Energiforsk Concrete Research Program Nuclear

Seminar: Instrumentation and Monitoring of Concrete Structures in Nuclear Power Plants

March 15, 2016
Vattenfall, SOLNA

Surveillance of concrete structures in cooling water ways

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LUNDS UNIVERSITET
Lunds Tekniska Högskola

This presentation is based on these ELFORSK/ENERGIFORSK reports:

Utvärdering av oförstörande prov-ningsmetoder med möjliga tillämp-ningar inom kärnkrafttekniska be-tongkonstruktioner

Elforsk rapport: 08:24

Litteraturstudier och test av oförstörande provningsmetoder (OFP) med möjliga tillämpningar på kärnkraftens betongkonstruktioner

Elforsk rapport 10:85

Impulsresponsmätningars be-roende av sprickdjup

Delaminering

Elforsk rapport 11:11

Instrumenterad bomknackning

Test av mätmetod och verifiering i verkliga skade-fall i Ringhals

Elforsk rapport 12:09

PROJEKTORSTYRD AVSÖKNING OCH DOKUMENTATION

RAPPORT 2015:162

The reports are retrievable at [www.energiforsk.se] and [www.elforsk.se]

Author: Peter Ulriksen

Utvärdering av oförstörande prov-ningsmetoder med möjliga tillämp-ningar inom kärnkrafttekniska be-tongkonstruktioner

Elforsk rapport: 08:24

Assessment (NDT) versus Monitoring (SHM)

State of the art study of 20 previous NPP NDT reports

A study in Finland revealed 100% strength variation in concrete cores from a Nuclear Power Plant

$$v = \sqrt{\frac{E}{\rho}}$$

<u>Assessment, used methods:</u>

-Radar (geometry of the construction)
-Standing waves (geometry)
-X-ray (geometry, cavities, ten-dons)
-Surface waves (geometry, strength),
-Shear wave reflection (geometry, cavities),
-Covermeters, Refraction seismics (strength),
-Galvanic methods (corrosion)
-Frequency response (delamination)

Only methods based on the propagation of *mechanical waves* are related to the strength of concrete and should be <u>developed further</u>:

-Shear wave reflection (geometry, cavities) ACSYS A1220
-Contact less surface wave measurements (strength)
-Nonlinearity detector (fissures)
-Impedance measurements (delamination)
-Use of tendons as wave guides.

For monitoring it is recommended to study Acoustic Emission, Seismic networks and Modal analysis.

METOD / RAPPORT	**1**	2	3	4	5	6	7	**8**	9	**10**	11	12	13	14	15	**16**	17	18	19	20	Σx
Ultraljudtransmission	x				x			x													3x
Ultraljudreflektion	x			x														x			3x
Stående vågor	**x**							x	x	x			**x**	**x**							6x
Ytvågseismik	**x**			x				**x**		**x**	x		**x**	**x**							7x
Akustisk emission	x									**x**	x										3x
Termografi	x																				1x
GPR Radar	x		x	x		x	x	**x**		x	x		x								9x
Skanner (ex vis radar)	**x**									**x**							x			x	4x
Resistivitet	x																				1x
Högenergiröntgen	**x**			x		x	x	x	x	x	x		x								9x
Skjuvvågreflektion		**x**					x	**x**	**x**				x								5x
Borrhålsvideo			**x**																		1x
Caliperlogging			**x**																		1x
Kärnborr					x																1x
Galvanostatik								x													1x
Ultraljudövertoner										x											1x
Optiska metoder										**x**									x	x	3x
Relativ fukthalt											x										1x
Täckskiktmätning													x								1x
Magnetometri																		x			1x
Elektrisk potential																		x			1x
TDR																			x		1x
GPS																			x	x	2x
Inbygda sensorer																				x	1x
Impulsresponsspektrum																		x			1x

Litteraturstudier och test av oförstörande provningsmetoder (OFP) med möjliga tillämpningar på kärnkraftens betongkonstruktioner

Elforsk rapport 10:85

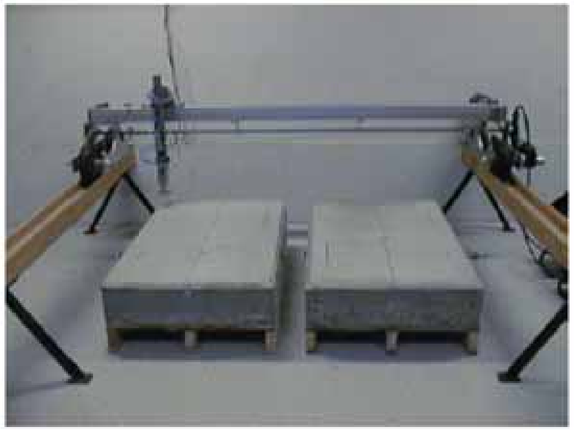
Litterature study and test of methods with possible applications to concrete structures in nuclear power plants

Methods suitable for locating delamination in cooling water ways

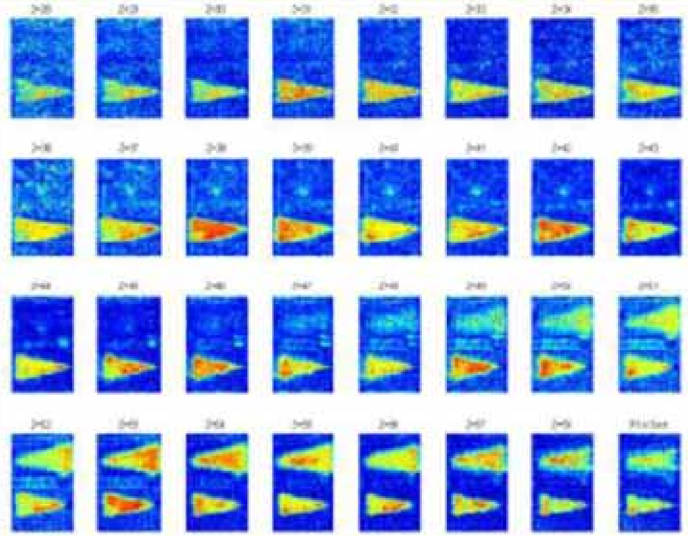
and

A closer study of the russian built ultrasonic instrument ACSYS A1220 which launches three novelties:
-Dry coupling between transducer and concrete
-Shear waves but also compression waves
-Transmitter and receiver part assembled by 12 elements each

Conclusions best options in water ways:
-Profiling with the ACSYS A1220 in dry conditions
-Profiling with parametric sonar in water
-Vibration measurements with water-jet (dry)
-Impedance measurements (dry)

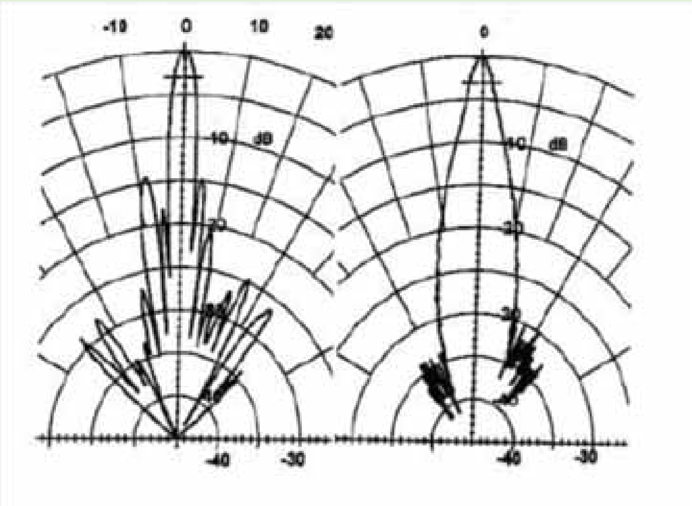


Delyta	Djup(mm)	Ppar	Port	Spar	Sort
P1s1	(40,160)	100411	100416	100407	*100410*
P1s2	(180,60)	091215	*091121*	091215	091205
P2s1	(100,140)	100412	100413	100408	*100409*
P2s2	(120,80)	091216	091207	091212	*091206*

