Magnetic Flux Leakage (MFL)

Non-destructive Detection of Fractures and Cracks at the Reinforcement of Prestressed Concrete Structures

Figure 1: Use of magnetic stray field measurement on the Kochertal Bridge BAB A 6.

Structures:	Roofs, halls, parking decks, bridges, tanks
Method:	**Magnetic Stray Field Measurement** (also known as Remanent-Magnetism-Method or Magnetic Flux Leakage (MFL)): non-destructive testing, no contact to the reinforcement is required, no interferences by layers (asphalt, coating, insulation)
Systems:	**MobiRem – Measurement System** REM 40: small measuring unit for bridge girders and roof or ceiling girders REM 150: medium measuring unit for road bridges, parking garages and container structures REM 350: large measuring unit for road and highway bridges Permanent magnets of different sizes
Power Supply:	Small measurement unit (REM 40) et. al. with standard voltage 230 Volts, middle (REM 175) and large measurement unit (REM 350) with 60 kVA and Isolation-monitoring

1. Magnetic Flux Leakage Method

Magnetic flux leakage method, also known as remanent magnetism method (RM-method) and prestressing steel fracture location, is a non-destructive test method with which cracks, cracks or pronounced corrosion areas in prestressing steels can be determined in prestressed concrete structures. It allows a quick and efficient examination and provides the result of a current state analysis of the tendons, which can be used for a mathematical estimate of the remaining load-bearing capacity of the structure. Depending on the respective influencing parameters, it is possible to determine cracks or breaks in tendons or wires with a cross-sectional reduction of approximately 20% of the total cross-section.

The magnetic flux leakage method can be carried out with prestressing steels both in the immediate bond (pre-fabricated concrete parts) and in the subsequent bond (in pressed cladding tubes) without the construction having to be destroyed locally.

With the test equipment available to IFDB-GmbH (see section 3 on page 4) we are able to examine nondestructive almost any prestressed concrete structure or prestressed concrete component for breaks in the tendons. The magnetic flux leakage method has already qualified for the following types of structures:

- Road slabs of bridge structures (road and highway bridges) with a checking performance of up to 3,600 m² per day,
- prestressed concrete beams of bridge structures,
- floor slabs of parking garages (parking decks),
- prestressed concrete girders of hall structures (swimming pools, sports and industrial halls) and floor ceilings,
- VT folds of hall roofs,
- Prestressed concrete tank.

The list of references at the end of this brochure provides an overview of the magnetic flux leakage method that have been carried out to date.

A measuring software specially programmed for the test procedure enables a first assessment of the condition of the component immediately after the measurement. The detailed evaluation of the measurement data follows analytically with computer support.

Failure of prestressing steels

There is a risk of failure of the tension wires in the case of prestressing steel grades that are sensitive to aging, inadequate corrosion protection or due to external influences such as the accidental drilling of the tendons.

Prestressed concrete structures that were manufactured before 1975 may be impaired in terms of durability and residual load-bearing capacity because prestressing steels are prone to brittle fracture. The "Neptun N40" and the "Sigma Oval" are among the prestressing prestressing steels sensitive to brittle fractures. Prestressing steels sensitive to stress corrosion cracking were installed until 1978. The hardened Hennigsdorfer prestressing steel up to the end of production in 1993 also shows this material sensitivity. The fracture sensitivity of these prestressing steels is independent of the ambient conditions, even if the cladding tubes are fully compressed.

Inadequate corrosion protection increases the probability of breakage of all prestressing steel grades, especially if chlorides penetrate the concrete due to diffusion through de-icing salts or aerosols (swimming pool atmosphere, disinfection).

2. The physical effect and the measuring principle

The magnetic stray field measurement, also known as the remanence magnetism method (RM method) and prestressing steel fracture location, is a non-destructive test method with which fractures, cracks or pronounced areas of corrosion in prestressing steels in prestressed concrete structures can be determined. It allows a quick and efficient investigation and provides as a result an up-to-date analysis of the condition of the tendons, which can be used for a computational estimate of the remaining load-bearing capacity of the structure. Depending on the respective influencing parameters, it is possible to detect cracks or breaks in tendons or tension wires with a cross-section reduction of around 20% of the total cross-section.

