Non-destructive Testing in Civil Engineering at BAM

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56° Congresso Brasileiro do Concreto, Natal, 2014

The Team

Campus Steglitz Unter den Eichen 87

Introduction

- **Non-Destructive Testing in Civil Engineering is a growing area**
- **It receives special attention after catastrophic failures (e.g. bridge collapse)**
- **The safety and reliability of the built infrastructure is one important foundation of industrial societies**

Introduction (cont.)

- **Reinforced concrete is the most widely used material for transportation infrastructure**
- **Assessment of existing structures are based on visual inspection**
- **Life time considerations for transportation infrastructure begin to play an important role**
- **Durability is mainly limited by poor quality construction**
- **NDT based quality control during construction is the future of NDT-CE**

Introduction (cont.)

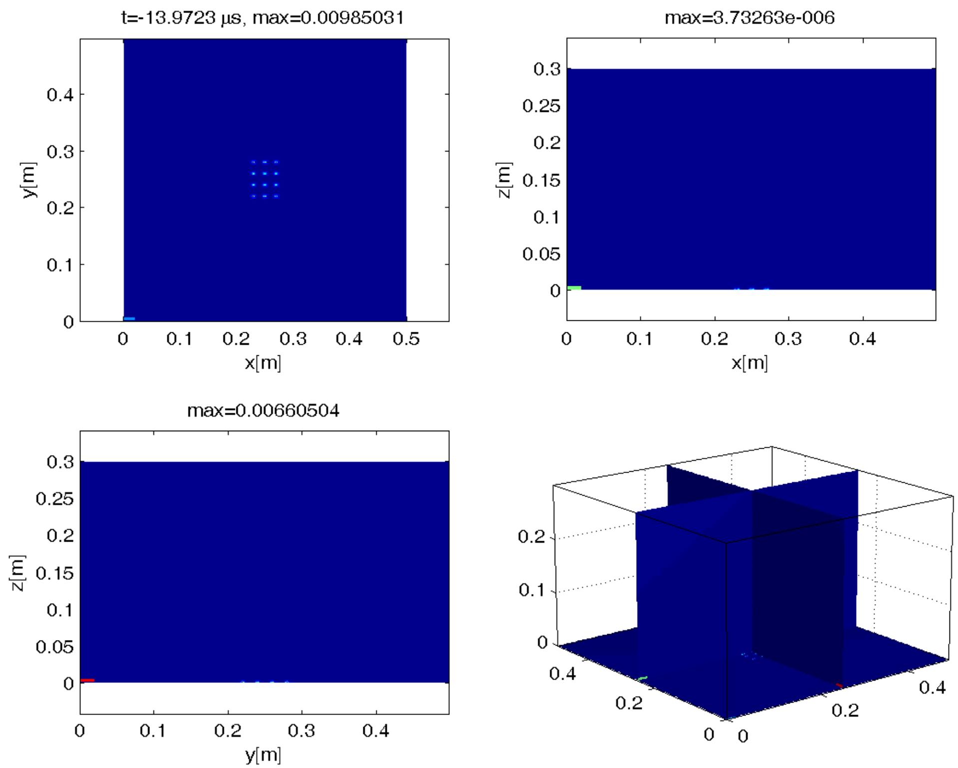
- **Post-tensioned concrete structures form a very large part of transportation infrastructure**
- **There is a worldwide concern about the durability of PT concrete structures with grouting defects**

- **Testing of tendon ducts for grouting defects became a major research effort at BAM**

Modeling of elastic and EM waves in concrete

- **has become a fast and reliable tool**
- **contributed largely to the understanding of experiments and test settings**
- **3D-objects can be simulated**

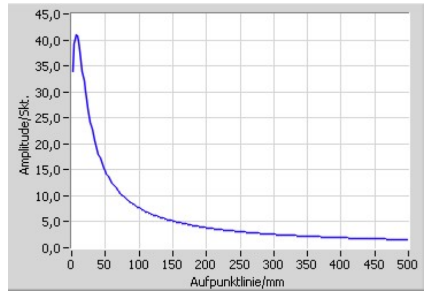
- **See the work of the group of Prof. K-J Langenberg**



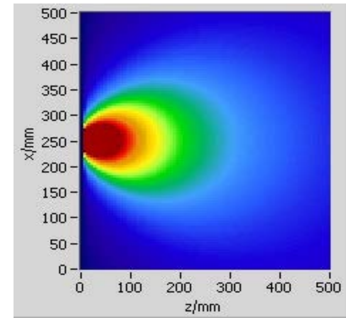
Modelling of Elastic Waves: e.g. Ultrasonic Phased Array

Standard low frequency probe (100 kHz)

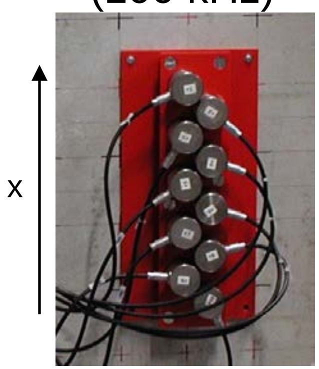
Sound pressure along the acoustic axis



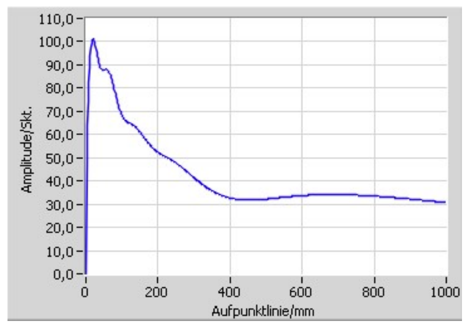
Calculated sound field

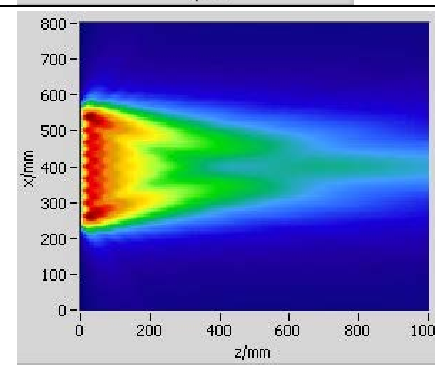


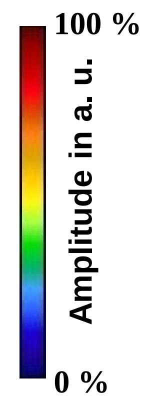
Phased array (100 kHz)



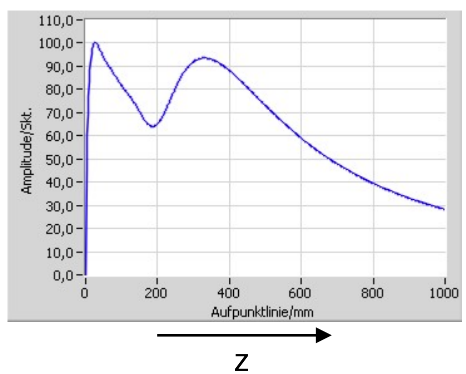
No focusing

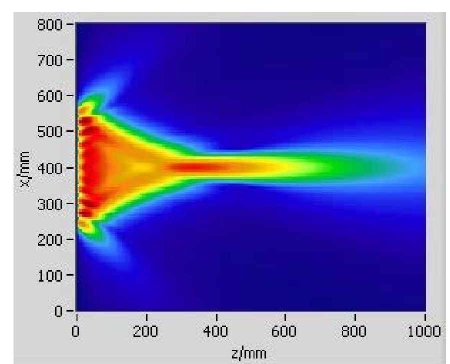






focusing





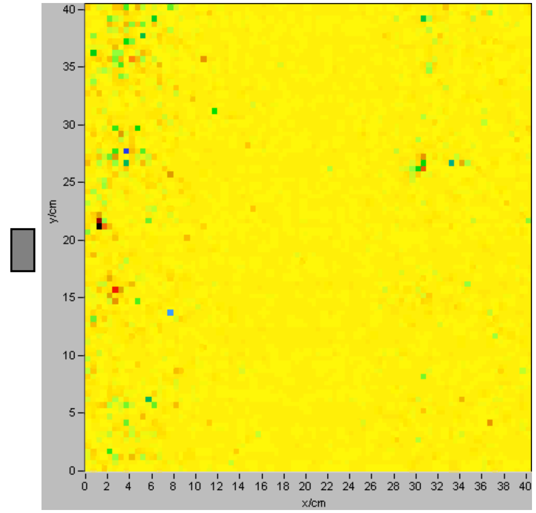
Visualization of the wave propagation

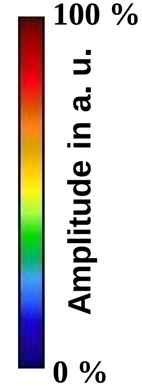
Standard Low frequency probe

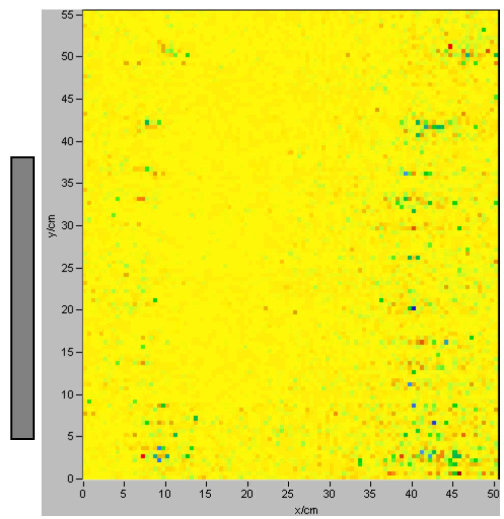
Sound beam control using a phased array

Array

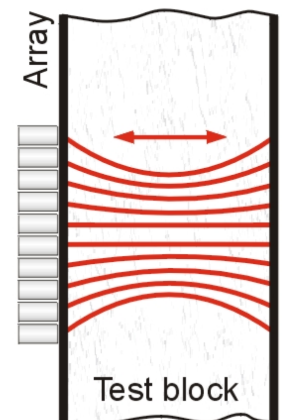
Laservibrometer







z



Reconstruction of 1D- and 2D-scanned data sets

- SAFT (synthetic aperture focussing technique) has become a standard data analysis tool
- 3D reconstruction of large data sets possible in minutes (compare to weeks 10y ago)
- Data evaluation and reconstruction is being done during testing on site

New US Device with Dry Coupling

Hand Held Device A1220

Frequeny Range:	33 kHz - 250 kHz
Max Depth Range:	700 mm (B35)

Min Size of Defect for 500 mm Depth:

Air filled cylinder:	12 mm
Air filled sphere:	55 mm

Accuracy: +/- 10%

Power supply: Battery

Dimensions:

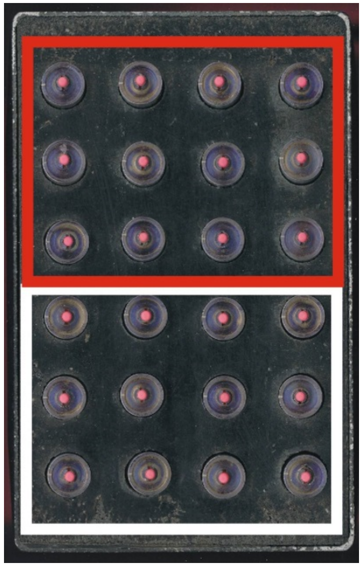
Handheld:	235 x 98 x 33 mm
Sensor:	145 x 90 x 75 mm

Weight:

Handheld	0,8 kg
Sensor:	0,76 kg

Dust and Water Class: Schutzart IP65

Transmission
12 Shear Wave
Transducers



Reveiving
12 Shear Wave
Transducers

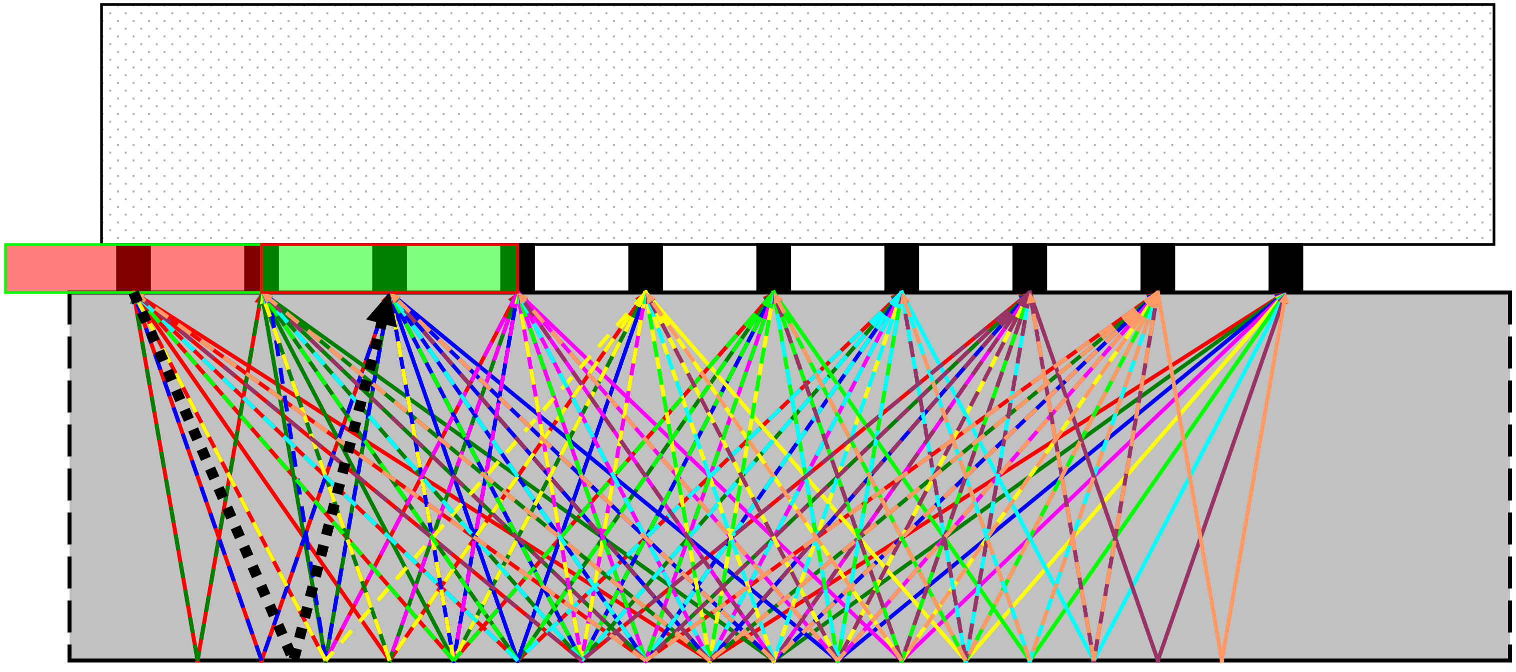
US Linear Array for Concrete (Sampling Phased Array)