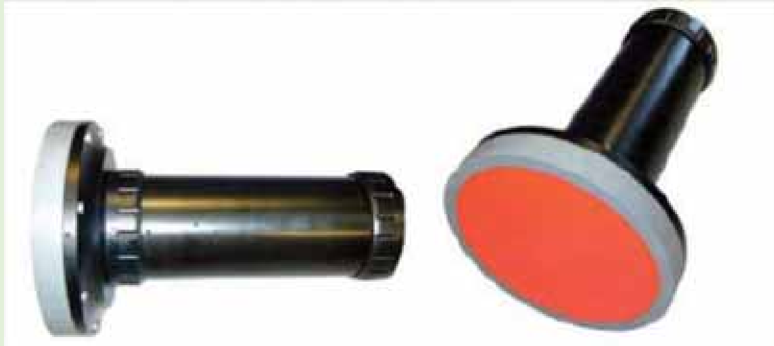


ACSYS A1220

Parametric sonar: Low frequency beam with a high frequency sonar



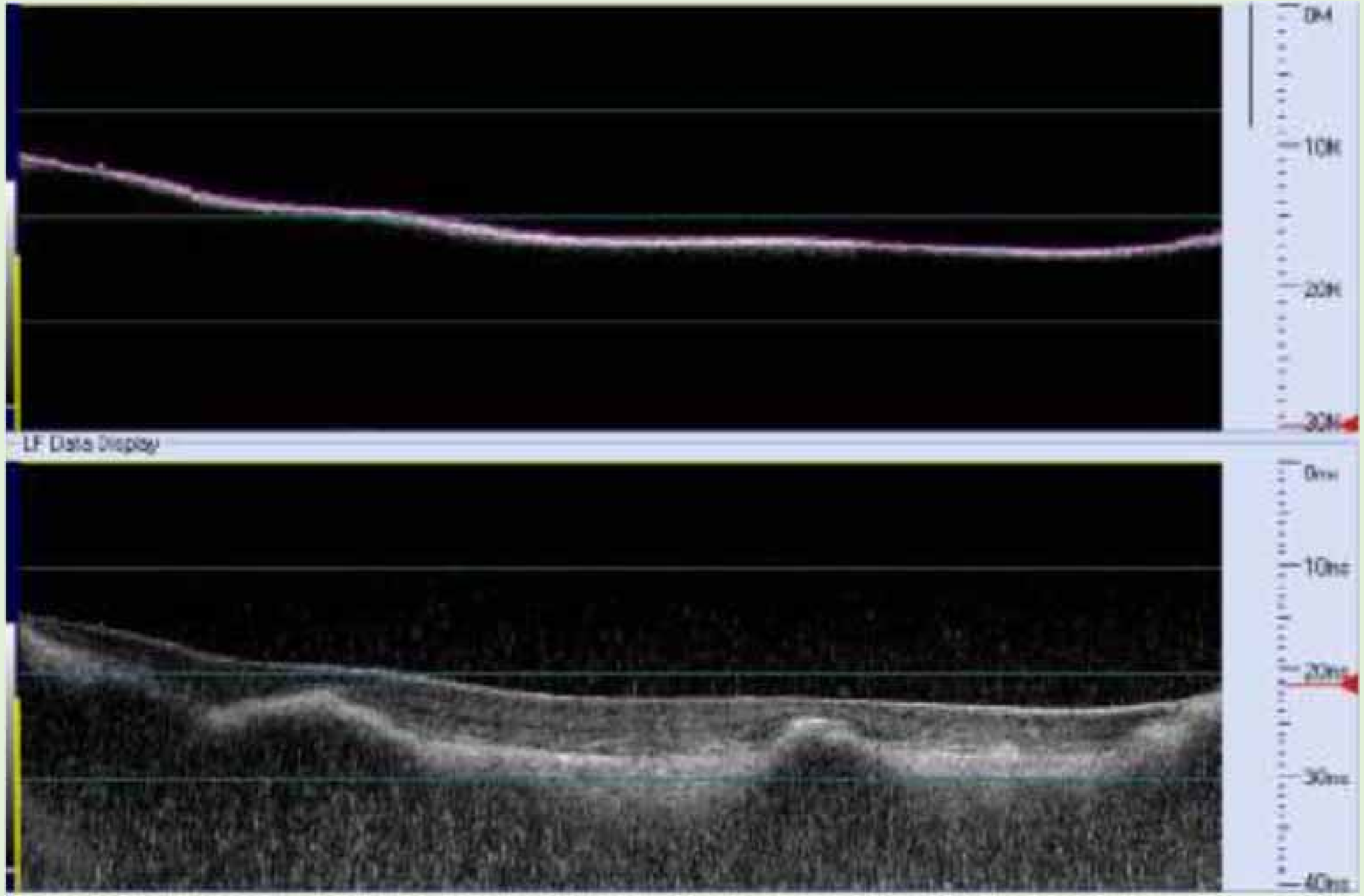
120 kHz / 10 kHz



Sea-King parametric sonar (300 x 200 mm)
Mounted on an ROV

200 kHz primary data

10-30 kHz secondary data



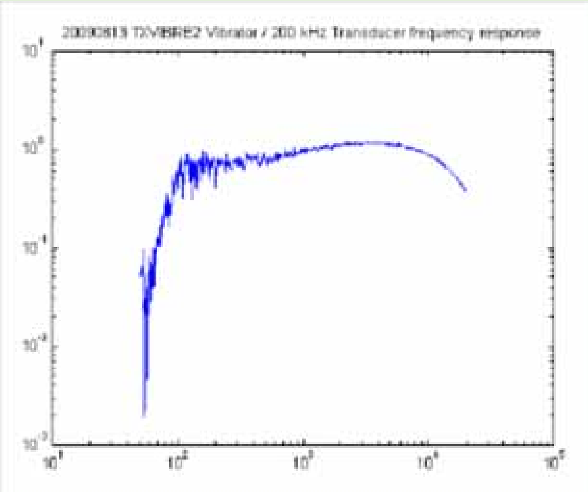
Water Jet

Nozzle

Inlet

Hydrophone

Hydrophone response curve



Water Jet

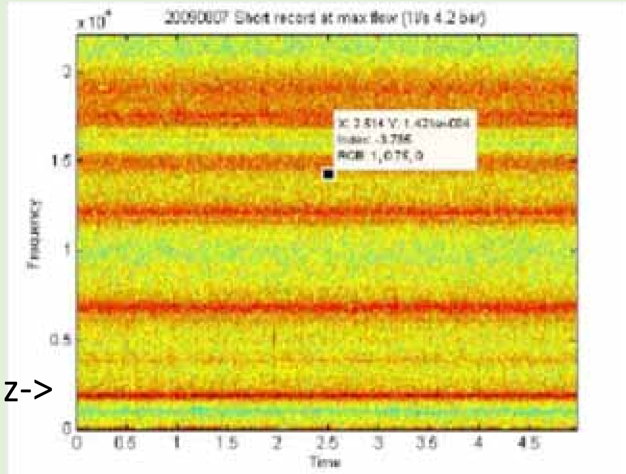
Test samples of concrete

Fundamental mode 1809 Hz

Test rig

Generated and recorded frequencies

1809 Hz->



Range 0 Hz – 22 kHz

Impulsresponsmätningars beroende av sprickdjup

Delaminering

Elforsk rapport 11:11

$$Z(f) = \frac{F(f)}{v(f)}$$

$a = j\omega v = -\omega^2 d$

$v = j\omega d = (1/j\omega)a$

$d = (1/j\omega)v = (1/-\omega^2)a$

där $\omega = 2\pi f$

Impulse response measurements´ dependence on horisontal crack depth
Delamination

The impulse response method is of particular interest, since some of it's realizations strongly resembles established methods like bowsing "bomknackning" or chain dragging. Thus there is a confidence in the method.

