Construction report BetonBrouwers

A Mythical design of a Concrete Canoe

Representing the University of Twente

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1 Preface

The season of 2022 was a season of reconstruction. After the long and draining times of Covid-19 where the BetonBrouwers had to stand still, a great deal has changed. With the exception of three, our team consists entirely out of new members since the last participation in a concrete canoe race. Learning the traditional methods have been important the past year, to maintain the gained knowledge regarding concrete canoes and being able to expand it.

Next to maintaining knowledge within the BetonBrouwers it has also been expanded by experimenting with innovative materials in our concrete, and initializing the collection of canoe performance data. Due to a fresh team of youngsters, and our brilliant efforts in construction and training, I am confident that we will appear and perform strong at the races.

BetonBrouwers, thank you for your efforts. It was an honour to be the chairman in this great year.
Torben Sozef
Chairman of the BetonBrouwers

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2 Introduction

This report will provide some information about season 2021/2022 of the BetonBrouwers. This was a very important year, as it is the first time in two years the race will take place again. This report will discuss the construction of our new canoes. Section 3 and 4.2 will highlight everyone who has made this new season possible for the BetonBrouwers. In section 5.4 the design of the canoe, as well as all working principles will be discussed. In section 6.3 the development of the concrete mixture is elaborated. In section 7 a few innovation introduced in 2022 will be noted and in section 8, the process of the canoe construction is discussed. Finally some notes about our training will be made in section 9.

3 Sponsoring

Without the financial help and supply of materials of several companies we would not be able to construct our canoes and participate in the Concrete Canoe Challenges. Therefore we want to thank the following companies for their much appreciated support:

Betoncentrale Twenthe BV
www.betoncentrale.nl

Halfen BV
www.halfen.com

University of Twente
www.utwente.com

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www.euroskano.nl

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Staalkabelstunter
www.staalkabelstunter.com

Sika Nederland BV
nld.sika.com

Van Haarst
http://www.hvanhaarst.nl/

4 Active BetonBrouwer team

- Torben Sozef (Chairman)
- Karla Korporaal (Secretary)
- Daan Knijnenburg (Treasurer & Chief of Deep Fry)
- Annetje van Hengstum (Chief of External Affairs & Chief of Media)
- Bram Denkers (Chief of Concrete)
- Arend de Bart (Chief of Concrete)
- Bauwe Jansma (Chief of Concrete)
- Niels van Dongen (Event Manager)
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- Luuk Spijker (Chief of Innovation & Construction)
- Rick Frazer (Chief of Innovation & Construction)
- Welmoed Spanjer (Chief of Media & Chief of CAD)
- Simon Beusen (Chief of CAD)
- Nick van Nijen (Vice Treasurer)

5 Design of the canoe

In the previous challenges the BetonBrouwers were quite successful. A part of this success was based on the balanced design of the canoe, which provided the basis of the success. For the season 2022, the shape of the canoe was analysed again with the help of Delftship, a computer program to model the canoe. In this chapter the principles of the perfect shape are described, separating the principles for shaping the canoe from the ones related to the construction. Within these families a subdivision is made between performance criteria related to the regulations of both competitions and functional principles, related to the function of the craft. The function on his turn is related to our general objective: creating a fast, innovative and robust concrete canoe design.

For this season the theme of the canoes were animals, we decided to make our canoes using the colours of different animals. Our three canoes made are the *Betonijn, Orkano,* and the *kanoleon.* These three canoes were made using the principles and designs described in the the document below.

5.1 Shape principles

Shape principles are bounded by race regulations. Within this framework many degrees of freedom remain to optimize the canoes final shape. Therefore functional principles are formulated.

5.1.1 Performance criteria

- **Crew:** The canoe must be propelled by two people with single-blade-paddles.
- **Length:** The length of the canoe must be at least 4m. The maximum length of the canoe is 6m.
- **Height:** The maximum height of the canoe is 1.0m
- **Width:** The minimum width if the canoe is 0.7m. It is not allowed to construct a canoe wider than 1.0m.
- **Failure:** The canoe must be provided with air chambers which prevent the canoe from sinking after breaking or capsizing. It is not allowed that the air chambers contribute to the stiffness of the canoe. The air chambers must be removable.

5.1.2 Functional Principles

The functional principles, which ultimately lead to a competitive canoe shape, are derived with help of the well documented experiences of John Winters (Winters, 2005).