The magnetic stray field measurement can be carried out with prestressing steels both in an immediate bond (prestressed concrete elements) and in a subsequent bond (in pressed ducts) without the construction having to be opened locally and destructively.

Measurement software specially programmed for the test procedure enables an initial assessment of the condition of the component immediately after the measurement. The detailed analysis of the measurement data follows analytically with computer support.

The remanence magnetism method uses the ferromagnetic properties of the prestressing steel in order to localize breaks or cracks in the tensioning wires in a non-destructive manner. As a result of the earth's magnetic field, the use of lifting magnets during manufacture or other magnetic influences, the prestressing steel has an undefined magnetic field. In order to obtain a defined magnetic field required for the investigation, the tendon to be investigated is magnetized from the component surface. Stray magnetic fields occur at break points of individual tension wires, which are comparable to stray fields on broken bar magnets (dipole formation at the break point, see Figure 2 left).

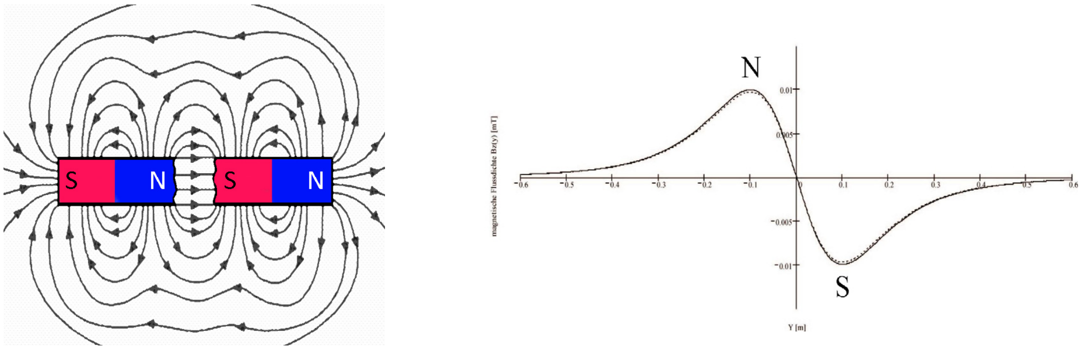


Figure 2: At the breaking point there is a magnetic north pole (N) and a magnetic south pole (S) opposite each other (picture on the left). The measurement signal (picture on the right) shows a characteristic course. Between the two poles (extreme values) is the turning point of the signal curve of the transverse component, which shows the exact center of the break point.

After magnetization, the magnetic flux density along the tendon course is measured and recorded on the concrete surface using magnetic sensors (e.g. Hall probes). From this measurement data, black-and-white scaled magnetic images are generated, which are analyzed with regard to the position and condition of the tendons. The magnetic flux density is composed of a transverse component (at right angles to the concrete surface) and an axial component (parallel to the concrete surface in the direction of the tendon). Tension wire breaks or possible broken signals cause a characteristic signal course (see Fig. 2 right), in which the break is at the point at which the transverse component has a turning point (dipole formation, pole change with turning point). These pole changes are recognizable in the magnetic images by a black-and-white change. If such fracture signals lie on the projection line of tendons, it can be assumed that they are fracture signals. These assumptions are then verified by a detailed analysis of the associated signal curves of the tendons.

The strength of the signal provides information about the cross-sectional weakening of the steel. Influence parameters for the measurement result are:

- the concrete cover (up to 25 cm),
- the arrangement and the degree of reinforced concrete reinforcement,
- steel components,
- metal-clad geomembranes.

3. The test devices of the MobiRem system

Depending on the type of construction or the course of the tendons, our various measuring units of the MobiRem system are used:

REM 40 (small measuring unit),

REM 150 (middle measuring unit),

REM 350 (large measuring unit).

