Construction report BetonBrouwers

A rock-solid Concrete Canoe design

Representing the University of Twente

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1 Preface

The season of 2023/2023 was a year of development. Throughout the existence of BetonBrouwers, the team has adhered to a typical design for their canoe shape. This canoe design is optimized and slightly modified throughout the years to arrive to the canoe shape we are using today. Since previous season, there were thoughts to completely redesign the canoe shape from scratch. Consequently, the team embarked on a journey to completely redesign the full canoe shape. Recognizing the enormity of this task, the decision was made to construct our canoes following our earlier canoe designs. We aim to present a magnificent, state-of-the-art canoe design to everyone next year.

Meanwhile, the BetonBrouwers team has been diligently working to expand our knowledge of innovative and sustainable materials in concrete, while also training rigorously for the upcoming concrete canoe races. I would like to express gratitude to all sponsors for their contributions in making this season possible. Additionally, I want to thank everyone in the BetonBrouwers team for their unwavering commitment this season. Together, we will ensure that this season and the races are truly unforgettable.

Lukas Raadschelders
Chairman of the BetonBrouwers

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2 Introduction

This report will provides information about the design and construction of the concrete canoes in season 2023/2024 of the BetonBrouwers. This report will discuss the construction of our new canoes. Section 3 and 4 will highlight everyone who has made this new season possible for the BetonBrouwers. In chapter 5, the design of the canoe, as well as all working principles will be discussed. In chapter 6, the applied reinforcements in the canoe are explained. Chapter 7 describes the developed concrete mixture is for the concrete. In chapter 8, the safety measures of the concrete canoe are described in case of failure and in chapter 9, the construction process of the canoe is described.

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:

Ecocem
https://www.ecocemglobal.com/nl/

Leviat
https://www.leviat.com/nl-nl/

Betoncentrale Twenthe BV
www.betoncentrale.nl

Bosch Beton
https://www.boschbeton.nl/

Drienerlose Kano Vereniging Euros
www.euroskano.nl

Study Association ConcepT
www.concept.utwente.nl

Sto Isoned BV
www.sto.nl

Liaver
www.liaver.com

4 Active BetonBrouwer team

Lukas Raadschelders	Current chairman & Chief of Mould
Nick van Nijen	Former chairman
Ramon Bonte	Treasurer
Joanne Ax	Eventmanager
Simon Beusen	Chief of CAD
Chris de Jong	Chief of CAD
Arend de Bart	Chief of Concrete
Madieke van Oosterhout	Chief of Concrete & Chief of deep-fry
Niels van Dongen	Chief of Concrete
Justus Meyer	Chief of Concrete
Minze Hamstra	Chief of Mould
Rick Frazer	Chief of Mould
Torben Sozef	Chief of Mould & Chief of External affairs
Loes Hazenberg	Chief of External affairs
Annetje van Hengstum	Chief of External affairs
Jaco Belaiyneh	Chief of External affairs
Luuk Spijker	Chief of Media
Bas Huting	Professional ‘Beunhaas’

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. 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.

In this season, the same canoe design is used as which is designed and optimized in the year 2018. This Chapter will describe all the technical aspects of this canoe design.

For this season the theme of the canoes were fruits and vegetables, we decided to make our canoes using the colours of different fruits and vegetables. Our three canoes made are the *Betomaat, Paprikano,* and the *Avocano.* 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 the assessment of this criteria, a maximum mass of two paddlers (2x80kg) and the mass of the canoe (60kg) is taken. Moreover, the canoe has an extra 20 cm to prevent wave overtopping. So, while designing the canoe a minimal volume of 220 L was taken into account, with a freeboard of 20 cm.
- **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 the equation here below. 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

$$u_{max} = 1.34 \times \sqrt{l_h}$$

- **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 2024 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.

5.2.1 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.

5.2 Technical aspects of the Concrete Canoe design

The concrete canoes which are constructed in the season 2023/2024 are based on the optimized concrete canoe design of the BetonBrouwers of 2018. The canoe design of 2018 is the most optimized version of our canoe shape as presented in figure 1. The canoe design of 2018 is design with the software package Delftship in order to determine the frictional and residual resistance. For the canoe design of 2018, the total surface area is minimized as much as possible which also reduces the total resistance of the canoe. These technical aspects of this concrete canoe design are listed here below.

- Design canoe length: 5.98 m
- Total surface area of the canoe: 5,427 m^2
- Total resistance at a speed of 6 knots: 0.0585 kN

The blueprint of CT2018 is given in figure 1. 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. The blue prints also show the incorporated longitudinal and transversal steel reinforcement cords. The reinforcement plan is further in detail described in chapter 6. The mesh is not shown.

