Condition Assessment of a 45-year old prestressed concrete bridge using NDT and verification of the results

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PREFACE

A relatively new field of application for non-destructive testing in civil-engineering (NDT-CE) is damage analysis in the process of regular bridge inspection. NDT-CE methods will be applied for an in-depth investigation if the cause or the extent of damage is not clear. In this paper the condition assessment of a 45-year old prestressed concrete bridge with fractured prestressed steel, pitting corrosion and delaminations in the bridge deck will be presented. This bridge was later demolished so that verification of the results became possible. Typical damage patterns especially for delamination in the bridge deck will be presented. For fracture detection in tendon ducts of the bridge deck the combined magnetization and tractor appliance from TU Berlin ready for testing up to 4000m² in one night shift was applied. The reliability of this method based on Magnetic Flux Leakage (MFL) has been quantified by excavating the tendon ducts with suspect of a fracture and compare them with number of true fractures. Additionally combined automated testing with so called "on-site scanning systems" was carried out. Results gained from ultrasonic-echo and radar testing are combined for reconstruction of the inner structure and location of injection faults. The 3-D imaging of the results may help to reconstruct lost as-build-plans and serve for static calculations of "unknown" structures.

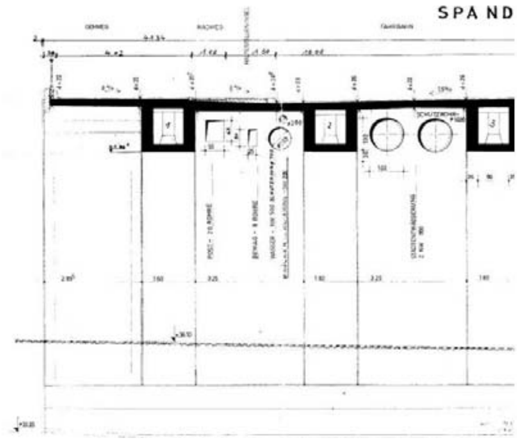
1 CONDITION ASSESSMENT OF THE BRIDGE DECK

1.1 Construction and history

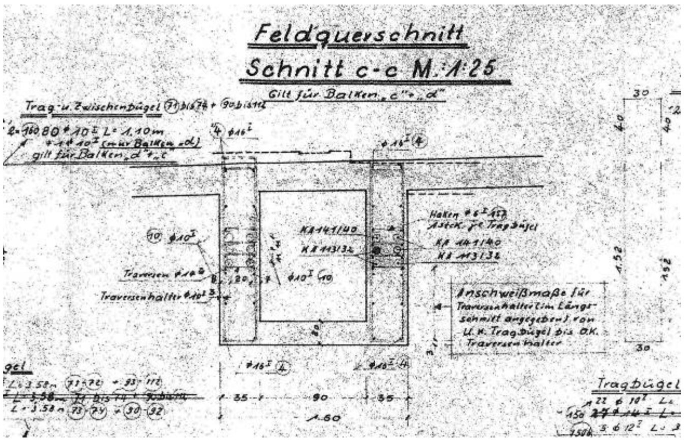
The 45-year old Spandauer-Damm-Brücke in Berlin-Charlottenburg was constructed between 1960 and 1963. The cross section of the prestressed bridge (total length of 116m and width of 39m) is shown in Fig. 1. The bridge was crossing the railway, S-Bahn and the Autobahn A100 and had one of the highest traffic loads in Berlin. Within a period of 13 years the bridge was under traffic without a sealing layer. In 1976 a sealing layer was added according to German standards. This period might be the reason for some preexisting damages that have been covered and became obvious after removing the sealing layer in the demolition process. The prestressed steel is a so called "Sigma Oval Stahl, alten Typs" with typical oval shape and is known for being vulnerable for stress-corrosion cracking. The transverse prestressing that is of great interest in this paper consists of tendon ducts with diameter of 40 mm with ten strings inside.