The three measuring units work according to the principle of magnetizing the prestressing steel described above and then recording the magnetic stray field with the aid of magnetic sensors.

3.1. REM 40 (small measuring unit)

The small measuring unit consists of a small special magnet and a sensor unit, with which almost all prestressed concrete components in building and hall construction can be examined. In order to be able to magnetize the respective tendon, the special magnet is guided over the concrete surface on the projection of the respective tendon. The sensor unit is then guided over the magnetized area and measures the stray magnetic field of the tension wires or tendons.

Over the past 17 years, the REM 40 has been used for around 70 measurements on bridge structures, parking garages, hall and ceiling structures and prestressed concrete tanks.

The following auxiliary systems can be used to adapt the small measuring unit to the different courses of the tendons:

Mobile guide system for straight tendons that lie on the top of the component, e.g. for floor slabs of parking decks or roof structures of sports halls (e.g. VT folds).

Figure 3: Examination of VT folds in a swimming pool.

Lattice girder rail system with lengths of up to 18 m with straight tendons in bridge girders and roof or ceiling trusses. The lattice girder rail system can be used both standing and hanging and its height can be adjusted. This means that both the tendons in the underside and the laterally in the lower flange can be examined (example images on the following page).

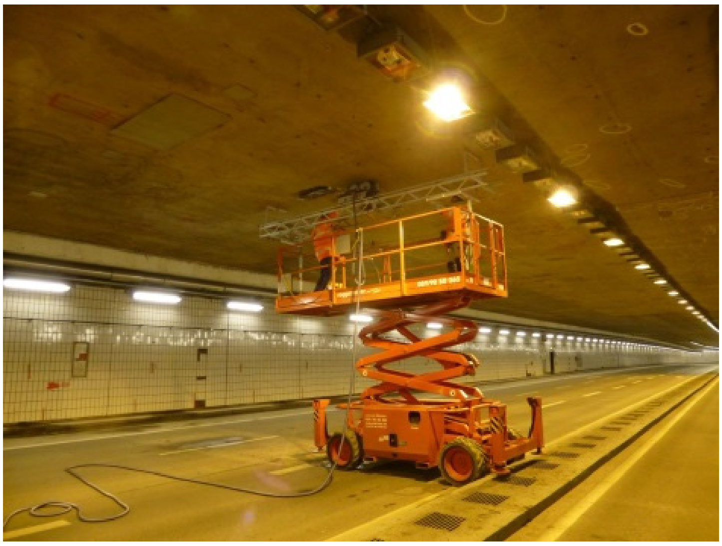


Figure 4: Examination of a tunnel ceiling.

Figure 5: Examination of bridge girders.

Figure 6: Examination of a prestressed concrete bridge with the help of a floating platform.

Figure 7: Examination of prestressed concrete girders in a sports hall.

Figure 6: Examination of double-curved hyperboloid shells (HP shells).

Figure 7: Examination of tendons of a digester.

Hanging pipe system with lengths up to 18 m with parabolic tendons e.g. Bridge girders or hollow box girders. The pipe system can be individually adapted to the tendon profile by means of holes in the beam itself or in the structure above.

Figure 9: Examination of bridge girders with parabolic tendons.

3.2. REM 150 (middle measuring unit)

The REM 150 (Figure 10) is based on the REM 350 and consists of an approximately 200 kg electromagnet with an attached sensor unit. The magnet has a width of 1.50 m and is mounted on a hand-held drive unit. The sensor unit measures both in the active magnetic field and in the passive (remanent) magnetic field. Due to the lower weight compared to the large measuring unit (REM 350), the REM 150 is very agile and easy to use. This qualifies him particularly for cramped measuring situations, e.g. Floor slabs in parking garages and narrow pedestrian bridges.

