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Fruttli-and Rigiaa-Bridge, Timber-UHPC composite structure

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1 Introduction

In 2020 and 2021, two obsolete concrete bridges in central Switzerland at the foot of the Rigi should be replaced.

Innovative timber-UHPC composite bridges were built for 40-tonne loads.

The Fruttli and Rigiaa bridges are located on the access road to the Rigi region. All log and freight transports are handled over this major freight road.

At a bridge inspection, it was determined that repair of the old bridges was no longer technically feasible. Two engineering offices submitted variants for the replacement of the 10 and 16 m long bridges: A conventional proposal for concrete bridges and another proposal for a timber-UHPC composite structure. Due to the lower costs, shorter construction time and ecological aspects, the decision was made in favour of the timber-UHPC composite construction.

After preparatory work on the existing support, the entire bridge superstructure was built within one week. After another 4 days, the bridge was open to traffic.

Figure 1:Fruttli Bridge, Goldau, Switzerland

Figure 2:Fruttli Bridge, Goldau, Switzerland

Figure 3: Rigiaa Bridge, Goldau, Switzerland

Figure 4: Rigiaa Bridge, Goldau, Switzerland

2 Construction

The bridges consist of glulam girders, which are shear-resistant connected with a UHPC slab cast on site.

The girders were placed on the abutments, whereby formwork for pouring the bridge slab made of UHPC was already pre-assembled on the outermost girders. The formwork between the timber girders was formed by superimposed 3-layer slabs, which remain in the bridge. The cross-section structure is inspired by that of the Gletschersand Bridge in Grindelwald, which was built by Emch+Berger in 2018 [1].

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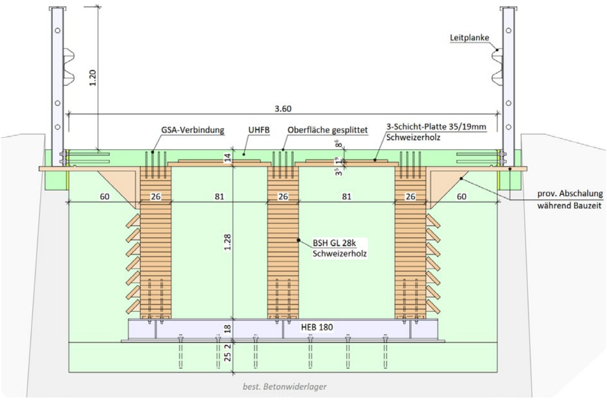

Figure 5: Rigiaa Bridge, Cross section

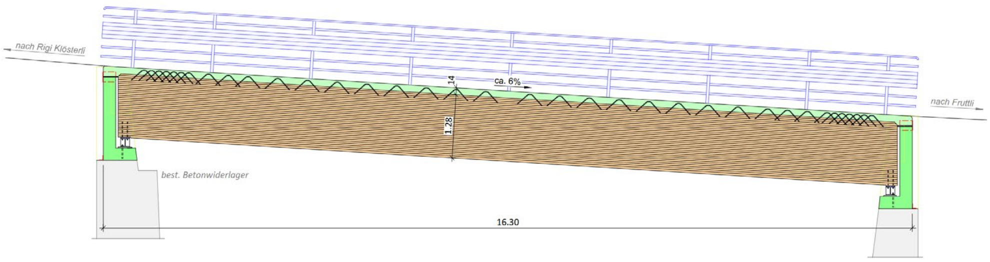

Figure 6: Rigiaa Bridge, Longitudinal section

The main girders at the abutments rest on HEB steel profiles. Threaded rods (GSA® technology) glued transversely to the girders transfer the bearing forces into the abutments via direct steel contact.

To protect the timber from weathering, the deck is cantilevered over the outermost beams. On the Fruttli Bridge, the cantilever is enough to prevent direct weathering of the timber at an assumed driving rain angle of 30°. On the Rigiaa bridge, the timber girders are additionally protected by boarding made of saw-rough boards. The damp-proof coating applied at the factory ensured protection during the construction phase. These measures optimally shield the timber and ensure a long service life.

The UHPC slab cast on site with a thickness of 8.5 cm to 14 cm can be driven over directly. It serves as a seal throughout the entire period of use and, due to the cantilevers, also as weather protection for the timber beams.

To increase sliding resistance of the deck, grooves were finally milled into the surface of the Fruttli bridge. The steel fibres contained in the UHPC that stood up more due to the milling were then flamed with a gas flame. This was a premiere that led to the desired, flawless result.