- **Displacement $D_{h;max}$**: Enough volume should be created to guarantee a floating hull under all conditions. In meeting this criterion a maximum displacement is assumed of 0.220 metric tonnes (2x80 kg for paddlers plus 55 kg for the canoe) over which a freeboard of 20 cm is sufficient to prevent wave overtopping. To have some certainty in the design, a weight of 220 kilogram is set to be the maximum calculation value.
- **Paddle positions**: In our philosophy, backed by some of Holland's top paddlers, the two headed crew should be placed in the bow and stern as much as possible, providing optimal canoe handling. This aspect is translated into a restriction in bow and stern angles. The hull beam should not be less than 0.3 m further than 1 m with respect to the canoes bow and stern.
- **Maximum Speed u_{max}:** A function of the maximum speed [knots] of the canoe in relation to the length [feet] is provided by equation **1**. Longer boats do increase displacement, drag and therefore decrease acceleration and manoeuvrability. From previous experience of our team favours long hulls over short ones since the loss in acceleration and manoeuvrability is well compensated by higher u_{max} and therefore the hull length l_h

$$u_max = 1.34 \times \sqrt{l_h} \tag{1}$$

- **Manoeuvrability and track ability:** A function of vertical curvature in the keel of the boat. The more the bow and stern are elevated relative to the boats turning point, the higher the manoeuvrability and the lower track ability. Based on earlier designs by USA competitors (Madison

Concrete Canoe Team, 2008) show that a keel and bow elevation of 5 and 7.5 cm respectively give a good compromise of both aspects. This aspect is not changed for the 2018 design, since the model provided the best results for this keel and bow elevation.

- **Resistance:** Within the hull restrictions and the optimization aspects mentioned above, the hull is designed according to the KAPER formula formulated by John Winters. Two types of resistance can be distinguished. Frictional resistance (Rf) and Residual resistance (Rr). Frictional resistance is the combined effects of wetted surface, surface condition, surface length and speed comprise the resistance due to friction. Residual resistance is caused by wave resistance. With the formula the velocity-resistance graph can be drawn. The hull resistance of the 2018 canoe is the same as the 2015 canoe, because the price of decreasing the stability in order to drastically decrease the resistance was too high. However the canoe has less resistance, because it is much lighter than the old one. So some changes are made to the canoe. These are described below.

5.2 Improvements

The canoe used in 2022 is the same as used in 2018. The canoe used in 2018 is less curved than the CT2010/2011 canoe. The latest design (CT2018) has almost the same curve, only the new design is lower in the middle part. The front of the canoe is a little bit higher, because water hindrance during the races in the last years. The bottom in the front and rear have an angle, so the canoe glide better over the water. The different design are shown below: The upper one is the current design (CT2018), the orange canoe is CT2011 and the green canoe is CT 2010.

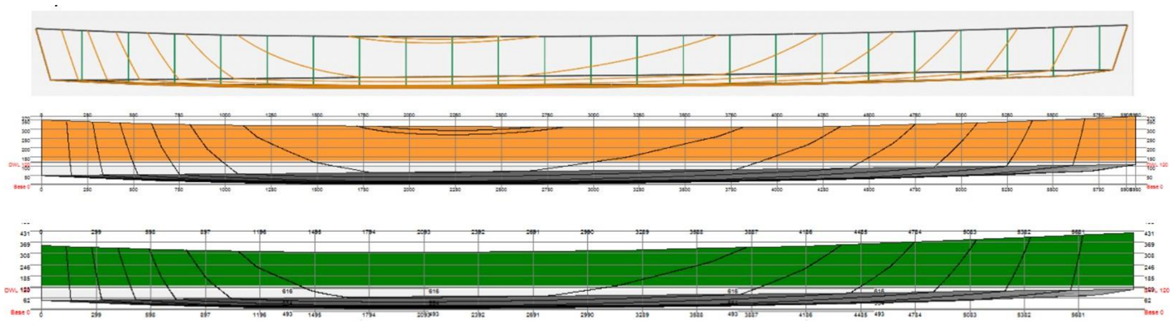


Figure 1: Canoe shapes of 2018 (upper), CT2011 (middle) and CT2010 (lower)

With the less curved upper line of the canoe and a lower bow, the total surface of the canoe is decreased from 5,849 m2 (CT2010) to 5,632 m2 (CT2011) to 5,427 m2 (CT2018). With a theoretical concrete weight of 1020,5 kg/m2 and a wall thickness of 5 mm, the reduction in weight is 1,108 kilogram. The main reduction in weight comes from the new concrete mixture, which drastically reduces the weight of the canoe. This will be described in section 5.3.