During repair of the sealing layer in 2004 severe damages of the transverse prestressing and the reinforcement became obvious. Due to reduced load capacity and economical reasons it was decided to demolish the bridge in 2008 (northern part) and 2009 (southern part) and reconstruct each part separately (2009 and 2010). This gave the rare occasion to identify certain structures for later investigation and large scale verification of the results (e.g. Fig. 6).

Before demolition the asphalt and the sealing layer of the whole bridge deck were removed as well as the concrete near the surface that was cut. So the condition assessment of the excavated reinforcement and the tendon ducts as shown in Fig. 2 became possible in the total bridge deck area. Also in-depth inspection became possible during demolition when parts of the bridge were cut into slices and along the edges condition assessment of the tendon ducts and the concrete over the depth became possible as shown in Fig. 3 and 4. After demolition several identified parts of the construction (10 and 12 m parts of the box-girders and 3 parts of the bridge decks with delaminations) were stored. These parts are available at the TTS test-site of BAM in Horstwalde close to Berlin.



(a)



(b)

Figure 1: (a) Cross section of the Spandauer-Damm-Brücke consisting of box girders and integrated bridge deck; (b) detail of one box girder with the arrangement of the tendon ducts


(a)


(b)

(c)


(d)

Figure 2: Large areas of visible corrosion damages after cutting the concrete near to the surface: (a) Close to joints and (b) road curbs. Details of (c) corroded reinforcement with pitting-corrosion and (d) prestressed steel with great loss of section.

1.2 Reinforcement and tendon ducts

Fig. 2 reveals the condition of parts of the excavated reinforcement. Damages occurred concentrated close to joints (Fig. 2a) and road curbs (Fig. 2b). The reinforcement showed pitting corrosion due to de-icing salts. This indicates the construction had preexisting damages from the 13-year period without sealing layer in combination with some leakages that occurred in the later period (Fig. 2c). Even the prestressed steel showed severe corrosion with great loss of section (Fig. 2d). It can be assumed that tendon ducts in that shape might have been fractured even before removing the concrete. This assumption is in accordance with the results of the investigation with Magnetic Flux Leakage (MFL) presented in chapter 2.


(a)


(b)


(c)

