Construction report BetonBrouwers

1. Preface

The season of 2022 was a season of reconstruction after Covid-19 times. The season of 2023 was then used to expand on the knowledge and enthusiasm gained in the previous year. Designing and constructing a concrete canoe became a tradition and habit again while pushing the concrete canoe to its limits. New designs and mixtures have been tested and some of them are already implemented in the canoes that we brought to Delft for the Concrete Canoe Regatta, such as a new integrated design for the longitudinal reinforcement.

A young and enthusiastic BetonBrouwers team was the key to making the canoes this year. Great effort and communication resulted in a steep learning curve for everyone on the committee and I am confident we can keep this steep incline during the races and perform strongly at them!

Nick van Nijen

Chairman of the BetonBrouwers 2023

Contents

1. Preface ... 2
2. Introduction ... 4
3. Sponsoring ... 5
4. Shape of the canoe ... 7
   - 4.1. Design criteria ... 7
   - 4.2. Shape ... 8
5. Concrete mixture ... 9
   - 5.1. Proportioning ... 9
   - 5.2. The mixture ... 9
6. Reinforcements ... 10
7. Failure catching ... 13
8. Construction process ... 13
9. Contact information ... 16

2. Introduction

This report will provide information about the construction of the canoes made by the BetonBrouwers in the season 2022/2023. The canoes are built on principles our predecessors made and this report will both explain the concepts behind the construction techniques and the design choices made for new generations of BetonBrouwers and the officials at the ConcreteCanoeRace. First, the shape of the canoe will be described, secondly, the concrete mixture will be explained, and then the reinforcement of the design will be explained. Thereafter, canoe failure preventions in the design are explained. Lastly, the construction process is explained.

Members

Name	Function
Nick van Nijen	Chairman
Daan Knijnenburg	Treasurer
Ramon Bonte	Eventmanager
Simon Beusen	Chief of CAD
Madieke van Oosterhout	Chief of Concrete
Arend de Bart	Chief of Concrete
Bram Denkers	Chief of Concrete
Niels van Dongen	Chief of Concrete & Innovation
Loes Hazenberg	Chief of Concrete & Innovation
Luuk Spijker	Chief of Innovation & Media & M&C
Welmoed Spanjer	Chief of Casting
Rick Frazer	Chief of Casting
Annetje van Hengstum	Chief of External Affairs
Jacob Belaiyneh	Chief of External Affairs
Torben Sozef	Chief of External Affairs & Training
Bas Huting	Chief of Construction
Lukas Raadschelders	Chief of Aerodynamics

3. Sponsoring

Betoncentrale Twenthe B.V.
www.betoncentrale.nl/twenthe

Universiteit Twente
www.utwente.nl

Liaver
www.liaver.com

Martens beton
martensgroep.eu

Leviat
www.leviat.com

conStabiel
constabiel.nl

Bosch Beton
www.boschbeton.nl

4. The shape of the canoe

The shape of the canoe plays an important role in the Concrete Canoe Races, the shape of the canoe dictates the flow of water around the canoe, but also the buoyancy. Therefore, if the shape is not well-designed the canoe might sink instantly when entered into the water. Moreover, if the shape is not aerodynamic too much friction will occur, which would highly influence the velocity. The shape has some restrictions indicated below.

4.1. Design criteria

Performance criteria:

- **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 maximum width of the canoe is 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 to contribute to the stiffness of the canoe. The air chambers must be removable.

Functional criteria:

- **Buoyancy -** 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** – The two paddlers should be placed in the bow and the stern as much as possible for optimal canoe handling. This aspect was converted into a restriction in the bow and stern angle to create space to sit. The hull beam should not be less than 0.3m or further than 1m concerning the bow and stern.
- **Maximum velocity** – 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. Previous experience of our team and USA competitors favour 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.
  $u_{max} = 1.34 \times \sqrt{l_h}$ (1)
- **Manoeuvrability and trackability** - A function of vertical curvature in the keel of the boat. The more the bow and stern are elevated relative to the boat's turning point, the higher the manoeuvrability and the lower trackability. 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 2011 design, since the model provided the best results for this keel and bow elevation.
- **Resistance** – 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 KAPER formula formulated by John Winters a velocity-resistance graph can be drawn. The least amount of resistance results in the best canoes.

4.2. Shape

Using all these criteria the following canoe was designed, see Figure 1: Side view canoe. The length of the canoe is 5.95 m, and the maximal width in the centre of the canoe is 0,7m. The height of the canoe is 0.4.

