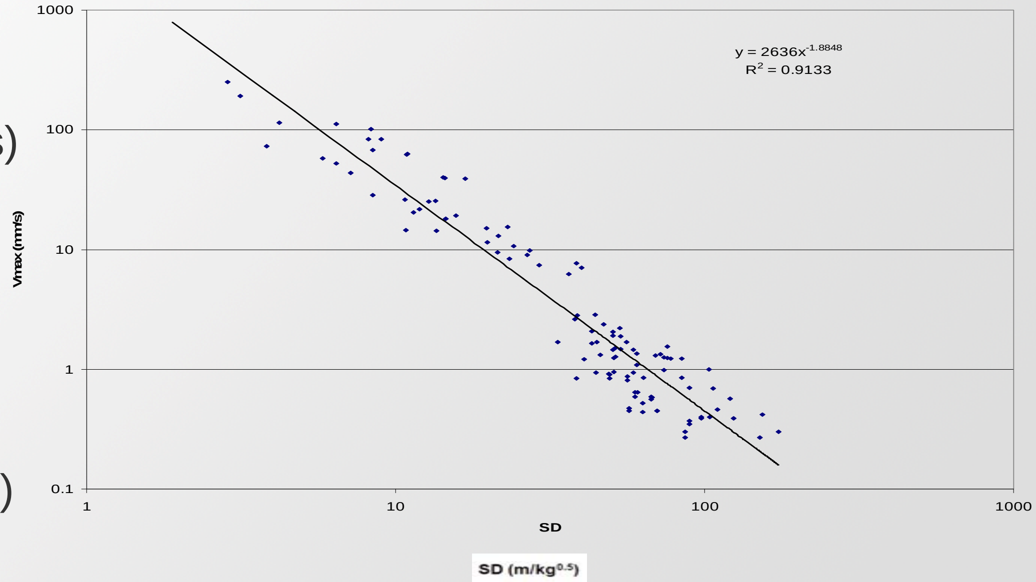
$v_{max}$ = maximum peak particle velocity (mm/s)

r= distance (m)

q= charge weight (kg)

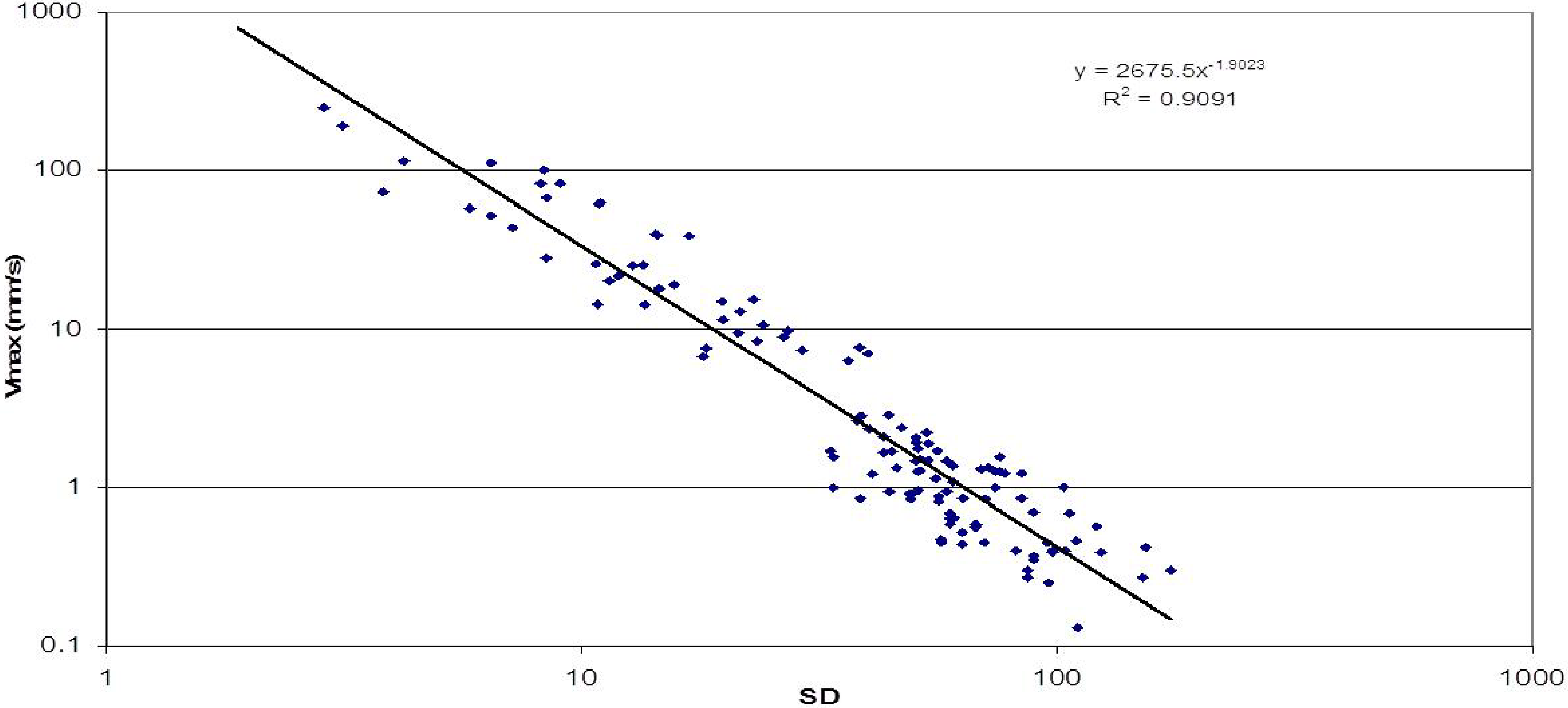
A= site specific constant

B= site specific constant




$\left( \frac{r}{\sqrt{q}} \right)$ is often called SD (scaled distance)

# Regression analysis – all data

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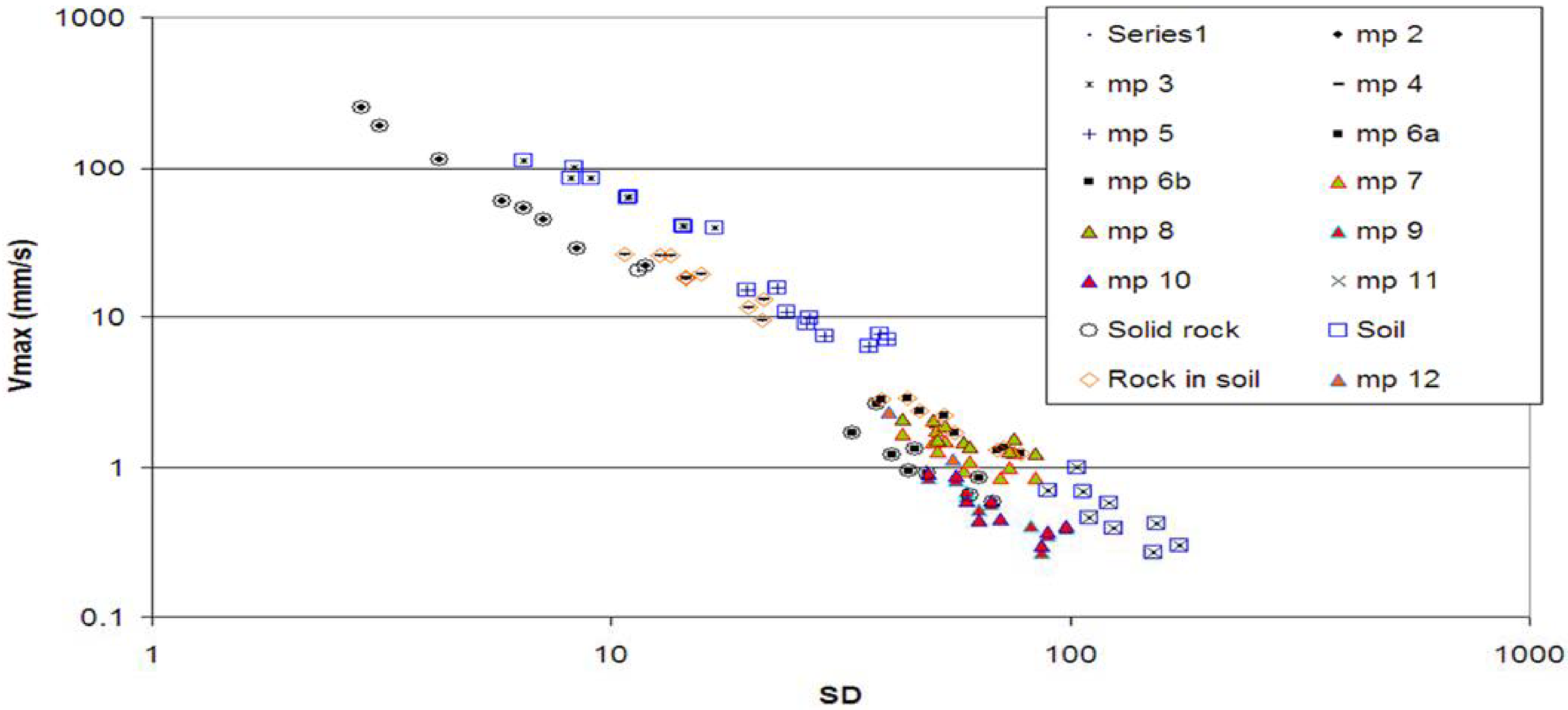
# Regression analysis – dependent on monitoring position

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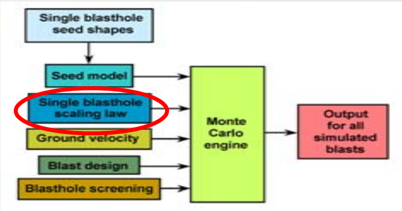
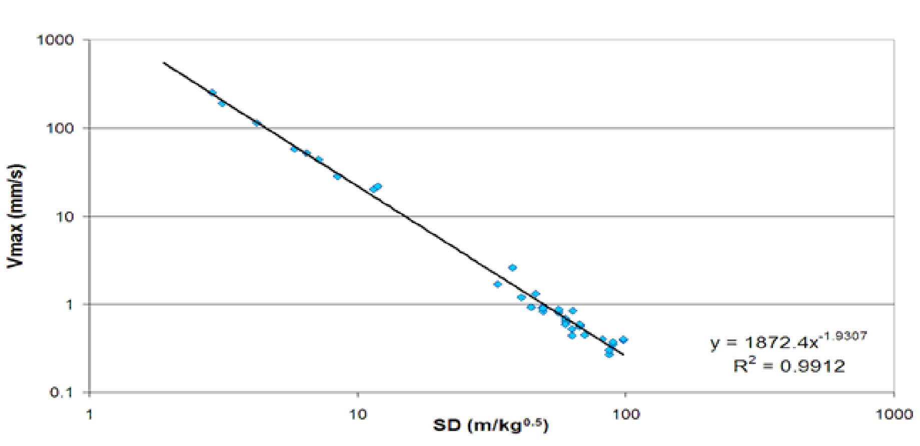
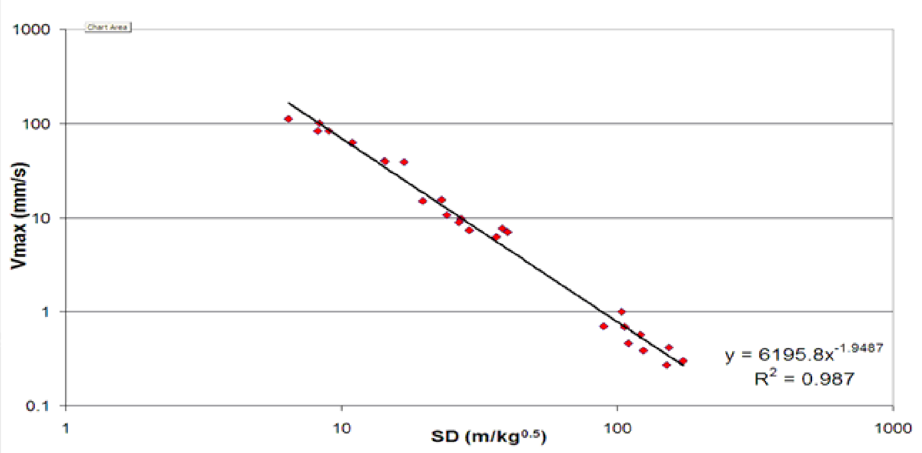
# Regression analysis – dependent on monitoring position




Solid rock




Soil

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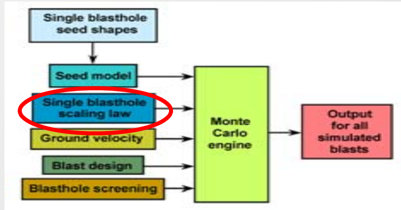
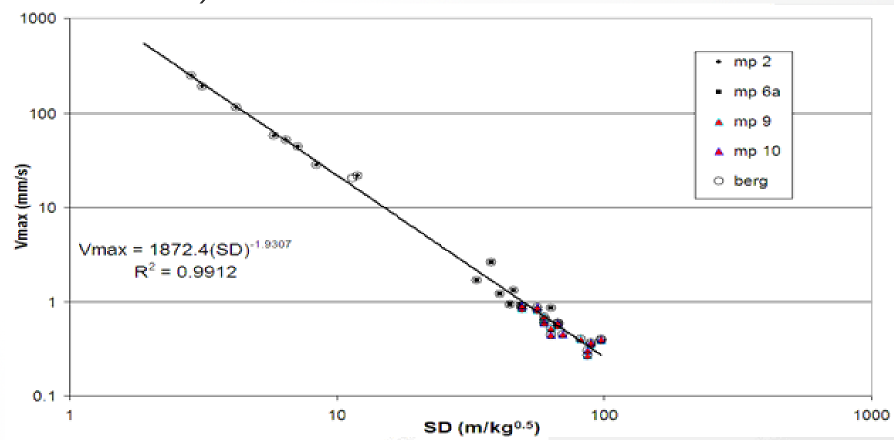
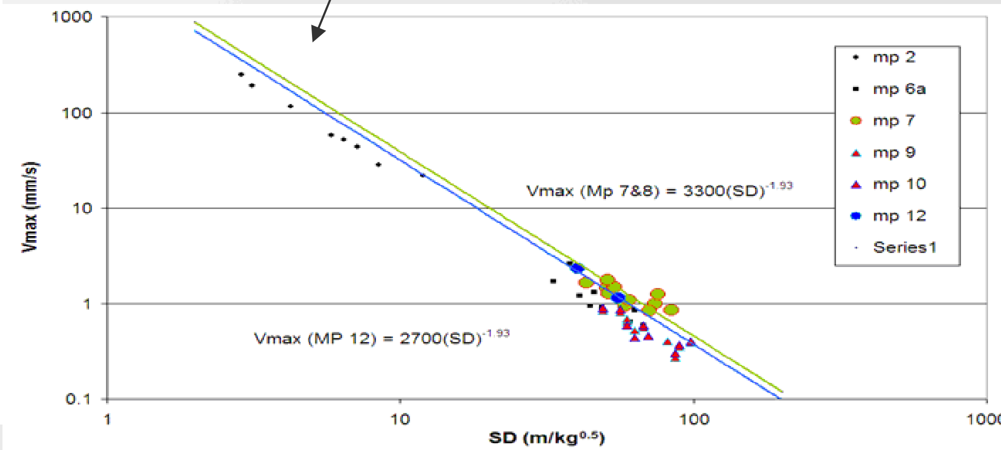
# Regression analysis – point of interest