A test platform (Figure 10) has been developed for all three measuring units, which enables us to simulate special reinforcement arrangements for the tendons as well as for normal reinforced concrete reinforcement. The test platform is primarily used to prepare a measurement application, but can also be set up elsewhere for presentations of the measurement process if desired.

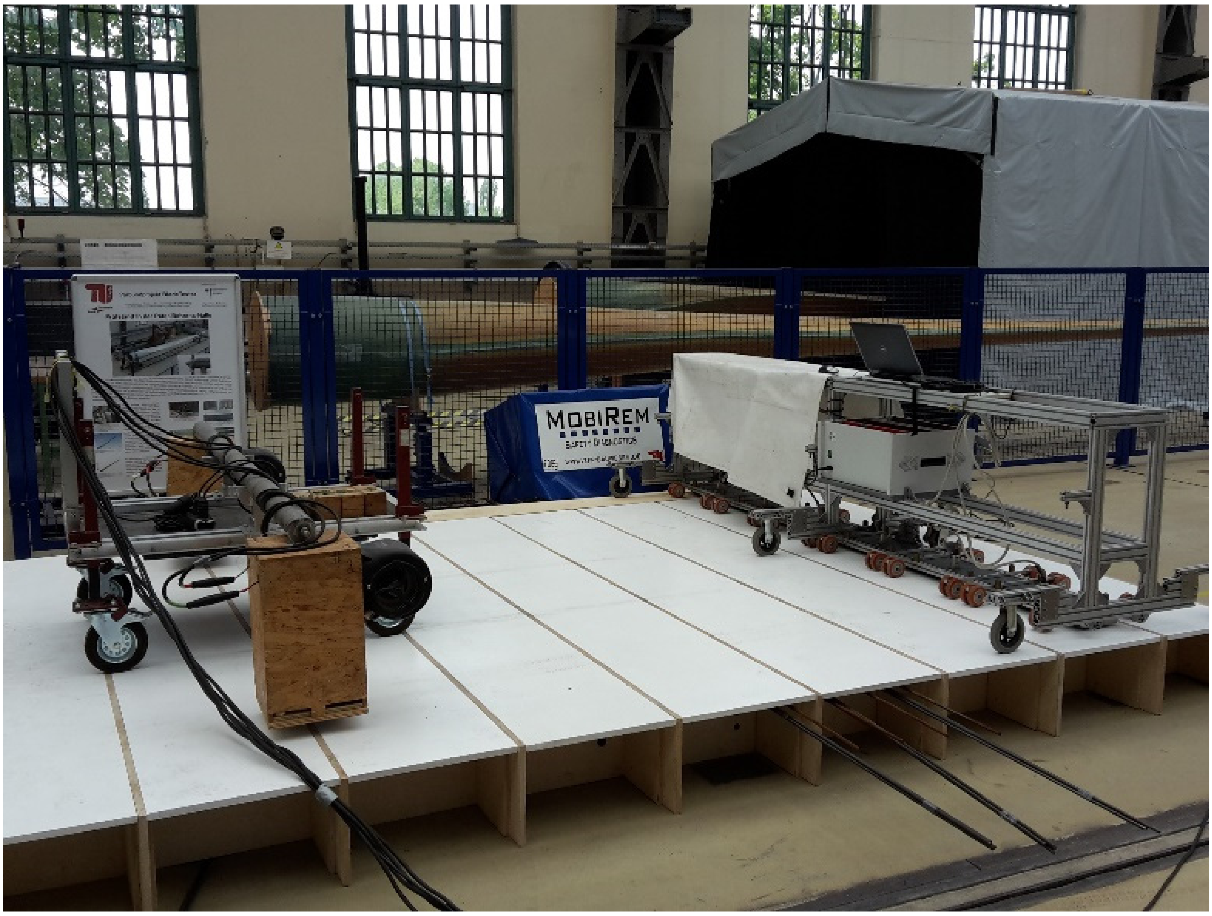


Figure 10: Test platform for re-adjusting individual reinforcement arrangements for prestressing steel as well as for slack steel, suitable for each of the three measuring units (REM 40, REM 150 and REM 350).

