Innovative Structural Products for Shear Strengthening of Concrete Bridges with pt Bars

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Abstract Shear strengthening with PT bars is a common method to extend the life of concrete bridges (e.g., from the 1960ies) – both vertically to upgrade webs and also horizontally to strengthen slabs and their connection to the web. This article presents product solutions that have been developed and applied in recent years to adapt the pt bar in a perfect way to the existing structure considering aspects like adapt to shape/form, minimize impact to old structure, minimize material consumption, durability and also ease of installation. The following products will be presented by showing the idea, the R&D process and application on structures with many case studies in the Danube basin.

- Hybridanker plates: these anchor plates are made of UHPC and can adapt to existing structure by flexible geometry. They are non-corroding and improve durability of the system. With the plate usually also transition to tendon and a cap are realized.

- Threaded end plate: These plates are perfect for anchorage in deck slabs, since they minimize the depth of concrete removal to house the anchorage.

- Traverse beams as structural components: standardized and flexible solution made of UHPC and cast-iron had been developed. They are lighter than typical double U beam solutions and qualified as structural product.

Case studies are amongst others: Isarbrücke Bad Tölz, Innbrücke Obernberg, Draubrücke Jauntal Viaduct , Viaduct de Huccorgne etc.

1 Introduction

The shear strengthening of concrete bridges with PT bars is one of the most used techniques, thanks to the possibility of effectively strengthening the construction while minimizing direct interventions. The post-tensioning (PT) bar systems can be located externally and internally, with a horizontal or vertical direction. The common applications involve different parts of the bridge, such as:

- the connection between the slab and web (horizontal system, e.g. as shown in Figure 1);
- the main girders (vertical system, e.g. as shown in Figure 2)
- the bridge piers (horizontal system, e.g. as shown in Figure 3).

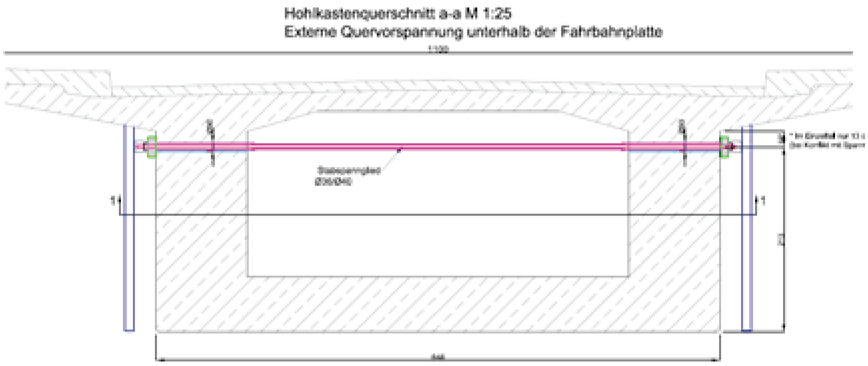

Figure 1: Example of external shear strengthening at the connection between slab and web of a bridge with pt bars.

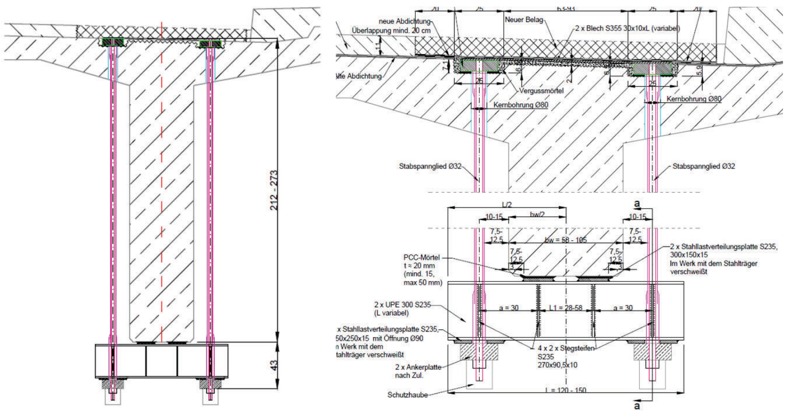

Figure 2: Example of external shear strengthening of a bridge girder with pt bars.