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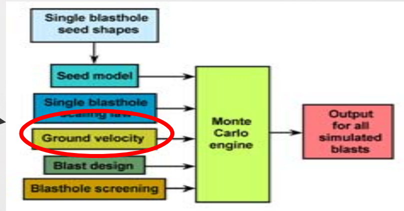
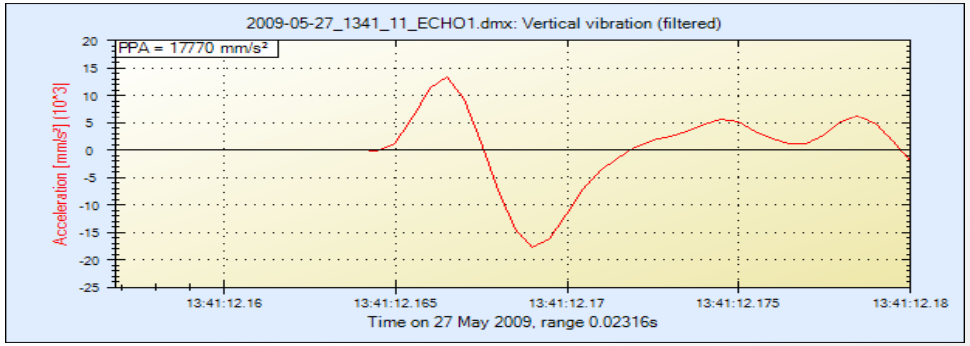
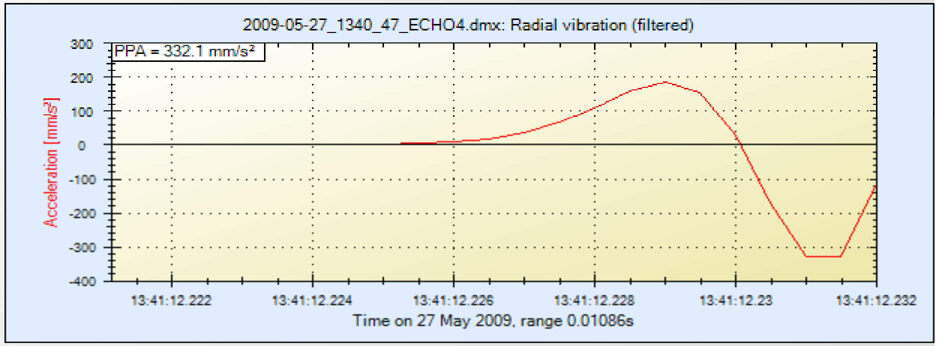
# P- wave velocity




monitor 1




monitor 2




324 m in 61 ms => approx 5300 m/s.

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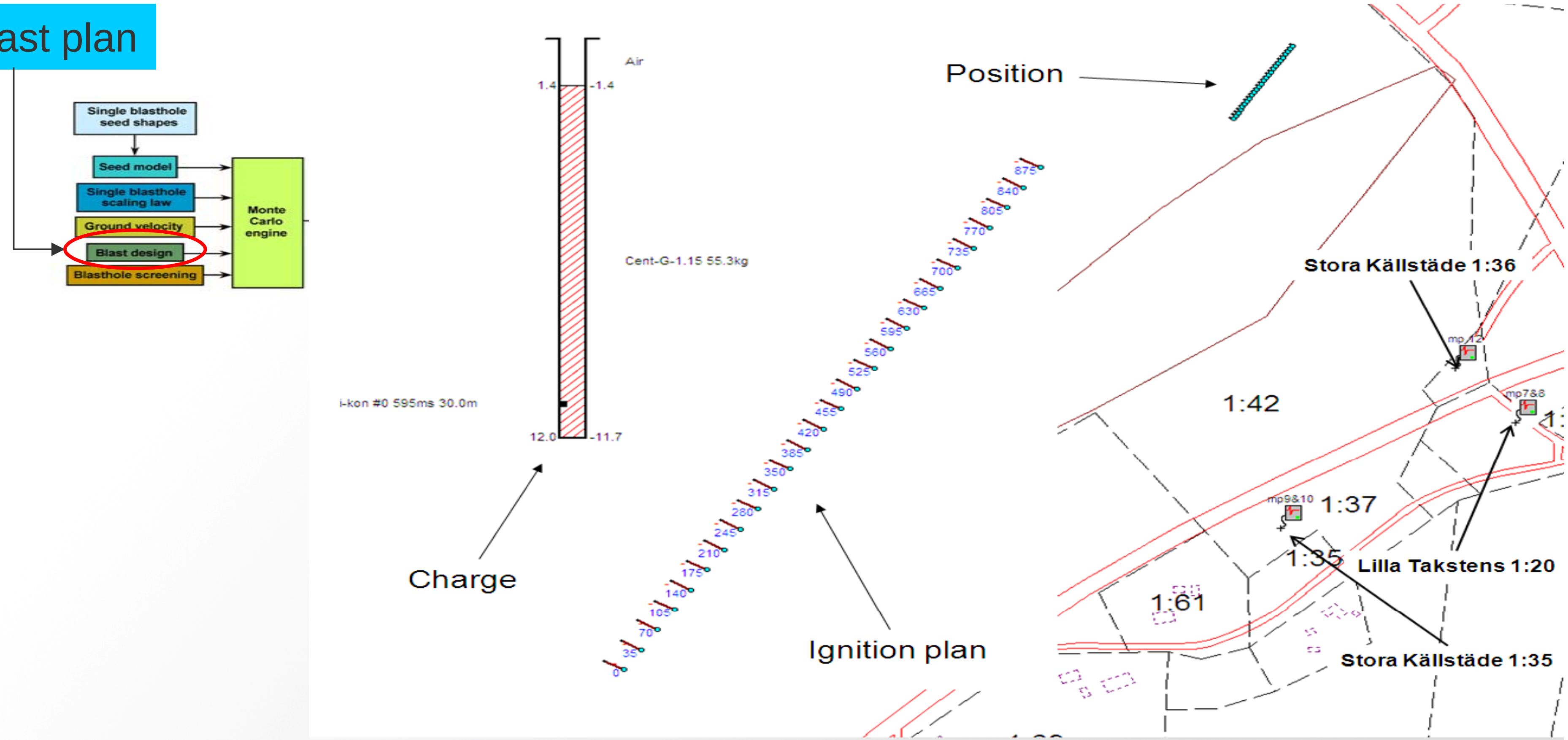
# Blast plan



Single blasthole seed shapes
Seed model
Single blasthole scaling law
Ground velocity
Blast design
Blasthole screening
Monte Carlo engine
Air
Cent-G-1.15 55.3kg
i-kon #0 595ms 30.0m
Charge
Position
Ignition plan
Stora Källstäde 1:36
Lilla Takstens 1:20
Stora Källstäde 1:35
1:42
1:37
1:35
1:61

# Calibration blasts

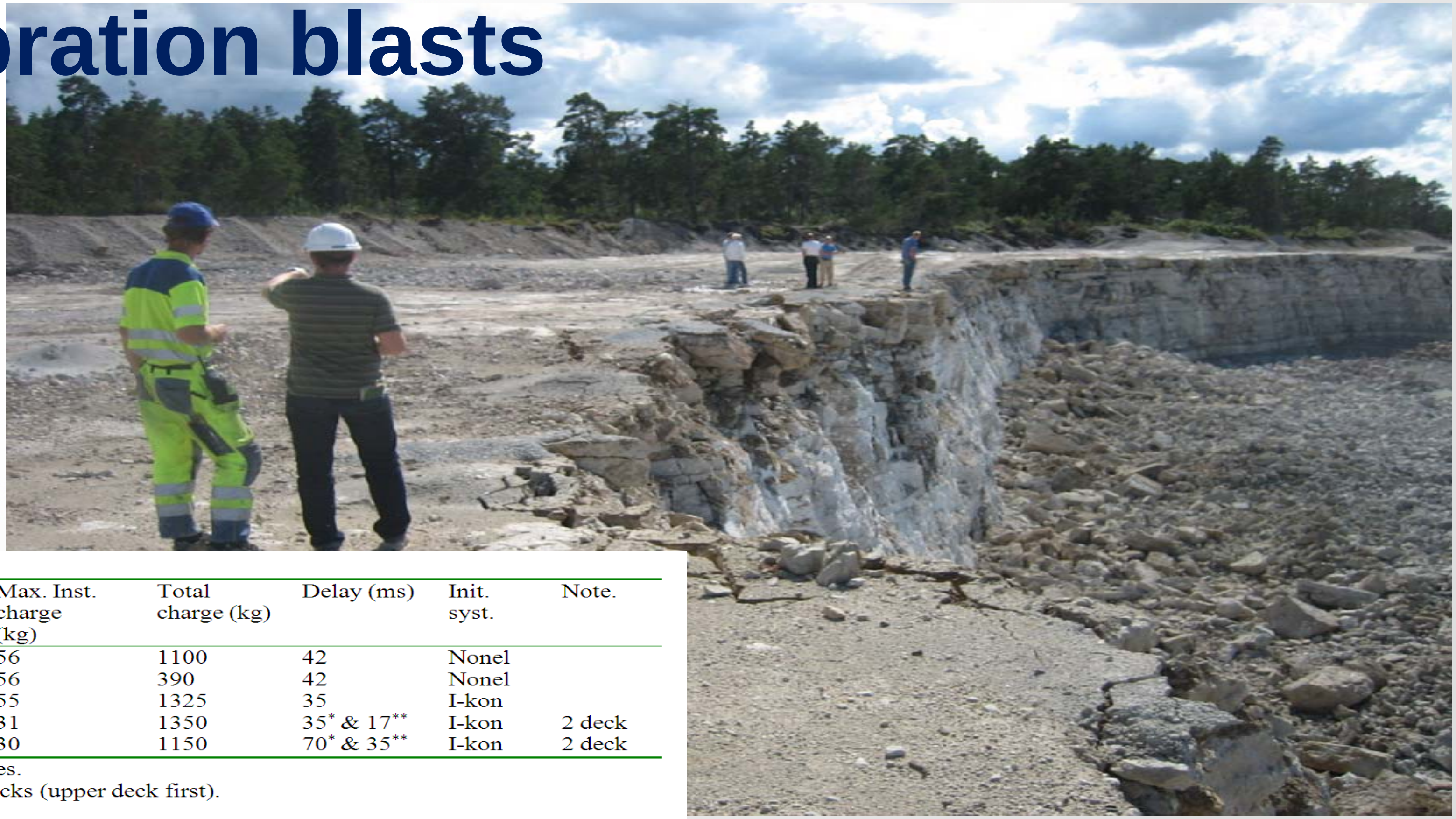
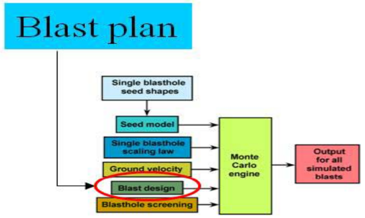


Table 2.

| Blast | Holes | Max. Inst. charge (kg) | Total charge (kg) | Delay (ms) | Init. syst. | Note. |
|---|---|---|---|---|---|---|
| 1 | 20 | 56 | 1100 | 42 | Nonel | |
| 2 | 7 | 56 | 390 | 42 | Nonel | |
| 3 | 26 | 55 | 1325 | 35 | I-kon | |
| 4 | 27 | 31 | 1350 | 35* & 17** | I-kon | 2 deck |
| 5 | 23 | 30 | 1150 | 70* & 35** | I-kon | 2 deck |

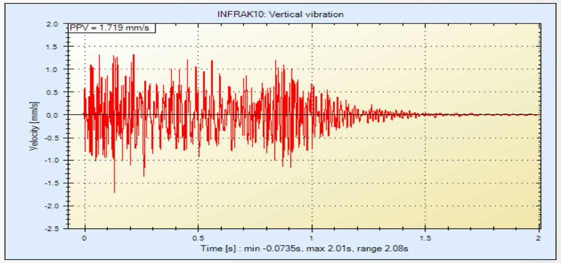
*delay between holes.
** delay between decks (upper deck first).