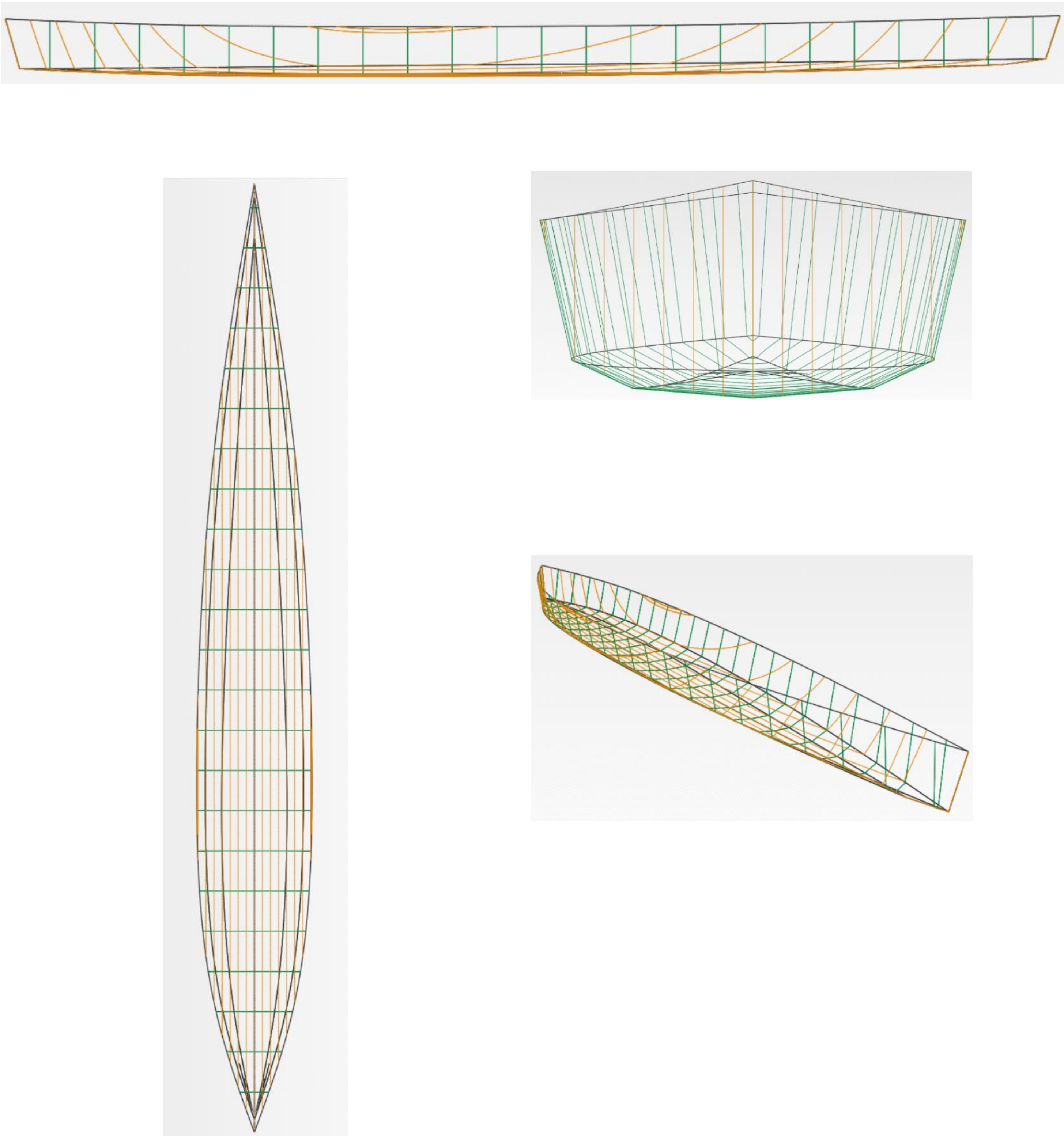

Figure 1: Side view canoe

5. 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.

5.1. Proportioning

Proportioning concrete means selecting materials and adding them together. This influences the following characteristics of the concrete;

5.1.1. 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 Construction process. 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 Construction process superplasticiser is used to increase workability, this has relatively little effect on the strength of the concrete.

5.1.2. 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.

5.1.3. 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.

5.2. The mixture

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 materials and their proportions are used in the concrete;

Table 1: Concrete mixture

Material	Mass [kg]	Density [kg/m3]	Volume [L]
CEM III/A 52,5 N-SR	667,052	3140	217,281
Water	270,084	1000	270,084
Microsillica	42,442	2330	18,215
Pigment	20,174	3900	5,173
Liaver 0.1-0.3	232,603	970	239,797
Liaver 0.25-0.5	66,915	570	117,394
Liaver 0.5-1.0	63,387	480	132,056
Totaal	**1362,876**	**12390**	**1000,000**

Depending on the workability of the mixture a small amount of superplasticiser is added. During testing no specific amount of superplasticiser was found, thus this is added by expert judgement on the workability of the concrete by the Chiefs of Concrete. The w/c ratio in this mixture is around 0.4. This ratio, together with the aggregate sizes, maximises the waterproofness.

6. Reinforcements

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:

The pre-stressed steel cords and the post-stressed steel cords are shown in the figures below.

- 3 pre-stressed steel cords in the bottom of the canoe over the whole bottom length of the canoe
- 2 post-stressed steel cords in the top of the side walls of the canoe over the whole top length of the canoe
- 4 pre-stressed steel cords in the bottom of the canoe at the position of the paddlers
- 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.

