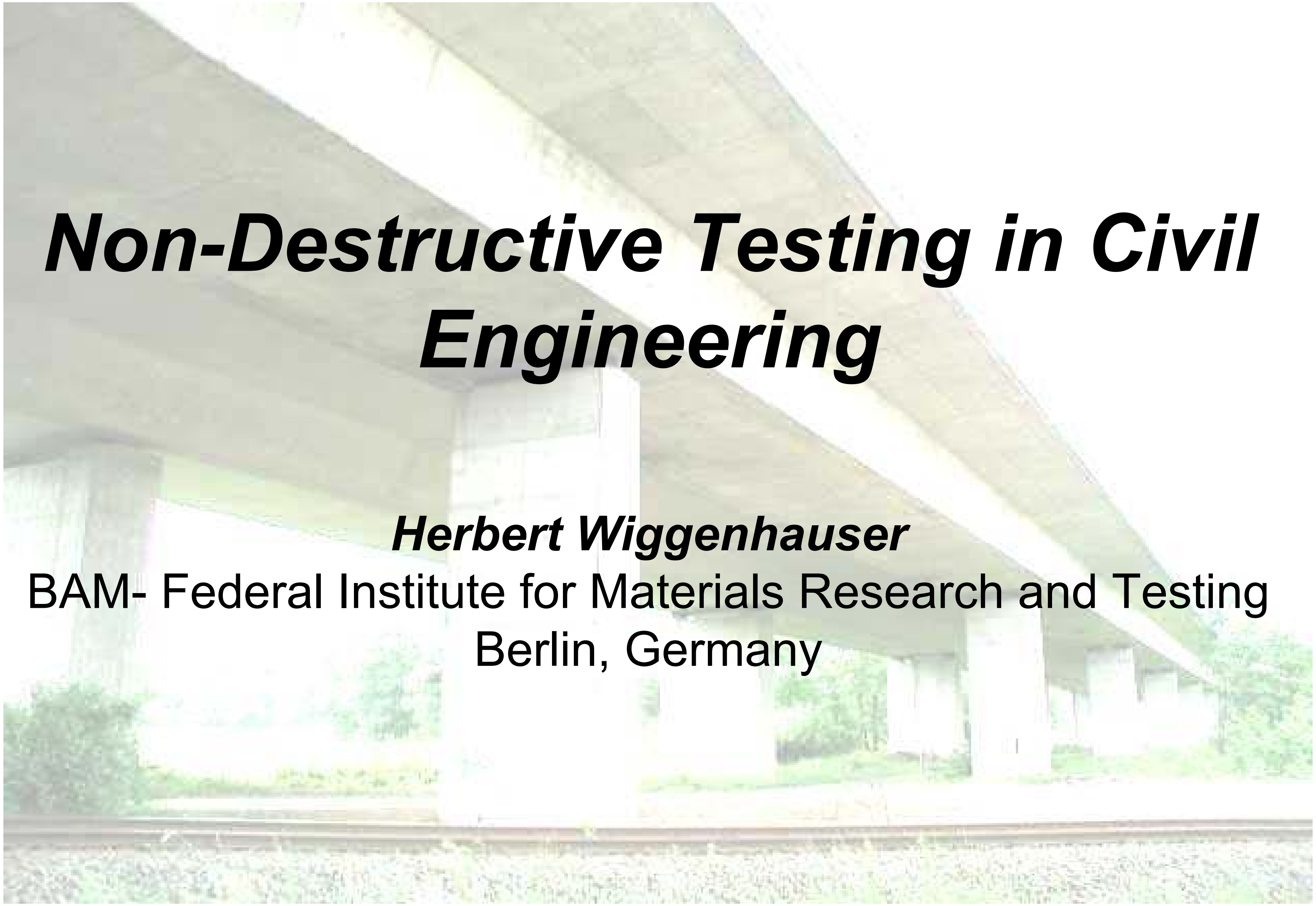


Non-Destructive Testing in Civil Engineering

Herbert Wiggenhauser

BAM- Federal Institute for Materials Research and Testing

Berlin, Germany

Bridge Testing

In Germany according to DIN 1076

- Regular inspection 3 y
- In depth inspection 3 y after Regular inspection
- Special inspection (e.g. after accident or climatic hazard)

NDT:

- Special Inspection
- Procedure

Bridge Damages

Ungrouted Tendon Ducts

Not uncommon problem in bridges built 1960-80

Non-Destructive Testing Problems

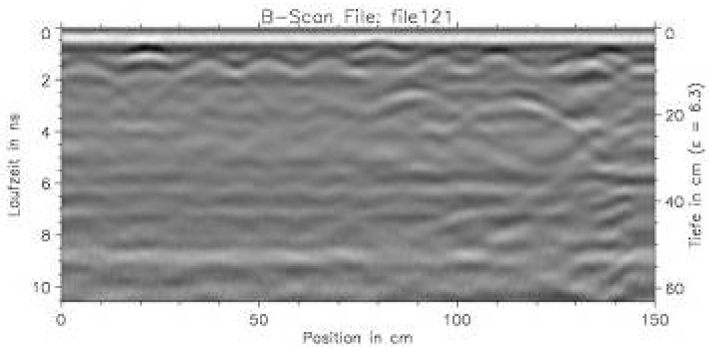
- Measuring the thickness and geometry
- Tendon ducts
  - Position
  - Concrete cover
  - Grouting
  - Honeycombs (around them)
  - Corrosion of strands
  - Cracks and fissures in strands
- Concerte
  - Reinforcement (position, cover, diameter)
  - Localisation of honeycombs
  - Delaminations
  - Cracks (position, depth)
- Quality assurance of construction
- ….

The Methods

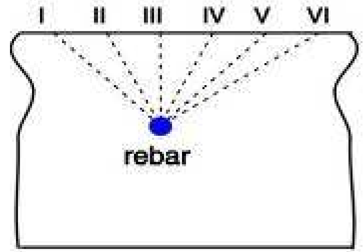
Impulse Echo Principle

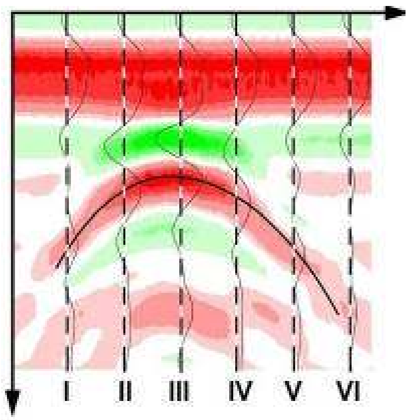
(1) Electro-Magnetic Method Radar

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



Position of antennas





Radar gram with hyperbola

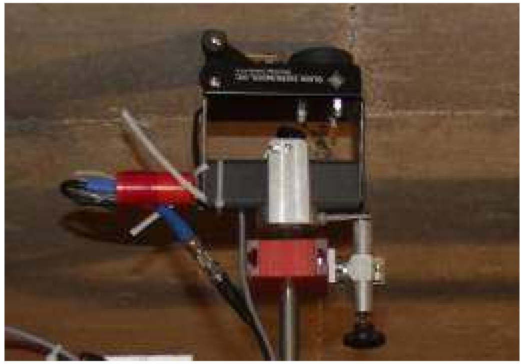
(2) Acoustic Methods Ultrasonic Echo/ Impact-Echo

- 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)

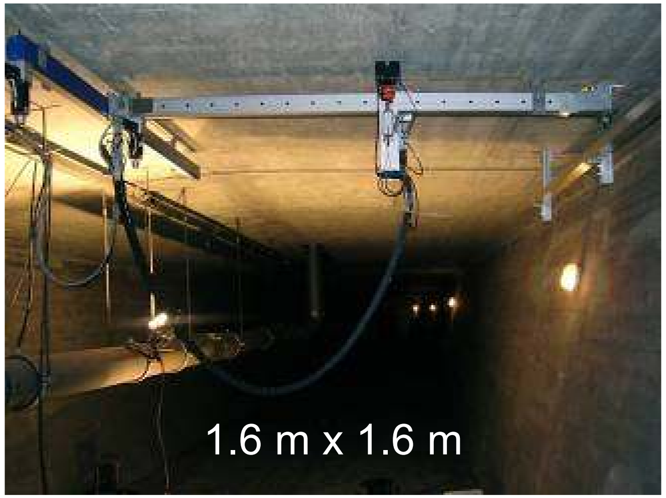
Automation and Scanning

Scanner Systems


4 m x 10 m

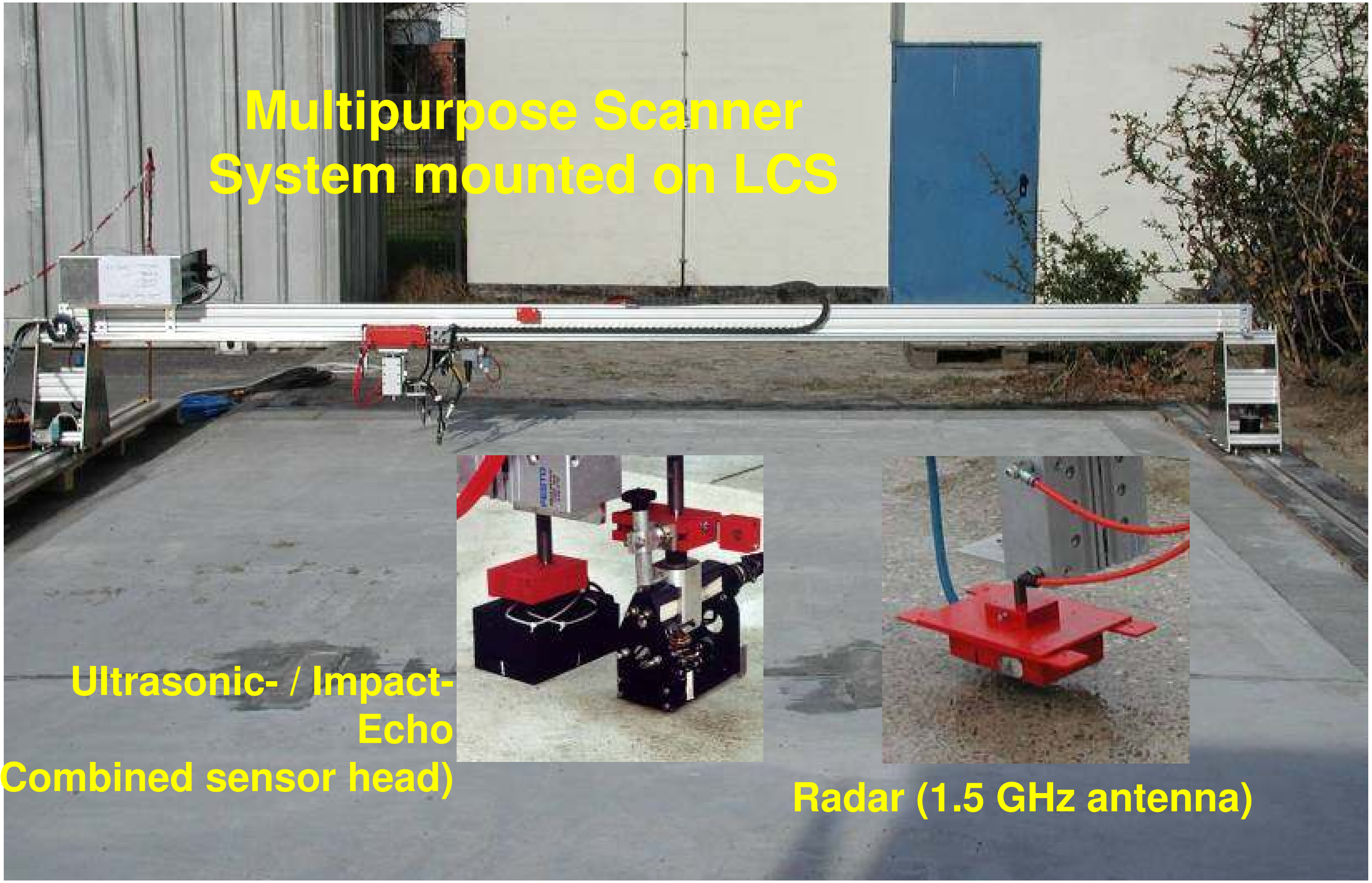

1.6 m x 10 m


1.2 m x 1.6 m


1.6 m x 1.6 m

Scanning Area Speed:

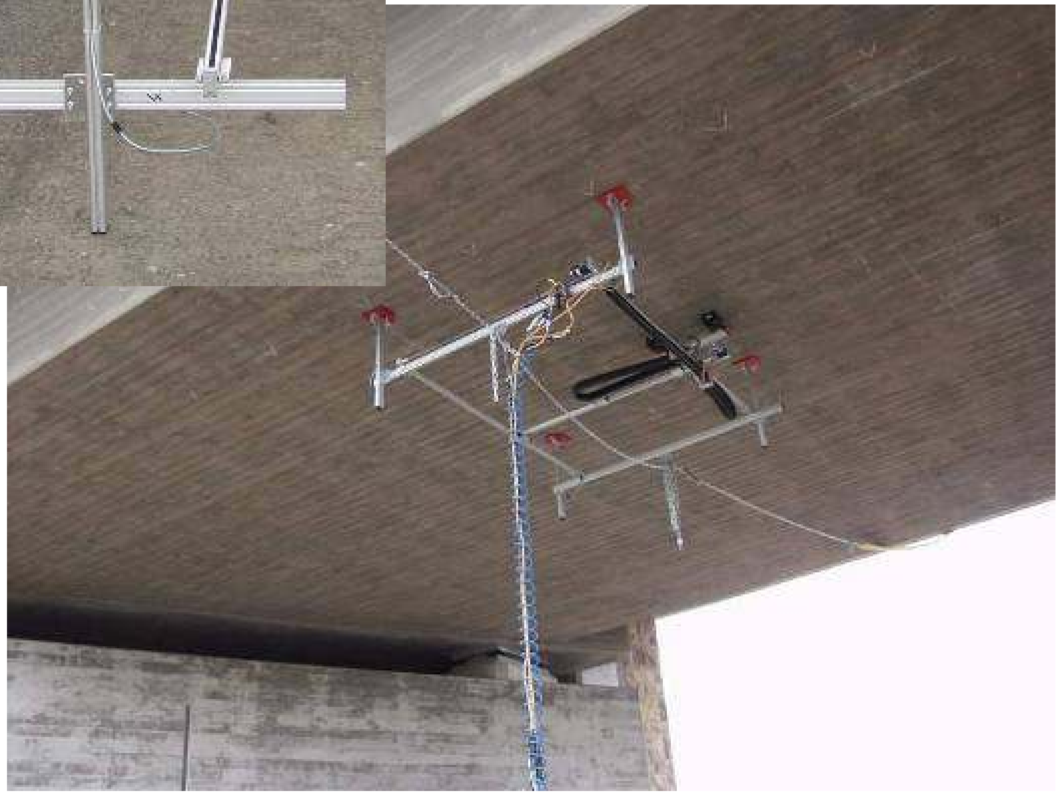
- **Ultrasonic Echo/Impact Echo**
  1m²/h, 0.02 m point grid
- **Radar**
  15m²/h, 0.05 m line grid



Multipurpose Scanner System mounted on LCS
Ultrasonic- / Impact-Echo (Combined sensor head)
Radar (1.5 GHz antenna)

Scanner Systems

Scanner Systems

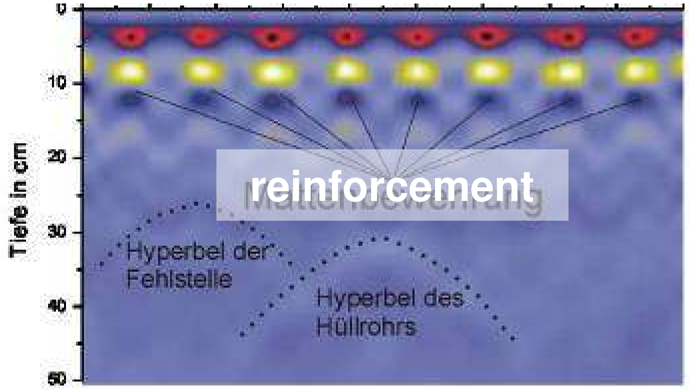


- Small leightweight scanner with vaccuum attachement
- Two ultrasound sensors (dry coupled) to reduce measurement time

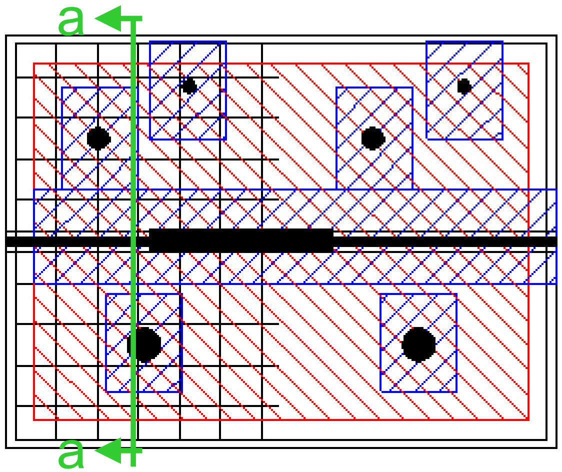
Data Fusion and Visualization

Radar – Data fusion and imaging

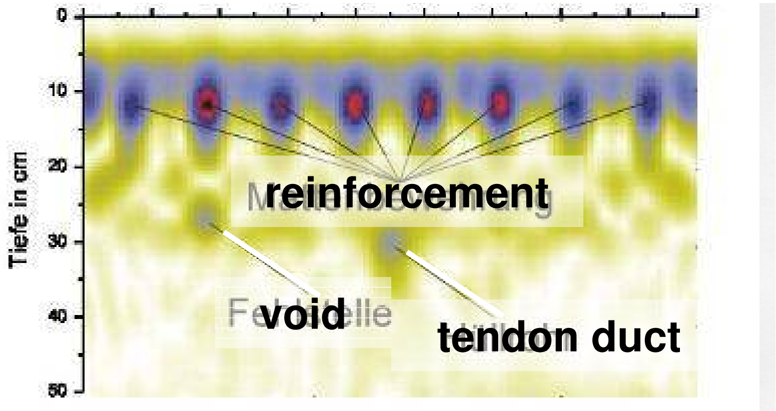
Section a-a without reconstruction calculation

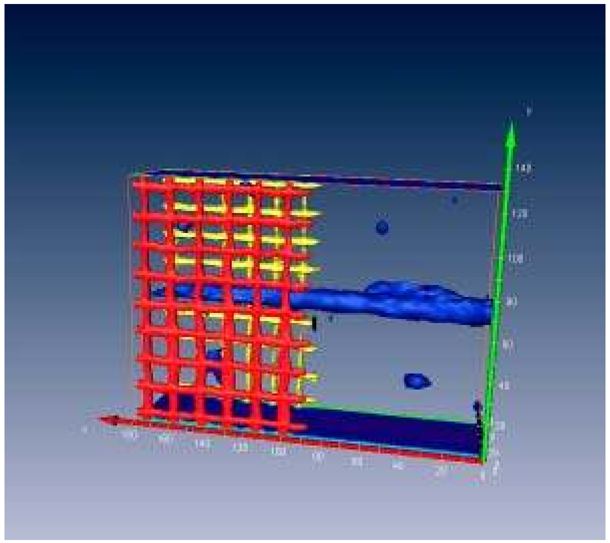


Reinforced concrete slab



Section a-a with reconstruction calculation





3-D imaging of the results

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)

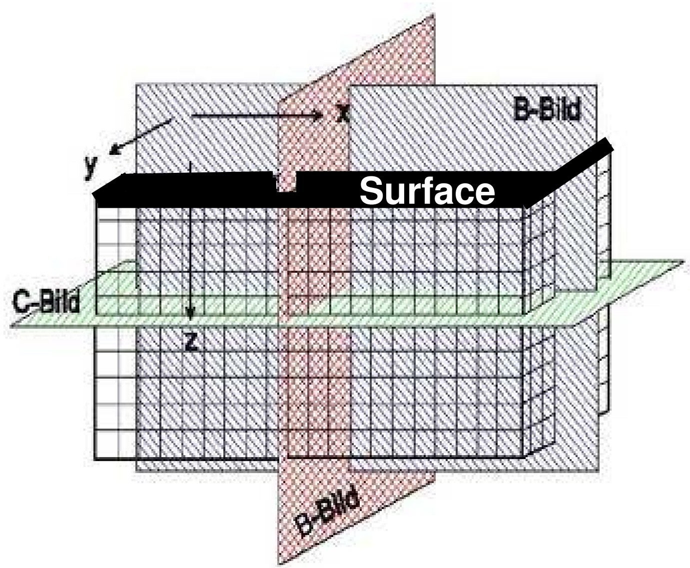
Projections and Animations of consecutive scans

3D-Reconstruction

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

Data Fusion

Superposition of data



Validation

Validation

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)

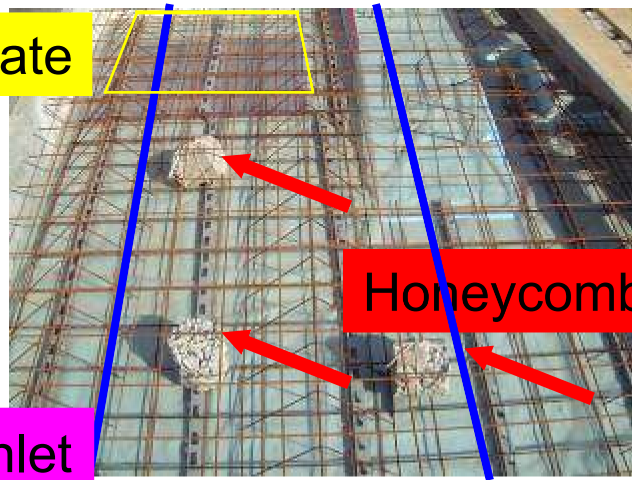
1. Section - Tendon ducts

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

2. Section - Voids and auxiliary devices

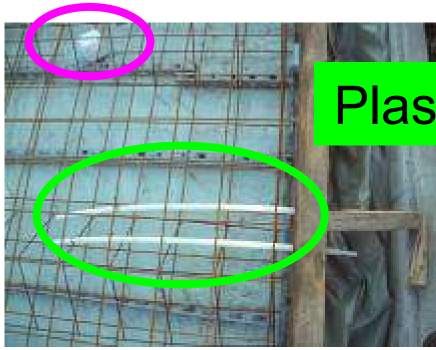
Voids:

- Compaction faults (gravel pockets)

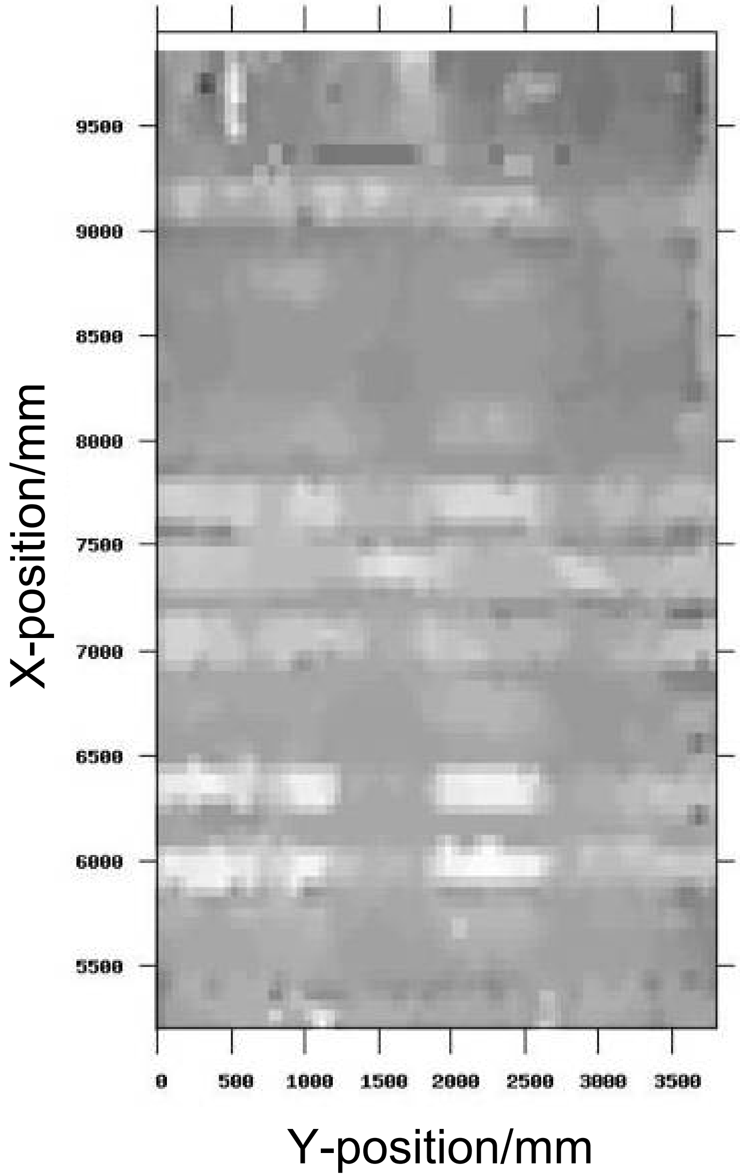


Auxiliary elements:

- 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)



Validation

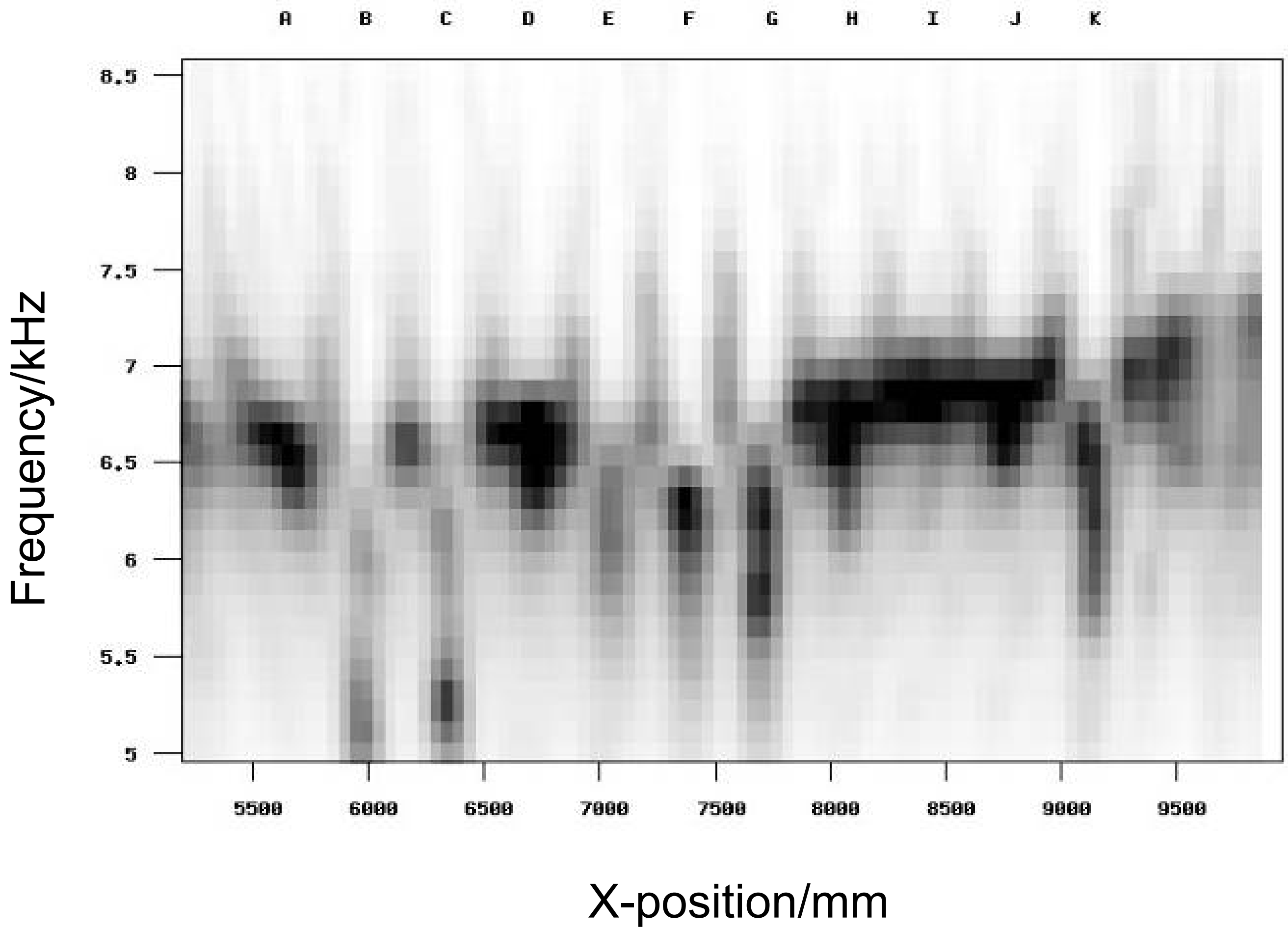


Impact-Echo:
Imaging of apparent thickness of slab (C-scan)

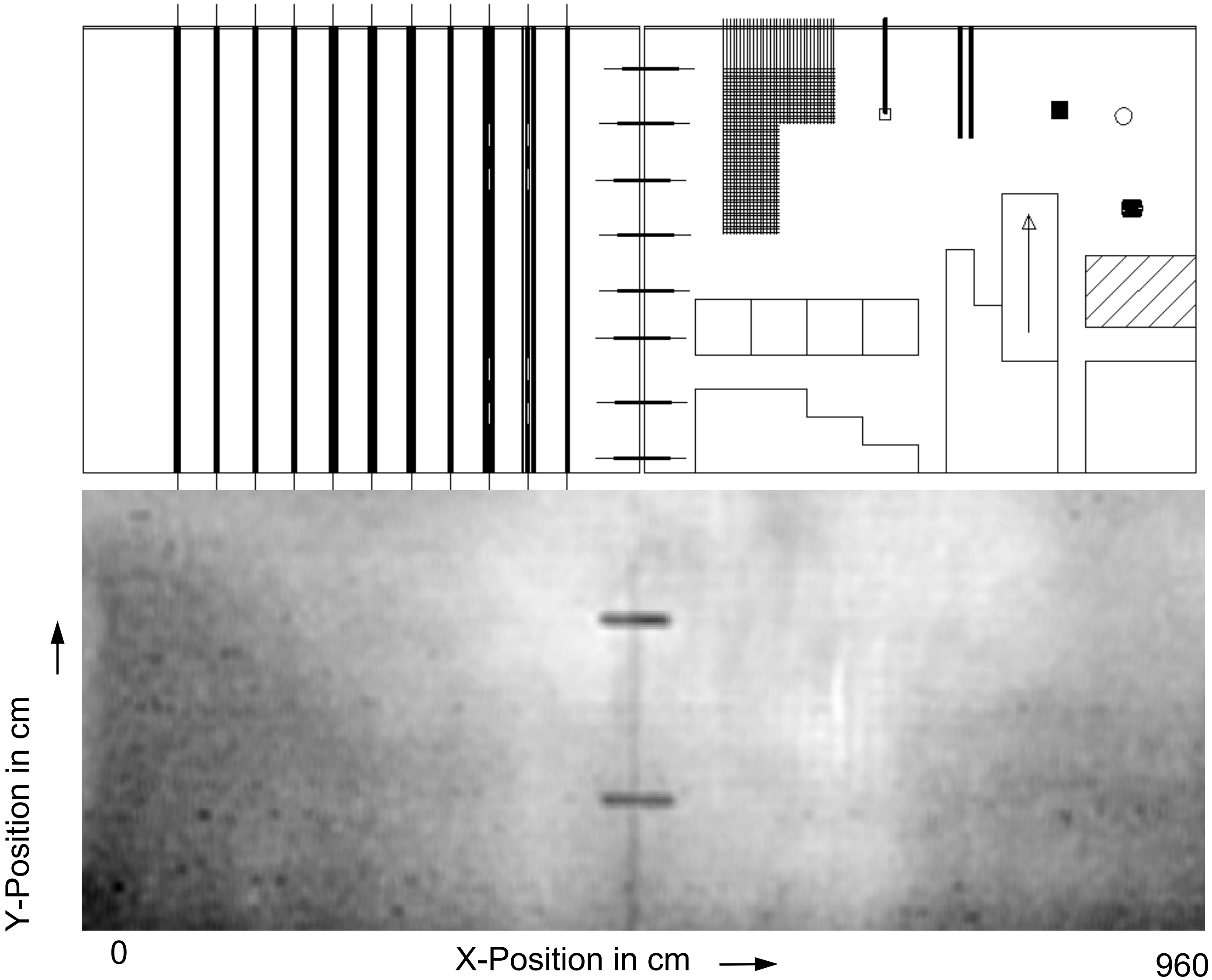
Indirect indication of grouting defects

Impact-Echo: D-Scan across Ducts

Shifting of back wall echo caused by the tendon ducts

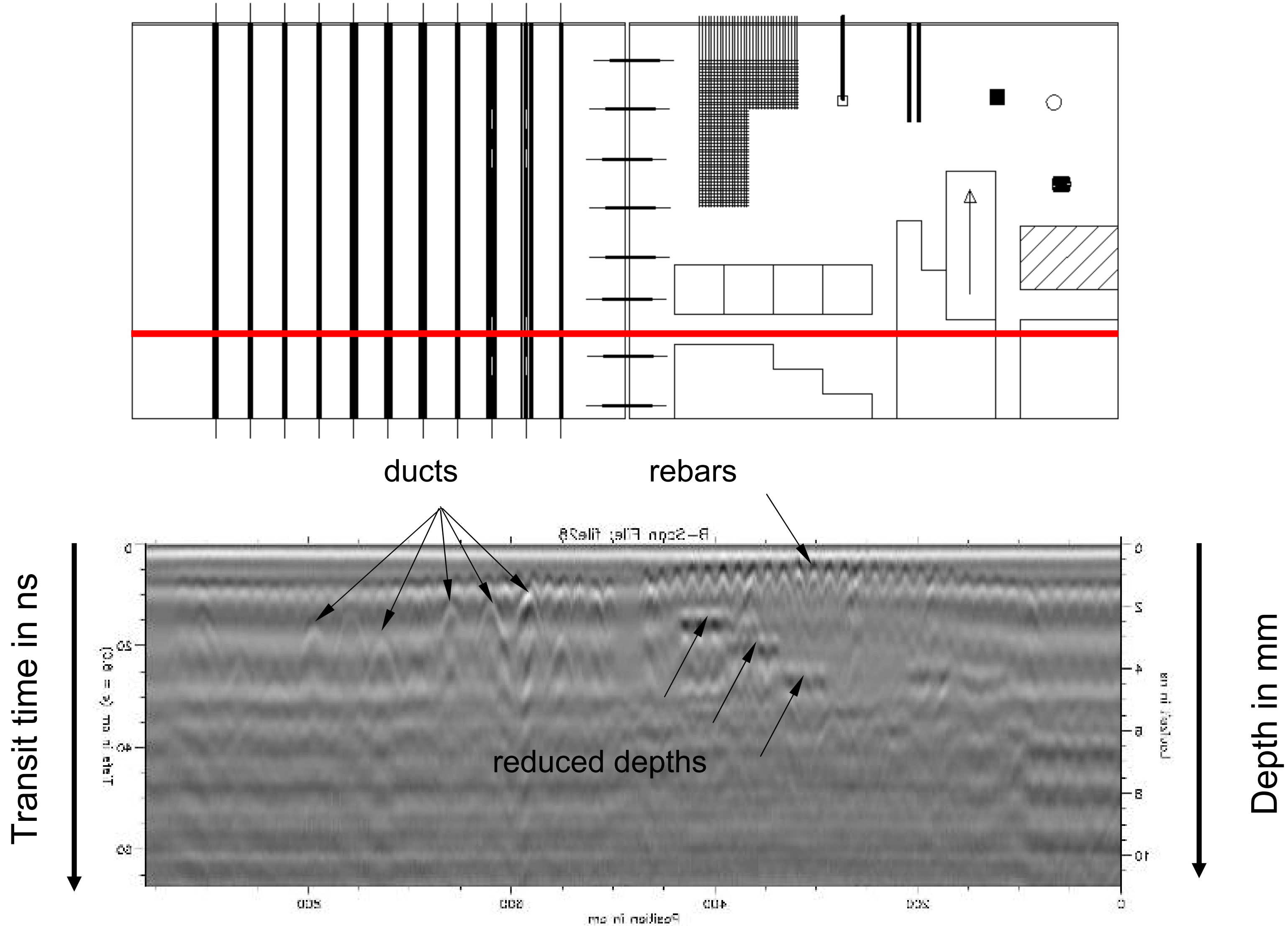


Raw data of GBP (3D)