Controlling Linear Arrays over TCP/IP


unit with 55 kHz shear wave transducers

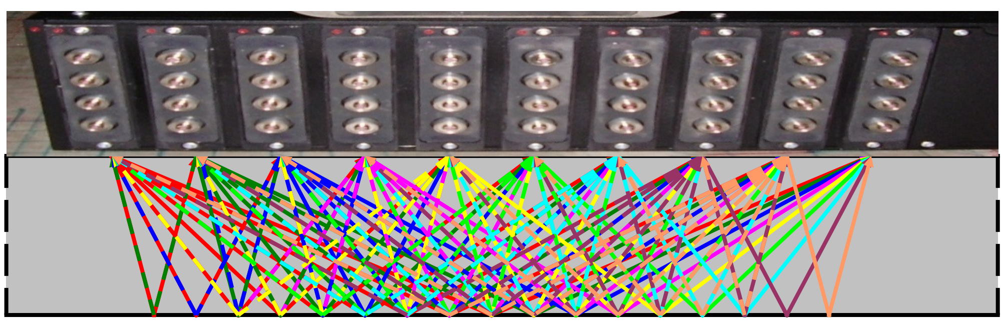

Controller with 10 transducer units

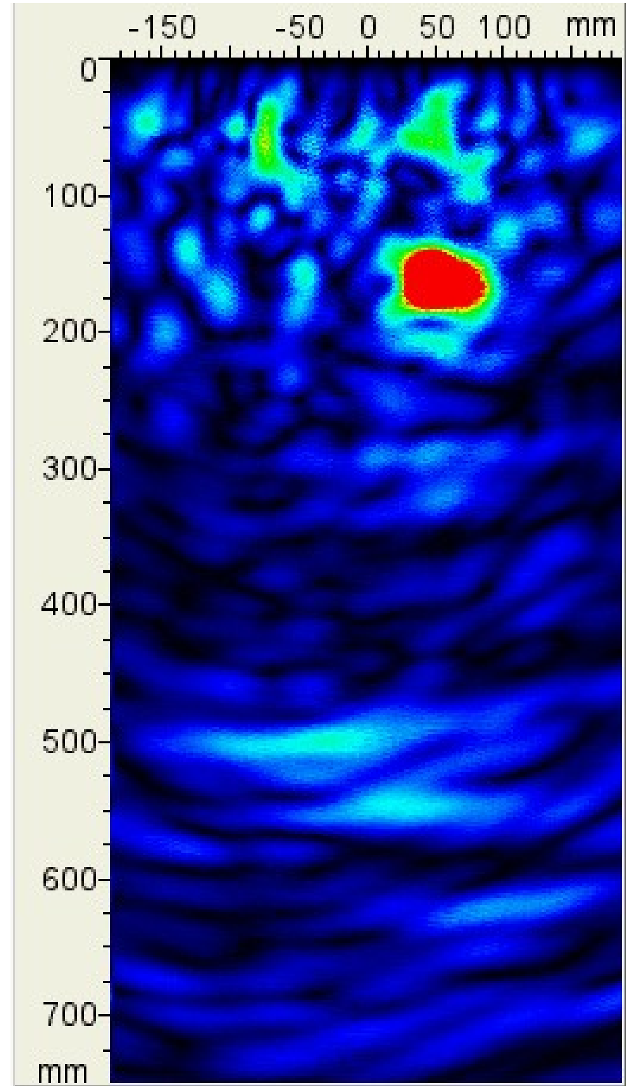
Scan Sequence 10 – duration: 350 ms



Averaging possible. Transfer time of data to control unit: 500 ms
Reconstruction time <3 sec

Ultrasonic Phased Array MIRA



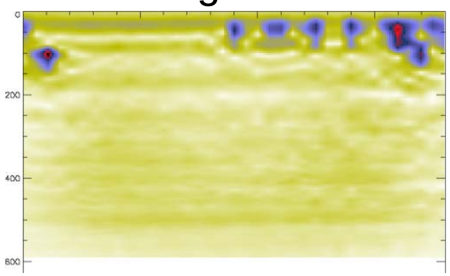


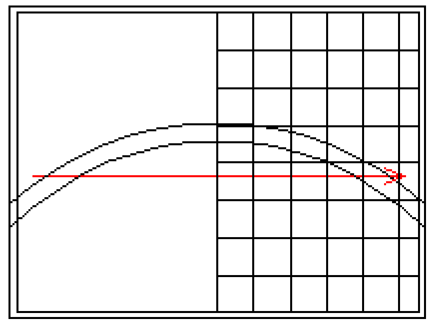
Data Fusion of Radar Measurements

Different radar antenna frequencies

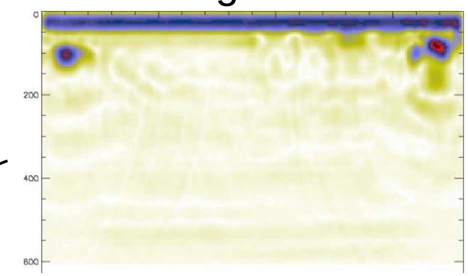
B-Scans measured with both antennas at the test specimen number 2

1,5 GHz antenna in vertical polarisation configuration



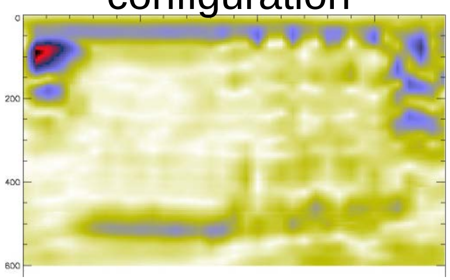


1,5 GHz antenna in horizontal polarisation configuration

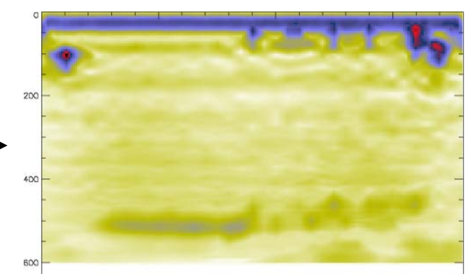


max. amplitudes

900 MHz antenna in vertical polarisation configuration



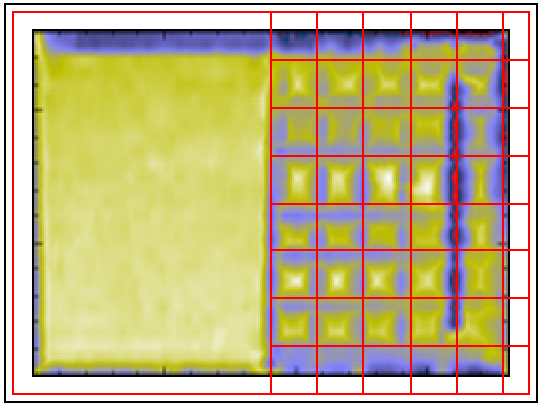
max. amplitudes with differenty weighted data sets



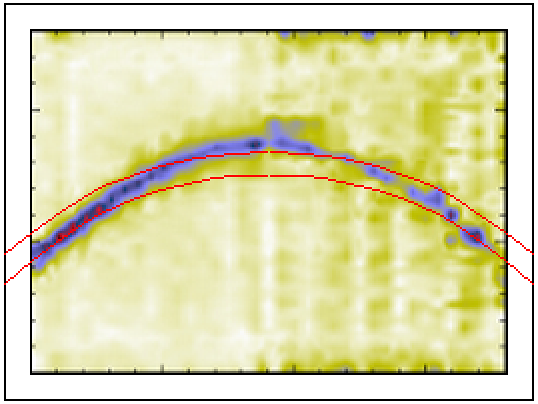
Data Fusion of Radar and Ultrasonic Measurements

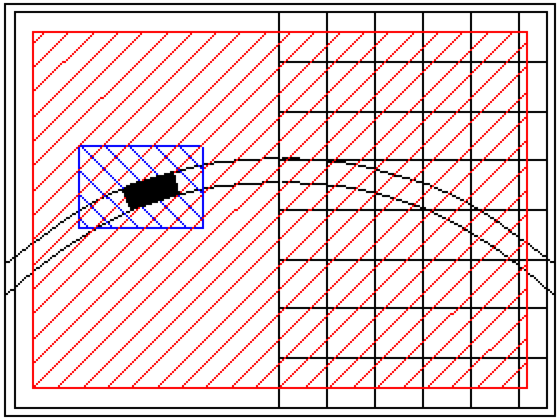
C-Scans in different depths of the test specimen number 2:

5 cm

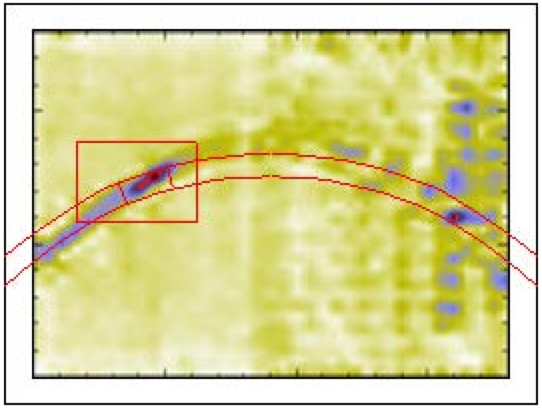


11 cm

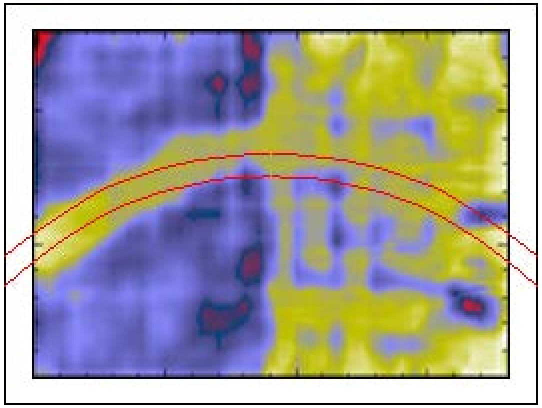




14 cm



50 cm



Testing problems for concrete elements

- Measuring the thickness and geometry
- Localisation and concrete cover of metal tendon ducts
- Localisation of inhomogeities in and around the tendon ducts (grouting faults)
- Localisation of compaction faults and honeycombing in concrete
- Localisation of delaminations in multilayered structures
- Crack characterisation (crack depth measurement)
- Quality assurance of construction

Bridge investigations applying NDT-CE

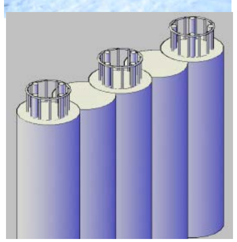
Bridge deck: Full field investigation
8 Measuring field for detailed investigation with Radar, Ultrasonic echo, impact-echo, (magnetic stray field) (1999)

Girder and Bridge deck: Scanning Echo methods for tendon ducts and honeycombing (2001)

New: Large field investigation with automated scanning system for echo methods (2003)





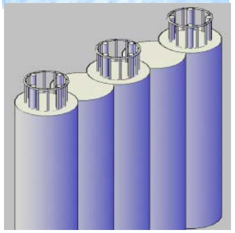


The BAM Site
for NDT-CE test and validation

- Dedicated to research, test, validation, education
- High quality 1:1 test specimen and real objects
- Piles, slabs, concrete railway track, bridge parts,….
- Long term availability
- open für partners from academia and industry

