HOW TO CONSTRUCT A CONCRETE CANOE

CONSTRUCTION REPORT 2011

Enschede, May 2011

BetonBrouwers
Study Association ConcepT
School of Civil Engineering - University of Twente

Preface

Preceding on what is coming we want to outline the amount of work that has been shifted by the BetonBrouwers[1] and everyone that bears a warm heart towards BetonBrouwen. The concrete canoe challenges in Eindhoven (NL) and Magdeburg (DU) are approaching rapidly, meaning that a year of hard work has passed. And how....

Based on our experiences from seasons 2007 & 2008 a new design and a lightweight concrete mixture were developed for season 2009. With an in theory very competitive concrete canoe, we participated in the Dutch and German competition. Luckily it turned out that it was not only a very competitive canoe in theory but also on the water. Season 2009 became the biggest success in the history of the BetonBrouwers. By dominating the Dutch competition and by winning the men's race in Germany the BetonBrouwers became 'European Champion'! In 2010 we dominated the Dutch competition again with the same successful design, but with a new concrete mixture.

Since the German competition only takes place once in two years, it's this year that we can defend our title of the men's race. Because our neighbours will be very keen on getting the challenge cup back to Germany, it meant that we had to develop even better canoes. As in fact this year's goal was to improve the design. Already in an early stage we found not much could be improved, but only optimised. A new model was build with an even better method than in 2009, resulting in sharp lines within the model. With the help of Ascom Polyester a new mould was made over the model. The new canoe was getting shape.

Next to a new design also extra effort was put into the second important pillar of a successful concrete canoe: the concrete. Besides experimenting with new concrete mixtures we did some experimenting concerning the construction method. This resulted in a strong concrete mixture which is great editable during the construction of the canoes.

At last we also put effort in designing the lightest concrete canoe. With a special developed model, we tried to finally get the price for lightest canoe in the Netherlands. The record still stands at 13 kg and we already know we beat that one!

Eventually all the work resulted in five new concrete canoes. With these five new canoes we will participate for the fifth time in the Dutch Concrete Canoe Challenge (BKR) in the history of the BetonBrouwers. And despite our dominance during the BKR of last year, season 2011 will still be a tense season since we don't know what our competitors did during the last year. So, were other students enjoyed their spare time, the BetonBrouwers worked hard to develop a new desgin, develop new concrete mixtures, construct five magnificent canoes and train their paddling skills in order to beat the competition for the fourth year in a row.

Finally we want to use this occasion to thank the people who have supported us during this project and bear a warm heart towards concrete canoeing. First we want to thank everybody assisting the BetonBrouwers with the construction of the canoes, without their assistance it would be impossible to build the canoes. Second we want to thank all the people and companies that have supported us to achieve our goals and building five beautiful concrete canoes.

Remains us nothing else than wishing the reader a lot of pleasure with reading this report.

BetonBrouwers 2011,

Bart Leferink	(Chairman & Webmaster)	Casper Rood	(Chief construction site)
Cindy Clevers	(Secretary & PR)	Peter Schoonderbeek	(Head of Design)
Yorick Keizer	(Treasurer)	Sevrien Ferrée	(Training coach)
Chiel de Wit	(Vice Chairman & PR)	Frank Aarns	(General Member)
Rik Goossens	(Eventmanager)	Ynze Goinga	(General member)

[1] Translated: ConcreteBrewers

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Introduction

In front of you lays the construction report of the construction committee 2011 of Study Association ConcepT. Since July 2010 this committee, consisting of ten 'BetonBrouwers', has put a lot of dedication and effort in designing and constructing four magnificent concrete canoes and also for the first time the lightest concrete canoe. 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 for the second time 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 competitions take place in Eindhoven and Magdeburg where we will try to beat our competitors and conquer the first price!

In this report we tried to describe the essential elements necessary to build a successful concrete canoe, that's why the report is entitled 'How to construct a concrete canoe'.

To construct successful concrete canoes, three essential elements are required. The first element is a motivated, well trained and well supported team. The second element is a optimal hydraulic design. The third element is a perfect concrete mixture. These elements form the three pillars to become successful in Concrete Canoeing and are described in the first three parts of this report. The first part covers the history of our fantastic team, it's team members and the supporting companies. The second part concerns the design of the canoe, starting with the principles it's based on followed by a mechanical analysis. In the third part the material concrete is explored. First the theoretical background is discussed after which the concrete mixtures are composed and analysed.

In addition to the first three parts, the fourth part of the report describes the process behind construction season 2011. Starting with the construction of the new mould followed by a training description. The fifth part concerns the construction of our lightest concrete canoe. Followed by a concluding chapter and an overview of the consulted literature. The report is concluded with three appendices. The appendices contain our contact information, background information behind the concrete mixtures and the highlighted materials.

Besides the information in this construction report, more information about our team, our activities, our achievements and pictures & video's can be found on our website: www.betonbrouwers.utwente.nl.

Part 1

BetonBrouwers – An honour to be part of

Success in concrete canoeing is based on three pillars. The first pillar is a solid team. Since 2007 the BetonBrouwers form the construction committee of Study Association ConcepT of the school Civil Engineering at the University of Twente. Only the real diehard Civil Engineering students with a heart of concrete, loads of motivation and a lot of persistence can become a BetonBrouwer. Before one is allowed to call himself a BetonBrouwer, he or she really has to earn it! That is why it's a real honour to be part of this committee! In this chapter we provide some background information about our committee: it's history, members and the supporting companies.

1.1 History in the Making

It all started in 2007 with a group of four students which were experimenting with fibre reinforced concrete. This project made them realise how much fame can be gained with brewing concrete. Thereby it made them clear that this fame was only achievable with blood, sweat and tears. Then dhr. Verhagen came on our path, making us enthusiastic about pre-stressed concrete. Unfortunately there were no bottles of champagne that could be deserved with experimenting with pre-stressed concrete. But on the other hand it was much better applicable in canoes, were it was about after all….

2007: Rising from the ashes

In the year 2006, Study Association ConcepT was asked by the Dutch concrete federation to organize the 30th Dutch concrete canoe challenge. Because of the 30th anniversary of this yearly race, the event in Twente had to become special and bigger than ever. A special guest was invited: the champions of the American Concrete Canoe Challenge!

To give this American team a challenge, four diehard students Civil Engineering joined forces in March 2007 to form the new construction committee of ConcepT. They called themselves the 'BetonBrouwers' (ConcreteBrewers). They soon concluded that the old canoe mould, at that time used for about six or seven years, had to be replaced by a new one. In combination with the mould a new construction method and concrete mixture were developed. So after months of hard work, the job was finished. In the second weekend of September 2007 three splendid canoes were shining in the Dutch evening sun. Like a phoenix rising from the ashes, the concrete canoes from Twente would turn out to be a threat to every team.

On the foggy morning of the 8th of September the races started. Although it wasn't possible to test the concrete canoes before the race, training effort in the months before with regular canoes paid off. It proofed that the canoes from Twente did a very good job. In direct battles, canoe 'Voortvarend' managed to beat seven canoes on the sprint. In the sprinting races, canoeists Frank Aarns and Sevrien Ferrée managed to qualify themselves for the final run. Their competitor being the Americans from Madison Wisconsin: David against Goliath. After a thrilling race the Americans won, though it was only by a minimum of two seconds.

During the 400 meter curvy trail, the men final was again the domain of the Americans and the Dutch heroes from Twente. This time the University of Wisconsin was a competitor of another class and the Yanks won again. The story of success of the two second place prices were widely spread during the weeks that lied after. The BetonBrouwers were determined to put everything up for the next edition of the concrete canoe challenge, which was to be held in May 2008 in Delft. The story continuous...

2008: We came, we saw, we kicked ass!

After being successful on the concrete canoe challenge of 2007, the BetonBrouwers agreed that this story of success had to be continued. Together with the board of ConcepT it was decided to make the construction committee a continuous committee, resulting in less loss of knowledge. The core activity would be designing and building concrete canoes, something in which we were getting very good at. After attracting some new team members, the BetonBrouwers started to work on the new season.

For all the work we had on making the mould the year before, we decided that for 2008 the mould of 2007 was to be used again. Better concrete, a slightly different method of building canoes and making the canoes as thin

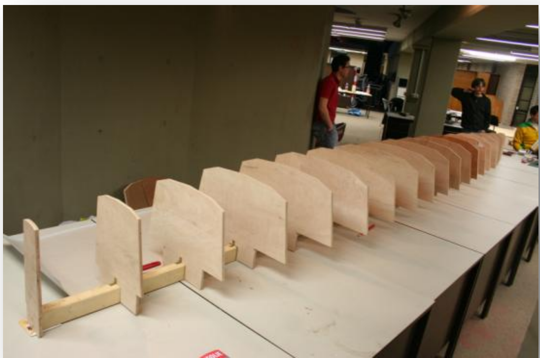
as possible were the key aspects of making better canoes than the year before. Besides that, pigments were used instead of paint to colour the canoes. The road to Delft 2008 wasn't as easy as we thought though. Making the first of three new canoes took us two full days. Though, we managed to build three canoes again. The three boats were named: Veni, Vidi and Vici. These famous words of Roman Julius Caesar (I came, I saw and I conquered) would turn out to describe our canoe challenge experiences in Delft pretty well.

On the rainy morning of 17 May 2008 hell was unleashed on the waters near Delft. On the water of the 'Delfste Hout' it all had to be done; it was the day of truth. Frank and Sevrien, the top canoeist of Twente, made it to the finals at the 200 meter sprint. The teams in the other divisions, mixed and ladies, were less fortunate. A French team from Le Bourges was considered to be our only competitor. Because the 200m final was sabotaged by another team, the French won the race.

Thanks to a great lunch, arranged by our sponsor, we regained strength in our muscles and minds. We now totally focused on the 400 meter races. Besides our men, the ladies performed very well on the 400 meter distance. They made it to the finals and actually won the race. But the ladies turned counter clockwise at the buoy and were disqualified. In the semi-finals, the men showed that they could beat the French and in the final they did it again. Victory was ours! Because the jury was very pleased with our canoes and our result on the tournament, they decided to call ConcepT the overall winner of the Concrete Canoe Challenge 2009. Our goals were achieved and the success was complete. We came, we saw and we kicked ass!

2009: Conquering Europe

After the Concrete canoe challenge of 2008, the BetonBrouwers were officially Dutch champion. Though we wanted even more; not only a good reputation in Holland but also abroad. Participate at the German BetonKanu-Regatta, which was to be held in Essen on the 19th and 20th June 2009, became the new challenge of 2009. Besides that, we had to protect our title at the Dutch concrete canoe challenge in Roermond.



This year, we were up to another new challenge: a new canoe design. Using experiences from the past years, the new design was based on speed and manoeuvrability. After constructing a 1:1 wooden model of the new canoe design, we succeeded to make a nice polyester mould. Constructing the canoes was succeeded without any large problems. A new orange lightweight concrete mixture with a perfect workability resulted in a smooth construction process. The concrete combined with synthetic meshes and steel cables as reinforcement turned out to be a perfect combination. This made it possible to make walls of just 5mm thick which were still flexible and strong enough to withstand some impacts. The nice orange canoes were finished with nice and catchy names and the steel cables in the top of the canoes were put under tension. We were ready to rock 'n roll on the water!

1On Friday the 5th of June, the transport of three nearly 6m long orange canoes to Roermond left Enschede. The next morning the races began. During the short distance (200 meter) our experienced canoe team, Frank and Sevrien, proved again to be best of the best. Without any problems, they reached the final round and won it with ease. Though, they were not the only ones to race with success. Our mixed and lady teams showed that they could paddle as well. This resulted in several prices, including one first price at the mixed teams. Also the long distance over 400 meters became the winning area of the BetonBrouwers. At the end of the day, 13 prices could be taken back to Enschede. The BetonBrouwers ruled the BetonKanoRace 2009! The results were devastating.

Two weeks later, we drove to Essen (D). The biggest challenge was yet to be come: participating in the German BetonKanu-Regatta. The first day was assigned to show the canoes to the different jury's and other interested people. Most of the eastern neighbours were sceptical about our design: we might win on the straight, but a canoe of nearly 6m long could never make the turns. Well, we proved them wrong that afternoon by giving a little demonstration, the shock was complete.

The next morning the races began early to make sure all of the canoes could sprint for the finish. During the qualification rounds, it was clear that our success in Holland was not exclusive; every canoe in the German races fought themselves to the final rounds. Unfortunately, two of the men teams were not good enough to go beyond the quarter finals. Frank and Sevrien however won every (final) round with ease and were the first couple to qualify for the final. Also two ladies managed to paddle themselves to their final. Unfortunately the ladies weren't able to paddle themselves to one of the first three places and finished fourth. Still a very good result!

After the ladies final, the waiting started for the men final. Although starting with a lot of confidence, the Dutch felt the pressure. The lighting start of Frank and Sevrien was again determining the course of the race. The two top canoeists from Twente eventually won the final overwhelming. Our success was complete and was rewarded with a very nice first price.

Because of the success in Germany, the BetonBrouwers got a lot of attention both at the University, in the region of Twente and nationwide in the Netherlands. Some new members were attracted to reinforce the team for the upcoming season.

2010: Scoring three hattricks

After the succesfull season of 2009, the start of the new study season in September was used to start on a new BetonBrouwers season as well. Now we had the confirmation that the design of the canoes was almost perfect, the BetonBrouwers decided to put effort in making the canoes even nicer, smoother and lighter by using all kinds of different concrete mixtures.

While our ‘cornerstones’ Frank and Chiel were studying civil engineering aspects abroad (Trondheim, Norway resp. Prague, Chzech Republik) the committee slowly worked to the new canoes. In the first weeks of 2010 our main sponsor ENCI was visited to gain some insights in the new concrete mixtures which were going to be used in the new canoes. Remarkable was that marble was to be ‘in the mix’ of one canoe: polishing that boat would make the canoe shine like a star.

The mould from the previous year was refurbished and a car paint shop put a nice and smooth new layer of paint on the mould. From this point the canoes could be constructed. Almost every week a canoe rolled of the assembly line. Trainings were hard as ever and also canoeists from ConcepT had to put a lot of effort in paddling to work themselves through the training. On the eve of Thursday the 3rd of June the BetonBrouwers were ready to rock again!

On the sunny morning of Friday the 4th of June the delegation from Twente searched their way to Utrecht. A camp site on the outskirts of Utrecht was used as base for the coming weekend. With a large army tent the BetonBrouwers base wasn’t to be overseen. During the examination of the canoes by the jury the canoes, the BetonBrouwers gained respect with the work they had done. The white canoes were the center of interest. The day was closed with a canoe trip over the town canals of Utrecht, the draw for the races of the next day and a party from hell with singing hero ‘Starkoo’.

The following day the races began early. Starting slowly, the races in the men and female disciplines were dominated by the white canoes from Twente. In the mixed raced the competition was fierce, though one duo was able to reach the semi-finals. In the men competition, our ‘canoe legends’ Frank and Sevrien did what they had to do: winning every race in de 200m an 400m sprint races. Even athletes from Prague weren’t able to stop the two. Also Casper and Chiel were able to reach the final, though only the 200m one. In de semi finals for the 400m their canoe was deliberatly crushed by the Czechs, which weren’t going to win the fair-play cup.

At the female competitions Nienke and Floor resp. Cindy and Leonie reached the final of the 400m. Both lady teams showed what they could and won the first and second price during the final run in the centre of Utrecht! Frank and Sevrien won the 200m and 400m (third year in a row = hattrick one) sprints overwhelming, while Chiel and Casper did a good job by winning the bronze medal on the 200m.

While the construction of the canoes from Twente was again not to be outclassed by other teams, the second hattrick came in sight and the construction price was won. The third hattrick was winning the overall-price.

The performance of the BetonBrouwers was unique. Never in the history of the Dutch Concrete Canoe Challenge one team managed to win the overall price three years on a row. The team from Enschede is predetermined to come up with good results also in 2011. Stay tuned!

1.2 Team members

As construction committee we strive to be a continuous committee which consists of a diversity of students, meaning students from different phases of the study Civil Engineering. In this way we try to pass the knowledge to the younger members instead of inventing the wheel over and over again. In this paragraph all members of the BetonBrouwers are introduced, giving an insight in their backgrounds and their functioning within the committee.

1.2.1 Bart Leferink alias 'Bartels'

BetonBrouwer since season 2010
Current function: Chairman & Webmaster
Birth date: 26 August 1988

During the day Bart appears to be a normal guy, a hard working student with a passion for concrete canoes. But when during the night the study books are closed, he transforms into Bartels, an irresistible womanizing party animal.

During the night the true nature of this pure bred Tukker becomes exposed as he enjoys music as Polka's, 'Smartlappen' and German 'Schlagers'. A musical taste that is well feared on the construction site during Barts presence. During party's as 'De Hoeve', 'Mega Piraten Festijn' and 'Dorf Munsterland' a mysterious winkle appears in his eyes and in combination with a big smile on his face you can tell that this party animal is in his elements.

Not only during the night Bart is at his best, also among the BetonBrouwers Bart feels like a fish in the water. As the chairman of the BetonBrouwers Bart has the tough task to keep the committee under control. Enthusiastic from his first season he decided to join the intense training program to improve his physical strength, endurance and paddle technique. With the combination of extensive body workouts and paddle training on the Twente Canal this will be the season that Bart is going to shine on the waters of Eindhoven en Magdenburg.

1.2.2 Cindy Clevers alias 'Cindieeeee'

BetonBrouwer since season 2011
Current function: Secretary & PR
Birth date: 31 July 1990

Since Cindy entered the committee, things changed internally. Some guys who always seemed to brave and macho, suddenly showed emotions. Which is quite dangerous while working with concrete canoes. The worst you could imagine happened. She fell in love with one of the respectable members of the "BetonBrouwers". His love for concrete changed in a deep love for Cindy.