5.2.1 Stiffer canoe

The main advantage with the straighter upper line of the canoe, lies in the fact that the canoe will be stiffer. The canoe has a reinforcement steel cable in the top line of the canoe. If the line of the cable is curved, it will have the tendency to bend the canoe. When the trajectory of the reinforcement cable is much straighter, this tendency will be decreased and the canoe will benefit more from the reinforcement.

5.2.2 Construction principles

Just like the shape principles, the construction principles are bounded by the regulations. Besides the criteria derived from the regulations a set of functional principles can be formulated.

- Performance criteria:
  - **Concrete mixture** – The canoe must be constructed from (reinforced) concrete. The binding element must be cement and the use of aggregates is obligated, although there are restrictions on the particle size. Fillers and admixtures are allowed on the condition that they don’t take over the binding function of the cement.
  - **Reinforcement** – The strength and stiffness of the canoe must be derived from the collaboration between the concrete and the reinforcement. The percentage reinforcement is not

restricted. The concrete must be the determining factor concerning the stiffness of the canoe, the reinforcement itself is not allowed to have a considerable stiffness.

- Functional Principles:
  - **Waterproof** – The skin of the canoe must have a low porosity to such a degree that it can be considered waterproof under nautical conditions.
  - **Mechanics** – Based on the expected forces on the construction, estimation can be made of its dimension (thickness) and the necessary reinforcement. Hereby it is also necessary to take into account the variable forces, following from the nautical function of the construction.

5.3 The art of shaping a concrete canoe

CT2018 was redesigned by using the software package Delftship. The shape principles as defined in section 4.1.1 give clear restrictions in the optimization of the hull. The CT2018 design has alsmost the same hull shape as the CT2011 and the CT2010 design, however the resistance is lower due to a small incline of the front nose compared to the CT2011 design. The total resistance of the canoe at 6 knots is 0.0585 kN. The CT2011 has a resistance of 0.061 kN and CT2010 0.0641 kN.

Though the difference in resistance might seem small, the increase in performance is 8% over the entire trajectory. The secret behind this result is a keen L/B ratio, whereby the maximum beam is reduced to 0.70 m, which is the minimum for the German competition. Moreover, the maximum beam is placed further to the stern, leading to a very low angle at the bow part of the hull. The length is optimized to 5.98 m to ensure a high top speed at the straight. The high prismatic coefficient favours the paddlers comfort during the race, but also reduces draft, therefore the hull area which is submerged and ultimately leads to a lower resistance. The lower draft also favours manoeuvrability. The loss in track ability is compromised by a high L/B ratio.

5.4 The Blueprint of CT2018

The blueprint of CT2018 is given in Figure 2. It gives a top view, side view as well as two cross sectional views. One showing the maximum beam section and one showing a ribbon section. Incorporated are the steel reinforcement cords. The mesh is not shown.

