CONSTRUCTION REPORT
BETONBROUWERS 2018

Enschede, April 2018

BetonBrouwers
Study association ConcepT
University of Twente

UNIVERSITY OF TWENTE.

Preface

A new year with new opportunities have started for the BetonBrouwers. To celebrate the 10 year anniversary of the committee, the Dutch Concrete Canoe Race will be held in our home town Enschede. This makes it even more important for us to try and make the best canoes.

This year, one of the most particular innovations is the creation of the UHPC canoe. In collaboration with the ENCI in Rotterdam, we have made a canoe made completely from this Ultra High Performance Concrete, to show what the possibilities of this new development in concrete innovations are. Due to the different properties of this new type of concrete, a new way of casting the canoe had to be developed, causing some problems, but also many new ideas for the following years.

Beside the one UHPC canoe, four canoes have been made with our normal concrete for making the canoes. After some minor improvements, the mixture should be strong and workable enough to cast some very fast and light canoes.

This construction report will give you a good view of the construction process of the canoes, and our road to hopefully another championship.

Content

Introduction

In front of you lays the construction report of the construction committee 2017 of Study Association ConcepT. Since September 2016 this committee, consisting of fourteen 'BetonBrouwers', has put a lot of dedication and effort in designing and constructing five magnificent concrete canoes. This report has been written in order to give the construction jury a clear insight in the applied design and construction as well as its implementation. Besides it gives the sponsors and other interested people an impression of the way the concrete canoes are build. Furthermore this report serves as documentation for future members of the committee.

The phenomenon Concrete Canoe Challenge can be found in many countries in Europe and abroad. This year will become a special year for us because once again we are participating in two of these competitions: the Dutch and German competition. In the Netherlands the Concrete Canoe Challenge (BetonKanoRace) is organized annually under the auspices of the Dutch concrete association (Betonvereniging). In Germany this event, the Betonkanu-Regatta, is organized once in every two years and is initiated by the Deutschen Zementindustrie e.V.. During the events students from different academies, universities and other institutions compete in their self-build concrete canoes for the honour. The aim of these fantastic events is to promote the multi-purpose product CONCRETE. This year the competition takes place in the BetonBrouwers' home town Enschede where we will try to beat our competitors and conquer the first price once again!

This report will give a summary of our sponsors who enable us to build these canoes, it will explain the design of our canoes, the mixture and the carriers of the canoes. Lastly it will briefly explain how we train and prepare our self for the big race.

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:

ENCI/ Heidelberg Cement Group
www.heidelbergcement.com

Liaver
www.liaver.com

Betoncentrale Twenthe BV
www.lievensecso.com

Halfen
www.halfen.com

University of Twente
Faculty of Engineering Technology
School of Civil Engineering
www.cit.utwente.nl

Study Association ConcepT
www.concept.utwente.nl

Scholz
www.scholz-benelux.nl

Sika Nederland BV
nld.sika.com

Drienerlose Kano Vereniging Euros
www.euroskano.nl

About the BetonBrouwers

3.1 Members

Luc Scholten	Chairman
Anne Hofman	Vice-Chairman
Sander Leusink	Secretary
Anne Hofman	Treasurer
Kai Hermann	Chef Concrete
Anouk van Daatselaar	Chef Concrete
Daan Kampherbeek	PR – External Affairs
Tim Pauli	Chef Innovations
Jeroen Scholten	Chef Innovations
Anja Mus	General Member
Irma van Roozendaal	General Member
Marit Lambers	General Member
Rutger Meester	General Member

3.2 History

It all started in 2007 when a group of 4 students, who were experimenting with concrete, realised how much fun and fame could be obtained by building concrete canoes. In August 2005 study association ConcepT was asked to hosted the “BetonKanoRace” in September 2007 in Enschede. That year 4 students formed the team of the BetonBrouwers and conquered 2 second places against no one less than the Americans.

From 2008 the BetonBrouwers started to actually develop. In collaboration with study association ConcepT a plan was formed to develop the BetonBrouwers and to focus on the future. Also the mixture was improved that year, and with the help of a lighter mixture the BetonBrouwers won the national championship in Delft on various distances, and in the overall class.

After the glorious victories in Delft, the BetonBrouwers creaved even more fame, and decided to go abroad. After some improvements on the mal and the mixture, we conquered the first places in both Roermond and Essen in 2009.

After the season of 2010 more and more innovative projects were accepted. IN 2011 the lightest canoe in Dutch history was built with only 11 kilo and in 2012 even a foldable canoe was built.

In 2012 the overall price of the French ChallengeCanoëBéton was conquered. In 2013 many prices were won in Utrecht, and for the 3th time in a row we conquered the overall price in the German BetonKanuRegatta in Nurnberg. In 2014 the heavies canoe ever was produced by the BetonBrouwers weighing 1156 kilo. This canoe obviously wasn’t the fastest of the race, but seemed to have excellent usage as a tribune or BBQ. In 2015 they obtained both the National and the European title, making it one of the best years in history. 2016 has been a learning year, due to many new members and the parting of some old members. We have used the year to transfer knowledge to the new members to make the committee more durable.

Design of the canoe

4.1 Principles of CT2015

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 2011, 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.

4.1.1 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.

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.

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. The average displacement is a lot less, since the weight of the canoe is 43.76 kilogram, with a theoretical weight of the concrete of 1020,5 kg/m^3 and a wall thickness of 5 mm. Since these theoretical values are not reached in practice, 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. Previous experience of our team and USA competitors 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

$$u_{max} = 1.34 \times \sqrt{l_h} \qquad (1)$$

- **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 2011 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 2011 canoe is the same as the 2010 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.

4.2 Improvements

Less weight

The canoe of 2011 was less curved than the CT2010 canoe. The latest design (CT2015) 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 (CT2015), the orange canoe is (CT2011) and the green canoe (CT 2010).

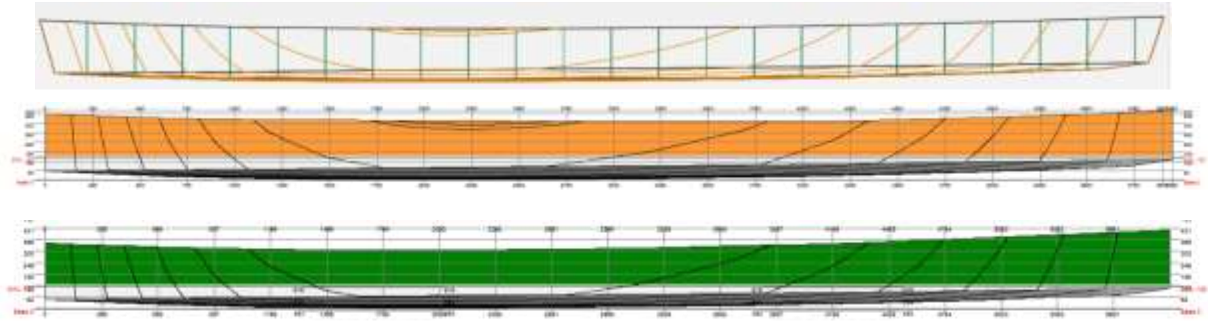

Figure 1: Canoe shapes of 2015 (upper), CT2011 (middle) and CT2010 (lower)

With the less curved upper line of the canoe and a lower bow, the total surface of the canoe is decreased from 5,849 m^2 (CT2010) to 5,632 m^2 (CT2011) to **5,427 m^2** (CT2015). With a theoretical concrete weight of 1020,5 kg/m^2 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 3.

4.2.1 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.

4.2.2 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 (CEM I – CEM V) and the use of aggregates is obligated, although there are no restriction on the amount or 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.

4.3 The art of shaping a concrete canoe

CT2015 is designed by using the software package Delftship 7.14.280 Thereby we consulted people of the Maritime Research Institute Netherlands (Marin) in 2011 to identify the possible improvements.

The shape principles as defined in section 4.1.1 give clear restrictions in the optimization of the hull. Stability was guaranteed by evaluating the programs output parameter Keel Mark *KM* which is a measure for stability. This value is kept the same as the CT2015 design, since this proved to be a very stable canoe. The optimization function was the hulls resistance measured by the KAPER method, described by John Winters. See Figure 2 for the modelled canoe in Delftship.

For the final design the resistance graph is given in Figure 3. The CT2015 design has the same hull shape as the CT2011 and the CT2010 design, however the resistance is lower. This is because the canoe is lighter and therefore the resistance is also lower. 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.