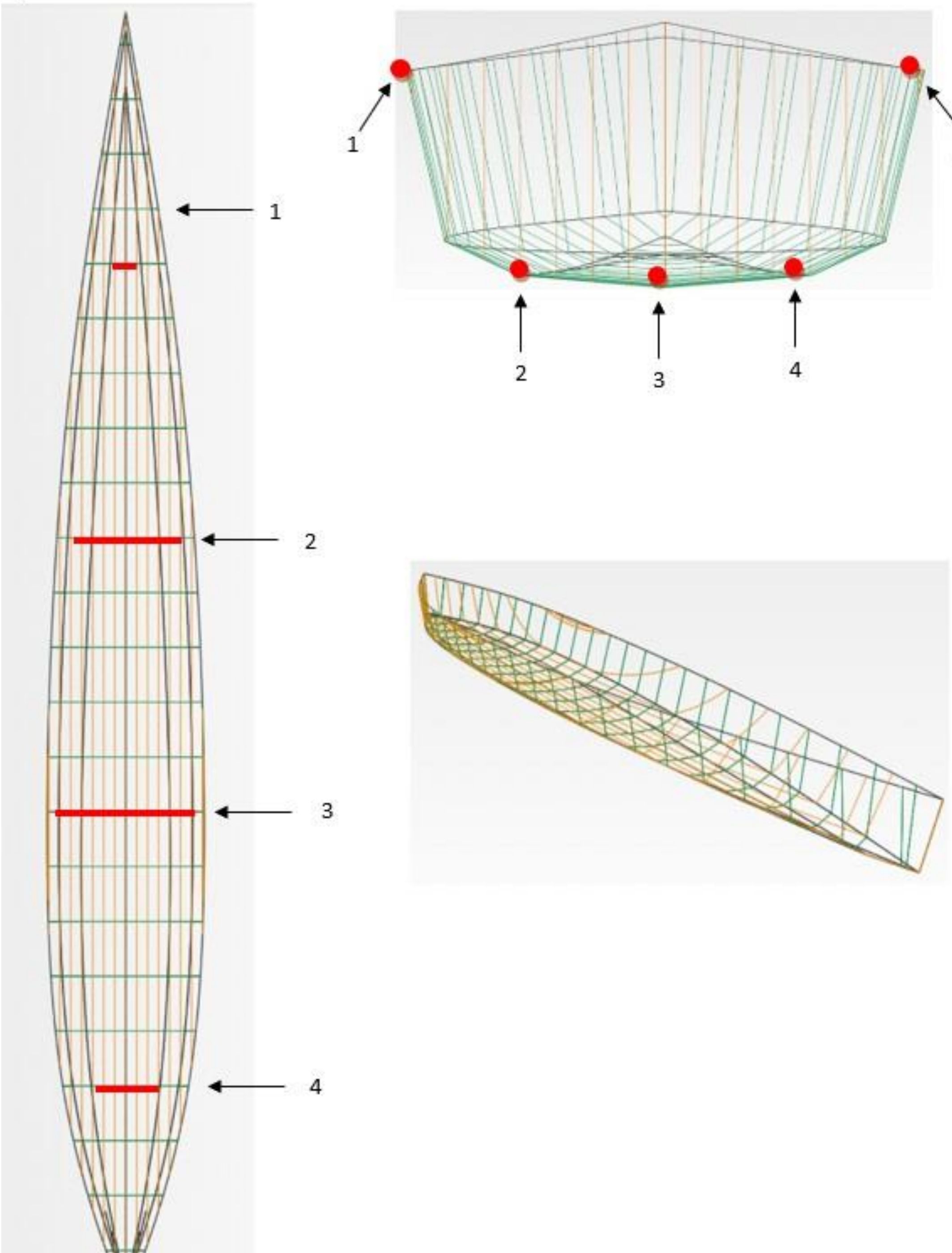

Figure 1: Blueprint of CT2018

6 Reinforcement

From a mechanical analysis done in 2015, it was found that the concrete's compressive strength is great enough to withstand all compressive forces acting on the canoe. But, as said before, the tensile strength of concrete is relatively weak. In the canoe, tensile forces still occur continuously. Especially, when the two paddlers create tensile forces in the hull. To counter these tensile forces, pre-stressed steel cords are placed. Three cords are placed in the longitudinal direction of the canoe and four cords in the width. The cords are located strategically at the positions of the paddlers to accommodate for the forces they create.

From the analysis, it was found that the tensile forces on the side walls of the canoe also exceed the concrete strength. By placing an extra two steel cords within the top of the walls, this force is compensated. These cords are stressed after the curing of the concrete, using two anchors at the bow and stern.

Static evaluations revealed some weak points in concrete canoes. Under racing conditions extreme stresses occur, as these conditions are very dynamic. Modelling hull stresses over time is not possible, wherefore a simple philosophy is applied: 'If it bends, it doesn't break!'. Over the entire hull two layers of stucco-mesh are applied which distribute the stresses from the hull to the cords and the mechanical structure, and to make sure that the canoe can have more impacts without cracking, caused by extreme racing conditions. These meshes are a combination of plastics and glass fibres with a mesh size of 5x5mm.