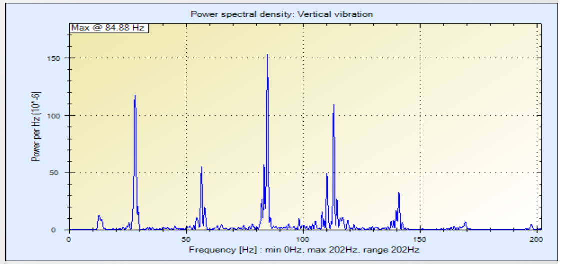
QUARRY ACADEMY



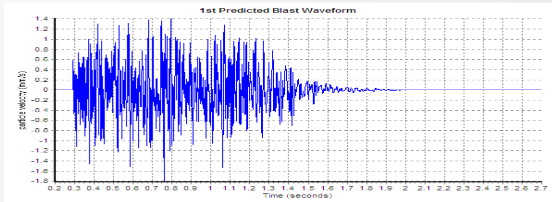

## Calibration

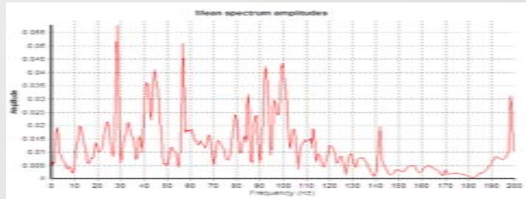
Data from blast

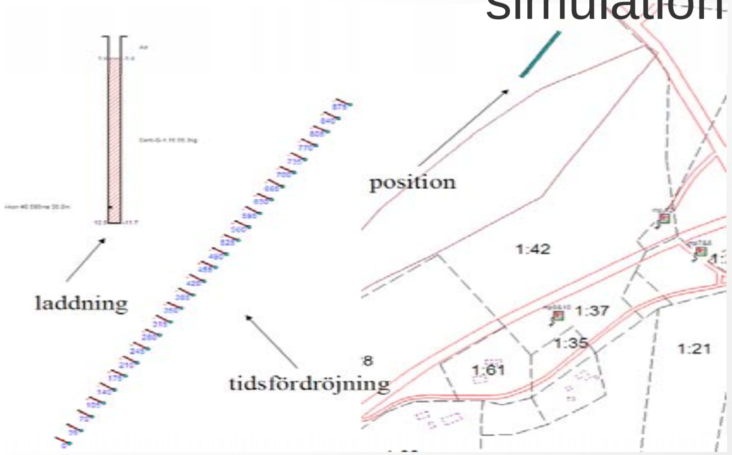


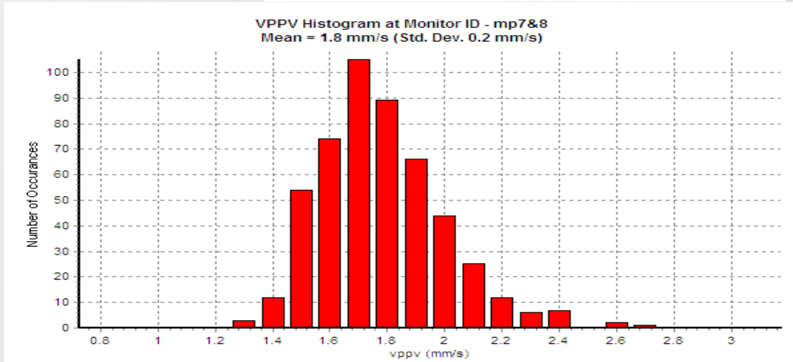




Result from simulation






QUARRY ACADEMY

# Result

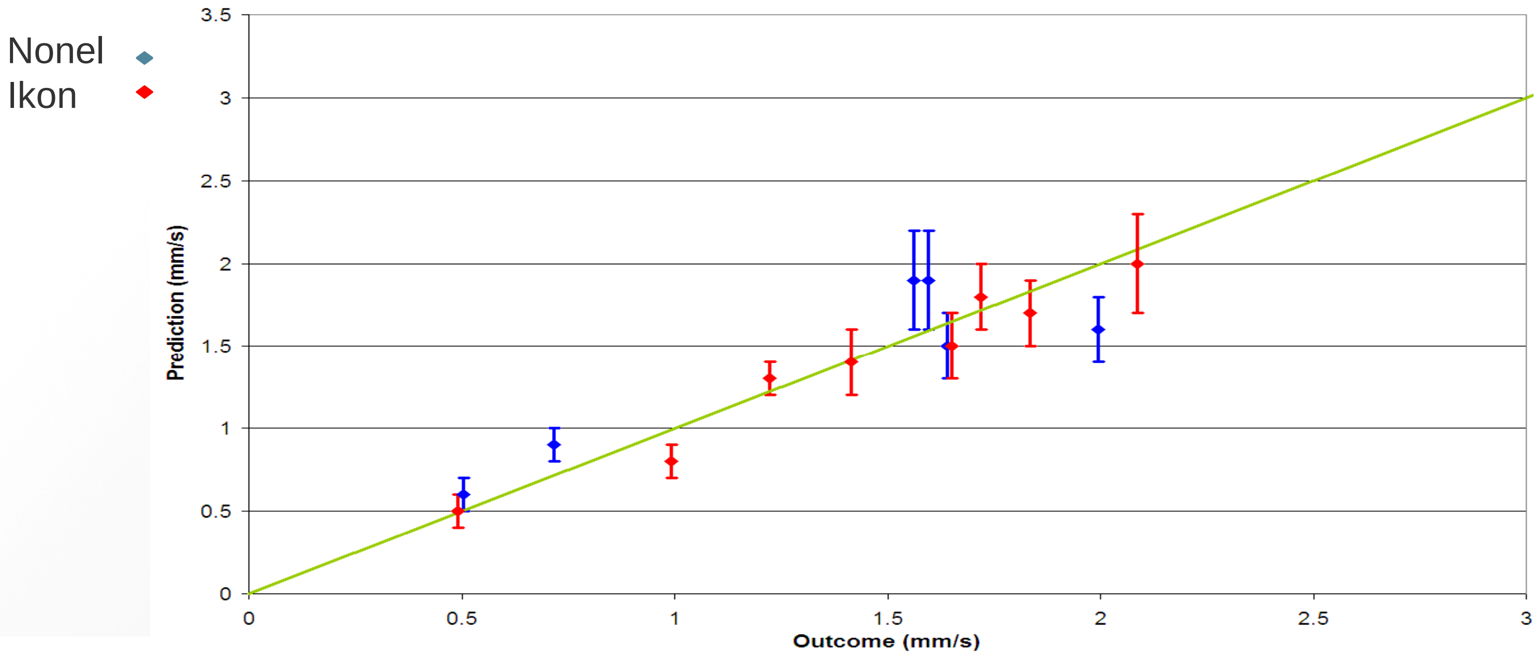


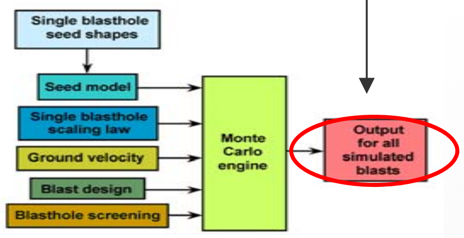

Table 2.

| Blast | Holes | Max. Inst. charge (kg) | Total charge (kg) | Delay (ms) | Init. syst. | Note. |
|---|---|---|---|---|---|---|
| 1 | 20 | 56 | 1100 | 42 | Nonel | |
| 2 | 7 | 56 | 390 | 42 | Nonel | |
| 3 | 26 | 55 | 1325 | 35 | I-kon | |
| 4 | 27 | 31 | 1350 | 35* & 17** | I-kon | 2 deck |
| 5 | 23 | 30 | 1150 | 70* & 35** | I-kon | 2 deck |

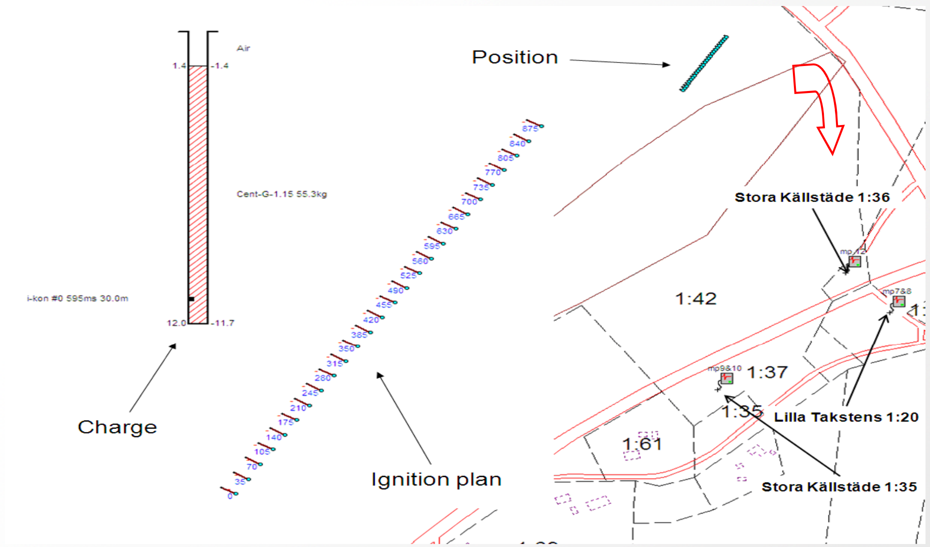
*delay between holes.
** delay between decks (upper deck first).

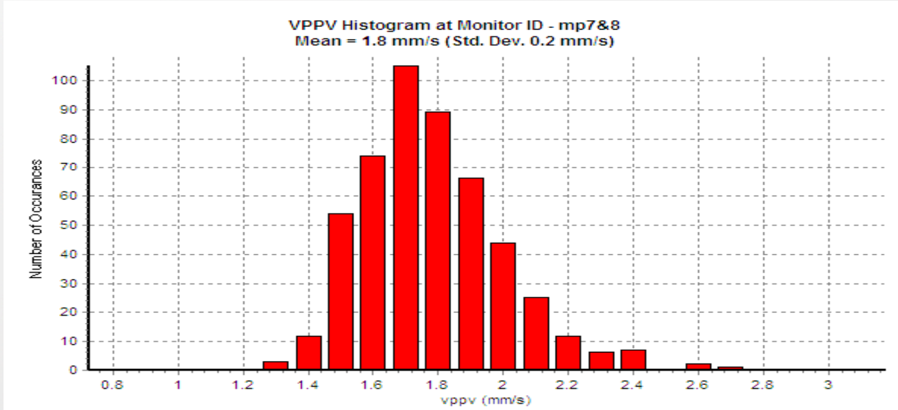
QUARRY ACADEMY

Result from the model

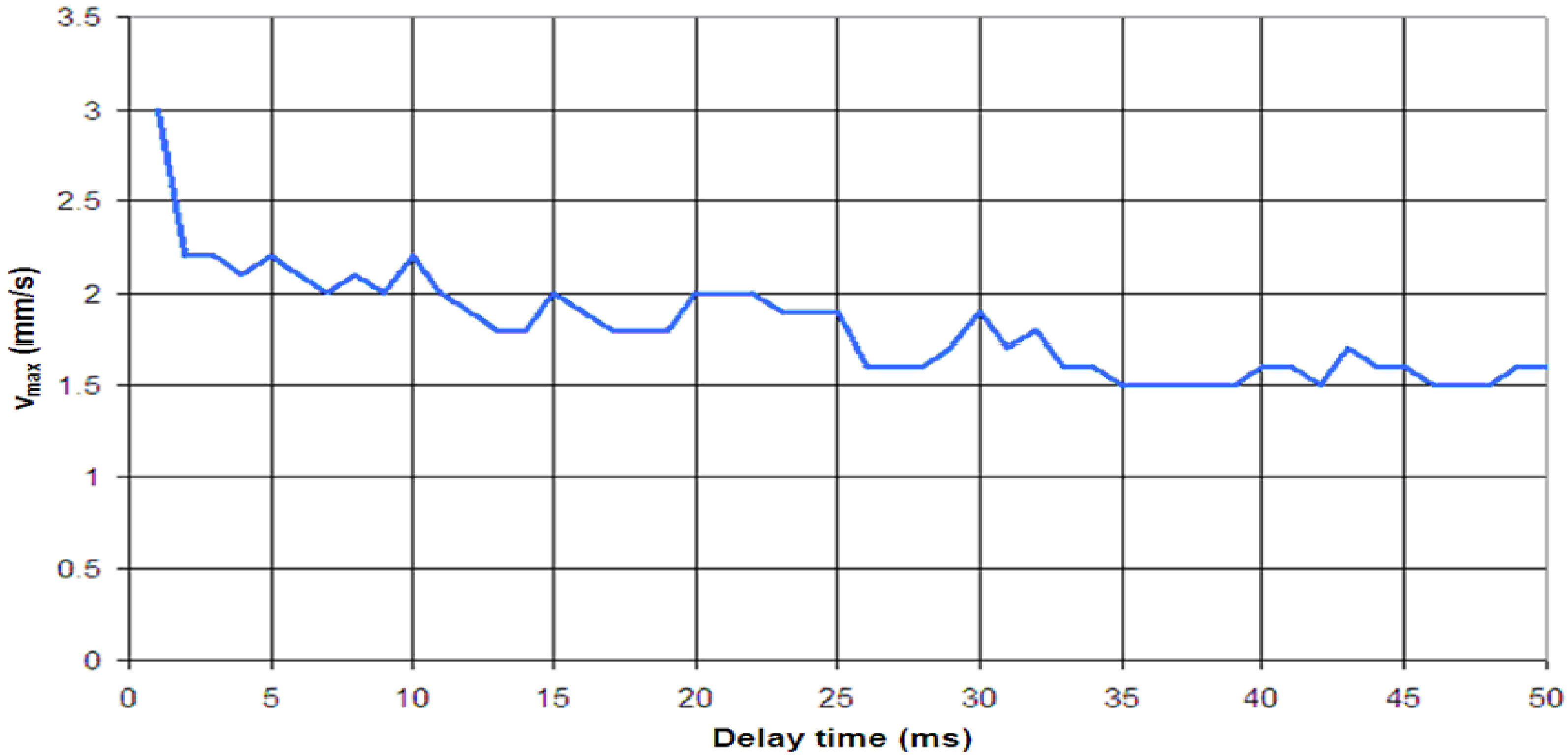



# Using the model



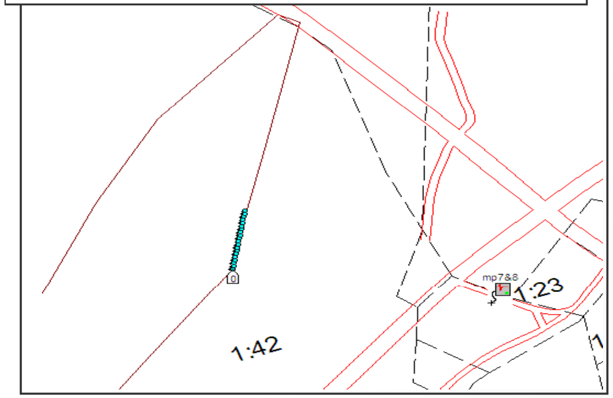



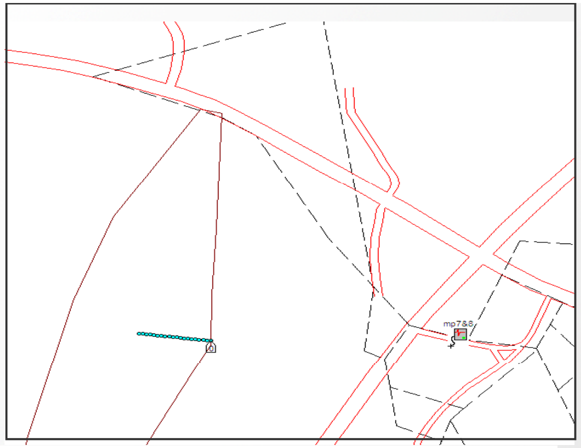
**Delay time**




Model of blast 3
Delay time 1-50 ms

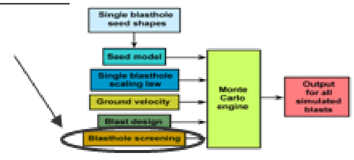
# Direction of excavation




distance from blast to mp 7 & 8 ca 215 m.

Blasthole Screening



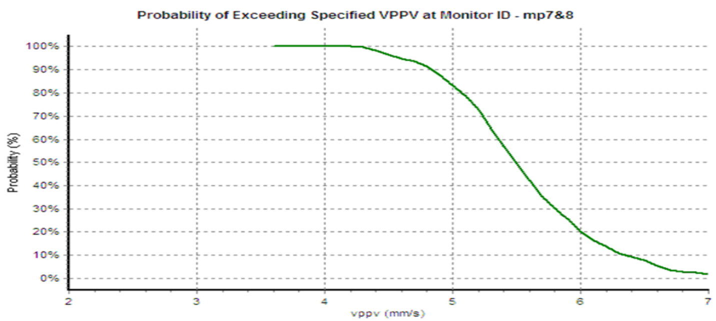




Figure 26, blasting direction 1. Probability of exceeding 4 mm/s is 100%, average value 5.5 mm/s.