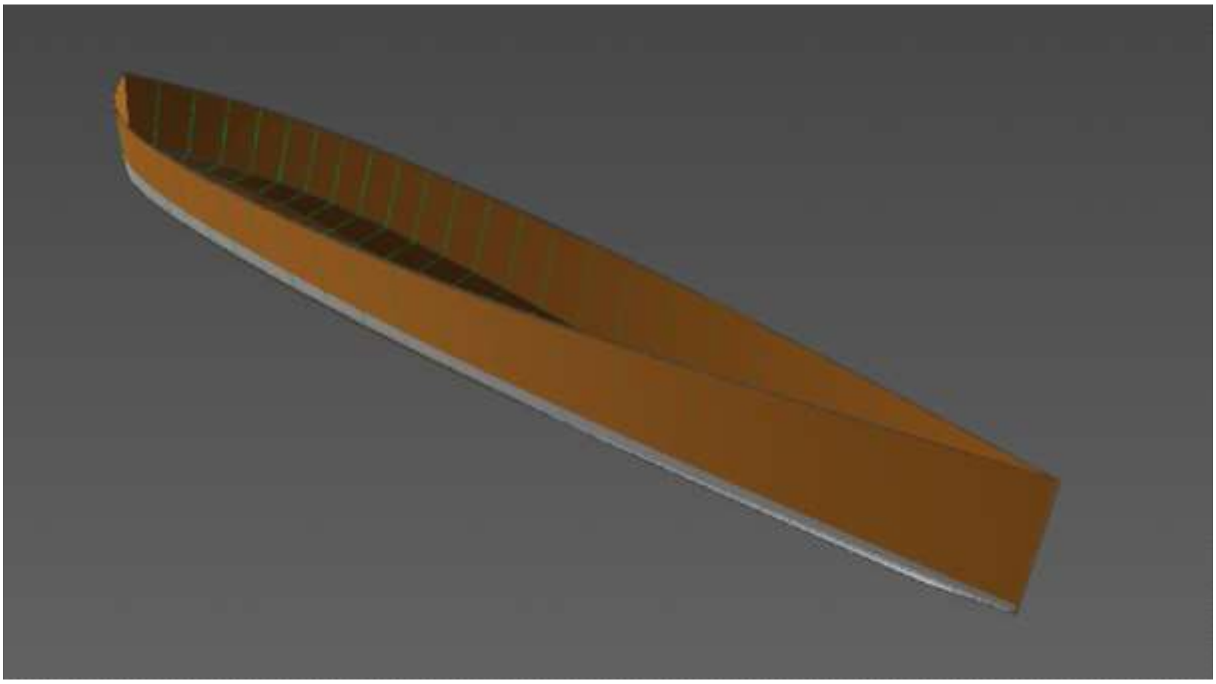

Figure 2: CT2015 as modelled in the software package Delftship

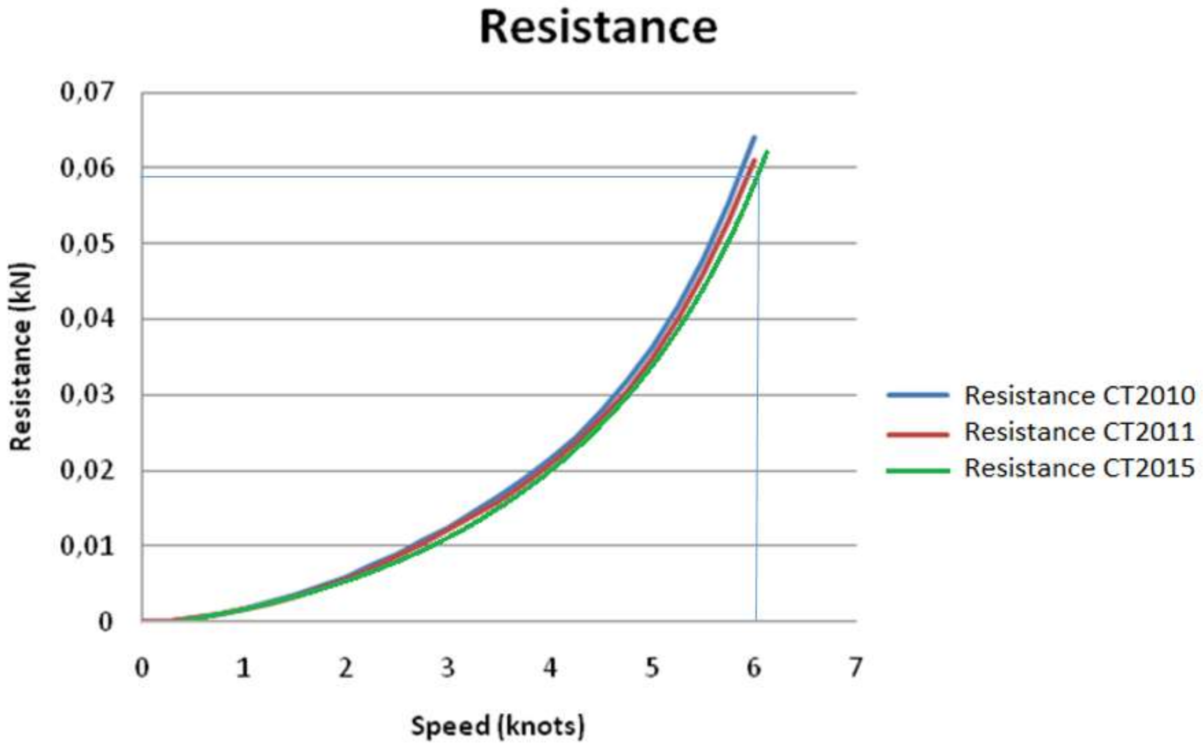

Figure 3: CT2015 Hull-resistance (2.3)

4.4 The Secret of Strength, Stiffness and Stability

In the academic triptych of Strength, Stiffness and Stability we based our first design on sound principles as described in the construction report of 2007. Since the CT2010 concerns a different design, a new mechanical analysis is carried out to gain insight in the forces on the hull. Over the last three years we experimented with the resulting design which brings us to an evaluation which we translated into Achilles Heels and solutions. For the CT2015 model, a new mechanical analysis was done.

4.4.1 Mechanical Analysis with Buildsoft

In order to carry out a mechanical analysis, insight in the forces acting on the hull is required. The load on the hull is determined by three components:

1. The weight of the paddlers: $F_{paddler}$ [N]
2. The weight of the canoe: F_c [N/m]
3. The upward water pressure: q_w [N/m]
4. The water pressure on the bow: F_w (N)

For the weight of the paddlers, it is assumed that they weigh 800N each. The weight of the canoe can be determined from the hull surface, the thickness of the wall and the density of the concrete. This results in a F_c of 600N, leading to an q_c of 100,8 N/m. The water pressure is determined by the weight of the paddlers together with the weight of the canoe (2200 N), divided by the length of the canoe (5,95 m): q_w = 369,8 N/m. Concerning F_c and q_w it is assumed that they are opposite of each other, giving a resulting force: q_{res} = 268,9 N/m. Furthermore a water pressure is acting on the bow of the canoe, this is assumed to be 100 N (equal to a water pressure of 10 kilogram on the bow because of the water displacement and waves acting on the bow)

4.4.2 Input

In Figure 4 the forces acting on the canoe are given. This picture shows the how the forces that act on the canoe are modelled in Buildsoft, a software package that can calculate stresses and deformations in our canoe.

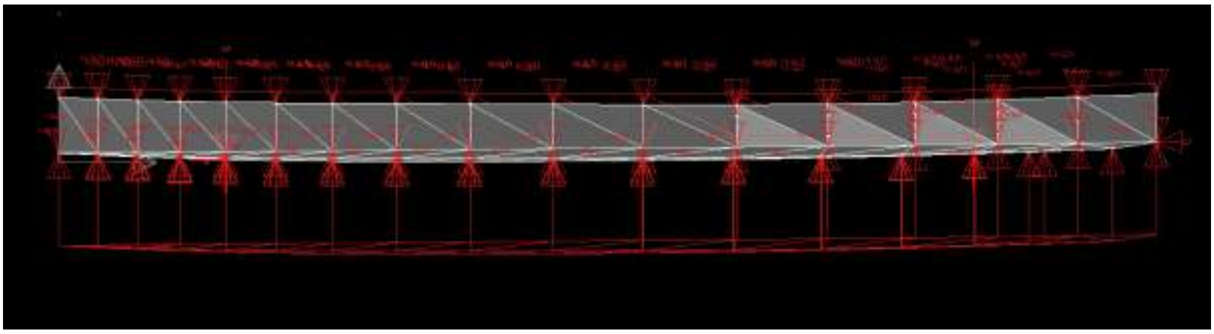

Figure 4: Force analysis on CT2015 2.4

To calculate the real forces acting on our canoes, the software package 'Buildsoft' is used ad mentioned above. First the hull design was modeled in Buildsoft, the result can be seen in Figure 5. The input for the mechanical analysis is:

- Concrete: CEM III 42,5
- Thickness of the walls: 5 mm
- Density of the concrete: 1020,5 kg/m^3
- Weight of the paddlers: 80 kg
- Position of the paddlers: 0.75m from the bow and 0.5m from the stern.

With this input the mechanical analysis is carried out. The result of the displacement analysis and the force analysis can be seen in Figures 6 and 7. This analysis doesn't take into account the loads and stresses on the canoe hull as result of transport, paddling and possible impacts.

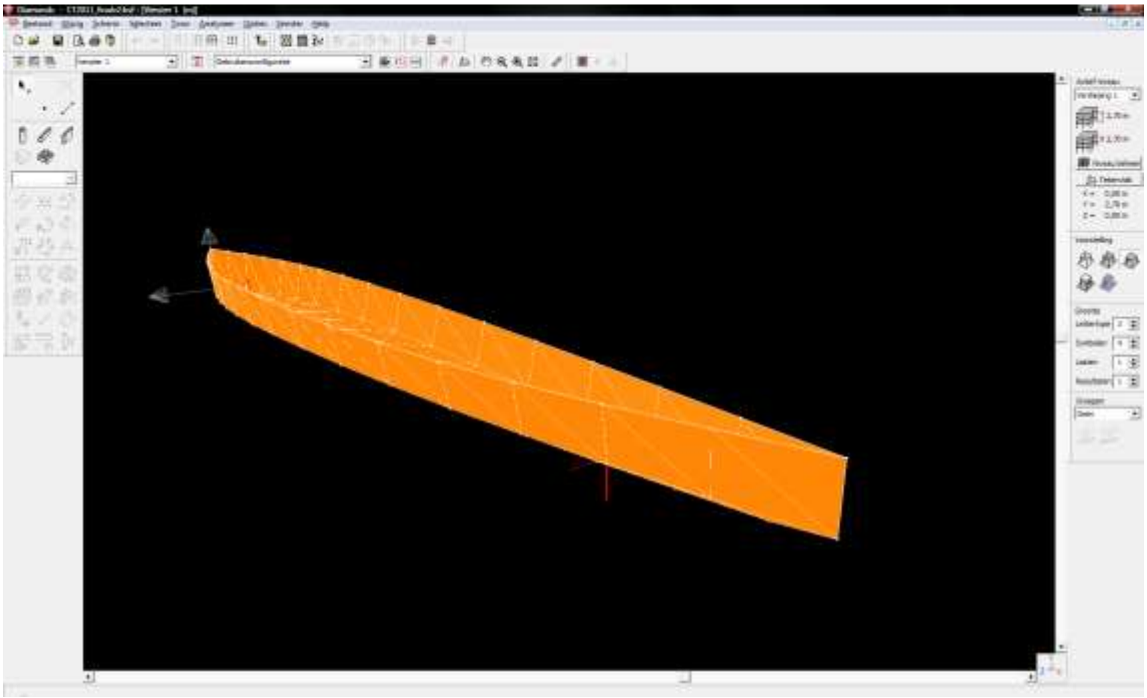

Figure 5: Modelling the design in Buildsoft (2.5)

The canoe is modelled as a raster of triangles, with plates between these triangles that form a watertight canoe. In order to calculate the forces acting on the canoe (shown in Figure 5), the program makes a fine raster of triangles (see Figure 6).