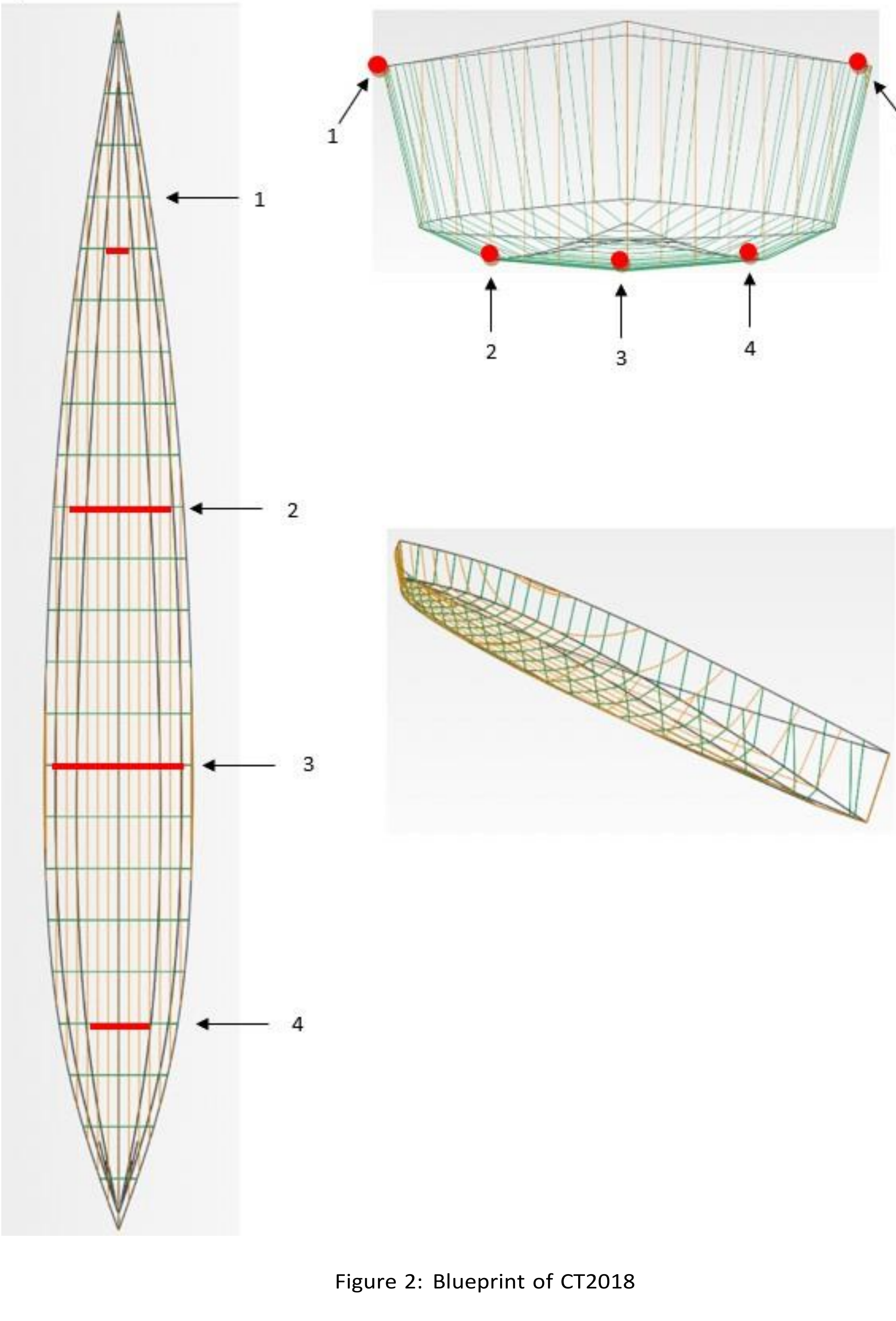


Figure 2: Blueprint of CT2018

6 Concrete mixture

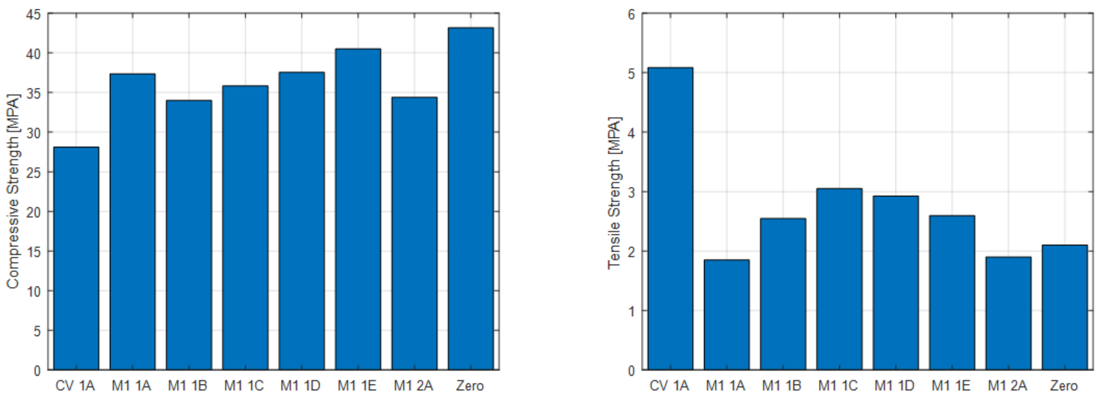
After many years of fine-tuning the previous mixture, the concrete required some new materials in the mix to improve the quality further. Therefore, several tests were performed to create a mixture for lighter and stronger canoes. After some tests 2 new materials were selected: 3M glass bubbles and Convez plastic fibres. These mixtures are optimized, and eventually resulted in two new canoes. This chapter will briefly describe the experiments, subsequently give the results of the tests and finally describe the properties of the final mixtures.