So, the reinforcement of the canoe consists of:

- 3 longitudinal pre-stressed steel cords in the bottom of the canoe over the whole bottom length of the canoe (shown in the right subfigure of figure 1 with the numbers 2, 3 and 4)
- 2 longitudinal post-stressed steel cords in the top of the side walls of the canoe over the whole top length of the canoe (shown in the right subfigure of figure 1 with the numbers 1 and 5)
- 4 transversal pre-stressed steel cords in the bottom of the canoe at the position of the paddlers (shown in the left subfigure of figure 1 with the numbers 1, 2, 3 and 4)
- 2 layers of full body mesh

With this reinforcement, the canoe is strong enough for the static forces according to the 2015 analysis, where all calculations took place. Also, it can withstand some impact caused by extreme stress conditions with the full body mesh.

7 Concrete mixture

After many years of testing and fine-tuning previous mixtures a very stable, and reliable mixture was found that is both sufficiently workable and strong enough. The current Chiefs of Concrete are new to the art of mixing concrete, so the knowledge gained by the predecessors was used this year to create the canoes. While the current Chiefs of Concrete started investigating the next steps in improving the mixture. The main points of interest for the concrete mixture will be explained below.

7.1 Concrete mixture principles

7.1.1 Workability

Workability is very important in the production process of the canoe. This is due to the casting technique used. Having a dry and coarse mixture will result in problems attaching the concrete to different layers, whereas a mixture that is too fluid will result in a mixture that cannot be handled in the construction process described in **Error! Reference source not found.**. The workability of concrete depends on the properties of the constituent materials, their relative proportions and the physical and chemical interactions between them. This means all different components are combined in well-designed proportions to create a workable mixture. If necessary, as further explained in the **Error! Reference source not found.** superplasticizer is used to increase workability, this has relatively little effect on the strength of the concrete.

7.1.2 Strength

Concrete is known for its high compressive strength, while the tensile strength of concrete is relatively low. In most concrete mixtures the tensile strength of concrete is around 10% of the compressive strength. Usually, the tensile strength is neglected as it is taken care of by the reinforcements. However, tensile strength still is important as it dictates the cracking in the concrete, affecting the durability of the concrete. Furthermore, it affects the shear capacity and the bonding to reinforcement and previously cast concrete.

7.1.3 Porosity & permeability

The porosity and permeability are also highly influenced by the proportions of the materials. In the hydration of concrete, the volume of the cement will decrease, creating voids inside the concrete. By decreasing the w/c ratio to below 0.5 the concrete will be more 'watertight' because the absolute value of voids decreases. Furthermore, the proportioning of aggregates will also decrease porosity and permeability. The aggregates should create a smooth transition between the cement water paste and the aggregates, when aggregates are relatively big many voids will arise. When smaller aggregates are used fewer voids are created, as the aggregates can fill those holes.

7.2 The concrete mixture recipe

The mixture has taken into account all these principles, while also taking the weight of every component is taken into consideration. The canoe should be as light as possible while still performing well. The following mixture of materials and their proportions shown in table 1 are used in the concrete. Table 1 shows the concrete mixture for a batch of 20 kilograms of concrete. For the construction of a full canoe, multiple of these batches need to be created.

Table 1: Concrete mixture

Materials	Massa [kg]	Volume [L]
CEM III/A 52,5 N-SR	9,791	3,189
Water	3,965	3,965
Microsillica	0,623	0,269
Pigment	0,298	0,076
Liaver 0.1-0.3	3,414	3,518
Liaver 0.25-0.5	0,981	1,725
Liaver 0.5-1.0	0,929	1,938
Superplasticizers (SP)	0.0044	0,004
Total	20	14.7

8 In case of failure of the Concrete canoe

When the canoe has failed in any case, e.g. rupture of the hull, collision with another canoe, toppling over, etc. The canoe should in all circumstances keep floating. The canoe will not be allowed to sink. To achieve this an air sac is attached to the middle of the canoe. Taking the weight of the canoe as 60 kg, the air sac should at least be 60 L.

If in any case, this method of floating fails through unforeseen circumstances, the canoe will remain visible due to the attached buoy. The buoy is attached to a rope of 10m and has a buoyancy of 2 kg.

9 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 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 throughthe middle while the other two cords run through the corners of the bottom. Besides three cords in lon- gitudinal 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 holesin 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 canbe 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 nottoo wet that it drips back down from the sides of the mould. The process of adding the SP therefore isa 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 thetop 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 2: 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 wherethe cords in cross direction are located. These tears are fixed by placing extra mesh on top of the tearsin 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 doneby 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 controlif 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 mouldis 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.

10 Contact information

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