Strengthening of Prestressed Concrete Bridges by External Tendons

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Summary

Prestressed concrete bridges built in the late last century are essential elements of the highway network. However they need to be retrofitted to ensure their continued operation under the increasing traffic loads. The retrofitting of these structures with external tendons requires the careful design of the end anchorage of the cables. The presently used anchorage concepts in Germany were investigated and evaluated. As a result some risks of this construction method could be identified. Based on this study new and improved end anchorage concepts were developed and their feasibility and effect on the existing superstructure was assessed. Finally the paper highlights crucial points in both design and construction of end anchorages for external tendons.

Keywords: bridges; prestressing; external tendons; post-tensioning; anchors; retrofitting; modeling

1. Introduction and Motivation

The success of prestressed concrete bridge constructions in Germany has been based on the development of high-strength steels in the fifties of the last century. These structures can be characterized by high pretensioning and efficient material usage, but have deficiencies in their shear force bearing capacity and transverse bending stiffness. The German highway network however, has seen an unpredicted rise in transport volume in the past decades and a further increase is prognosticated. Therefore in the past years the imminent necessity has arisen to strengthen these structures to suffice the requirement of today's traffic volume and loads for a reasonable remaining usage period. Within the responsibility of the road administration of the federal state of Hessen in the last 10 years 15 of 18 bridges had to be strengthened in order to increase the shear and fatigue resistance. The retrofitting is done by installing additional external tendons on the existing superstructure. To transfer the external prestressing forces into the old superstructure, anchor and deviation concrete blocks have been fixed to the existing webs using pre-stressed high strength steel bars in the cross direction. The load transfer has been realized by friction in the interface between the anchor- and deviation blocks and the webs.

To investigate the structural safety of such retrofitting measures a systematic analysis and assessment of all completed, ongoing or planned retrofitting measures on prestressed concrete highway bridges in the federal state of Hessen was carried out. The report came to the conclusion that the presently used system of retrofitting is subject to a number of liabilities which have to be addressed. Due to the rigid frame behavior of the superstructure a non-negligible portion of the pre-stressing force eludes the contact surface between anchorage block and existing bridge, thus decreasing the orthogonal force on this interface and reducing the shear capacity of the connection. This effect is amplified by constraining actions such as creep, shrinkage, heat of hydration and thermal actions. Often the webs of the bridge are haunched towards the end of the bridge, thus causing a diminished robustness of the system. The transmission of forces through the interface is highly sensible to the roughness of the contact surface. Exact requirements on surface preparation and quality control on the construction site are therefore of great importance.

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2. New Proposals for Anchorage Concepts

The outcomes of the study clearly indicated that many of the presently used concepts for anchorage show a significant risk. Based on these results, new improved proposals for anchor and deviation construction concepts of multi webbed and hollow box concrete girders have been developed. These concepts had to fulfill the requirements on:

- structural safety, serviceability and durability;
- feasibility of construction, suitability for quality control and inspection on the construction site;
- clear load-bearing behavior.

A brief survey of the investigated retrofitting measures shows, that the applied external prestressing typically ranges from 3 to 6 MN for each web, therefore the anchorage concepts were developed for one and two external tendons with 3MN prestressing force respectively. It can be distinguished between frictional connections and interlocking connections. For the former the quality of the interface preparation and a statically determined system for the transverse post tensioning bars is of uttermost importance. In respect of interlocking connections the local effects due to the transmitted concentrated forces have to be taken into account.

Not all anchorage concepts are equally applicable for each bridge that needs to be strengthened. The availability of space between the end cross girder and the abutments, the requirements on aesthetics, safety and security furthermore the stiffness of the superstructure, thickness of the webs and finally the location of internal longitudinal prestressing cables and stirrups all influence the selection of the optimal solution for the end anchorage. To verify the feasibility of these concepts three dimensional finite-element simulations were carried out, to asses the effects of eccentric concentrated loads on the superstructure of multi webbed and hollow boxed girders.

3. Observations and Conclusions

In several applications of post tensioned members in the ultimate limit state the losses of the prestressing force do not influence the structural safety, as in case of large deformations the stresses increase and the full yield strength of the member can be activated. For the present application it has to be observed that a failure of the contact interface due to a reduced orthogonal force will result in the shearing off of the post tensioning bars and – especially with increasing number of bars – only negligible additional normal stresses will appear. Therefore the correct assessment of prestressing losses is crucial for this type of application.

During the design of the shear force transmission from the anchorage concrete block into the superstructure several factors need to be considered. Whereas the equations given in the German standards account for the effects due to adhesive bonding, this resistance mechanism is not being considered in case of dynamic or fatigue loads. As the forces in the external tendons are influenced strongly by the current traffic conditions they are not to be considered constant and resistance due to adhesive bonding has to be omitted.

The frictional connections typically use short transversal post tensioning rods, this has the consequence that the losses due to slip gain on significance. For the ribbed bars commonly used in Germany and thin webs, like in hollow box girders, losses can reach up to 50 %. Plain bars show somewhat better characteristics. To achieve a minimum of additional deteriorations of the existing bridge structure – especially of the existing shear reinforcement and prestressed tendons – in addition to the original plans of the bridge the use of nondestructive testing methods to locate the prestressing cables and stirrups is strongly recommended. The plans for the retrofitting measures in several cases prescribed the use of low shrinkage concrete for the anchorage blocks. The authors recommend regulating the characteristics of such concrete mixtures in the coming building codes.

It can be concluded that the retrofitting of prestressed bridges by external tendons is a suitable strengthening measure to ensure an extended lifespan, however the design and construction of the end anchorages requires special care and diligence. The present paper provides some suitable concepts for end anchorages and highlights the crucial points in both design and construction.