13th International Conference on
Structural Health Monitoring of Intelligent Infrastructure
DOI: 10.3217/978-3-99161-057-1-098

Lifetime elongation of existing prestressed bridges with a lack of structural integrity using DFOS

Sören Neumann[1], Harald Burger[1], Sebastian Lamatsch[1], Oliver Fischer[1]
[1]Chair of Concrete and Masonry Structures, TUM School of Engineering and Design, Technical University of Munich, Theresienstraße 90, Building N6, 80333 München, Germany
email: soeren.neumann@tum.de, harald.burger@tum.de, sebastian.lamatsch@tum.de, oliver.fischer@tum.de

ABSTRACT: Existing prestressed concrete bridges without minimum shear or flexural reinforcement are at increased risk of sudden failure, even if they appear undamaged. To prevent such a sudden failure surface mounted Distributed Fiber Optical Sensors (DFOS) can detect local strain changes prior to cracking and visible damage. Failure mechanism analysis, laboratory tests and numerical simulations are used to identify relevant strain indicators. These strain changes could be detected by DFOS even if the failure location is not known exactly in advance. From these results, limits for a universal monitoring concept could be derived considering the individual failure mechanisms and the limitations of the sensor system.

KEY WORDS: SHMII-13; distributed fiber optical sensors; existing prestressed bridges; shear failure; brittle failure; monitoring.

1 INTRODUCTION

Existing prestressed concrete bridges often no longer meet current safety standards, even though they were originally designed and constructed in accordance with the standards in force at the time, and show no visible damage. Particularly critical are structures lacking minimum shear or flexural reinforcement, where sudden failure without sufficient prior warning can occur [1].

Reassessments of such structures according to the German Reassessment Guidelines and their supplements increasingly reveal structural deficiencies [2][3]. Some of these affect shear capacity, transverse reinforcement between flanges and web, and the structures bending robustness. Due to these deficiencies, early indications of failure become less likely or may not occur at all when conducting structural inspections in accordance with current German standards (e.g., DIN 1076 [4]) [1].

A further challenge is the accurate measurement of local strain changes in existing structures, where irregular surface conditions, structural tolerances and limited accessibility significantly affect the reliable application of both established and innovative monitoring methods.

To ensure the long-term structural safety of this existing structures, it is essential to develop and implement tailored monitoring strategies. This requires the development of practical principles that provide engineering consultants, clients and inspection authorities with a sound basis for decision making.

2 FAILURE MECHANISM

The absence of minimum reinforcement or corrosion damage, especially stress corrosion cracking in prestressing steel, can lead to brittle, unannounced failures in prestressed concrete bridges.

Figure 1 Applied DFOS on the Hammelburg bridge girder web, taken from [6]

DOI: 10.3217/978-3-99161-057-1-098

2.1 Shear

Previous test programs have shown that, despite low shear reinforcement, redistribution in the tension chord can result in a certain increase in shear capacity [5]. In contrast, shear tests at the Hammelburg bridge revealed early failure after initial cracking due to pre-damaged and unfavourably oriented tendons, as well as smooth reinforcement bars [6]. Figure 1 shows the girder web of the Hammelburg bridge after the shear test.

2.2 Bending Robustness

Significant problems on prestressed structures with a lack of flexural reinforcement became apparent with increasing operational experience. In Germany the introduction of robustness reinforcement was consequently introduced in 1995 [7]. In bridges that were built before this time, calculative proof of sufficient warning behavior as a crack before structural failure is not always given. Moreover, even with proven sufficient warning behavior, the implementation of condition monitoring is required to prevent sudden failure [8].

3 SURFACE MOUNTED DFOS ON PRESTRESSED CONCRETE BRIDGES

Fiber optical measurement technology based on Rayleigh backscattering offers advantages on prestressed concrete structures. As there is generally little or no tensile stress in the cross-section of existing prestressed concrete bridges, there is less likelihood of significant cracking. Nevertheless, it is possible to follow the stress under temporary loading and thus detect cracks that may have been overstressed by the prestressing. Strain changes are detected continuously and with high spatial resolution up to 0.65 mm along a bonded fiber optical sensor with lengths exceeding 100 m.