-Vibrator with impedance head [F/a] (80-100 mm) generates clear resonance peak

-Instrumented hammer [F] + accelerometer and microphone (120 mm)

-Hammer + handheld impedance head [F/a and F/v]

-Impact accelerometer (future test, not yet performed)

Theory

Det är intressant att jämföra uttrycken för den första membranresonansen enligt (4)

$$f_0 = 0.47 \cdot \sqrt{\frac{E}{\rho \cdot (1-\upsilon^2)}} \cdot \frac{h}{d^2} \qquad \text{Ekv 19}$$

E = Elasticitetsmodulen N/m^2

ρ = Densiteten kg/m^3
ν = Tvärkontraktionstalet (-)
h = Delamineringens tjocklek (m)
d = Delaminerade ytans diameter (m)

och uttrycket för IE-metodens fundamentala resonans (13)

$$f_0 = \frac{\beta \cdot C_p}{2 \cdot h} \qquad \text{Ekv 20}$$

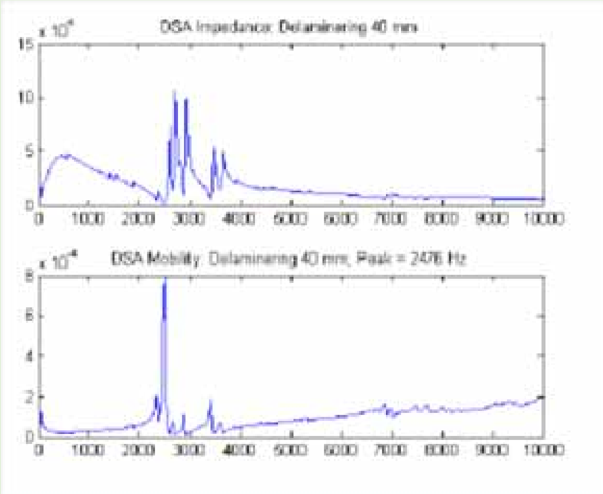
där

β = konstant som för en plattliknande struktur är 0.96. Hade IE mätt en stående våg skulle faktorn β ha varit 1, men randvillkoren komplicerar sambandet.
C_p = kompressionsvåghastigheten i materialet
h = det delaminerade skiktets tjocklek

The IE frequency is hard to measure because of the high frequency

Vibrator + impedance head

Vibrator on impedance head

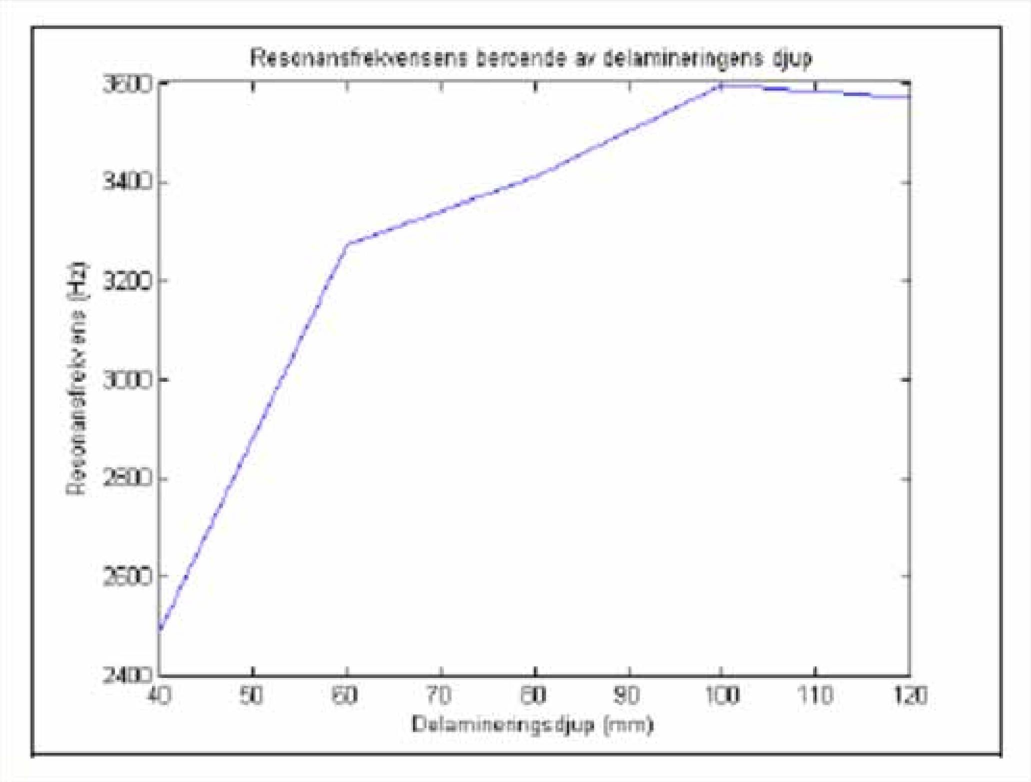


Impedance (F/v)

Mobility (v/F)

Resonance at 2476 Hz for a delamination at 40 mm depth

Vibrator + impedance head



Resonance peak as a function of delamination depth

Instrumented hammer (F) + accelerometer and microphone

Hammers

Liten Mellan Stor

Accelerometer

Force

Hammartyp:	Liten	Liten	Mellan	Mellan	Stor	Stor
Objekt	Acc	Mik	Acc	Mik	Acc	Mik
D040mm	2539	2539	2539	2539	-	-
D060mm	3320	3223	-	3223	-	-
D080mm	3418	3418	-	-	-	-
D100mm	3711	3711	-	3711	-	-
D120mm	3613	3613	-	3125	-	-
D140mm	-	-	-	-	-	-
D160mm	-	-	-	(3223)	-	-
D180mm	-	-	-	-	-	-

Hammer + handheld impedance head [F/v]

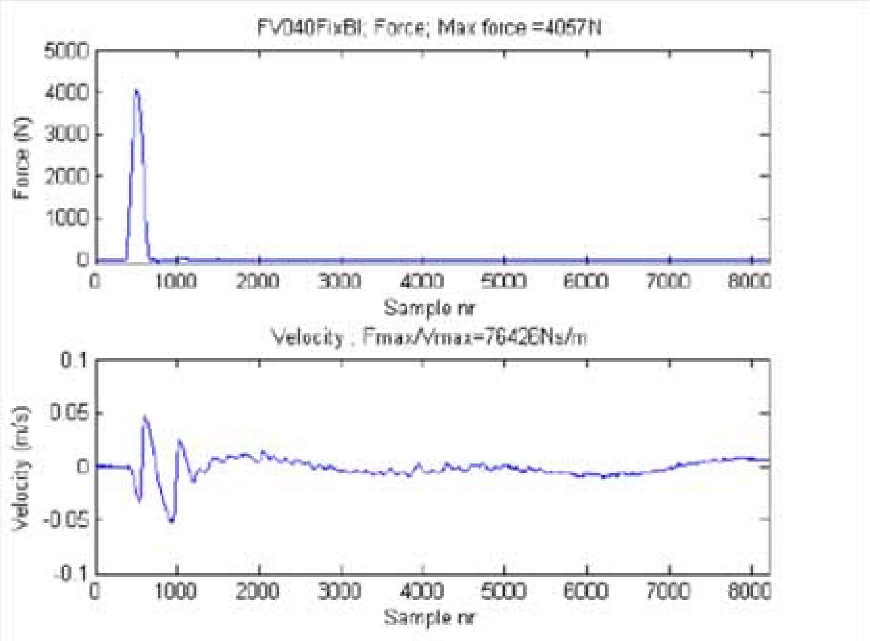
(No need for a cable to the hammer)