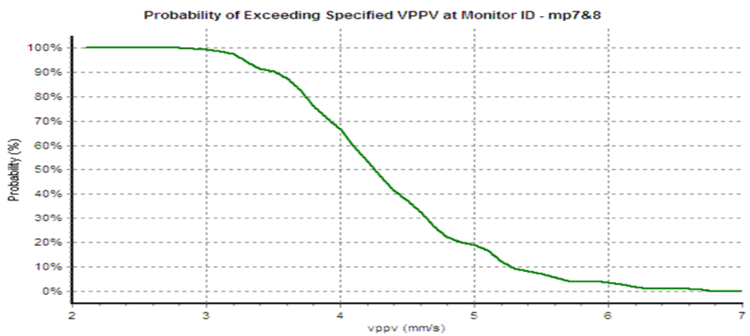
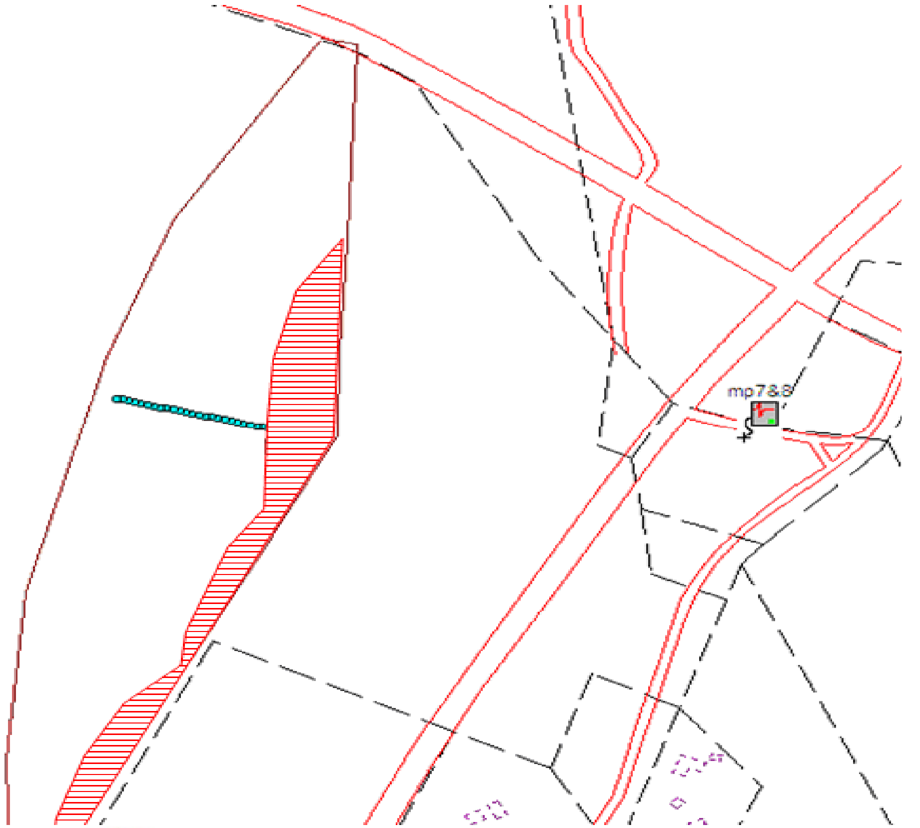



Figure 27, blasting direction 2. Probability of exceeding 4 mm/s is 70%, average value 4.3 mm/s

QUARRY ACADEMY

# Distance



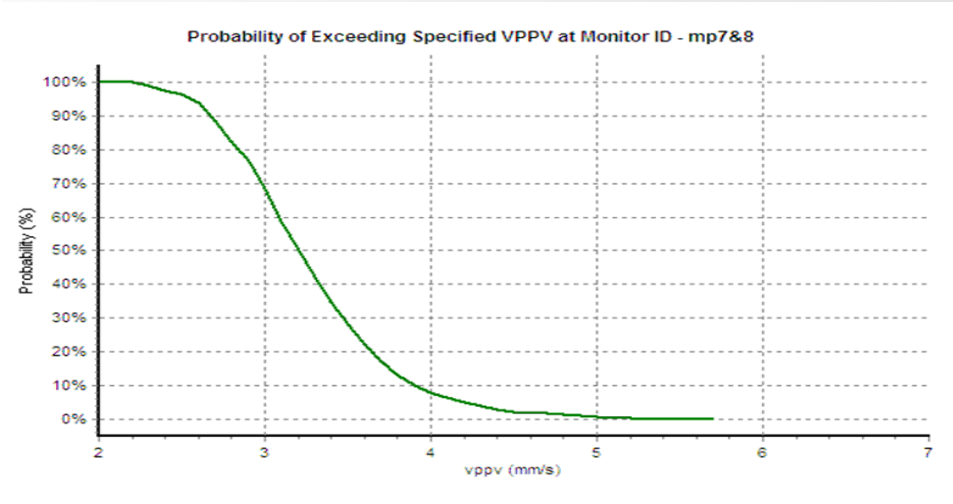




Figure 28. Mp 7&8, 255m distance. Probability to be above 4 mm/s is 8 %, average value is 3.2 mm/s.

## Initiation system


I-kon (electronic)

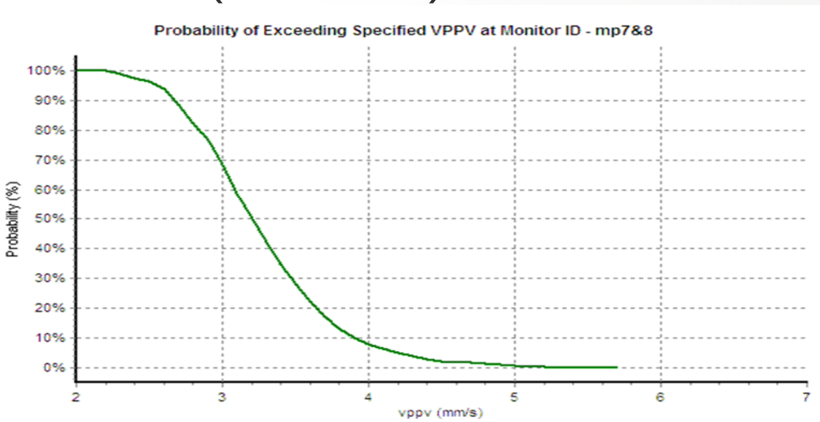



Figure 28. Mp 7&8, 255m distance. Probability to be above 4 mm/s is 8 %, average value is 3.2 mm/s.

Nonel (pyrotechnic)

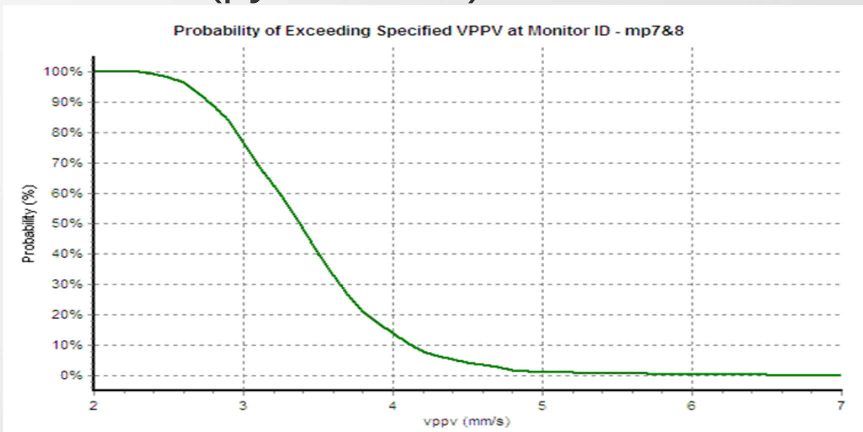



Figure 30. Mp 7 & 8, 255m distance. The risk of exceeding 4 mm/s is 13 %, average value 3.4 mm/s (Nonel detonators).

# Decked charges

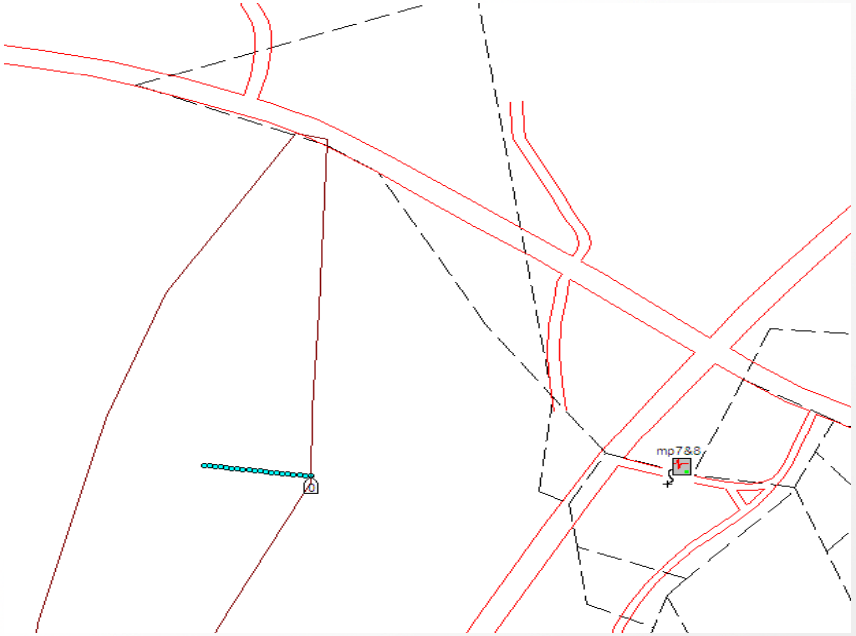
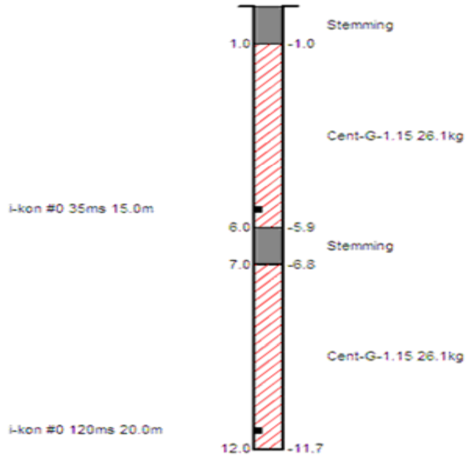
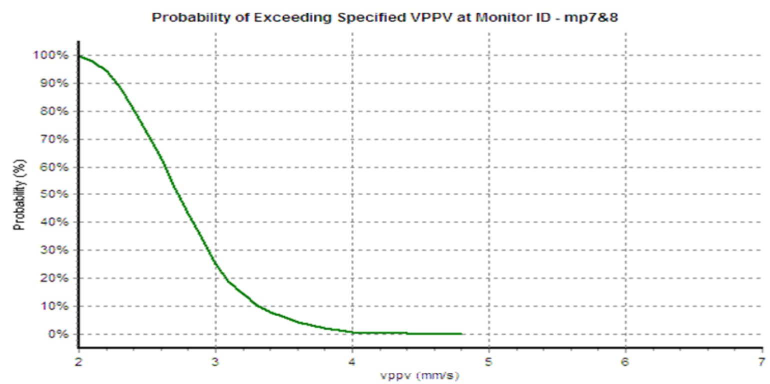



Figure 32. Mp 7and Mp 8 approx. 1% risk to be above 4 mm/s. Average value: 2.8 mm/s. Delay times: 70 ms between holes and 35 ms between decks.

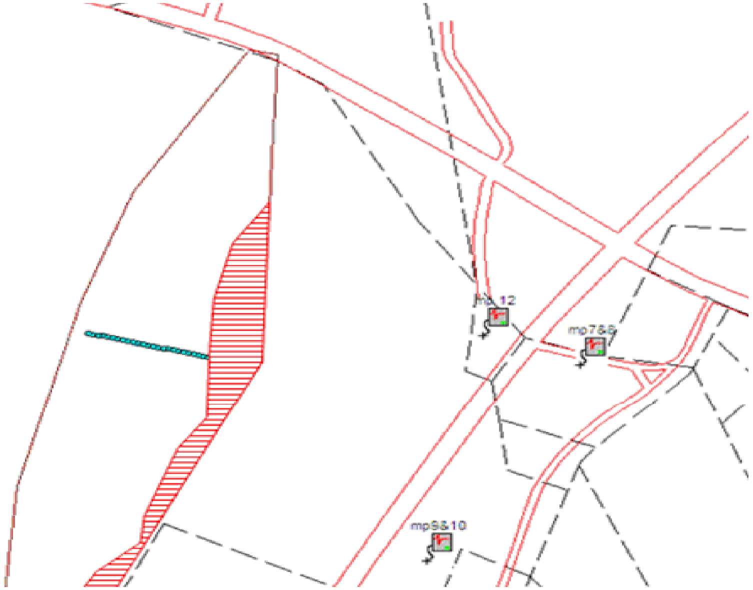


## Conclusions

•If fully charged holes are used together with 35 ms delay time,
•It is possible to blast at 255 m distance from POI (without exceeding 4 mm/s). At shorter distances other actions ex. decked charges are needed.

•The advantage with the MC model is that its possible to investigate the effect of different blast patterns, delay times etc.
•The model also reduces the spread in predicted data since more parameters can be determined.




QUARRY ACADEMY

# Monte Carlo model VS Charge Weight Scaling Law only

MC: prediction:

At 255 m distance the risk is 8% to go above 4 mm/s (average 3.2mm/s)

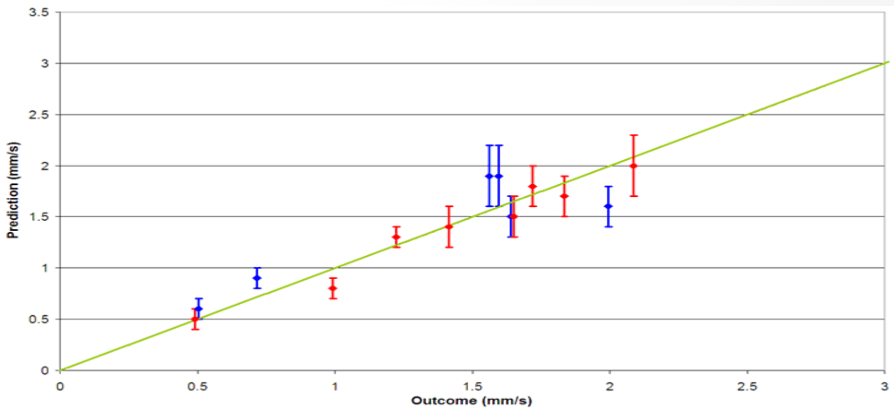



Figure 33, outcome from the Monte Carlo model.

CWSL: prediktion

At 300 m distance the risk is 8 % to go above 4 mm/s (average 2.5 mm/s)

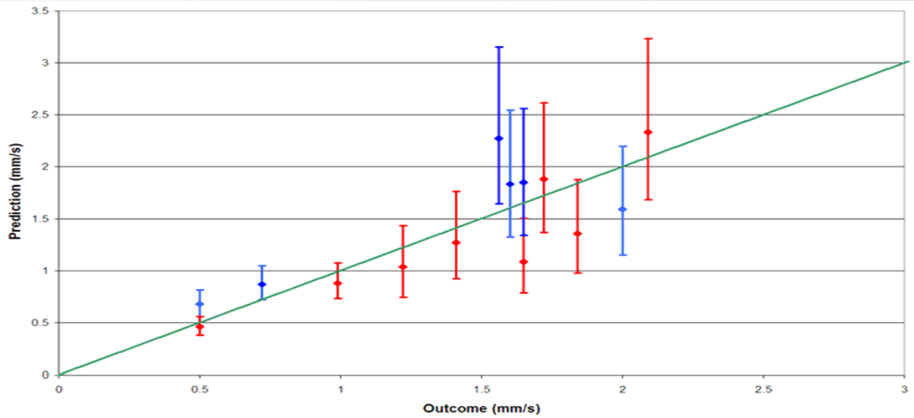



Figure 34, outcome from the charge weight scaling law equation model only.