Cindy is not a regular girly girl, she is really active in sports as cycling, football, ice-skating and so on. With all these sports see is as fanatic as she was last year while paddling in a concrete canoe. The rest of the committee hopes that this year she also learnt to control the canoe, since paddling in a straight line can be useful.

Beside her sports she is busy with her tasks for the public relations. She really does this tasks well. She is really quick with contacting, in Dutch:" She doesn't let grass grow over it" by using all kinds of relations, her father, or some people she met on a symposium or else she made sure the BetonBrouwers had enough money to realize five awesome canoes!

1.2.3 Yorick Keizer alias 'Foppe'

BetonBrouwer since season 2010
Current function: Treasurer
Birth date: 24 April 1991

Yorick alias Foppe, is the rookie of our team. Nineteen years ago he was born in Stadskanaal, a small city in Grunn. Since he speaks exactly like football coach Foppe de Haan, he has the nickname 'Foppe'. But because of his love for Grunn and the rivalry between Grunn and Friesland, the birthplace of Foppe de Haan, he is not really contented with his nickname.

After his secondary school he left the north for the very east. He decided to study Civil Engineering and Management in the beautiful city of Enschede. A decision that directly seemed to be the right one. Before his first day in college he met the BetonBrouwers. During the introduction week he had the opportunity to paddle a bit in one of the beautiful concrete canoes of season 2009. The goal of the BetonBrouwers was to discover the maximum impact of a concrete canoe. Yorick succeeded by destroying two of our canoes. Thanks to his experiment we knew something more about the strength of our canoes.

After seven months of studying he learned enough about concrete to make him suitable for a position within the team. From then on everything went quick. After two times of helping with constructing a canoe, the team offered him a contract. because it was his dream to become a BetonBrouwer he directly signed. From then on there was another proud member of the BetonBrouwers.

1.2.4 Chiel de Wit alias 'Guus'

BetonBrouwer since season 2009
Current function: PR & Vice-Chairman
Birth date: 15 April 1989

It is said that Chiel sleeps with a concrete bible besides his bed and that concrete is running through his veins. If it's true nobody knows, what we do know is that Chiel is fanatic about concrete and its applications. This passion for the material and his practical insight make him a perfect member of the BetonBrouwers. After being the chairmen for a while Chiel decide it was time for somebody else to take over the stick and he started working as PR-materials this year. Beside this job he was responsible for making an even better concrete mixture then the previous years.
Beside working hard for the BetonBrouwers Chiel has some more passions. One of these is playing soccer. Chiel is an fanatic player and plays for multiple teams. Most times he plays as a defender and his favourite position is left back. On the pitch Chiel is a hard worker and feared by many opponents, something he also achieved by participating at the canoe races. By becoming third in last year's races he is a competitor people should keep in mind.

After telling last year Chiel was into croissants, brie and red wine we can happily announce this year is all about burritos and sombrero's. As a team we are happy with his change of flavour because she offered to help us building the canoes, and that is good news because everybody knows Mexicans are hard workers. Hopefully Chiel will be able to win a price just like last year and with his Mexican girlfriend supporting him during the races Chiel will be a tough one to beat.

1.2.5 Rik Goossens alias 'Fry king Rik'

BetonBrouwer since season 2009
Current function: Eventmanager
Birth date: 7 December 1987

Our very own 'fry king' was born in the city of Arnhem, but still manages to be a jolly fellow. Proud of his heritage and full of love for the game of football, he's a devoted supporter of Vitesse (sadly not a particularly good team in the Dutch Eredivisie, but they try to become champion in 2013).

As Event Manager, Rik makes sure every detail about our being at the races is as it should be. He is the one that is always in contact with the BKR organization about things that are not sure or still has to be done. He also makes a great deal about the team structure during the races, making sure that everything goes as smoothly as possible.

Rik isn't the best constructor on the team, but provides something way more important: his famous minced-meat hot dogs, frikadellen. This is actually how he got the name "Fry King Rik". Rik keeps the team nourished during the long hours of development and construction of the canoes. He also makes sure that there always is a fresh box of beer to celebrate the birth of yet another canoe! By doing this, Rik keeps the team hard-working and happy during construction. Nothings speeds up a building process more than the prospect of a cold Grolsch Beer accompanied by Rik's famous minced-meat hot dogs!

In short: Rik has one of the most important roles in our team. He motivates the others to always give their best effort!

1.2.6 Casper Rood alias 'The Blister'

BetonBrouwer since season 2010
Current function: Chief construction site
Birth date: 17 November 1987

In November 1987 Casper was born in the most beautiful town of Limmen, a small town with approximately 7000 inhabitants. In 2006 Casper moved to Enschede, to study Civil Engineering, which was highly appreciated by the inhabitants of Limmen. Sadly enough for them he returns weekly to drive a forklift for work.

Luckily the people of Enschede did like Casper, and in 2009 he decided to enter the BetonBrouwers when he finished his year on the board of the Study Association of ConcepT. Casper is of great value to the BetonBrouwers, with his hard working mentality if he manages to finally start doing something. Nowadays, Casper is the manager of our workplace, where he tries to see where everyone puts the equipment and to put it in the right place. Casper can be really serious if it's necessary, and he is putting all his effort in trying fix the isolation of our workplace, since our workplace is not isolated at the moment.

Casper is training hard for the Concrete canoe race, where he tries to beat everyone. Time will tell if his anger to win will result in the first place. This are the kind of people the BetonBrouwers need to make sure that this year's title again is claimed by the BetonBrouwers.

To sum up: Casper can be seen as our cheerful, motivated and knowledgeable, but particular cheerful team member and with him the BKR 2011 will come to a good end.

1.2.7 Peter Schoonderbeek alias 'The Pun King'

BetonBrouwer since season 2011
Current function: Head of Design
Birth date: 30 July 1987

One of the rookies of the committee this season is Peter Schoonderbeek. Just as Rik, Peter is born in beautiful Arnhem twenty-two years ago. Despite of his inexperience with concrete canoes Peter has already lived up to several reputations in the committee. The best way to describe Peter is to tell about these reputations.

The first reputation is about his task. Peter is the head of design and is responsible for the shape of the 2011 canoes. Peter can be really smart, serious and perfectionistic. He optimized the 2010 design and managed to reduce weight and improve speed!

But Peter has more reputations. After a day of hard work for his study Construction Management & Engineering, the BetonBrouwers, or his hobby cycling, Peter really likes to drink beer with his friends. When doing that, he is still smart, serious and perfectionistic. In the end Peter is always the last man standing, because his friends quit one by one. Well that's what you call a perfectionist!

Luckily, Peter is not always smart and serious. However, we always have to listen to Peter twice. Not because he speaks unclear, but Peter makes almost permanent jokes while no one notices. Puns are the specialty of this young man. And that's why we call him 'The Pun King'!

1.2.8 Sevrien Ferrée alias 'The Bear of Boekelo'

BetonBrouwer since season 2007
Current function: Training coach
Birth date: 25 October 1987

As one of the founders of the BetonBrouwers, Sevrien is still a dedicated member of the committee. He is born in the scenic hamlet Boekelo and is still living there after 23 years. Six years ago he started his study Civil Engineering in Twente. Now, almost graduating he slowly let his student life behind him to become a real citizen.

Some things don't need an explanation, like Sevrien's nickname. You only have to watch him and his first paddle strokes, connect that to his beloved hometown and you will understand why we call him 'The bear of Boekelo'.

2011 will be a special year for Sevrien and his canoe buddy Frank, because this will be the last chance for the legendary couple to defend their titles. After a new year of training and a canoe even better than before this is their last chance to become champions for the fourth time in a row in the Netherlands and defend their title in the international field in the German competition.

Beside his passion for our 'dondersgeile' concrete canoes, described in his own words, we can find Sevrien by his beloved trains. He is putting a lot of time in driving them, doing maintenance, dreaming about it and travel around the world with his photo camera to get them on picture. Also in the little community of Boekelo he is always busy, as a diehard supporter of the best football club of the country, FC Twente. In the winter Sevrien is still training but also busy with his other passion: carnival. Every year he helps building their own carnival trailer and drinking beer with 'The Pummels uit Boekelo'. Maybe we should not dwell on...

1.2.9 Frank Aarns alias 'Prof. Arms'

BetonBrouwer since season 2007
Current function: General member
Birth date: 27 December 1985

On the 27th of December 1985 a bright star in heaven wasn't guiding three kings to the promised land, but towards the city of Nijmegen: the birth of the young miracle Frank Aarns was a fact. His sporting capabilities became evident when he swam the Waal river towards the small village of Elst, where he grew up and his interest in Civil Engineering rose. Because Frank was attracted to the nice atmosphere at the University of Twente, he decided to move to Enschede.

During his years in Twente, it was clear that Frank wanted to do 'some' work besides his study. Together with fellow students he organized the 'BuLa' to Gdansk in Poland, was one of the founders of the BetonBrouwers, and became chairman of the study tour committee 'Gateway to Africa' to perform some development aid in South Africa. Besides that, in a possible Third World War situation, Frank will put his life in line for our beautiful country as a 'Saturday and Sunday' soldier of the National Reserves of the Royal Dutch Army.

Though that was not yet the summit for this blond 'womanizer'. In 2010 Frank was chosen to perform the role of Technical Manager in the Solar Team Twente. Although nothing is so interesting and challenging as building concrete canoes, Professor Arms decided to construct a solar car to compete with other teams in the famous World Solar Challenge in Australia in October 2011. Because Frank knows from concrete canoeing experiences how to deal with teams as from other universities, he will therefore, together with his team, also beat the competition 'down under'.

2011 will be the last year of Frank's career as a BetonBrouwer. Together with another concrete canoe legend, Sevrien, Frank was unbeata ble on the water from 2008 to 2011. The races in Eindhoven and Magdeburg (D) will be the last trick this legendary couple will fulfill. Frank's name will have a prominent name on ConcepT's 'wall of fame' and will be remembererd forever as one of the most dedicated to concrete canoeing in the history of this study association.

1.2.10 Ynze Goinga alias 'Johan'

BetonBrouwer since season 2011
Current function: General member
Birth date: 20 December 1986

On the stormy day of 20 December 1986, the Fries' town of Leeuwarden was startled by the birth of Ynze Goinga. After having an interesting youth in the litte town of Lippenhuizen (near Gorredijk, Friesland), he didn't know what to do after his years on the secondary school. That's why this sober Fries decided to undertake a complete foot trip to China! Only crazy people think about walking to Beijing, but Ynze really did it. Visiting nice and picturesque countries as Israel, Libanon and Iran. Even Afghanistan was crossed. Though there came a time that our 'Afghan warrior' had to choose for his future.

Because Ynze didn't like Delft (and he's right!) he decided to choose for the best option: studying Civil Engineering at the University of Twente in Enschede. In Twente Ynze became notorious as 'Johan' of 'Josef'. As the responsible board member for the Betonbrouwers, Ynze was triggered by the success and sociably atmosphere of this concrete canoe team. He therefore paddled a few heats with 'the Slagtand' in the concrete canoe challenge of 2010 in Utrecht. Although this canoe weight almost 100 kg, Ynze made it, together with Laura, to the finals 400 meter mixed. Ynze decided, already as board member, that he had not yet reached the summit of his capabilities. That's why the BetonBrouwers could welcome Ynze as a new member in January 2011. Within the last few months Ynze proved he is a good catch for the BetonBrouwers. He keeps the atmosphere relaxed and goes along with everything. Ynze claims that he has helped constructing every single concrete canoe of the last two years and he is determined to keep this record. After a day of construction he likes to drink a nice cold beer, that's why he also joined the bubble commission. But the best characteristic of Ynze is his well developed taste for woman, although this doesn't always result in a good score.

1.3. Reinforced by….

This paragraph is dedicated to the companies that support our project through financial sponsoring and through supplying the required materials. We want to thank these companies for reinforcing our project.

ENCI/ Heidelberg Cement Group
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Ascom Polyester
www.ascom-polyester.nl

HSV
www.hsv.nl

Besix Group
www.besix.com

Scholz
http://www.scholz-benelux.nl

Buildsoft
http://www.buildsoft.eu

Study Association ConcepT
www.concept.utwente.nl

Drienerlose Kano Vereniging Euros
www.euroskano.nl

Part 2

A Winning Design

The second pillar for success in concrete canoeing is developing a winning shape and an optimal construction. The formulation of some design principles serves as starting point in the design process. When this part is covered one starts to develop the shape and an optimal construction. The shape of the canoe highly determines the hydrodynamic properties of the canoe which are of major importance in winning races. Finally, the construction of the canoe is the major factor in determining the canoes mechanical properties relative to its weight, with concrete being the binding element where the whole canoe relies on.

2.1. Principles of CT2011

In the previous challenge in 2010 the BetonBrouwers where 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 analyzed 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.

2.1.1. 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 60 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 28,753 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.

2.1.1.1. Improvements

Less weight

The upper shape of the canoe, is less curved than the CT2010 canoe. This is shown in figure 2.1 below. The orange canoe (CT2011, on the top) is less curved then the green canoe (CT 2010).

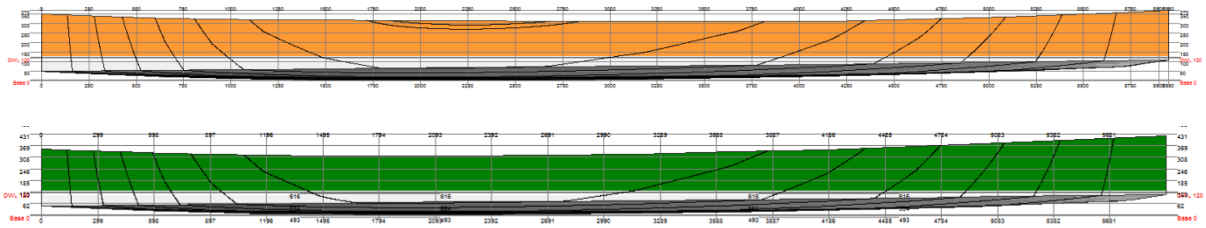


Figure 2.1: Canoe shapes of 2011 (upper) and 2010 (lower)

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 to 5,632 m^2. 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.

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.

2.1.2. 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.

2.2. The art of shaping a concrete canoe

CT2011 is designed by using the software package Delftship 4.30.108. Thereby we consulted people of the Maritime Research Institute Netherlands (Marin) to identify the possible improvements.

The shape principles as defined in section 2.1.1 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 CT2010 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 2.2 for the modelled canoe in Delftship.

For the final design the resistance graph is given in figure 2.3. The CT2011 design has the same hull shape as 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 0.061 kN. The CT2010 design has a resistance of 0.0641.

Though the difference in resistance might seem small, the increase in performance is 5% over the entire trajectory, which should lead to a clear victory for our fit paddlers. The secret behind this result is a keen *L/B* ratio, whereby the maximum beam is reduced to 0.71 m, just above the minimum required 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 5.85 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.

