Non-Destructive Testing in Civil Engineering

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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
• Concrete
  • 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

Radar gram with hyperbola

Position of antennas

Rebar

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

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 lightweight scanner with vacuum attachment
- 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
Validation

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

Indirect indication of grouting defects
Validation

**Impact-Echo:** D-Scan across Ducts

Shifting of back wall echo caused by the tendon ducts
Validation

Raw data of GBP (3D)
Validation

RADAR: Raw radargram of a long trace

Transit time in ns

Depth in mm

reduced depths

ducts
rebars
Validation

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

![Diagram showing a raw C-scan at a depth of 10 cm, indicating the presence of a duct and a corrosion mat.]
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)

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:
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

B-Projection
(for a certain y-range)

D-Projection
(perpendicular to the bridge axis)
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: Destructive 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)
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
SAFT-C-Scan parallel to the surface in a measurement depth of 7.5 cm
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

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

SAFT-B-Scan

Inside of the web

SAFT-B-Projection

Depth of test area: 1.20 m

Outside of the web
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

Reinforcement bars
Tendon duct
Back wall of the structure in a depth of 1.75 m
Pulse Behaviour of Ultrasonic Echo-Signals

Reflections on steel in concrete
→ No transfers of phase

Reflection on air-inclusions in concrete
→ Transfer of phase

Transmitted pulse

Reflected pulse
Reflection on the back wall of the structures (topside in a depth of 1.75 m): transfer of phase (red-green-red)

Reflection on the upper side of a tendon duct: no transfer of phase (green-red-green)

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:

<table>
<thead>
<tr>
<th>Localization, Concrete Cover reinforcing rebars, tendon ducts</th>
<th>RADAR:</th>
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<tbody>
<tr>
<td>Condition of tendon ducts</td>
<td>Fast accurate 3D-imaging (Visualization)</td>
</tr>
<tr>
<td></td>
<td>• Measuring with high precision</td>
</tr>
<tr>
<td>Verification</td>
<td>Impact-echo: Large area imaging</td>
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<tr>
<td>43 cores, endoscopy</td>
<td>and back wall echo shift</td>
</tr>
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<td></td>
<td>Ultrasonic echo: Direct imaging</td>
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<td></td>
<td>• No clear indication of grouting faults</td>
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<td></td>
<td>Confirmation: No grouting fault</td>
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What’s next?
• Crack documentation on Metropolitan (1995) Highways Tokyo (View area 2 x 2 m²)
Self navigating Robot for horizontal surfaces (Park decks)

Video on YouTube: BestoScan
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 ($\varepsilon$: 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

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Thank you for attention!