The application of DFOS on the surface of existing structures faces many challenges. Uneven adhesive layer thicknesses, rough formwork surfaces, and positional inaccuracies due to construction tolerances are just a few, which have to be considered in the data evaluation. Discontinuities in the adhesive or surface irregularities can lead to strain peaks in the signal, but these can be validated through visual inspections [9].

The early detection of localized strain changes long before the appearance of visible cracks enables innovative condition monitoring strategies, which can significantly extend the service life of existing structures and support more efficient and economical maintenance planning.

4 ACTUAL RESEARCH

The current research at the Chair of Concrete and Masonry Structures at the Technical University of Munich includes numerical simulations to identify strain fields associated with failure mechanisms. Various damage scenarios are analyzed to map critical strain zones for shear and flexural failure. The results serve as the basis for defining expected measurement quantities and developing robust sensor layouts.

Parallel experimental investigations are conducted. In small-scale tests different sensor-adhesive combinations, application techniques, and environmental influences are compared. Particular attention is given to overhead applications and the detection of strains over irregular surfaces. Long-term tests examine the effects of temperature cycles and potential creep phenomena within the sensor.

Building upon these results, current research focuses on the development of a monitoring concept for prestressed concrete bridges with static and structural deficiencies. The study emphasizes the identification of suitable sensors, application methods, sensor placement, and the definition of meaningful measurement intervals. The outcomes are intended to provide consulting engineers, clients, and inspection authorities with a solid basis for developing and implementing individually adapted monitoring strategies.

Large-scale tests on prestressed concrete girders will be carried out based on the numerical and experimental results. The focus of these tests lies on the application of a developed monitoring concept to detect the initial signs of a shear or flexural failure described in chapter 2. The load cycles are designed to induce microcracking and pre-damage, which, although not visibly detectable after unloading, can still be measured by DFOS

The outcomings should lead to a comprehensive guideline for the use of DFOS on existing prestressed bridges. It will include recommendations for sensor layouts, suitable adhesive and application techniques, and methods for determining appropriate measurement intervals. The guideline also provides information on installation requirements and data interpretation. Validation will be carried out on two bridges with different types of structural deficiencies: one suffering from shear capacity issues and another from missing robustness reinforcement combined with susceptibility to stress corrosion cracking.

5 CONCLUSION

Effective use of DFOS on bridges has already been demonstrated by several studies, i.e. [10][11][12][13]. This shows that the general and widespread use of this sensor technology can be useful for extending service life of existing bridges. Therefore, limits can be developed for a universal monitoring concept for prestressed concrete bridges with known deficiencies using DFOS. Therefore, reliable sensor layouts for typical failure mechanisms and recommendations for the selection of suitable sensor and adhesive combinations have to be analyzed. Moreover, the development of methodological approaches for defining measurement intervals, considering damage probabilities and degradation processes have to be considered.

Through practical validation, the feasibility of the developed concepts will be demonstrated. Thus, the project contributes significantly to the sustainable maintenance of existing prestressed concrete bridges and the extension of their service life.

ACKNOWLEDGMENTS

The authors wish to express their gratitude to the German Federal Highway Research Institute. The research project FE 88.0221/2024/AE04 is funded by the German Federal Highway Research Institute on behalf of the Federal Ministry for Digital and Transport. The responsibility for the content lies solely with the author.