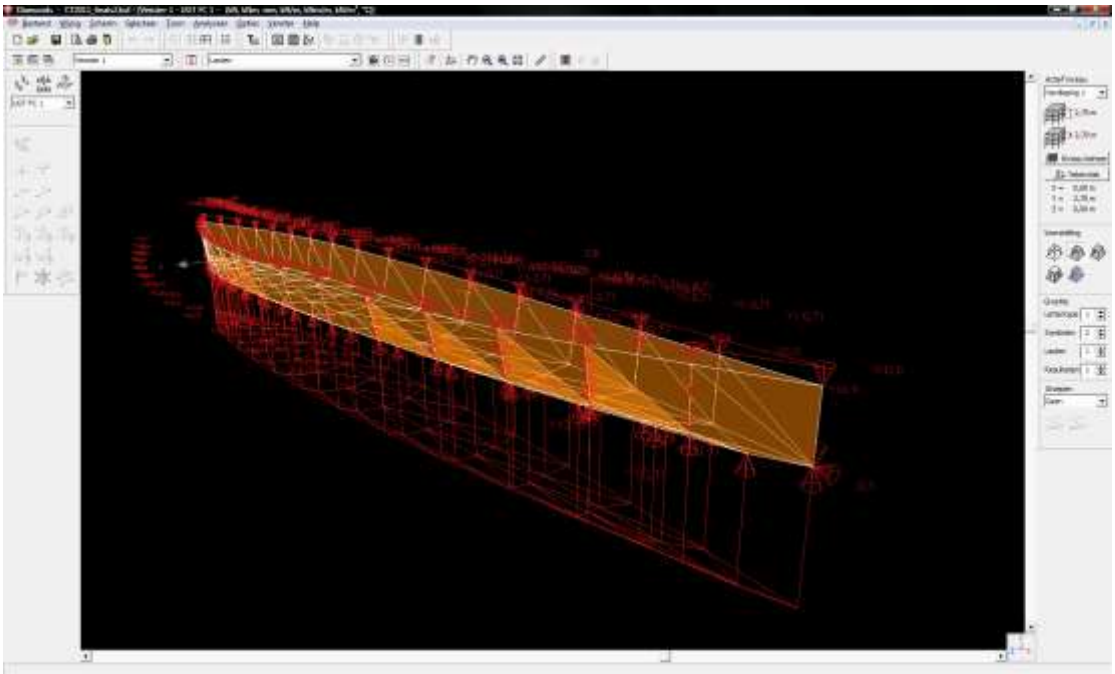

Figure 6: Forces acting on the canoe (2.6)

Because the rotation or movement of the canoe must be prevented, two points are added to prevent the canoe from rotating or moving. These two points are made at the point where the two forces of the paddlers are acting on the canoe. Because of this measure, the canoe does not deform precisely as in reality, but it gives a very good impression of the deformation of the canoe.

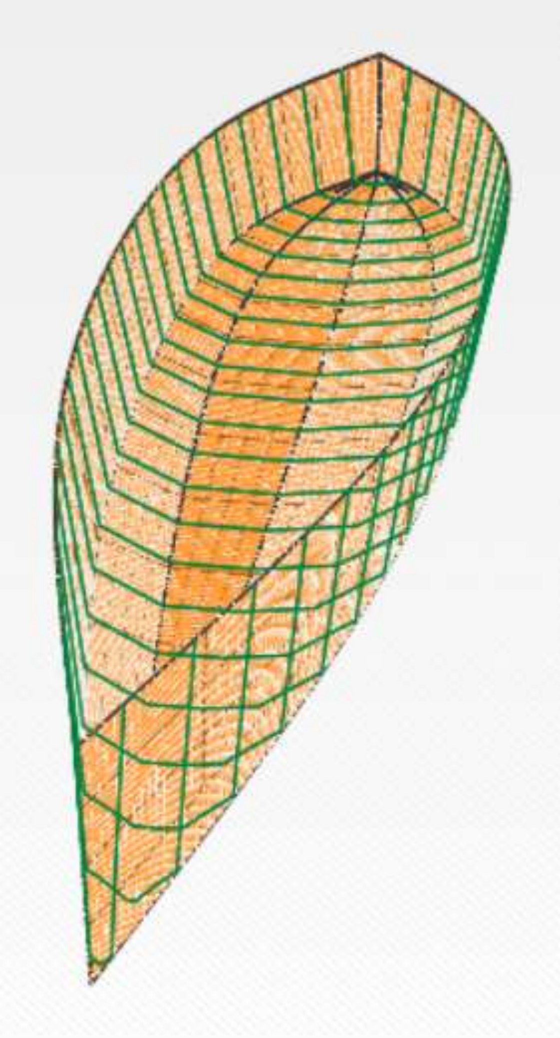

Figure 7: Fine mesh grid in the canoe (2.7)

4.4.3 Results

Tensions in the canoe

It is very important to know where great tensions in the concrete are because of the forces acting on it. Figure 8 shows the tensions in the concrete. The concrete can have 2,6 N/mm^2 tensile force and 15 N/mm^2 compressive force (0,6 * 25 N / mm^2, in order to be safe). The bright red colours indicate that the maximum tensions in the concrete are exceeded, and reinforcement is absolutely necessary in order to keep the canoe intact.

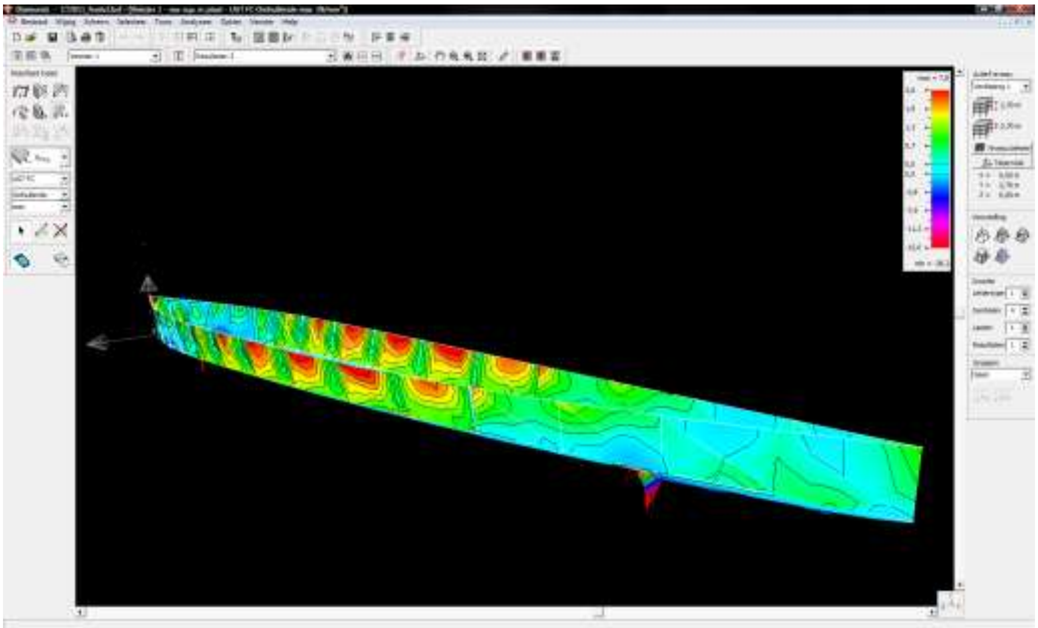

Figure 8: Modelling tensions in the canoe (2.8)

Deformation of the canoe

The Figures below show how the canoe has the tendency to deform under the pressure of the forces acting on it shown in the Figure above. The deformation is exaggerated in order to show how the canoe has the tendency to deform. This deformation must be countered with reinforcement.

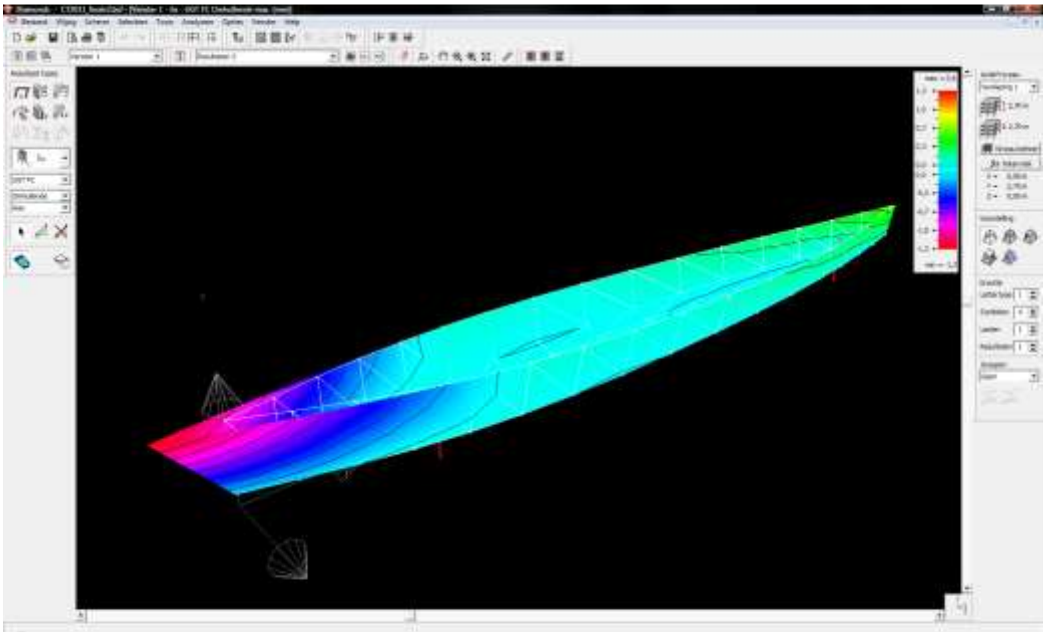

Figure 9: tendency to deform in the length direction (x) of the canoe (2.9)