Force transducer and
velocity transducer (geophone)

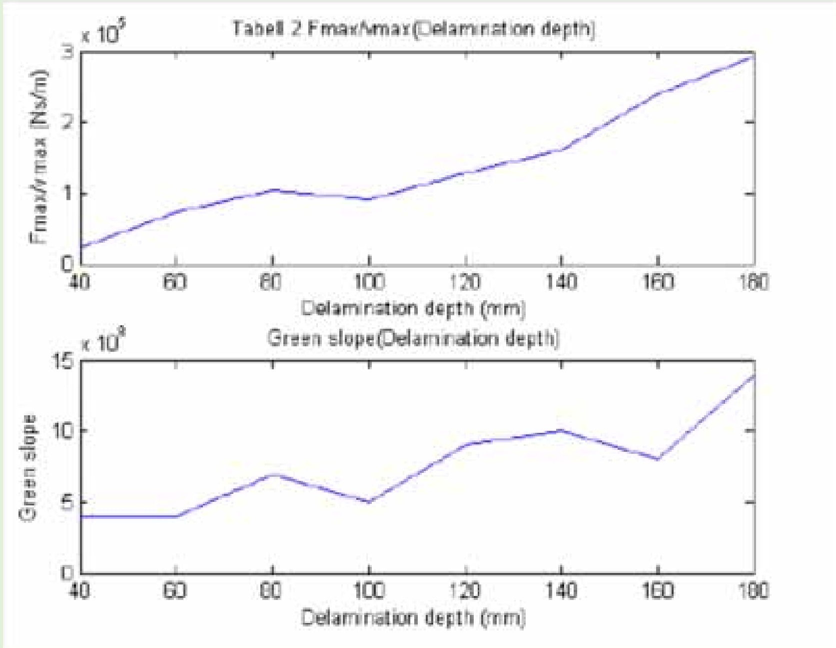
Central spring loaded geophone
Force transmitted through tube

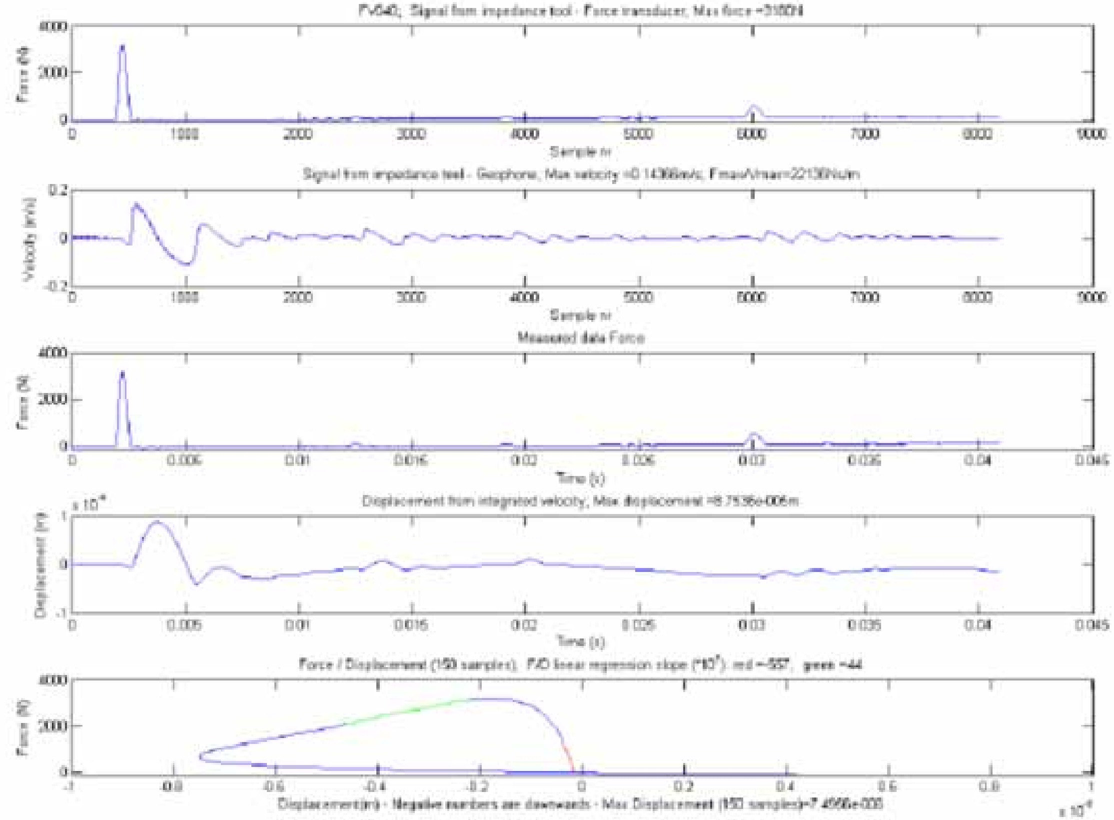
Djup	F_{max}/v_{max}	Red slope	Green slope
40	22136	-6*10^9	4*10^8
60	73597	-4	4
80	104700	-5	7
100	91505	-5	5
120	127632	-7	9
140	160822	-6	10
160	239051	-6	8
180	292118	-6	14

Impedance vs delamination depth



Measured parameters F, v




Measured data Force
Sample nr
Time (s)
Force (N)

Impact accelerometer (future test, not yet performed)

Electromechanic pneumatic valve

High speed pneumatic cylinder

Accelerometer support

As the accelerometer hits the surface the impact will generate an oscillation.

By pressing the accelerometer towards the concrete after the impact the frequency of the oscillation can be measured

Instrumenterad bomknackning

Test av mätmetod och verifiering i verkliga skade-fall i Ringhals

Elforsk rapport 12:09

Application of the previously tested methods to a real situation in the Ringhals NPP

Instrumented bowsing. Tests in Ringhals.

1 The earlier developed impedance handle containing a force and a velocity sensor is hit by a so called “dead-blow” hammer of type “Thorace”

2 Same handle as in test 1 but with the addition of a microphone which was located with the data acquisition equipment, about 1.5 m from the concrete wall.

3 A large modally tuned hammer from PCB equipped with a force sensor and with a microphone located as in test 2.

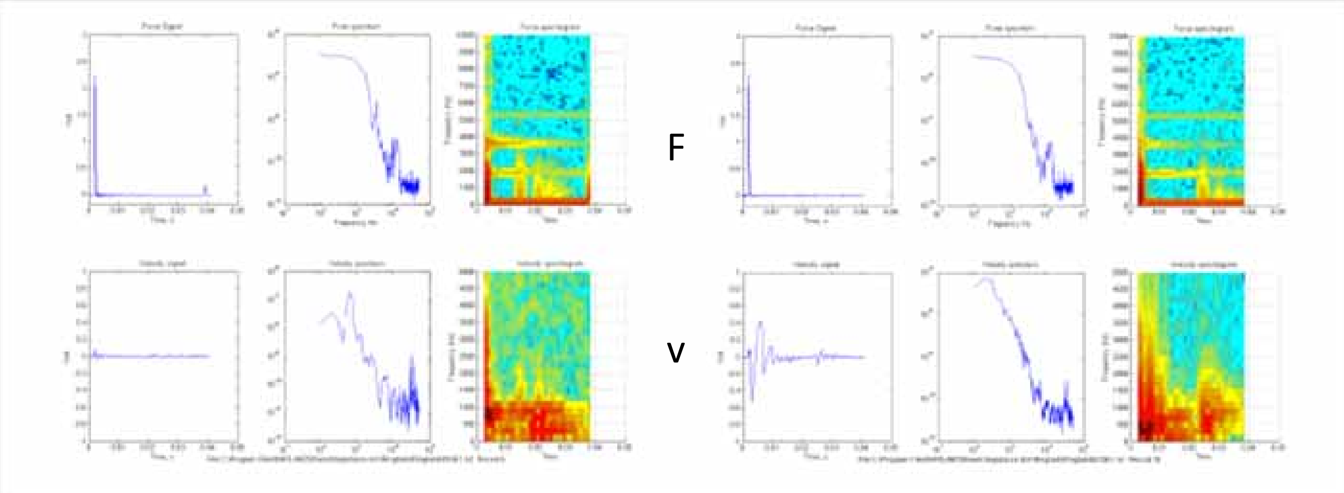
4 A common carpenters hammer without any sensors and with the microphone as in test 2. This setup requires no cables between the operator and the acquisition equipment.