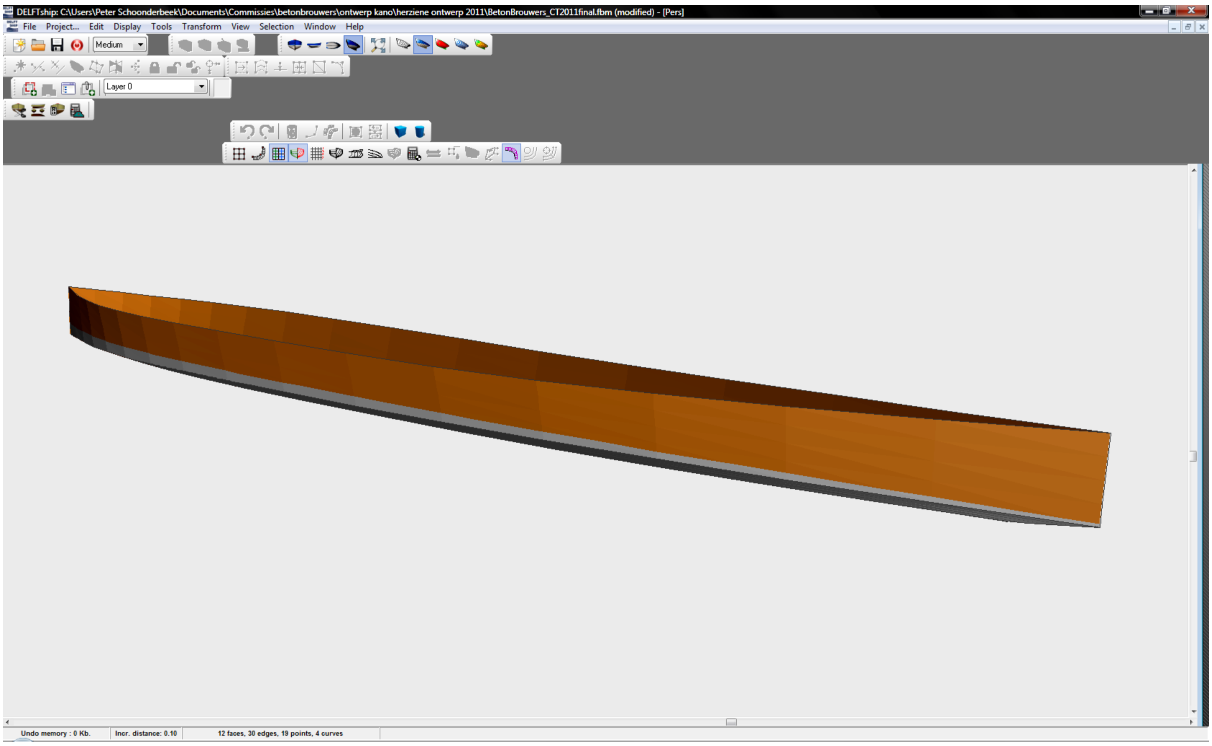


Figure 2.2: CT2011 as modeled in the software package Delftship

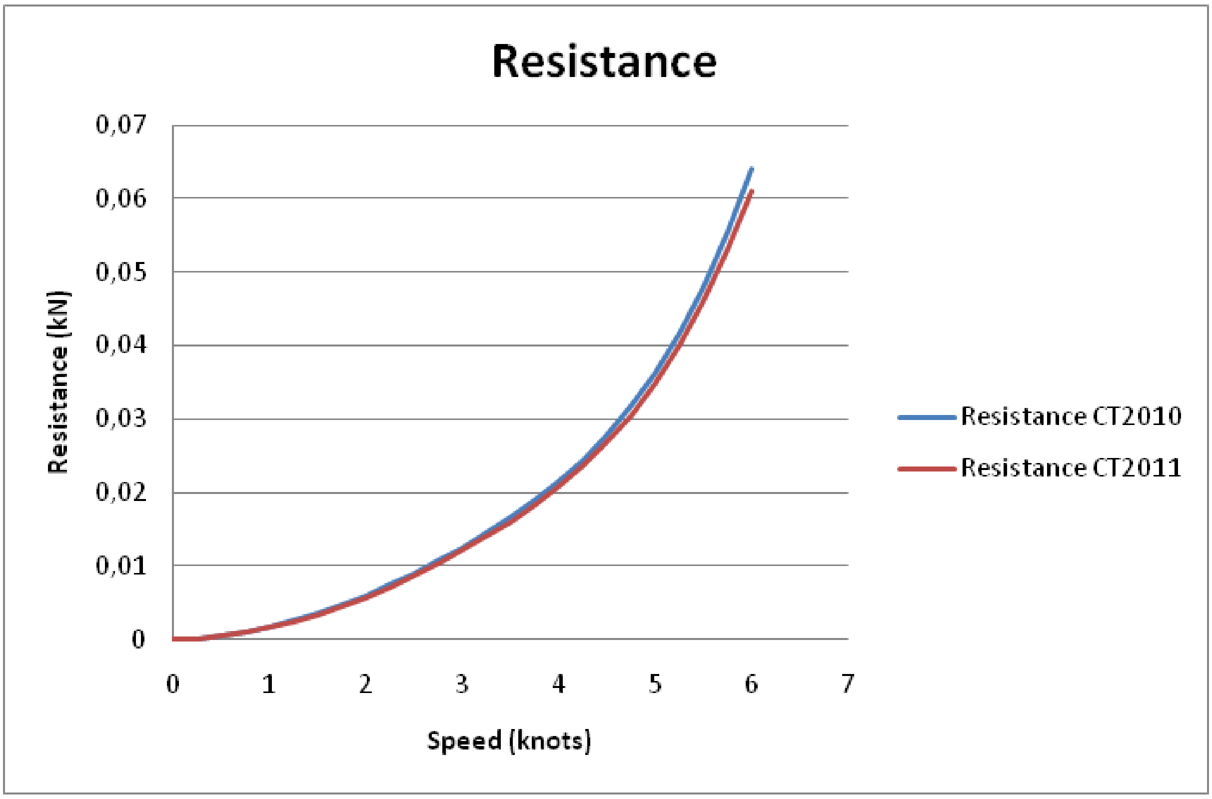


Figure 2.3: CT2011 Hull-resistance

2.3. The Secret of Strength, Stiffness and Stability

Since in our academic philosophy a well engineered design should always be backed by a sound mechanic hull assessment, we started the design of CT2007 with the necessary mechanical models to determine the canoes maximum stresses under most unfavourable conditions (BetonBrouwers, 2007). Though these models provide a good first indication of the strength required, they are also limited in the practice of concrete canoeing, since hull stresses under race conditions are hard to model.

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 CT2011 model, a new mechanical analysis is done.

2.3.1. 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)

2.3.1.1. Input

In figure 2.4 the forces acting on the canoe are given. This picture shows the how the forces that act on the canoe are modeled in Buildsoft, a software package that can calculate stresses and deformations in our canoe.

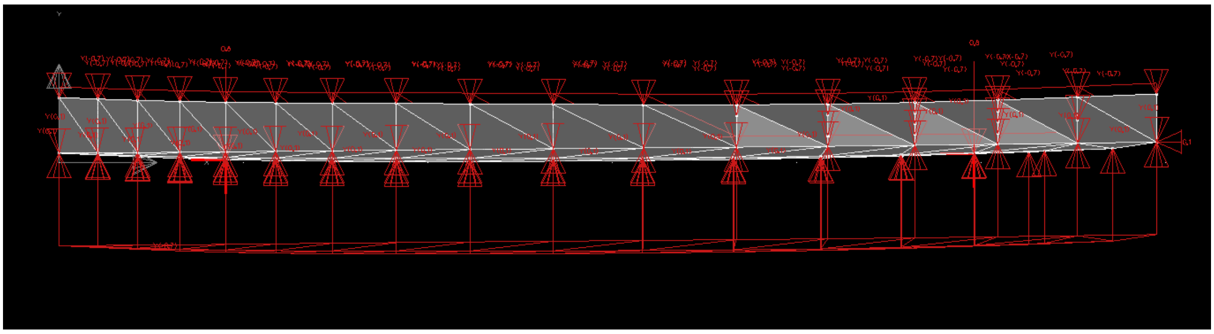


Figure 2.4: Force analysis on CT2011

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 2.5. The input for the mechanical analysis is:

- Concrete: C25/30
- 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 2.6 and 2.7. This analysis doesn't take into account the loads and stresses on the canoe hull as result of transport, paddling and possible impacts.

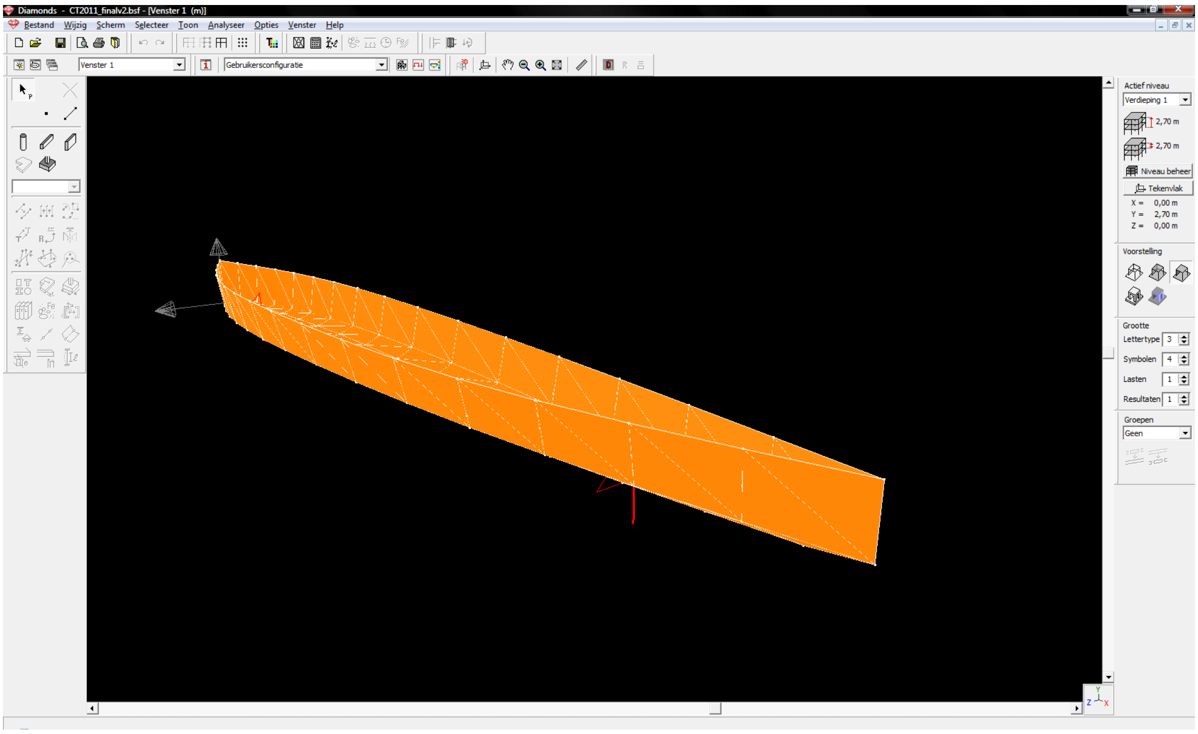


Figure 2.5: Modeling the design in Buildsoft

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 2.5), the program makes a fine raster of triangles (see figure 2.6).

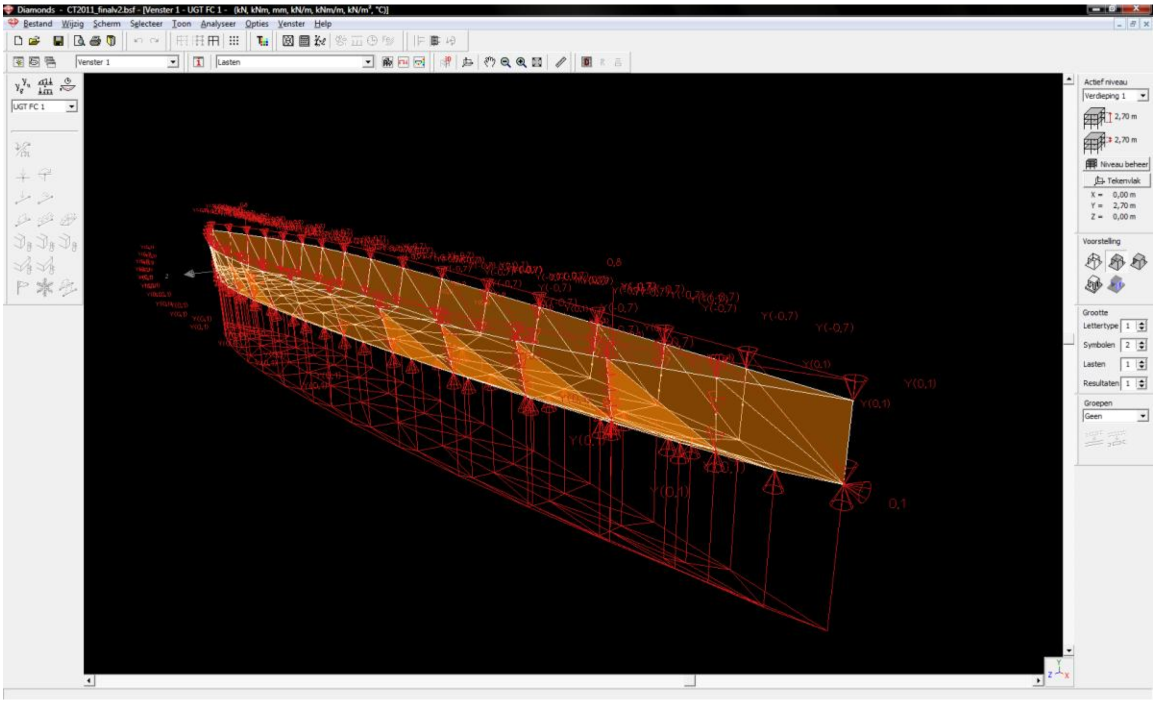


Figure 2.6: Forces acting on the canoe

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.

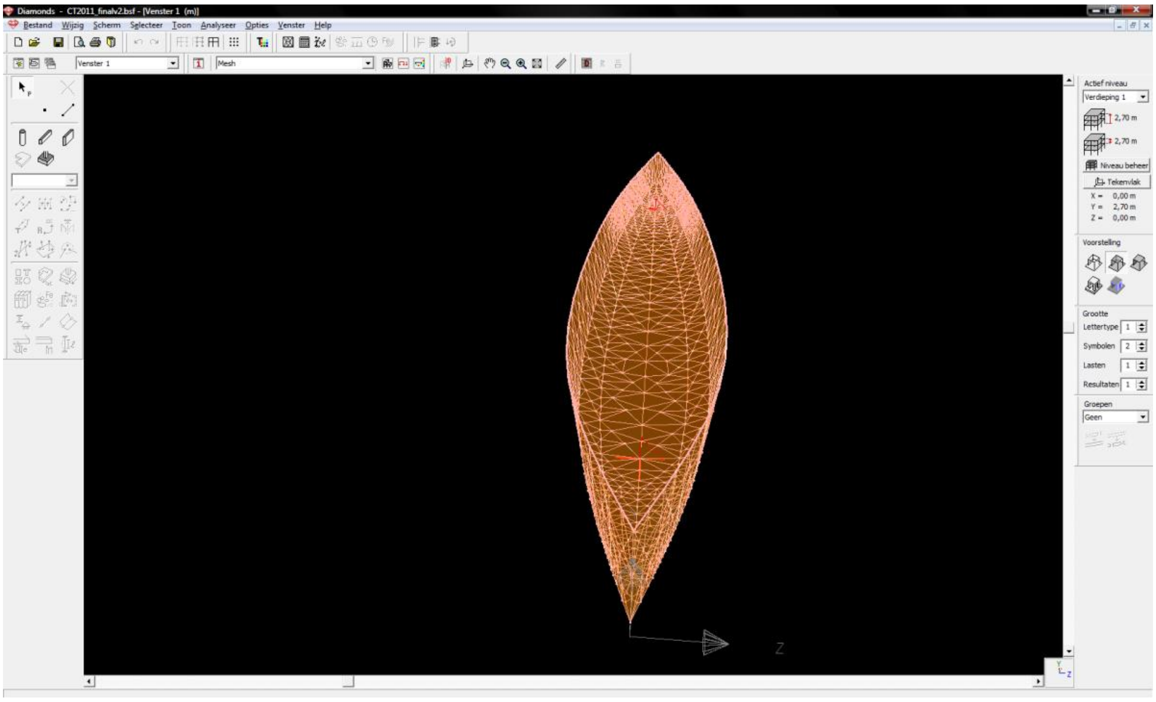


Figure 2.7: Fine mesh grid in the canoe

2.3.1.2. 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 2.8 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 colors indicate that the maximum tensions in the concrete are exceeded, and reinforcement is absolutely necessary in order to keep the canoe intact.

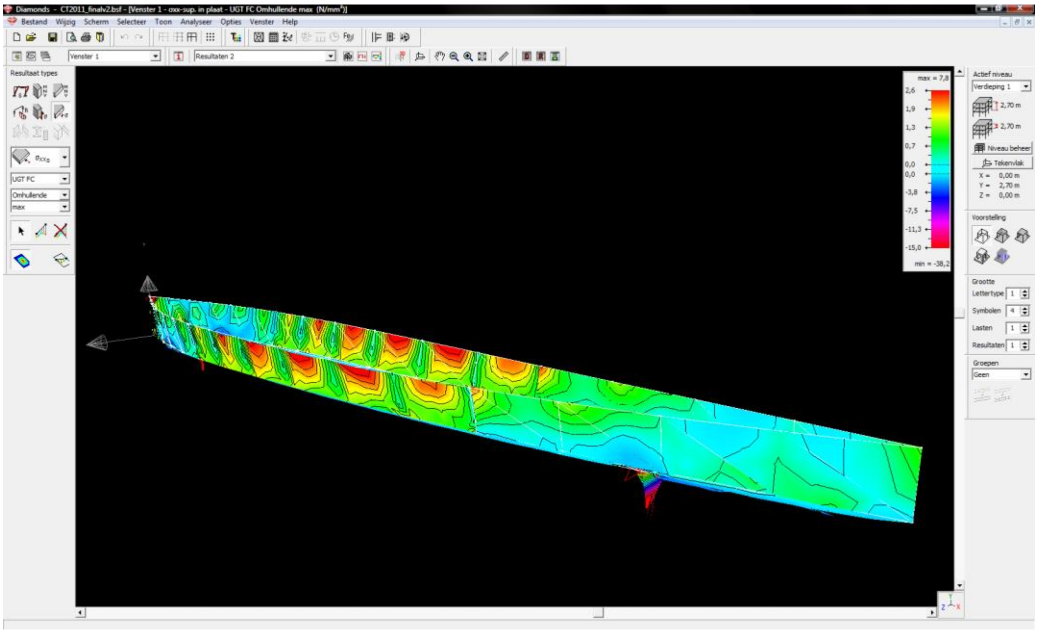


Figure 2.8: Modeling tensions in the canoe

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.