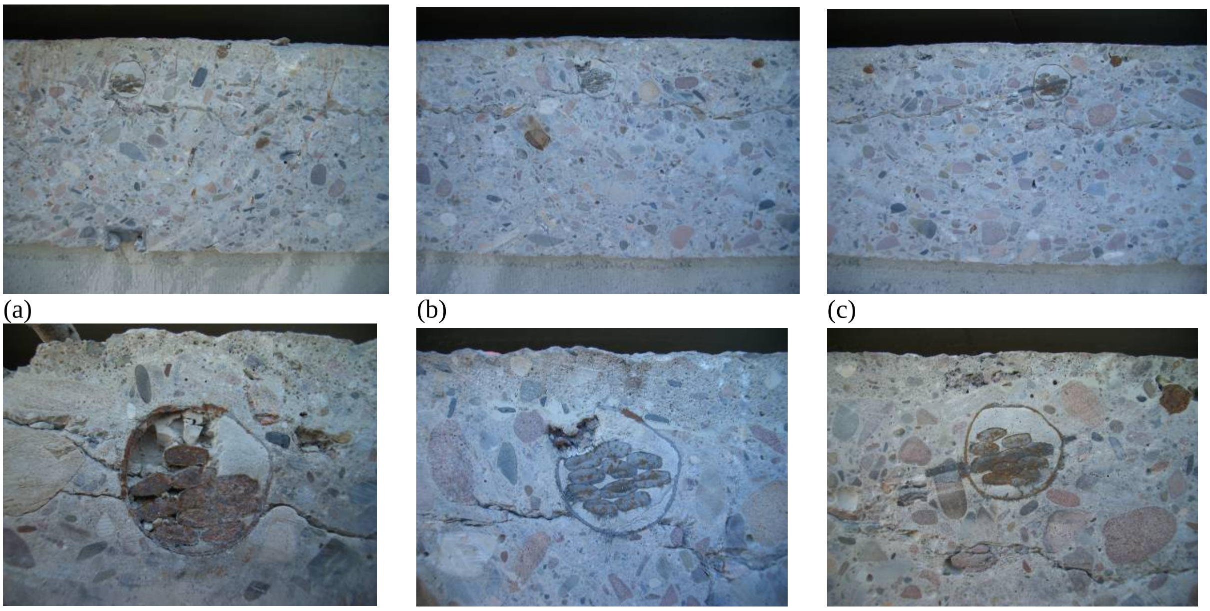

(d)

Figure 3: (a) Poor concrete quality and corroded rebar near to the surface. (b) Detail of (a) with corrosion of the tendon duct but no corrosion of the prestressed steel. (c) Good concrete quality with partly ungrouted tendon duct and (d) severe corrosion of the prestressed steel.

Large areas showed a poor concrete quality of the concrete near to the surface. Reasons for that might be the combination of insufficient curing of the concrete surface after casting together with dynamic (traffic), chemical (de-icing salts) and climate (frost-thawing) stress. Fig. 3 shows two typical patterns. Fig. 3a and b show that poor concrete quality of the concrete cover even with corrosion of the reinforcement and the tendon ducts does not necessarily mean corrosion of the prestressed steel. But injection faults as shown in Fig. 3c and d have lead to severe corrosion of the prestressed steel even with a concrete cover of good quality. That means in consequence that injection faults affected in this case already the stability of the bridge deck. Normally injections faults are only estimated to be spots of high risk of further damages.

1.3 Concrete of the bridge deck

After cutting into slices in the demolition process the cross section of large areas of the bridge could be investigated. For approx. 10% of the investigated bridge deck (approx. 50% of the total bridge deck of approx. 4500m²) delaminations as shown in Fig. 4 became visible. This damage pattern is in US of great interest and part of current research works (e.g. [1] and [2]).



(a) (b) (c)

(d) (e) (f)

Figure 4: (a)-(c) Delamination in the concrete near to the surface with details in (d)-(f). The depth of the delamination is varying: (d) in depth of tendon duct, (e) at the lower edge of the tendon duct or (f) beneath the tendon duct.

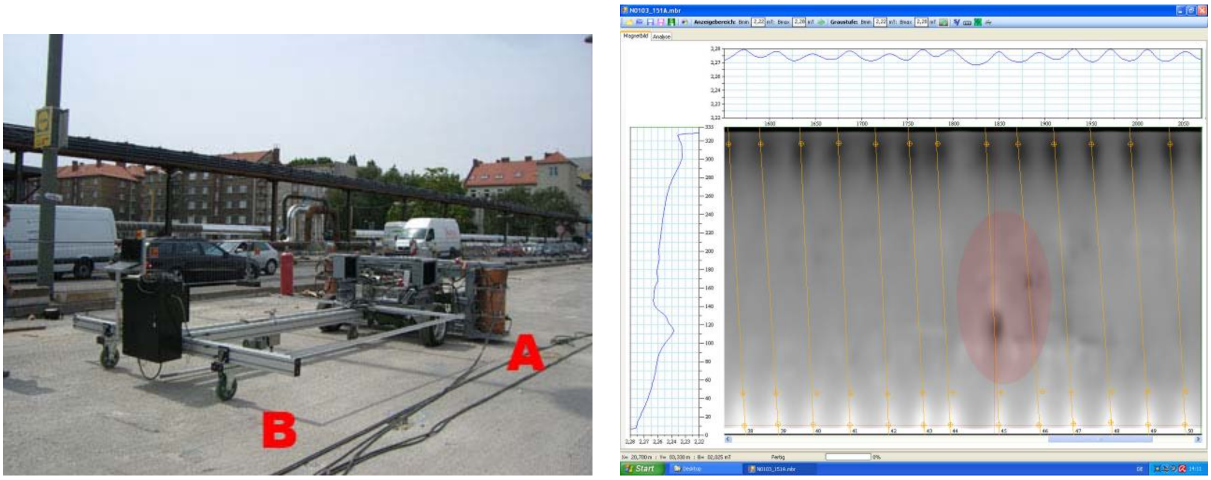
Fig. 4a-c shows a delamination along one part of the bridge within a distance of 10m. The details of the photos shown in Fig. 4d-f reveal that the depth of the delamination layer is varying. The delamination either crosses the tendon duct (Fig. 4d, as expected), runs at the bottom of the tendon duct (Fig. 4e) and even beneath (Fig. 4f). Unlikely to the case of poor concrete quality shown in Fig. 3a typical delaminations occur normally not in combination with corrosion. This leads to the conclusion that the location of areas with active corrosion (e.g. with potential mapping) does not necessarily identify areas of delamination.