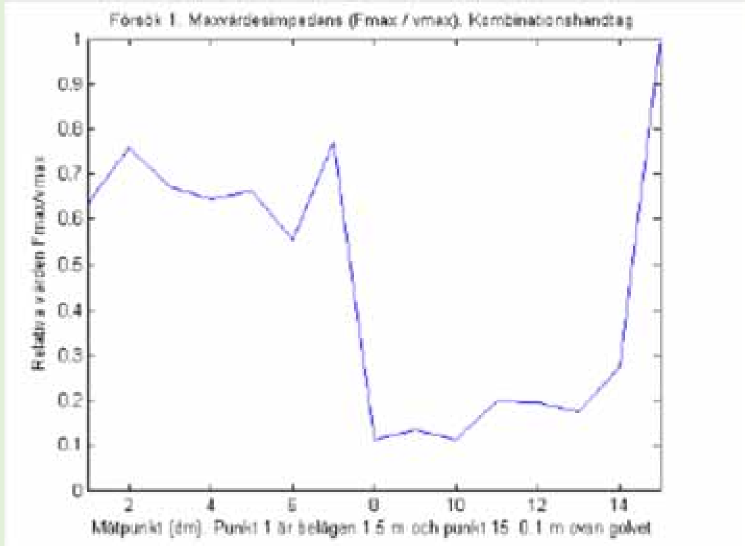
Test situation in Ringhals

1 The earlier developed impedance handle containing a force and a velocity sensor is hit by a so called “dead-blow” hammer of type “Thorace”

The max-value-impedance is in average 0.7 for solid concrete and 0.2 for delaminated concrete. The peak frequency is 700 Hz for solid concrete and 250 Hz for de-laminated concrete.

Amplitude Spectrum Spectrogram Amplitude Spectrum Spectrogram



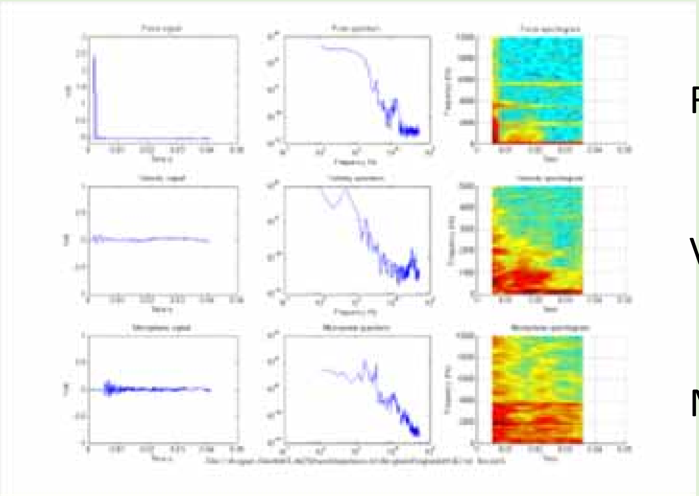


Solid concrete Delaminated concrete Impedance profile Fmax/vmax

2 Same handle as in test 1 but with the addition of a microphone which was located with the data acquisition equipment, about 1.5 m from the concrete wall.

The results regarding force and velocity are the same as in test 1. The sound strength is 0.2 for the solid concrete and increases to 1.0 for the delaminated concrete, but the variance is large within the delaminated part.

Amplitude Spectrum Spectrogram

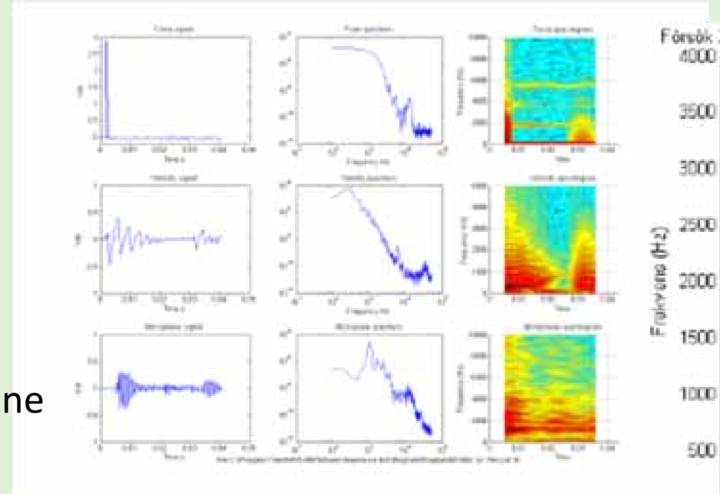


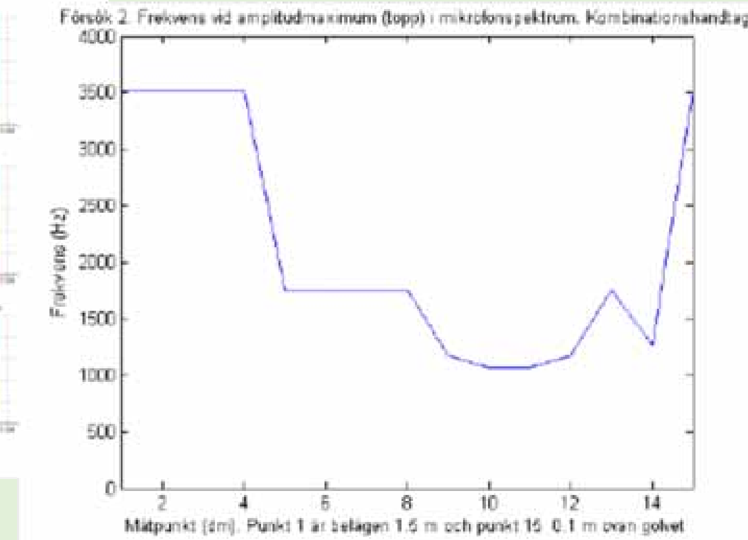
Force

Velocity

Microphone

Amplitude Spectrum Spectrogram





Solid concrete

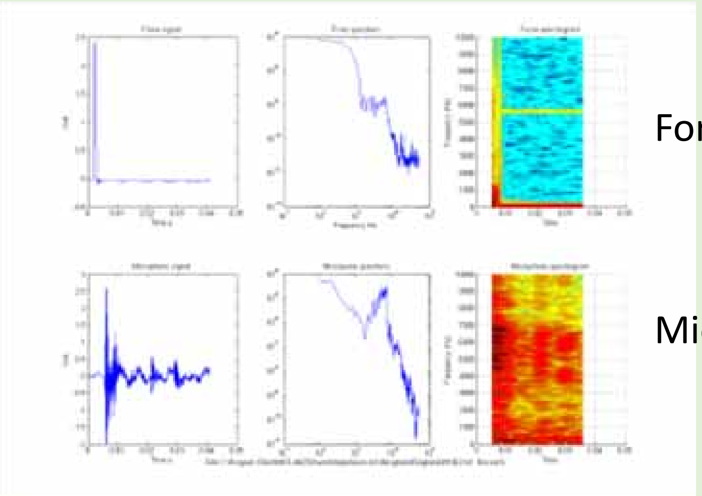
Delaminated concrete

Acoustic spectrum peak profile

3 A large modally tuned hammer from PCB equipped with a force sensor and with a microphone located as in test 2.

Solid concrete generates frequencies around 6000 Hz while delaminated concrete generates frequencies around 1000 Hz.