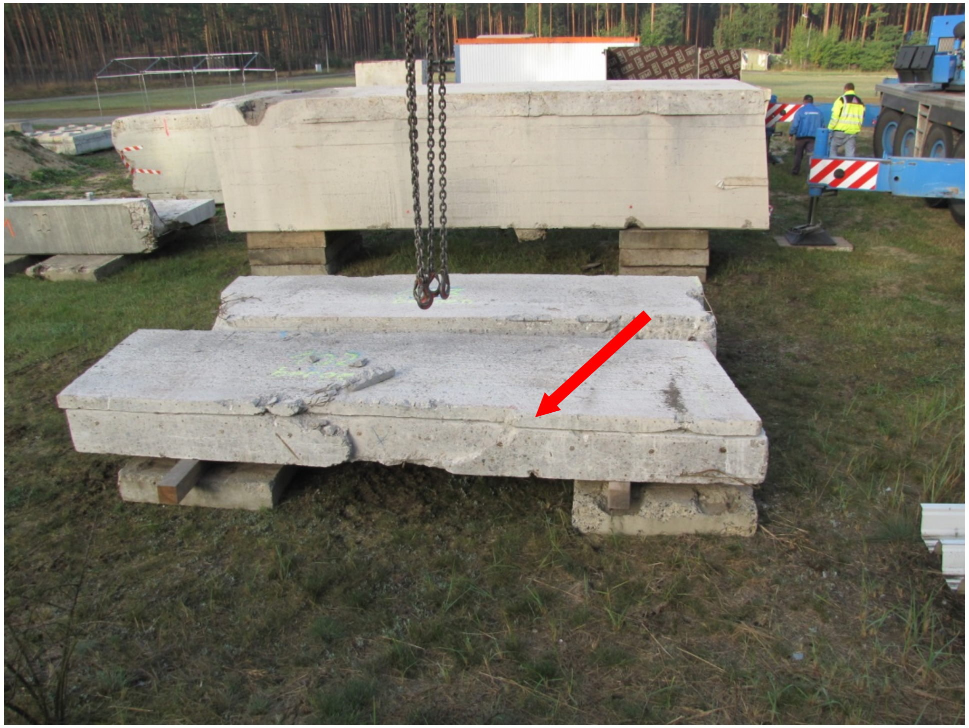




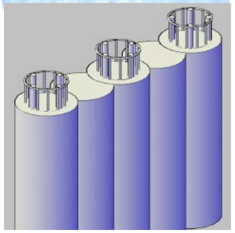


What's new

- Real bridge parts, containing tendon ducts and delaminations



3 box girders (L = 6-12 m)
3 slabs (5-10 m²)



What's new

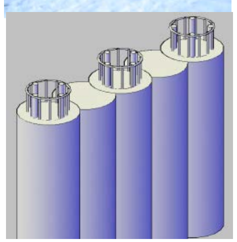
- 1:1 model of secant pile wall (checking joints by crosshole sonic logging)

see separate presentation

TTS – Validation Test Site







What else in 2009

- Facility upgrade (office , lab, data connections…

Tasks in 2010

- Sheet piles (length and shape)
- Piles under slab (load, length and integrity)
- Reinforced concrete wall (thickness, rebar location)

Large Concrete Slab (LCS) at BAM

Facility for various tests and measurements for the improvement of NDT-CE methods

Reference specimen for comparison of different methods (=>validation)

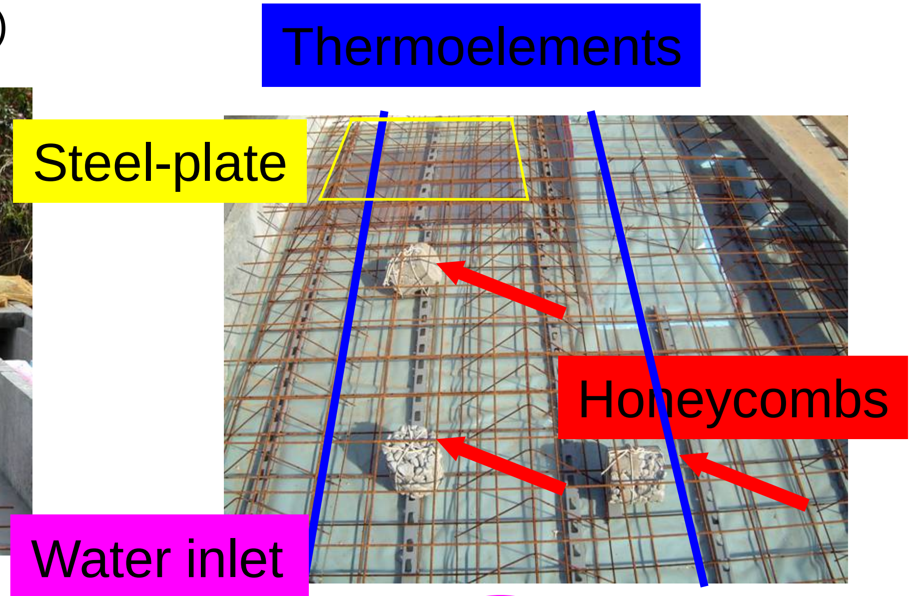
1. Section - Tendon ducts

11 Tendon ducts with strands
(length 4 m, diameter 40 … 100 mm)
Grouting defects, Grouting by DSI

2. Section - Voids and auxiliary devices

Voids:

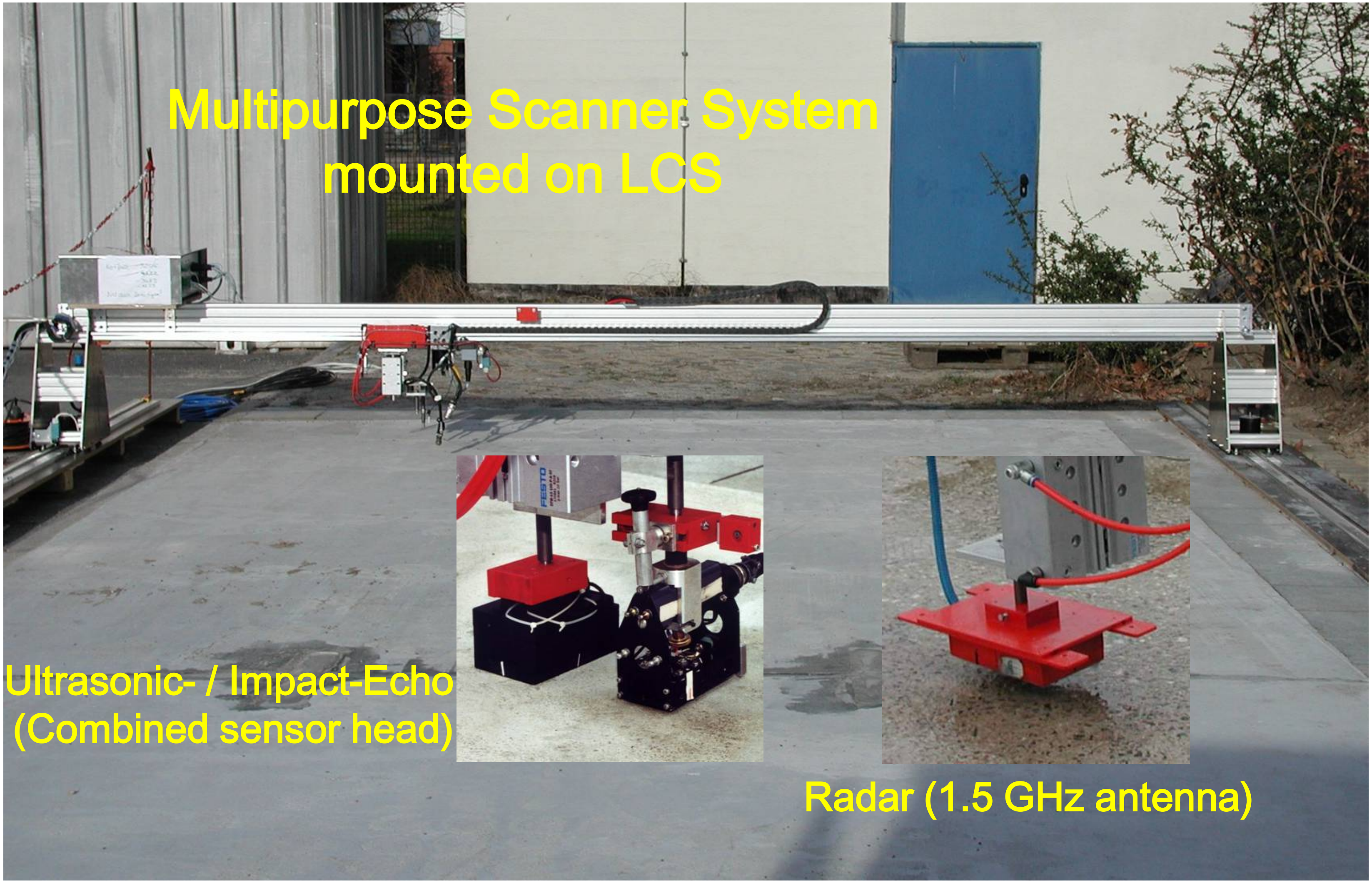
- Compaction faults (gravel pockets)



Auxiliary elements:

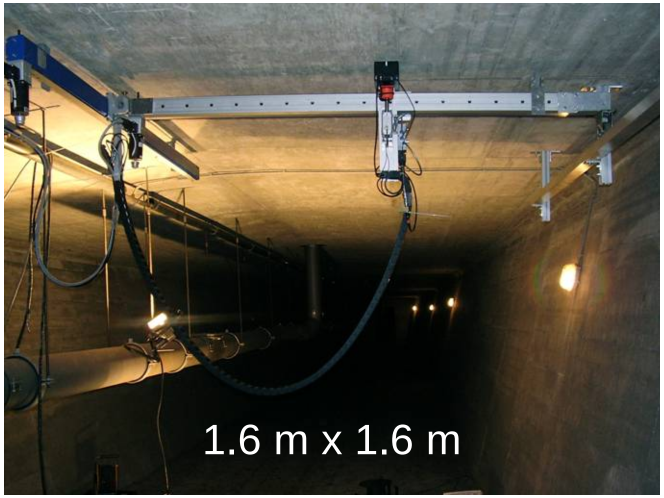
- Inlet for water and salt-solution through a tube from the bottom side into high porosity structure
- Thermoelements (for Thermography)
- Stainless steel-plate for backside reflection calibration
- Plastic tubes (for Radiography)

Automation and Scanning



Scanning Systems

1.6 m x 10 m



Scanning Area Speed:

- **Ultrasonic Echo/Impact Echo**
  $1 m^2/h$, 0.02 m point grid
- **Radar**
  $15 m^2/h$, 0.05 m line grid

2-dimensional measurement on the surface of structures

- B-Scan

  plots perpendicular to the measurement surface (x-y plane)

- C-Scan

  plots parallel to the measurement surface (x-y plane)

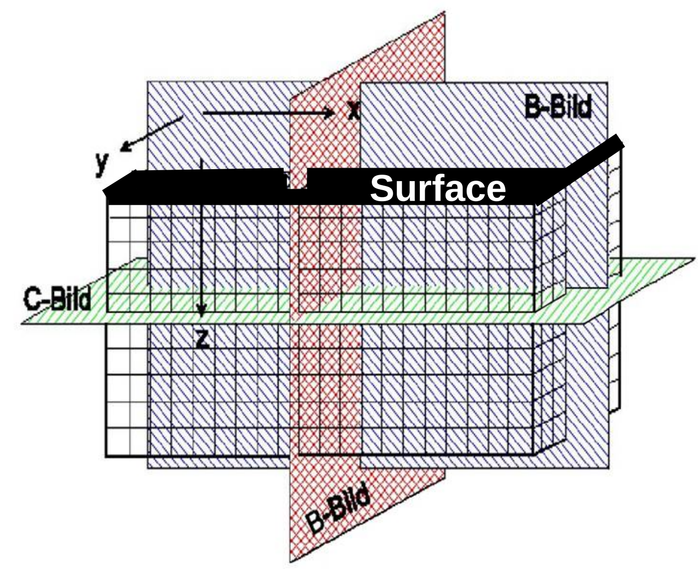
Projections and Animations of consecutive scans

3D-Reconstruction

Focusing of reflected signals using SAFT
(Synthetic Aperture Focusing Technique)

Data Fusion

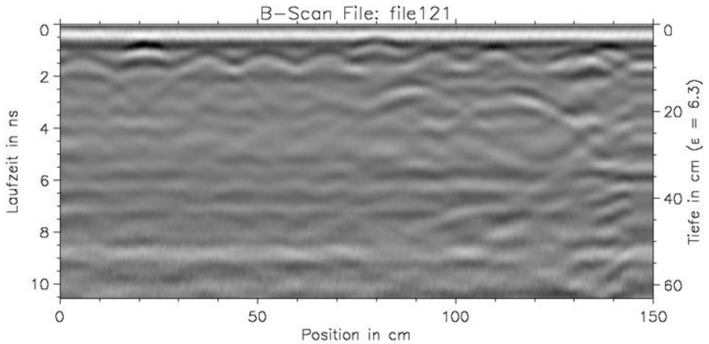
Superposition of data



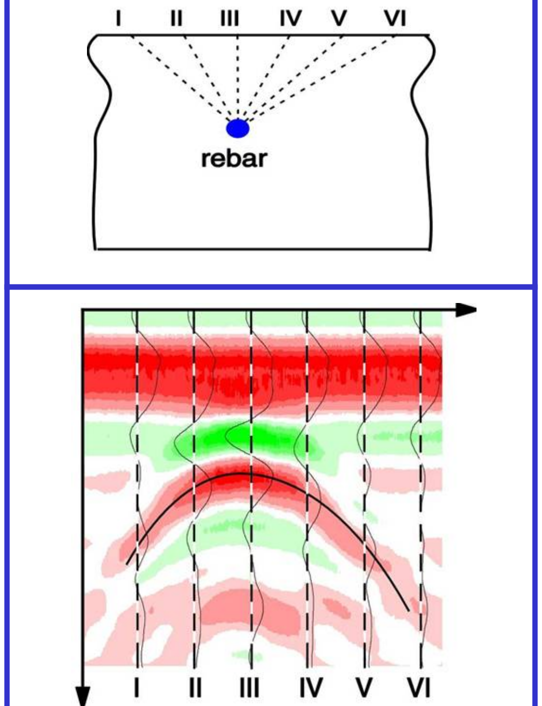
Impulse Echo Principle

(1) Electro-Magnetic Method Radar

- Reflections at interfaces of materials with different dielectric properties
- Antenna of 900 MHz and 1.5 GHz