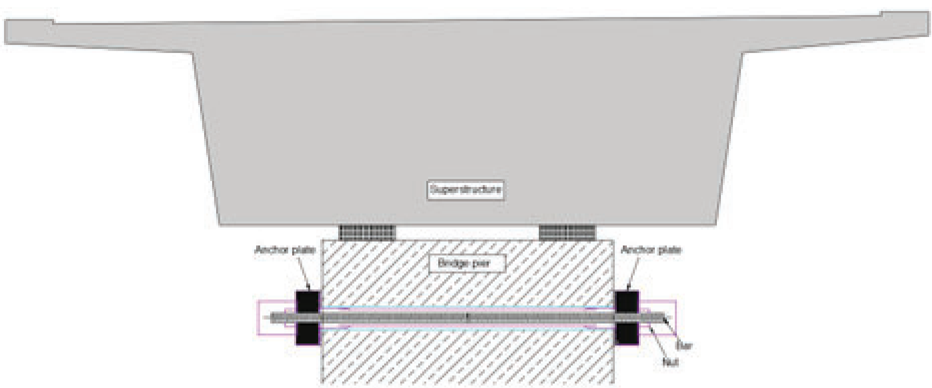

Figure 3: Example of internal shear strengthening of a bridge pier with pt bars.

The most critical part of the PT systems is certainly the anchoring to the existing structure. Here, the PT loads are transferred directly to the old construction, and the anchors not only need to

ensure a sufficient capacity by taking into account the strength of the existing structure, but must also consider the surrounding conditions, such as: non-uniform geometry, available space for installation or the presence of aggressive environmental factors.
In these terms the anchoring parts require the following properties and qualities:

- Adequate structural capacity;
- Adaptability to the geometry of the existing structure;
- Durability
- Easy handling for straightforward application

The structural products introduced in this article represent innovative solutions for these critical components in shear strengthening of concrete bridges with PT bars.

2 Innovative structural solution in the pt shear strengthening

The introduced products are the result of a continuous process of research and development not only based on the above requirements and characteristics but also on the results and observations from specific tests conducted in authorized laboratories such as MPA-TUM (Munich), MPA-KIT (Karlsruhe), and TU Braunschweig.
As a matter of fact, all types follow a design based on full-scale testing (e.g., according to EAD16, [1]).
Most are covered by ETAs or national regulations issued by DIBt (GER), OIB (AUT), Eurofins (FIN), or Cerema (FRA). Some e.g. are [2], [3].

2.1 Hybridanker plates

The Hybridanker (HA) plates were conceived to create an anchor plate that would be as versatile as possible, capable to adapt to the existing construction, unlike standard steel solutions. Therefore, the research and development process focused on using a completely innovative material: UHPC (Ultra-High-Performance-Concrete). This material, thanks to the flexibility of concrete shaping, allows the production of any form without material waste. Furthermore, due to the high density of the UHPC, the plate offers high strength, robustness and durability - being non-corroding.
There are also advantages in terms of handling, as the weight is significantly lower compared to steel solutions. Figure 4 shows some of the Hybridanker plates that vary in geometry, system, and application. The tightening nuts of the PT bars are directly anchored to them.

The Hybridanker have been used since 2011 with the first pilot project to strengthen of the Iffezheim lock along the Rhine River with a permanent strand anchor, [4].

Figure 4: HA for bars SAS 1050 47WR with double inclination (*left*); HA-Round for bar Macalloy 1030 32 mm (*center*); HA for FB 98 mm (*right*)

2.2 Threaded ended plates

The threaded ended plates made of steel were developed to minimize space requirements due to space constraints and / or installation needs. These plates are used, for instance, in the upper anchoring of vertical shear reinforcements with PT threaded bars for the girders of a bridge, generally located in the roadway, where height must be limited beneath the road surface.
In Figure 5, the cross section and the top view of the plate are shown, with the tightening nut ideally embedded in the steel plate, so that the thread is directly integrated into the hole. The height of the plate becomes the total height of the anchorage.