Amplitude Spectrum Spectrogram

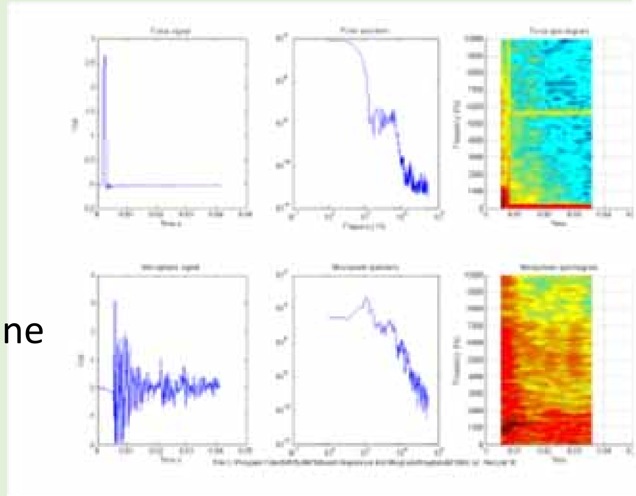


Force

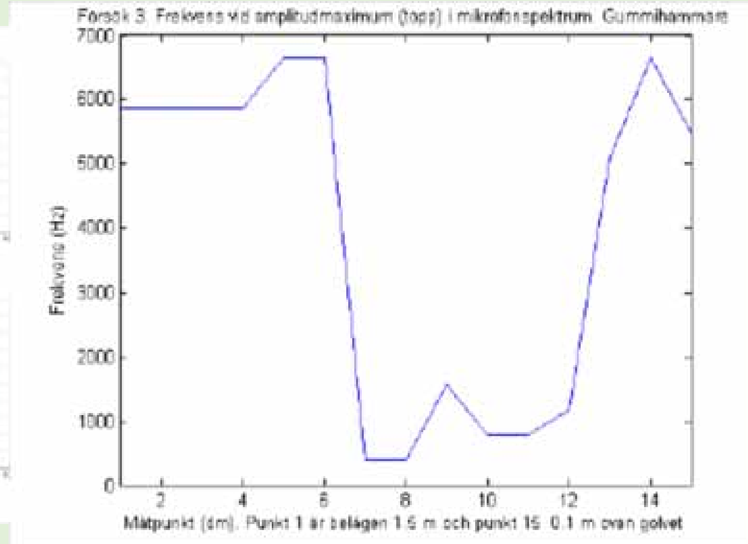
Microphone

Solid concrete

Amplitude Spectrum Spectrogram



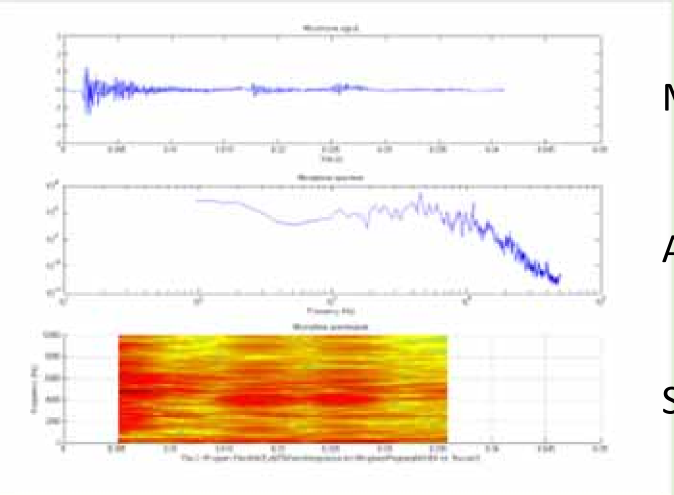
Delaminated concrete



Acoustic spectrum peak profile

4 A common carpenters hammer without any sensors and with the microphone as in test 2. This setup requires no cables between the operator and the acquisition equipment

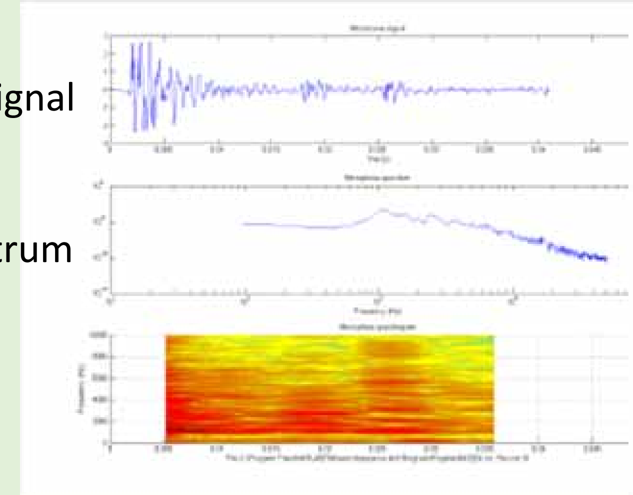
The sound strength for solid concrete is around 0.35 and for delaminated concrete it is 0.9 in average. The border between solid and delaminated concrete is correctly indicated. Regarding the frequency content it is about 4500 Hz for most points in the solid concrete, but the very first ones show a lower value, around 2000 Hz. In the delaminated concrete the frequency amplitude peaks at about 1500 Hz in average.

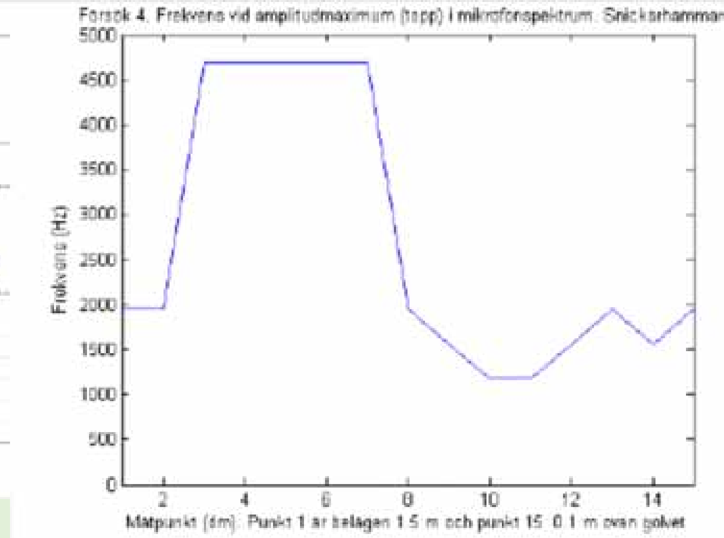


Microphone signal

Acoustic spectrum

Spectrogram





Solid concrete

Delaminated concrete

Acoustic spectrum peak profile

Parameter	Försök 1	Försök 2	Försök 3	Försök 4
Amplitud solid	0.7 (Z_m)	0.2	-	0.35
Amplitud delaminerad	0.2 (Z_m)	1.0	-	0.90
Frekvens solid	700 Hz	2500 Hz	6000 Hz	4800 Hz
Frekvens delaminerad	200 Hz	1500 Hz	1000 Hz	1600 Hz
Amplitudkvot	3.5	5	-	3
Frekvenskvot	3.5	1.7	6	3