# Airblast

- Parameters
- Prediction
- Responce – houses
- Actions to reduce airblast

# Airblast

## Important parameters

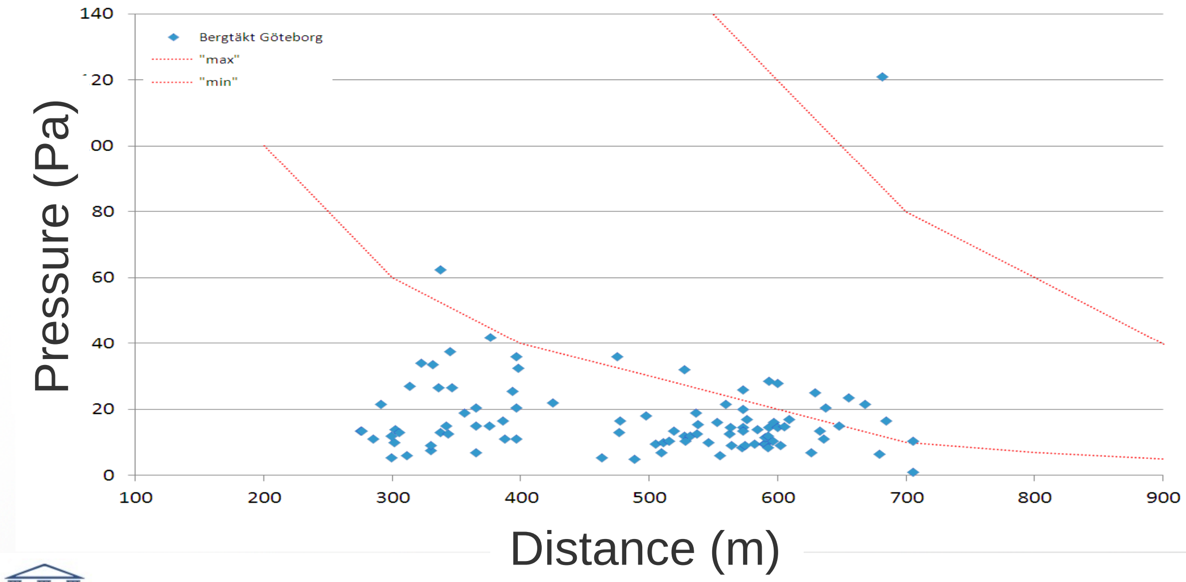
Many important parameters, some difficult to control (Low frequency, you can not hear it):

- Distance
- Maximum instantaneous charge:
- Coupling – explosive/air
- Height and direction of bench , burden
- Topography
- Direction of initiation
- Weather conditions

# Airblast- prediction

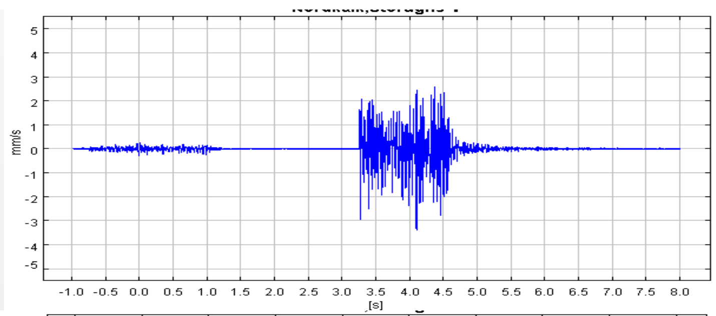
$$P_{\max} = A \cdot \left( \frac{r}{\sqrt[3]{q}} \right)^{-B}$$

Where
$P_{max}$ = pressure (Pa)
r = distance (m)
q= max instantanious charge(kg)
A= constant
B= constant

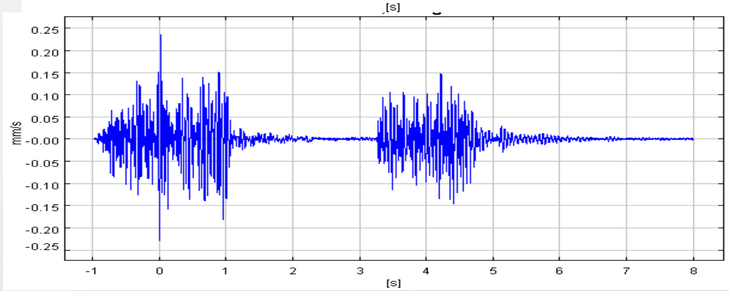


# Airblast - responce

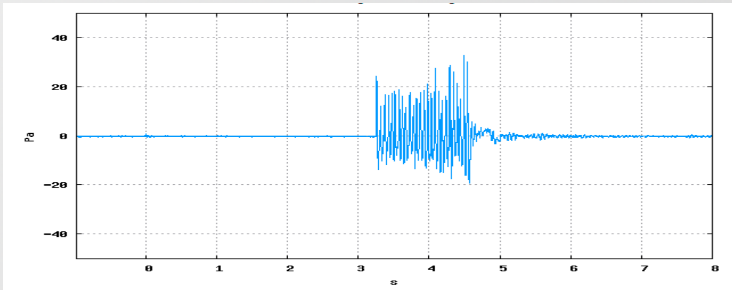
Floor




Foundation




Air Shock




QUARRY ACADEMY

# Blasting Management

## Airblast – How to reduce airblast

$$P_{max} = A \cdot \left( \frac{r}{\sqrt[3]{q}} \right)^{-B}$$

- High levels of air pressure have often its cause from explosives that detonates into free air. This does in its turn often depends on that close by detonations has removed the “cover” from the explosive.
- The air overpressure can often be reduced if the stemming is properly placed and consists of a proper material.
- Bad weather conditions can sometimes be the cause and some quarries chose to wait for better weather if possible (i.e. change in wind direction)

# Vibrations and Airblasts

## How are they monitored?

Mini

LR20 batteries
Normally used
by Nitro


QUARRY ACADEMY

# Only one bus cable

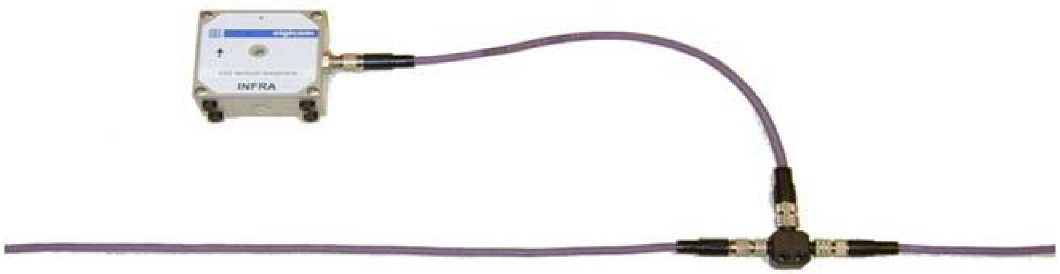
-INFRA sensors are connected with T-couplings

-Up  to 15 sensors on one logger (Mini/Master)

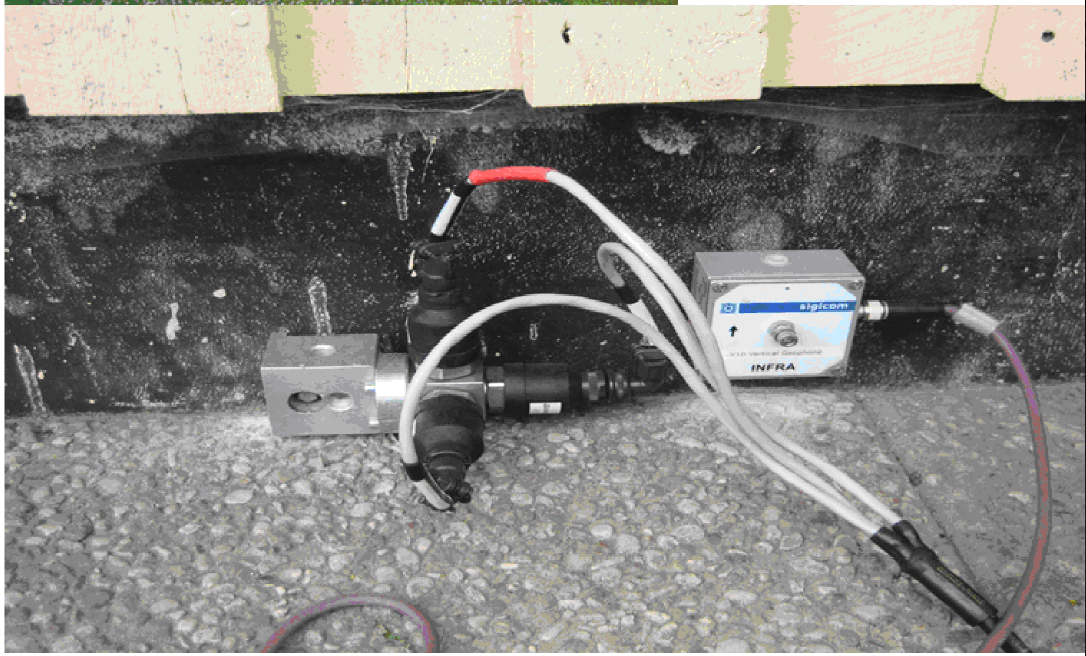
-Up  to 800 m cable length

-6 meter drop cable

-The logger supplies power

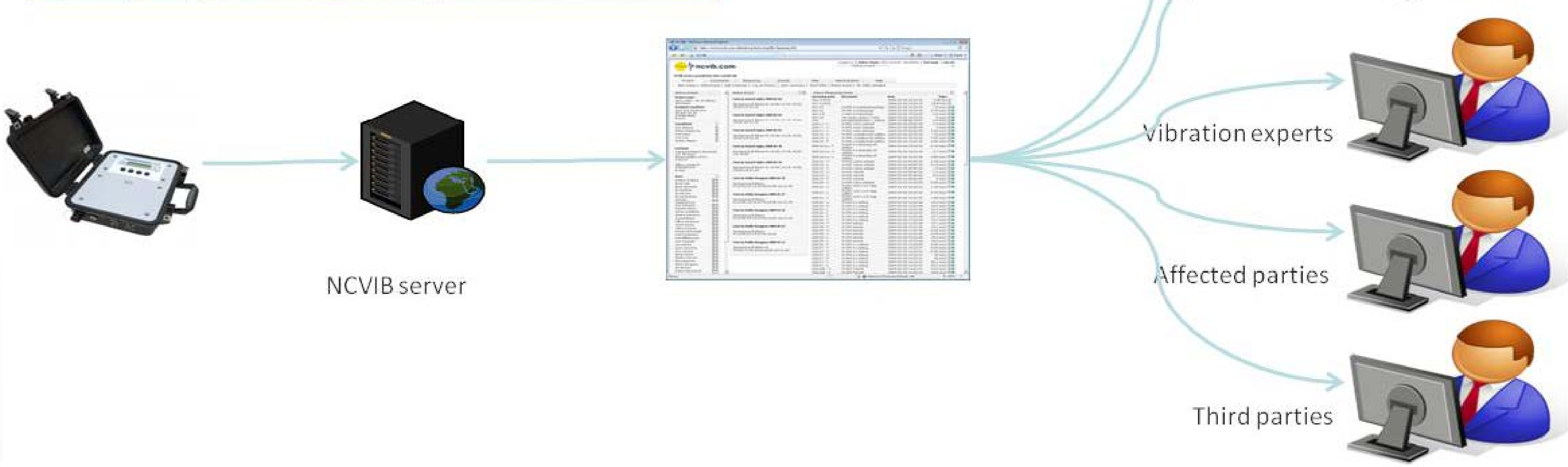


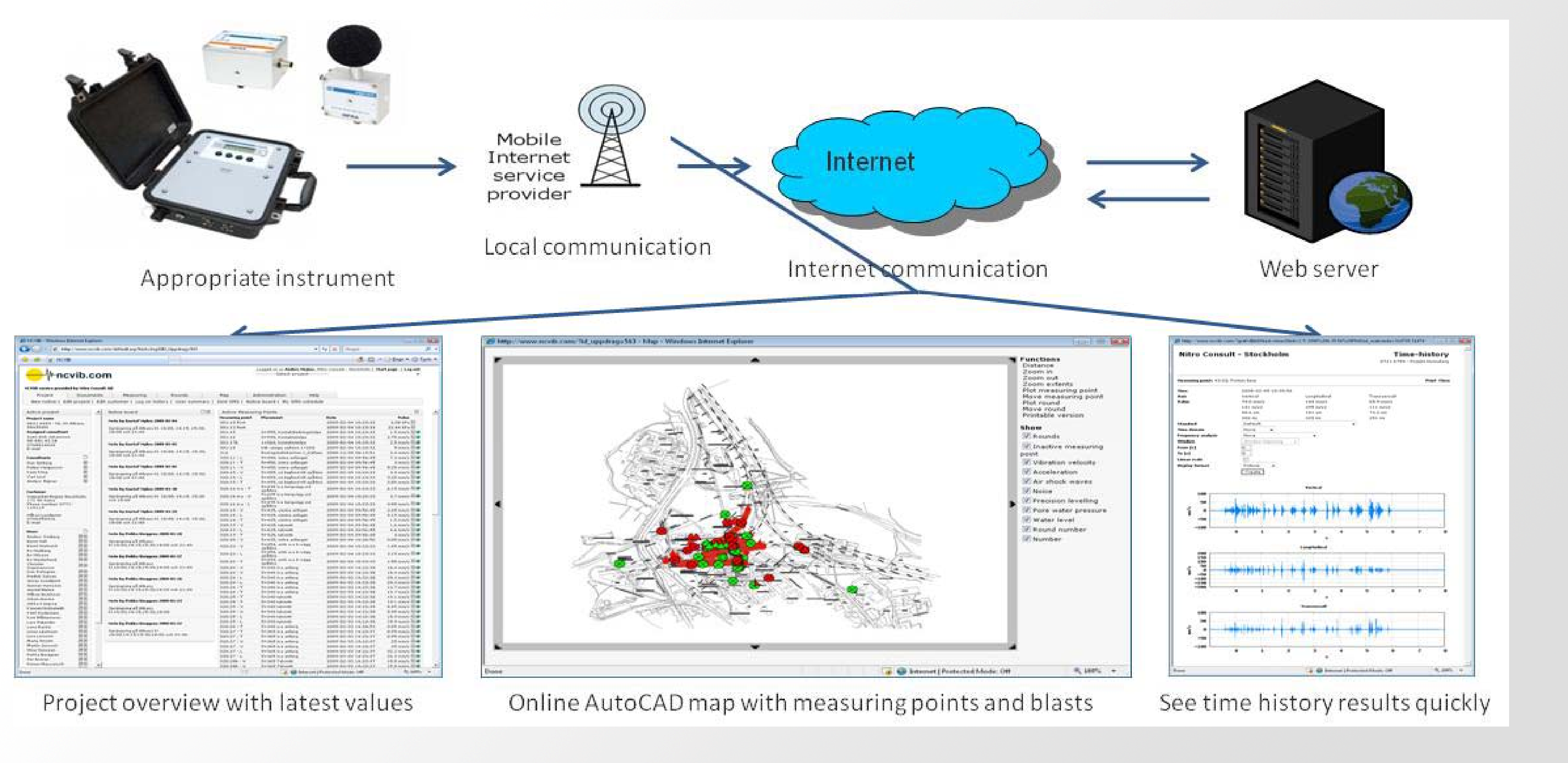
# Monitoring





NCVIB
Blast & Environmental Monitoring System
NCVIB
ENVIRONMENTAL MONITORING


NCVIB server
Blaster
Project owner
Vibration experts
Affected parties
Third parties