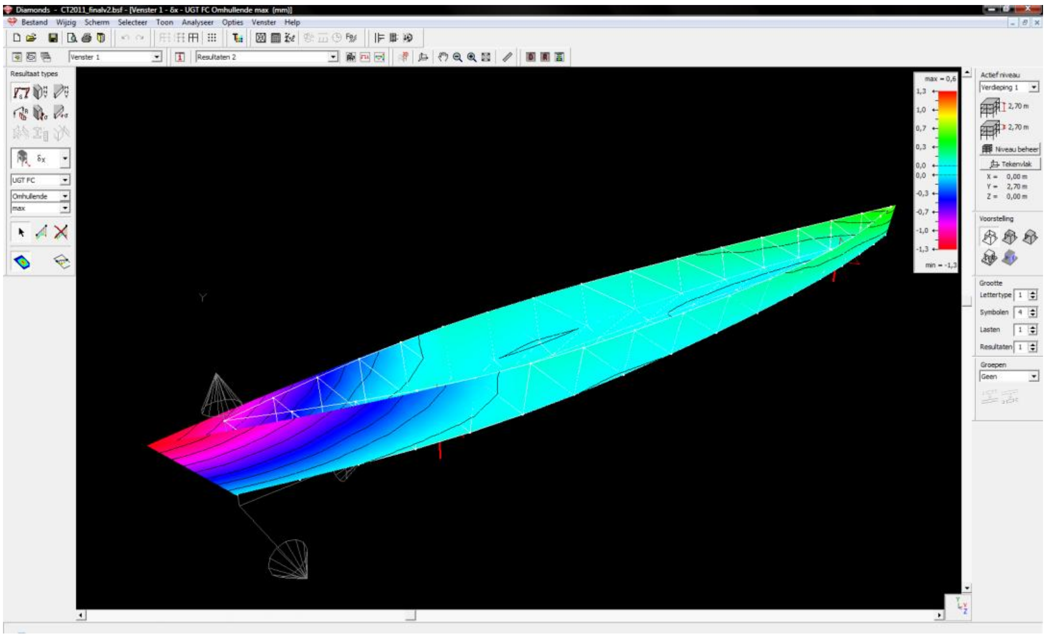


Figure 2.9: tendency to deform in the length direction (x) of the canoe

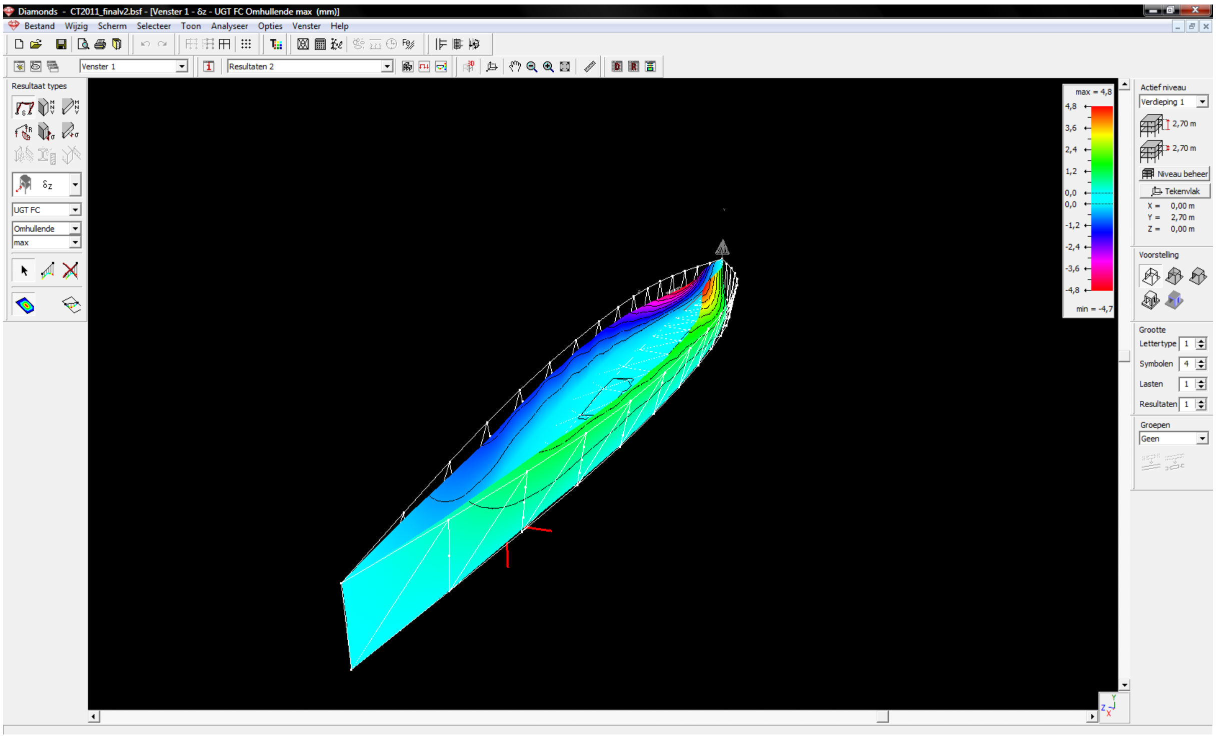


Figure 2.10: Tendency to deform in the height direction (y) of the canoe

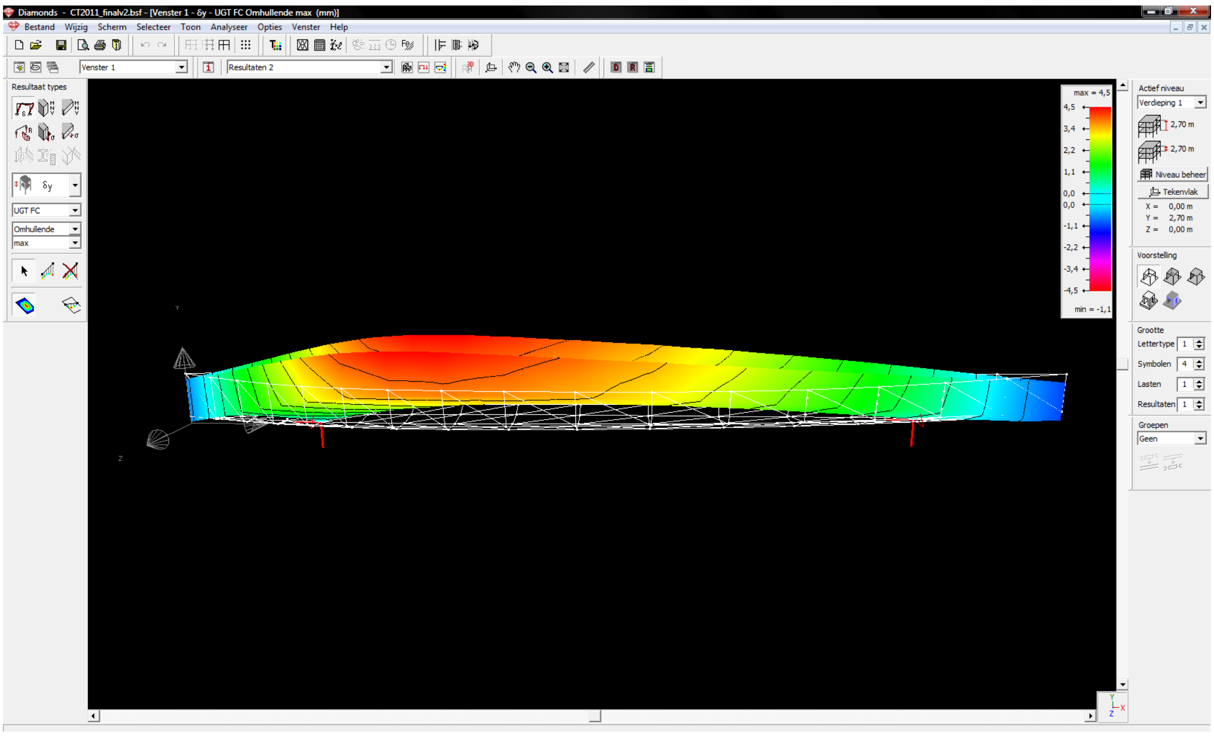


Figure 2.11: Tendency to deform in the width direction (z) of the canoe

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 modeled as a point force, this force is extreme (38,2 N/mm^2). See figure 2.12 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 centimeter. 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 (type 1) is placed and pre-stressed with 500 kN.

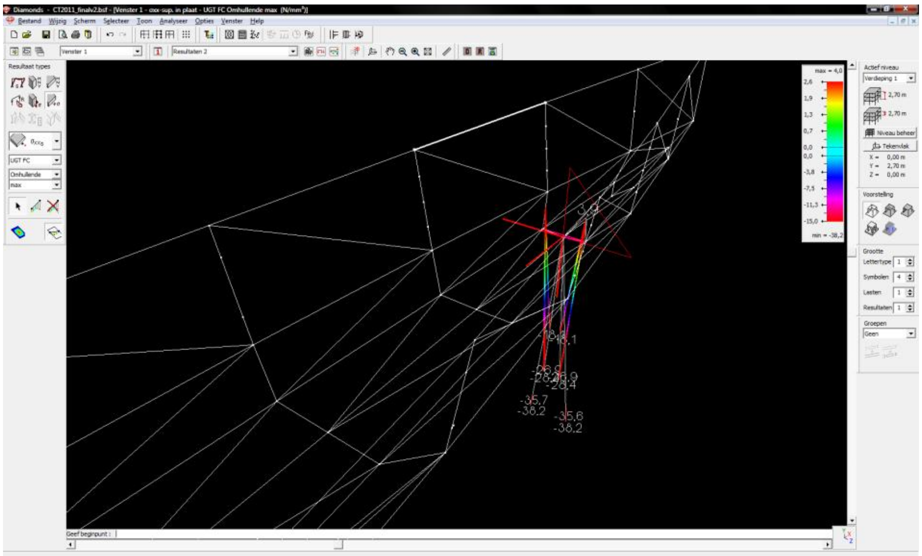


Figure 2.12: better insight in forces caused by the paddler

Figure 2.13 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 2.13). 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 2.13). 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. These cables are from now on referred to as 'type 2' cables.

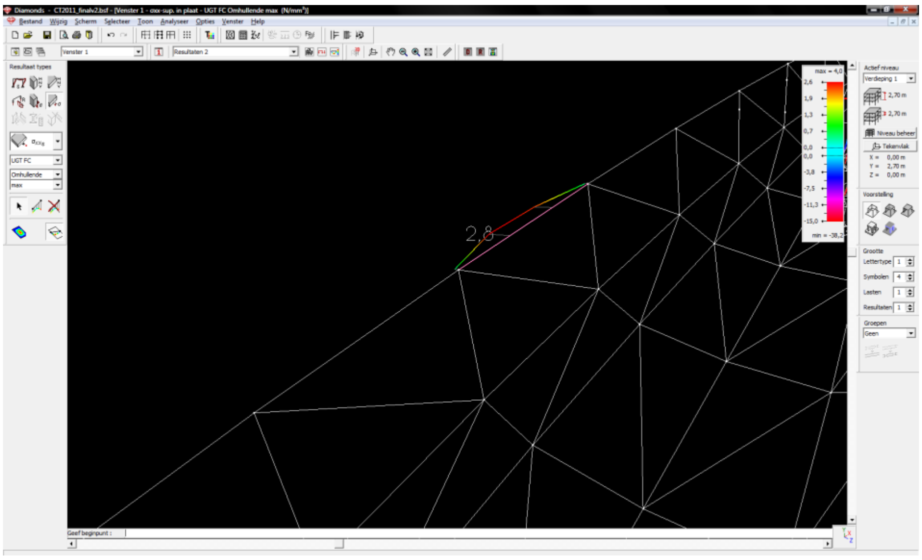


Figure 2.13: tensile strength in side wall of the canoe

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.

2.3.2. 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 2.9 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 (type 1 cables).

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 types 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 2.6. 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 (type 1) 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:

- three pre-stressed steel cables (type 1) in bottom of the canoe over the whole bottom length (x) of the canoe (see 1, *figure 2.15: Blueprint of CT2011*)
- three pre-stressed steel cables(type 1) in the bottom of the canoe over the whole bottom width (z) of the canoe (see 2, *figure 2.15: Blueprint of CT2011).*
- two post-stressed steel cables (type 2) in the top of the side walls of the canoe over the whole top length (x) of the canoe (see 3, *figure 2.15: Blueprint of CT2011*)
- full body mesh

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

2.4. The Blueprint of CT2010

The blueprint of CT2011 is given in *figure 2.15: Blueprint of CT2011*. It gives a top view, side view as well as two cross sectional views. It is compared with the old CT2010 design (*Figure 2.14: Blueprint of CT2010)*. One showing the maximum beam section and one showing a ribbon section. Incorporated are the steel reinforcement cords. The stucco-mesh is not shown.

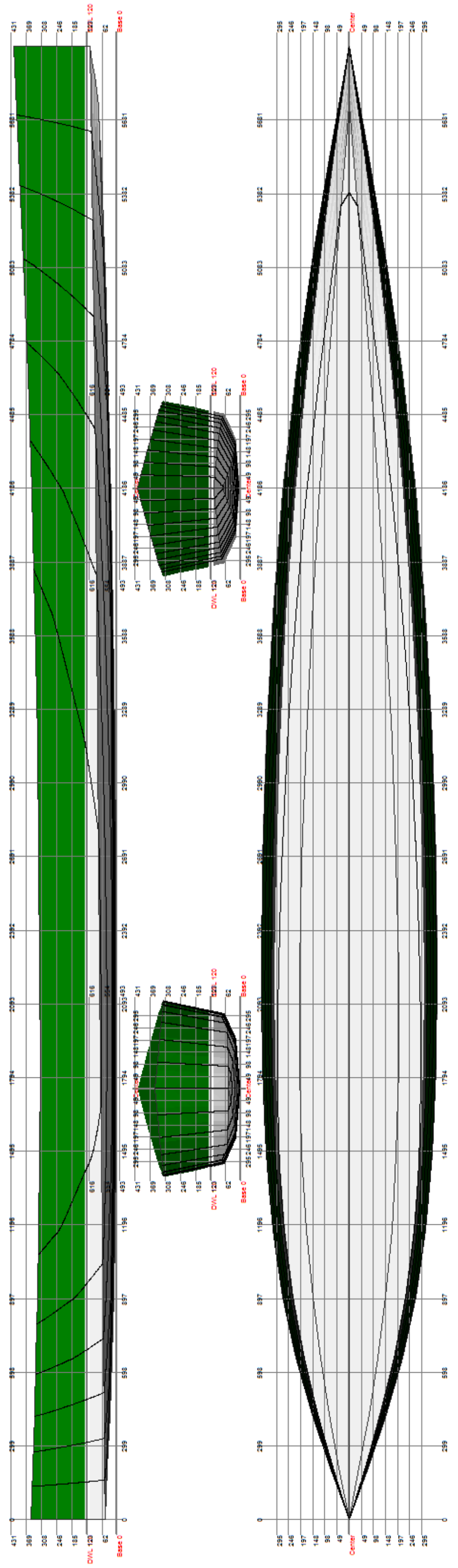


Figure 2.14: Blueprint of CT2010

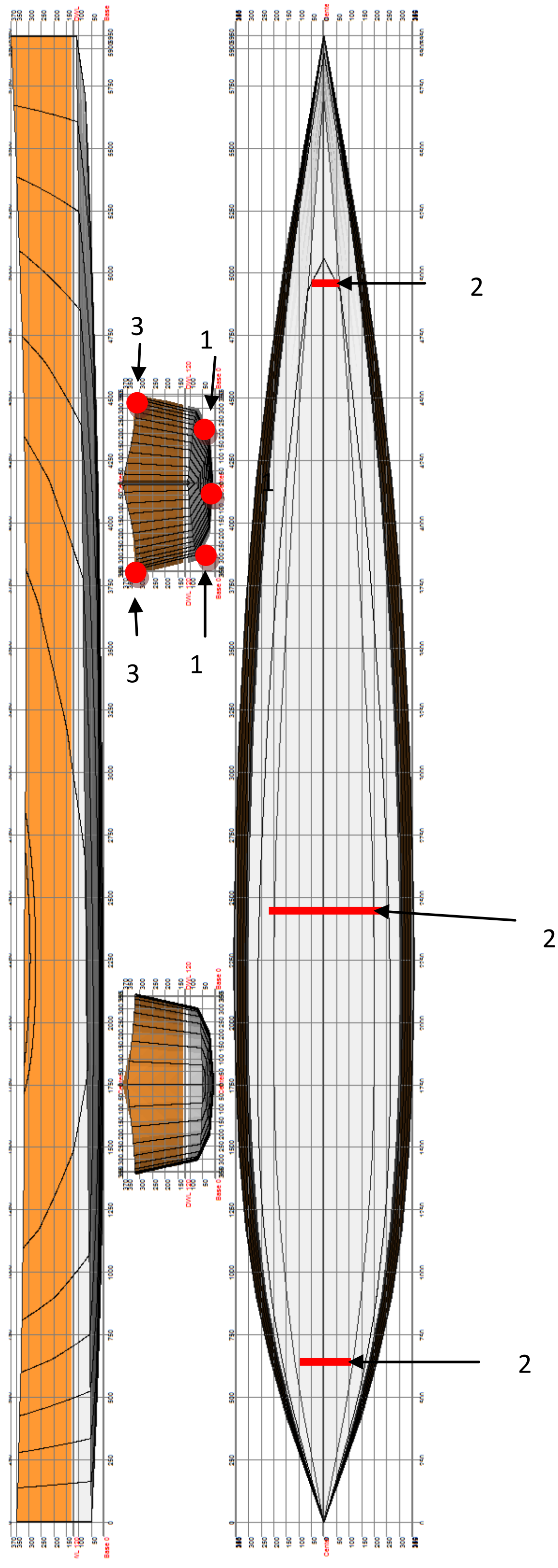


Figure 2.15: Blueprint of CT2011

Part 3

It's all in the mix(ture)

The third pillar for success in concrete canoeing is developing an optimal concrete mixture. During their study Civil Engineering, students acquire a broad theoretical background concerning the fascinating material concrete. This background in combination with the experiences from preceding years serve as valuable input for the composition of the mixtures. Optimizing the compositions based on the particle size distribution is the last step before entering the concrete lab. During long days in the concrete laboratory the mixtures are analysed on their workability, colour and strength. The result: the optimal mixtures to serve as binding element of the canoe.

3.1. The theory behind concrete

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).

3.1.1. 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.

3.1.2. 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.

3.1.3. 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.

3.1.4. 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.

3.1.5. 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 unfavorable 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.

3.1.6. 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.

3.1.7. 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.

3.1.8. Cracking

Concrete is a material sensitive for cracking. Generally speaking cracks develop due to:

1) Volume changes produced by the concrete itself
    a. Plastic shrinkage: caused by water evaporating from the surface of the concrete during the fresh phase. Measures against this type of shrinkage are moderate watering or covering the surface (for example with a foil).
    b. Plastic settlement: the downward (vertical) movement of the solid particles in fresh concrete. Measures are reducing the bleeding tendency and early covering to avoid evaporation.
    c. Autogenous shrinkage: the concrete's self-produced shrinkage and it is determined by the choice of constituents and the concrete mix design. The reaction between water and cement is associated with a loss in volume because the reaction product fills a lesser volume than the

reactants. The phenomenon is called chemical shrinkage and is a fundamental property of cement hydration.

d. Thermal effects: the concrete structure moves thermally, it expands during the heating phase and contracts during the subsequent cooling phase.
e. Drying shrinkage: hardened concrete surfaces exposed to dry air will gradually dry out and develop drying shrinkage. A gradual build-up of capillary stresses and negative pore pressure is the driving force behind drying shrinkage, just as it is for plastic shrinkage, but the drying is now taking place in a stiff material. Drying shrinkage consists of a reversible and an irreversible component.

