External Prestressing, Bavarian Examples

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Abstract: External prestressing gets more and more important as a method for bridges. During the last years it has evolved from the status of pilot application to a standard design method for box girder bridges in Germany. The development will be shown using bavarian examples.

1. The Development in Review

The first bridge world-wide with external prestressing was built in Aue, Saxony from 1935 to 1937 according to a concept of Dischinger (DRP 727429). It was a haunched beam with three spans (25.2 m - 69.0 m - 23.4 m) with a drop-in girder in the middle span. Suspended no-bond tendons running outside the concrete cross-section were used. A short time later, from 1938 to 1943, the Knockestrand bridge (40.5 m - 71.5 m - 40.5 m) in Sweden was built with external prestressing, too. After Second World War the development of bridge structures in Germany was concentrated on internally post-tensioned systems. However, external prestressing was applied by Magnel in Belgium and to some bridges in France. Where as in Germany the corrosion resistance of external tendons was considered to be insufficient at the time. Post-tensioned bridges with internal tendons appeared as unproblematic and only this method was further developed and applied. Nevertheless, the corrosion protection system were improved and beginning in the mid ‘80s, external prestressing emerged as an alternative to conventional internal prestressing, first for special purposes, e.g. strengthenings, and later as a general method with regard to durability and maintenance. Some pilot projects were executed. The bridge Ruderting in Bavaria was one of these. This construction method was very successful. The good experiences with the external prestressing in construction of bridges and the benefits in maintenance were the main reason that the external prestressing will be set up as a standard design method for box girder bridges.

2. Technology

2.1 Layout of Tendons

In principle two deferent layouts of the external prestressing tendons can be chosen.

1. Deflected tendons

The tendons are deflected over the columns as well as in the spans, e.g. at mid-spans (Fig. 1a). Deflection saddles must be used in this case. The deflection saddles must have a relatively high precision, therefore often precast concrete or steel units are used. Only light cross girders are necessary for bearing the deflection saddles.
2. Straight tendons

The tendons are running straight and eccentric between span cross girders. Two cross girders or other anchorage systems are necessary in any span to anchor the tendon forces (Fig. 1b).

2.2 Construction Methods

As construction methods span-by-span implementation with falsework or scaffold carriage as well as incremental launching were used in the pilot projects.

Dependent upon the construction method the tendon layout may be chosen.
- straight or deflected
- combination of both
- altering tendons partial rebuilding from centric straight to deflected shape (for example by applying the incremental launching technique)
- furthermore mixed internal and external prestressing in combination is possible (incremental launching)

The external prestressing offers the following variations of implementation (Fig. 2).

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**Fig. 1: Possibilities for layout of tendons**

a) Deflected tendons  
b) Straight tendons

**Fig. 2: Possibilities of implementation**
2.3 External Prestressing Systems

At the moment several external prestressing systems are approved by the building authorities and on the market in Germany. In addition almost any producer is developing new systems and it is expected that the variety on the market will be extend. Some systems are shown in figure 3.

![Diagram of external tendons](image)

Fig. 3: Types of external tendons

3. Pilotprojekt Ruderting

In 1994, the valley bridge Ruderting, on route 85 from Passau to Cham, was designed as a Bavarian pilot project using external prestressing. This bridge has 6 spans - 36 m - 4x45m - 36m (Fig. 4), and crosses the valley Haselbachtal at a height of approximately 43 m. The straight routing and light curvature of the gradient offer the optimal requirements for the use of external prestressing.

A detailed invitation to bid was prepared by the highway administration in Passau, with co-operation from the author. A box section was chosen for the superstructure, with height of 2.7 m and regular span of 45.0 m (slenderness = 1/16.7). Partial pre-stressing was planned.
No construction method was specified in the plans. The 252 m long bridge could be implemented with falsework or with incremental launching. Therefore, both possibilities were pre-investigated and included in the plans.

No concrete pre-stressing system was specified. However, all prestressing systems should be approved by the appropriate regulatory authority, or at least be in preparation for this end.