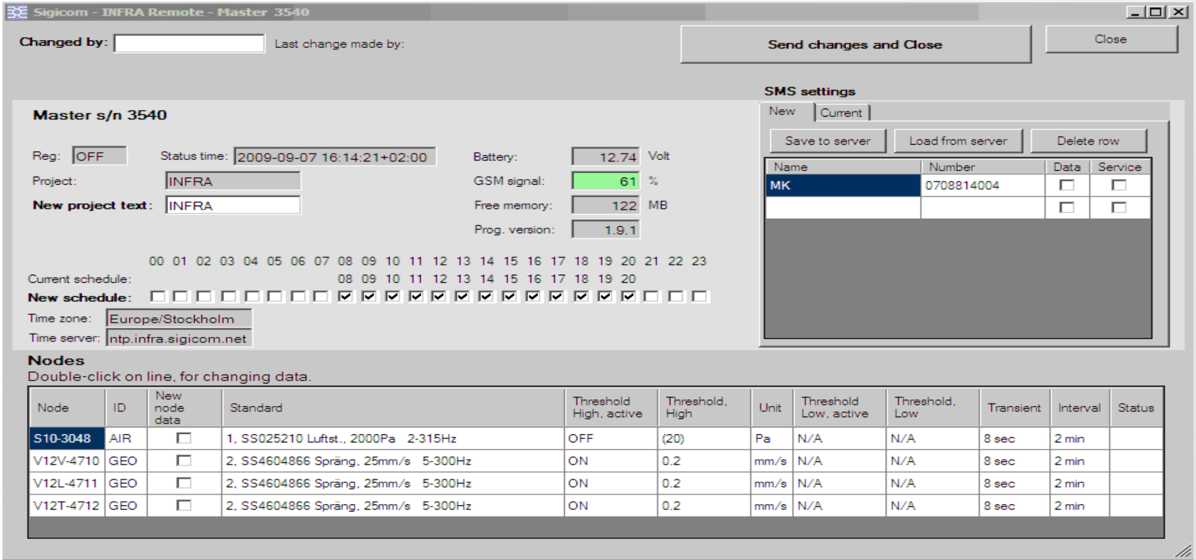



QUARRY ACADEMY

# Remote configuration of instruments

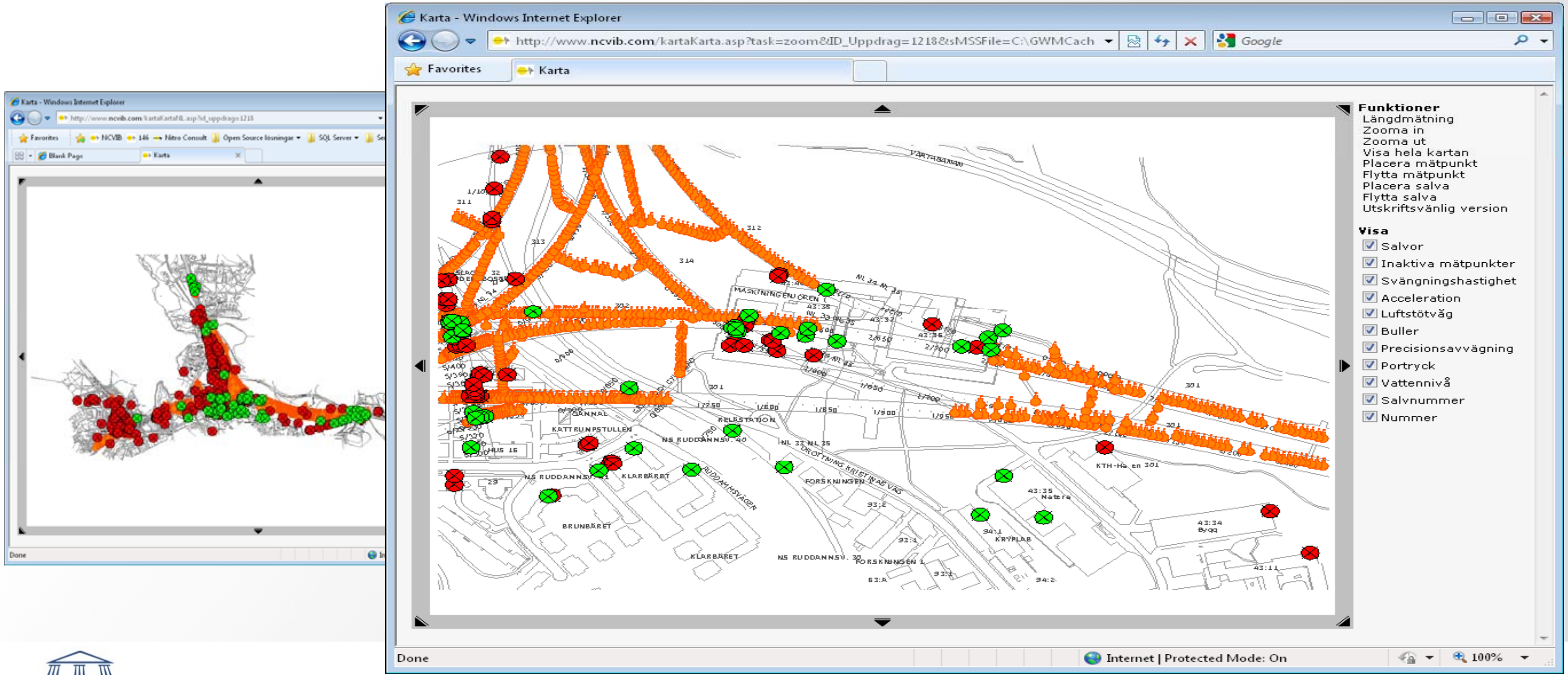
With INFRA Remote you can change standards, trigg levels, etc.

You can see battery-, gsm- and memory status.



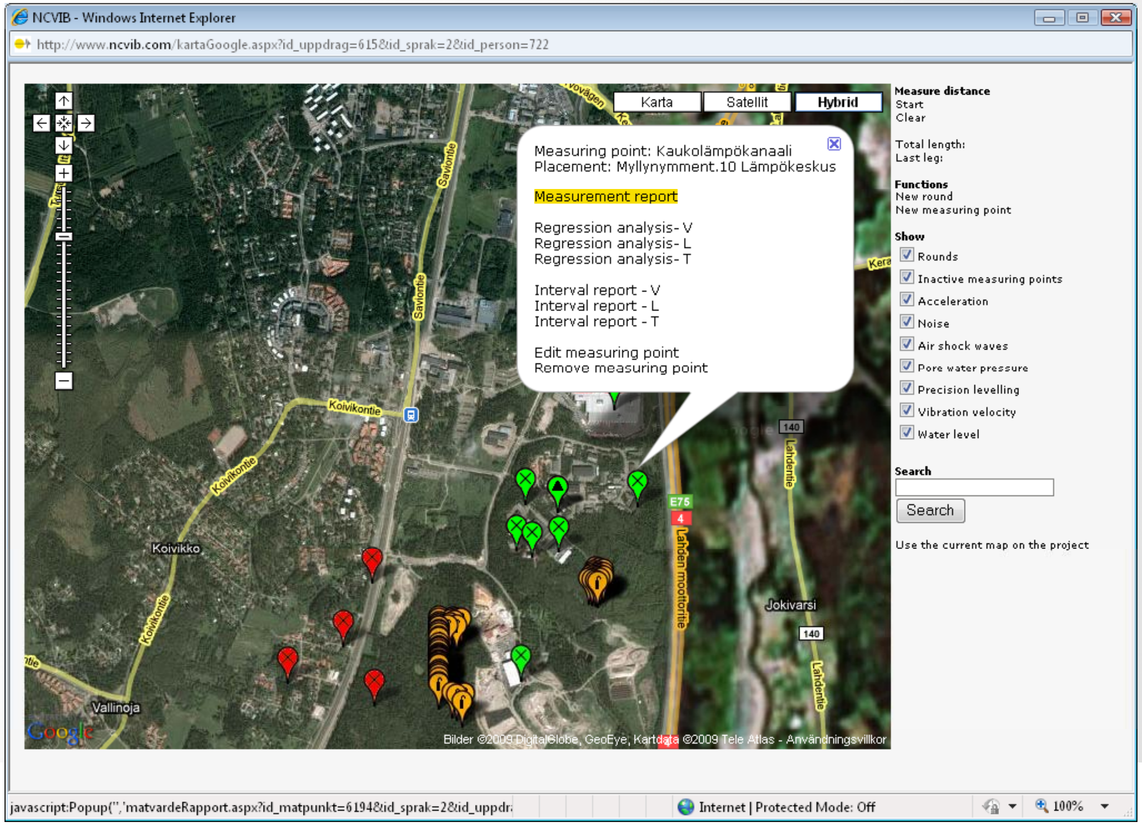

QUARRY ACADEMY

# AutoCAD map support




QUARRY ACADEMY

# Support for Google Maps



# Measurement report

Measurement report - Windows Internet Explorer

http://www.ncvib.com/matvardeRapport.aspx?id_person=528&id_sprak=2&id_uppdrag=565&typ=matvardeperrad&ordnaRiktning=DESC&id_matpunkt=0&komposant=&fran=2(

**Nitro Consult - Stockholm**

**Measurement report**

0621 6604 - NL 51

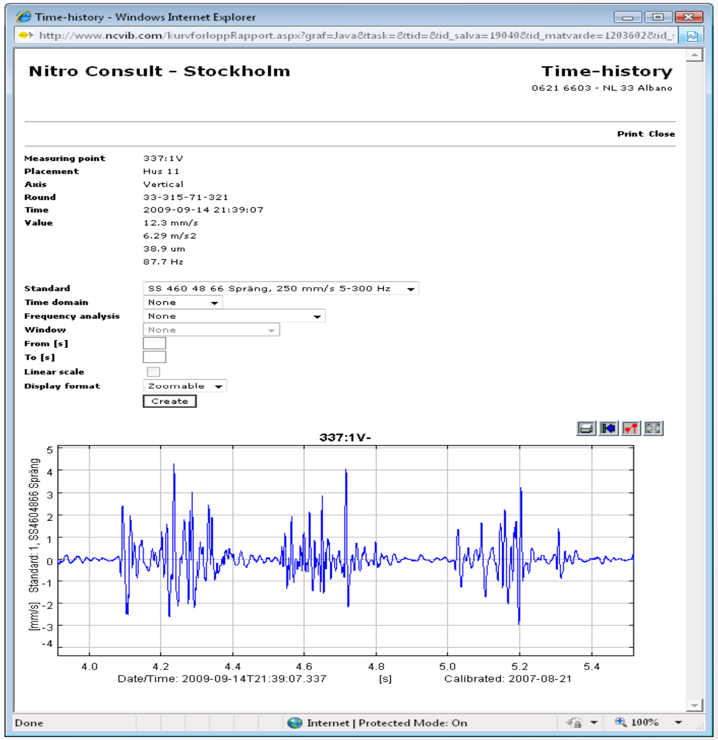
**Report filter** **From:** 2009-11-03 00:00 **To:** 2009-11-09 23:59 **Export Print Close**

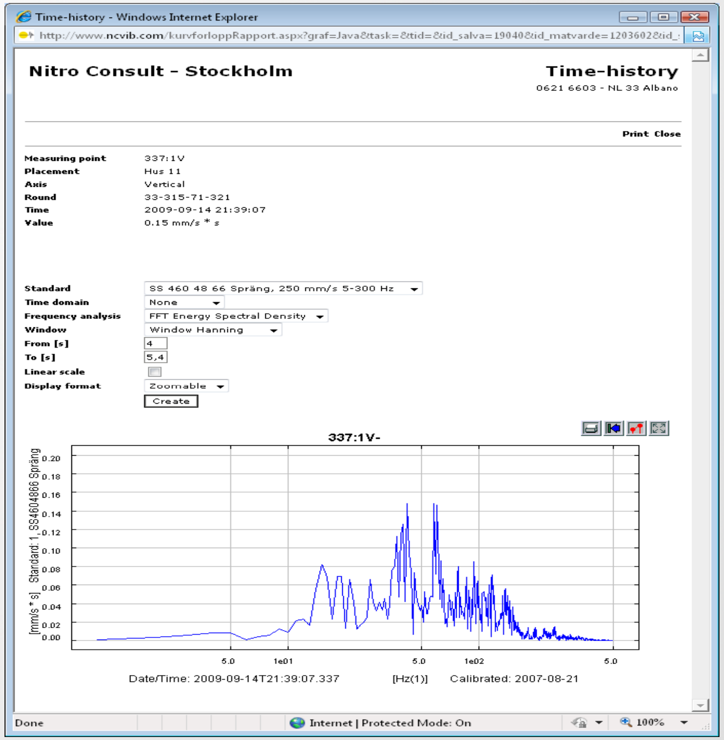
| Measuring point | Placement | Date | Value | Limit | Part of limit | Distance | Round | Remark |
|---|---|---|---|---|---|---|---|---|
| 523:02 | Home Ängsbotten 6 | 2009-11-09 15:03:32 | 1.95 mm/s | (18) | (11)% | (10) | 101 | |
| 524:02 | Prisextra Ängsbotten 6 | 2009-11-09 15:03:32 | 5.9 mm/s | (26) | (23)% | (10) | 101 | |
| 380:64 - V | VG60 Lyra Berg | 2009-11-09 15:03:31 | 1.35 mm/s | 100 | 1% | | 101 | |
| 380:64 - L | VG60 Lyra Berg | 2009-11-09 15:03:31 | 1.15 mm/s | 100 | 1% | | 101 | |
| 380:64 - T | VG60 Lyra Berg | 2009-11-09 15:03:31 | 1.25 mm/s | 100 | 1% | | 101 | |
| 380:65 - V | VG54 Berg 0/780 | 2009-11-09 15:03:31 | 3.4 mm/s | 100 | 3% | | 101 | |
| 380:65 - L | VG54 Berg 0/780 | 2009-11-09 15:03:31 | 7.4 mm/s | 100 | 7% | | 101 | |
| 380:65 - T | VG54 Berg 0/780 | 2009-11-09 15:03:31 | 2.95 mm/s | 100 | 3% | | 101 | |
| 380:66 - V | VG51 Berg 0/726 | 2009-11-09 15:03:31 | 23.3 mm/s | 100 | 23% | | 101 | |
| 380:66 - L | VG51 Berg 0/726 | 2009-11-09 15:03:31 | 43.8 mm/s | 100 | 44% | | 101 | |
| 380:66 - T | VG51 Berg 0/726 | 2009-11-09 15:03:31 | 39.9 mm/s | 100 | 40% | | 101 | |
| 612:01 | Betongpelare JVG bro | 2009-11-09 15:03:31 | 4.2 mm/s | (140) | (3)% | (10) | 101 | |
| 591:02 | Ryttarstadion, Svenska Bil | 2009-11-09 11:39:06 | 7.95 mm/s | (70) | (11)% | (10) | 100 | |
| 612:01 | Betongpelare JVG bro | 2009-11-09 11:39:06 | 19.3 mm/s | (140) | (14)% | (10) | 100 | |
| 380:64 - V | VG60 Lyra Berg | 2009-11-09 11:39:05 | 6.75 mm/s | 100 | 7% | | 100 | |
| 380:64 - L | VG60 Lyra Berg | 2009-11-09 11:39:05 | 4.4 mm/s | 100 | 4% | | 100 | |
| 380:64 - T | VG60 Lyra Berg | 2009-11-09 11:39:05 | 6.05 mm/s | 100 | 6% | | 100 | |
| 380:65 - V | VG54 Berg 0/780 | 2009-11-09 11:39:05 | 98.7 mm/s | 100 | 99% | | 100 | |
| 380:65 - L | VG54 Berg 0/780 | 2009-11-09 11:39:05 | 102 mm/s | 100 | 102% | | 100 | |
| 380:65 - T | VG54 Berg 0/780 | 2009-11-09 11:39:05 | 55.2 mm/s | 100 | 55% | | 100 | |
| 380:66 - V | VG51 Berg 0/726 | 2009-11-09 11:39:05 | 12.2 mm/s | 100 | 12% | | 100 | |
| 380:66 - L | VG51 Berg 0/726 | 2009-11-09 11:39:05 | 16.2 mm/s | 100 | 16% | | 100 | |
| 380:66 - T | VG51 Berg 0/726 | 2009-11-09 11:39:05 | 9.9 mm/s | 100 | 10% | | 100 | |
| 523:02 | Home Ängsbotten 6 | 2009-11-09 11:39:05 | 2.6 mm/s | (18) | (14)% | (10) | 100 | |
| 524:02 | Prisextra Ängsbotten 6 | 2009-11-09 11:39:05 | 6.95 mm/s | (26) | (27)% | (10) | 100 | |
| 612:01 | Betongpelare JVG bro | 2009-11-06 07:11:30 | 3 mm/s | (140) | (2)% | (10) | | |
| 380:64 - L | VG60 Lyra Berg | 2009-11-05 15:32:28 | 7.05 mm/s | 100 | 7% | | | |
| 380:64 - T | VG60 Lyra Berg | 2009-11-05 15:32:28 | 5.05 mm/s | 100 | 5% | | | |
| 380:65 - V | VG54 Berg 0/780 | 2009-11-05 15:32:28 | 5.2 mm/s | 100 | 5% | | | |
| 380:65 - L | VG54 Berg 0/780 | 2009-11-05 15:32:28 | 8.75 mm/s | 100 | 9% | | | |
| 380:65 - T | VG54 Berg 0/780 | 2009-11-05 15:32:28 | 2.6 mm/s | 100 | 3% | | | |
| 380:66 - V | VG51 Berg 0/726 | 2009-11-05 15:32:28 | 1.4 mm/s | 100 | 1% | | | |
| 380:66 - L | VG51 Berg 0/726 | 2009-11-05 15:32:28 | 1.55 mm/s | 100 | 2% | | | |
| 380:66 - T | VG51 Berg 0/726 | 2009-11-05 15:32:28 | 1.05 mm/s | 100 | 1% | | | |