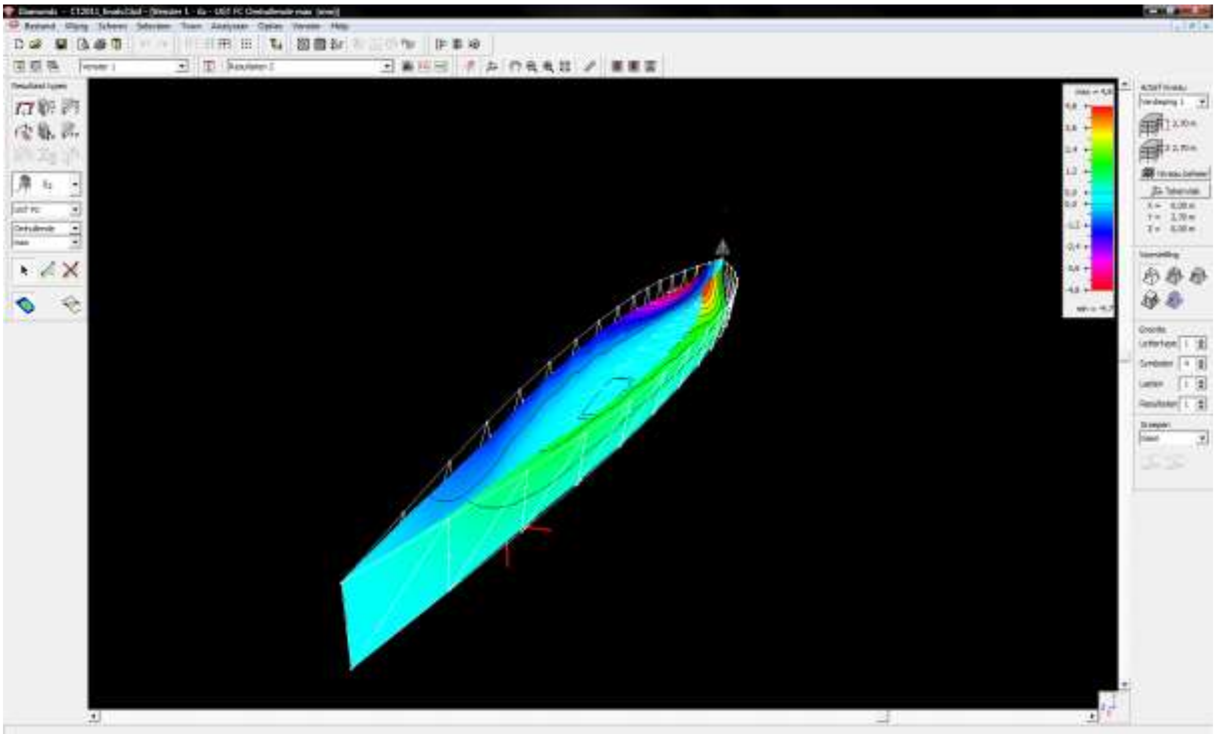

Figure 10: Tendency to deform in the height direction (y) of the canoe (2.10)

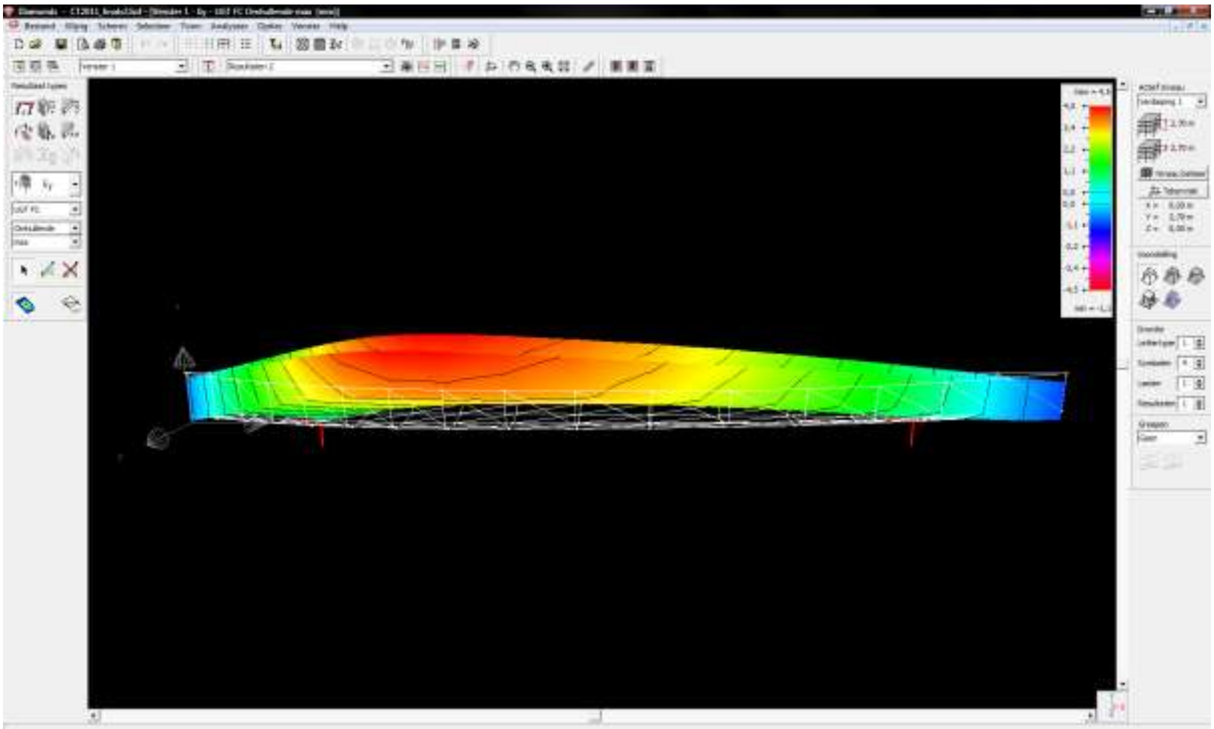

Figure 11: Tendency to deform in the width direction (z) of the canoe

4.4.4 Reinforcement

From the mechanical analysis that concrete with a compressive strength of 25N/mm^2 or higher is sufficient, except for the positions where the paddlers are. However, since the force of the weight of the paddlers is modelled as a point force, this force is extreme (38,2 N/mm^2). See Figure 12 for a closer look. This extreme force of 38,2 N/ mm^2 is in reality distributed over a greater surface. Even if it's an area force over 6 cm, the force will be (38,2 + 3,9 = 42,1 N/mm^2 / 6 cm = 7 N/mm^2 per centimetre. So the compressive strength of the concrete is great enough. However, because the concrete also will have tensile forces at the positions of the two paddlers that exceed the maximum of the concrete, cracks are likely to arise. So on the position of the paddlers high forces are acting on the canoe, therefore pre-stressed cords are certainly required. In the length direction of the canoe, three pre-stressed steel cables are placed, pre-stressed with 10 kN. These cables will from now on be referred to as Type 1 Cords. Also, in the width direction, on the two positions of the paddlers a steel cable is placed and pre-stressed with 500 kN.

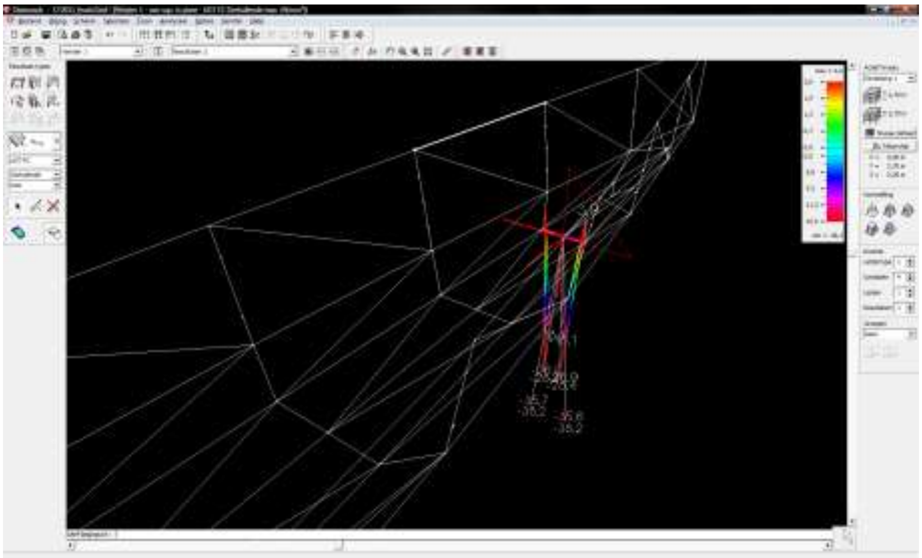

Figure 12: better insight in forces caused by the paddler

Figure 13 shows that the tensile strength of the concrete are also not big enough in the side walls of the canoe. The large forces in the longitudinal section occur at 2/3 of the length (see Figure 13). So reinforcement is placed by putting two steel cords in top of the walls. These should compensate a normal force (σ_n) of about 2,8 N/mm^2 (see Figure 13). The cables are stressed with 10 kN when the concrete is sufficiently hardened with anchors at the bow and stern, and are called after-stressed cables.

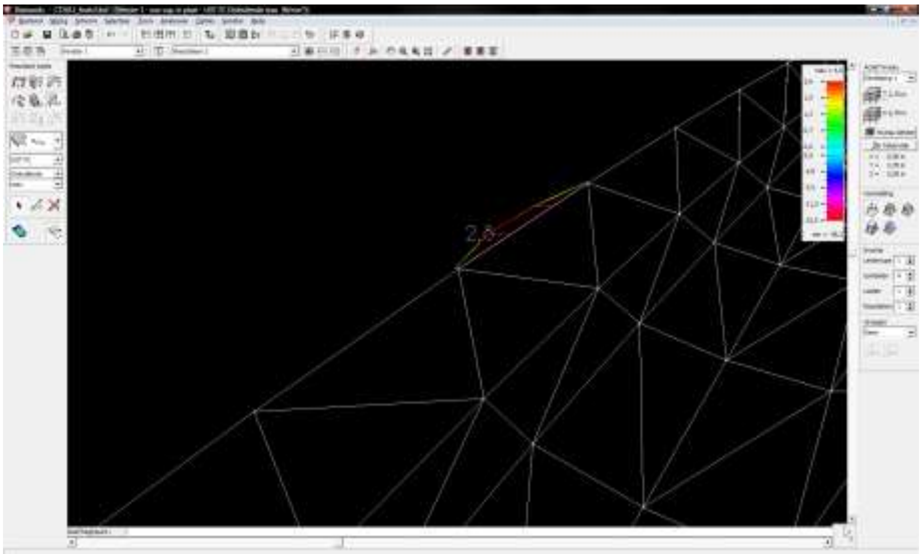

Figure 13: tensile strength in side wall of the canoe

Next to the mechanical analysis, we also have experience from the previous years. This experience is shown below, where the Achilles heels of the canoe are mentioned and countermeasures are made.

