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CONSTRUCTIEF ONTWERPEN

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Bridges

Editorial

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Dear reader,

Seven continental landmasses are spread out over the earth's surface. Some continents are naturally separated from each other by oceans. Within the continents, we also find a lot of separations such as rivers, ravines, and rough terrains. To counter these natural obstacles often a specific type of structure is used: bridges.

Compared to the previous theme about water engineering, this theme shows a completely different side of water-related structural projects. This edition contains projects which stand out by their materials, construction process, or design such as: the first fully bio-based bridge, the Kissing Bridge, and the Magdeburg canal bridge. The theme also contains non water-related structures like The Zhangjiajie Grand Canyon Glass Bridge, spanning between two mountain cliffs.

Besides the theme articles, Master's theses, and the column of Hans Lamers, the editorial board introduces some new (and in the future returning) topics in the KOersief. The topics like TU/news and the experience of an exchange student give the reader more insight in what is going on within our unit of Structural Design.

The 103th edition of the KOersief is my third edition, but my first edition as editor-in-chief. I would like to thank the editorial board for their enthusiasm and support and I hope you will enjoy reading this edition as much as I enjoyed being part of its development.

On behalf of the editorial board,

Caroline Koks
Editor-in-chief KOersief 103

We're committed to a sustainable partnership

ENCI. The cement for a secure future.

In the construction sector everyone must take on his ecological, social and economic responsibility. ENCI is committed to doing that together with the customer. So we develop sustainable products suited to the economic and ecological realities, and we support a strong partnership. We share experiences and offer solutions. Eco-responsibility means working together for a secure future for the generations to come.

Chairman's note

Dear KOers members and relations,

A new academic year and almost a new board! While I am writing this, the summer holiday is still in front of us, like a bridge to the new academic year. I hope your very own summer bridge was constructed well and brought you joy. The theme of this edition, bridges, also coincides with the switch between boards. And seeing that this is my last chairman's note, I would like to wish the 48th board of KOers all the best in this new exciting year, and of course, a lot of fun. To get to know the 48th board, read their introduction in this edition.

Since the previous KOersief, twenty KOers members went to the city of Copenhagen for a study trip. The trip included visits to different, well respected, engineering companies, stunning buildings, and of course a bit of sightseeing. In another excursion, a bit closer to home this time, we visited the impressively complex projects around Utrecht Central Station. An area where six different projects are closely woven together into a logistical and structural puzzle.

In addition, the physical aspect got a lot of attention this quartile. KOers members showed their sporting skills in the Hajraa outdoor volleyball tournament as well as in the two concrete canoe races. A team of KOers members looked forward to these races since they spent the better part of a year to design, calculate, and produce two types of canoes that would race against numerous other teams from other European universities and colleges. Our 3D printed concrete canoe even won the innovation price as well as the price for the heaviest canoe during the event in Enschede. I would like to thank the concrete canoe committee for representing Eindhoven's structural engineering skills at the races in Enschede and Cologne.

In traditional fashion, the year was concluded with the KOers barbecue with plenty of food, drinks, and ice cream. Looking back to this year, I would like to thank my fellow board members: you have made this year very special. In addition, I wish to thank all members and partners of KOers who made all the activities of last year possible.

On behalf of the 47th board of KOers,

Lars Croes
Chairman of the 47th board of KOers

Expand your social and professional life
Join one of our committees

E-mail to KOers@bwk.tue.nl or visit us in the KOerscorner at Vertigo floor 2

Agenda

Concrete Canoe Race Enschede *May 12th*

Huizen en Disputenrace *May 17th*

Continu Career Event *May 30th*

Excursion Royal Haskoning DHV *June 2nd*

General Member Meeting & Constitution Drink

September 11th SkyBar! Underground, Eindhoven

The reign of the 47th board will come to an end and the 48th board will be installed in the General Members Meeting. The past year will be reviewed and a new year is about to start. After the meeting, the constitution drink takes place to congratulate the new board on their inauguration. Every KOers member is welcome to join the meeting and the drink!

KOers Coffee Time

Weekly KOerscorner, Vertigo floor 2, TU/e

Every Wednesday during the lunch break, KOers serves a nice cup of coffee or tea. So, allow yourself to have a break and join us on Wednesday between 12:30-13:30h on floor 2.

Nationale Staalbouwdag

October 10th Kromhouthal, Amsterdam

The 'Nationale Staalbouwdag' is a perfect moment to acquire knowledge about the latest trends and developments in commissioning, designing, and constructing with steel. Host Bouwen met Staal offers a versatile program with a full day plenary conference and practical seminars for specific target groups. On this day also the StudentenSTAALprijs will be awarded.

Betondag

November 16th De Doelen, Rotterdam

For years, the 'Betondag' has been a household name and the largest single-day event at which Dutch structural engineers meet. It is a unique combination of networking and learning. The 'Betondag' provides the possibility to meet known and lesser known companies at the concrete convention, to meet students of other programs or universities in the student cafe, and to visit interesting presentations. This year, the 'Betondag' will celebrate its 60th anniversary.

KOers has a limited number of tickets. If you want to attend this activity, you have to subscribe at the KOers website. First come, first served.