Done Internet | Protected Mode: On 100%

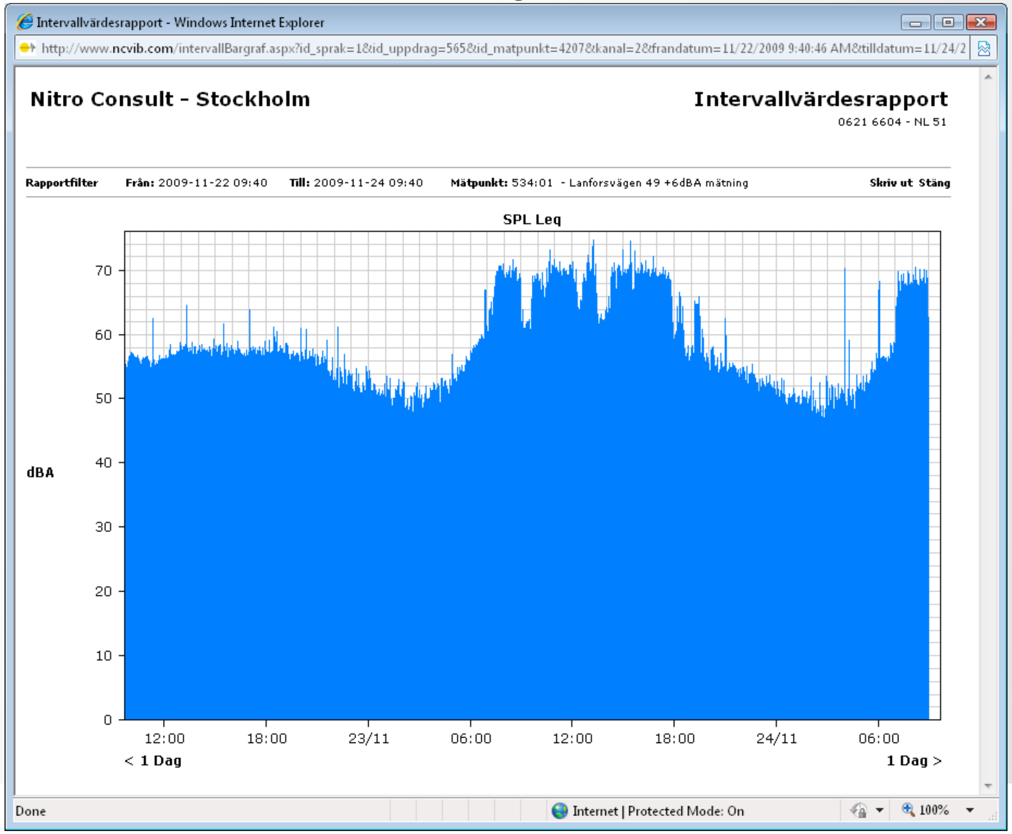
QUARRY ACADEMY

# Wave forms with frequency analysis

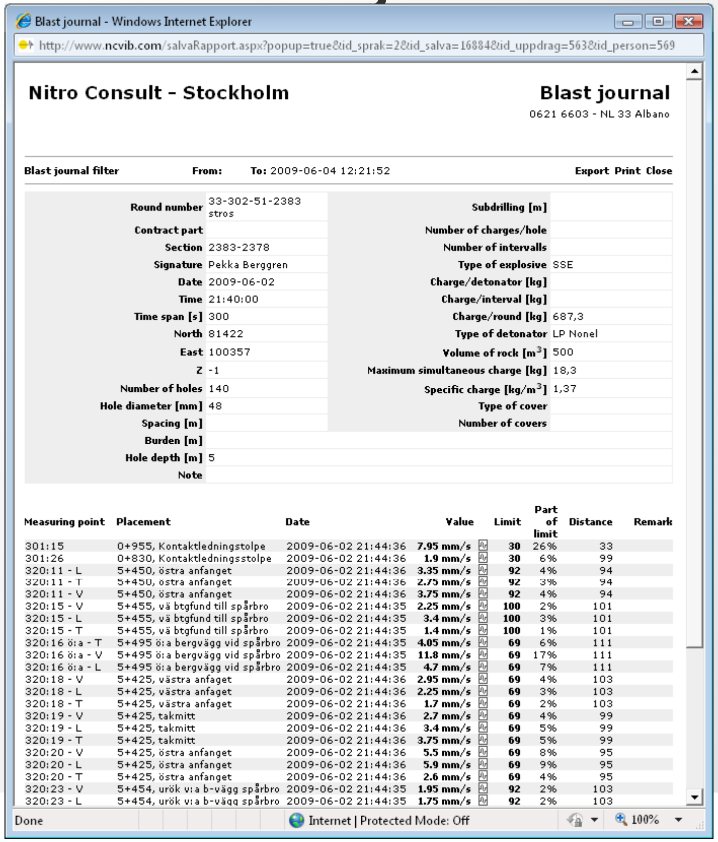


# Continoues peak values



# Blast journal



Blast journal - Windows Internet Explorer

http://www.ncvib.com/salvaRapport.aspx?popup=true&id_sprak=2&id_salva=16884&id_uppdrag=563&id_person=569

**Nitro Consult - Stockholm**

**Blast journal**

0621 6603 - NL 33 Albano

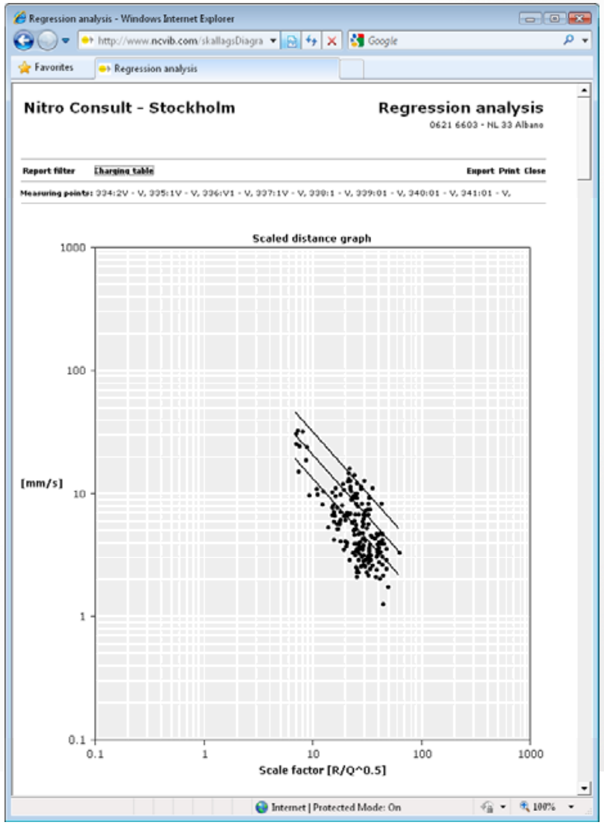
**Blast journal filter** **From:** **To:** 2009-06-04 12:21:52 **Export** **Print** **Close**

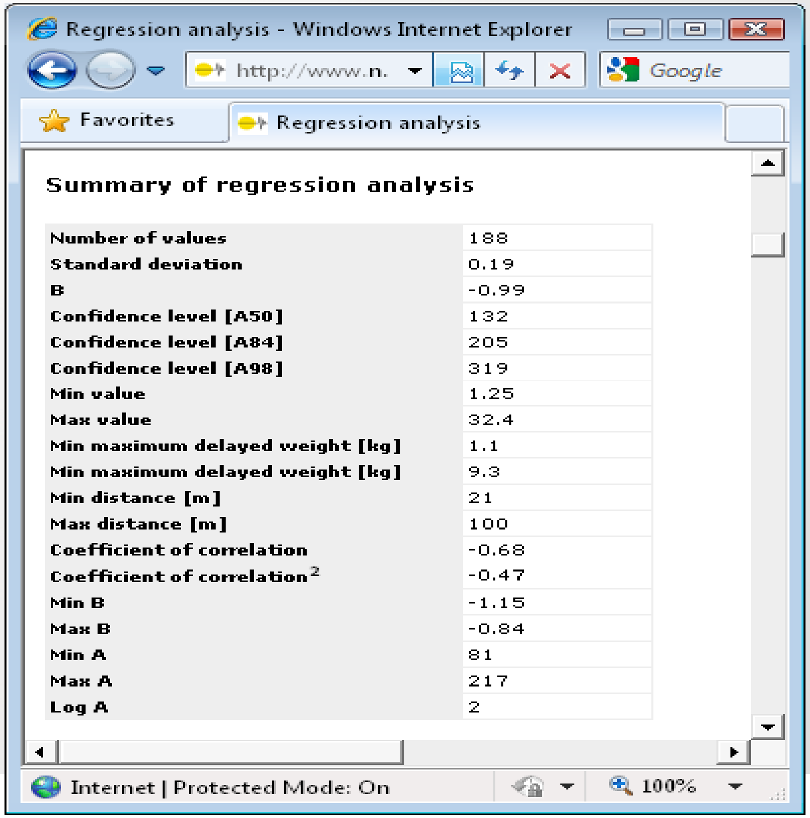
| | | | |
|---|---|---|---|
| **Round number** | 33-302-51-2383 stros | **Subdrilling [m]** | |
| **Contract part** | | **Number of charges/hole** | |
| **Section** | 2383-2378 | **Number of intervalls** | |
| **Signature** | Pekka Berggren | **Type of explosive** | SSE |
| **Date** | 2009-06-02 | **Charge/detonator [kg]** | |
| **Time** | 21:40:00 | **Charge/interval [kg]** | |
| **Time span [s]** | 300 | **Charge/round [kg]** | 687,3 |
| **North** | 81422 | **Type of detonator** | LP Nonel |
| **East** | 100357 | **Volume of rock [$m^3$]** | 500 |
| **Z** | -1 | **Maximum simultaneous charge [kg]** | 18,3 |
| **Number of holes** | 140 | **Specific charge [$kg/m^3$]** | 1,37 |
| **Hole diameter [mm]** | 48 | **Type of cover** | |
| **Spacing [m]** | | **Number of covers** | |
| **Burden [m]** | | | |
| **Hole depth [m]** | 5 | | |
| **Note** | | | |

| Measuring point | Placement | Date | Value | Limit | Part of limit | Distance | Remark |
|---|---|---|---|---|---|---|---|
| 301:15 | 0+955, Kontaktledningstolpe | 2009-06-02 21:44:36 | **7.95 mm/s** | **30** | 26% | 33 | |
| 301:26 | 0+830, Kontaktledningsstolpe | 2009-06-02 21:44:36 | **1.9 mm/s** | **30** | 6% | 99 | |
| 320:11 - L | 5+450, östra anfanget | 2009-06-02 21:44:36 | **3.35 mm/s** | **92** | 4% | 94 | |
| 320:11 - T | 5+450, östra anfanget | 2009-06-02 21:44:36 | **2.75 mm/s** | **92** | 3% | 94 | |
| 320:11 - V | 5+450, östra anfanget | 2009-06-02 21:44:36 | **3.75 mm/s** | **92** | 4% | 94 | |
| 320:15 - V | 5+455, vä btgfund till spårbro | 2009-06-02 21:44:35 | **2.25 mm/s** | **100** | 2% | 101 | |
| 320:15 - L | 5+455, vä btgfund till spårbro | 2009-06-02 21:44:35 | **3.4 mm/s** | **100** | 3% | 101 | |
| 320:15 - T | 5+455, vä btgfund till spårbro | 2009-06-02 21:44:35 | **1.4 mm/s** | **100** | 1% | 101 | |
| 320:16 ö:a - T | 5+495 ö:a bergvägg vid spårbro | 2009-06-02 21:44:35 | **4.05 mm/s** | **69** | 6% | 111 | |
| 320:16 ö:a - V | 5+495 ö:a bergvägg vid spårbro | 2009-06-02 21:44:35 | **11.8 mm/s** | **69** | 17% | 111 | |
| 320:16 ö:a - L | 5+495 ö:a bergvägg vid spårbro | 2009-06-02 21:44:35 | **4.7 mm/s** | **69** | 7% | 111 | |
| 320:18 - V | 5+425, västra anfaget | 2009-06-02 21:44:36 | **2.95 mm/s** | **69** | 4% | 103 | |
| 320:18 - L | 5+425, västra anfaget | 2009-06-02 21:44:36 | **2.25 mm/s** | **69** | 3% | 103 | |
| 320:18 - T | 5+425, västra anfaget | 2009-06-02 21:44:36 | **1.7 mm/s** | **69** | 2% | 103 | |
| 320:19 - V | 5+425, takmitt | 2009-06-02 21:44:36 | **2.7 mm/s** | **69** | 4% | 99 | |
| 320:19 - L | 5+425, takmitt | 2009-06-02 21:44:36 | **3.4 mm/s** | **69** | 5% | 99 | |
| 320:19 - T | 5+425, takmitt | 2009-06-02 21:44:36 | **3.75 mm/s** | **69** | 5% | 99 | |
| 320:20 - V | 5+425, östra anfanget | 2009-06-02 21:44:36 | **5.5 mm/s** | **69** | 8% | 95 | |
| 320:20 - L | 5+425, östra anfanget | 2009-06-02 21:44:36 | **5.9 mm/s** | **69** | 9% | 95 | |
| 320:20 - T | 5+425, östra anfanget | 2009-06-02 21:44:36 | **2.6 mm/s** | **69** | 4% | 95 | |
| 320:23 - V | 5+454, urök v:a b-vägg spårbro | 2009-06-02 21:44:35 | **1.95 mm/s** | **92** | 2% | 103 | |
| 320:23 - L | 5+454, urök v:a b-vägg spårbro | 2009-06-02 21:44:35 | **1.75 mm/s** | **92** | 2% | 103 | |