2) Degradation
3) Loads (own weight, working load, etc.)

The volume changes and cracking tendency may be strongly influenced by the concrete constituents and their volume proportions. Therefore it is important to keep these cracking mechanisms in mind when composing a concrete mixture. The reinforcement is considered to prevent cracking as a result from the loads.

3.2. Composition of the mixtures

In this section the concrete mixtures 2011 (CM2011) are composed. For the composition of a mixture is it important to know what kind of concrete you are looking for. Based on the objective the ingredients of the mixture can be determined. The second step is to proportion the materials, this is done based on the particle size distribution.

In addition to our own (basic) knowledge concerning concrete and the experiences from preceding years, a workshop was organised at the ENCI to develop the new mixture.

3.2.1. The Objective

The objective concerning the concrete mixture is to develop a impermeable lightweight and sustainable concrete that can cope with the forces acting on it. Additional, we want the concrete with three colours, red, white and blue like the Dutch flag.

Colour:
To promote the Netherlands during the race in Germany, the objective is to develop three different colours which are close to the colours of the Dutch flag. To obtain the best colours a white mixture as basis is necessary. The 2010 mixture was a white mixture, to obtain the colours this mixture was the basis.

Permeability:
The easiest way to make the canoes watertight is to use a coating (paint, varnish, etc.). But since we want to show the material itself, concrete in three different colours, painting is not an option. Thereby we don’t want to use any other type of coating (like varnish). With a little more effort during the development of the concrete, it is possible to develop a concrete mixture that is watertight itself. Since our walls are just 5mm thick, it is important to keep the influence of the ingredients on the permeability in mind.

Density:
The lower the density of the concrete, the lighter the canoe will become. The lighter the canoe, the faster the top speed is reached, the easier the canoes can be carried and the smaller the change of cracking as result of its own weight. Enough reason to reduce the density of the concrete were possible. The density of the concrete is largely determined by the aggregate. A use of lightweight aggregates seems to be necessary. Since the density of the 2010 concrete was 1203 kg/m^3 the objective is to decrease this, if possible below 1000 kg/m^3.

Sustainability:
Over the last years the environment is getting a more and more important issue. This environmental awareness can be noticed in the concrete industry as well. Although our canoes require small amounts of concrete and are used for just one year, there is no direct need to develop a sustainable concrete. Despite that we would like to contribute to a healthier world. Thereby concrete has an unjust negative image concerning its environmental impact. Therefore we want to develop a sustainable concrete.

Develop a sustainable concrete is a combination of three phases. During the developing phase one can chose renewable/recycled materials and/or chose local materials. For the second phase it is important that the concrete has a high quality and is durable. The longer the concrete stays in good condition (no cracks or other degradation) the longer the lifespan and the smaller the environmental impact. The third phase is the recycling phase. In case the concrete can be reused (road filling or as aggregate in new concrete) in case a construction is broken down, it is more sustainable than in case it is considered as waste.

3.2.2. Ingredients

The first step in composing the mixture is to select the materials. Since every material has its specific characteristics and contribution to the mixture, this chapter highlights the materials used in our canoes.

Cement:

The Heidelberg Cement Group provided us with three types of cement, being:

- CEM I 52.5R LA – White
- CEM I 42.5N Waterproof white
- CEM I 52.5 TX (TIO CEM)

All three cements are white and will provide enough strength. Thereby the addition 'LA' is indicating that it has a Low Alkali content. This means that the cement has a limited alkali content. This low alkali content has a positive influence on the durability of the concrete since it reduces the occurrence of AAR. The waterproof cement should lead to less water absorption of the concrete and thereby save weight when the canoes are in the water. In case walls would be incredibly smooth it might even result in less resistance. To take care of the environment this year we chose to use TioCem, this cement is self cleaning and de-polluting. Because of the addition of TiO_2 in the cement, together with the sun a chemical self cleaning reaction will start. The TiO_2 also starts a reaction with lots of pollutions in the air (NOx SOx CO NH_3) the pollutions will bind to the TiO_2 and the air will be cleaner around the concrete object. This is not only good for the environment but also for our paddlers, who will have the cleanest air of the field.

Aggregates:

Aggregates are the bearing material in concrete. It has an important influence on the concrete properties, both in the fresh- and hardened state. Aggregates can be distinguished in grain size. Sieve curves determine how much aggregate from each grain size is needed. The aim is a perfect fit for small and bigger grain sizes, such that there is no space left for air. Other important factors to keep in mind when selecting an aggregate are the particle shape and water absorption.
Our aim is to make the canoes as light as possible, therefore we keep the walls as thin as possible (< 5 mm). To keep the workability we need small grain sizes, no bigger than 1 mm. As lightweight aggregate the LIAS Benelux Company provided us expanded glass, called Liaver 0.1-0.3, Liaver 0.25-0.5 and Liaver 0.5-1.0. Some specifications of the materials are shown in table 3.4 and the sieve curves are shown in Appendix C.

Type	Particle density	Particle strength	Water absorption
Liaver 0.1-0.3	800 ± 15% kg/m^3	> 3.5 N/mm^2	1.5 mass%
Liaver 0.25-0.5	540 ± 10% kg/m^3	> 2.9 N/mm^2	3.0 mass%
Liaver 0.5-1.0	450 ± 10% kg/m^3	> 2.6 N/mm^2	4.0 mass%

Table 3.5: Specifications of the used Liaver [Source: Datenblatt Liaver, 2010]

Admixtures:

Admixtures are parts of the concrete composition (<5 mass%), who achieve a significant modification in the properties of the cement paste and/or the concrete. In our concrete four types of admixtures are used: air entraining admixture, encapsuled air, retarding admixture and pigments. Since the workability of our mix design is good, no (super)plasticizers are used.

Air entraining

Air entraining admixtures form very small and evenly distributed air bubbles (voids) in the concrete. Air entraining admixtures are mainly added to improve the frost resistance of the concrete. Use of air entrainers also leads to improved concrete workability due to the 'ball bearing effect' of the air bubbles.
Notice that the small entrained voids/pores do not easily fill with water even when the concrete is saturated. They are too big for capillary suction, so entrained air voids do not suck water. This contributes to a low

permeability of the concrete and slightly reduces weight. Air bubbles that are entrapped during the mixing process however are much bigger and have a negative influence on the permeability.

Encapsuled air

Encapsuled air are small air capsules with an flexible plastic coating and have a cross section of 0.02-0.08 mm. This material also leads to a slight reduce of strength, but not as much as air entrainers. Encapsuled air also improves the workability and permeability of the concrete.

Retarding admixture

Chemical admixtures affecting the hydration of cement to produce a delay in the process of cement paste stiffening and/or rate of hydration are termed retarding admixtures. Since the casting of the canoe takes about 5 hours, it is important that the hardening of the first batches of concrete is delayed. In this way the first chemical bonds are not destroyed during the casting process.

Pigment

Our aim is to build canoes with three different colors. Therefore Scholz delivered us three different colors of pigment. Since we use white cement, the colors of the pigment are highlighted better.



Figure 3.4, 3.5 and 3.6: Three pigment colours used

In the table below the ingredients for the concrete mixtures of 2011 are listed.

Material:	Supplier:	Details:
CEM I 52.5R LA – White	CBR	-
CEM I 42.5N Waterproof white	CBR	Water repellent
CEM I 52.5 TX	CBR	Self cleaning de-polluting
Liaver 0.1-0.3	Liaver	Water absorption: 1.5 mass%
Liaver 0.25-0.5	Liaver	Water absorption: 3.0 mass%
Liaver 0.5-1.0	Liaver	Water absorption: 4.0 mass%
SikaAer Solid	Sika	Encapsuled air
White pigment (TiO_2)	Scholz	-
Red pigment (HS 130 P)	Scholz	-
Blue Pigment (G2828)	Scholz	-
Plasticizer GL51	Basf	-
Retarder	Cugla	Add 0.3% of cement weight
Air entrainer (LPS A94)	Sika	-

Table 3.1: Ingredients concrete mixtures 2011

3.2.3. Mixtures

The second step is to determine the optimal composition. During a workshop at the ENCI in Rotterdam we gained some new ideas and composed three mixtures based on the concrete mixture of 2010. Based on the new ideas/ingredients new mixtures had to be composed. In order to determine the composition the a mixdesign method of ENCI is used. The proportioning of concrete mixtures, also referred to as mix design, covers the combination of varying ingredients to produce concrete of appropriate workability, strength and durability. The composition of a good and workable concrete mix shows that the granulometric properties of the aggregates are of utmost importance as a strong relationship exists between the granulometric properties of the aggregates and the concrete properties in fresh and hardened stage. The concrete properties are strongly influenced by the particle packing of the aggregates and the therewith connected granulometric properties.

Based on the workshop at ENCI Rotterdam and the selected ingredients, several mixtures are composed. Since this is an iterative process, several series of mixtures are composed and tested. Below these mixtures are shortly explained, their exact composition can be found in appendix B.

Colour mixtures		*Adaption mixture 2010*
Mixture 1	Series 0	Replacing the white pigment for several red and blue pigments
ENCI mixture		*Increase cement amount to decrease the density with Liaver as aggregate*
Mixture 1.1	Series 1	Based on mixture 2010 and air entrainer
Mixture 1.2	Series 1	No limestone and cembinder, more cement, air antrainer
Mixture 1.3	Series 1	Less cement than 1.2
Combined mixtures		*Colourful and lightweight combined*
Mixture 2.1	Series 2	Based on mixture 1.1, retarder and pigment added
Mixture 2.2	Series 2	Based on mixture 1.2, retarder and pigment added
Mixture 2.3	Series 2	Based on mixture 1.3, retarder and pigment added
Mixture 2.2.1	Series 3	Based on mixture 2.2, less water
Mixture 2.2.2	Series 3	Based on mixture 2.2, extra air
Mixture 3	Series 4	Based on mixture 2.2.1. Ordinary cement replaced by waterproof cement
Mixture 4	Series 4	Based on mixture 2.2.1. Ordinary cement replaced by TioCem

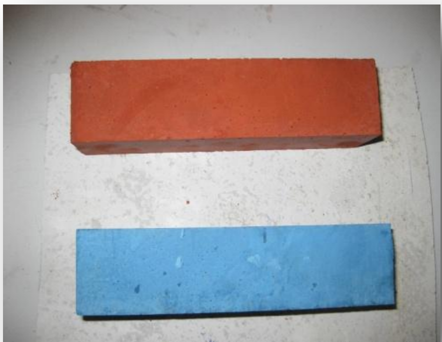
All these mixtures were tested in the concrete lab. For each mixture the amount of Super Plasticiser required to give the mixture the perfect workability characteristics, was determined. From each mixture three prisms were made, besides we filled some small plastic boxes with concrete and mesh to obtain the permeability and the workability. The prisms were tested after 28 days and based on the results (see next section), the colour the workability and the density of the mixtures the best mixture for our canoes could be determined.

3.3. Analysis

This section concerns the analysis of the test results. All mixtures mentioned above have been tested. Based on the experiences in the concrete lab new mixtures were developed, making the proportioning of the mixtures an iterative process.

3.3.1. Workability and Colour

Two important indicators were the workability and the colour. The workability could be tested at the moment of casting and the colour during demoulding (the day after casting). Meaning that feedback concerning these indicators was available fast, making it possible to adjust the proportioning in a short time span.



During the first series the colour of the mixture was the main objective, four different pigments were added to the mixture of 2010, since this was a white mixture the colours were as bright as possible. Two different red pigments and two different blue pigments were used. The colours which matched the best with the Dutch flag were chosen. The final pigments were: Red Bayferrox 110, and Blue G2828. With these mixtures as a basis ENCI was visited.

After the visit of ENCI series 2 were tested, at ENCI we obtained three new mixtures to test. The workability of these mixtures was perfect, without any addition of the plasticizer. There was one problem with the workability, it reduced quick after casting. This is not wishful since the process takes approximately 6 hours to make one canoe and 4 batches of concrete are made. This means the workability should be ok for at least 1.5 hours. To improve this, a retarding admixture was added in series 2, together with the pigments. The results of this were perfect and still all three mixtures were possible to use according to our requirements for workability and colour.

During the production of the first canoe it was obtained that the workability had to change slightly. Since no plasticizer was added, we choose to reduce the amount of water, which lowers the w/c-ratio. This results in a les permeable and stronger mixture. Mixture 2.2.1 encounters this mixture.

In mixture 2.2.2. the possibility to decrease the density while using air entrainers was explored. By this way it was possible to decrease the density below 1000 kg/m^3 but the workability decreased so much that was chosen to not use this mixture.

Figure 3.1: New concrete colours for CT2011

Finally the air entrainer added so much to the workability of the mixture that the canoes can be constructed much easier, and reduce a wall thickness. Besides this better workability allows the mesh(reinforcement mesh 4x4 mm) better to go in to te concrete. Which results in the fact that the mesh is closer to the surface on the in and outside of the walls, this contributes to a better use of the mesh since when an impact comes from out or inside the mesh will be on tension.
For the colours can be concluded that using a white mixture as basis adding pigments results in a bright colour.

3.3.2. Density

Since the addition of expanded glass in the 2009 mixture the density of the mixture decreased drastically. Since we as "BetonBrouwers" always want to improve ourselves this year the objective was to create a mixture with a density below 1000 kg/m^3. To discuss the possibilities for this we went to visit ENCI Rotterdam. The results of this workshop were clear: The strength of the 2010 mixture was around 30 N/mm^2. This strength is enough for a concrete canoe. In the 2010 mixture limestone was used as a filler, the particle sieve distribution of limestone is similar to cement but doesn't contribute to the strength. Since limestone has nearly the same density as cement, this could be replaced for cement which results in a much stronger mixture. Since this strength is not needed it can be lowered by increasing the amount of air bubbles in the mixture. Since air has no weight a contribution of air will lower the density of the concrete. The air bubbles will be created with an air entraining admixture. The sieve distribution of the air bubbles is the same as from the cembinder in the 2010 mixture. Remove the cembinder out of the mixture will reduce the density as well.

The workshop at ENCI resulted in three new mixtures from which the final mixture was developed. Mixture 1.1 is similar to the 2010 mixture with air entrainer, mixture 1.2 and 1.3 are the mixtures without limestone and cembinder and with extra cement.

These mixtures were made and tested on density.(for mixtures see appendix 1) According to the different mix designs the density of these mixtures should differ between 1115 kg/m^3 and 943 kg/m^3. Since these densities depend on the content of air bubbles the use of air entraining admixture is really important. The densities measured were far above 1000 kg/m^3. Explanation for this is that the amount of entrainer was too low.

To explore the possibilities of a density below 1000 kg/m^3 mixture 2.2.2 was made. During the casting a cup of concrete was calibrated with a cup of water, air entraining admixture was added till the density was equal to the water density. The result was a mixture with a really low density but also a bad workability.

The goal to decrease the density of the mixture drastically without losing properties as good workability and strength seems to need extra attention. Especially while using fine aggregates (< 1 mm) it is hard to create a mixture with a strength around 30 N/mm^2. Since the lack of time to develop this, our knowledge will be used next year to create lighter mixtures with a comparable strength.

3.3.3. Strength

Because of the workability and the colour, several mixtures were not applicable for our canoes. Therefore only the remaining suitable mixtures are tested concerning their strength. Since the equipment at our University was not working as a result of missing parts and is not really made for testing flexural strength, the testing took place at the laboratory of Rokramix Enschede. The flexural strength was tested with a 3 point bending test. With the two remaining pieces of the prisms the compressive strength was tested.

The table below shows the density of each mixture and the flexural - and the compressive strength after 28 days of curing. It concerns the averages, the exact test results can be found in appendix B.

Mixture:	Density [kg/m^3]*:	Flexural Strength [N/mm^2]:	Compressive Strength [N/mm^2]:
Mixture 1	1264	5.25	33.22
Mixture 1.1	-	-	-
Mixture 1.2	-	-	-
Mixture 1.3	-	-	-
Mixture 2.1	1396	4.75	31.29
Mixture 2.2	1276	5.20	27.82
Mixture 2.3	1270	4.85	27.94
Mixture 2.2.1	1255	5.10	28.83
Mixture 2.2.2	1000	3.03	14.36

Table 3.2: Density and average strength of the mixtures (measured).*

As can be seen in the table the mixtures all slightly differ from each other. Only mixture 2.2.2. which has a really low density really differs from the rest. The flexural and compressive strength is much lower than for the other mixtures. Concluding, when not much air entrainer is used the lightweight aggregate (Liaver) determines the strength of the mixture.

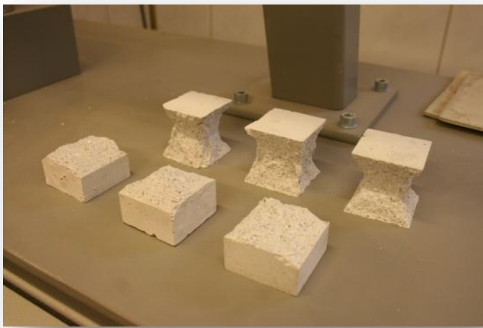


Figure 3.3: Broken test samples

In 2009 plates were produced of +/- 4mm thick containing two layers of fibreglass mesh. In order to prevent disturbance at the edges, three slabs of 450mm x 150mm x 4mm were cut from each plate. These slabs would represent the walls of the canoe and were tested on elasticity at BAS bv. These plates turned out to be very flexible and therefore fulfil our requirements abundantly.

Since it requires a lot of effort and time to produce these slabs for the vast amount of mixtures this year and to test these slabs, we argued if this test was necessary again. Because the reinforcement is similar to that of last year and the concrete shows similar characteristics as that of last year, we expect that the concrete will show the same flexibility. Therefore it was decided not to put a lot of effort in testing the flexibility again.