Best discrimination is obtained in test 3 with PCB hammer (large) and microphone
Second best is test 2 with Thorace hammer with the impedance handle

PROJEKTORSTYRD AVSÖKNING
OCH DOKUMENTATION

RAPPORT 2015:162

Video projector controlled data acquisition and documentation
A virtual scanner

“When a large area must be surveyed by a method applying some form of sensor to the surface, the preparatory work of establishing a measurement grid can take as long time as the measurements themselves. “

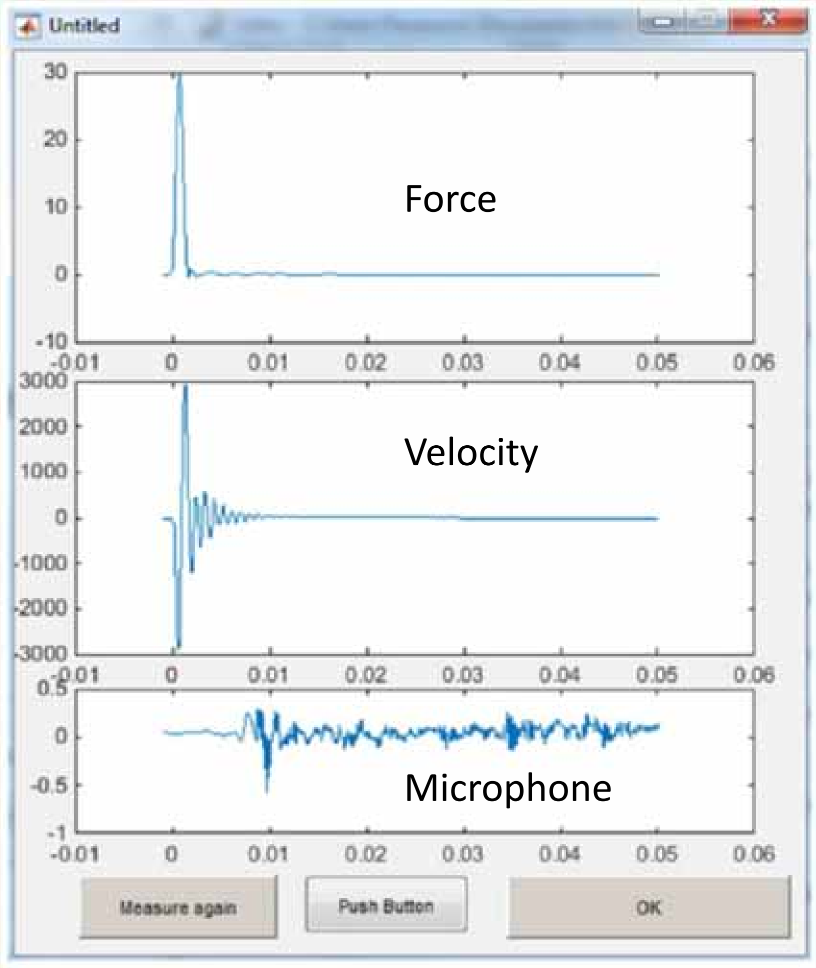
Component search and acquisition (Peter Ulriksen)
Software development (Peter Jonsson)