Position of antennas



Radar gram with hyperbola

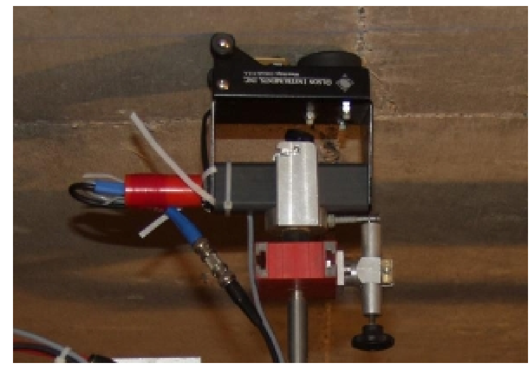
(2) Acoustic Methods Ultrasonic Echo/ Impact-Echo

- Reflections at interfaces of materials with different acoustical properties

Ultrasonic Measurement Device

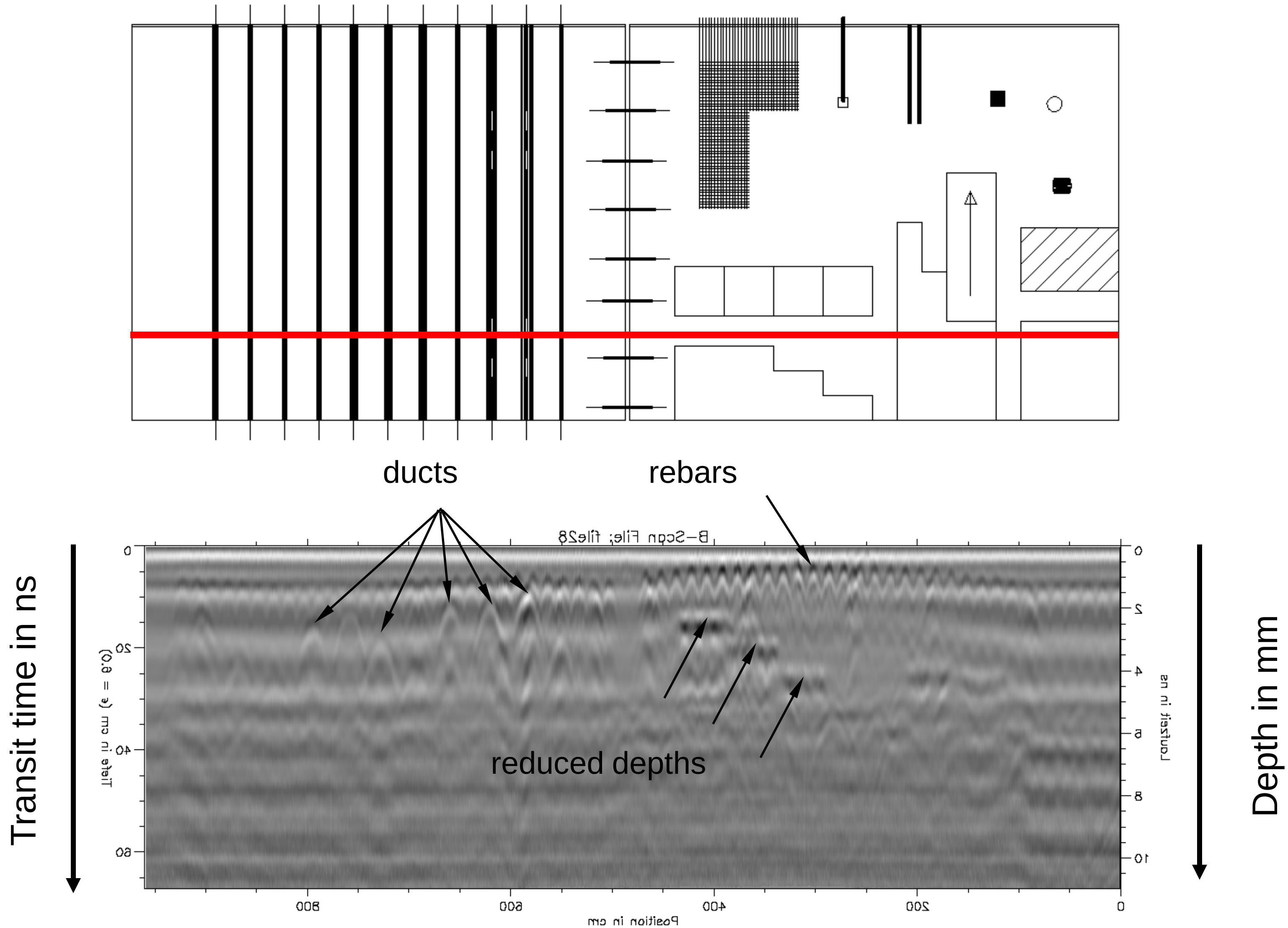
- **Shear waves**
  - center frequency of 50 kHz
- **Measurement head**
  - 24 point-contact transducers
  - without coupling agent

Impact-Echo Measurement Device

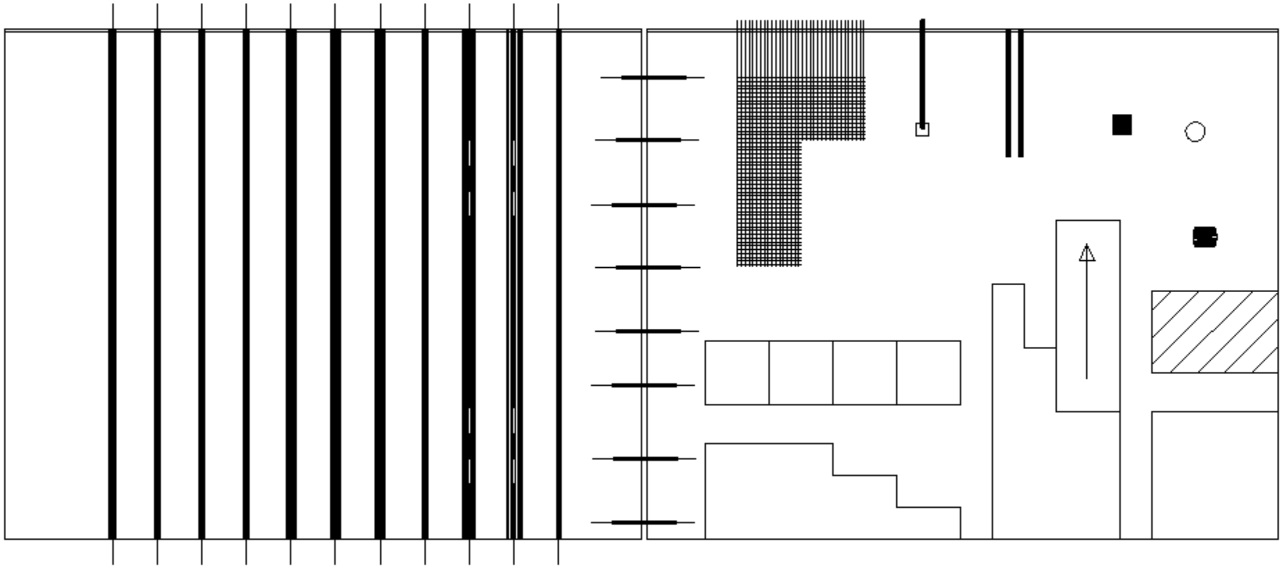


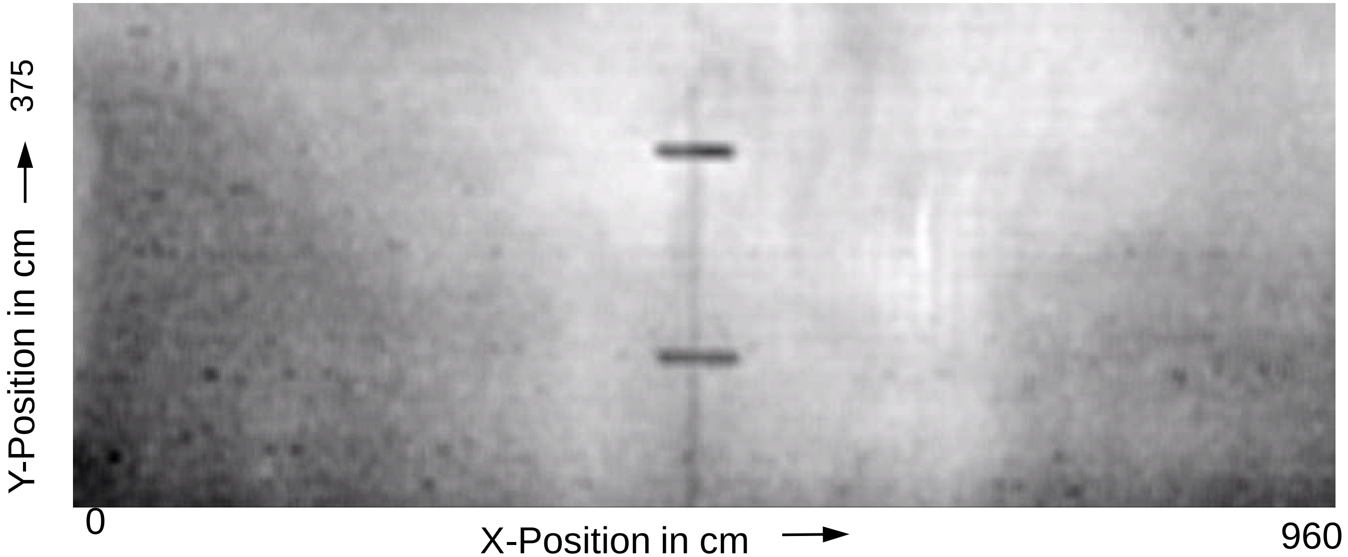
- **Frequency range**
  - from 1Hz to 40 kHz
- **Frequency spectrum analysis**
  - multiple reflections
    (recorded in the time domain)