2 LOCATION OF PRESTRESSED STEEL FRACTURES

For reliable location of prestressed steel fractures the testing method called “Magnetic Flux Leakage” (MFL) has been developed in the late 1980ies and proven its ability in precasted concrete members and later in tendon ducts in bridges. The physical basics are published in [3]. Examples are given in [4]. The application of the method always consists of two steps. The first step is the magnetization of the tendon duct and the prestressed steel inside. Depending on the reinforcement in the concrete close to the surface magnetization will be possible up to a depth of

30cm. After magnetization a hall-sensor is moved along the magnetized tendon duct. Fractures will produce a typical signal. The fracture signal can be displayed color-coded as shown in Fig. 5b.

The two step process of an investigation along tendon ducts is especially in case of transverse prestressing a very time consuming procedure. To investigate bridge decks for a reliable location of fractures in the transverse prestressing TU Berlin developed a tractor appliance as shown in Fig. 5a ready for testing up to 4,000m² in one night-shift. In the first step it runs along the axis of the bridge (perpendicular to the tendon ducts) magnetizing the tendon ducts along 3.5m. The magnetic unit is shown in Fig. 5a (A). In the second step it runs back collecting data with the rotating sensor unit shown in Fig. 5a (B). Typical results presented color-coded are shown in Fig. 5b. The location of the tendon ducts is done automatically by specially developed computer software and is marked by lines on the screen. Two typical fracture signals with a color change from white grey within a short distance are marked.



(a) (b)

Figure 5: (a) Combined magnetization (A) and rotating sensor unit (B) in a tractor appliance developed from TU Berlin ready for testing up to 4000m² in one night shift. (b) Results of investigated tendon ducts with two typical fracture signals marked (white to grey).

Figure 6: Excavated tendon duct of an area with typical fracture signal; all strings have been fractured.

For the investigation of the Spandauer-Damm-Brücke described in chapter 1 a total bridge deck area of more than 600m² with later verification of the results was investigated with the tractor appliance shown in Fig. 5a. At the northern part of the bridge (2008) eleven signals with suspect of a fracture have been detected. Five of them could be verified as true fractures. At the southern part of the bridge (2009) six signals with suspect of a fracture have been detected. Two of them proved to be true fractures. The so called "Positive predictive value" of this method (relation TP/(TP+FP) with **T**rue **P**ositive and **F**alse **P**ositive, [5] in German: "Relevanz") can be quantified with approx. 30 to 50%. It is the probability that an estimated fracture is a true fracture. Considering the fact that these seven fractures have been identified out of a total area of more than 600m² allows very precise, fast and reliable detection.