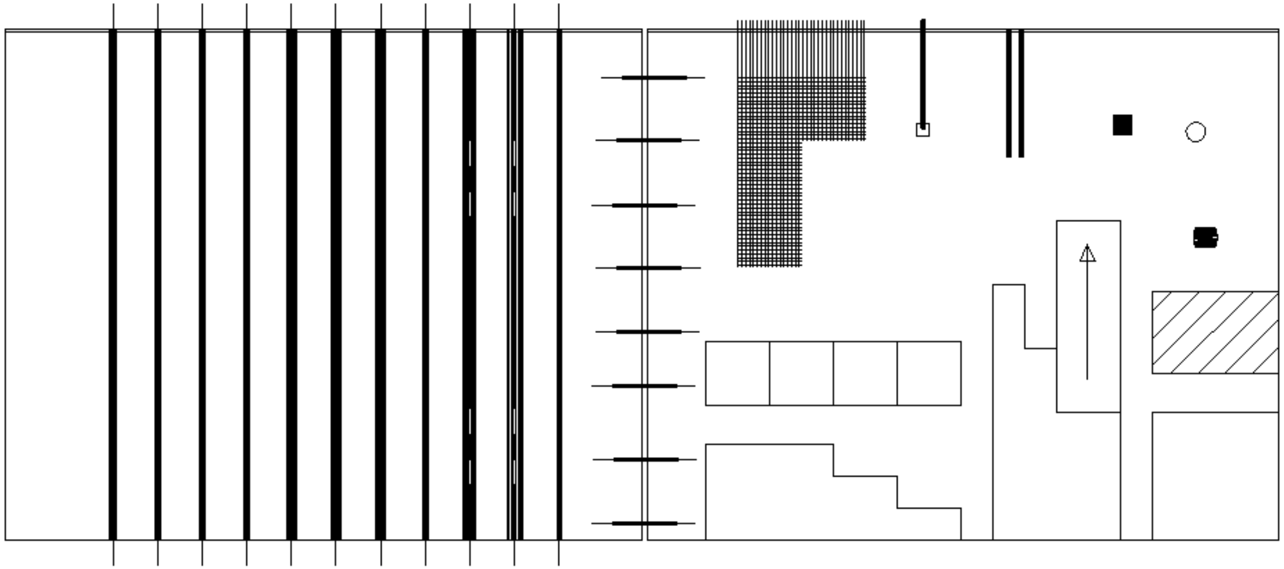
Validation

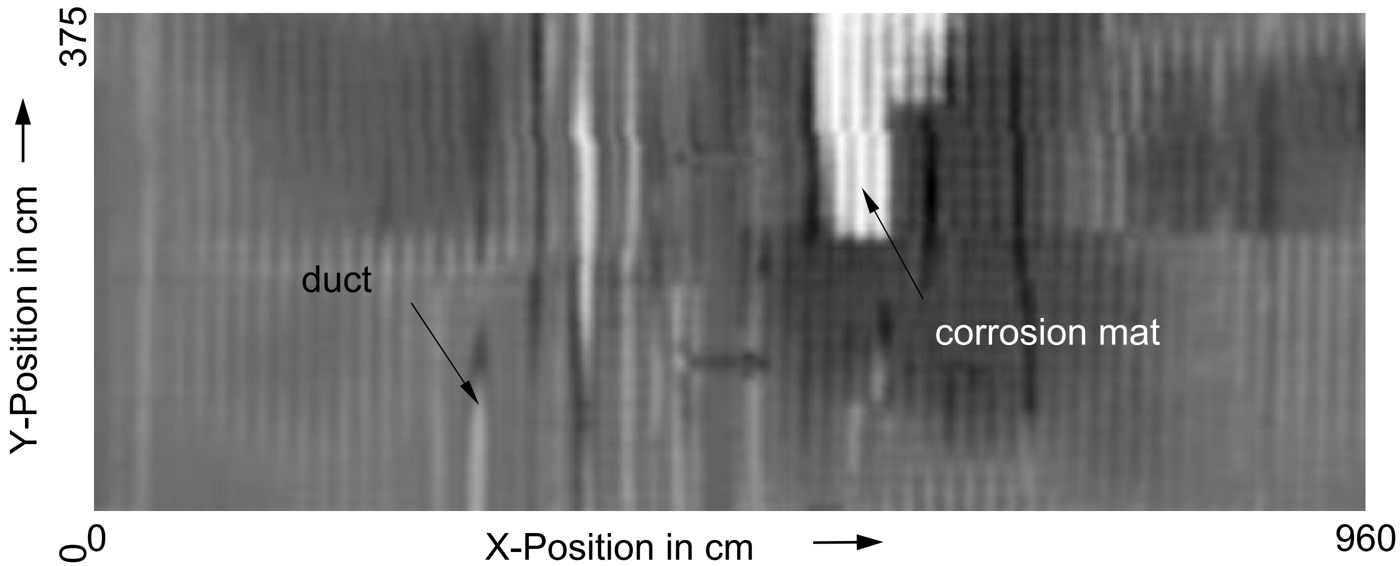
RADAR: Raw radargram of a long trace



Validation

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





Bridge Examples

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)

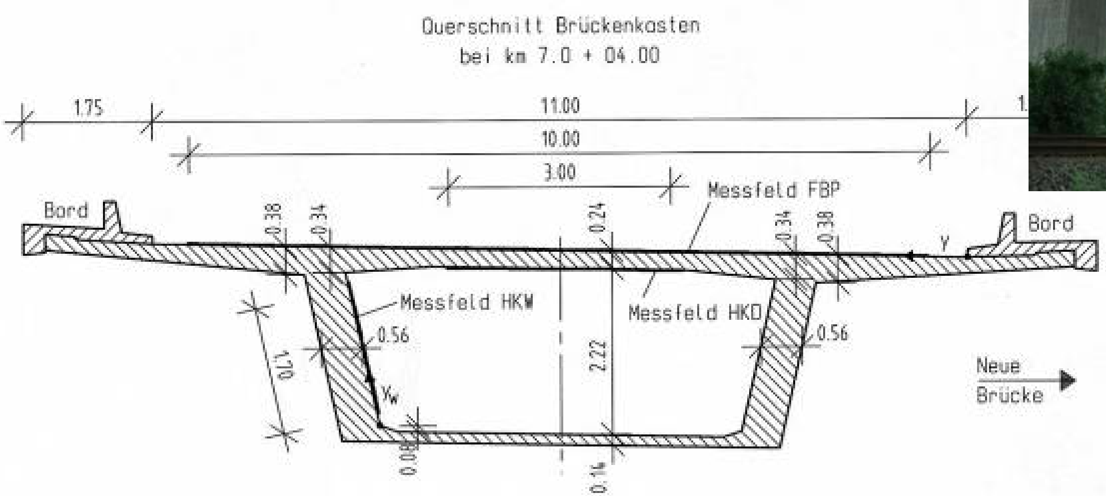
New: Large field investigation with automated scanning system for echo methods (2003)

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

See: P. Haardt
ThM-I

Construction

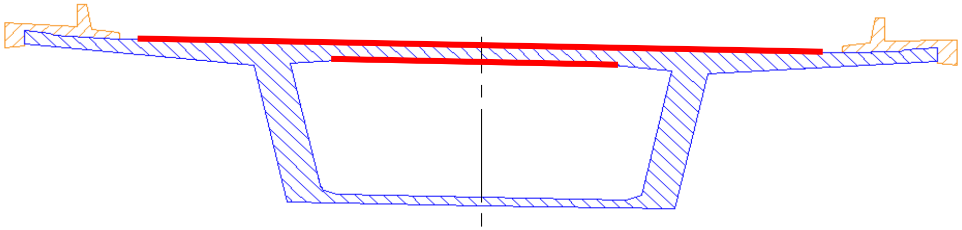
Cantilever unicellular box bridge
Length: 480 m
Prestressed in longitudinal and transversal direction
Constructed 1966, deconstruction 2004



- Radar
- Impact-Echo
- Ultrasonic Echo

Results

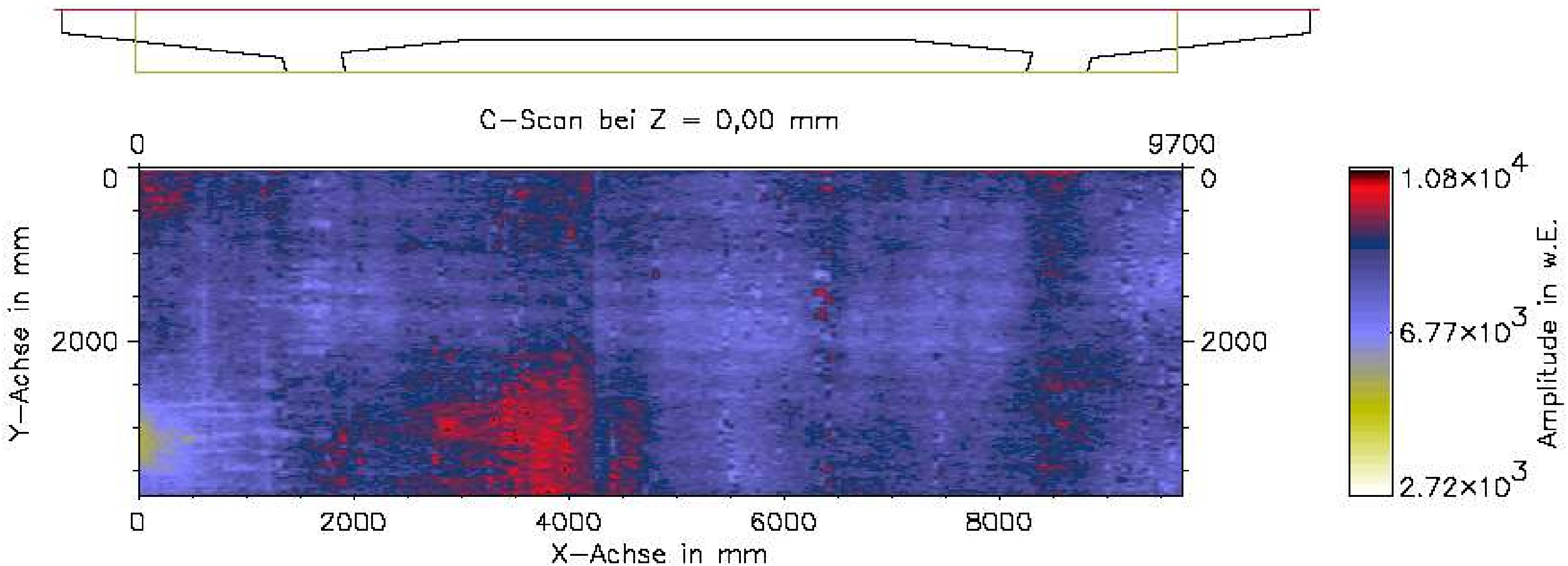
Measurements on a post-tensioned bridge deck



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

Bridge deck: of radar data from the top side and bottom side Superposition (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