Done | Internet | Protected Mode: Off | 100%

# Automated regression analysis

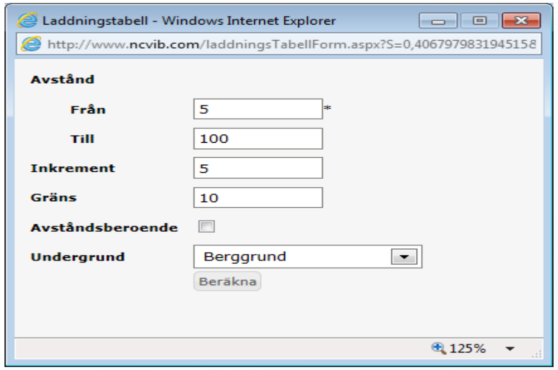


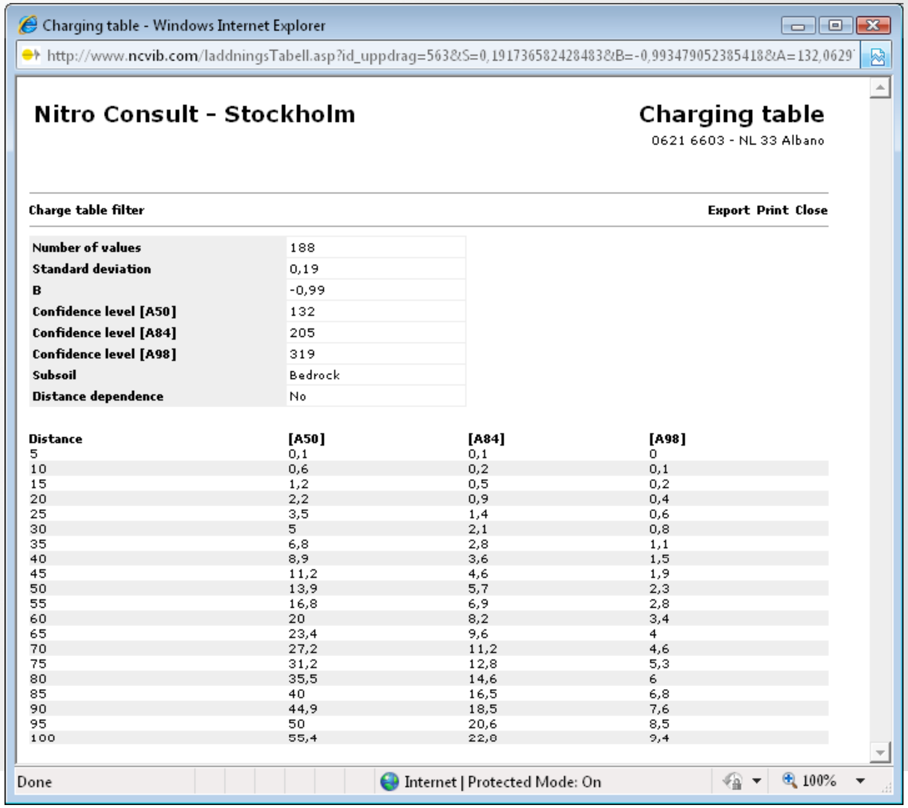




**Summary of regression analysis**

| | |
|---|---|
| Number of values | 188 |
| Standard deviation | 0.19 |
| B | -0.99 |
| Confidence level [A50] | 132 |
| Confidence level [A84] | 205 |
| Confidence level [A98] | 319 |
| Min value | 1.25 |
| Max value | 32.4 |
| Min maximum delayed weight [kg] | 1.1 |
| Min maximum delayed weight [kg] | 9.3 |
| Min distance [m] | 21 |
| Max distance [m] | 100 |
| Coefficient of correlation | -0.68 |
| Coefficient of correlation$^2$ | -0.47 |
| Min B | -1.15 |
| Max B | -0.84 |
| Min A | 81 |
| Max A | 217 |
| Log A | 2 |

# Charging table




| | |
|---|---|
| Number of values | 188 |
| Standard deviation | 0,19 |
| B | -0,99 |
| Confidence level [A50] | 132 |
| Confidence level [A84] | 205 |
| Confidence level [A98] | 319 |
| Subsoil | Bedrock |
| Distance dependence | No |

| Distance | [A50] | [A84] | [A98] |
|---|---|---|---|
| 5 | 0,1 | 0,1 | 0 |
| 10 | 0,6 | 0,2 | 0,1 |
| 15 | 1,2 | 0,5 | 0,2 |
| 20 | 2,2 | 0,9 | 0,4 |
| 25 | 3,5 | 1,4 | 0,6 |
| 30 | 5 | 2,1 | 0,8 |
| 35 | 6,8 | 2,8 | 1,1 |
| 40 | 8,9 | 3,6 | 1,5 |
| 45 | 11,2 | 4,6 | 1,9 |
| 50 | 13,9 | 5,7 | 2,3 |
| 55 | 16,8 | 6,9 | 2,8 |
| 60 | 20 | 8,2 | 3,4 |
| 65 | 23,4 | 9,6 | 4 |
| 70 | 27,2 | 11,2 | 4,6 |
| 75 | 31,2 | 12,8 | 5,3 |
| 80 | 35,5 | 14,6 | 6 |
| 85 | 40 | 16,5 | 6,8 |
| 90 | 44,9 | 18,5 | 7,6 |
| 95 | 50 | 20,6 | 8,5 |
| 100 | 55,4 | 22,8 | 9,4 |

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# Blasting Management

## Flyrock

- Lundborg (Svedefo)

$$L_{max} = 260 \cdot \left( \frac{d}{25} \right)^{2/3}$$

| Charge diameter (mm) | max Throw distance (m) |
|---|---|
| 25 | 260 |
| 32 | 307 |
| 40 | 356 |
| 45 | 385 |
| 50 | 413 |
| 70 | 517 |
| 76 | 546 |
| 89 | 606 |
| 300 | 1363 |
| 375 | 1581 |

# Blasting Management

## Flyrock

**The cause of fly rock can be divided in to 4 categories:**

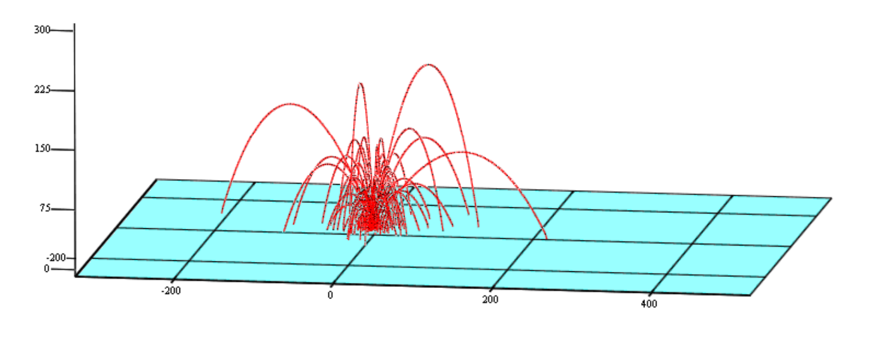
- Cratering
- “Face bursting”
- ”Rifling”
- Secondary blasting

# Blasting Management

## Flyrock

### Cratering

- The stemming column of a blast pattern usually lies in a weakened layer due to subgrade damage from previous blasts. In this region, blast gases can propagate through cracks to the horizontal free surface and cause cratering and associated flyrock. Similar effects can occur if the vertical burden is insufficient. Fly rock can in this case fly in almost any direction

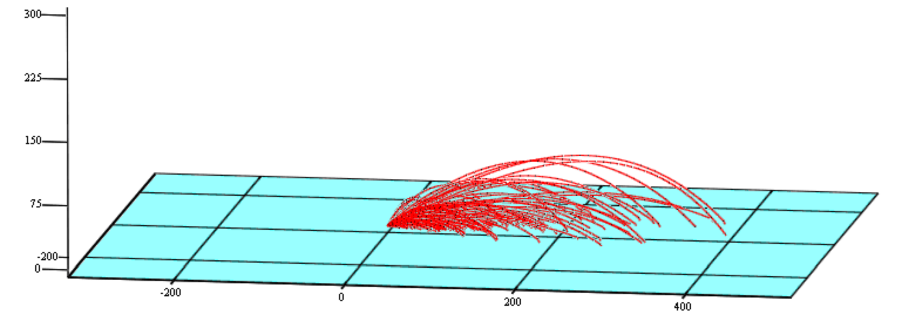


# Blasting Management

## Flyrock

**“Face bursting”**

- This occurs when explosive charges intersect or are in close proximity to major geological structures or zones of weakness in the face region. The high pressure can then readily vent to atmosphere and also impart high velocities to fragmented portions of the face. Face bursting can also occur when the front row has insufficient burden or drilling deviations from design. Fly rock does in this case mainly fly in a horizontal direction in front of the bench face and in an approx 120° sector in the direction of the blast (forward) .

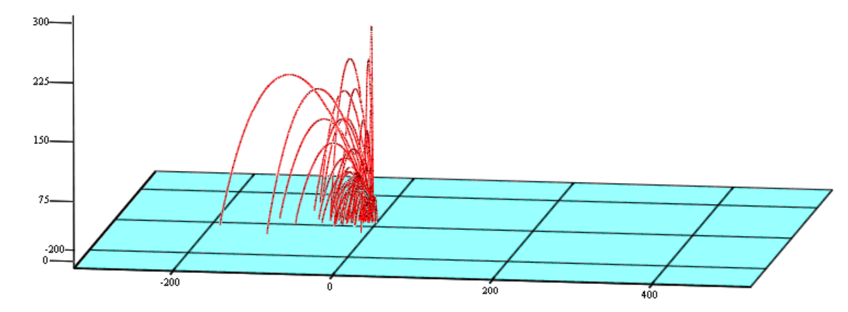


# Blasting Management

## Flyrock

**”Rifling”**

- This occurs when stemming material is inefficient or insufficient. Blast gases can vent up along the blast hole to launch stemming material and/or fragments from the collar region. The direction of fly rock does in this case coincide with the direction of the bore hole

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# Blasting Management

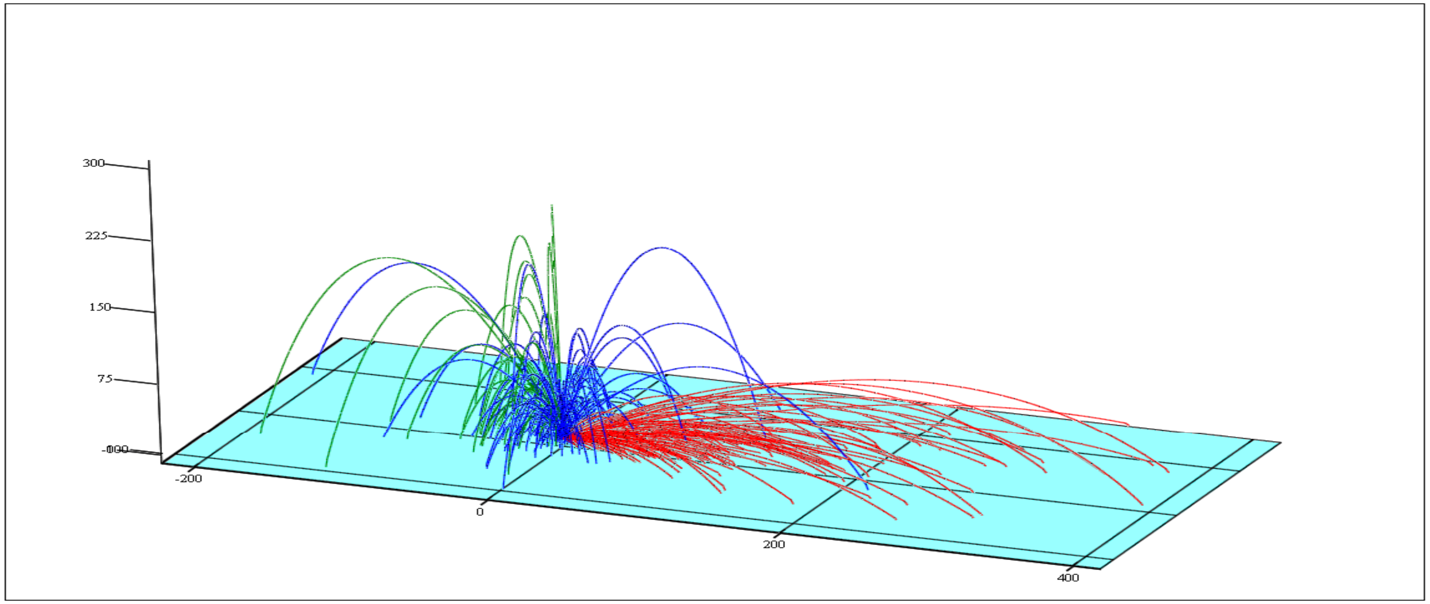
## Flyrock

### Secondary blasting

- Secondary blasting can include toe blasts and blasts used to break boulders. Although secondary blasting employs relatively small charges, all charges are relatively close to many free faces and so have the potential to launch high velocity fly rock due to these small burdens. This type of fly rock is less predictable than the fly rock caused by primary blasting. It might be a good idea to place the boulder in a place where the risk of dangerous fly rock is minimized; another solution is to cover the boulders with heavy rubber mats before blasting.

# Blasting Management

## Flyrock




faceburst, cratering, rifle

# Blasting Management

## Flyrock

| Charge diameter | | Theoretical maximum fly length | "Normal fly length" | Safety distance | "Normal fly length" | Safety distance |
|---|---|---|---|---|---|---|
| inch | mm | SveDeFo | In front (m) | In front(m) | Back (m) | Back (m) |
| 2 | 51 | 420 | 85-150 | 300 | 45-85 | 170 |
| 3 | 76 | 540 | 110-190 | 380 | 55-110 | 220 |
| 3 $^{1}/_{2}$ | 89 | 600 | 120-210 | 420 | 60-120 | 240 |
| 4 | 102 | 660 | 130-220 | 440 | 70-130 | 260 |
| 6 | 152 | 870 | 170-290 | 580 | 90-170 | 340 |

# Blasting Management

## Flyrock – How to reduce fly rock

- Reduce charge concentration
- Increase stemming/ burden (stemming length should be larger than burden in fly rock backwards should be minimised)
- Cover (rubber mats/ sand)

The condition for fly lengths described here, is that the blasting is totally controlled concerning stemming, ignition plan, cleanup of bench, bore hole precision, charging of first row etc. The thoroughness of these precautions defines the risk of fly distances longer than “normal”.

In order to keep control: Scan rock face, measure hole deviation (law in many countries), good quality stemming material. Not to many rows in the round (≤4),

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