3.3.4. Conclusion

This paragraph will draw a conclusion about the design of the concrete mixture. Our four main requirements were: Colour, Workability, Density and Strength. With an overall requirement that the concrete should not be permeable. Out of all these requirements mixture 2.2.1 was chosen because:

The colours were good, since the basic mixture is white. Also the workability of this mixture was perfect, by adding the retarder and the air entraining admixture the concrete was usable for a long time, very sticky to the walls of the mould, and it was possible to create very thin walls, which makes it possible to create very light canoes.

Since the goal of this year was also to the decrease the density of the concrete the air entraining admixture was added. This resulted in a theoretical density of 1018 kg/m^3, since air entrainer didn't work out that good this theoretical density was not reached with this amount of entrainer. Tests to get the density below 1000 kg/m^3 resulted in a mixture with a very low strength and bad workability.

The strength of the mixture is ok to our requirements 28.83 N/mm^2, since we approximately need 30 N/mm^3 the really light mixture had a lower strength than estimated, it was only 14.36 N/mm^2 this was another reason why this mixture was not suitable to use for our canoes.

Since the workability was so much better than previous years, the colours were good, the density quite good, and the strength just ok for the requirements. Mixture 2.2.1 was chosen as mixture. The actual density is 1255 kg/m^3.

Mixture 2.2.1:

Material:	Mass [kg]	Volume [dm^3]
CEM I 52.5R LA White / CEM I 42.5N Waterproof White CEM I 52,5 TX	550.3	179.3
Liaver 0.1-0.3	121.1	201.8
Liaver 0.25-0.5	53.0	98.2
Liaver 0.5-1.0	50.0	111.2
SikaAer	8.0	40.0
Pigment	27.5	7.0
Water	206.7	210.2
GL 51	0.0	0.0
Retarder	1.7	1.7
LPS A94	0.7	0.7
Air	0.0	150.0
Total:	**1018.5**	**1000.0**

Additional information:	
Glenium 51:	1.3kg/m^3
w/c ratio:	0.38
w/b ratio:	0.38
w/p ratio:	0.36
Pigment:	5% cem. mass
Natural air:	2%
Entrained air:	13%

Table 3.3: Mixture 2.2.1

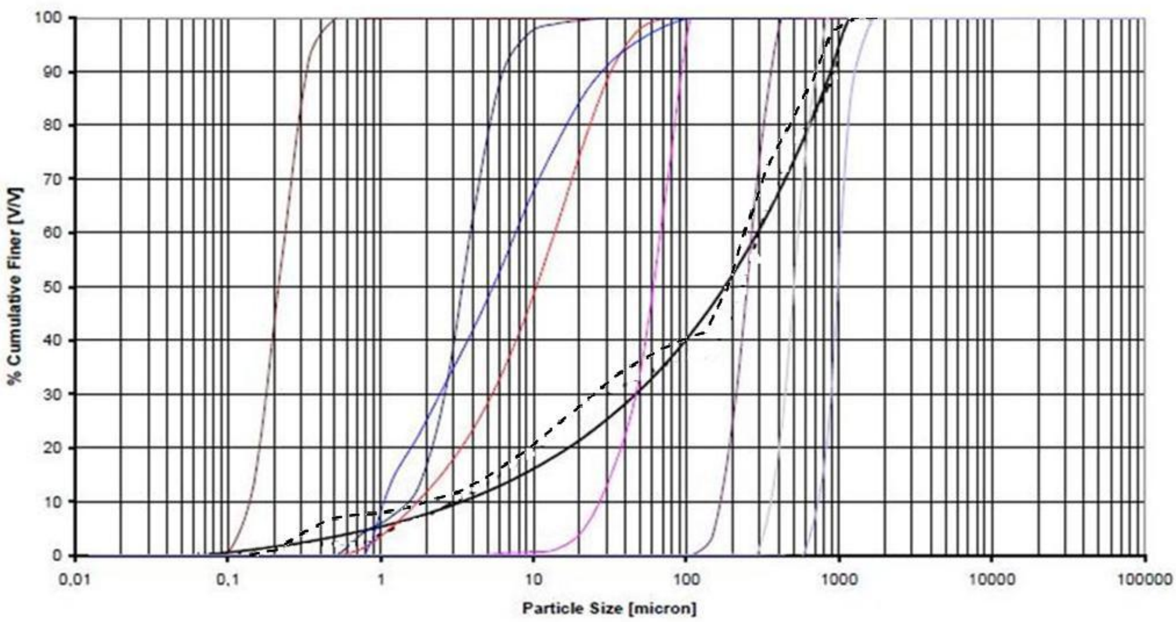


Figure 3.4: Particle Size Distribution of mixture 2.2.1

3.4. Three color ConcepT

In the past years the color of the canoes was even. In 2010 the canoes were white. This white cement looked really nice, but for this year we wanted to take it a step further. We wanted to have a three color canoe. The canoe has the colors of the Dutch flag: red, white and blue. See figure Xc1. The colors are equally distributed on the canoe, ***also on the bottom*** of the canoe. Figure Xc1 does not show that, it shows the waterline of the canoe (grey). So everything above this grey line is visible when the canoe is in the water and the canoe has a water displacement of 220 kilogram. If the displacement is less, the waterline will be lower and more of the canoe and its colors will be visible.

Since the canoe cannot be painted, a solution had to be made to make give the canoe different colors. One can imagine that when the different colors are applied, the concrete will mix and the lines where the color transition is are blurred. To fix this problem, lines are made in the canoe at the places where the color transitions had to be. These lines are made with a steel cable that is taped on the mould. Since the concrete is poured against these lines, are very straight line is accomplished. At the spots of the steel cable, there is no concrete. To prevent the canoe from breaking, this cable is very thin and only the outside layer of concrete has a dent. Inside in the canoe the whole canoe is filled with white concrete and has an equal surface. The concrete and mesh provides the necessary strength at the places of the dent. It depends on the forces whether the outside of the wall of the canoe has tensile or compressive forces. With the more extreme stresses, tensile forces are present in the outside of the wall. Because concrete is very bad in handling tensile forces, it is no problem that there is a bit less concrete since the mesh will take the tensile forces. When the canoe is in the water, the outside wall in the bottom on the middle of the canoe will have compressive forces. These forces are low and are working in one direction, and the dents are distributed diagonally across the canoe. So the concrete at the place of the dent together with the surrounding concrete will be able to handle these compressive forces.

With this technique, that asks for accuracy and carefulness when pouring, unique canoes are created that have three colors of concrete at the outside (red/white/blue) and one color (white) at the inside.

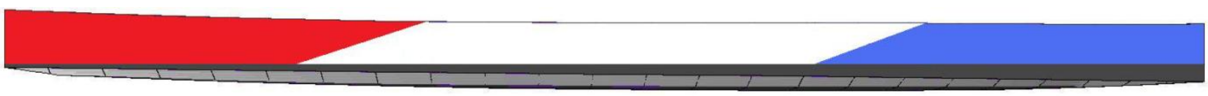


Figure 3.3: the colors of the canoe with the bow of the canoe on the right

3.5. Highlighting reinforcement materials

In this section we will highlight the reinforcement materials used in the concrete.

3.5.1 Reinforcement materials

To provide strength, stiffness and stability in our canoes, we reinforced them with steel and stucco-mesh.

3.5.1.1. Steel

In the length of the canoe we use pre-stretched steel cords. This is to provide the stiffness of our concrete. The two types of steel cords are:

- Steel cord 0.59+6x0.52, Ø4.4mm^2, F_{max} = 5160N
- Steel cord 0.66+6x0.59, Ø5.0mm^2, F_{max} = 7560N

The two upper steel cords are inside plastic tubes, which are placed in the edges of the canoe. In the front- and back end the steel cords are connected and stretched with an iron anchor plate.

3.5.1.2. Mesh

The canoe is reinforced with glass fiber reinforcement fabric. This 5x5 mm stucco-mesh fabric catches the tensions in the concrete. Glass fiber is a relatively light material: the weight is 75 gram per square meter. In order to test the tensile strength of the material we did several tests at the university laboratory (thanks to Dr. Vitaly Koissin).

To test the tensile strength we used strips from the mesh fabric as specimens, as visible in figure 3.7. These strips were placed one by one in special measurement equipment (figure 3.8).

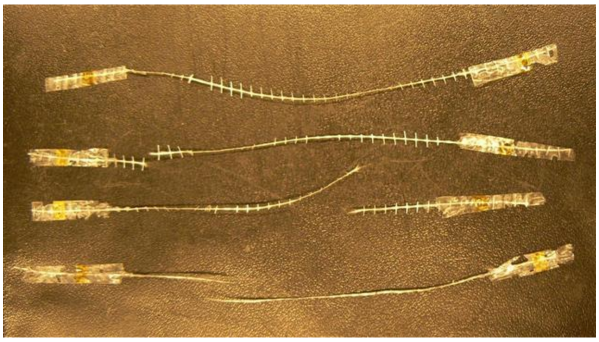


Figure 3.7: Specimens of mesh fabric

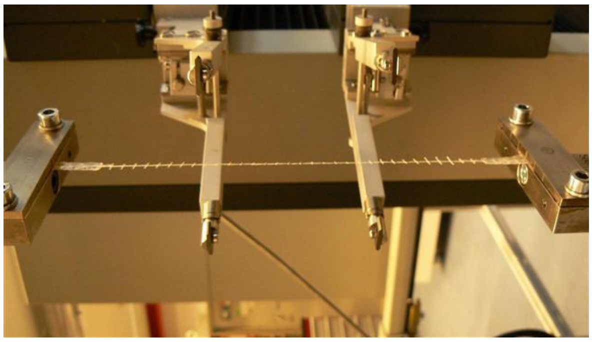


Figure 3.8: Testing the specimens

We tested eleven specimens. At the first three specimens the cross wires were removed (the lowest specimen in figure 3.7). The results are shown in figure C4 and table C1 in Appendix C. The three specimens without the cross wires do have significant lower tensile strengths.
To determine the tensile strength, we calculate the mean and standard deviation of the eight specimens with cross wires.

$$\bar{F}_{0.2\%} = 68.9N$$
$$S(F) = 6.9N$$

In order to test the quality of the material it is possible to calculate the tensile strength in MPa. Therefore we have to know the surface of the cross section of the material. In figure 3.9 the cross section of one specimen is visible. The surface per wire is about 12 microns (figure 3.10).

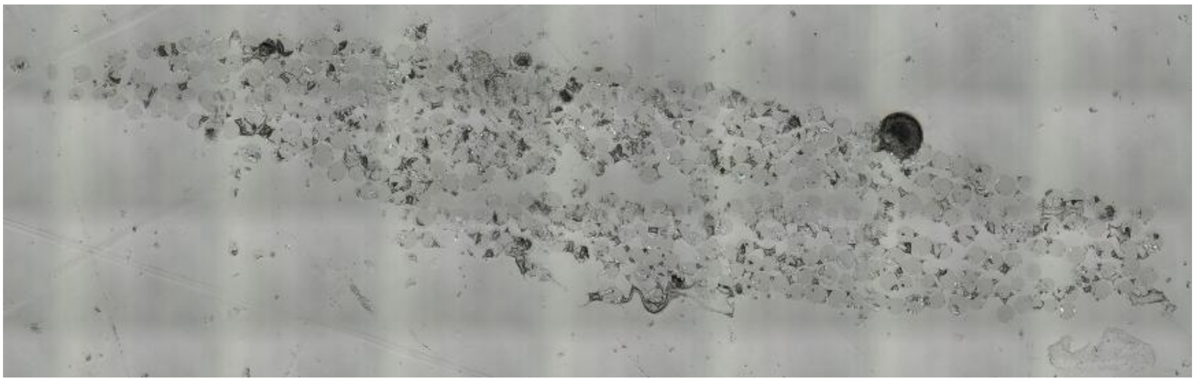


Figure 3.9: Cross section of a specimen

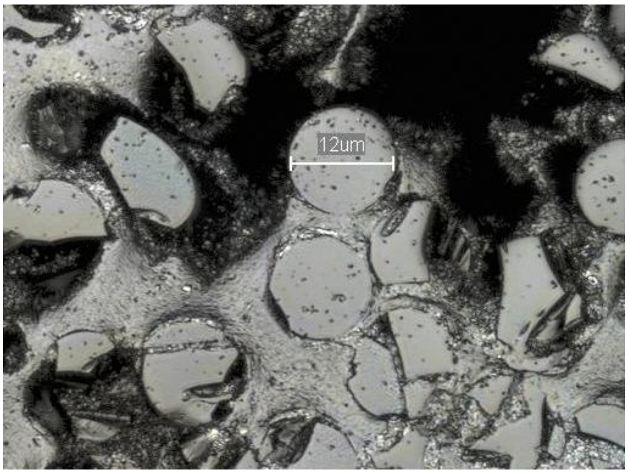


Figure 3.10: Closer look to cross section of a specimen

The total amount of wires per specimen is estimated at 360. Since the diameter of a wire is estimated at 12 microns, the surface is equal to about $360 \cdot (6 \cdot 10^{-6}\ m)^2 \cdot \pi = 40 \cdot 10^{-9}\ m^2$. When we divide the average tensile strength with this value, we get the tensile strength per square meter: $\frac{68.9N}{40 \cdot 10^{-9}\ m^2} = 1.7 \pm 0.2\ GPa$.

The normal tensile strength from E-glass fiber is about 2000 MPa [Azom.com] This indicates that our specimens are from a rather good quality.

3.6. Material Status

While the construction (reinforcement) and the concrete mixture are known, only the materials for the finishing touch remain. Because the canoes are not allowed to sink in case of breaking or capsizing, air chambers are needed. Therefore a big air balloon of 65 litres is used. Furthermore tubes are placed on the edges for aesthetics and safety (prevents scratches from sharp edges). Finally the name, sponsors and number are painted on the walls. In the table below (table 3.5) the material status of our canoes is given, in this table all used materials and their specification are mentioned.

Element:	Material:	Specification:	Amount:	Total:
Lightweight Concrete	CEM I 52.5R LA - white	0,550 kg/l	50 l	8,255 kg
	Liaver 0.1-0.3	0,121 kg/l		1,816 kg
	Liaver 0.25-0.5	0,053 kg/l		0,795 kg
	Liaver 0.5-1.0	0,050 kg/l		0,750 kg
	SikaAer	0,008 kg/l		0,120 kg
	Pigment	0,028 kg/l		0,413 kg
	Water	0,206 kg/l		3,093 kg
	Gl 51	0,000 kg/l		0,000 kg
	Vertrager (0,3% cement gewicht)	0,002 kg/l		0,025 kg
	LPS A94	0,001 kg/l		0,011 kg
Reinforcement	Steel cord 0.59+6x0.52 Ø=4.40 mm^2 MBL=5016N	1140 N/mm^2	18m	18m
	Steel cord 0.66+6x0.59 Ø=5.0 mm^2 MBL=7560N	1540N/mm^2	12m	12m
	Stucco-Mesh	4x4mm	2 layers	13.5 m^2
	Anchor plate	250X100mm	2 pcs	2 pcs
	Anchor connection ironware	-	4 pcs	4 pcs
Air chambers	Air bags	65l	1pcs	65l
	Connection ironware	-	6 pcs	6pcs
	D shackle	-	6 pcs	6 pcs
Completion	Paint	Dark blue	1 l	1l
	Tube	-	2 pcs	12 m
	Seating foam	-	2 pcs	2 pcs

Table 3.4: Material Status Concrete Canoes

Part 4

A process description of construction year 2011

In this fourth part of the report the focus is on the process of construction year 2011. From a nice design on a computer screen to a beautiful concrete canoe requires a lot of blood, sweat and sometimes even tears. Things sometimes seem to work in theory, but practice can prove otherwise. That's why it is important to be creative, flexible and always looking for solutions. This part gives a clear insight in the construction process of our canoes and everything that comes along with it. But only building a beautiful concrete canoe doesn't guarantee victory during the race. That's why also training plays an important role in our way to success!

4.1 The workshop

The workshop is one of the important key parts of the concrete canoe building process. The BetonBrouwers use two different locations as a workshop. First, there is the general workshop, the CAD terrain. Second, we use the concrete laboratory based in one of the buildings of the University of Twente. The main reason that we use two locations instead of one, is that the development and testing of the mixture requires instruments of a smaller scale than the actual building of the concrete canoes. Thus, we use a more specialized location to develop and test the mixtures.

The concrete laboratory basically is a laboratory with all kinds of (specialized) tools used for mixing and measuring concrete mixtures. These tools are used to make the multiple test mixtures, which determine the final mixture.

The CAD terrain, our main workshop, is used for the actual casting of the canoes. It basically is a big hangar with all the tools needed to cast a high quality canoe. Within the hangar, a construction (consisting of a frame with the canoe mold on it) is present, in which we construct the actual canoes. By using a contraption with spanners and pulleys, the reinforcement is pre-stressed. The CAD terrain is also used as a storage for the finished canoes, building materials and tools. During the winter period, an isolated and heated part of the CAD terrain is used to construct the canoes. This is done to prevent frost damage to the freshly casted concrete. This isolated part is a smaller part of the CAD terrain hangar and thus provides less workspace. That is why we also use the hangar (bigger, but less sheltered against the weather) to cast our canoes during non-frost periods.

The CAD terrain is furnished for efficiency. All aspects are placed so that the work on the canoes can be done without obstructions. The setting is created so that the work on the canoes is carried out as fluently as possible. Each part of the process has its own space within the CAD terrain.

4.2 Building the new mould

After the victories our last design brought us we thought it was time to improve the design even further. With the knowledge of previous years, our head of design worked on a new design for a new canoe. After many hours of work the perfect design was obtained. Now the new design finished we could start thinking about the new mould.