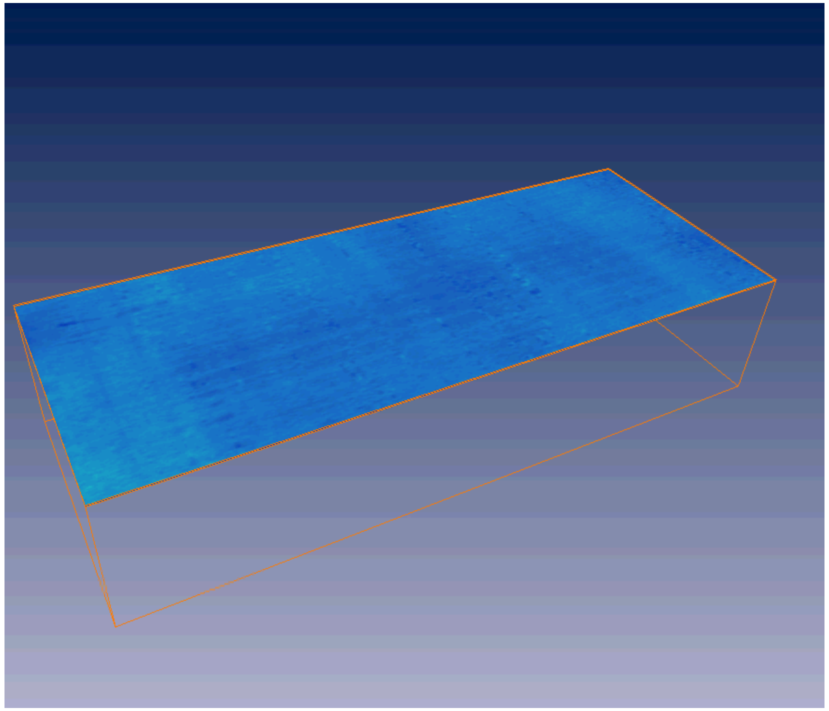
↓

3D-Reconstruction with SAFT

(Synthetic Aperture Focusing Technique)

↓

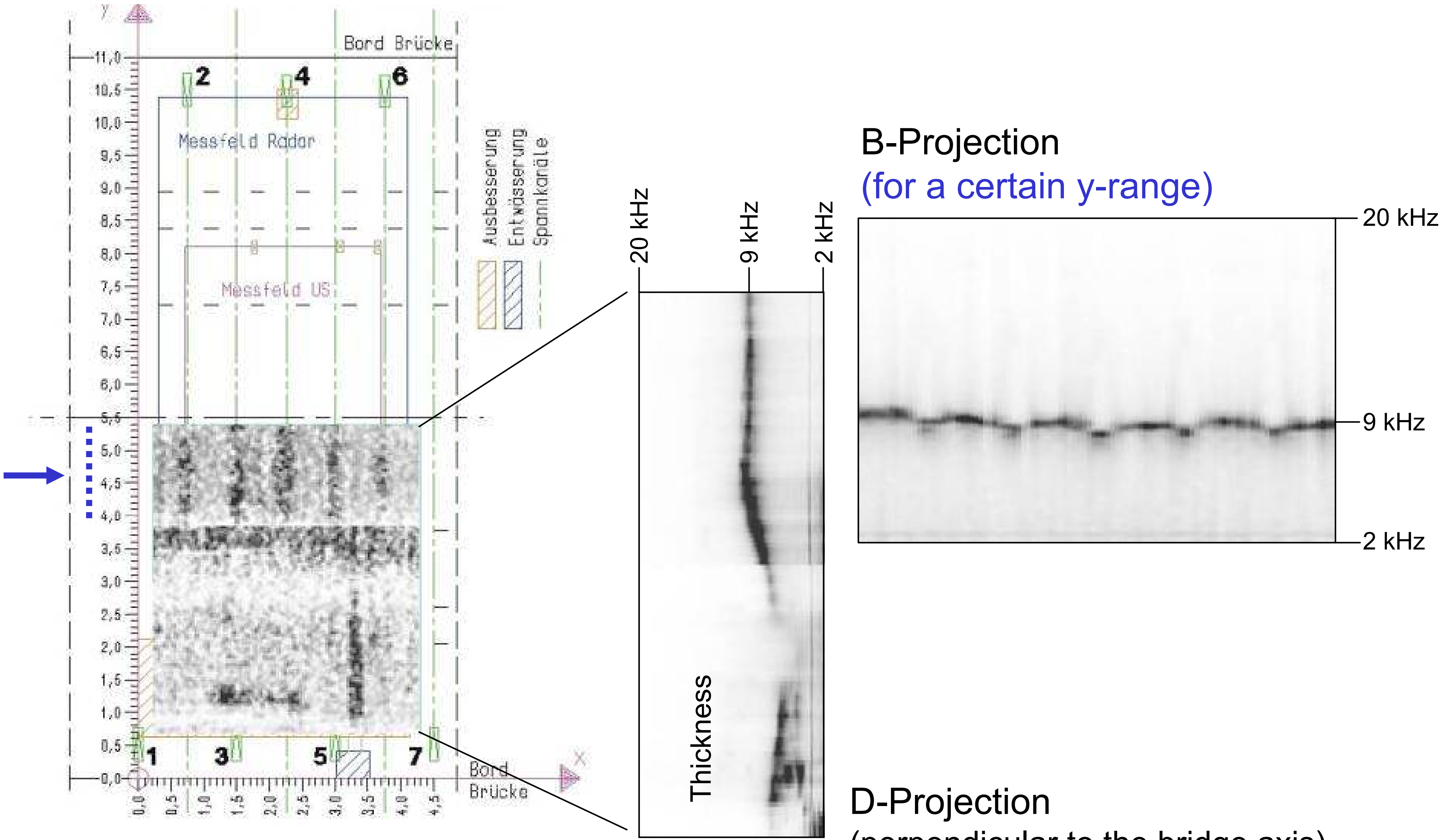
Data Fusion



Test Area 4.0 m x 10.0 m

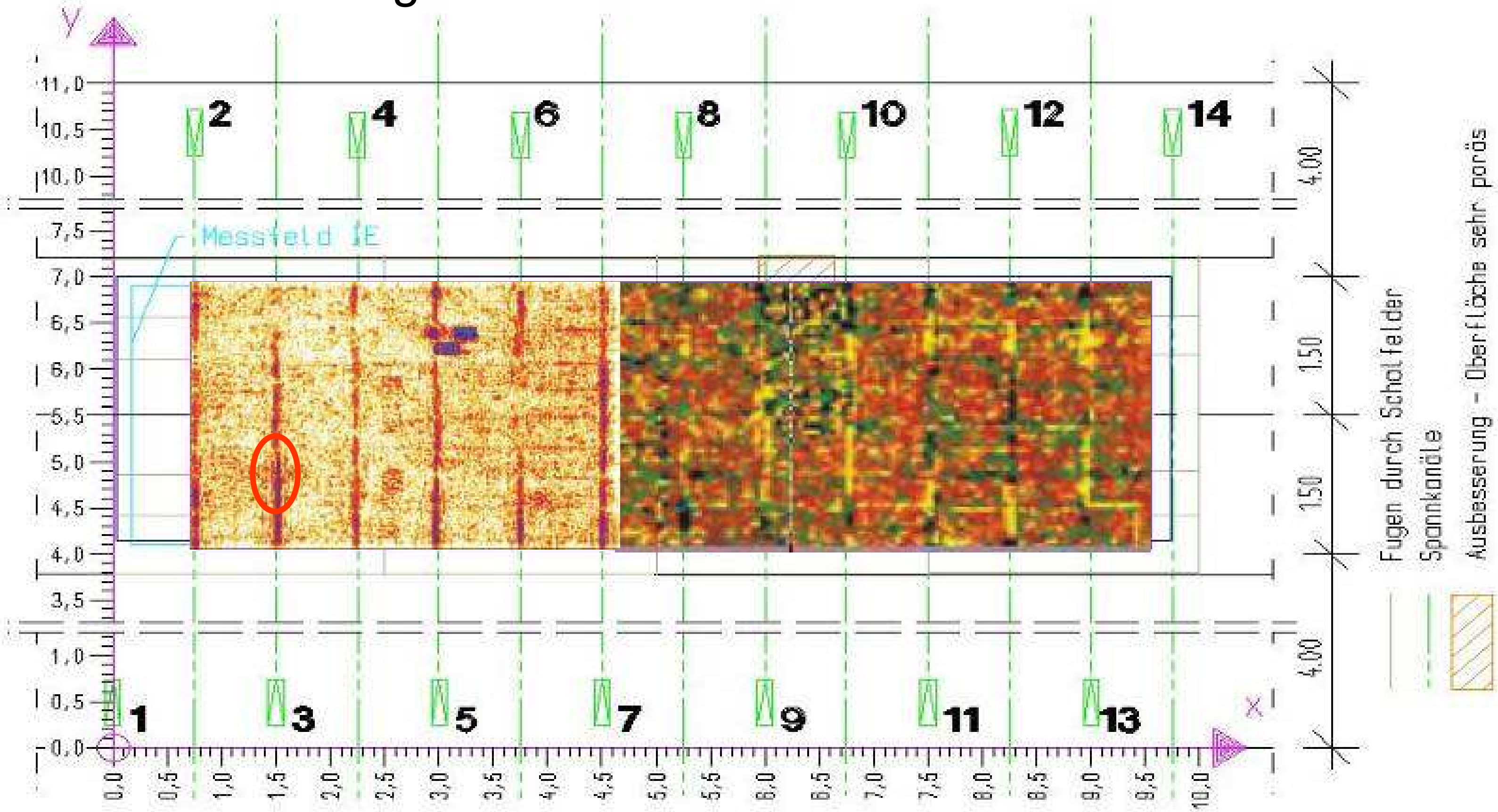
Duct investigation (Impact-Echo)

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



Ultrasound: Duct investigation

Bridge deck bottom side



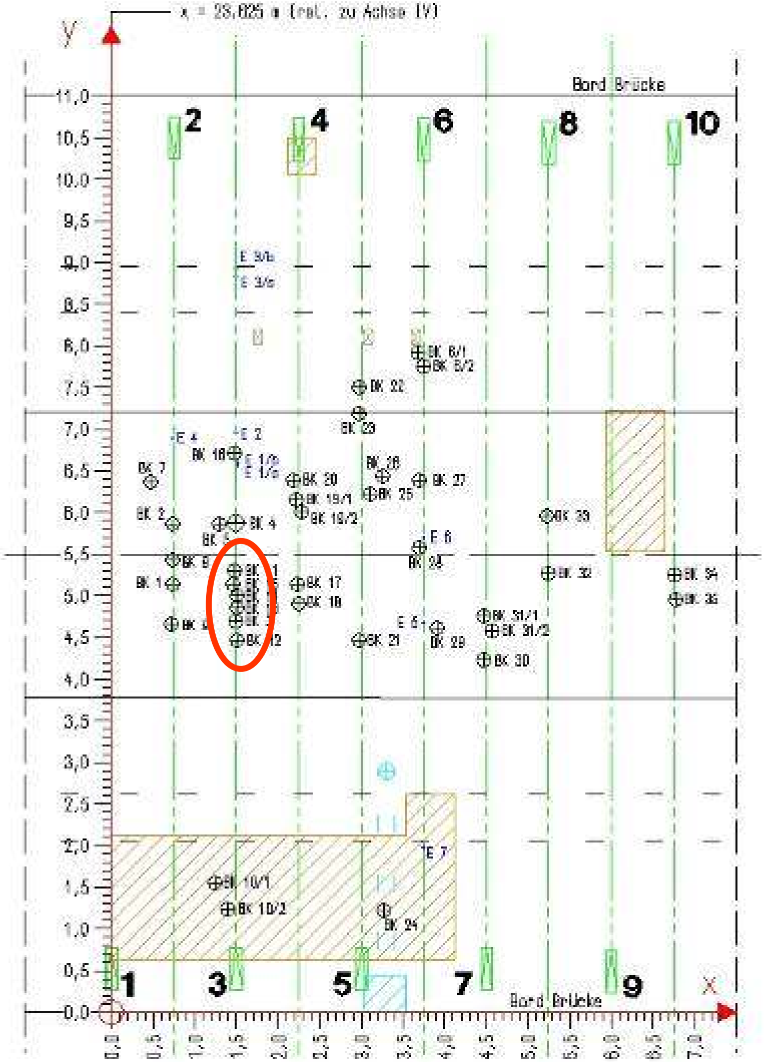
Left:
SAFT-C-Projection
depth 11,7 cm … 12,1 cm
step width 2,5 cm