The draft by the highway administration was advertised Europe-wide. Alternative bids were allowed under the following conditions:

- no change in spans and overall length
- Slenderness of superstructure $h/L \leq 1/16$
- The tendons must be exchangeable under the full traffic load of bridge class 30/30
- announcement of failure through crack formation
- possibility of an increase in traffic load by 20% through structural provisions for 4 additional tendons
- no transverse prestressing

The technology of implementation could be free chosen through calculations and construction management in the design process.

It should be mentioned, however, that at the moment the price is very high per ton of the external tendons, due to the small number of existing applications of external pre-stressing. As prices were approximate three times higher than the internal pre-stressing steel, it is necessary to devise simple construction elements and as little tonnage of pre-stressing steel as possible.

The provided partial pre-stressing gives the engineer more freedom of choice in structural materials for shielding the tensile force. Prestressing steel and conventional steel are the two possibilities, with the present price differences leaning toward the use of typical reinforcement steel.

Initially, 9 bidders submitted 9 main offers and 12 secondary offers.
On analysing the offers, a special offer 1 from the company Bilfinger & Berger Bau AG was the most economical and so obtained the contract.

The special offer chose straight tendons for pre-stressing of the 2.60 m high box girder.

Fig. 5: Layout of tendons

About 2/3 of tendons were eccentric. They ran along the bottom of the spans and above over the columns (Fig. 5). The anchoring of these tendons was done in the opening of the span cross girders, which were placed 8 m in front and behind of the column cross girders. The remaining tendons were placed at the centroid of the cross-sectional area and are only anchored in the final state in the end cross girders. Due to the slight sag of the bridge, the continuous, coupled tendons had be deflected at two saddles.

The construction of the superstructure followed in three sections on falsework.

The cross girder and tendons are shown in Fig. 6
4. Standard Design Method

Because of the good experience gathered by the pilot project and the advantages of external prestressing the road administration made a decision to introduce this prestressing method as a standard design method for bridges with box girders. The administration expects the following advantages, especially with regard to durability and maintenance:

- the tendons are easy controllable and verifiable
- they are exchangeable
- they can be subjected to a secondary tensioning (re-stressing)
- they have a high-quality, industrial corrosion resistance
- the stress from traffic vibration is small
- partial prestressing can be utilized for economic construction, exhibiting ductile behaviour equivalent to a larger quantity of conventional reinforcing
- the web of the superstructure is free of tendons, making placing of the concrete easier
- The construction site is less weather dependent because no cement injection of tendons is necessary

In Germany a code for the prestressing with external tendons is not introduced by the building administration. Therefore the road administration has invited experts to formulate regulations which are based on the experience of the undertaken pilot projects. For further structures the following regulations have to be used:

- limit state of decompression

\[ \sigma_{c,t} (G, P(t), Q_k / 3) \leq 0.0 \]
\( \sigma_{c,x} \)  axial concrete stress  
G  dead load of the structure  
P(t)  value of prestressing force at time \( t \) including loss of prestress due to creep, shrinkage and relaxation  
\( Q_k \)  road traffic load according to the model of DIN 1072  

- limit state of tensile stresses in concrete during construction

\[
\begin{align*}
\sigma_c(G,P(t),Q) & \leq 3.0 \, \text{N} / \text{mm}^2 \text{ für B 35} \\
\sigma_c(G,P(t),Q) & \leq 3.5 \, \text{N} / \text{mm}^2 \text{ für B 45} \\
\sigma_c & \text{ concrete stress in the extreme fibre of the section} \\
G & \text{ dead load of the structure} \\
P(t) & \text{ value of prestressing force at time } t \text{ including loss of prestress due to creep, shrinkage and relaxation} \\
Q & \text{ variable actions according (snow, wind, settlement )}
\end{align*}
\]

- limit state of tensile stresses in concrete in transverse direction

\[
\begin{align*}
\sigma_c(G,P(t),Q) & \leq 4.0 \, \text{N} / \text{mm}^2 \text{ für B 35} \\
\sigma_c(G,P(t),Q) & \leq 5.0 \, \text{N} / \text{mm}^2 \text{ für B 45} \\
\sigma_c & \text{ concrete stress in the extreme fibre of the section} \\
G & \text{ dead load of the structure} \\
P(t) & \text{ value of prestressing force in transvers direction at time } t \text{ including loss of prestress due to creep, shrinkage and relaxation} \\
Q & \text{ variable actions (snow, wind, traffic )}
\end{align*}
\]