4.4.5 Achilles heels

Achilles Heel 1 – Bottom of Mid Cross section
When lifting a concrete canoe at the bow and stern the maximal momentum of the canoe is found in the mid section. When the length view of Figure 9 is considered a critical vertical line can be drawn over which this momentum is transferred into pressure in the top and tensile stress in the bottom. This force is compensated by the pre stress of 10 kN in the bottom of the canoe by the three steel cords.

Achilles Heel 2 – Top of Mid Cross section
When the same cross section is considered problems emerge in marine conditions. When the canoe is propelled by two paddlers located in the far bow and stern, most of the downward force is applied in these locations. The upward reaction force, however, is equally distributed over the canoe hull. Over the last two years many teams have seen cracks caused by this problem. This problem solved with the two steel cables in the top of the walls of the canoe.

Achilles Heel 3 – Cracking under its weight and water pressure
At CT2007 we observed a crack in longitudinal direction of the canoe, shown in Figure 6. It is believed that this crack occurs when the canoe is rested on its bottom. Since the bottom is slightly curved in both directions, the weight of the sides is transferred to the middle, which couldn't cope with these high stresses, resulting in a crack at the inner side of the canoe. The opposite occurs when water presses on the sides of the hull. In this case the tensile stress occurs in the outer side of the hull, but over the same profile. To overcome this problem an extra cable is used in the middle of the canoe to increase stiffness. To even further decrease this problem, the cable is pre stressed over the width of the canoe. The cables are pre stressed under 500 N of pre stress, just as the two other cables at the place of the paddlers.

Achilles Heel 4 – Extreme stress under race conditions
Though static evaluations can reveal some weak points in concrete canoes, extreme stresses occur under racing conditions, where the stress distributions 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 diameter of 5x5mm.

So, the reinforcement of the canoe consists of:

The pre-stressed steel cables and the post-stresses steel cables are shown in Figure 13:

- 3 pre-stressed steel cables in bottom of the canoe over the whole bottom length of the canoe
- 2 post-stressed steel cables in the top of the side walls of the canoe over the whole top length of the canoe
- full body mesh

So with this reinforcement, the canoe is strong enough for the static forces modelled in Buildsoft. Also, it is able to withstand some impact caused by extreme stress conditions with the full body mesh.

4.5 The Blueprint of CT2016

The blueprint of CT2016 is given in Figure 14. 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.

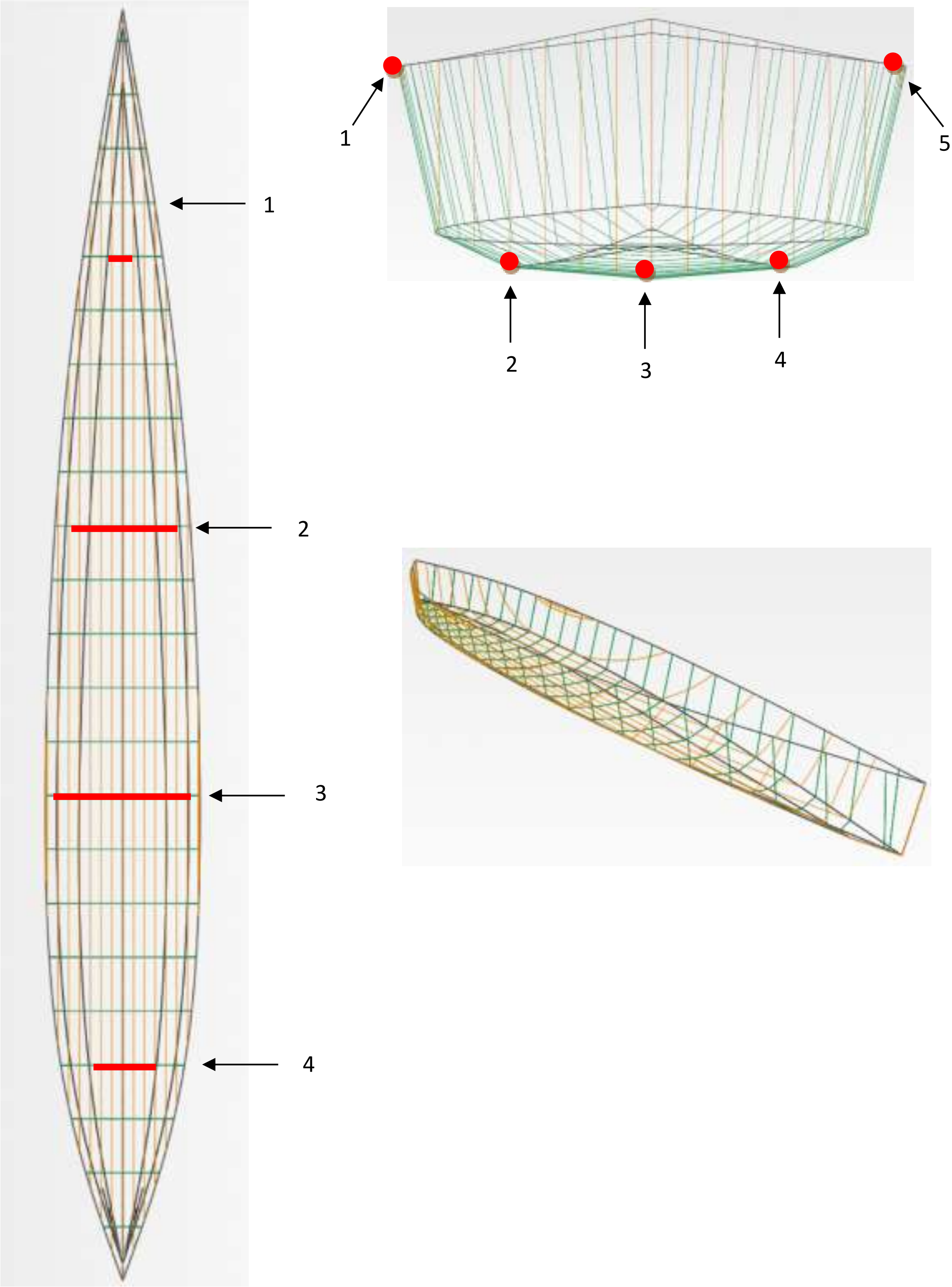

Figure 14: Blueprint of CT2015

Concrete mixture

Before one starts composing a concrete mixture, it is important to understand the principles behind the material. Therefore it is important to be familiar with the (basic) theory behind the material and/or have some experience with it. In this section the basic theory behind the material concrete is highlighted. This basic theory is derived from the compendium 'Concrete Technology 1' from the Department of Structural Engineering of the Norwegian University of Science and Technology (NTNU).

5.1 Introduction to Concrete

5.1.1 Concrete

In general concrete is a mixture of cement, mineral additives (such as pozzolans), aggregates (gravel, sand), water and admixtures. The coarse aggregates make up approximately 70% of volume, cement paste makes up around 30% of the volume.

Both material choice and proportions of the materials, i.e. the proportioning, determine the properties of the concrete for both fresh and hardened condition. It is possible to control this to a large extent, but improvement of one property will often lead to worsening of some other property. One will therefore constantly be facing an optimization of prioritized properties.

Cement:
Cement is the binding element within concrete. The most common used cements are Portland clinker and derivates of Portland clinker, containing slag, pozzolana or fly ash. According to their composition, the cement types are divided into five main types, being: CEM I, CEM II, CEM III, CEM IV and CEM V.

Cement mixed with water is often called cement paste. The properties of the cement paste are mainly determined by the mass ratio between water and cement, the w/c-ratio. During the reaction between cement and water a high concentration of hydroxide ions (OH^-) develops in the remaining pore solution. Hydroxide ions may react with certain types of silica that can occur in some aggregate. This may result in internal stresses that can cause expansion and cracking, known as alkali silica reaction (ASR), or more generally alkali aggregate reactions (AAR).

Mineral Additives:
The most common used additions are Fly Ash (FA), Silica Fume (SF) and blast-furnace slag, also termed pozzolans. All three of these additions are industrial by-products. When used in concrete they reduce the demand for Portland cement clinker. Hence their use is advantageous both from economic and environmental points of view – particularly w.r.t. reducing the large amounts of CO_2 emission associated with Portland cement production.

Pozzolana are active mineral additions. This implies chemical reactivity either alone or in combination with Portland cement clinker and/or its hydration products. Pozzolans are included in the mass ratio $m = w/(c+k*p)$, where k is an efficiency factor for the actual property and the actual material. Non active additions are also used extensively, and are commonly referred to as fillers, i.e. normally finer than 125µm and close to chemically inert. Note that fillers may be chemically inert, but may accelerate cement hydration by providing surfaces for precipitation of hydration products.

The pozzolanic reaction is:
$2S + 3\ CH \rightarrow C_3S_2H_3$

Thus the reactive silica in the pozzolanic material reacts with the calcium hydroxide (which is a reaction product of the Portland cement hydration) to produce more of the C-S-H binder, i.e. it leads to more efficient use of the Portland cement. The pozzolanic reaction involves somewhat greater heat release than cement hydration, but the reaction is slower – and therefore does not produce increased temperatures.

Aggregates:

Aggregates have an important influence on the concrete properties, both in the fresh- and hardened state. In our project only fine aggregates (0-1mm) are used as a result of the thickness of the canoe. Important factors to keep in mind when selecting an aggregate are the material grading, the particle shape and water absorption.

In our project it is not very important to have a high durability, the canoes are used for only one year. Despite that we want to develop a high-quality concrete, and thus take into account the durability. A very important issue for a concrete that requires a high durability are Alkali-Aggregate-Reactions (AAR). AAR are reactions between certain aggregate types and the alkaline pore water in the cement paste. A certain amount of moisture is required within the concrete. During the reaction a gel is formed in the concrete. This may suck water and swell, which can lead to a volume increase and cause a characteristic crack pattern on the concrete surface after several years. Three condition must be fulfilled before AAR will occur: Alkalis, Water and Reactive aggregates.