RADAR: Raw radargram of a long trace

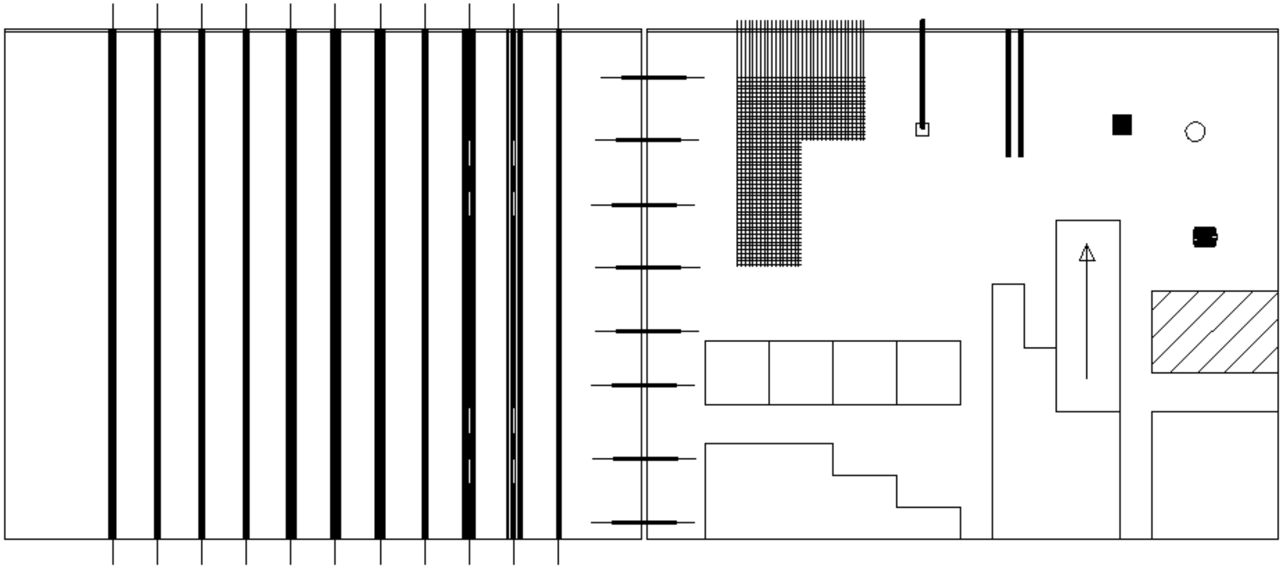


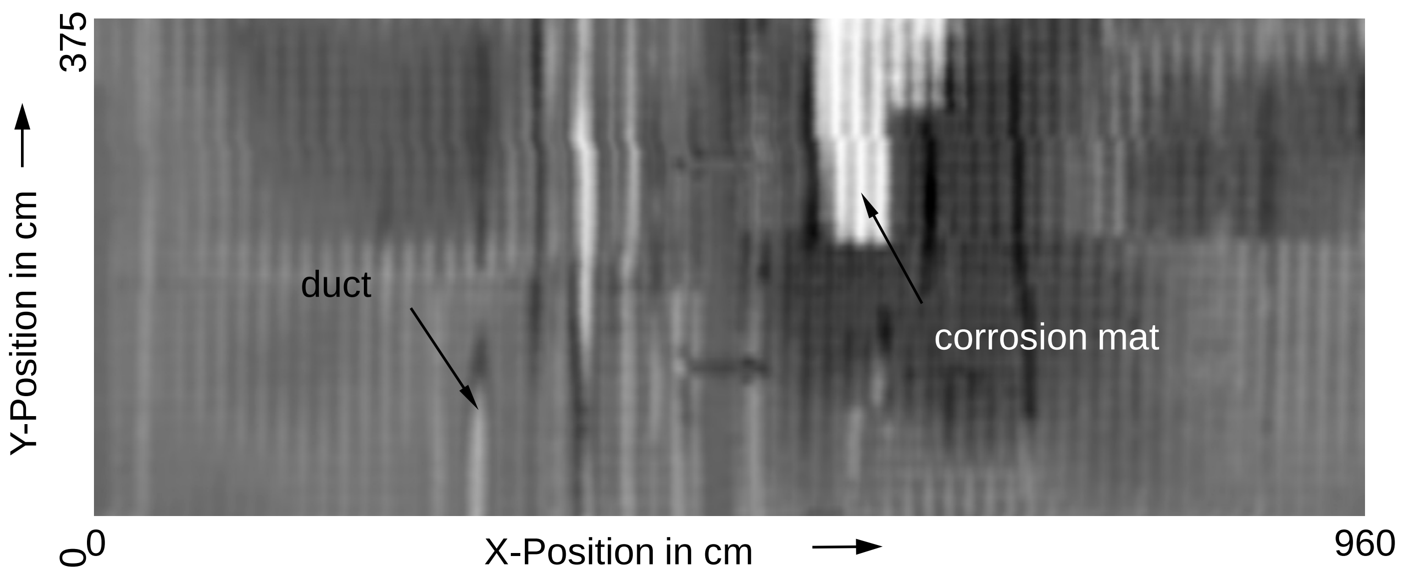
Raw data of GBP (3D)





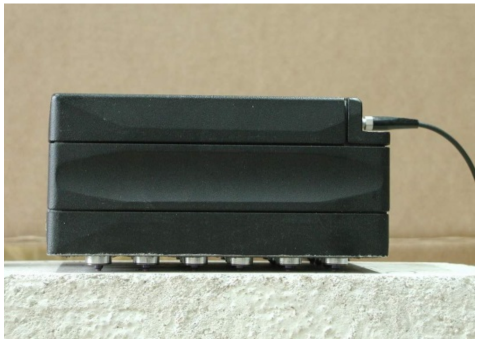
Raw C-scan (depth slice) at a depth of 10 cm

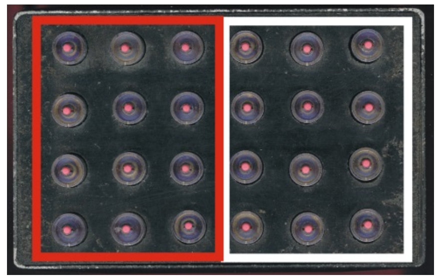




Ultrasonic echo

Point contact transducer

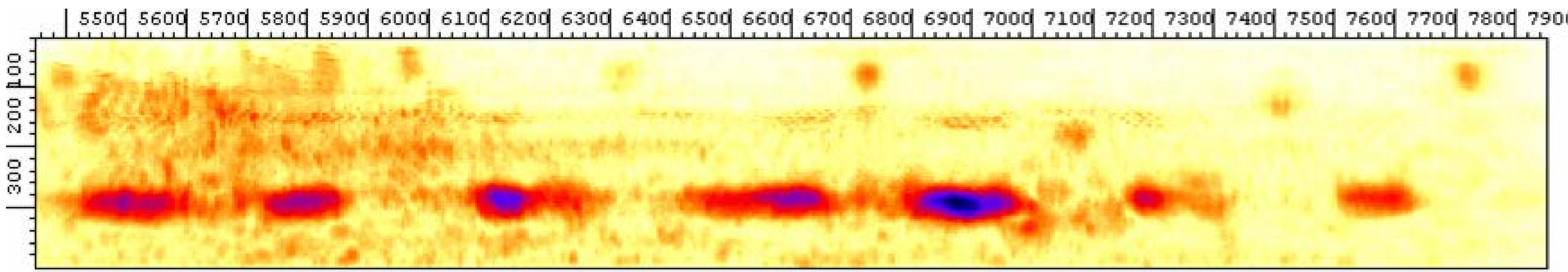




Transm. Receiv.

Acoustical imaging of 6 tendon ducts in LCS:
2 D Scanning and 3D-SAFT
(**S**ythetic **A**perture **F**ocusing **T**echnique)

A B C D E F G



Depth in mm

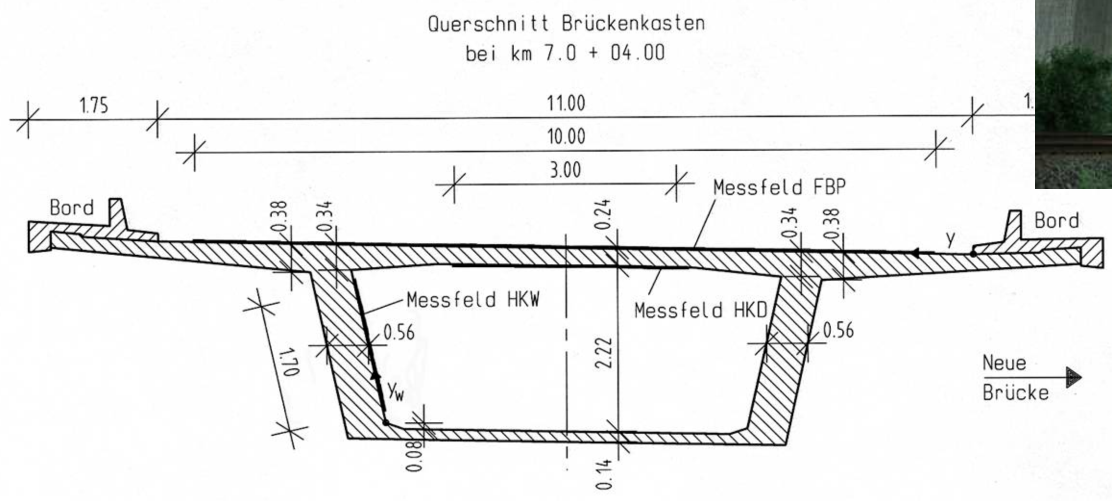
X in mm

Depth distribution of reflection vs. X-axis (B-scan)

Shadowing additionally caused by reinforcing bar spacer

Application at post-tensioned concrete bridge
Large Area Investigation (Scanner)

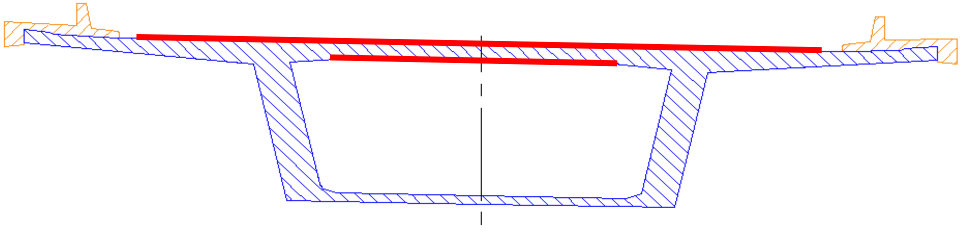
Construction
Cantilever unicellular box bridge
Length: 480 m
Prestressed in longitudinal and transversal direction
Constructed 1966, deconstruction 2004



- Radar
- Impact-Echo
- Ultrasonic Echo

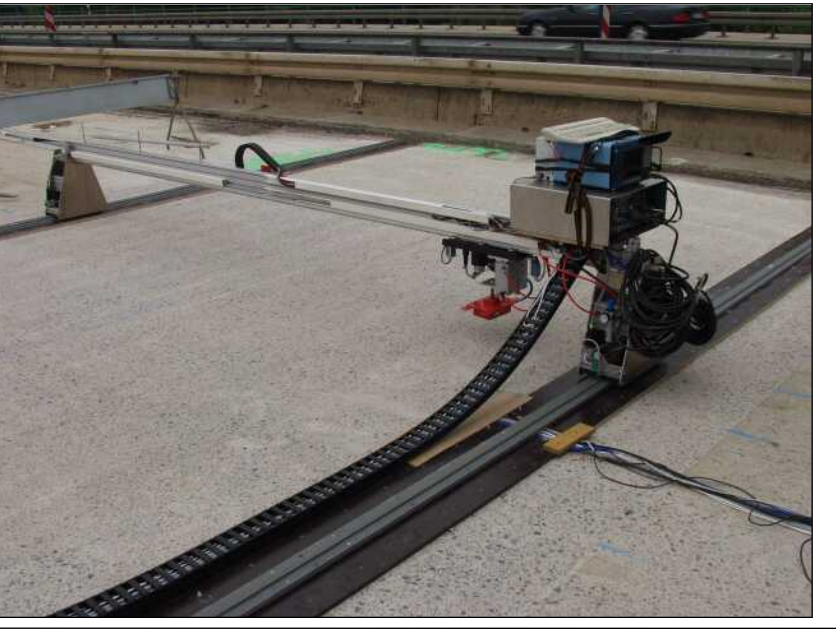
Results

Measurements on a post-tensioned bridge deck



Test Area on the top: 4.0 m x 10.0 m
Test Area on the bottom: 3.0 m x 10.0 m

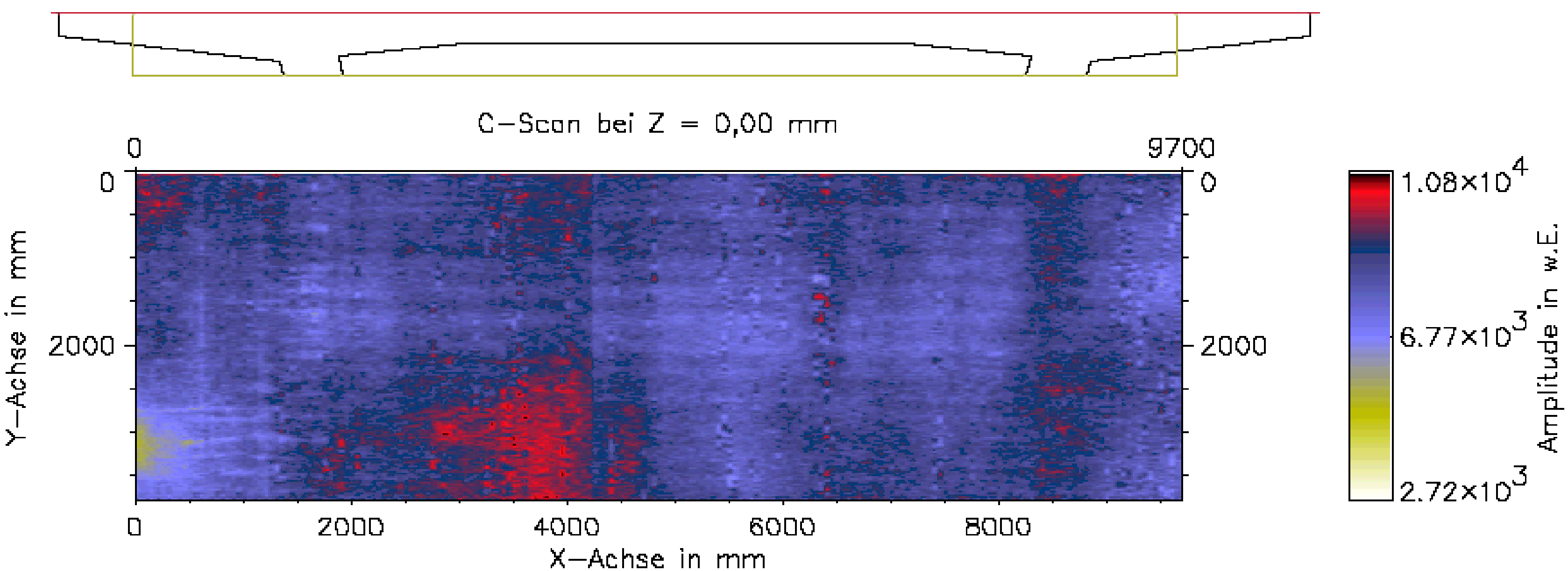
- tendon ducts with diameters of 45 mm, each with 6 wires
- thickness of the deck 23 - 38 cm