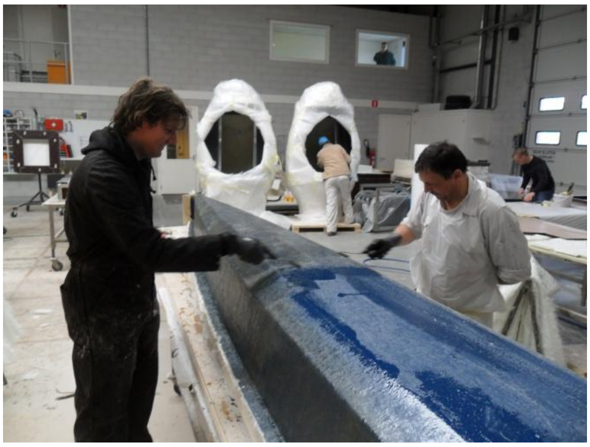
The last time we had to build a mould we used wood to do this. A lot of the building we had to do ourselves and this had the problem that little inaccuracies were made. This resulted in small bumps in the mould and eventually the canoes. Our goal was to prevent this from happening in the new mould. The easiest way to prevent this was to get a specialized company to build or mould, but unfortunately this was too expensive. This meant that we still had to do a lot of the work ourselves.

After a few brainstorming sessions the plan for making the new mould was finished. Instead of wood we used foam to make the model. Out of foam plates a milling company cut 60 sections with a width of 10 centimeters each. All these sections were then placed on a metal bar and attached to each other with two component glue. As expected the glue led to an increase of the canoe length which meant the canoe would exceed the permitted length of six meters. Because of this we decided to cut one of the layers in half so that the model would be less than six meters long. Now all the sections were stuck to each other the shaping of the canoe could start. To prevent small inaccuracies pieces of sandpaper were taped on long beams of timber. This way it was impossible to sandpaper only a small part of the model. To get a smooth surface different fractions of sandpaper were used.

The next step in the process was brushing a liquid filler on the model. The filler was put on the model so that later on the model wouldn't suck up all the polyester filler which needed to be on the outside of the model. This polyester filler was also used to fill any gaps between two sections. In total 8 liters of liquid filler and 1,5 liters of polyester filler were used. All the work that we could do in our own workshop till than was finished and it was time to put the model in the trailer of a glider and transport it to Beek and Donk. Beek and Donk is a place in Noord-Brabant were Ascom polyester is located. This is the same company that helped us build the mould in 2009 and the offered to help us again this year.

In total we worked three days in Beek and Donk to finish the mould. The first day consisted mostly out of sandpapering the model. Because the polyester layer was put on the model all of the sandpapering had to be redone. This was done with three different fractions, 80, 120 and 240. Before switching to a smaller fraction a special powder was put on the model. The function of the powder was to indicate on which places there were dents. This way we knew were to sandpaper a bit more. If the dents were too big putty was used to close the gaps. On the end of the day the model was as smooth as a baby buttocks. Before returning to Enschede the model was discomposed of dust and lacquered with double coat.

After the double coat was dried the second day of hard work at Ascom polyester could start. This day the model had to be waxed. This had to be done nine times. The wax had to made sure the model could be separated from the mould easily. After the waxing was done a special gel coat was put on the model. The gel coat ensured that the mould can be used multiple times and functions as a protective layer. We also put plates made of pvc on the end of the canoe. The plates make it possible to make the mould so that both sides can be opened separately.



The last day at Ascom polyester meant we finaly could start working on the mould. The model was first covered with polyester resin and then with fiberglass. This procedure was repeated four times. After this the resin had dried the edges of the mould were sawn off en the offside of the mould was sandpapered. This was done so that later on nobody could cut his hands on any fiberglass that was still on the outside of the mould. After sandpapering the mould it was ready to transport back to Enschede. Back in Enschede the last thing that needed to be done was separate the mould from the model. After a few minutes of struggling we were able to get the mould loose, unfortunately this also meant the end of the model because it broke in half.

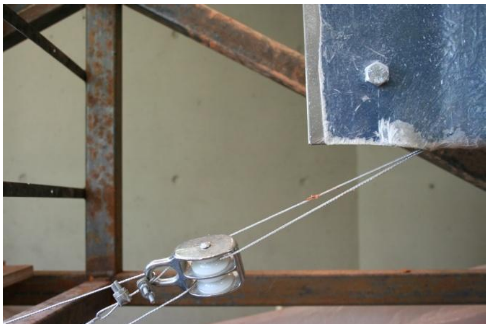
4.3 Construction of the canoes

Above it is explained how the new mould is constructed. 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:

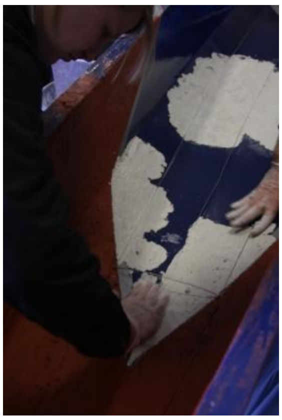
- Adequate formwork quality
- Concrete workability
- Casting technique
- Curing conditions

Throughout the description of the casting process below, these points can be recognized.

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 alignments in the mould. The alignments will be the borders between the different colours of concrete, as we want a red-white-blue canoe. 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 three cords in cross direction were placed. These cords are intended to make the cracks in the longitudinal direction smaller or even disappear. 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. This for obvious reasons.

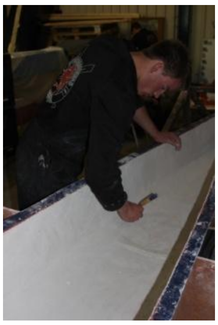

When we got the mould in the condition of a greased surface and ungreased cords it's time for casting. This means that all materials can be weighted in the right proportions and the mixture can be made. First the dry materials are put into the mixer. We use a batch mixer, type forced action mixer, whereby 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 – and eventually the last layer of concrete. This process will go step by step starting in the front and working towards the back 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. Extra focus is needed for the three different colours of the concrete, which at the outside of the canoes (the first layer) may not mix.



As told earlier 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. While working from front to the back three ribs were created at the location where the cords in cross direction are located. After reaching the back of the canoe the cords could 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. This was done by wrap the concrete with paper and spray this paper wet. Finally a foil was put over the mould sealing the canoe. During wrapping the canoe with paper some delicious snacks were fried. Meaning that after the work was done everybody could enjoy a cold Grolsch beer and the snacks from our very own Fry King.


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 meanwhile it is important that the canoe is cured properly. Meaning that the canoe is covered in foil and once in a while is sprayed with water.



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 to, these air chambers consist of large balloons. Now the canoes themselves are finished and ready for the battle. But, we are not finished yet. There are still some things that have to be taken care of. The first thing is that is under construction at the moment is a fourth canoe bearer. In these bearers the canoes can be transported and stored safely and on site we can carry them easily without damaging them. The second thing that we want to construct are some foam seat for the canoeists to sit on and to distribute the forces of the canoeists more equally towards the bottom.

4.4 Training the body and improving the canoeing skills

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".

5.3.1 Cold season

During the winter period (i.e. short days, cold weather) training on the Twente canal is not possible (prohibited). That is why the training for the BKR is relocated to the indoor swimming pool on the University of Twente campus. During this period, a lot of attention goes to pedaling technique and cardio. The training consists of three separate parts: pedaling, swimming and fitness exercises. This mixture of different elements of training makes the cold season a very effective training season.


BetonBrouwers training in the indoor swimming pool

5.3.2 Warm 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 accelerate. To get used to the feeling of the concrete canoe, our top canoe of season 2009, 'Das Phantom', was transported to the water sports complex. This gave us the possibility to train in a concrete canoe preceding on the races in Eindhoven.
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 behavior 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).

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 harbor. During a normal training, a distance of about 7 kilometers is coffered. "Normal pedaling" is alternated with short sprints (200-400 meters) and tight turns, to simulate the race elements of the BKR. Also, the pedaling technique is trained during the outside training, so that the feeling for the behavior 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.

Training on the Twente canal, reaching the harbour Enschede

Part 5

Constructing the lightest concrete canoe

Every year we try to make our canoes as light as possible. Therefore we create thin walls and use lightweight concrete. Nevertheless we never won the price for the lightest canoe. This season the BetonBrouwers will appear with a light canoe with some smart theoretical background.

5.1. Objective

Our objective is to create a concrete canoe which is light as possible, and which meets the minimum requirements to participate at the concrete canoe race.

The requirements are:

- The canoe must be at least 4 meters long
- The canoe must be at least 40 cm wide
- The canoe must reach the finish line in one of the races
    - 2 persons of 70 kg must fit inside
    - It needs to survive a distance of 100 m.

Besides, it needs to be as light a possible, since the record of Eindhoven is 13 kg, our goal is to decrease this weight and set a new record.

5.2. Design

An ultimate light canoe starts with a good design. To obtain a light canoe, the amount of concrete used should be reduced. This can take place in two ways. First of all the walls can be made as thin as possible, secondly the surface area of the canoe should be minimized.

5.2.1. Thin walls

In order to create as thin walls as possible the shape of the mould should be really simple. When minimizing edges and complicated forms the mesh (our reinforcement) can be placed very easily without any crops. This will result in optimal thickness of the walls.

5.2.2. Minimizing the surface area

The sphere has the smallest surface area among all surfaces enclosing a given volume and it encloses the largest volume among all closed surfaces with a given surface area. (Wikipedia, 2011)

With this principle in mind the BetonBrouwers started to think about a suitable shape for the canoe. A sphere has for its volume the smallest surface area. Subject to our constraints (length >4m and width >40 cm) the sphere is not an optimal shape. Fact is that a round surface can be useful.
After the sphere a cylinder has the largest volume for the surface area. Since a half cylinder can meet our requirements the choice fell for a half cylinder.

Before searching for useful moulds first a design which should work should be made. Since the minimum width of the canoe is 40 cm and the minimum length is 4 meters. Three options were compared, as visible in table 5.1

Option	Buoyancy [kg]	Surface area [m^2]	Concrete use [l] 3 mm thick walls
Half cylinder ø 400 mm	251	2.64	7.9
Half cylinder ø 500 mm	393	3.33	10
Half cylinder ø 500 mm with plate in bottom (see figure 5.1)	350	3.21	9.65

Table 5.1: Possible mould options

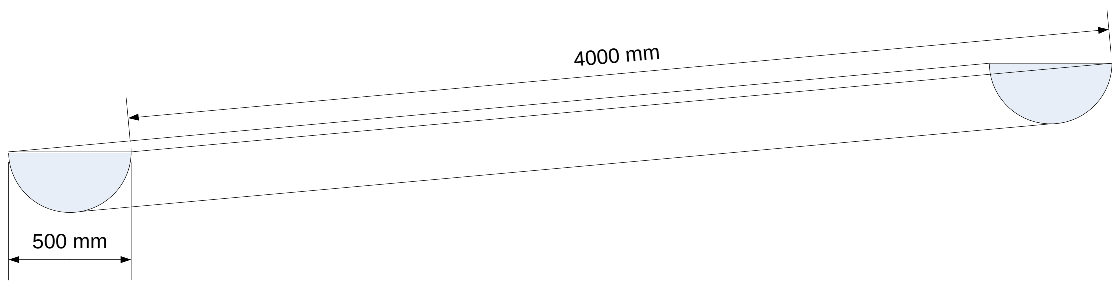


Figure 5.1: Half cylinder ø 500 mm

These options depend on the possibilities for the mould. With these options in mind we started to search for the possibilities for a mould.

5.2.3. How to get a mould

Since making a mould for concrete canoes usually is the most expensive and time consuming part of the process a cheap and easy mold for the canoe was necessary. Long half cylinders are quite often used as pvc drainage pipes. On several fairs for building companies we contacted pvc pipe suppliers with the question for a 4 meter long pvc pipe with a diameter of around 40 cm. We found a company that could deliver us a pvc pipe of 50 cm, which was rejected for its regular use. Since the inner diameter was 48 cm, and we were not sure about the stability we saw the pipe in two parts and closed the ends with wooden plates (see figure 5.2). This mould was then used as canoe in the swimming pool to test the stability (see figure 5.3).

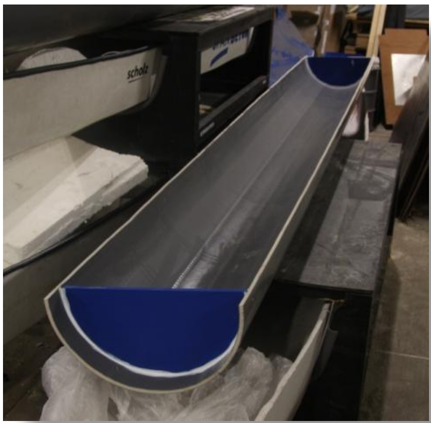


Figure 5.2: The mould

Figure 5.3: Testing the mould in the university swimming pool

Results of this test were the following:

- The stability was sufficient
- The place of the people in the canoe is really important, to keep the center of gravity in the middle of the canoe and prevent it from water coming in
- Reducing the weight by putting a plate in the bottom of the mould will result in a canoe which has not enough buoyancy for our requirements

After this the construction of the lightest canoe could start. But how could we fulfill our requirements for stiffness and strength?

5.3. Construction

The BetonBrouwers know how to perfectly use the characteristics of concrete. Since concrete can resist a lot more pressure than tension the choice fell to pre-stress this canoe. Five steel wires were used to prestress the canoe: three at the bottom and two in the top. Beside that we used two layers of our regular mesh, with a grid of 4x4 mm. To make sure these layers of mesh are placed at the very inside and the very outside of the wall, first a layer of mesh was placed in the mould and the concrete was casted on top of this layer. Then the steel wires were put in the mould and then the last layer of mesh was pushed in the concrete.

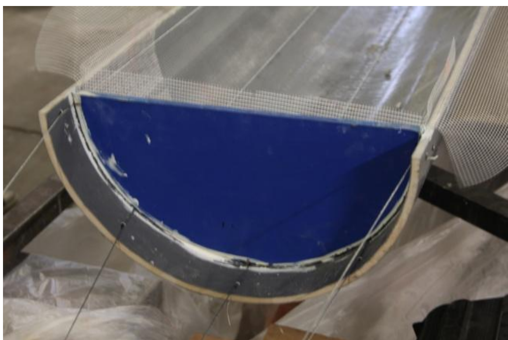


Figure 5.4 and 5.5:Reinforcement details

Just after casting, 2 tons of tension was put on the five cables to obtain enough pressure on the concrete. Finally the following materials were used for the concrete (table 5.2):

Element:	Material:	Specification:	Amount:	Total:
Lightweight Concrete	CEM I 52.5R LA - white	0,550 kg/l	15 l	8,255 kg
	Liaver 0.1-0.3	0,121 kg/l		1,816 kg
	Liaver 0.25-0.5	0,053 kg/l		0,795 kg
	Liaver 0.5-1.0	0,050 kg/l		0,750 kg
	SikaAer	0,008 kg/l		0,120 kg
	Pigment	0,028 kg/l		0,413 kg
	Water	0,206 kg/l		3,093 kg
	Gl 51	0,000 kg/l		0,000 kg
	Vertrager (0,3% cement gewicht)	0,002 kg/l		0,025 kg
	LPS A94	0,001 kg/l		0,011 kg
Reinforcement	Steel cord 0.59+6x0.52 Ø=4.40 mm^2 MBL=5016N	1140 N/mm^2	20m	20m
	Stucco-Mesh	4x4mm	2 layers	6.4 m^2
Floating device	Floating concrete block	prism	1 pc	1 pc
	Rope	white	6 m	6 m
Completion	Paint	Dark blue	0,25 l	0,25l
	Seating foam	-	2 pcs	2 pcs

Table 5.2: Used materials in the lightest canoe

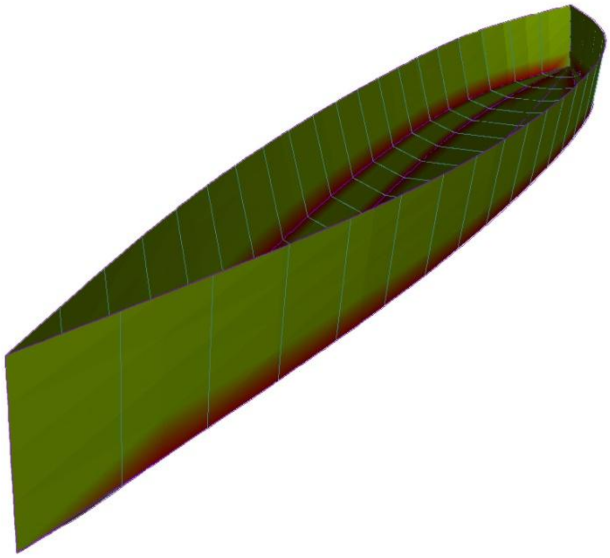
5.4. The result

When the canoe was made, of course the result must be checked. Since our goal was to make the lightest canoe ever, everybody was excited about the final weight of the canoe, the strength and the stiffness. After we weighted it we knew it, if this canoe could survive one race, (100 m) it will be the lightest ever! The weight was 11.96 kg (figures 5.6 and 5.7).

Figures 5.6 and 5.7: The result

Concluding

In the first part of this report we said that only the real diehard Civil Engineering students with a heart of concrete, loads of motivation and a lot of persistence can become a BetonBrouwer. This certainly has proven to be true. If we look back on what we have reached in the last eight months within the scarce spare time of just ten students, it is really something to be very proud of and shows the loads of motivation and dedication. So without questioning we can conclude that building concrete canoes is a very time consuming hobby, but that a lot of satisfaction can be gained. And although no study credits can be gained, it is a real addition to the standard curriculum while it provides a perfect learning environment in regard of putting theory into practice, think creative and always look for solutions.



The goal this year was to optimise the mould and the concrete mixture, with the design of 2010 as basis. A completely new mould has been designed and build. Besides that, implementing three colours of concrete in one canoe has put ourselves for a challenge. Though as a team we were able to deal with this. Also the experiment of designing and constructing a very light weight canoe was achieved.

During the Concrete Canoe Challenge we will know if the new design performs better than that of the two previous years. At least the walls are smoother, the canoes are lighter and the paddlers are better trained than before. It is a very satisfying thought that when we look at the canoe, we can say that everything from the design until the mould and from the first batch of concrete until the finishing touch is done by ourselves. No matter if it becomes a great success or a big failure, it absolutely was a wonderful project to work on! But of course we hope to put a crown on our work with some heroic and memorable victories and return with some nice Cups to Enschede.