In contrast, for the Rigiaa bridge, a two-layer UHPC slab with the same overall thickness as for the Fruttli bridge was chosen. On top of the first layer of conventional UHPC with steel fibres, a second layer of UHPC was poured. This second layer contains chippings instead of steel fibers

Figure 7: Rigiaa bridge, Transport of the girders with pre-assembled formwork

Figure 8: Fruttli bridge, Assembly of the girders with the pre-assembled formwork

Figure 9: Rigiaa bridge, the glulam girders placed on the abutments

Figure 10: Fruttli bridge, the reinforced bridge slab

Figure 11: Rigiaa bridge, Mixing UHPC

Figure 12: Fruttli bridge, Mixing UHPC

Figure 13: Rigiaa bridge, casting of the UHPC

Figure 14: Rigiaa bridge, casting of the UHPC

Figure 15: Rigiaa bridge, smoothing of the first layer of the UHPC deck

Figure 16: Fruttli bridge, smoothing of the UHPC deck

Figure 17: Fruttli bridge, Milling the grooves to increase skid resistance

Figure 18: Fruttli bridge, Flaming the surface

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Figure 19: Rigiaa bridge, casting the second layer

Figure 20: Rigiaa bridge, surface

Figure 21: Rigiaa bridge, lateral view of the girders and the bridge slab

Figure 22: Fruttli bridge, soffit with beams and 3-layer panels

3 UHPC

UHPC stands for **U**ltra-**H**igh **P**erformance, cement-bonded fibre **C**omposite building material. Building with UHPC is regulated in Switzerland in the 2052 standard of the SIA (Swiss Society of Engineers and Architects). Another Name for the material is UHPFRC (**U**ltra-**H**igh **P**erformance, cement-bonded **F**ibre **R**einforced **C**omposite).

The building material UHPC is neither steel nor concrete, but a new type of building material with an independent mode of action.

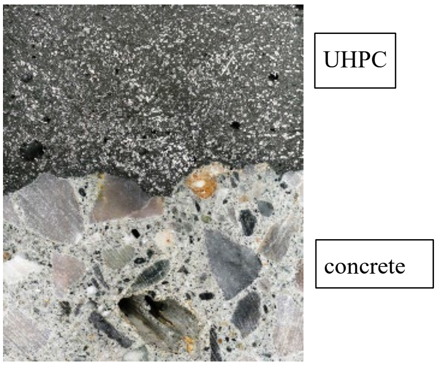

Figure 23: Comparison UHPC and concrete (EPFL, Switzerland)

Figure 23 shows the obvious, pictorial difference between the two building materials. UHPC consists of cement, other fines and hard particles (quartz) with a maximum size of 1 mm. The packing density of these particles is optimised so that the resulting building material no longer has any voids (pores). This cement-bound building material is reinforced by slender short fibres in high dosage. These fibres are made of steel, 15 mm long and 0.2 mm thick, and make up at least 3% of the building material volume. The amount of water needed to set the cement (binder) is so small that during the hardening process of UHPC, the added water is completely consumed for cement setting. Since there is no more free water, no drying process can take place, as is usual with mortar and concrete and leads to the formation of capillary pores. The capillary pores common in conventional concrete are interconnected and thus allow water to enter the concrete from the outside. Water is the necessary precondition for corrosion of the steel reinforcing bars or chemical reactions in the concrete (alkali aggregate reaction), which are the two most common damage mechanisms of reinforced concrete. In contrast, UHPC - as previously explained - has no capillary pores, which means

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that no water ingress can take place and thus no damage to the building material can occur. The building material UHPC is waterproof. This watertightness has been proven by many tests. In addition, tests have shown that UHPC is waterproof even under tensile stress. These properties guarantee the building material UHPC a very high durability against climatic influences with water and de-icing salts. UHPC has been used on bridges in Switzerland for 18 years. The experience gained from these applications confirms this very high durability. Accordingly, significantly lower maintenance costs are expected for the Fruttli and Rigiaa bridges than for a conventional concrete bridge.

Due to the impermeability and the very high abrasion resistance of the UHPC, the sealing and waterproofing work required for a concrete or timber bridge can be omitted and no wear layer is required for the roadway.

4 Composite effect

The bond between the glulam girders and the bridge slab is ensured by means of GSA®-HBV shear bond.

Together with the UHPC deck slab, the timber girders form the desired composite girder. Due to its high performance and ductility, the GSA-HBV composite system is ideally suited for bonding with the high-strength UHPC. The GSA® technology is based on threaded rods glued into the timber or, in the case of the HBV system, on glued-in reinforcing steel. The connection is designed in such a way that the reinforcing rods fail ductilely in the fracture state. This excludes the brittle failure modes of the timber or the adhesive. Due to the high stiffness, a practically rigid connection with high fracture resistance is created. GSA-HBV also behaves in an extremely ductile manner (see graphic) and thus reliably distributes the shear flow to all connectors used. The efficient fastener corresponds to the high-quality individual materials, which ultimately results in a beneficial overall system.