The threaded plates serve as passive anchors, as the prestressing load cannot be applied directly but instead by tensioning the bar from the opposite side. In the case of vertical shear strengthening of a girder, these plates are usually part of a double-bar system anchored at the top to the threaded plates and at the bottom to a crossbeam that supports the bridge section, as shown in Figure 2. The application in a horizontal system is generally used when the space for installation needs to be as minimal as possible.

The example in Figure 5 (right) shows a threaded plate for a 32 mm bar with a total height of about 65 mm, including the mortar layer between the plate and the bridge slab. The installation and the required footprint take the smallest possible space , making the work easier and faster, with the installation area backfilled with asphalt without difficulty.

2.3 Traverse Beams

The application field of these post-tensioning solutions is the shear strengthening with multiple anchorage of PT bars. For example, the external system for shear strengthening of a bridge girder in Figure 2, involves passive anchoring on the slab of the bridge and a crossbeam beneath the girder that acts as a support once prestressing is activated. This can be conceived also in a horizontal direction, e.g., for the shear strengthening of a pier with an external PT bar system, as shown in Figure 6 below.

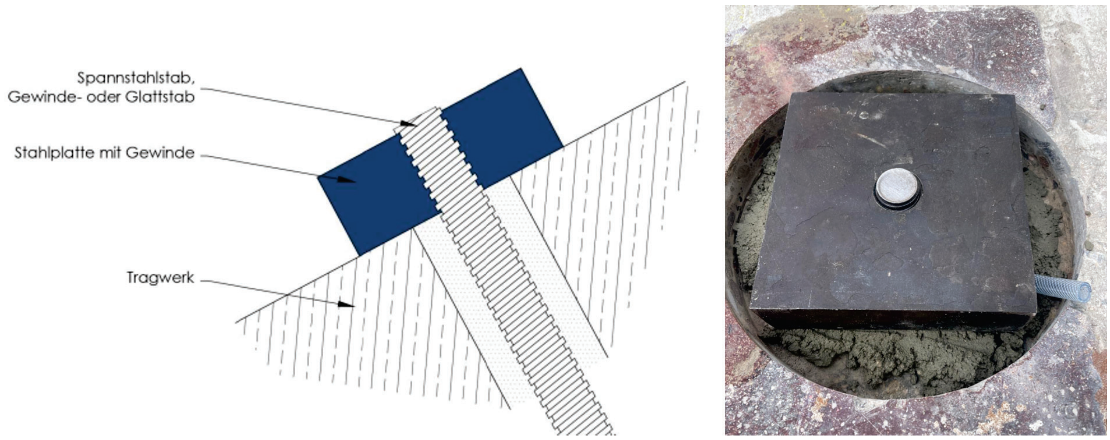

Figure 5: Cross-Section of the threaded ended plates (*left*); example of installation of the plate in a bridge slab (*right*)

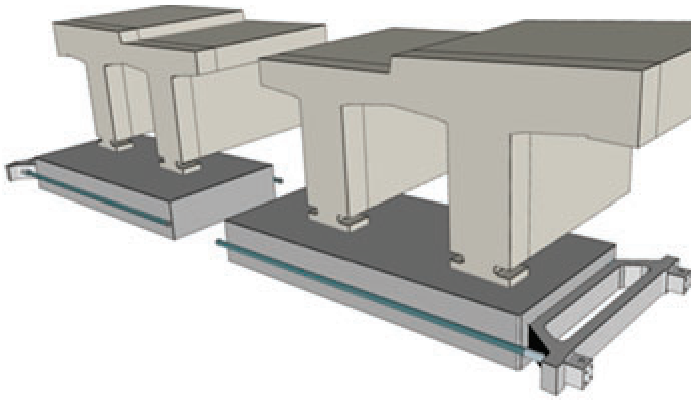

Figure 6: Example of external shear strengthening of a pier with CoBeam traverse.