High reflection intensity at both sides

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

Verification

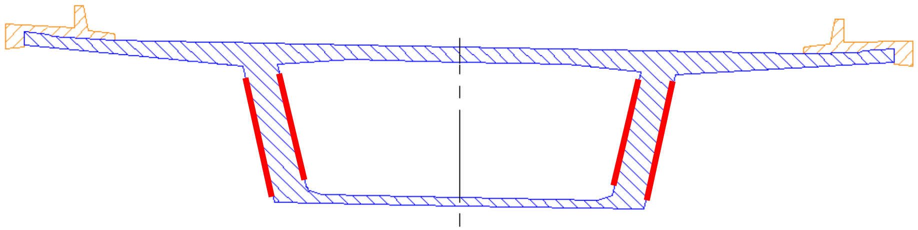
Bridge-deck: Destructiv testing: 35 cores, endoscopy



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

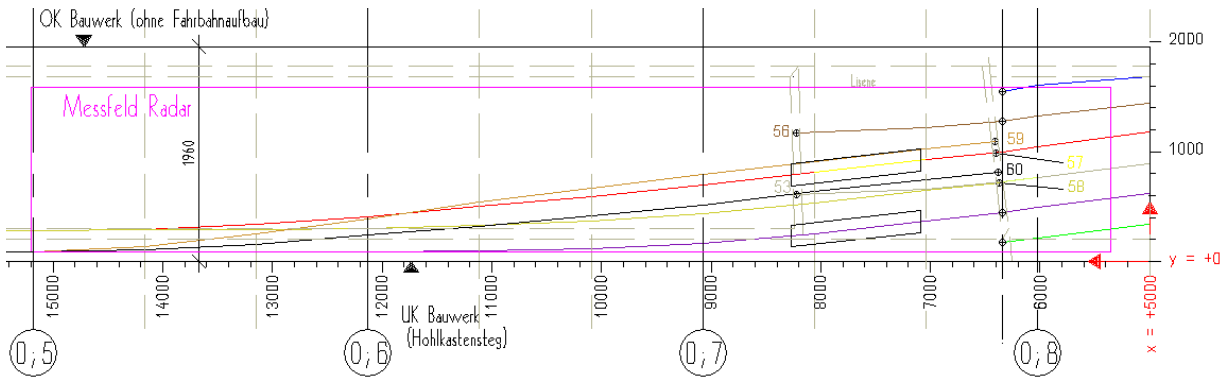
Box girder wall (longitudinal tendon ducts)

Measurements on webs of box girder bridges



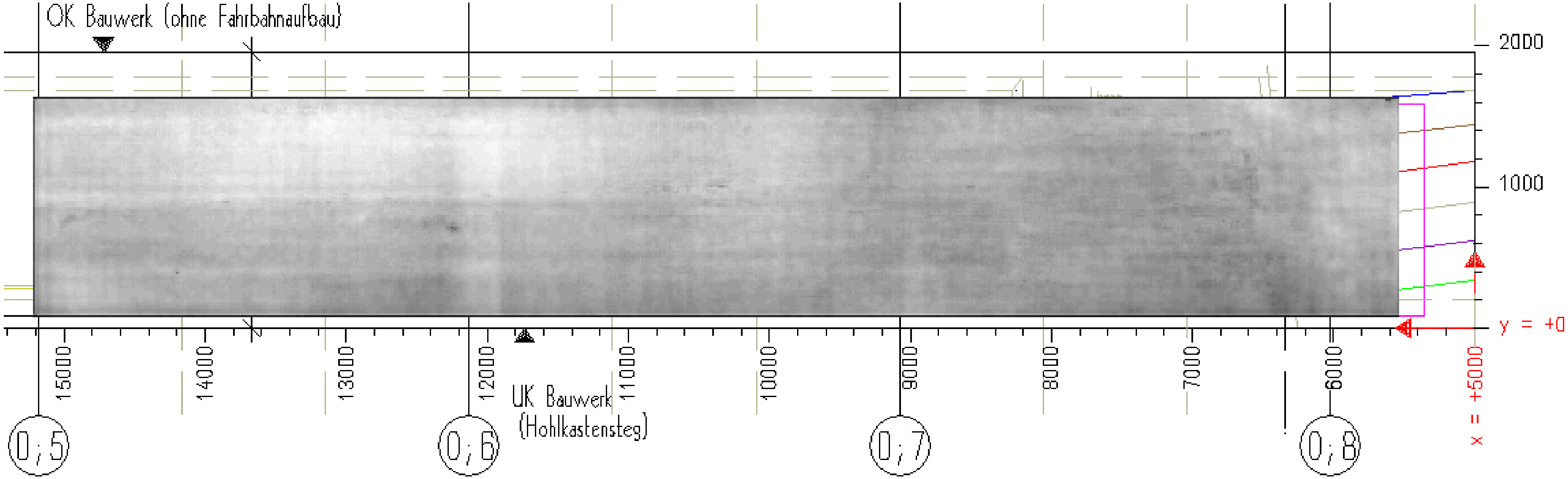
- thickness of the web 50 cm
  (83 cm in the area of anchoring of the pre-stressing)
- bridge under unaffected traffic
- simultaneous mounting of the impact-echo and ultrasonic sensors on the scanner

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



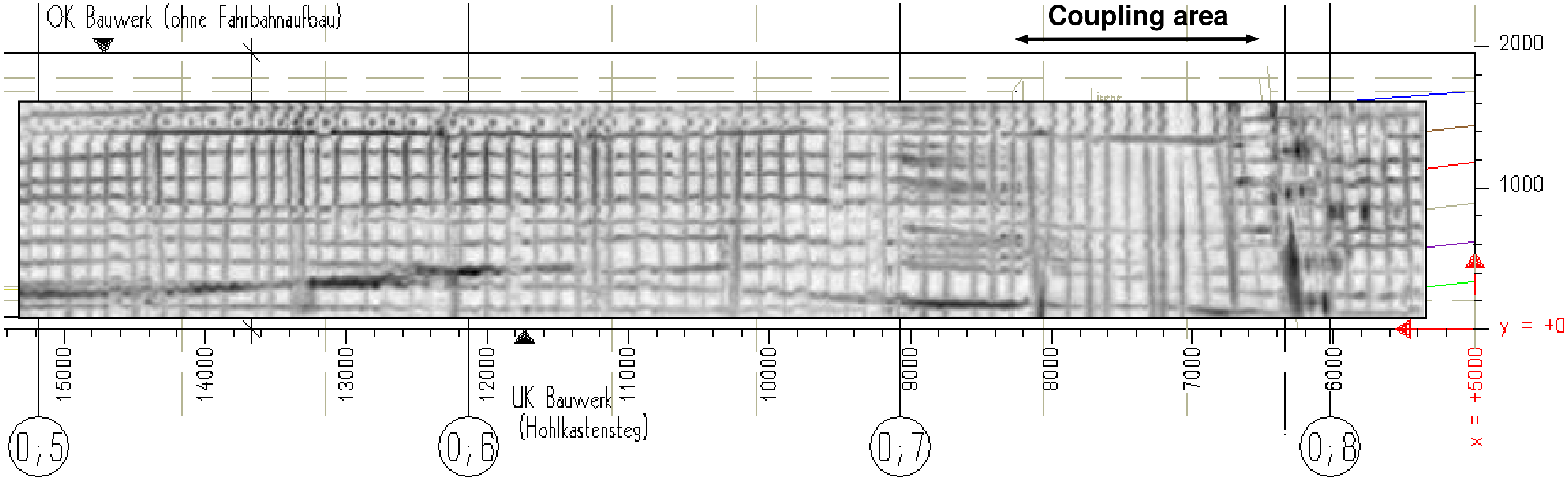
Data Fusion of Radar and Ultrasonic Echo

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



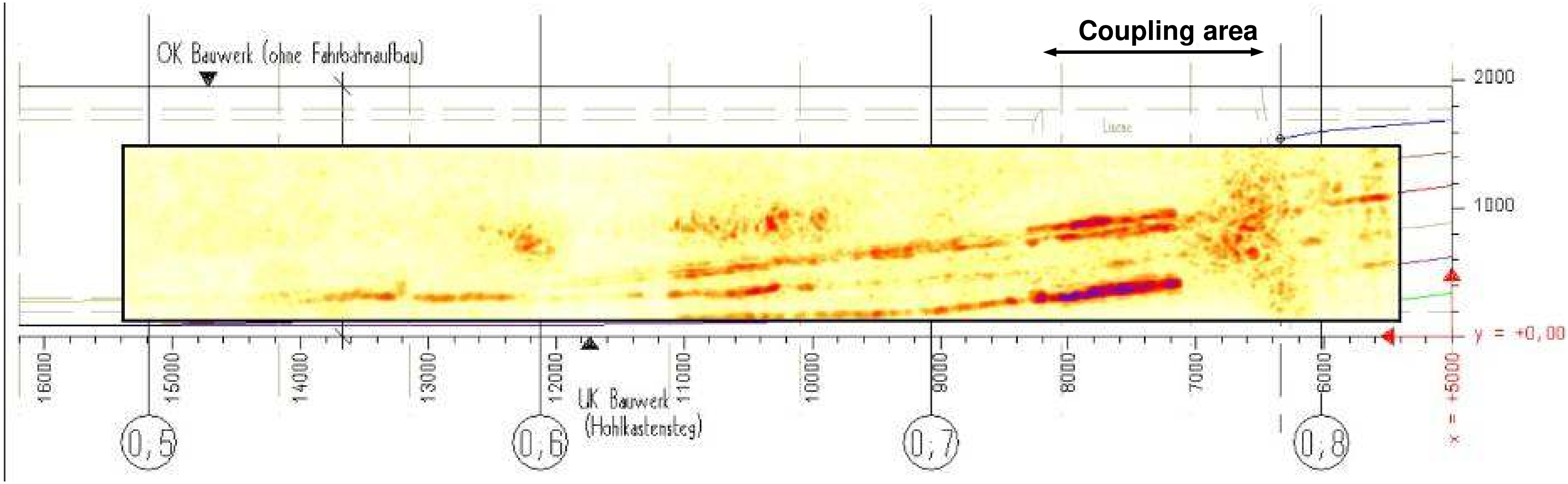
Animated sections parallel to the surface
through the measurement depths from 0 cm to 60 cm

Radar



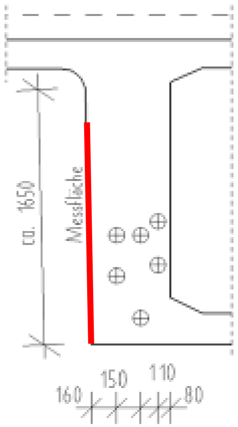
SAFT-C-Scan parallel to the surface in a measurement depth of 7.5 cm

Ultrasonic Echo



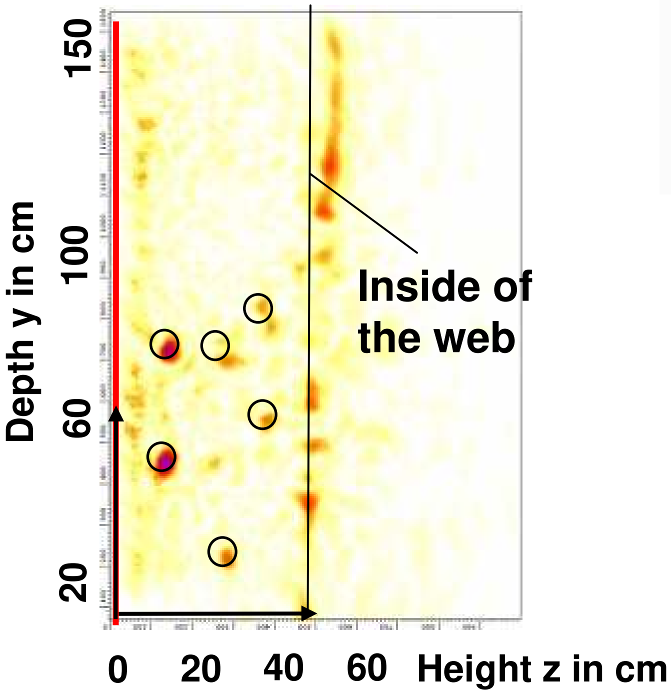
SAFT-C-Projection parallel to the measurement surface at the range of depth from 22 cm to 28 cm

