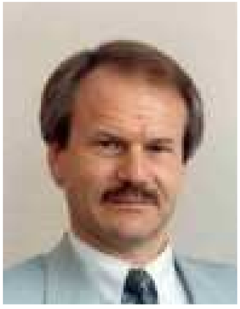
ULTRA-HIGH-PERFORMANCE CONCRETE: BASIS FOR SUSTAINABLE STRUCTURES

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Summary

Ultra-High Performance Concrete (UHPC) is a very dense and corrosion resistant concrete with a compressive strength of about 150 to 200 MPa. It allows for material saving filigree but nevertheless highly loadable and durable constructions. One actual example is the Gaertnerplatz bridge in Kassel. The 136 long hybrid structure consists of a light 3-D steel truss being combined with two upper chords and a min. 80 mm thin bridge deck - both made of UHPC. For the first time in the world the load bearing concrete elements are connected by an epoxy resin only. Due to the filigree structural layout the mass of the bridge is 349 tons only compared to about 850 tons for a conventional bridge made of prestressed concrete. In correlation with the reduced mass the amount of raw materials, of energy and of emissions is significantly reduced and the impact on the environment is lowered. Considering the fact that the costs of the bridge did not exceed those for a “traditional” construction and that UHPC has a much longer service live, one can state that the use of UHPC is a very effective way to increase the sustainability of concrete structures.

Keywords: Gaertnerplatz bridge, ultra-high-performance concrete, ecological impact, sustainability

1 Introduction

Ultra-High Performance Concrete is characterized by an extremely dense structure free of capillary pores, an increased corrosion resistance and a compressive strength of about 150 to 200 MPa. Reinforced by a sufficient amount of steel or other high performance fibres the tensile strength can be increased up 15 MPa and the bending tensile strength up to about 35 to 45 MPa. The high compressive strength especially allows for high degrees of prestressing. The material and its application is extensively described in [1, 2]. The 136 m long Gaertnerplatz bridge in Kassel is the first application of UHPC for a wide span pedestrian bridge in Germany and the first bridge in the world whose load bearing concrete elements are connected by epoxy resin only [3, 6]. **Fig. 1** gives an impression of the hybrid bridge structure shortly before it was finished in July 2007.

Fig. 1 View of the Gaertnerplatz Bridge in Kassel.

Fig. 2 shows its cross section together with an alternative solution, a “traditional” structure with the same load bearing capacity based on prestressed ordinary concrete C35/45 acc. to EN 206. The upper chords of the 3D-truss structure of the Gaertnerplatz bridge consist of spaghetti-like filigree prefabricated and prestressed elements with a length of 12 to 36 m and a cross section of 300×400 mm only. They were fitted to the steel framework and the premounted elements were placed on the pillars. Afterwards, the 5 m wide and 8.5 to 12 cm thin deck slabs were glued onto the girders and finally they were posttensioned internally over the whole length of the bridge.

The composition of the UHPC used for the Gaertnerplatz bridge is given in **Tab. 1**. It is characterized by an comparatively high amount of cement and silica fume, a very low w/c-ratio of about 0.20 and the use of one or more fine grained mineral powders, primarily quartz to achieve an optimum of the packing density of the fine components of the matrix [2, 4, 5]. **Tab. 1** shows that due to the high amount of cement especially the energy demand of one m^3 of the UHPC is about double as high as for ordinary concrete. Corresponding to that the greenhouse effect is doubled as well.

Tab. 1 Energy demand and greenhouse effect of 1 m^3 of ordinary concrete and of UHPC

Concrete		C35/45	UHPC
Cement	kg/m³	350	733
Quartz powder		-	183
Quartz sand/gravel	kg/m³	1802	1008
Water	kg/m³	175	161
Silica fume	kg/m³	-	230
Steel fibres	kg/m³	-	75
Primary energy demand [1)]	MJ/m³	1702	3440
Greenhouse effect	kg/m³	282	571

[1)] Calculated using commonly accepted impact data given in [7, 8, 9, 10]

However, the material itself is not the appropriate measure. One has to relate it to the total mass of concrete, reinforcing steel etc. being used for a certain object. **Fig. 2** elucidates the differences between the two alternatives being considered. Due to the larger size of all structural parts the total mass of a conventional massive structure with the same function adds up to about 850 tons compared to 350 tons only of the hybrid bridge. Just as one example, the prefabricated slabs of the bridge deck have a minimum thickness of 85 mm which is only about 34 % of the massive alternative. Replacing the tubes of the steel truss by prestressed UHPC elements of the same size would lead to a further reduction of the weight by another 15 tons (version 2 in **Tab. 2**). It is technically feasible to design a truss structure consisting purely of UHPC. As an example **Fig. 3** shows a model of the Gaertnerplatz bridge scaled 1:2