Computer

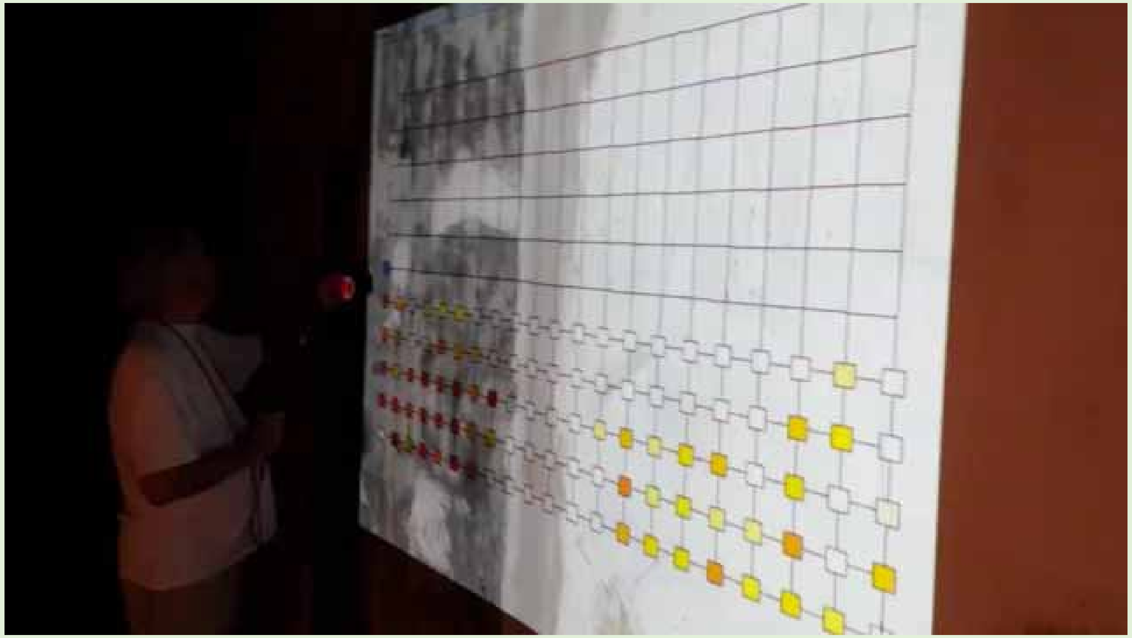
Video projector

Computer operated
Camera with wide-
Angle zoom lens

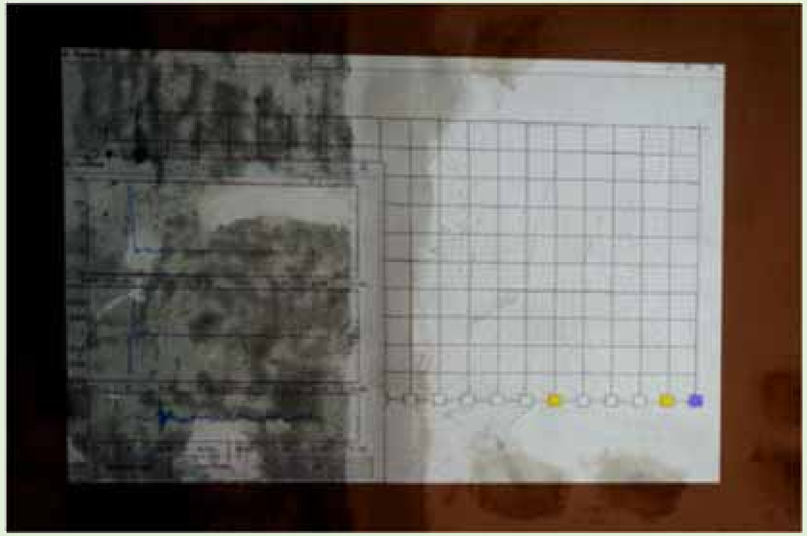
Projected image



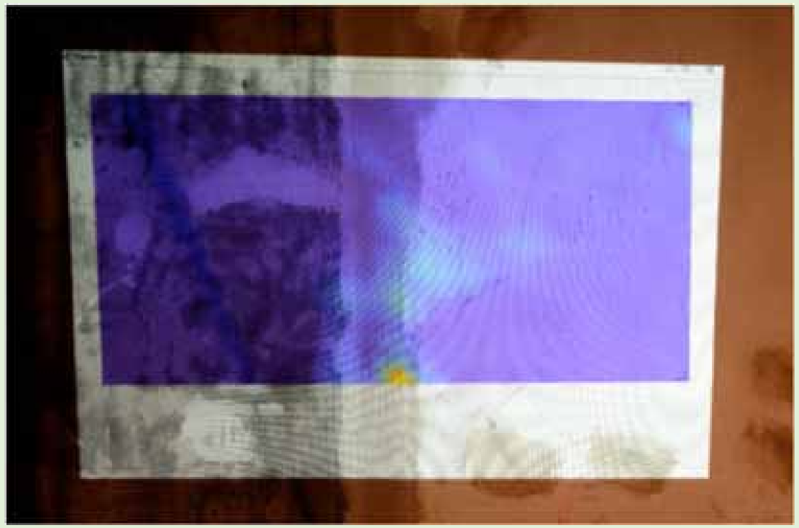
Operator GUI



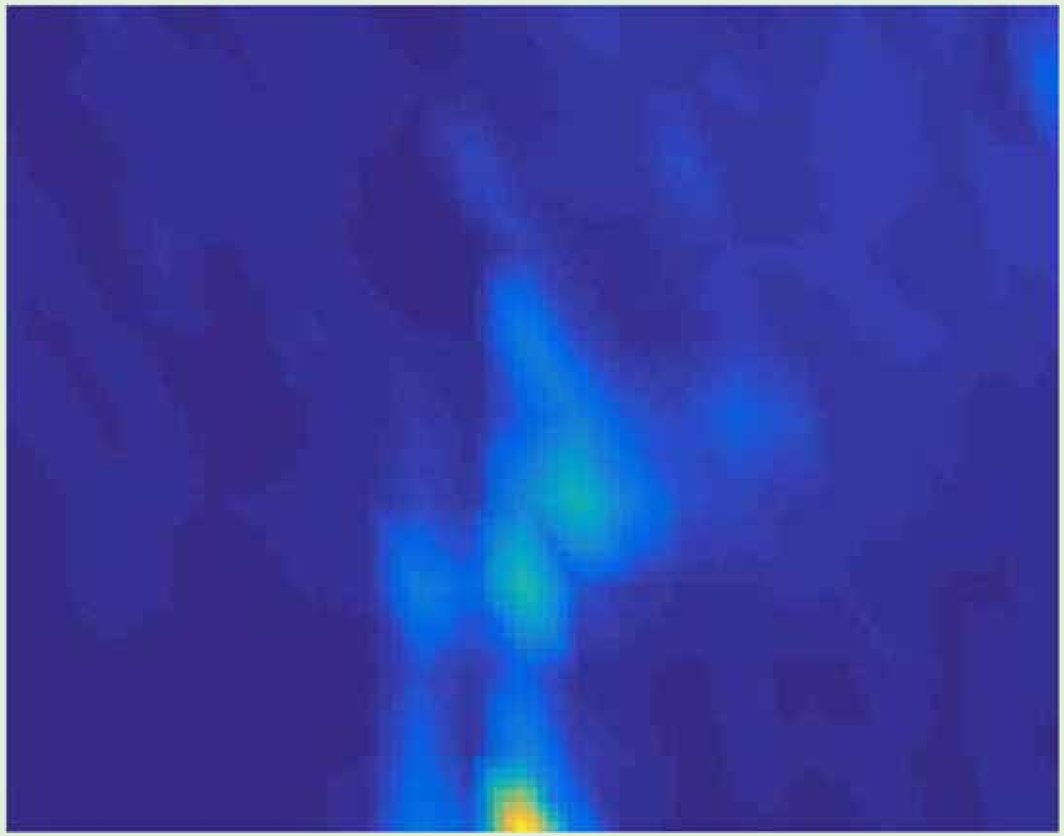
Operating the system. A headset helmet is now added. Since the force is measured, hammer strikes need not be equally strong (video by Patrik Fröjd)



Projected grid with some points indicated

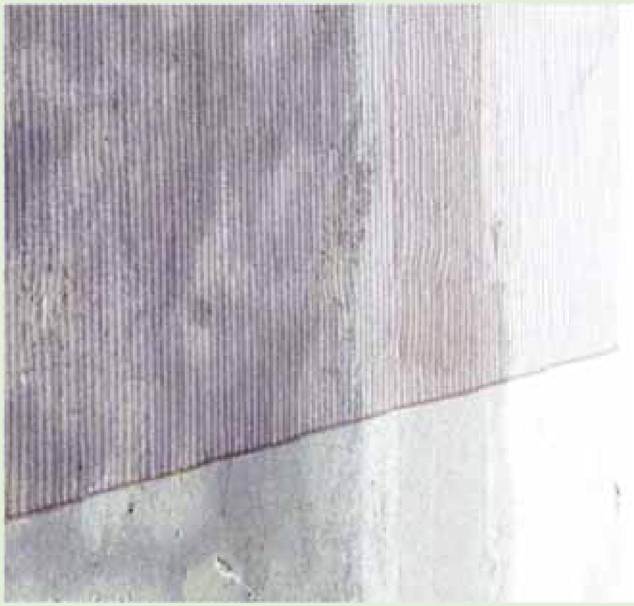


Projected interpolated end-result



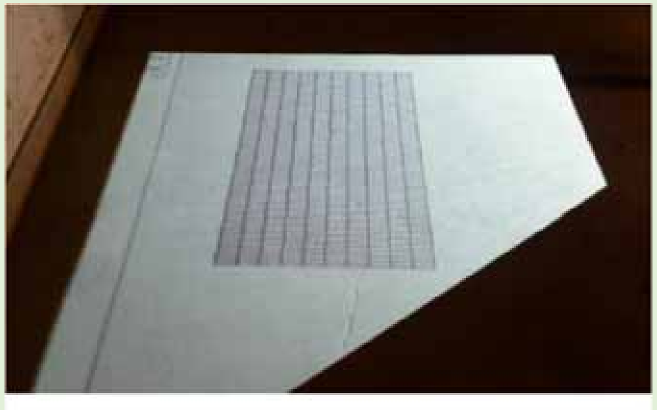
Digital interpolated impedance image can be incorporated into CAD model

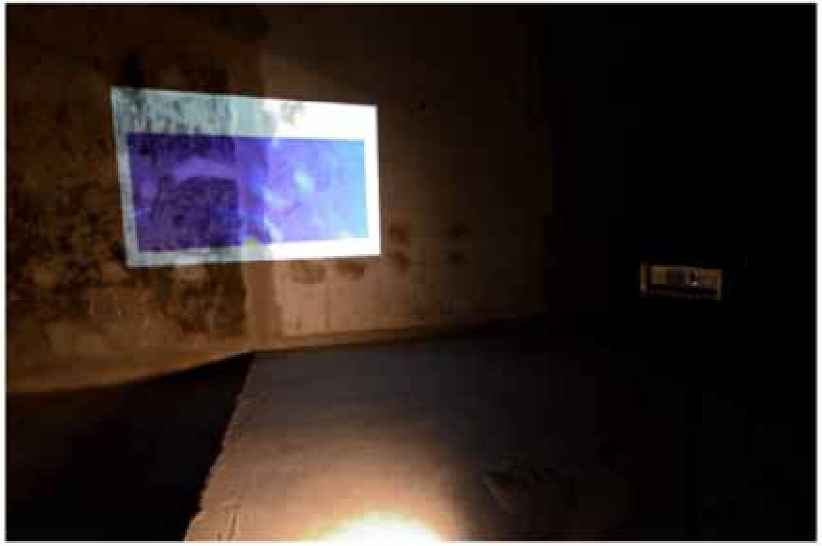
Crack mapping



Line pattern for topographic analysis

Floor grid projection





Same projected results from two positions