A lifting platform has been designed for the REM 150 for the examination of prestressed tank containers (Figure 11), which enables a vertical examination of the horizontally running tendons in the wall plane. Wall areas with an area of up to 600 m² are examined non-destructively for prestressing steel breaks in about three days.

Figure 11: Examination of horizontally running tendons in the wall area of prestressed tank containers using a lifting platform.

About 15 prestressed concrete tank containers and 2 bridges have been examined with the REM 150 in recent years.

3.3. REM 350 (large measuring unit)

In Germany, almost 70% of the bridge structures on federal highways are constructed as pre-stressed concrete structures (as of 2004). Due to the trust in pre-stressed concrete construction at the time of motorway bridges from the 1950s to 1970s, these structures were often constructed with too little reinforced concrete reinforcement. For this reason, the integrity of the prestressing steel is so important for the stability of the bridge structures, especially since prestressing steel breaks can lead to failure without prior notice.

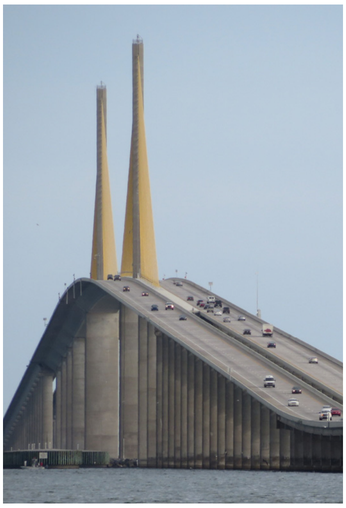
In prestressed concrete bridge structures, the cross tendons with partly small concrete coverings lie in the carriageway slab. The condition of the tendons must be kept in mind with regard to the increasing traffic in the German road and motorway network, the type of prestressing steel used and the use of de-icing salts. The requirements for the examination methods of cross tendons in bridge structures are freedom from destruction, speed, low traffic obstruction and the resulting economy. All criteria are met with the large measuring unit (REM 350).

The REM 350 consists of a controllable electromagnet, mounted on an electrohydraulically driving unit and an attached sensor unit. The driving unit with the electromagnet has a weight of three tons and a width of 3.50 m. The REM 350 runs the bridge structure in the longitudinal direction. During the passage of the transverse tendons lying crossways in the carriageway slab, they are magnetized. The tracked sensor unit records the stray magnetic field of the magnetized tendons. In contrast to the REM 40 measuring unit, it is not necessary to locate the tendons with other non-destructive examination methods before the measurement. A one-time crossing is also sufficient to obtain the desired magnetic information of the cross tendons. The REM 350 thus enables quick and meaningful non-destructive testing of the cross tendons in roadway slabs of bridge structures. The advantages of this measuring system are summarized below:

- the measurement can be carried out regardless of the surface condition of the bridge carriageway slab (asphalt surface course / milled concrete surface),
- the width of the measurement data acquisition of the attached sensor unit is 3.0 m,
- no previous position determination of the cross tendons with e.g. GPR,
- up to 1,200 m of a lane can be measured per day corresponding to an area of approximately 3,600 m²,
- the measurement software enables a first assessment of the condition immediately after the measurement,
- A detailed assessment of the measurement data will be made later using a computer-aided fine evaluation.

Around 30 bridge structures have been examined with the REM 350 in the past eleven years e.g. the Kochertalbrücke, the Schüpfbachtalbrücke, the Taubertalbrücke and the Sunshine Skyway Bridge (USA / Florida), as well as 3 parking garages. The result of the evaluated measurement data reflects the actual condition of the cross-tendons and enables the client to realistically assess the load reserves and the reliability of his structure.

(a)



(b)

Figure 12: Prestressed concrete highway bridges. The transverse tendons in the bridge slab were examined, which are highly susceptible to corrosion through the use of de-icing salts (a: Schüpfbach Valley Bridge BAB A 81, b: Sunshine Skyway Bridge Florida / USA).