Radar – Datafusion

Bridge deck: Superposition of radar data from the top side and bottom side (Polarization in x- und y-direction, maximum of magnitude is represented)

Movie of slices parallel to the surface:



Radar-Visualization of the Results as 3D-Animation

2 Data Sets

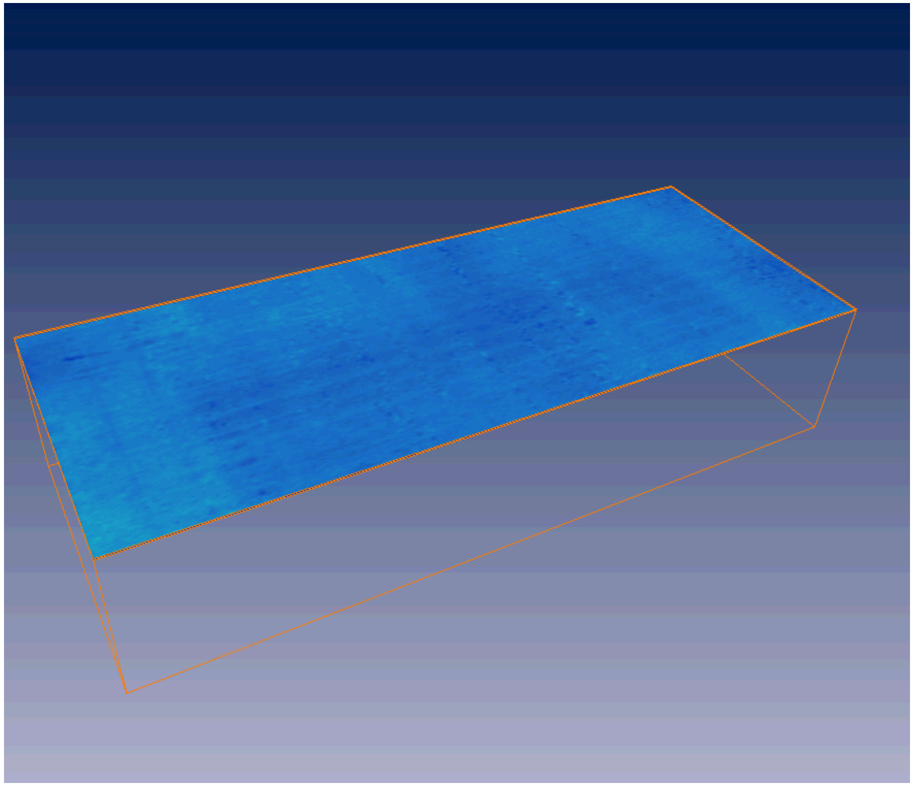
recorded with the 1.5 GHz-antenna

with polarization in x and y-direction

3D-Reconstruction with SAFT

(Synthetic Aperture Focusing Technique)

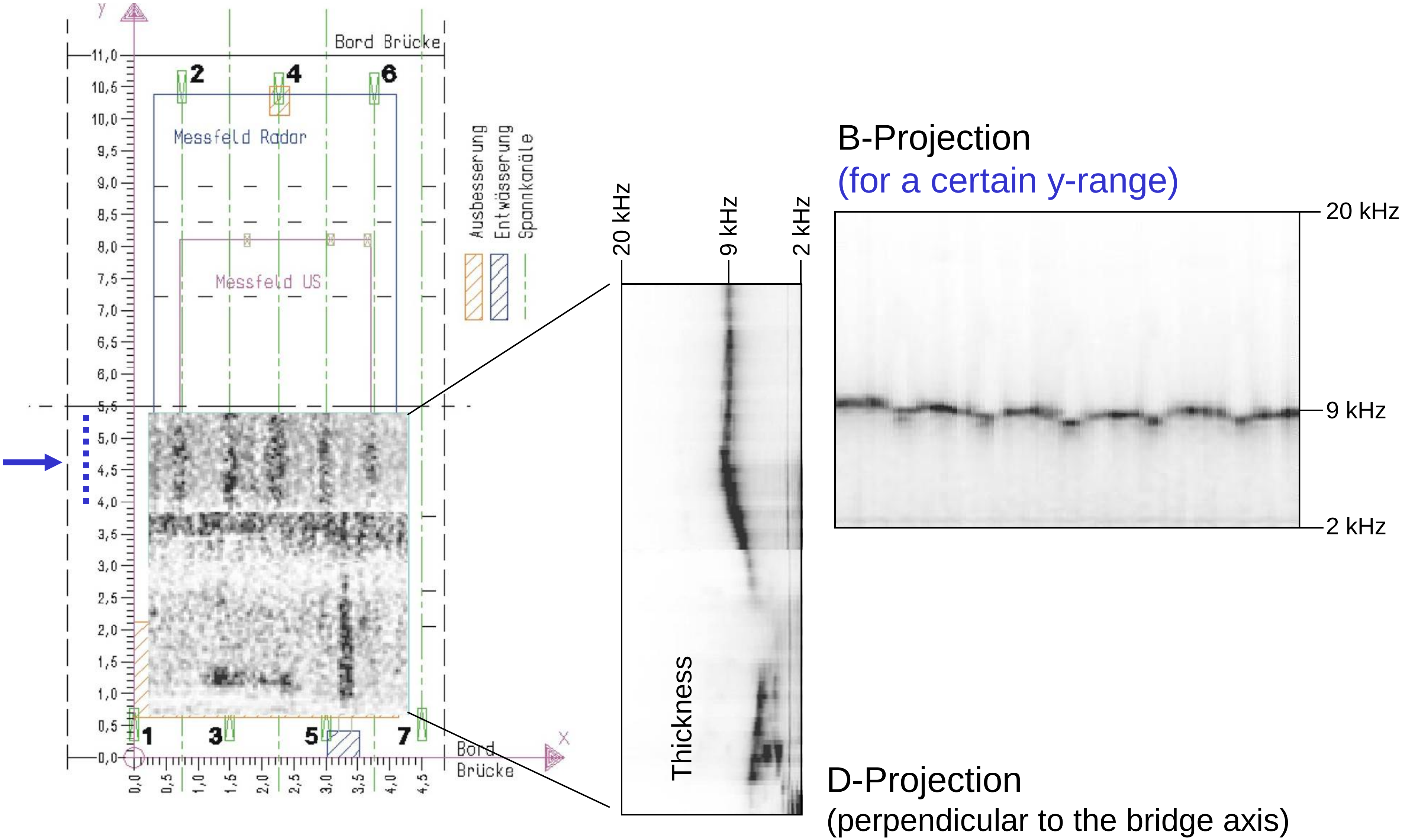
Data Fusion



Test Area 4.0 m x 10.0 m

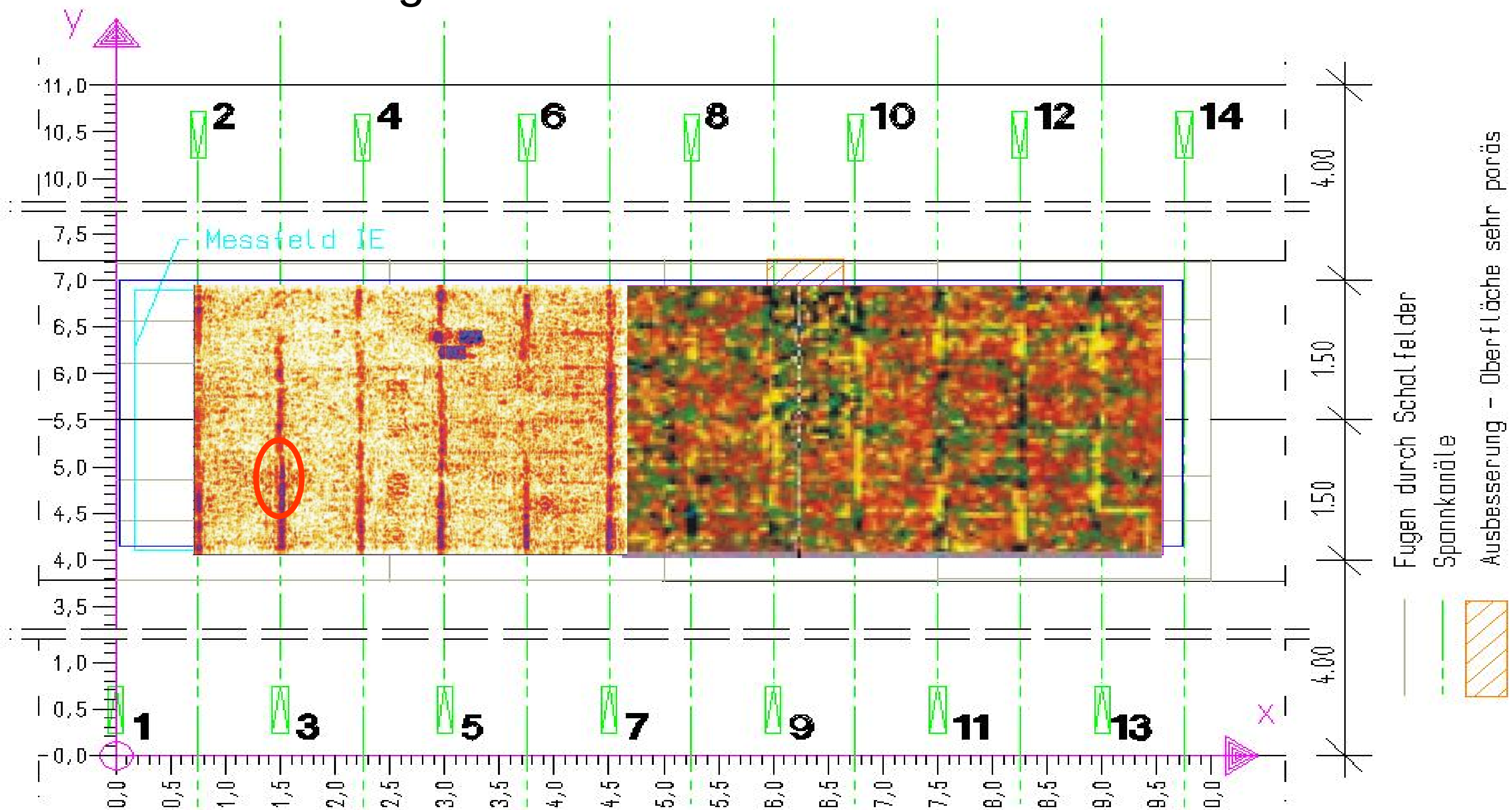
Duct investigation (Impact-Echo)

Bridge deck top side: C-Projection close behind the back wall



Ultrasound: Duct investigation

Bridge deck bottom side



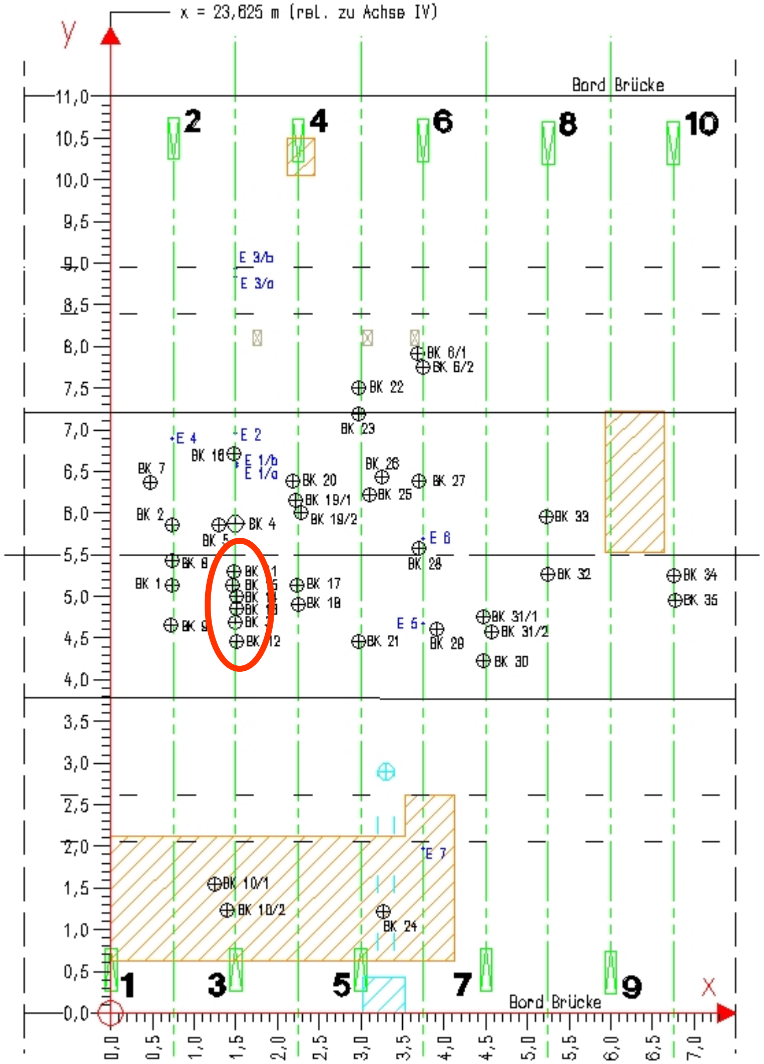
Left:
SAFT-C-Projection
depth 11,7 cm … 12,1 cm
step width 2,5 cm