DOI: 10.3217/978-3-99161-057-1-098

REFERENCES

[1] Marzahn, G.; Hegger, J.; Maurer, R.; Zilch, K.; Dunkelberg, D.; Kolodziejczyk, A.; Teworte, F. Die Nachrechnung von Betonbrücken – Fortschreibung der Nachrechnungsrichtlinie. In: Bergmeister, K.; Fingerloos, F.;Worner, J.-D. [eds.] Beton-Kalender 2015. Berlin: Ernst&Sohn, (2015)

[2] Fischer, O.; Lingemann, J.; Jähring, J.; Sonnabend, S..: Massivbrücken - Aktuelle Entwicklungen und Beispiele zu Neubau und Bestand. In: Bergmeister, K. et al. [eds.] Beton-Kalender 2023. Berlin: Ernst&Sohn. (2023)

[3] Fischer, O.; Müller, A.; Lechner, T.; Wild, M.; Kessner, K.: Ergebnisse und Erkenntnisse zu durchgeführten Nachrechnungen von Betonbrücken in Deutschland, in: Beton- und Stahlbetonbau 109 (2), (2014).

[4] DIN Deutsches Institut für Normung e.V. DIN 1076: Ingenieurbauwerke im Zuge von Straßen und Wegen. Berlin: Beuth Verlag GmbH, (1999)

[5] Lamatsch, S.; Fischer, O.: Querkraftversuche an unterschiedlich hoch vorgespannten Balkenelementen mit baupraktischen Bauteilabmessungen. In: Bauingenieur 99 Heft 1/2, (2024),

[6] Gehrlein, S; Fischer, O.: Großversuche zur Querkrafttragfähigkeit bestehender Spannbetonbrücken an der Saalebrücke Hammelburg. Teil 2: Messprogramm, Versuchsergebnisse, Vergleich mit verschiedenen Berechnungsansätzen. Beton- und Stahlbetonbau 113 Heft 10, S. 696-704.doi.org/10.1002/best.201800068 (2018)

[7] Zilch, K.; Zehetmaier, G.: Bemessung im konstruktiven Betonbau: Nach DIN 1045-1 (Fassung 2008) und EN 1992-1-1 (Eurocode 2), Springer, Berlin, Heidelberg, (2010)

[8] BMVBS: Handlungsanweisung Spannungsrisskorrosion - Handlungsanweisung zur Überprüfung und Beurteilung von älteren Brückenbauwerken, die mit vergütetem, spannungsrisskorrosionsgefährdetem Spannstahl erstellt wurden. Bundesministerium für Verkehr, Bau und Stadtentwicklung – Abteilung Straßenbau, (2011)

[9] Burger, H; Tepho, T.; Fischer, O.; Schramm, S. Performance assessment of existing prestressed concrete bridges utilizing distributed optical fiber sensors. Biondini, F.; et al. [eds.] Life-Cycle of Structures and Infrastructure Systems. London: CRC Press. (2023)

[10] Wild, M.; Schmidt-Thrö, G.; Fischer, O.: Faseroptische Dehnungsmessung im Laborversuch und an Bauwerken – Anwendungsmöglichkeiten und -beispiele im Betonbau, in: Fischer, O. (ed.): 18. Münchener Massivbau Seminar, München, (2014)

[11] Novák, B.; Stein, F.; Reinhard, J.; Dudonu, A.: Einsatz kontinuierlicher faseroptischer Sensoren zum Monitoring von Bestandsbrücken. In: Beton- und Stahlbetonbau Volume 116, Issue 10, S.s 718-726. https://doi.org/10.1002/best.202100070 (2021)

[12] Bednarski, L.; Sienko, R.; Howiacki, T.; Zuziak, K.: The Smart Nervous System for Cracked Concrete Structures: Theory, Design, Research, and Field Proof of Monolithic DFOS-Based Sensors. Sensors, 22, 8713. https://doi.org/10.3390/s22228713 (2022)

[13] Strasser,L; Lienhart, W.: Distributed fiber optic sensing during static and dynamic bridge loading. Jensen, J. S. et al. [edit.] Bridge Maintenance, Safety, Management, Digitalization and Sustainability. London: CRC Press. (2024)