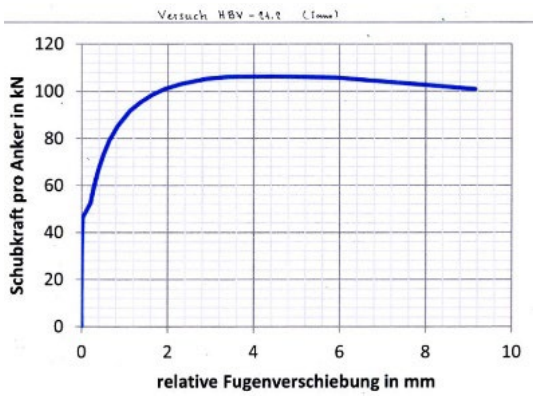

Figure 24: Load-deformation diagram of GSA connections, neue Holzbau AG, Switzerland

5 Sustainability

In terms of global warming potential and resource consumption, the timber-UHPC composite construction has major advantages compared to a conventional concrete construction. There are also small advantages in comparison with a pure UHPC construction, as the following graph shows.

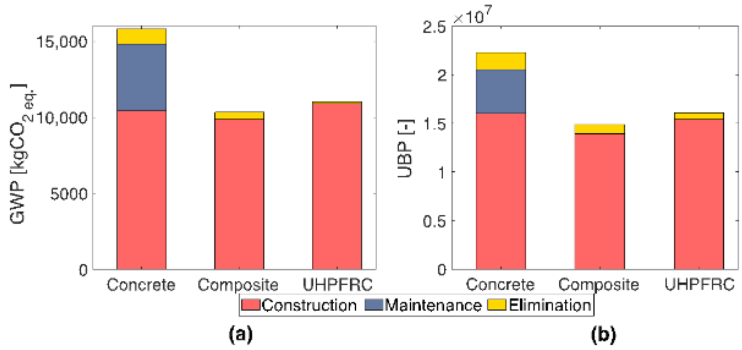

*Figure 25: Environmental impacts of bridge designs over the use span, including construction, maintenance, and elimination processes: (**a**) Global warming potential; (**b**) Ecological scarcity (UBP points) [2]*

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The eco-balance can be improved significantly in the future by using an environmentally friendly UHPC mix. An environmentally friendly mix of UHPC has been developed recently where two improvements are made to the standard mix [3]. First, steel fibres are replaced by ultra-high molecular weight polyethylene (UHMW-PE) fibres. Second, 50% of clinker is replaced with limestone fillers.

As this ECO-UHPC provides similar mechanical properties to the standard mix, similar bridge designs are obtained. Additionally, the maintenance and elimination processes of UHPC are not affected as the durability properties of ECO-UHPC are equivalent to the conventional mix. The influence of ECO-UHPC in terms of global warming potential is presented in Figure 24.

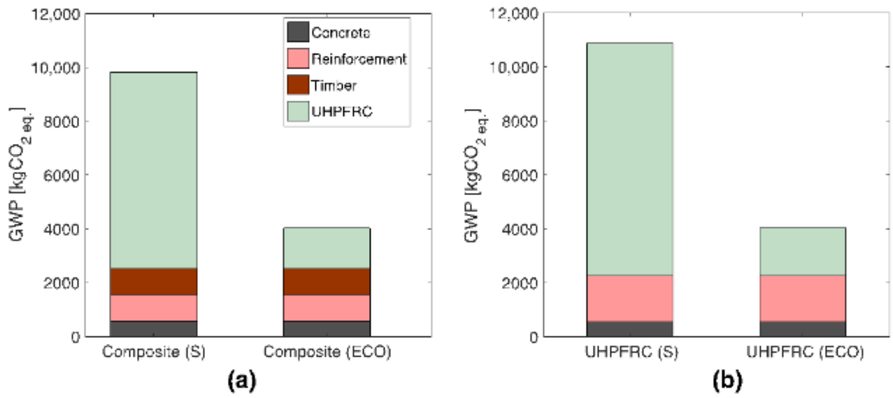

*Figure 26: Influence of using an environmentally friendly UHPC on the bridge's ecological footprint in terms of global warming potential: (**a**) Timber–UHPC composite bridge; (**b**) UHPC bridge.*

For smaller spans and lower loads, the use of sawn timber instead of glulam also improves the life cycle assessment significantly.

6 Conclusions

Today, timber bridges are mainly used as pedestrian bridges, whereas concrete or steel construction dominates in road traffic.

The two bridges on the Rigi are the first timber-UHPC composite bridges in Switzerland that can be driven over by 40 t trucks. They show that this construction method can compete with a conventional concrete construction in terms of price, while at the same time offering great advantages in terms of construction time, durability and ecology. Due to the multifunctionality of the UHPC, very simple constructions with extremely favourable maintenance costs result.

These bridges can therefore be exemplary for other road bridges, also with larger spans.

7 References

[1] Emch +Berger (2018), https://www.emchberger.ch/de/gletschersand-bruecke)

[2] Bertola N., Küpfer C., Kälin E., Brühwiler E. (2021) Assessment of the Environmental Impacts of Bridge Designs Involving UHPFRC, Sustainability, Special Issue "Prefabricated Bridge Elements and Connections: Towards Sustainability in Bridge Construction"

[3] Hajiesmaeili, A.; Denarié, E. Next Generation UHPFRC for Sustainable Structural Applications. In Proceedings of the DSCS 2018: 2nd International Workshop on Durability and Sustainability of Concrete Structures, Moscow, Russia, 6–7 June 2018.