6.1 Experiments

To optimize a mixture 3 factors are essential: the workability, the strength and the weight. The plastic fibres were relatively easy to optimize, since a previous (already optimized) mixture was used and the fibres were simply added as long as the workability of the mixture was sufficient. The 3M glass bubbles on the other hand proved to be a very difficult material to work with. Five mixtures were made with different proportions of Liaver, Silica Fume, Glass Bubbles, Water, SP, and Cement. The strength and weight of all mixtures was very promising, but the workability was very poor. Eventually a mixture with a good workability was created.

6.2 Results

The results of the compressive tests are displayed in figure 3a. The compressive strength of the mixture M1 1E is the highest of the experiments, but not better than the original mixture (zero). Only one of the mixtures with 3M was combined with Liaver, which was M1 2A. This has a relatively poor value for the compressive strength, and therefore a combination of Liaver and Glass Bubbles is not likely to succeed. Also the compressive strength of the Convez fibres mixture is less than the original mixture.



(a) Results of compressive strength test

(b) Results of tensile strength test

Figure 3: Results of laboratory tests

The results of the tensile tests are displayed in figure 3b. The Convez fibres mixture performs significantly better than any other mixture. However a tensile strength of 5 MPa is not sufficient to account for the full strength, so excluding the glass fibre reinforcement in the canoe is not an option.

6.3 Final mixtures

The final mixtures for the design were M1 1E and CV 1A because of their favourable compressive strength/weight ratio and tensile strength respectively. The density of the M1 1E and CV 1A mixtures are 863 kg/m3 and 1299 kg/m3 respectively.

7 Innovations

For the first time the Betonbrouwers have experimented with sensor in the canoe. During this BKR least one canoe features sensors. Specifically it is about one sensor: the GPS sensor. The rest of the set-up consists of a battery, a Arduino Uno to make the sensor work. The components are lay loose in the cano, without being incorporated in the canoe to make reuse possible.

This set-up ensure the location and velocity of the canoe can be traced. This can be read using a laptop, or even in real time within the canoe using a dashboard. This works similarly as a cycle computer, however this was specifically designed for canoe use. The goal using the set-up is to gain insight on the performance of the canoeists, and possibly see the places where time can be gained. This can be used within normal training to see progress but also see the performance during competition.

8 Construction process

In this section it is explained how the concrete mixture in combination with the reinforcement and the new mould result in beautiful concrete canoes. The following points are important for successful casting: adequate formwork quality, concrete workability, casting technique and curing conditions. Throughout the description of the casting process below, these points can be recognized. Since 2018, a new type of canoe is constructed with the use of 3M Glassbubbles. The process used to cast this canoe is similar to the casting process of the regular canoes, and will therefore not be elaborated on.

At the start of creating a concrete canoe stands the construction of the stability framework for the mould. The framework is made of iron segments which can be secured with nuts and bolts in order to create a framework which can be used for the stabilizing the mould during the casting and for applying the pre-stressing. A clean mould is placed on the steel framework, so a usable work platform for casting is created. The idea of the mould is that it will give the concrete the right shape and that the concrete canoe can be taken out of it. This is achieved by using an outer mould, which also has the benefit that the outside of the canoe will be smooth and therefore will glide through the water quicker.

When we have the clean mould in place it is time for putting the creative templates, like the thunderbolt of the 2019 Zeus canoe, in the mould. Next, the demoulding oil is sprayed onto the mould. In the mould, on the bottom, three steel cords are placed, intended for pre-stressing. One cord is going through the middle while the other two cords run through the corners of the bottom. Besides three cords in longitudinal direction, also four cords in cross direction were placed. These cords are intended to make the cracks in the longitudinal direction smaller. The cords are held in position with the help of little holes in the mould and the use of iron wire and wire strainers. After placing the longitudinal cords, they are put on tension, however not with the final force because the mesh has to be placed underneath the cords.