Admixtures:

Admixtures are chemical agents added in small dosages to improve certain properties of the concrete. The European Standard (EN 934-2:2001) defines an admixture for concrete as: *"Material added during the mixing process of concrete in a quantity not more than 5% by mass of the cement content of the concrete, to modify the properties of the mix in the fresh and/or hardened state."* The European Standard classifies chemical admixtures for concrete in 11 classes, based on the main effect of the admixture on the concrete properties.

5.1.2 Lightweight concrete

To construct the concrete canoes, lightweight concrete is used. Generally speaking, lightweight concrete includes all types of concrete with density less than 2000 kg/m^3. At mixing, lightweight aggregate (LWA) will absorb water from the cement paste and a larger loss of workability in the form of slump loss than in normal density concrete results. As a consequence of the absorption into the LWA, the real or effective mass ratio (w/c or w/b ratio) is reduced. This must be taken into consideration for accurate control of mass ratio.

It has been documented that high strength LWAC generally is less permeable than normal density concrete (NDC) of the same strength class. This is first and foremost a result of an improved Interfacial Transition Zone (ITZ) between aggregate and cement paste.

5.1.3 Workability

Because of the casting technique of the concrete canoes, the workability of the concrete is a very important aspect concerning the composition. The workability of concrete depends on the properties of the constituent materials, their relative proportions and physical and chemical interactions between them. The simplest way of modeling this complex system of multiple constituents, is to consider concrete as a two-phase system consisting of a matrix- and particle phase, or described by the properties of the two phases, one liquid phase and a friction material.

- The matrix phase: consists of water, all additives, all admixtures and all particles less than 0,125mm. That is cement, pozzolana, fillers and the finest particles of the aggregate. The matrix phase can be regarded as a heavy viscous fluid and can in principle be characterized in the same way as other fluids.

- The particle phase: consists of all particles larger than 0.125mm. The particle phase is a friction material and characterized as such.

A disadvantage of the particle-matrix model is that it provides little or no information about the stability of the concrete, i.e. robustness against separation.

The properties of fresh concrete can be described by the concept workability. The workability concept may be divided into three basic elements: stability, mobility and compactability.

Stability:

Stability may be defined as the ability of concrete to retain its homogeneity through the fresh phase, both at rest and subject to loads to transport, form filling and compaction. Lack of stability may lead to separation. There are three different forms of separation. Separation of water occurs in ordinary concrete qualities, paste separation occurs mostly in high strength concrete, whereas separation of mortar and coarse aggregate occurs in both ordinary and high strength qualities.

- Separation of water, or ‘bleeding’ is characterized by a part of the water in the concrete flowing upwards to the concrete surface, collecting in pockets under coarse aggregate and forming a film of water at the surface.
- Paste separation can arise as one tries to obtain flowing concrete consistency and the amount of cement paste is too large compared to the amount of sand, or as the sand partly lacks the finer fractions.
- Mortar- of coarse aggregate separation or ‘segregation’ occurs as the coarse aggregate sinks in the concrete, and mostly results from inadequate aggregate composition by the partial or complete lack of certain aggregate sizes.

Mobility:

Mobility may be defined as the ability of the fresh concrete to move due to forces acting on it. The resistance against motion depends on:

- Friction between particles
- Internal cohesion
- Resistance to internal flow of the liquid phase

To make a continuous compactable zero-slump concrete (0-20mm), the matrix volume must typically be 20-40l/m3 larger than the void space (in the particle phase). An increase in the matrix volume means a slight increase in the distance between the particles such that the particles can move with less interaction/friction.

Compactability:

The ability to be compacted is the ability of fresh concrete to fill out the formwork and let off encapsulated air pockets during reworking. Effective compaction is one of the most important factors determining to which extent the concrete strength potential can be exploited.

5.1.4 Proportioning

Proportioning concrete means selecting materials and putting them together so that:

- The hardened concrete obtains required properties with good margin
- The fresh concrete obtains sufficient workability to be placed and compacted with the actual method
- Low risk of errors
- Economical composition is obtained

The following basic rules apply when proportioning concrete from scratch:

- The matrix composition controls the properties of the fresh concrete. The cement paste has in most cases lower durability and strength than the aggregate (“the weakest link”). Therefore

the required compressive strength and durability of the concrete controls the matrix composition.
- The aggregate composition controls the properties of the fresh concrete. The properties of the aggregate (shape, particles size distribution and void content or packing) determine how large the matrix volume must be to give desired or required workability.

5.1.5 Strength

The definition of strength is as following: the strength is the average value of maximum load converted to nominal stress for a series of standardized specimens loaded until failure in a given load test-set up.

The tensile strength of concrete is low compared to its compressive strength, 10-12% for ordinary structural concrete, 4-6% for high-strength concrete. In the design of concrete structures one usually assumes that all tensile forces must be taken care of by the reinforcement. Still, for some cases, it is obvious that the tensile strength is significant. E.g. for shear capacity of concrete and for the bond towards the reinforcement or previously cast concrete. Further, the tensile strength of concrete will to a high degree govern if and how cracking possibly will occur in tensile zones, and possibly affecting the durability of the concrete.

The concrete should have enough strength to cope with the forces as discussed in the mechanical analysis (Part 2). Factors that influence the strength potential of the concrete are:

- Cement type: The clinker composition of the cement influences the strength potential because the clinker leads to different hydration products and structure in the cement paste.
- The fineness of the cement: Normally the strength potential will be larger at higher grinding fineness. This is due to the fact that larger reaction surfaces lead to larger degree of hydration, and thus lower porosity.
- Properties of the aggregate: The mechanical properties of the aggregate are usually not a limiting factor, but surface properties of the aggregate can have an influence. Grain shape and roughness can also influence the bond and thus mechanical properties.
- Degree of compaction: Lack of compaction causing large voids, cavities and discontinuities in the concrete, and reduced strength.
- Curing conditions: Early drying gives reduced degree of hydration and risk of cracking due to shrinkage. Both factors will lead to reduced strength.
- Temperature level: High curing temperatures is unfavourable for the porous structure formation in the cement paste and will reduce the concrete strength. Large temperature differences in the cross section lead to strain differences and possible cracking.
- Air entrainment: a good rule of thumb states that the compressive strength is reduced by 5% for each 1% air.

In general concrete becomes more brittle as the strength level increases. Concerning the concrete canoes a more flexible concrete is desired. Therefore it is important to develop a concrete that is strong enough to cope with the forces acting on it, but doesn't becomes too strong.

5.1.6 Porosity & Permeability

The internal consequences of the hydration are large changes in solid volume and thereby in the porosity. Porosity means here the internal volume that can be filled with water.

The reaction of water and cement during hydration is associated with a volume change, i.e. the volume of the reaction products is smaller than the volumes of the reactants cement and water. We assign the entire volume change to the water, which means that the chemically bound water has lost 25,4% of its volume before hydration. This is called chemical shrinkage. When looking at the permeability coefficient (K') for stationary water transport in well hardened cement paste at different w/c-ratios, and as a function of hardening time for a fixed w/c-ratio, two effect become clear:

1) Improved hydration reduces both the porosity and the continuity in the pore system, which reduces the K' with several magnitude.
2) Over a w/c-ratio of approximately 0.50 increase K' markedly with increasing w/c-ratio as the volume of capillary pores and their continuity are increasing sharply.

The general international requirement is that "watertight" concrete shall have a w/c-ratio below 0.50.

For a given w/c-ratio the permeability is increasing with D_{max} of the aggregates. The reason lies in the transition zone between aggregates and paste. Another factor that has a negative influence on the permeability is drying from early age. This is unfortunate since the surface might experience low degree of hydration and cracks might form with reduced permeability as a result. Since our canoes don't have any coating (like paint) and the walls are very thin (max 5mm), it is important to keep the permeability in mind.

5.1.7 Curing

When cement is hydrated, considerable amounts of heat develops. In most concrete structures this leads to temperature increase the first days after casting. This might give production rate benefits, but also disadvantages. High temperature results in fast hydration and thus fast strength development. The heat of curing can also lead to damage (cracking) or reduced material quality in massive structures unless the heat evolved and resulting temperature increase is not taken care of in a controlled manner. Since our canoes have very thin walls, the temperature will not reach a level at which it leads to damage.

In order to achieve a full hydration and therefore increase the impermeability of the canoe it is important that the concrete is cured in a moist environment.

5.2 Concrete mixture 2016

The concrete team this year has been replaced by two new members of the BetonBrouwers with a relatively short period until the construction process.. The goals of this season regarding the concrete are therefore not the most ambitious. Firstly it was decided to take the time to truly understand the mixtures of the past several years. Thereafter 3 theoretical mixtures would be designed and tested. Whichever would be tested the best mix will be used the coming year.

5.2.1 Test Mixtures

Mixture 1 a&b – 2011 with r cement

This is a mixture composed in a previous year and still considered the best design so far. If there would be no success in finding a new mixture, this is always a good backup. Besides that it is a great way to compare the new mixtures. The a variant is with R-cement, and the b variant is with N-cement.

Material	Mass [kg]
CEM I 52.5R/N LA - white	550,0
Water	206,0
Liaver 0.1-0.3	198,9
Liaver 0.25-0.5	57,3
Liaver 0.5-1.0	54,2
Superplasticizer	4,0
Air entrainer (LPS A94)	0,7
Retarder	1,7
Sikear	8,0
Air	
Total	**1080,8**

Figure 15: Brewing the concrete at the construction site

Mixture 2 – Simplified 2011

This is a mixture containing far less aggregates and admixtures. This mixture was composed to compare the effectiveness of these ingredients.

Material	**Mass**
	[kg]
CEM I 52.5R LA - white	550,0
Water	206,0
Liaver 0.1-0.3	0,0
Liaver 0.25-0.5	262,9
Liaver 0.5-1.0	0,0
Superplasticizer	4,0
Total	**1022,9**

Mixture 3 – Proposed improved mixture

This was really the mixture what it was all about. Hoping to apply some small improvements on the mixture it was decided to add microsilica. This is an aggregate with an extremely small grain size improving the grain storage, waterproofing and workability. Also some ingredients were removed like Sikear and Air entertainer.

Material	**Mass**
	[kg]
CEM I 52.5R LA - white	550,0
Microsilica sika	35,0
Water	206,0
Liaver 0.1-0.3	191,8
Liaver 0.25-0.5	55,2
Liaver 0.5-1.0	52,3
Superplasticizer	4,0
Air entrainer (LPS A94)	0,7
Retarder	1,7
Sikear	8,0
Air	
Total	**1104,7**

5.2.2 Results

The mixtures were tested on 40x40x160mm prisms. Because some lack in time only the 7 days tests were considered. The results are presented in the following table.