High reflection intensity at both sides

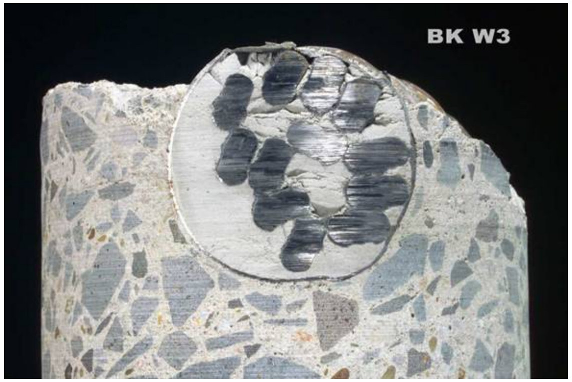
Right:
C-scan depth about 8 cm
step width 5 cm

Verification

Bridge-deck: Destructiv testing: 35 cores, endoscopy

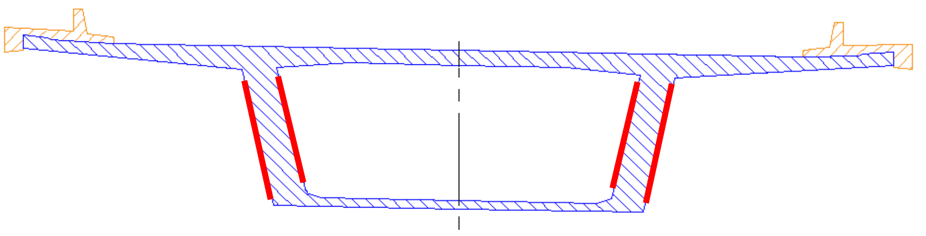


Bridge deck (transverse tendon ducts):
Very good grouting condition



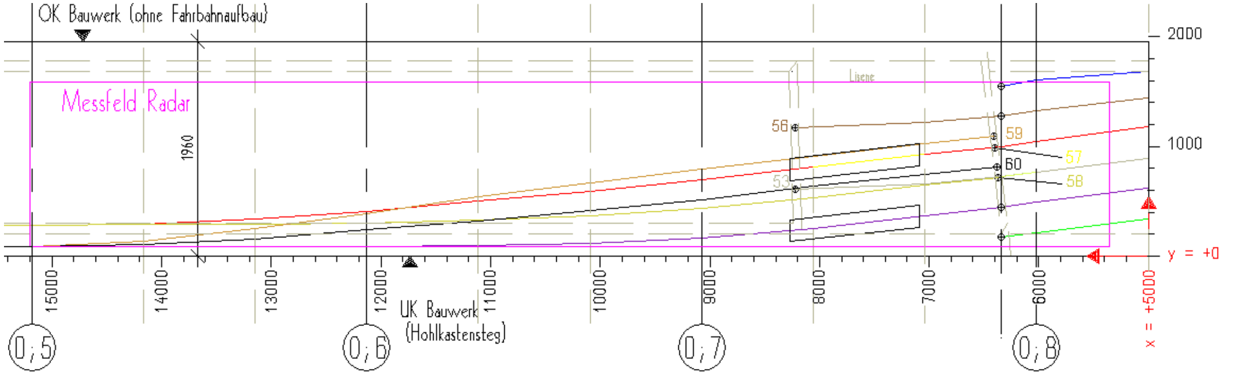
Box girder wall (longitudinal tendon ducts)

Measurements on webs of box girder bridges



- thickness of the web 50 cm
  (83 cm in the area of anchoring of the pre-stressing)
- bridge under unaffected traffic
- simultaneous mounting of the impact-echo and ultrasonic sensors on the scanner

Test Area: 10 m (length) x 1.5 m (height)

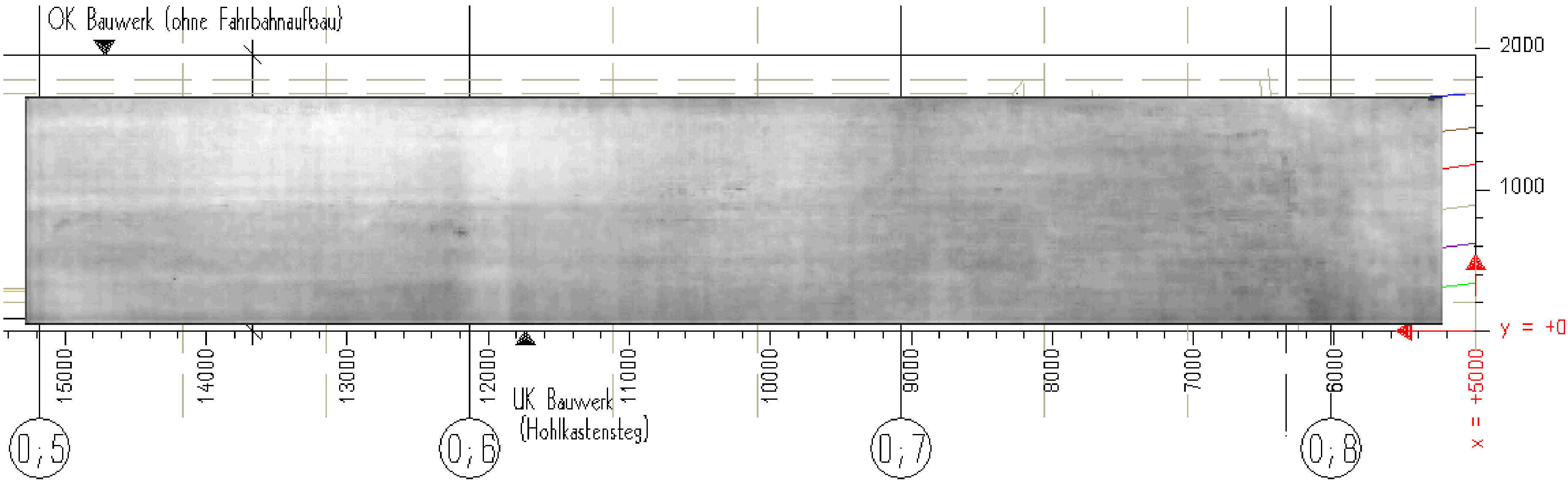


Data Fusion of Radar and Ultrasonic Echo

3D-reconstructed and fused radar data sets (1.5 GHz-antenna)

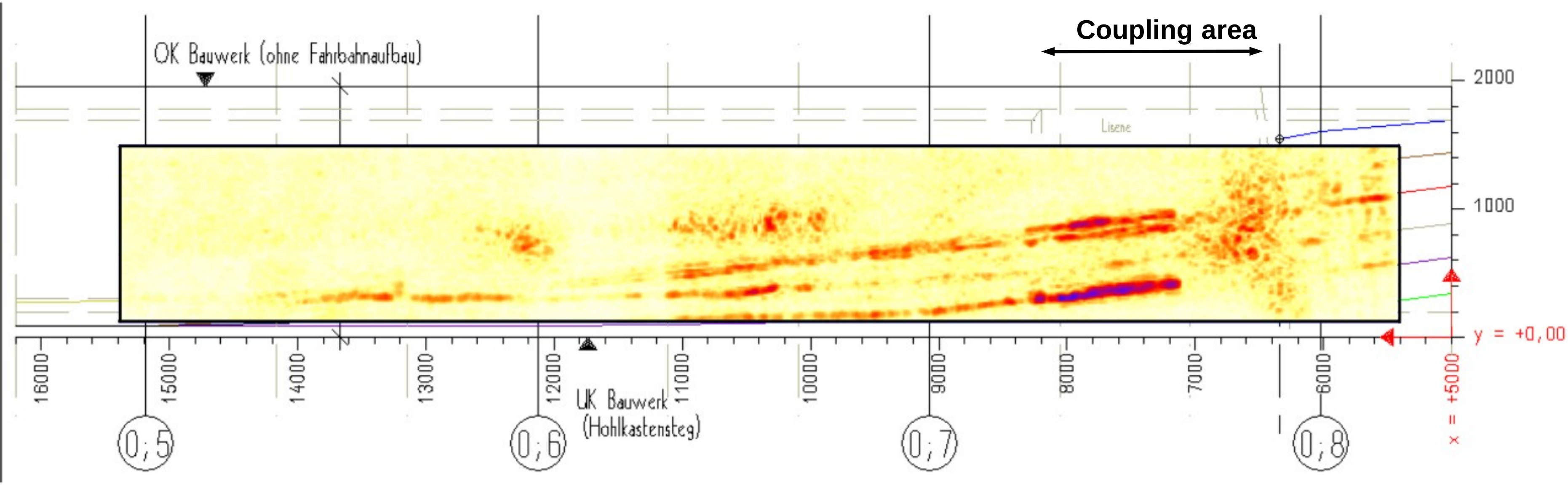
and

3D-reconstructed ultrasonic echo data set



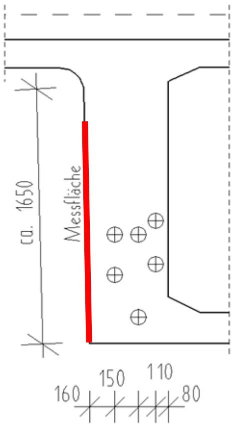
Animated sections parallel to the surface
through the measurement depths from 0 cm to 60 cm

Ultrasonic Echo



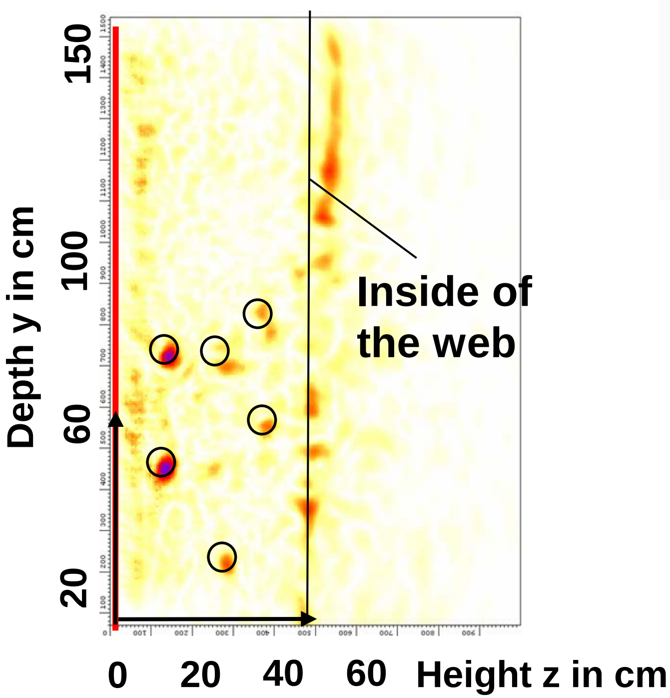
SAFT-C-Projection parallel to the measurement surface at the range of depth from 22 cm to 28 cm