Traditional solutions are composed of U-shaped profiles joined by welding, with additional reinforcement plates in the most stressed areas of the cross beams. The development of this product group has focused primarily on optimizing both shape and material, conceiving two categories of "traverse": the **Proma traverse**, made of cast iron, and the **CoBeam traverse**, made of UHPC.
The concept for both products is a truss model, designed to streamline the bulky shape of U-profile solutions, removing areas not subjected to stress, and consequently making the traverse beam lighter and easier to handle.
The **ProMa traverse** is modular, allowing it to cover a typical spacing range between the two vertical bars, from 60 to 200 cm. Installation is completed using anchoring plates positioned at the extremities beneath the crossbeam, which can be angled to follow the shape of the girders.

The **CoBeam traverse** takes advantage of the flexibility in concrete shaping, making larger dimensions easier to manufacture. For instance, in internal testing, a CoBeam XXL with 4.7 meters length was produced and tested in the laboratory of matrics engineering. The CoBeam does not require additional anchoring plates at the ends, and any inclinations or adjustments in geometry can be easily accommodated due to the material's flexibility (Figure 9). More information can be found in [5].

Figure 7: Traverse Beam ProMa (*right*); ProMa Mock up with HA-Rund and coating (*left*)

Figure 8: CoBeam A1200 for axis distance of 1200 mm of 2x pt bar (*left*); CoBeam XXL with 4,70 m length (*right*)

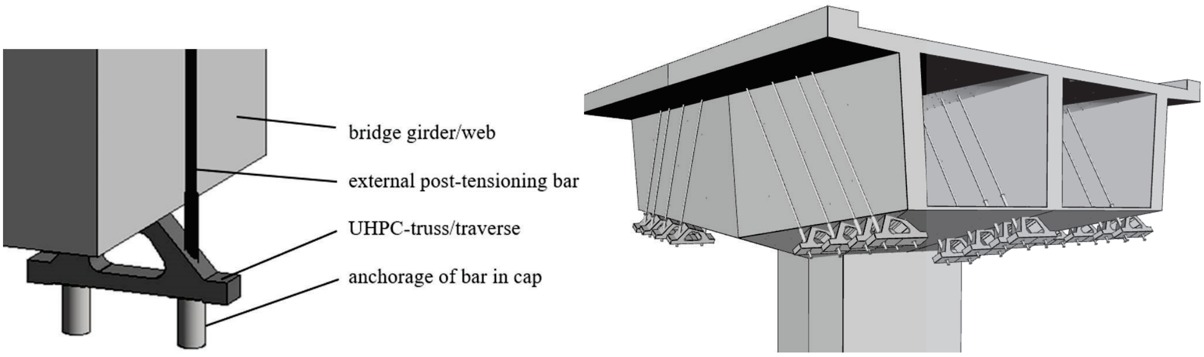

Figure 9: 3D-Model of CoBeam for a girder with regular geometry (*left*); 3D-Modle of multiple CoBeams for girders with irregular geometries (*right*)

3 Case studies

Follow various case studies involving shear strengthening of bridges with PT bars, where the Hybridanker plates, the threaded ended plates and the traverse beam are part of the PT systems.

3.1 Case 1: Isarbrücke Bad Tölz

This bridge is located along the B472 next to the town of Bad Tölz, Germany, crossing the Isar River. It is a pre-stressed reinforced concrete bridge from the year 1981, with a double T-section. The construction works for strengthening took place in 2019, involving various parts of the bridge.