	Compressive strength (MPa)	**Flexural strength (MPa)**	**Workability**
Mix 1a	31,20	6,02	Medium
Mix 1b	21,24	4,71	Medium
Mix 2	39,29	8,35	Bad
Mix 3	28,48	6,17	Good

5.2.3 Further improvements

The third mixture seemed the best mixture. Although mix 2 was the strongest mixture, the workability was not sufficient to build a canoe. The workability of the 3rd mixture was significantly better than the mixture 1a, while the strength difference was quite small. However there were some improvements necessary, because the workability of the mixture still wasn't not optimal. These were pure practical changes with no theoretical foundation. The final mixture looked as following:

Material	Mass [kg]	Density [kg/dm3]	Volume [dm^3]
CEM I 52.5R LA - white	605,1	3,07	197,1
Microsilica sika	38,5	2,33	16,5
Water	245,0	1,00	245,0
Liaver 0.1-0.3	211,0	0,97	260,1
Liaver 0.25-0.5	60,7	0,57	127,4
Liaver 0.5-1.0	57,5	0,48	143,3
Superplasticizer	4,4	1,10	4,0
Retarder	1,8	1,00	1,8
Pigment Black	18,3	3,90	4,7
Total	**1242,4**		**1000,0**

When plotting a particle size distribution curve of this mixture the following result presented:

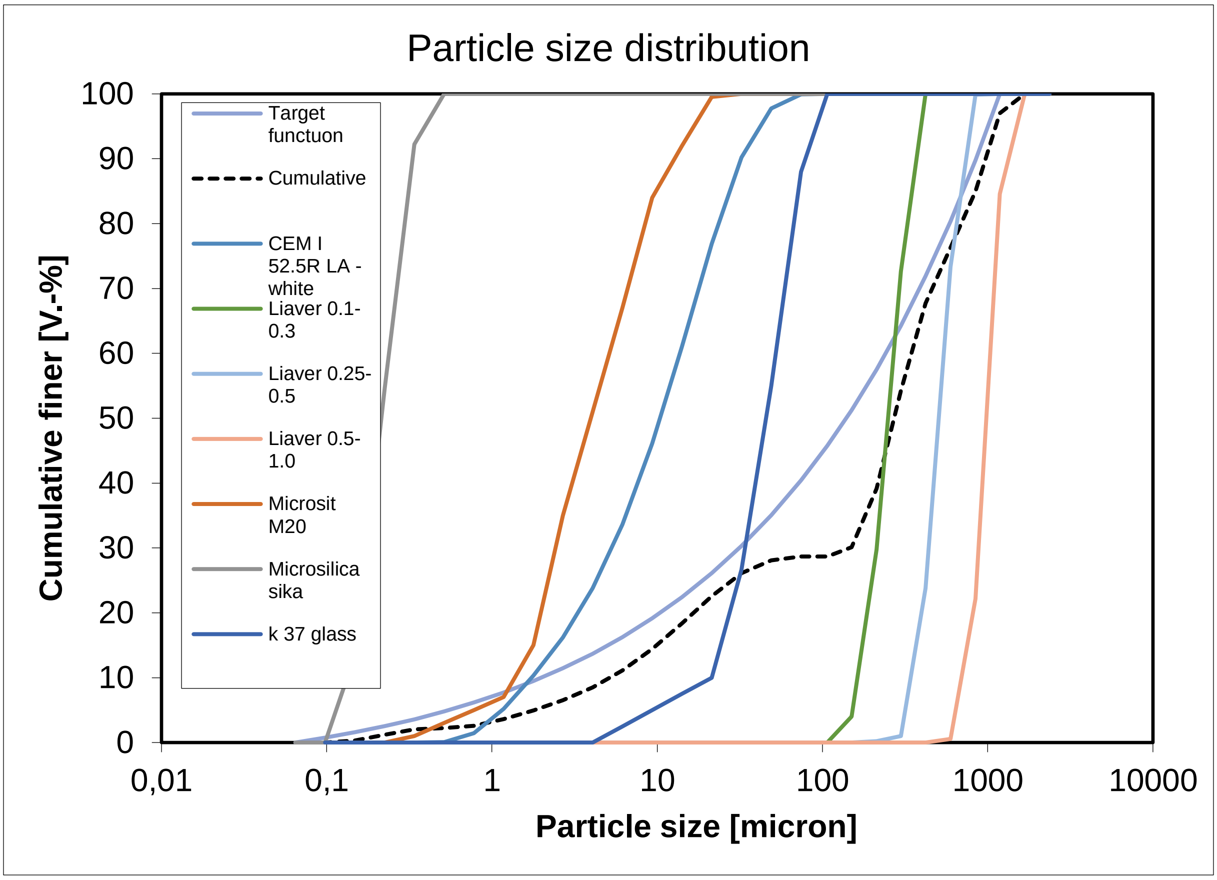

Figure 16: Particle size distribution of mixture 2015

Although the curve departs from the target curve with quite some extend, this mixture proved to be the most practical mixture. In addition to the mixture some aggregates of 4mm were added to the bridges in the mixture, for extra strength.

5.2 Mixture 2017

For 2017 5 mixtures were composed and tested. The principles of these mixtures will be discussed briefly. These mixtures are slight variations on the mixtures of 2016.

- **Mixture 1:** Balanced composition of material - 1306 kg/m3
- **Mixture 2:** More cement to improve strength - 1454 kg/m3
- **Mixture 3:** More microsillica to improve workability - 1435 kg/m3
- **Mixture 4:** Different liaver ratios to reduce weight - 1271 kg/m3
- **Mixture 5:** Less cement to reduce weight - 1105 kg/m3

All mixtures were tested on tensile- and compressive strength. The results are displayed in the table below. The strongest mixture by far is *mixture 2* indicating that cement has the largest effect on the strength of the concrete. A compressive strength of 25 MPa is expected to be sufficient, and therefore *mixture 2* is not beneficial considering the weight accompanying it. Therefore the second strongest mixture, *mixture 1* will be more convenient to use.

Table 1: Results of tests mixtures

Prisma	Buigtrekst. [kN]	**Buigtrekst. [MPa]**	Druksterkte 1 [kN]	**Druksterkte 1 [kN]**	Druksterkte 2 [MPa]	**Druksterkte 2 [MPa]**
1-1	0.76	**1.78**	29.01	**18.13**	29.31	**18.32**
1-2	1.04	**2.43**	23.77	**14.86**	27.66	**17.29**
1-3	0.75	**1.77**	30.32	**18.95**	31.52	**19.70**
2-1	1.35	**3.17**	47.26	**29.54**	45.95	**28.72**
2-2	0.94	**2.21**	49.37	**30.86**	48.48	**30.30**
2-3	1.90	**4.45**	42.15	**26.34**	40.10	**25.06**
3-1	0.84	**1.98**	7.60	**4.75**	11.42	**7.14**
3-2	0.87	**2.03**	10.87	**6.79**	11.88	**7.43**
3-3	0.73	**1.70**	10.85	**6.78**	11.17	**6.98**
4-1	1.25	**2.93**	15.93	**9.96**	17.58	**10.99**
4-2	1.08	**2.53**	19.30	**12.06**	17.97	**11.23**
4-3	1.03	**2.41**	17.72	**11.08**	16.24	**10.15**
5-1	1.118	**2.62**	11.87	**7.42**	12.43	**7.77**
5-2	1.37	**3.22**	16.34	**10.21**	19.69	**12.31**

5.3 Mixture of 2018

5.3.1 Concrete

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 fibers. 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. Furthermore, is in every mixture a 4 millimeters grain used.

5.3.2 Experiments

To optimize a mixture 3 factors are essential: the workability, the strength and the weight. The plastic fibers were relatively easy to optimize, since a previous (already optimized) mixture was used and the fibers 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 which 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.

5.3.3 Results

The results of the compressive tests are displayed in Figure 17. 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 Fibers mixture is less than the original mixture.

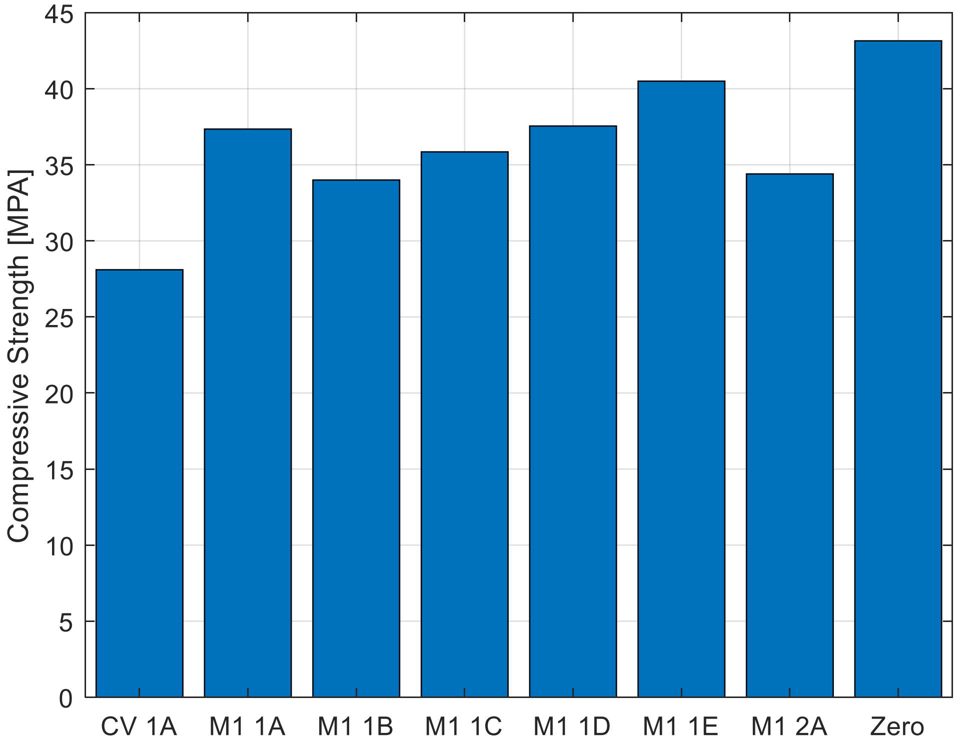

Figure 17: Results of compressive strength test

The results of the tensile tests are displayed in Figure 18. The Convez fibers 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 fiber reinforcement in the canoe is not an option.