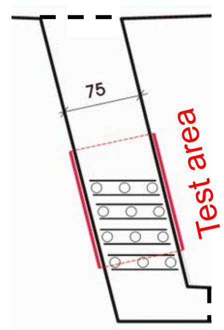
Ultrasonic Echo



Box girder web
Thickness: 50 cm
Height of test area: 1.40 m

SAFT-B-Scan

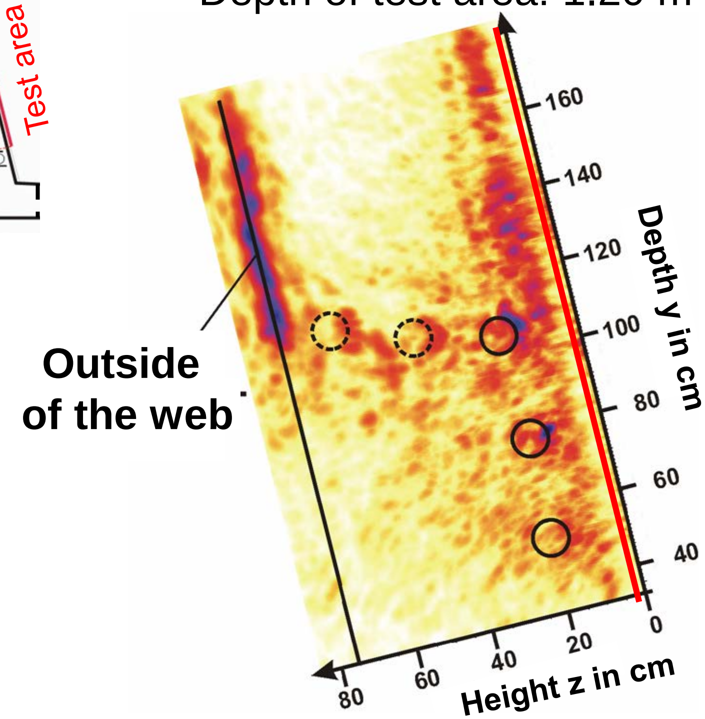




Box girder web
Thickness: 75 cm
Height of test area: 1.60 m

SAFT-B-Projection

Depth of test area: 1.20 m

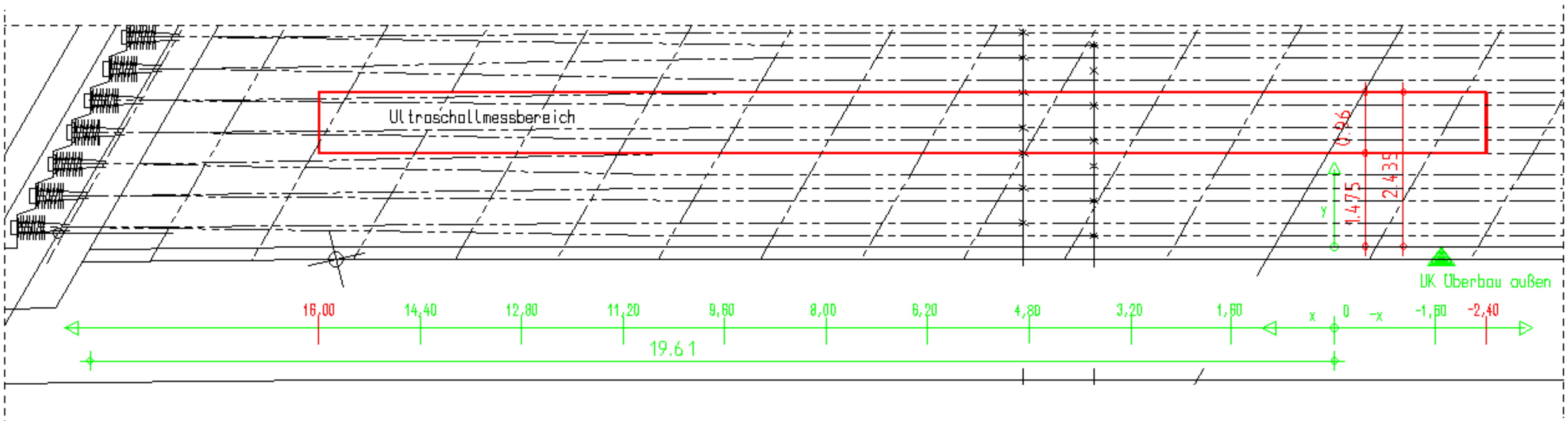


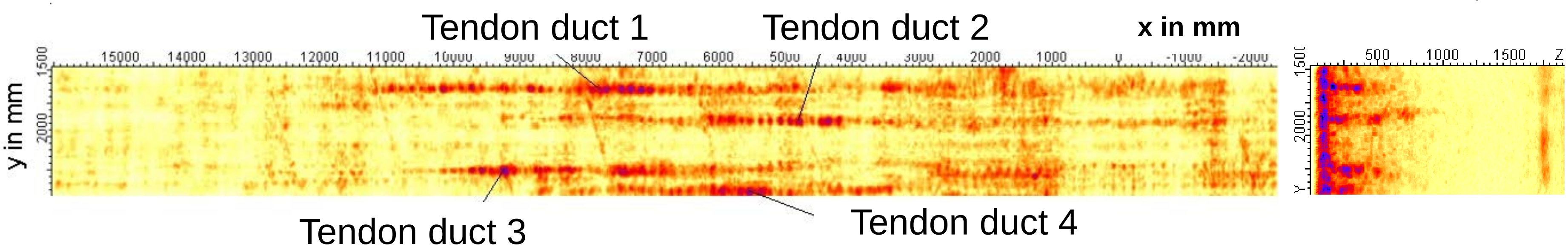
Measurements on a bridge deck, pre-stressed in longitudinal direction

Test Area on the bottom side of the deck, 0.96 m x 18.40 m:

ultrasonic echo measurements were done in 23 scanning areas length of 2 m x 0.40 m

Ultrasonic Echo

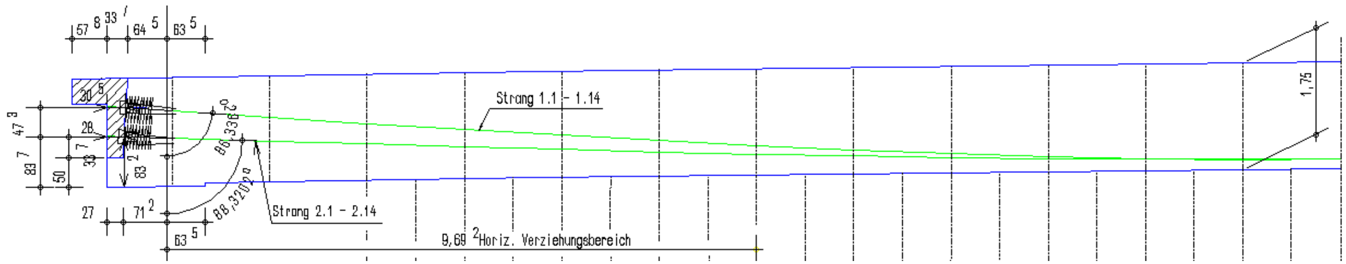


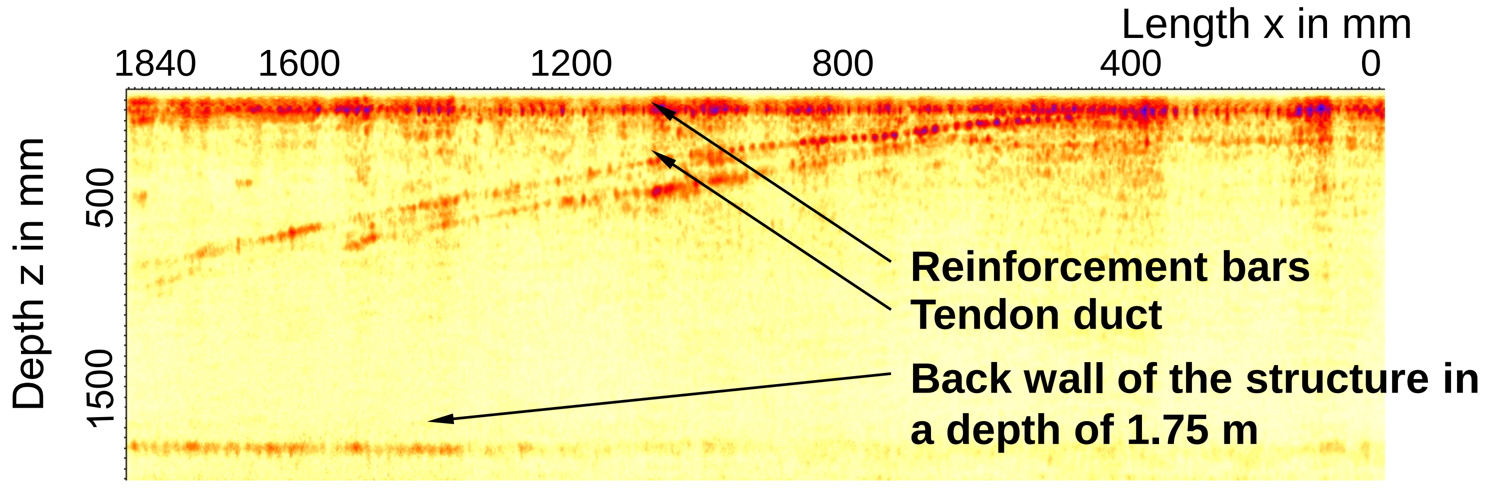


SAFT-C-Projection in the depth range of z = 200 – 400 mm

Right: SAFT-B-Projection about the whole length of 18.40 m

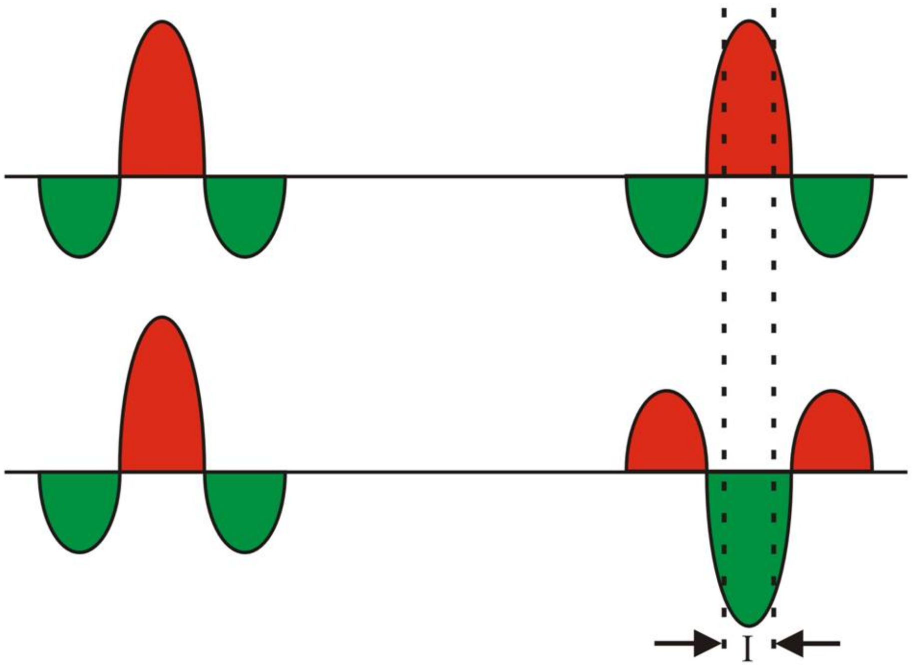
Evaluation of the Intensity of Ultrasonic Echo-Signals





SAFT-B-Projection about the range with the tendon duct 2

Pulse Behaviour of Ultrasonic Echo-Signals



Transmitted pulse

Reflected pulse

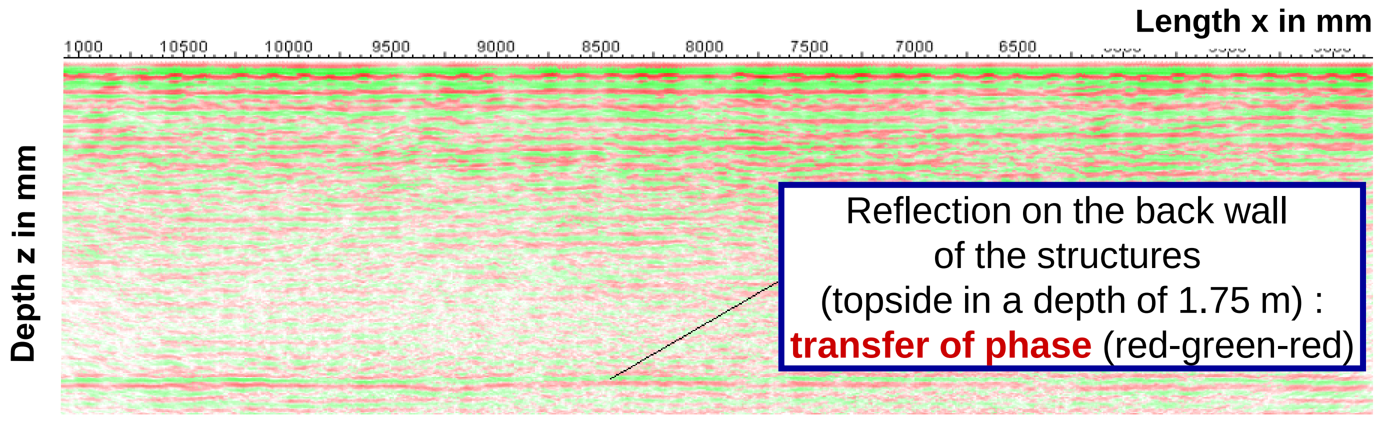
Reflections on steel in concrete

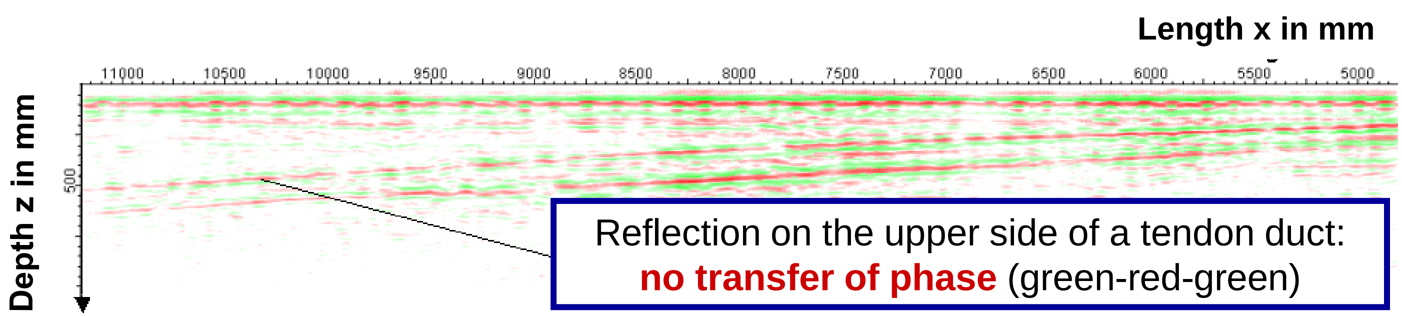
→ **No transfers of phase**

Reflection on air-inclusions in concrete

→ **Transfer of phase**

Evaluation of Pulse Behaviour of Ultrasonic Echo-Signals





SAFT-B-Projection (Phase)

Top: about y=1940-2100 mm, Down: about y=1828-1926 mm (tendon duct 2)

Vielen Dank! Thank you!

bast

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Research group supported by the DFG (Deutsche Forschungsgemeinschaft)

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