Special attention was given to the False Alarms (estimated fracture but no true fracture; FP: False Positive). As one reason two rebars along the tendon duct that were not built in accordance with standards lead to this false suspect. A detailed radar investigation in such an area would help to reduce the rate of false alarm. In addition to that the question about the risk to miss fractures (FN: False Negative) hast to be answered. Therefore systematical tests representing the investigated structures (e.g. reinforcement ratio, depth of tendon ducts, amounts fractured strings to sound strings) have to be carried out. In case of this bridge with tendon ducts in a depth of approx. 10cm plus asphalt layer fractures with more than 50% of the total steel amount will be detected. In case of the removed asphalt layer fractures with more than 30% will be detected. To come to reliable conclusions concerning the stability questions about True Positive (hit), False Positive (false alarm) and False Negative (miss) have to be answered.

3 IMAGING OF RESULTS OF RADAR AND ULTRASONIC TESTING

The imaging of results helps even non NDT-experts to understand the inner structure of investigated concrete members. This is very important for the acceptance of NDT-methods in the field of structural engineering. Detailed information about the inner structure requires a dense measuring grid in combination with advanced data processing. BAM has developed several scanning systems over the last decade. Fig. 7 shows one of the latest developments the so called OSSCAR-scanner (On-Site Scanner). It is a robust and very flexible system consisting of three axes that are connected on-site. This allows scanning even in box-girders with limited access. Fig. 7a shows its first on-site application at one of the box-girders of the Spandauer-Damm-Brücke. Fig 7b shows the same scanning system after a redesign in April 2010. In this scanning system three hand held devices – available on the regular market – have been integrated (Radar: ProEx-system from Mala for 1.2, 1.6 and 2.3 GHz antennas; Ultrasonic: A1220 from ACSYS with dry-point contact sensors for transverse waves [6]; Eddy-current: Profoscope from Proceq).

In case of radar the antenna is moved continuously over the surface in lines with 5cm spacing. To detect rebars in all directions the antenna is moved horizontally and after recording the whole area vertically over the surface. The dry-point contact sensor of ultrasonic is moved discontinuously up and down in 2cm steps.

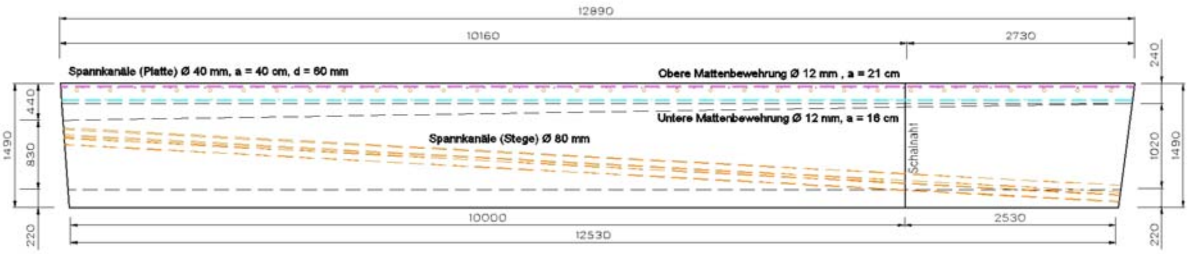
(a) (b)

Figure 7: (a) Application of the OSSCAR-system at one of the box-girders of the Spandauer-Damm-Brücke. (b) OSSCAR-system after redesign for on-site application

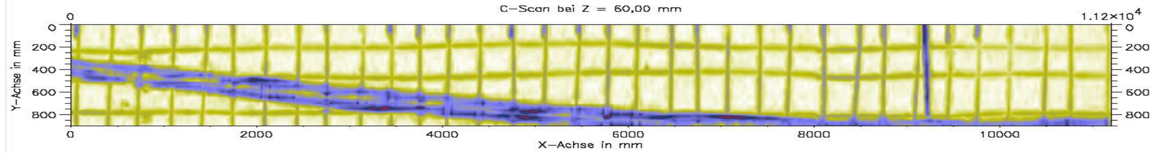
In this chapter results from radar and ultrasonic testing recorded at one of the box-girders of the Spandauer-Damm-Brücke (stored at the TTS of BAM close to Berlin and available for interested researchers) are presented. Though the data has been collected with another BAM scanning system the same data assessment for radar (migration) and ultrasonic (SAFT-reconstruction [7]) was carried out. The results are presented in Fig. 8 in sections parallel to the surface (C-Scans and C-Scan projections).