Shear strengthening of the bridge girders

During the construction phases, due to a provisory traffic configuration, it was necessary to install a temporary shear strengthening system with PT bars in one of the main girders. The anchoring to the old structure was ensured with **threaded ended plates** on the bridge slab and **CoBeams** below the girders. This was the first pilot project, in which CoBeams were used.

System: temporary PT horizontal bar systems type Macalloy 1030 32 mm. Max PT load = 638 kN.

Figure 10: Drawing of the shear strengthening (1); installation of the threaded ended plates (2); CoBeam traverses before installation (3); overview of the shear strengthening from below(4)

3.2 Case 2: Innbrücke Obernberg

This bridge is located on the German-Austrian border along the St2117 over the Inn River. It was built in the 1963 with pre-stressed concrete, featuring a double T-section and a reinforced lower slab on the external piers. The strengthening project, aimed at extending the bridge’s lifespan by 30 additional years, began in 2023 and targeted various parts of the structure.

Shear strengthening at the connections between web and slab and between web and bottom plate

Shear strengthening with horizontal PT bar systems in the main beams near the piers to enhance shear strength in the connections between beams and flanges of the slab and of the bottom plates. The Hybridanker Plates installed have a 13° inclination.

System: permanent PT horizontal bar systems type Macalloy 1030 36 and 40 mm. Max PT load = 997 kN.

Figure 11: Cross-Section of the shear strengthening near the piers (*left*); overview of the pt system from below (*middle*); side view of the pt system with the HA plates, highlighted in the blue framed boxes (*right*)

Shear strengthening of the bridge girders Vertical shear pt strengthening system along the bridge girders. The shear reinforcement consists of a two-bars system with a single **threaded ended plate** (approximately 1,50 m) as anchor above the bridge slab and a standard solution with a steel crossbeam + Hybridanker plates below the girders.
System: permanent PT vertical bar systems type Macalloy 1030 32 mm. Max PT load = 638 kN per bar.

Figure 12: Cross-Section of the pt system (*left*); threaded ended plate with 1,5 m length (*middle*); steel crossbeam with HA plates (*right*)

3.3 Case 3: Draubrücke Jauntal Viaduct

This bridge is located in Austria over the Drava River near the Slovenian border. Completed in 1962, it is a railway bridge that underwent modernization in 2022, from single to dual railways, necessitating significant strengthening of the piers to improve the structural capacity from the new loads of the superstructure.

Shear strengthening of the bridge piers
Hybridanker plates were installed at the anchorages of the pt bar system. Due to aggressive environmental conditions, concrete caps were used to create a completely sealed system that is externally protected from corrosion.
System: permanent PT horizontal bar systems type SAS 1050 47 WR. Max PT load = 1.566 kN.

Figure 13: Construction works for the widening of the superstructure (*left*); overview of the shear strengthening with HA (*middle*); Detail of the HA plate during installation (*right*)

3.4 Case 4: Viaduct de Huccorgen

Completed in 1971, the structure consists of two parallel viaducts with a length of 547 meters, along the A15 in Wanze, Belgium. Each viaduct is composed of four main beams connected by an upper slab (box girder bridge). The works began in 2021 and involved mainly the superstructure, where the 72 beams of the bridge were replaced. The construction stages foreseen to proceed one viaduct at the time, to be able to ensure bidirectional traffic flow. So, while in one viaduct the replacement work was proceeding, in the other was necessary to strengthen of the bridge girders, due to the increased traffic loads.

Shear strengthening of the bridge girders
A vertical PT strengthening with a two bars system was installed in the old girders. The upper anchor in the slab includes a **threaded ended plate**, while the lower anchor consists of a welded steel crossbeam system with a double U-profile and **Hybridanker Plates** to transfer concentrated loads.
System: temporary PT vertical bar systems type Macalloy 1030 32 mm. Max PT load = 638 kN per bar.

