Application of UHPC thin-walled elements for multi-purpose use table

O Slaby\textsuperscript{1}, J Vašková\textsuperscript{1} and V Veselý\textsuperscript{2}

\textsuperscript{1}Department of Concrete and Masonry Structures, Faculty of Civil Engineering, CTU in Prague, Thákurova 7, 166 29 Prague 6, Czech Republic
\textsuperscript{2}Betotech, s.r.o., Beroun 660, 266 01 Beroun, Czech Republic

E-mail: ondrej.slaby@fsv.cvut.cz

Abstract. This paper deals with thin-walled elements made of high performance concrete and the application of these elements in practice. This material is nowadays used more often in civil engineering and also in architecture, it enables realization of lighter and thinner products. The paper presents design and manufacturing of a ping-pong table for multi-purpose use, which is assembled from thin-walled UHPC elements. The intention was to utilize the advantages of the material and design and construct a demountable table, which could be easily transported; hence the weight of each element will be lower than 100 kg. The thickness of the concrete board of the table was only 15 mm. The paper describes the whole development of the product – from the design and the software verification, the development of casting technologies and the development of suitable concrete composite to the final realization and testing of the manufactured table.

1. Introduction

Nowadays progress and research in the area of high performance concrete and concrete technology allows to produce more interesting and thin-walled structures and concrete products. The research of UHPC is mainly focused on increasing the load-bearing capacity, ductility, durability and other required properties. The application of various types of fibres in the composite is significant in the development of UHPC. The usage of suitable additives and admixtures is also necessary. Nowadays concrete is used not only as a structural material, but it is used more often also as a material for furniture, for construction of machines, for façades tiles or other complex shape products. High performance fibre reinforced concrete compared to the composite without fibre material has significantly higher tensile strength and toughness and can be successfully used for thin-walled components with thicknesses of 10-15 mm without traditional reinforcement.

The aim of the research was to exploit the advantages of the UHPC material and make a ping pong table for multi-purpose use. Common existing tables are mostly represented by green, massive, heavy and relatively unattractive products. The main idea was to design a table from separate elements that can be easily transported without lifting machine, only by two persons. So the maximum weight of each element could be 100 kg. It was necessary to optimize the dimensions of each element. The aim was also to design simple shape of particular elements that could be simply joined together.

The concreting of the samples, the testing and the final production of the pilot table were realized in cooperation with Betotech, s.r.o. in Kráľův Dvůr.
The realization of the project was divided in stages:
- Design of elements and their optimization
- Numerical analysis of load cases
- Design of the suitable concrete mixture and its testing
- Technology of concreting and production of pilot samples
- Manufacturing of the table and its testing

2. Product design
The table consists of two halves – two separate tables. Each table is composed of two basic elements – the table board and the table legs. The advantage of the proposed table is that each half can be used separately – for example as a dining table for outdoor or indoor use.

![Figure 1. UHPC table from thin-walled elements](image)

The table board is rectangular with dimensions of 1525 x 1370 mm and its weight is almost 100 kg. The thickness of the board is only 15 mm. The board is stiffened by the ribs – edge rib around the periphery and two lengthways ribs. The ribs provide better load distribution. Holes in the lengthways ribs are used for connection the board with the legs.

The table leg is a closed frame with cross sectional dimensions of 120 x 60 mm. The total size of the table leg is 1100 x 745 mm and the weight is 60 kg. There is a pair of notches in the upper part of leg used as a supporting of the table board.

The table composed of two boards and four table legs weighs 440 kg, that is one half 220 kg.

3. Load cases and numerical analysis
In the next step the designed table was analyzed by Finite Element Method in the Software Dlubal RFEM. Various load cases and load combinations, which may with high probability occur during use, manufacturing or transport, were analyzed. There are no prescribed load values and load combinations in standards for this type of product. Therefore seven load cases were proposed that are likely to happen with high probability. As an example, load cases that are simulating people sitting on the edge of the table, uniformly distributed load on the table board or load case that is simulating the transport the assembled table, are mentioned here. One of the load cases was horizontally applied force, simulating pushing the table by a table tennis player. This load case was important for the design of the connection between the board and the leg. The stability and straining of the joints were also checked. All the results were compared with the strength characteristics of the designed concrete. The maximum tensile stress from all the load cases was 14,9 MPa. The table was designed assuming linear
behavior. The tension stresses calculated in numerical analysis for all loading cases were lower than tensile strength measured in laboratory tests, the cracks in concrete would not occur.

**Figure 2.** Load case – line load on the edge of the board 1,5 kN/m’ and numerical analysis of the load case

**Figure 3.** Load case – uniformly distributed load 1,5 kN/m2 and the result of board deformation

The results of the numerical analysis pointed out that the peaks of tension stress in area of contact and connection of the board and the leg must be eliminated. That was realized simply by an intermediate 4 mm thick layer made of special rubber. The rubber elements provide better contact of both elements (board and leg) and also compensate the irregularities and deviations generated during manufacturing. The rubber layer was also considered in the numerical analysis.