Finally we want to outline that it was real fun and instructive but also very time consuming to write this construction report. Hopefully it will contribute to the precious construction price and provide a clear view on how our canoes have been constructed. We hope you have enjoyed reading this construction report.

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Appendices

Background information

In this section of the report you will find the appendices. These appendices provide some background information for the people interested. First of all the contact information of Study Association ConcepT, the Chairman and the Event Manager of the committee is given. In the second appendix the background information behind the concrete mixtures is given. Third some extra information about highlighted materials will be given.

Appendix A: Contact Information

In this appendix the contact information is provided of Study Association ConcepT, our Chairman (and team captain), Chiel de Wit, and Event Manager Frank Aarns.

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Appendix B : In search of the optimal Mixture

This appendix contains more detailed information concerning the different mixtures that have been composed and tested. First the composition of all mixtures is shown, after which the test results are given.

Compositions:

Mixture 1

Material:	Mass [kg]	Volume [dm^3]
CEM I 52.5R LA White	400	129.9
Cembinder 8	48.2	34.4
➢ Solid content	40.1	17.2
➢ Water content	17.2	17.2
Limestone powder	296.4	111.8
Marble 0-2mm	1219.6	460.2
Red/White/Blue Pigment	20.0	5.1
$Water_{total}$	255.8	255.8
$Water_{add}$	238.6	238.6
Air		20.0
Total:	**2231.9**	**1000.0**

Additional information:	
Glenium 51:	0.3kg/m^3
w/c ratio:	0.64
w/b ratio:	0.53
w/p ratio:	0.30
Pigment:	5% cem. mass
Air:	2%

Mixture 1.1

Material:	Mass [kg]	Volume [dm^3]
CEM I 52.5R LA White	400	130
Limestone powder	250	92
Cembinder (dry part)	24	10
Liaver 0.1-0.3	114	190
Liaver 0.25-0.5	50	92
Liaver 0.5-1.0	47	105
Sika Solid air	8	40
GL 51	5	5
LPS A 94 (air entrainer)	0,5	-
Water	216	216
Air	-	120
Total:	**1115**	**1000**

Additional information:	
Glenium 51:	5
w/c ratio:	0,54
w/b ratio:	0,51
Air:	12%

Mixture 1.2

Material:	Mass [kg]	Volume [dm^3]
CEM I 52.5R LA White	550	179
Liaver 0.1-0.3	121	202
Liaver 0.25-0.5	53	98
Liaver 0.5-1.0	50	111
Sika Solid air	8	40
GL 51	4	4
LPS A 94 (air entrainer)	0,7	-
Water	214	216
Air	-	150
Total:	**1001**	**1000**

Additional information:	
Glenium 51:	4
w/c ratio:	0,39
w/b ratio:	0,39
Air:	15%

Mixture 1.3

Material:	Mass [kg]	Volume [dm^3]
CEM I 52.5R LA White	490	159
Liaver 0.1-0.3	134	223
Liaver 0.25-0.5	58	108
Liaver 0.5-1.0	55	123
Sika Solid air	8	40
GL 51	5	5
LPS A 94 (air entrainer)	0,7	-
Water	192	192
Air	-	150
Total:	**943**	**1000**

Additional information:	
Glenium 51:	5
w/c ratio:	0,39
w/b ratio:	0,39
Air:	15%

Mixture 2.1

Material:	Mass [kg]	Volume [dm^3]
CEM I 52.5R LA White	491	160
Limestone powder	224	83
Cembinder (dry part)	22	9
Liaver 0.1-0.3	108	180
Liaver 0.25-0.5	47	88
Liaver 0.5-1.0	45	99
Sika Solid air	7	36
GL 51	-	-
LPS A 94 (air entrainer)	1	1
Retarder	1	1
Pigment	25	6
Water	184	188
Air	0	150
Total	**1155**	**1000**

Additional information:	
Glenium 51:	5
w/c ratio:	0,37
w/b ratio:	0,37
Air:	15%

Mixture 2.2

Material:	Mass [kg]	Volume [dm^3]
CEM I 52.5R LA White	547	178
Liaver 0.1-0.3	120	201
Liaver 0.25-0.5	53	98
Liaver 0.5-1.0	50	110
SikaAer	8	40
Pigment	27	7
Water	213	215
GL 51	0	0
Retarder	2	2
LPS A94	1	1
Air	0.0	150
Total:	**1020.4**	**1000.0**

Additional information:	
Glenium 51:	1.3kg/m^3
w/c ratio:	0.39
w/b ratio:	0.39
w/p ratio:	0.36
Pigment:	5% cem. mass
Natural air:	2%
Entrained air:	13%

Mixture 2.3

Material:	Mass [kg]	Volume [dm^3]
CEM I 52.5R LA White	488	178
Liaver 0.1-0.3	133	201
Liaver 0.25-0.5	58	98
Liaver 0.5-1.0	55	111
Sika Solid air	8	40
GL 51	5	5
LPS A 94 (air entrainer)	0	0
Retarder	2	2
Pigment	24	6
Water	191	215
Air	-	149
Total	**959**	**1000**

Additional information:	
Glenium 51:	5
w/c ratio:	0,39
w/b ratio:	0,39
Air:	15%

Mixture 2.2.1

Material:	Mass [kg]	Volume [dm^3]
CEM I 52.5R LA White / CEM I 42.5N Waterproof White CEM I 52,5 TX	550.3	179.3
Liaver 0.1-0.3	121.1	201.8
Liaver 0.25-0.5	53.0	98.2
Liaver 0.5-1.0	50.0	111.2
SikaAer	8.0	40.0
Pigment	27.5	7.0
Water	206.7	210.2
GL 51	0.0	0.0
Retarder	1.7	1.7
LPS A94	0.7	0.7
Air	0.0	150.0
Total:	**1018.5**	**1000.0**

Additional information:	
Glenium 51:	1.3kg/m^3
w/c ratio:	0.38
w/b ratio:	0.38
w/p ratio:	0.36
Pigment:	5% cem. mass
Natural air:	2%
Entrained air:	13%

Mixture 2.2.2

Material:	Mass [kg]	Volume [dm^3]
CEM I 52.5R LA White	535	174
Liaver 0.1-0.3	118	196
Liaver 0.25-0.5	52	95
Liaver 0.5-1.0	59	108
SikaAer	8	40
Pigment	27	7
Water	200	204
GL 51	0	0
Retarder	1	1
LPS A94	4.4	4.4
Air	0.0	170.0
Total:	**994**	**1000.0**

Additional information:	
Glenium 51:	1.3kg/m^3
w/c ratio:	0.37
w/b ratio:	0.37
w/p ratio:	0.36
Pigment:	5% cem. mass
Natural air:	2%
Entrained air:	15%

Test Results

In the tables below the test results concerning the Flexural and the Compressive Strength are given for each composed mixture.

Mixture:	Prism	Density [kg/l]:	Tensile Strength [N/mm^2]:	Compressive Strength [N/mm^2]:
2.1	**1**	1,39	4,49	31,69
	2	1,42	4,70	31,00
	3	1,38	5,05	31,19
2.2	**1**	1,26	5,40	27,87
	2	1,27	5,00	28,61
	3	1,30	5,19	26,99
2.3	**1**	1,27	4,74	27,73
	2	1,27	4,55	28,15
	3	1,26	5,26	27,94
2.2.1	**1**	1,26	5,05	28,86
	2	1,25	5,11	28,76
	3	1,27	5,15	28,90
2.2.2	**1**	1,00	3,09	14,69
	2	1,00	2,72	14,66
	3	1,00	3,29	13,74

Appendix C: Highlighted materials

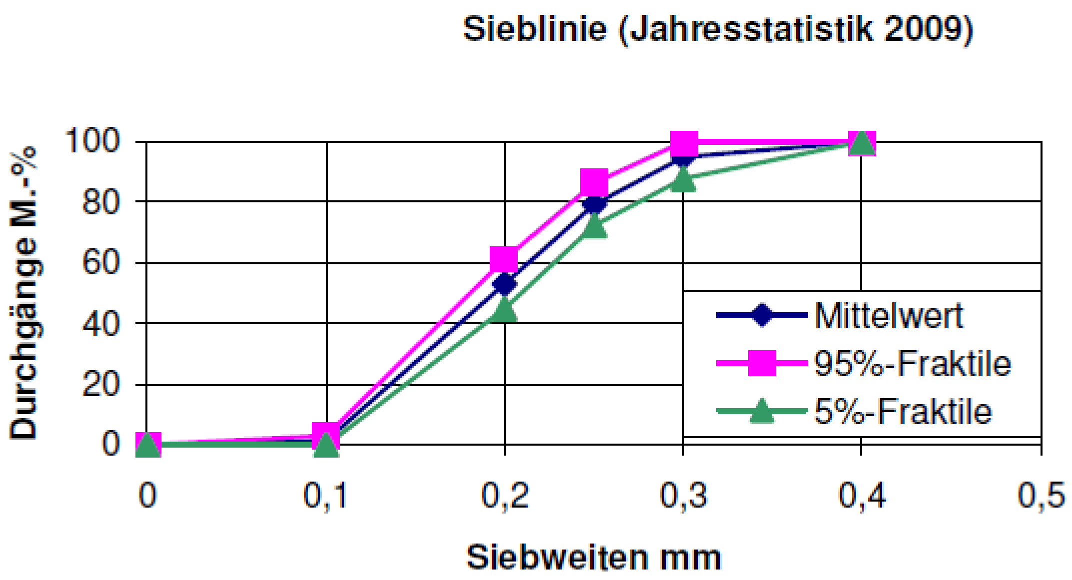

Figure C1: Sieve curve Liaver 0.1-0.3 [Source: Datenblatt Liaver, 2010]

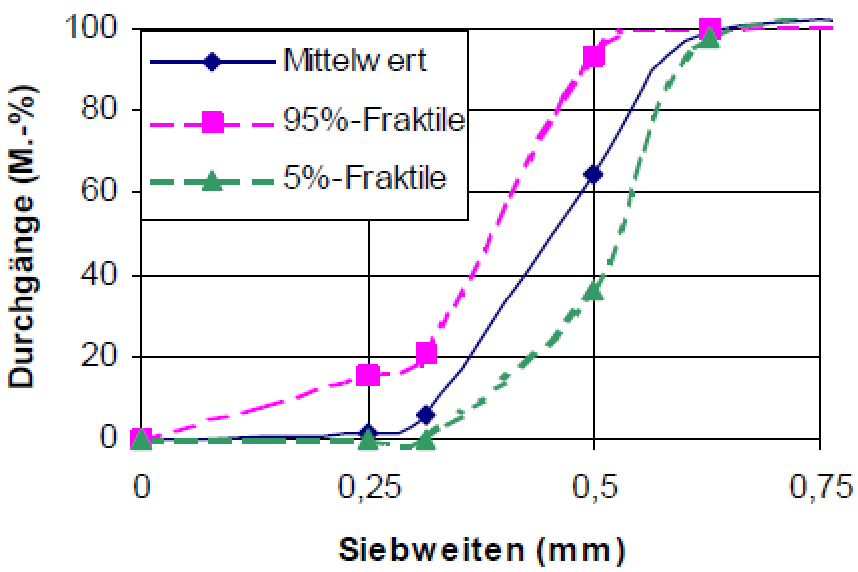

Figure C2: Sieve curve Liaver 0.25-0.5 [Source: Datenblatt Liaver, 2010]

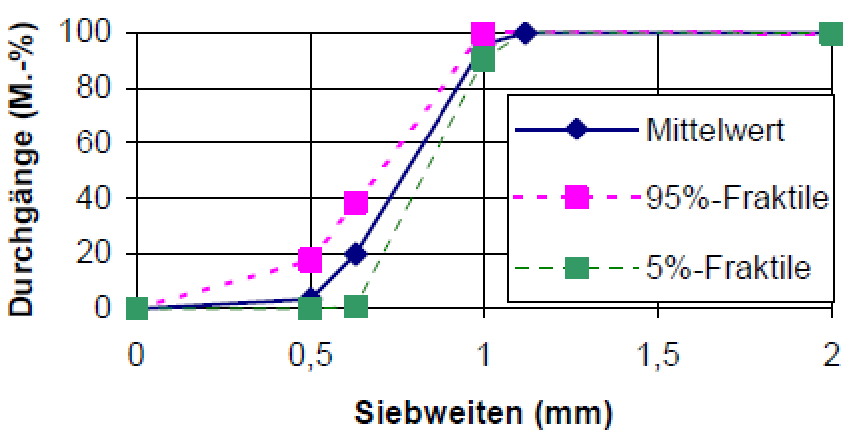

Figure C3: Sieve curve Liaver 0.5-1.0 [Source: Datenblatt Liaver, 2010]

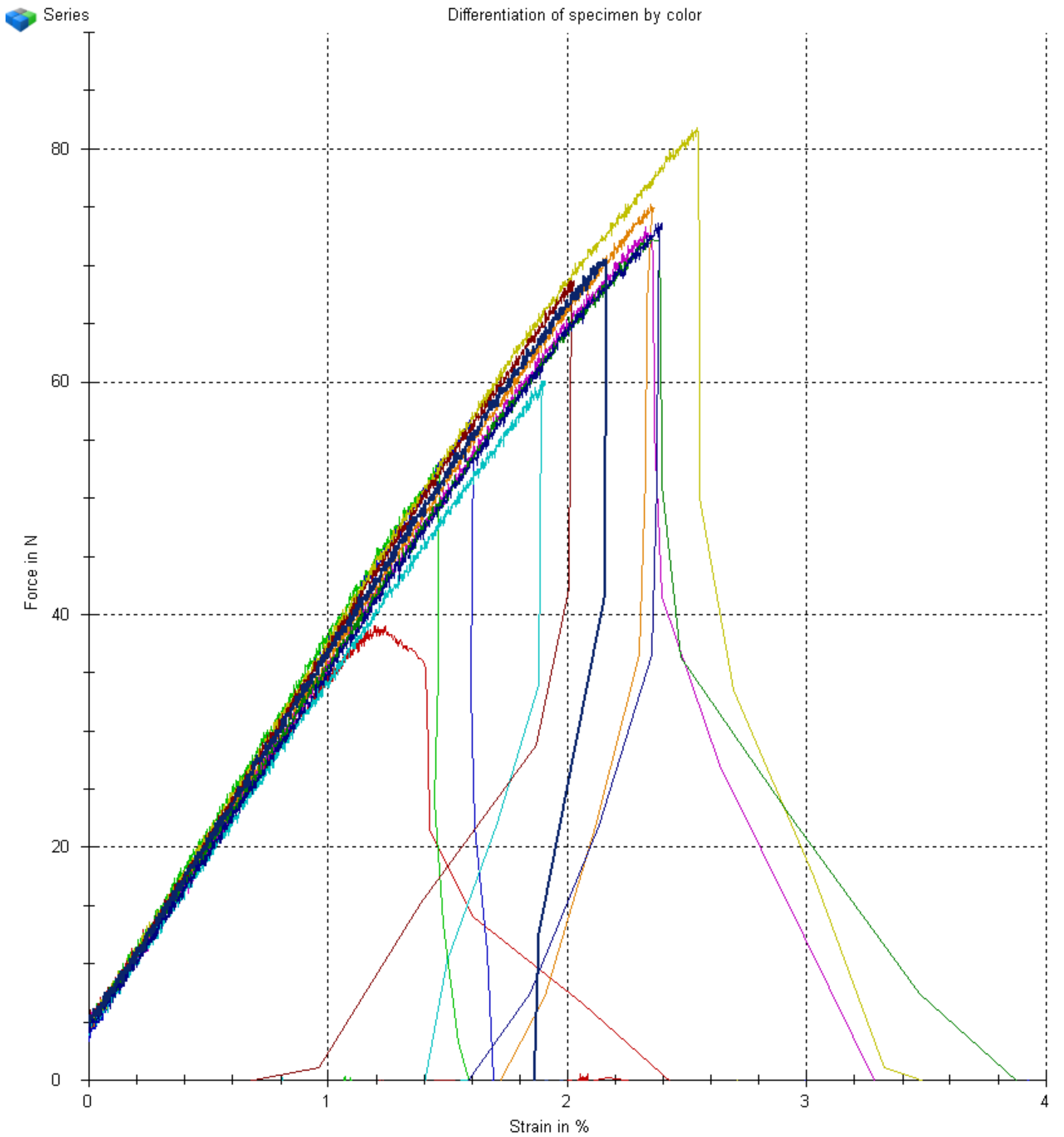

Figure C4: Visualization of specimens measurement results

Nr	Clock time	Date/Clock time	Emod GPa	F at 0.2% plastic strain N	Fmax N	dL(plast.) at Fmax mm
1	4:42:03 PM	3/21/2011 4:42:03 PM	293	38.0	39.0	0.1
2	4:51:41 PM	3/21/2011 4:51:41 PM	314	46.4	53.3	-0.0
3	4:57:17 PM	3/21/2011 4:57:17 PM	319	50.7	56.7	0.0
4	5:02:57 PM	3/21/2011 5:02:57 PM	300	72.0	75.2	0.1
5	5:09:47 PM	3/21/2011 5:09:47 PM	297	71.3	73.3	0.1
6	5:15:56 PM	3/21/2011 5:15:56 PM	288	55.2	60.0	0.0
7	5:20:46 PM	3/21/2011 5:20:46 PM	321	78.3	81.8	0.2
8	5:25:52 PM	3/21/2011 5:25:52 PM	312	63.7	68.7	0.0
9	5:38:53 PM	3/21/2011 5:38:53 PM	294	71.8	72.6	0.1
10	5:44:05 PM	3/21/2011 5:44:05 PM	295	71.6	73.6	0.1
11	5:51:06 PM	3/21/2011 5:51:06 PM	306	67.4	70.5	0.1

Table C1: Specimens measurement results