- limit state of steel stresses

stresses at tensioning  
\[
\begin{align*}
\sigma_{po,max} & = 0.85 f_{p tk} \text{ or } \sigma_{po,max} = 0.75 f_{p tk} \text{ whichever is lesser} \\
\sigma_{po,max} & = 0.80 f_{p tk} \text{ or } \sigma_{po,max} = 0.70 f_{p tk} \text{ whichever is lesser}
\end{align*}
\]

- limit state of cracking  
The minimum reinforcement is provided according to DIN 4227-1  

- ultimate limit state of fatigue
Crack width is controlled according to DIN 4227

- ultimate limit state

\[
\begin{align*}
\left\{ \begin{array}{l}
1.75 G \\
1.25 Q \\
1.0 P
\end{array} \right\} \leq R
\end{align*}
\]

- shear

For the limit state of serviceability no analysis of the stresses is necessary. In ultimate state the analysis has to be undertaken according to DIN 4227 -1.

In the addition regulation contains some detailing constructions rules for the anchorages, deviators size of tendons and provisions for fixing additional tendons.

5. New Bavarian Bridges - Standard Construction Method

After introducing of external prestressing as a standard design method five new bridges are built or designed in Bavaria. They are listed in the Tab.1.

<table>
<thead>
<tr>
<th>Name</th>
<th>Road</th>
<th>Spans</th>
<th>Alignment</th>
<th>Implementation Method + Trajectory of tendon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ruderting (finished)</td>
<td>B 85</td>
<td>36+4x45+36 = 252 m</td>
<td>straight</td>
<td>falsework</td>
</tr>
<tr>
<td>Höllthalbrücke</td>
<td>St 2116</td>
<td>35+43+50+43+35= 206 m</td>
<td>straight</td>
<td>falsework</td>
</tr>
<tr>
<td>Talbrücke Münchberg</td>
<td>A9</td>
<td>44.25+7x52+44+42.25= 496.50 m</td>
<td>straight</td>
<td>incremental lauching</td>
</tr>
<tr>
<td></td>
<td></td>
<td>51+55+60+85+100+85+60+55+51= 602 m</td>
<td>double bend</td>
<td>internal straight + external deflected tendons</td>
</tr>
<tr>
<td>Talbrücke Trockau</td>
<td>A9</td>
<td>39.5 + 7x48.5 + 41.5 + 37.0= 457.5 m</td>
<td>circle R=1800 m</td>
<td>straight + deflected tendons</td>
</tr>
<tr>
<td>Naabtalbrücke</td>
<td>A6</td>
<td>41.6+2x52.0+41.6= 187.2 m</td>
<td>circle R=2200m</td>
<td>falsework</td>
</tr>
<tr>
<td>Schilternbachtalbrücke</td>
<td>A6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Tab.1: Bavarian bridges with external pre-stressing

The Höllthalbrücke (Fig.7) is now under construction. The conditions of the bid were similar to the Ruderting bridge. The offer from the company DYWIDAG AG was the most economical. The superstructure is a single box girder with high of 3.0 m, the slenderness of the middle span h / L = 1/16.7 (Fig.8). The tendons are straight and the span-by-span implementation method with falsework was chosen.
The superstructures of the other new bridges are still in the state of planning and design. The length and alignment of the bridges give good conditions to application of different technologies and implementation methods. Both the external pre-stressing only and the combination of external and internal prestressing will be applied. The straight and deflected layout of tendons as well as their combination will be used.

The different possible construction methods are planned. The incremental launching as well as span-by-span with falsework and scaffold carriage will be applied.

Therefore, interesting structures are expected.

The variety of the bridge buildings shows that the external pre-stressing is able to fulfil the same requirements as the traditional internal prestressing and sets no limitations for the design.
6. References