Connection of the legs and board is provided by eight steel connections – two in each leg. There is an internal thread glued in the lengthway rib of the board and a hole for the screw in the leg. The joint is then simply realized by a wrench for tightening the screws. The screw passes through the hole in the leg and is anchored into the internal thread in the board. The designed connection ensures perfect connection of elements, the overall stability and also enables fast and easy installation.

**Figure 4.** Visualization of board and table leg joint

### 4. Ultra-high performance fibre reinforced concrete

It was necessary to design completely new mixture of concrete for the designed table that will meet all the requirements – especially the high tensile strength (there is no other additional reinforcement in addition to fibres in the concrete mixture) and very good workability (because of the thickness of the board is only 15 mm). For the final mixture, Portland cement CEM I 52,5 was used, aggregate size up to 2 mm, microsilica, slag, superplasticizer and high strength steel fibres 10 mm long. The water-cement ratio was less than 0,27.

Several testing samples were realized for the verification of the designed concrete mixture. Tensile strength was determined in a three-point bending tests of prisms 40x40x160 mm. The tensile strength was 22 MPa after 28 days. A board with dimensions 700x150x15 mm was concreted to verify the
surface quality and edge quality. Smaller samples 150x40x15 mm were prepared by cutting of the 700x150x15 mm sample and they were tested in three-point bending test. These samples were important, because the thickness of the sample was same as the thickness of the final board of the table. The strength of these samples (influenced by “size effect” of the smaller thickness) was 15.5 MPa. The compressive strength tested on cubes 100x100x100 mm was 152 MPa. All the strength values satisfy all considered calculated load cases. After strength tests it was found that the fracture surface of the specimens contained an amount of air pores. This problem was solved by modifying the aggregate fractions and by modifying the amount of superplasticizer.

![Figure 5](image5.png) Concreting of the board sample 700x150x15 mm in vertical position

![Figure 6](image6.png) Detail of the fracture surface

There were manufactured more pilot products after all necessary strength tests. The aim of these pilot elements was to verify the possibility of concreting such thin and large elements, namely of the board. Pilot tests showed some problems that had to be solved and considered before the producing of final functional pilot table. The changes were made in the technology of concreting above all – originally it was supposed that the board will be concreted in the vertical position but after the pilot concreting it was necessary to change the technology and concrete the board in horizontal position. Pilot products also verified in terms of appearance; the smooth surface of the concrete board and the edges. The good formwork was the most important thing for the next production of the table.

5. Manufacture and installation of the pilot table

The formwork of the board comprised of two parts and the concreting was realized in two phases. In the first phase, precise dose of concrete corresponding exactly with the thickness of 15 mm was concreted in the flat formwork. After the first phase the formwork was covered from above with the “negative” form and all the ribs were concreted. The formwork had to be very stiff and accurate because of the precise dimensions of each element. The formwork of the legs was more simple; it was comprised of a “closed frame”.
After the maturity – 28 days it was possible to complete the table. It was necessary to drill the holes in the legs for the connecting elements, glue the threaded fitting into the holes in the ribs of the board and to put the rubber inserts. The first step of the installation was the placing of the legs which were provisionally fixed, then the boards were placed on the legs and connected with the connecting joints. The table was finally seated and leveled.

There were examined some of load cases considered in the numerical analyses after assembling the table. Perhaps most interesting was loading of the table board by 6 persons. In all load conditions the table met the expectations and safely comply with the requirements. The table was also tested by professional table tennis players J. Panský and M. Orlowski in an exhibition and the properties are convenient for the table tennis game.

6. Conclusion
The aim of the research was to show the excellent properties of UHPC in reality and manufacturing of very thin and elegant elements of UHPC for the table for multipurpose use. All the elements had maximum weight of 100 kg, smooth surface and good durability in comparison with common tables. The advantage is also the simple and quick installation.

The technology of concreting and manufacturing of thin UHPC elements was verified by experiments and pilot products. The realization of this table enabled also testing the theory in practice and improving some manufacturing processes. It was verified that it is possible to produce such a thin and large elements that will withstand high levels of load. It should be mentioned that the price of this
manufactured table is higher than tables from common materials, but the look, multipurpose use and the durability in exterior are significant advantages.

The article points out one of the possible usage of UHPC material with a great potential.

Acknowledgement

The work was supported by the grant No. SGS17/049/OHK1/1T/11 "Fibre Reinforced Concrete with Specific Structures - Behavioural Analysis and Applications". The tests and the final production were realized in the laboratory of Betotech s.r.o. The formwork was developed and realized in cooperation with PERI, spol. s.r.o.

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