Upgrade of Concrete Bridges by Adaptive Prestressing

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Summary

The constantly increasing traffic intensity on bridges and their ageing process represent new challenges in the field of bridge engineering. An innovative method to retrofit concrete bridges to meet these and further future challenges is the utilisation of an adaptive prestressing of tendons depending on the amount of acting loads. In this paper, the functionality of an adaptive prestressing control system is demonstrated by means of two prototypes, a prestressed aluminium truss and an externally prestressed reinforced concrete T-beam. Through the application of the control system on the prototypes, the deflections could be effectively decreased and critical stress situations in the cross section avoided. The experiments confirmed the potential of the use of adaptive prestressing in concrete bridge constructions.

Keywords: adaptive prestressing, fuzzy logic, hydraulic actuators, closed-loop control system

1. Introduction

The continuous increase in traffic loads acting on bridges is gaining more and more attention at the traffic administration authorities in Germany and worldwide. The future consequences of this increase for the serviceability and bearing capacity of existing as well as newly constructed bridges and specially prestressed concrete bridges can be immense. The use of classical design and strengthening methods will no longer enable concrete bridges to meet this future challenge. An innovative approach to solve these problems is the use of an adaptive prestressing system. Adaptive control allows for the prestressing force to be adjusted in order to balance the service loads applied to the structure at any time. Critical stresses can be avoided and long term losses in the prestressing force are compensated. Moreover, the design of more slender and hence more economical bridge structures becomes possible. In this paper, an adaptive prestressing system with a fuzzy logic controller is presented and evaluated through laboratory experiments. In this adaptive prestressing system, the control-relevant structure reactions are measured by a group of sensors and forwarded as inputs to the control program. The program determines the necessary adjustment of the prestressing force depending on the stress condition. The adjustment is then realised by hydraulic hollow piston cylinders.

2. Fuzzy Control Concept

The input data feeding the fuzzy controller are measured by sensors. After evaluating the sensor data using the fuzzy system, the control program determines two output parameters: the needed adjustment of the prestressing force ΔP which is applied to the structure by means of hydraulic actuators, and a decision value that determines the necessity of an adjustment by comparing it with a previously defined limit value. Through the evaluation of the measured displacements by the fuzzy system, the program determines whether or not the decision value exceeds the limit value. In case it does, an adjustment of prestressing force is triggered.

https://doi.org/10.2749/222137813806501795
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3. Prototype 1: Prestressed Aluminium Truss

The aluminium truss (Fig. 1) had a single span with a length of 7,3 m and a depth / width of 35 cm. The prestressing force (max. 226 kN) was applied using three mono strands and adjusted through the hydraulic actuators. The centrically anchored strands were deviated twice at the third-points of the beam by means of steel constructions. The fuzzy control objective defined for this prototype was the reduction of deflections. For this purpose, the displacements measured at the deviation points were defined as input data for the controller. The experiments included the application of a slowly increasing loading followed by a slowly decreasing loading to the truss. This scenario was repeated with and without adaptive control for five different load cases. A direct comparison of the displacements in two experiments of the same loading case with and without adaptive control shows a substantial reduction of displacements in the adaptively controlled truss. In general, the measured displacements could be reduced by 88 % and 97 %. The prestressing force as well as the strains and deflections remained mostly within the permissible ranges.

Fig. 1: Adaptively prestressed aluminium truss

4. Prototype 2: Externally Prestressed Concrete T-beam

The reinforced concrete T-beam (Fig. 2) had a single span with a length of 5,0 m, a flange width of 40 cm and a total depth of 44 cm. The prestressing force (max. 300 kN) was applied using four mono strands. The strands were deviated at the mid-span of the beam by means of a U-shaped steel construction. The fuzzy control objective for the reinforced concrete T-beam was the control of stresses depending on measured strains in the longitudinal reinforcement bars. For this purpose, the strains measured at 12 discrete points were defined as input data for the controller. The first part of the experiments on the T-beam included the application of a slowly increasing loading followed by a slowly decreasing loading to the non-cracked concrete beam. The scenario was repeated for seven loading cases.

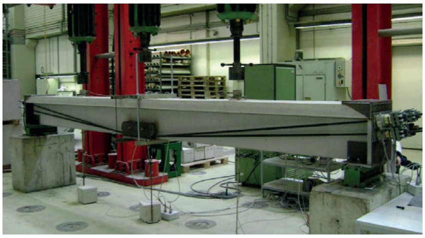

Fig. 2: Adaptively prestressed concrete beam

The next step was to test the controller performance in case of a cracked beam. For this purpose, the beam was overloaded in order to induce bending cracks along its span. The tests were then carried out again. The analysis of the measured strains showed that the cross section remained mostly under pressure. In cases of critical load conditions, tension strains could not be prevented, but they were always kept lower than 1 N/mm^2 so that the control objectives were still fulfilled. The results of the experiments on the cracked beam show a more critical but relatively stable controller performance. Nevertheless, the bearing capacity of the beam was ensured during these experiments, which confirms the applicability of the developed controller for the strengthening of existing or "damaged" concrete structures. In general, the applicable loads were increased by around 3 to 15 times with adaptive control. The prestressing force as well as the strains and deflections, remained mostly within the permissible ranges.

5. Conclusions

The method of fuzzy logic provided the possibility of creating model-free control concepts by using linguistic variables based on experience knowledge. The developed controller showed a high robustness and reliability. Effects resulting from unforeseen loading situations as well as from the use of a hydraulic system not individually designed for the prototypes could be compensated and did not have to be directly considered in the control programs. Currently, further research is carried out to install an adaptive prestressing system on a concrete bridge superstructure.