Figure 13: Examination of the slab of a highway bridge in Wolfsburg.

Figure 14: Examination of the carriageway slab of a highway bridge on the BAB A 81.

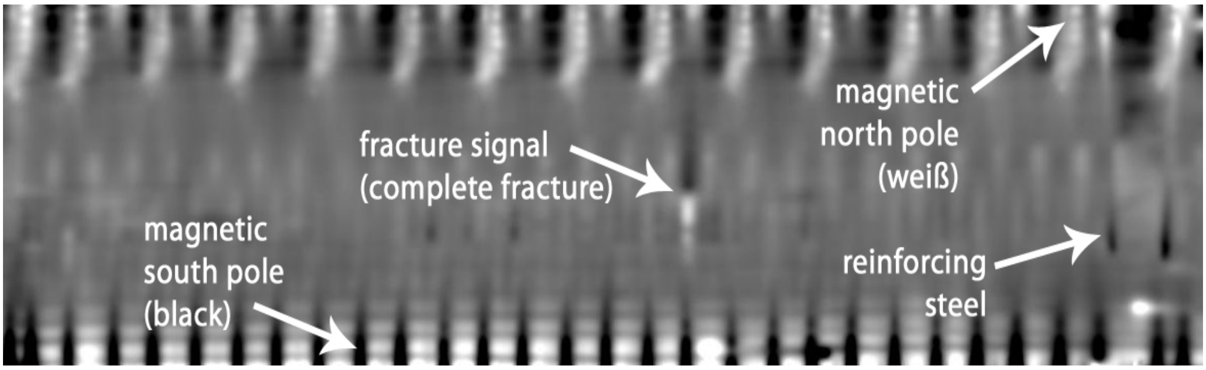


Figure 15: Evaluated magnetic image of a measuring track with the RM 350 with identification of the tendons and a fractured signal.

4. Literature

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5. References - Performed Projects

Bridges:

2002	Fuldatal Bridge; Hessian Road and Traffic Administration (HSVV)
2003	Spandauer Damm Bridge, Berlin; Senate Department for Urban Development Berlin
2004	Highway Bridge Bismarckstraße, Leverkusen
2006	Mörsch Bridge, Berlin; Senate Department for Urban Development Berlin
2007	Elsen Bridge, Berlin; Senate Department for Urban Development Berlin
2007	Lahntal Bridge, Wetzlar Ost; Hessian Road and Traffic Administration (HSVV)
2008	Husberg Bridge, Werdohl; City Administration Werdohl
2008	Spandauer Damm Bridge, Berlin; BASt, Bergisch Gladbach
2008	Champlain Bridge, Montreal – Kanada; Vector Corrosion Technology
2008	Footbridge KaDeWe, Berlin; Karstadt AG
2009	Champlain Bridge, Montreal – Kanada; Vector Corrosion Technology
2009	Hannoversche Bridge and Hohenfelder Bridge, Hamburg; State Office for Roads, Bridges and Waters Hamburg
2009	Uttrichshausen Viaduct BAB A 7, Fulda; Hochtief Construction Materials AG
2009	Lützelbach and Marbach Viaducts, BAB A 45; Hochtief Construction Materials AG
2010	Uttrichshausen Viaduct BAB A 7, Fulda; Hochtief Construction Materials AG
2010	Jubilee Overpass (Road bridge), Winnipeg – Kanada; Vector Corrosion Technology
2011	Lahntal Viaduct Dorlar BAB A 45, Wetzlar; Hochtief Construction Materials AG
2011	Taubertal Viaduct BAB A 81, Tauberbischofsheim; Leonhard Weiss GmbH & Co. KG
2012	Highway Bridge BAB A 81 bei Eubigheim, Abschnitt AS 4 Ahorn – AS 5 Boxberg; Englert Engineering office
2012	Road Bridge on Federal Highway 6, Hildesheim; Hochtief Construction Materials AG