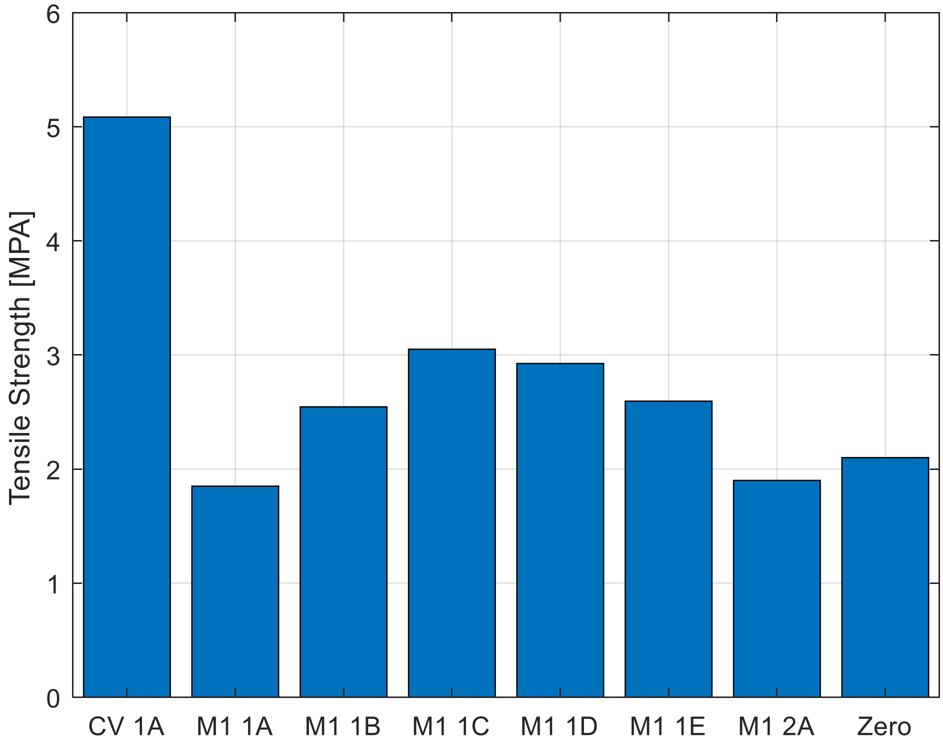

Figure 18: Results of tensile strength test

5.3.4 Final mixtures

The final mixtures for the design were M1 1E and CV 1A because of their favorable compressive strength/weight ration and tensile strength respectively. The density of the M1 1E and CV 1A mixtures are 863 kg/m^3 and 1299 kg/m^3 respectively.

Construction Process

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. This year, a new type of canoe is constructed with the use of UHPC. Because of the characteristics of this concrete, a new way of casting had to be developed. This will also be explained in this chapter.

6.1 Normal canoes

At the start of creating a concrete canoe stands a cleaned mould. This clean mould is placed on a steel framework, which forms the work platform during construction. 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. When we have the clean mould in place it is time for putting the 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 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 were hold in position with the help of little holes in the mould and the use of iron wire. After placing the cords, they were put on tension (not with the final force because the mesh has to be placed underneath the cords). After this it is almost time for starting the casting, but first we need to try rub the surface in with grease and on the other hand to make the cords grease free.

When we got the mould in the condition of a greased surface and ungreased cords it's 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 paddles rotating through the concrete. When the dry materials are mixed properly the liquids are added. This created a stiff mix of materials. To make obtain the right workability, Super Plasticizer (SP) is added. The process of adding the SP 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 if 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 the back and working towards the front of the canoe. The challenge with this process is that it needs a constant flow of concrete, because the layer concrete won't dry out in such degree that it won't adhere with the next one.

Figure 19: applying the concrete to the canoe

As earlier mentioned in this report we used five cords per canoe. The remaining two cords are placed on the top of the walls of the canoe during the process. When the concrete had enough time to harden these cords are stressed afterwards. The two steel cords are put through thin plastic tubes which have been roughened to increase the contact surface with the concrete. The plastic tubes are fixed onto the canoe with the mesh you simply double fold a thin part of mesh and then put the plastic tube into it. While working from back to the front four ribs were created at the location where the cords in cross direction are located. After reaching the front of the canoe the cords in the longitude direction 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 was considered finished. When all this is done, it's 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 it is necessary to add some water.

After at least one day of hardening the canoe could be demoulded. To do this the prestressed cords have 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 connection are removed, the mould can be bended outwards and lifted, leaving a beautiful concrete canoe on the floor. At this moment 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.

In the last stage of the construction, the names, the sponsors and start numbers were painted onto the canoes. On top of the walls tubes are placed as protection against sharp edges and because of the aesthetics. At the wall some bolds are constructed in order to attach the air chambers, these air chambers consist of large balloons. Now the canoes themselves are finished and ready for the battle.

Figure 20: BBQ in an old canoe to celebrate the successful construction of the last canoe

6.2 UHPC canoe

Due to the properties of the Ultra High Performance Concrete (UHPC) our normal way of casting the canoes could not be used. This is because of the viscosity and fluidity of the concrete. When we would use our default way of casting, the concrete would stick to the walls of the mould for just a moment and then slide to the bottom. After many unsuccessful attempts to find a mixture in which this would not happen, we have decided to develop a new way of casting the canoe.

Instead of using only an outer mould, we have decided to cast the UHPC canoe with both an inner and outer mould. However, because of the characteristics of the UHPC, the canoe could not be casted in one continuous flow, but only in layers of 10 cm at most. Therefore, we needed to come up with a mould that could be built op in layers.

Our inner mould was created by one of our old moulds (CT2011). This mould was fixed onto a base plate made from MDF plates. Some parts of the old mould had to be removed to create a usable inner mould. The inner mould is then greased to prevent sticking of the concrete.


Figure 21: Gluing together the MDF strips

The outer mould was made from long strips of MDF, fixed onto the base plate using small wooden bars and corner anchors. The strips have been painted, such that the surface is smoother and that the wood would not withdraw too much water from the concrete. Thereafter, the strips have been greased to prevent the concrete from adhering. The strips have been placed in such a way that the distance between the inner and outer mould would be 6 mm. The strips with a height of 10 cm can then be fixed onto these bars one for one, bottom down, to make it possible to pour the UHPC in in layers of 10 centimetres. To prevent leakages, these strips have been glued together in the process. Using small wooden sticks, the concrete could be guided into the gap between the moulds. With this method, we have created the walls of the canoe.


Figure 22: Pouring the floor of the canoe

To create the floor of the canoe, we had to come up with some creative techniques. Because the floor of the canoe is slightly sloped, we could not just pour the concrete on top of the inner mould. Therefore, we have fixed small boards onto the strips that form the outer mould. The boards could then be placed with the same slope as the inner mould, also with a gap of 6 mm in between. The boards have also been painted and greased. The horizontal part of the floor could then be poured right onto the mould, such that no outer mould was needed for this final part.

Demoulding the canoe can be done after several days. For this, we have deconstructed the mould in the reverse order of how we built it. Then, to make it easier for the inner mould to be removed, it has been sliced into parts. After demoulding, some gaps appeared in the canoe. These have been filled up with a new mixture of concrete to create a watertight canoe.

Figure 23: Final mould

Canoe carriers

The transportation of the concrete canoes presents a risky challenge for the BetonBrouwers every year. The loads to which the canoes are exposed during the transport can result in irreparable damage. Last years the BetonBrouwers used canoe carriers that were doing really well, but they didn't have the right appearance. So we made new canoe carriers with strengthened elastics. These elastics perfectly fit around the canoe and also look pretty. We also made new canoe cover to make the canoe carriers more stable during transport. Because of the light construction the canoes can easily be (un)loaded.

The following picture gives an illustration of the canoe carriers.

Figure 24: Canoe in a canoe-carrier

Training

During the building season, a second important factor in the success of the BetonBrouwers is also carried out. The canoes provide roughly 50% of the chances of winning the BKR, the other 50% is achieved by training. To ensure that the training is effective, the BetonBrouwers train year-round. There are two parts that can be separated: the “warm season” and the “cold season”.

At the start of spring the swimming pool is exchanged by the Twente Canal. In aluminium Canadian canoes the BetonBrouwers encounter the Twente Canal. For the new paddlers this is the moment of some important (safety) lessons:

- Lesson 1: In case of a thunderstorm the training is cancelled. In all other weather conditions, the training continues.
- Lesson 2: Always register in the logbook. Write down the time of departure and the time of return.
- Lesson 3: When on the water, never lose your paddle! Our motto: my paddle, without me, is useless. Without my paddle, I’m useless.
- Lesson 4: Keep your balance, don’t fall into the water. Despite the Canadian canoes are relatively stable, it is important to keep your balance. Especially when it is cold, the risk of falling into the water should be avoided at all costs. Thereby the water doesn’t looks very attractive to swim in...
- Lesson 5: Avoid getting close to fishermen. It isn’t a pleasure when a fishermen gets you on his hook.

With these lessons in mind the BetonBrouwers paddle the Twente Canal, practicing sprints, endurance races, turning and acceleration. It is important to train outside, because weather conditions (i.e. wind, rain, waves) can make a big difference during the BKR. To get familiar with different weather conditions and the behaviour of a canoe on open water, the training is intensified as the BKR approaches. In general, our top athletes train year-round, but in the month prior to the BKR, they train about 10 times (roughly 2,5 times the normal training intensity).

Figure 25: Training curves

The “training grounds” consist of a manmade canal that is normally used for large barges. It is a wide canal with a long straight part between the Hengelo sluice complex and the Enschede harbour. During a normal training, a distance of about seven kilometres is coffered. “Normal pedalling” is alternated with short sprints (200-400 meters) and tight turns, to simulate the race elements of the BKR. Also, the pedalling technique is trained during the outside training, so that the feeling for the behaviour of the canoe is achieved.

A few weeks before the BKR, a tight schedule is created to maximize the training effect. Hereby, a good mixture of experienced and less experienced peddlers is ensured every training session. This greatly enhances the training effect on the participants

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