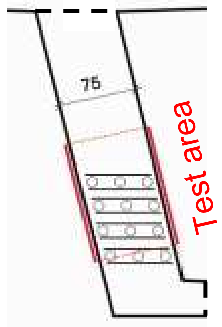
Ultrasonic Echo



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

SAFT-B-Scan

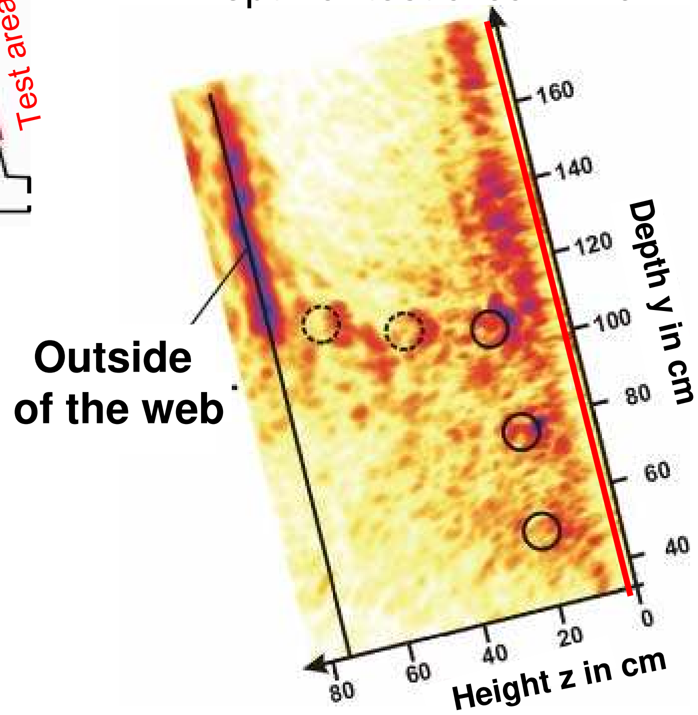




Box girder web
Thickness: 75 cm
Height of test area: 1.60 m

SAFT-B-Projection

Depth of test area: 1.20 m

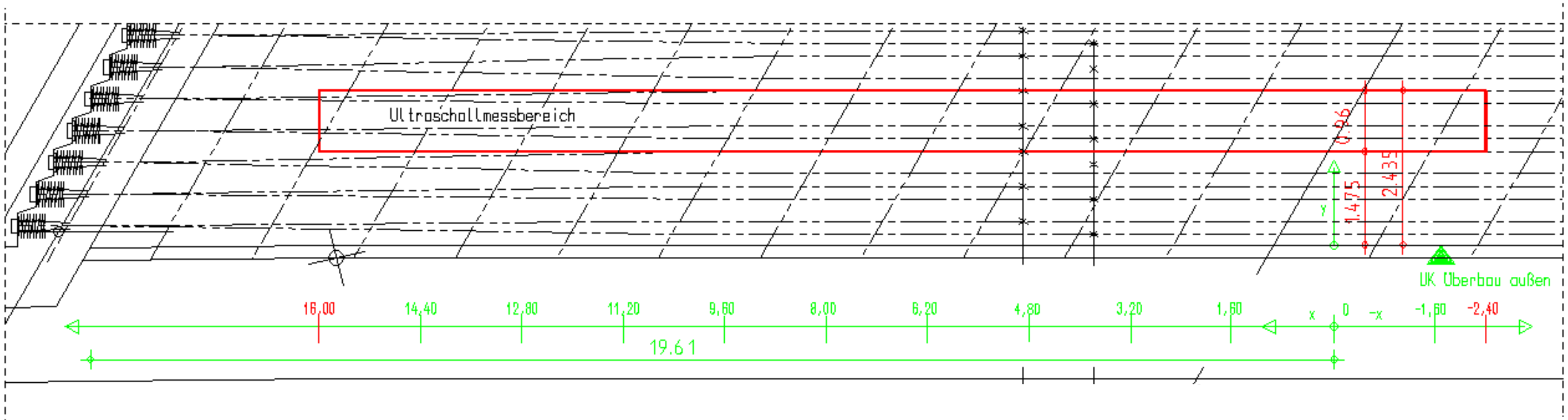


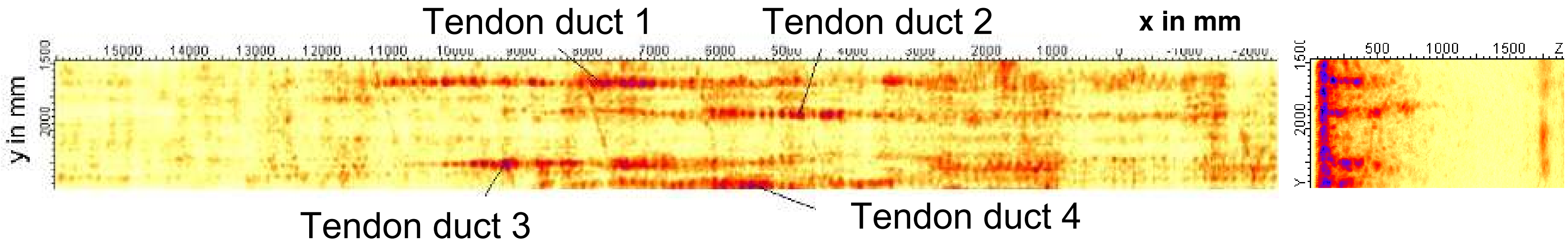
Measurements on a bridge deck, pre-stressed in longitudinal direction

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

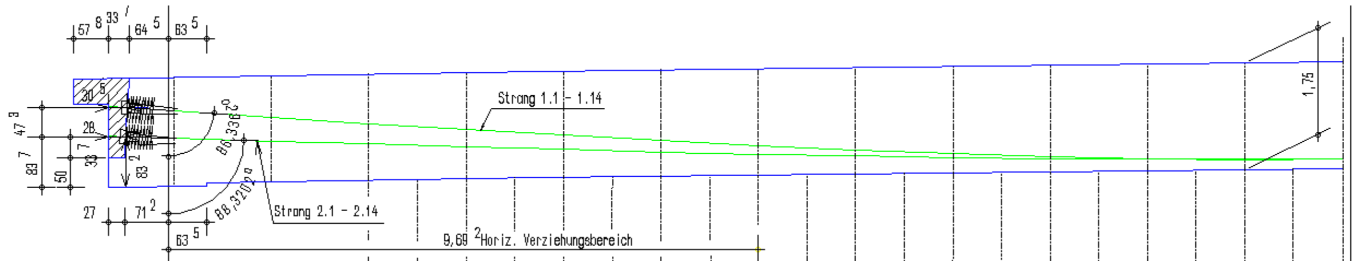


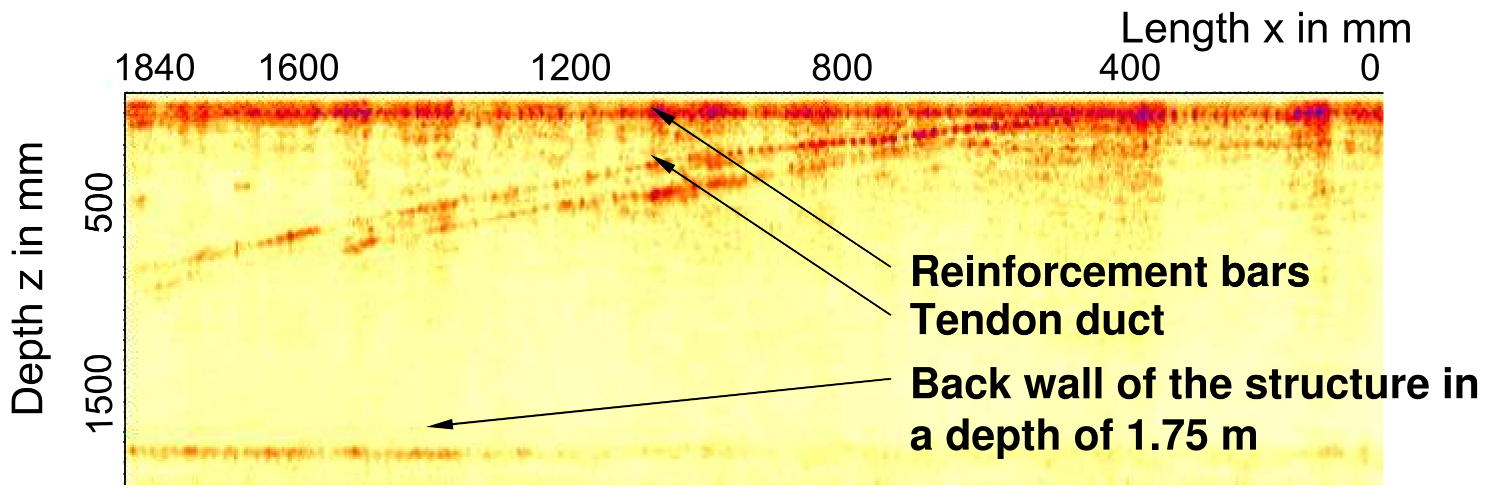


SAFT-C-Projection in the depth range of $z = 200 – 400$ mm

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

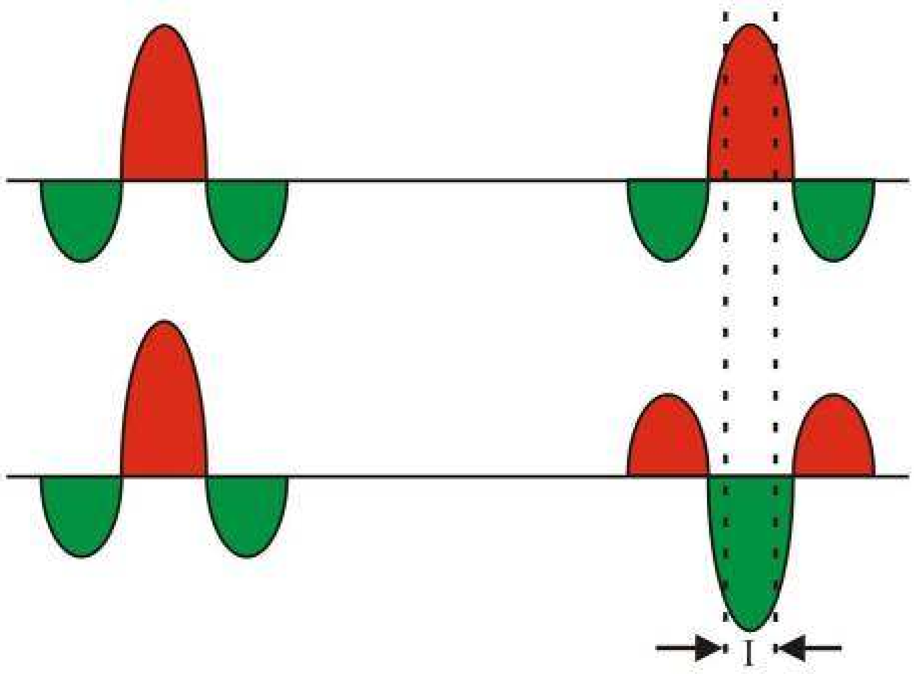
Evaluation of the Intensity of Ultrasonic Echo-Signals