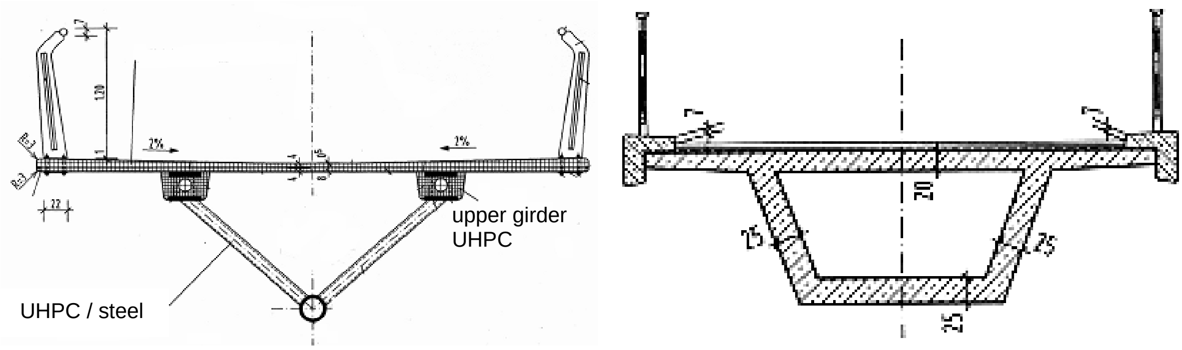

Fig. 2 Comparison of the cross sections evaluated. Left: existing design with UHPC and a steel truss (version 1 in **Tab. 2**) or with a truss made of UHPC (version 2 in **Tab. 2**). Right: Conventional design consisting of prestressed ordinary concrete (version 3 in **Tab. 2**).

Fig. 3 Model of the Gaertnerplatz bridge, scale 1:2: truss structure made of UHPC

The tree alternatives mentioned in **Fig. 2** are compared to each other in **Tab. 2** with regard to the consumption of raw materials and energy. Despite the higher amount of cement in each m^3 of UHPC, the bridge would contain not more than 80 % of the cement needed for an ordinary concrete structure even if the truss structure would be made of UHPC instead of steel (version 2). The total energy content – including the energy being used for the production and the transportation of the steel and the concrete elements– is by far dominated by the steel being used for the truss, the steel fibre reinforcement and the prestressing steel within the UHPC elements as well as by the conventional reinforcement of the foundations, the abutments and the pillars. Regarding the energetic aspect the actual hybrid structure is not really an ecologically optimized solution because of the high energy content of the steel for the truss structure and the elements fitting the UHPC girders to the framework. A truss structure made of UHPC (version 2) would mean a reduction of energy by more than 50 %.

To be able to compare and to summarize different ecological criteria – raw materials, energy and emissions – impact factors has been established which are commonly accepted weighing the different "burdens" with regard to their individual impact on the environment. They have been adopted from [7-10]. In **Fig. 4** the most important impact criteria – the potential to form ozone, the acidifying potential, the contribution to the greenhouse effect (a global value) as well as the consumption of non regenerative energy and of primary raw materials are compared for version 3 (ordinary concrete structure) and for version 2, the optimized truss structure made of UHPC only. It is obvious that the lightweight filigree structure made of ultra-high performance concrete is ecologically superior regarding all five main criteria.

Tab. 2 Demand in raw materials and energy of 3 alternative bridge designs

Material	UHPC + Steel (Version 1) (truss structure of steel)		UHPC+UHPC (Version 2) (truss made of UHPC)		Ordinary concrete (Version 3) (presstressed massive)	
	Raw material	Energy	Raw material	Energy	Raw material	Energy t
	to	MJ	to	MJ	to	MJ
Cement	87	31.000	98	35.199	120	43.080
Silica fume	16	-	18	-	-	-
Aggregates	151	2.200	170	2.518	620	9.176
Water	19	-	21	-	60	-
Steel fibres	7.2	171.000	10	242.800	-	-
Reinforcing steel (incl.foundation, abutment, pillars)	22	541.000	22	541.000	70	1.720.000
Prestressing steel	8	223.000	12	327.000	10	278.000
Steel truss incl. connectors	51 62	1.441.000	-	-	-	-
Sum	-	**2.409.200**	-	**1.148.517**	-	**2.050.256**

Despite the ecological aspect one has to consider that UHPC due to its dense structure free of capillary pores is much more resistant to harmful gases or liquids than ordinary concrete or even high-performance concrete. Its durability is increased and thus the service life is significantly prolonged without or even with a reduced need of protection or repair of the structure. The practical experiences gained with the Gaertnerplatz bridge proved that the costs for such an innovative structure are adequate to a conventional concrete or steel bridge with the same load bearing capacity.

Considering all three aspects – ecological impact, durability and costs – one can summarize that structures made of UHPC which are adequately designed to really exploit the very special performance of this high strength, highly durable material are of superiour sustainability compared to common concrete or to steel structures.

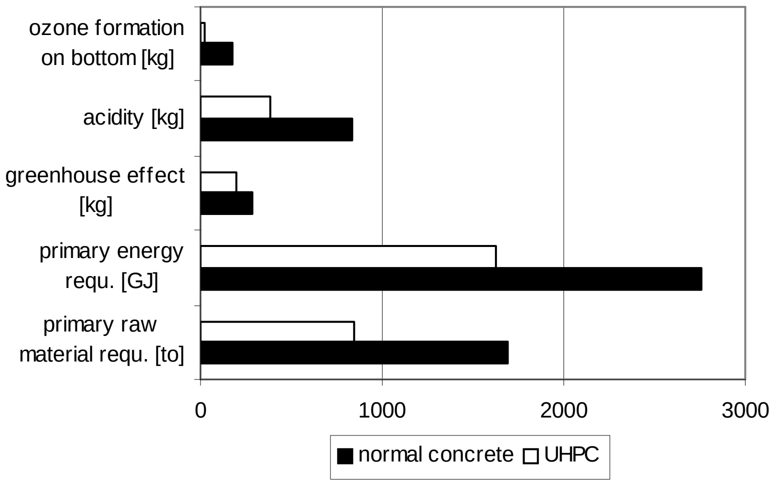

Fig. 4 Comparison of the impact on the environment caused by an optimized bridge construction consisting of UHPC (version 2) or of ordinary concrete (version 3 in **Tab. 2**)

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