Fig. 8a is a drawing of one of the box-girders from Spandauer-Damm-Brücke stored at the TTS of BAM. It shows the estimated location of the tendon ducts drawn from the knowledge of the location of the ducts at the edges. The results of radar and ultrasonic reveal, that the true location is different. It can be easily read out with an accuracy of

1 to 2cm. Radar provides very detailed information about the reinforcement near the surface (Fig. 8b) and even at the back wall of depth of 29cm (Fig. 8c). Ultrasonic produces a very clear image of the two tendon ducts that run in very close distance. Processing cross-sections out of these 3-D data cubes containing the results will allow in the future reconstructing lost as-built drawings. It will also be possible to verify the “true” construction in critical parts after static calculation. For the future it is planned to add to each reflector its depth and location together with the expected uncertainty of measurement. Also the detection of injection faults is possible, but a reliable detection requires further research in combination with modeling [8].



(a)



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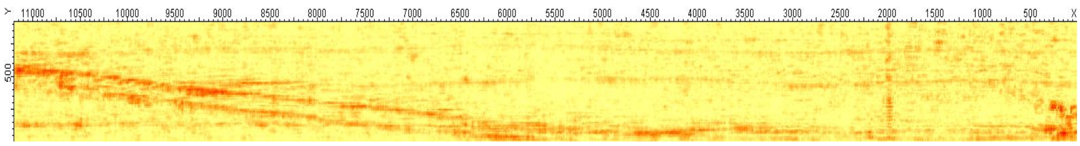

(d)

Figure 8: (a) Drawing of one box-girder from Spandauer-Damm-Brücke with estimated location of the tendon ducts. The imaging of results from radar and ultrasonic testing reveals the true location of reinforcement and tendon ducts. (b) Radar: Section of depth of 50 mm with reinforcement and tendon ducts. (c) Radar: Section of depth of 290 mm with reinforcement of the backwall of the box-girder web. (d) Ultrasonic: Projection of depth between 25 and55 mm with reinforcement and tendon ducts

4 SUMMARY AND OUTLOOK

In this paper typical damage patterns of a 45-year old bridge have been presented. It became obvious that grouting defects occurred relatively seldom. But when indicated they have lead at this bridge to severe corrosion due to the missing grouting mortar. This leads to the conclusion that bridges with the same history should be investigated with Magnetic Flux Leakage (MFL).

In the bridge deck areas with delamination have been identified. Due to the high interest in this damage pattern in the US and due to the difficulties to built realistic artificial deleminations it was decided to store three parts of a bridge deck a the TTS test-site of BAM in Horstwalde close to Berlin and make it accessible for interested researchers (Fig. 9a). Also two box-girders from that bridge are accessible (Fig. 9b).

The MFL method together with the tractor appliance developed from TU Berlin was presented as a very powerful and reliable device for large area detection of fractures in the transverse prestressing. Areas up to 4,000m² in one night-shift will be possible.


(a)


(b)

Figure 9: Available real-size test specimens at the TTS from BAM: (a) Bridge deck of the Spandauer-Damm-Brücke with delamination and (b) box girders.

For detailed information about the inner structure of a concrete construction the latest BAM-development– the so called OSSCAR-scanner – was presented for combined measurement of radar, ultrasonic and eddy-current. The imaging of the results together with information about the uncertainty of measurement (concerning depth and location of rebars and tendon ducts) will contribute to reconstruct lost as-build drawings.

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