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

Pulse Behaviour of Ultrasonic Echo-Signals



Transmitted pulse

Reflected pulse

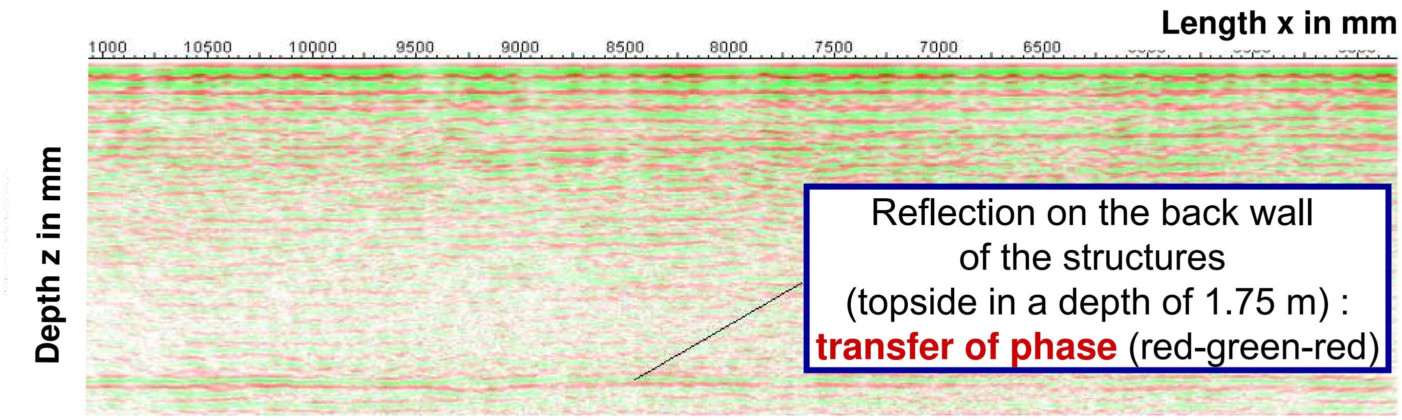
Reflections on steel in concrete

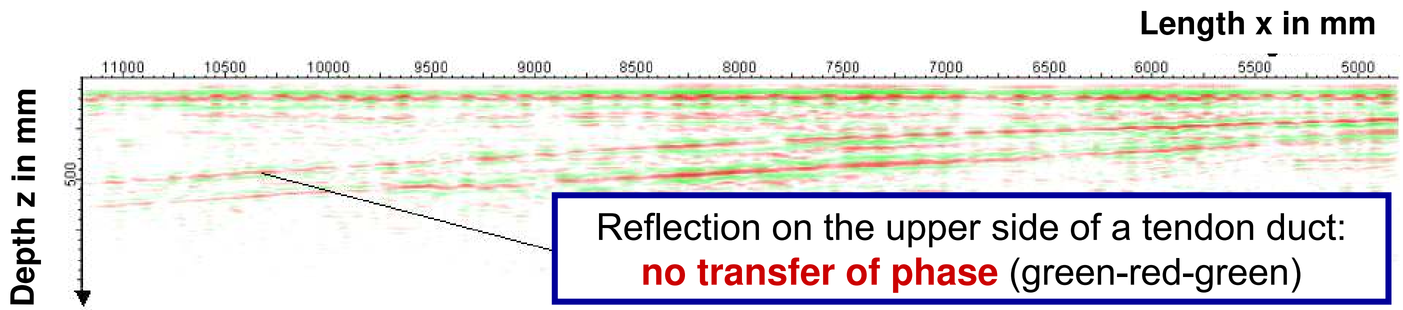
→ **No transfers of phase**

Reflection on air-inclusions in concrete

→ **Transfer of phase**

Evaluation of Pulse Behaviour of Ultrasonic Echo-Signals

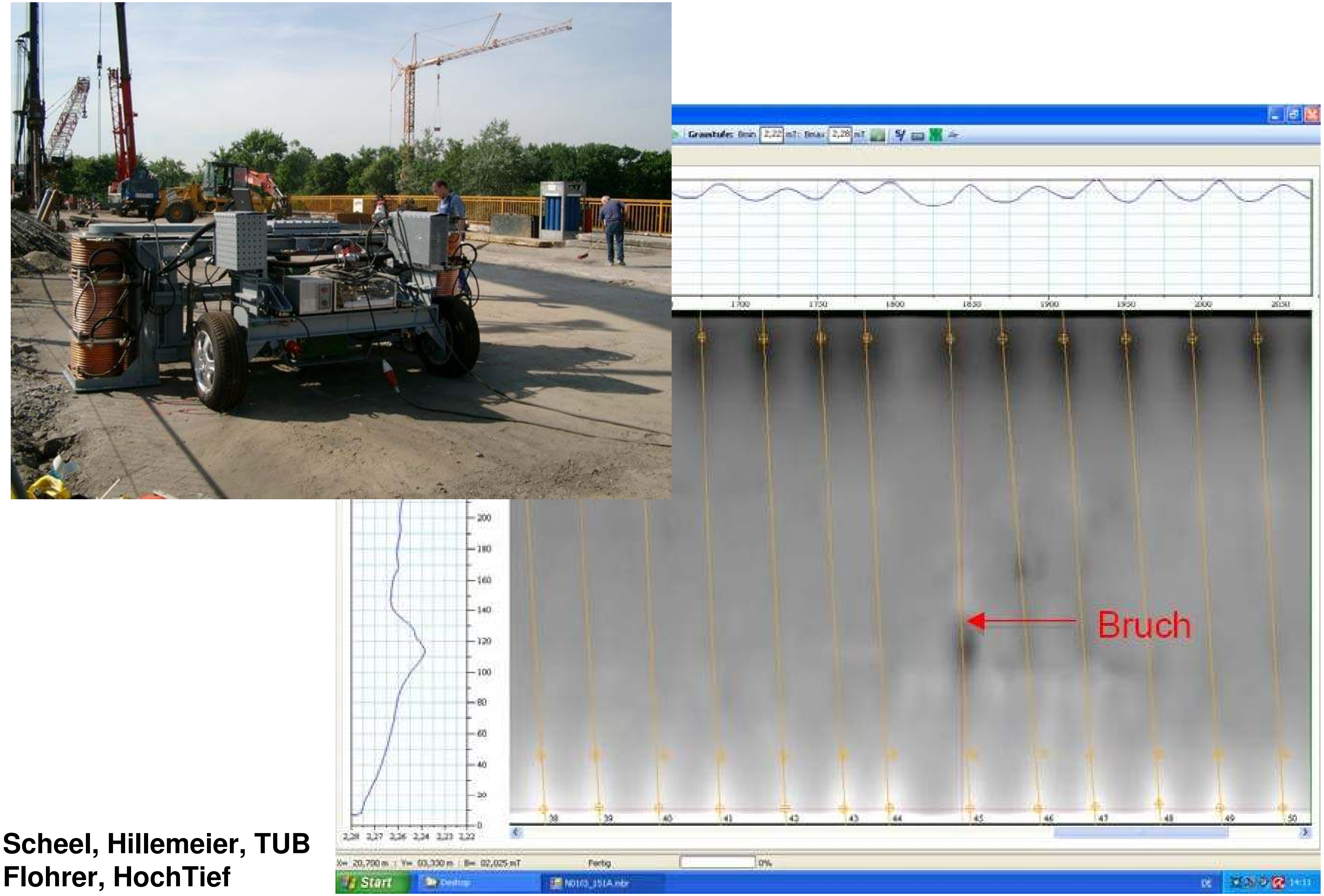




SAFT-B-Projection (Phase)

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

Locating tendon cracks in PT Concrete



Scheel, Hillemeier, TUB
Flohrer, HochTief

Conclusions

Conclusion

Automated Measuring system (scanner): Successful application at large concrete slab (LCS) and on bridges

- LCS is very well suited for comparison of test methods
- RADAR can localize tendons with high accuracy
- Ultrasonic echo (dry contact) can localize ducts and identify grouting defects
- Impact-echo gives indirect indication of grouting defects

Successful application at a post-tensioned concrete bridge:

Localization, Concrete Cover
reinforcing rebars, tendon ducts

RADAR:
Fast accurate 3D-imaging (Visualization)

- Measuring with high precision

Condition of tendon ducts

Impact-echo: Large area imaging and back wall echo shift

Ultrasonic echo: Direct imaging

- No clear indication of grouting faults

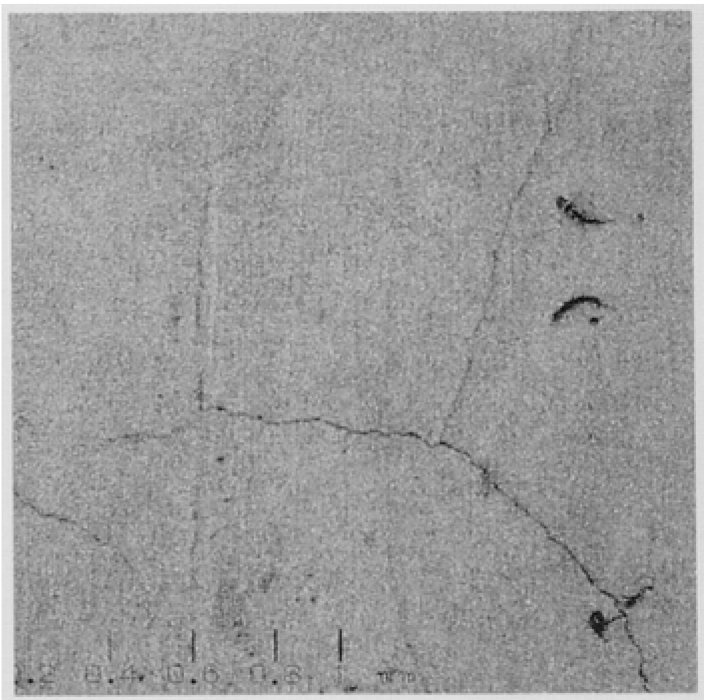
Verification
43 cores, endoscopy

Confirmation: No grouting fault

What‘s next?

Robot

- **Crack documentation on Metropolitan (1995) Highways Tokyo**
  (View area 2 x 2 m²)



Robot

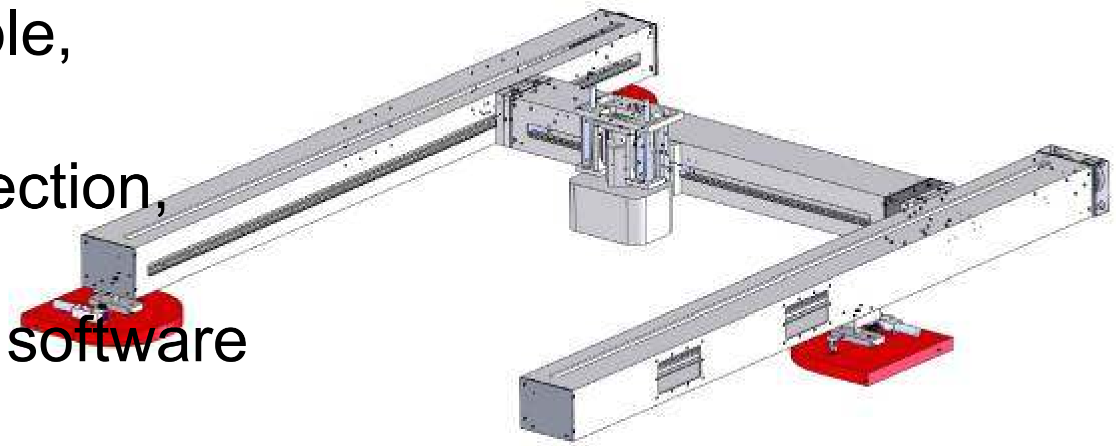
Video on YouTube: BestoScan

Self navigating Robot for horizontal surfaces (Park decks)

Robot: Possible sensors

Development of the On-Site SCAnneR (OSSCAR)

- **Requirements:**
  Robust, transportable,
  on-site results,
  controller, data collection,
  data analysis and
  presentation in *one* software



- **Consortium:** Integrated project OSSCAR
  founded by BMWi, Coordinator: BAM

Method combination in OSSCAR

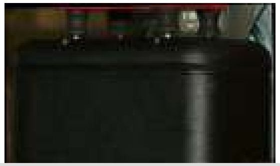
- Synergy by combination of radar, ultrasonic echo and eddy current

Radar

Suitable for metallic reflectors

Limited penetration depth (young concrete)

Ultrasonic echo



Larger penetration depth also in areas with high reinforcement ratio

Limited resolution of single rebars

Eddy current

Measurement of reinforcement diameter

Information only about upper layer

Calibration of radar (ε: dielectric constant)

First on-site application

- Bridge close to Frankfurt over the river *Main* (2009-Sep)

Robot

- **Climbing machine equipped with**
  - **camera**
  - **radar**
  - **impact-echo**
  - **...**

ROSY climbing machine (Yberle)

Robot

EC Project: Robosense

Thank you for attention !

Vienna City Administration

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FOR 384

Research group
supported by the DFG (Deutsche Forschungsgemeinschaft)

bast

ASFiNAG

ASV Fulda

UNI KASSEL VERSITÄT

Die Bahn DB

Sustainable Bridges

BAM Zerstörungsfreie Schadensdiagnose und Umweltmessverfahren VIII.2