2012	Taubertal Bridge BAB A 81, Tauberbischofsheim; Leonhard Weiss GmbH & Co. KG
2012	Talbachtal Bridge BAB A 81, Engen; Bilfinger Berger SE
2013	Kochertal Bridge BAB A 6, Geislingen; Leonhard Weiss GmbH & Co. KG
2013	Aichtal Bridge B 312, Neckartailfingen; EUROVIA Concrete GmbH
2014	Hanns-Martin-Schleyer-Bridge, Esslingen near Stuttgart; Leonhardt, Andrä and Partner (LAP)
2014	Kochertal Bridge BAB A 6, Geislingen; Leonhard Weiss GmbH & Co. KG
2015	Sunshine Skyway Bridge, Florida – St. Petersburg (USA); Vector Corrosion Services, Florida Department of Transportation (FDOT)
2015	Road Bridge over the Schweinitzer Fliess (B 187), Schweinitz – Wittenberg; State Road Construction Authority Saxony-Anhalt (Zentrale, FG 234)
2015	Schüpfbachtal Bridge BAB A 81 – Partial structure 2, Lauda-Königshofen; Ed. Züblin AG (Stuttgart Directorate - Building maintenance area)
2016	Schüpfbachtal Bridge BAB A 81 – Partial structure 1, Lauda-Königshofen; Ed. Züblin AG (Stuttgart Directorate - Building maintenance area)
2016	Donau Bridge an der B 20, Straubing; State Building Authority Passau
2016	Hunte Bridge BAB A 29, Oldenburg; BauConsulting Dr. Walther GmbH & Co. KG
2016	Road Bridge Haar over the Coastal Channel, Dörpen; Meppen Waterways and Shipping Office
2017	Volmarstein Viaduct BAB A 1, Hagen; DEGES German Unity of Highway Planning and Construction GmbH
2018	Wöhlertal Bridge BAB A 7, Hildesheim; Lower Saxony State Authority for Road Construction and Transport (Gandersheim Division)
2018	Highway Bridge over the County Road K 306 BAB A 7, near Hildesheim; Lower Saxony State Authority for Road Construction and Transport (Gandersheim Division)
2018	Highway Bridge BAB A 29 (Underpass of the L815), near Wilhelmshaven; Lindschulte + Schulze Ingenieurgesellschaft mbH
2019	Kochertal Bridge BAB A 81; near Neuenstadt am Kocher; DEGES German Unity of Highway Planning and Construction GmbH
2020	Highway Bridge on the BAB A 39, Wolfsburg; Lower Saxony State Authority for Road Construction and Transport (Wolfenbüttel Division)
2020	Railway Bridge on the B 13, Triesdorf; State Building Authority Ansbach

2021	Skyway-Bridge “Weidetor”, Hanover, Lower Saxony state authority for road construction and transport (Hanover division)
2021	Uttrichshausen Viaduct, BAB A 7, Fulda, DEGES German Unity Fernstraßenplanungs- und -bau GmbH
2021	Highway Bridge on the BAB A 27 (Interchange Wulsdorf), Bremerhaven, The Federal Highway GmbH (Northwest branch / Verden branch)
2021 + 2022	Railway Overpass St.-Martin-Straße, Garmisch-Partenkirchen, DB Netz AG – Regional Area South

Buildings:

1998 - 2005	Investigations of roof girders in Traunreut (Upper Bavaria) BSH GmbH at time intervals
2001	Hall roof girders of the Bergader private cheese dairy, Waging
2003	Investigation of containment, KKW Gundremmingen
2004	Henry Ford Bau, FU Berlin; GSE Ingenieurgesellschaft mbH Saar, Enseleit und Partner
2005	VT folds of a roof structure, OKZ Berlin-Mahrzahn; Land Berlin
2007	Prestressed concrete girders Stadtbad Rheydt, Mönchengladbach; NVV AG
2007	VT folds of a sports hall roof construction, Berlin-Mitte primary school; Leonhardt, Andrä and Partner (Berlin branch)
2007	Prestressed concrete girders of a factory hall, Renolit Werke, Worms; Renolit AG
2008	Prestressed concrete girders, Parking garage Railroad Station Neumünster; Dywidag AG
2008	Parking Garage Dixi Road, Delta Hotel, Toronto (Kanada); Vector Corrosion Technology
2008	Prestressed concrete girders, Waterpark Panoramablick Eschenburg; Hochtief Construction Materials AG
seit 2009	Investigation of gasoline tanks, Cunnersdorf, Thüringen und Medewitz; TABEG Tanklagerbetriebsgesellschaft mbH
2009	Parking Garage Foxhall Square, Washington D.C. - USA; Vector Corrosion Technology
2009	Parking Garage Monongahela Valley Hospital, USA; Vector Corrosion Technology
2010	Prestressed concrete girders of a Swimming hall, Rheydt - Mönchengladbach; NVV AG
2011	HP shells of a prestressed concrete roof construction of a multi-purpose hall, München-Neuried; Schießl, Gehlen, Sodeikat GmbH
2011	Prestressed concrete girders of a Swimming hall, Rheydt - Mönchengladbach; NVV AG
2012	Prestressed concrete girders of a hall roof, Münchehofe sewage treatment plant; BARG Building Materials Laboratory GmbH & Co. KG

2012	Hall roof girders of the Bergader private cheese dairy, Waging
2013	Prestressed concrete roof girders in the Old Town Ring Tunnel in Munich; Construction Department Civil Engineering BAU J 124 (Munich)
2014	Prestressed concrete girders in the seawater pool “Grömitzer Welle“, Grömitz; BauConsulting Dr. Walther GmbH & Co. KG
2014	Prestressed concrete girders in the Office Building „Walton Court“, London - England; Hochtief Engineering GmbH
2015	VT-folds of a swimming hall roof construction, Bundeswehr base at Holzdorf Air Base; BauConsulting Dr. Walther GmbH & Co. KG
2015	Prestressed concrete girders of a Swimming hall (Repeat inspection after 5 years), Rheydt - Mönchengladbach; NEW AG
2015	Prestressed concrete girders in the new "New Control Center" building of the fire brigade, Karlsruhe; Building Department of the City of Karlsruhe
2016	HP shells of a swimming hall roof construction, Federal Police Academy Lübeck; KSK engineers
2017	Prestressed concrete girders of a factory hall, Renolit Werke, Worms; Renolit AG
2017	Prestressed concrete tank from SKW nitrogen factory Piesteritz GmbH, Wittenberg; IGU engineering & expert company Ubbelohde mbH
2018	Prestressed concrete roof construction of a congress building, Biel (Switzerland); TFB AG
2018	VT folds of the roof structure of the “Rollibad” swimming pool, Haldensleben; Public utilities Haldensleben GmbH
2019	Prestressed concrete ceiling construction over the Praetorium (Spanish building) at Cologne City Hall, Cologne; City of Cologne - building management
2020	HP shells of the roof structure of a production hall, Bad Aibling; Wendelstein Käsewerk GmbH (Bergader cheese dairy)
2020	Digester of a sewage treatment plant, Köhlbrandthöft-Hamburg; Hamburg city drainage AöR
2020	Prestressed concrete girders of a sports hall, IGMH Mannheim-Herzogenried; BBS Bau- und Betriebsservice GmbH
2020	Prestressed concrete girders of a swimming hall, Bad Segeberg; City of Bad Segeberg, Office for Building and Environment
2021	Prestressed concrete Pi-panels of the city ring center Neukölln, Berlin, AEdicula Stadtringcenter Neukölln GmbH
2021	Prestressed concrete T-beam of the parking garage of the FU Berlin, Berlin, BARG Baustofflabor GmbH & Co. KG

2021	Prestressed concrete ceiling construction over the Praetorium (Spanish building) at Cologne City Hall, Cologne; City of Cologne - building management