When we got the mould in the condition of a greased surface and ungreased cords it is time for casting. This means that all materials can be weighted in the right proportions and the mixture can be made. First the dry materials are put into the mixer. We use a batch mixer, type forced action mixer, whereby the concrete is mixed by a rotating bin with stagnant paddels. When the dry materials (cement, 3M Glassbubbles or Liaver, microsilica and pigment) are mixed properly the water is added. This created a stiff mix of materials. To obtain the right workability, Super Plasticizer (SP) is added. A batch is workable if it is not too dried out that it is impossible to knead it in the mould or if it is not too wet that it drips back down from the sides of the mould. The process of adding the SP therefore is a delicate matter. A little bit too much turns the mixture in a soup and is far from ideal, but a little bit too less makes the mixture to dry and not workable either. But, when the right consistency is found, the mixture is ready to be processed. For a strong and flexible canoe the section of the canoe will be layered as follows:

- a thin layer concrete;
- mesh (underneath the cords);
- another layer of concrete;
- mesh again (above the cords);
- and eventually the last layer of concrete.

This process will go step by step starting in one end of the canoe and working towards the other end. The challenge with this process is that it needs a constant flow of concrete, because the layer concrete will not dry out in such degree that it may not adhere with the next one.

As mentioned earlier in this report, five longitudinal cords are used per canoe. Three cords are already placed in the bottom of the canoe. The remaining two cords are placed in plastic tubes in the top of the vertical walls of the canoe during the process. When the concrete had enough time to harden these cords are stressed. The thin plastic tubes have been roughened to increase the contact surface with the concrete. The plastic tubes are either fixed onto the canoe with the mesh where simply a thin part of mesh is folded and with a plastic tube in it, or fixed on the top directly.

Figure 4: Applying the first layer of concrete to the mould.

While working from one end of the canoe to the other, four tears were created at the location where the cords in cross direction are located. These tears are fixed by placing extra mesh on top of the tears in order to create a so-called ‘bridge’ of mesh between the two torn mesh layers. These bridges are added as extra layers to the canoe.

After completing the casting, the longitudinal cords can be put on the right tension. This was done by pushing the framework apart with the use of two jacks. After a check if everything stayed in place after stressing the cords and scratch away the surplus concrete, the canoe is considered finished. When all this is done, it is time to create an ideal atmosphere for the concrete to cure, this means creating a high humidity. To create an ideal humidity some extra water is put onto the surface of the last layer. Finally a foil was put over the mould sealing the canoe. During the next days it is important to control if the atmosphere, and, if necessary, to add some water.

After at least three days of hardening the canoe could be demoulded. To do this, the prestressed cords have to be cut at the point where they exit the mould. The next step is to turn the mould around and remove all steel wire coming out of the mould. When all connections are removed, the mould can be bended outwards and lifted, leaving a beautiful concrete canoe on the floor. The canoe can now be put in a canoe carrier to wait for finishing, or can be finished immediately. Most of the time, the mould is cleaned first, so it is ready for the next day of casting.

All that is left is the finalizing of the canoe. First of all, all the cords that are still sticking out of the canoe are cut or sanded using a grinder. Moreover, the sharp edges of the remaining excess concrete are removed with the grinder as well, and covered with polystyrene tubes so the canoers do not get any cuts in their arms when paddling. Next, the two upper cords can be post stressed. This is done by placing two metal plates on the bow and stern of the canoe and attach the cords to them with the use of a bold. By turning the bolds the cords gets tensioned and the canoe is compressed. The tension is gradually increased until the required tension is reached. By increasing the tension in several steps the concrete can 'get used to' the new forces acting on it. Some bolds are constructed in the wall to attach the air sacs, these air sacs are simply made of large balloons. In the last stage of the finishing, the names, the sponsors and start numbers are painted onto the canoe. Noticeable here is the fact that the painted parts of the canoe are all above the water line, so the paint does not contribute to the airancy of the canoe. Now the canoe itself is finished and ready for the battle.

9 Contact information

Study Association ConcepT
Study Association of the department Civil Engineering (& Management) at the University of Twente.

A: Horst C-016 C-018
Postbox 217
7500 AE Enschede
T: +3153 489 3884
E: ConcepT@ConcepT.uwente.nl
I: http://www.ConcepT.utwente.nl

Eventmanager BetonBrouwers

Niels van Dongen
T: +316 83388435
E: nielsvandongen1@gmail.com

General information Betonbrouwers

E: betonbrouwers@concept.utwente.nl
I: http://www.betonbrouwers.nl/