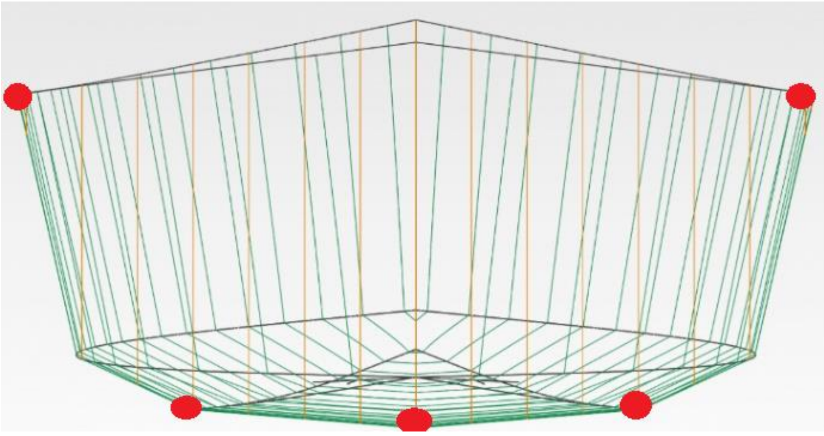

Figure 3: The 4 cross-directional cords

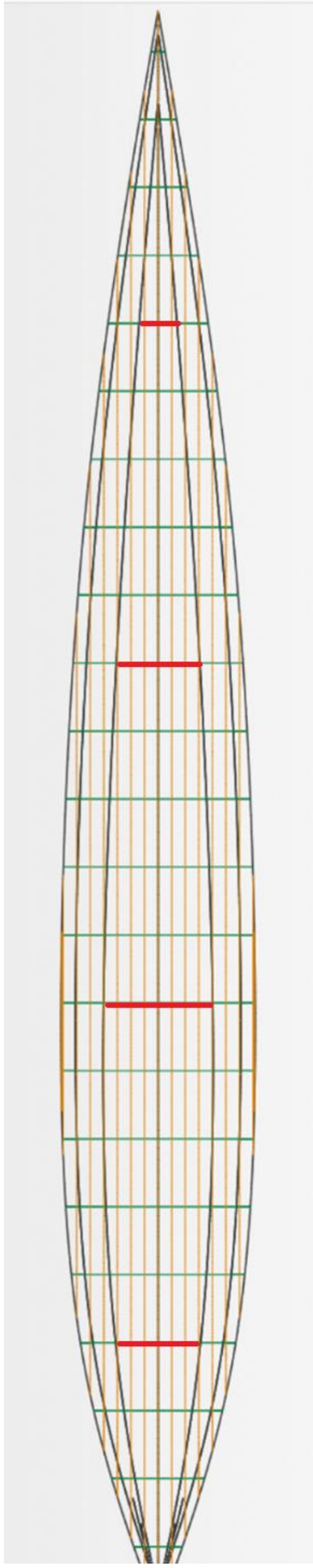

Figure 2: The 5 longitudinal cords

7. Failure catching

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.

8. Construction process

This section it is explained how the concrete mixture in combination with the reinforcement and the mould results 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.

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 to create a framework which is used for 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 form and that the concrete canoe can be taken out of it, when the concrete is cured. 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 more quickly.

First, the mould is quickly cleaned with wet wipes to ensure no dust is inside, and then the mould is covered in demoulding spray, 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 the longitudinal direction, also four cords in the cross direction were placed (see Reinforcement). 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, but 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 concrete 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 paddles. When the dry materials (cement, Liaver, micro-silica and pigment) are mixed properly, the water is added.

This created a stiff mix of materials. To obtain the right workability, a very little amount of 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 into a soup and is far from ideal, but a little bit too less makes the mixture too 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 of 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 at 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 layered concrete will not dry out to such a degree that it may not adhere to the next one.

Three longitudinal cords are already placed in the bottom of the canoe, as explained before. Two other cords are added at the top of the vertical walls of the canoe during the process, the cords are put inside a plastic tube to create more area, which reduces stress inside the concrete. 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. This year, a new type of reinforcement implementation was used. The plastic tubes can be fixed onto the canoe with two different methods. In one instance, the one we normally use, the tubes have been added to the last layer of concrete, with an extra layer of concrete. The other new method tried this year was to add the cords between the first and second layers of mesh. Essentially removing the extra layer of concrete to reduce weight. The new method of attaching the top reinforcement had some more difficulty in execution.

While working from one end of the canoe to the other, four tears were created at the location where the cords in the cross direction are located. These tears are fixed by placing extra mesh on top of the tears 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 scratching 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 environment. 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 few days, it is important to control 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 bent 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 canoe.

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 on 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 attaching the cords to them with the use of a bold. By turning the bolds, the cords get tensioned, and the canoe is compressed in the upper section. The tension is gradually increased until the required tension is reached. By increasing the tension in several steps, the concrete can adapt to the new forces acting on it.

Additionally, 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. Now the canoe itself is finished and ready for the battle.

9. Contact information

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