Figure 14: Cross-section of the shear strengthening (*left*); overview of the pt system (*middle*); Detail of the crossbeam with the HA plate (*right*)

3.5 Case 5: Weidetorbrücke

The Weidetor Bridge was built in the 1964 in Hannover, Germany, and it is one of the major arterial roads through the city center. The structure consists of 14 individual so-called mushroom head supports, which - as the name suggests - widen upwards in a mushroom shape. Suspension plates lie between each of these supports with a total support span of 439 meters. The bridge was already in the 2017 no longer fit for the future due to the increasing traffic loads and came the decision to replace the whole infrastructure. The new construction project is still in the preliminary planning stage and it was necessary a strengthening measure of the old structure in order to guaranty the traffic flow. The construction works started in 2024.

Shear strengthening of the cantilever joints

The most important strengthening measure involved the cantilever joints (half-joints) between the top plates. The joint works as a shear connection and a strengthening was conceived to reduce the loads in the joints themselves. The shear strengthening consists in a system of a steel construction anchored below the bridge slab thanks to a pt bar with some 60 cm distance from the joint and acting as support for the plate next to it. For the anchoring of the steel beam was applied a threaded ended plate above the bridge slab and a Hybridanker plate below the steel.

System: temporary PT vertical bar systems type Macalloy 1030 32 mm. Max PT load = 638 kN.

Shear strengthening of the bridge slab

To increase the shear capacity of the top plate, were installed a series of punctual pt bar systems in vertical direction. Also in this case the top anchor consists of a **threaded ended plates** and the bottom anchor of a **Hybridanker plates.**

System: temporary PT vertical bar systems type Macalloy 1030 32 mm. Max PT load = 638 kN.

Figure 15: Overview of the strengthening system from below (*left*); Detail of the threaded ended plate on the bridge slab (*middle*); Detail of the Hybridanker plate below the steel construction (*right*)

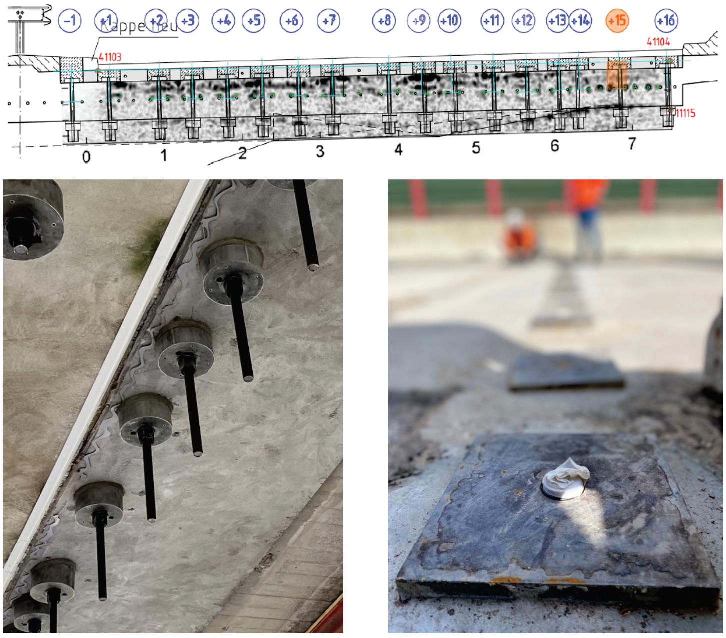

Figure 16: Cross section of the punctual pt bar systems (*top*); HA Plates below the slab (*bottom left*); threaded ended Plates above the deck (*bottom right*)

4 Conclusion

This paper aimed to present innovative solutions for PT shear strengthening in concrete bridges, focusing on anchoring systems developed through the study of materials and the behavior of the systems themselves. The advantages derive from using versatile materials like UHPC and from shape optimization in cast iron solutions.
From a technical perspective, compared to traditional products, these solutions can offer greater durability, optimal structural performance, reduced material usage, and associated benefits in terms of handling and sustainability. It is also evident that there are economic advantages.
The case studies presented demonstrate the effective application of the products in shear strengthening with pt bars, verifying their capacity and applicability.

5 References

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