Annual barbecue *July 6th*

48th board of KOers

Introducing the new board of KOers

The board of the year 2017-2018 is formed and will be introduced. The members of the board can be seen on the picture above. From left to right you see: Derk Bos, Gido Dielemans, Maisa van Genderen, Denise Kerindongo, and Caroline Koks. In order to get to know the new board, questions are formulated to share their thougths and the way of thinking about certain all day issues.

Chairman

What is your full name?
A lot of KOers members know me only as Dork Bes, but my actual name is Derk Bos.
What is your age?
I am 22 years old.
Where were you born?
I was born in Arnhem, but grew up in Oosterbeek.
What food would you never recommend to someone?
I would not recommend eating concrete. No matter how big the structural material is, it just tastes very bad.
What does hardly anyone know about you?
For some reason almost no one knows where the 'H' stand for in my middle name. But luckily, you are not asking me to reveal my secrets.
What is your motto in life?
If your canoe doesn't fit,
You better use some kit.
What is your favorite color?
R: 74, G: 158, B: 198
Describe your ideal pizza?
Pizza ham/cheese croissants.
What can make you very mad?
When you decide to do something different, something completely out of the box. You decide to buy orange-kiwi juice instead of the regular orange juice for breakfast. Pay 20 cents extra for only 20% of kiwi, and it tastes horrible!
Are you a morning person or evening person?
I try to be a morning person, but I have a very comfortable bed.

Secretary and Vice Chairman

What is your full name?
Gido Dielemans
What is your age?
I am 22 years old.
Where were you born?
I was born in Breda and grew up in Prinsenbeek.
What food would you never recommend to someone?
Nothing so drastic, I am however not a fan of asparagus and chicory.
What is your biggest fear?
I have a fear of heights or rather depths; looking straight down makes my head spin.
What does hardly anyone know about you?
When I was a young boy, I had glasses with strength +6.5 and cylinder. My parents found out after seeing me run into walls multiple times. With age, my eyes improved and since the age of 13, I no longer need eye correction.
Would you want to be famous?
No, I have no desire to become famous. However, I would like to make a great contribution to the world by doing what I love. Getting known is a result rather than a goal.
What is your motto in life?
Be yourself!
What is your favorite color?
My favorite color is green. It reminds me of the beauty of nature which I enjoy experiencing through sports and traveling.
Which were your favorite cartoons when you were little?
When I was little I really enjoyed the books of Pinkeltje, I ended up collecting all the books.

Describe your ideal pizza?
My ideal pizza would be a combination of Quattro Formaggi and a Supreme. Though the combination of the two does frighten me a little.
What can make you very mad?
Something that can get me boiling with rage is when something unfair happens to friends of mine.
Are you a morning person or evening person?
Definitely an evening person, I find staying awake easier than waking up. Therefore, my most productive hours are usually past 16:00h.

Treasurer

What is your full name?
Maisa Naomi Georgine van Genderen
What is your age?
22
Where were you born?
Rotterdam
What food would you never recommend to someone?
I don't know. Maybe blue cheese? It makes me gag.
What is your biggest fear?
Cockroaches. I absolutely hate them. I can already freak out over just one cockroach.
What does hardly anyone know about you?
I am almost always nervous without a reason. I can work myself up over every little thing.
Would you want to be famous?
No not really, I do not want everybody up in my business. I would like to be rich though.
What is your motto in life?
Be positive. Happiness is a choice.
What is your favorite color?
Blue of course!
Which were your favorite cartoons when you were little?
SpongeBob SquarePants. He is the best. Someday I would like to taste a Krabby Patty.
Describe your ideal pizza?
Thin crust, with tuna and red onion. Once in Italy I had a pizza with a crust as thin as paper, I loved it!
What can make you very mad?
I do not get mad very often, so when I am mad, I am mad. But I think maybe disloyalty and lying.
Are you a morning person or evening person?
I am most definitely not a morning person. Also not really an evening person though. I like to sleep.

Commissioner Education and Activities

What is your full name?
Denise Tessa Kerindongo
What is your age?
I am 22 years old.
Where were you born?
I was born in Tilburg.
What is your biggest fear?
I do not like insects, especially wasps. One time, I got stung by a wasp and there is still a small scar on my hand.
What does hardly anyone know about you?
Nothing really, I am a pretty open book. When interest is shown, I will tell you almost everything.
Would you want to be famous?
No, I would not like to be famous. I cannot imagine being followed around all the time. I like being around people, but that's too much.
What is your motto in life?
Treat others like you would like to be treated.
What is your favorite color?
My favorite color is ochre yellow.
Which were your favorite cartoons when you were little?
When I was young, I watched a lot of different cartoons. I think The Powerpuff girls and Tom & Jerry were my favorite.
Describe your ideal pizza?
My ideal pizza would be crunchy, with crispy chicken and bacon, barbeque sauce, red onions, and some mushrooms.
What can make you very mad?
I cannot really get mad, I rather get upset. For example, when people lie and act fake, are rude, or only think about themselves.
Are you a morning person or evening person?
I am a morning person. I have no problems with getting up early. When I get up early, it feels like I am going to make the most of my day. But, that does not mean that I always do.

Commissioner Public Relations

What is your full name?
My full name is Caroline Renee Koks.
What is your age?
I am 22 years young.
Where were you born?
I was born and raised in Veldhoven, a village next to Eindhoven.
What food would you never recommend to someone?
A grilled mussel in a sushi restaurant. That was not a good experience.
What is your biggest fear?
A deep, dark, humid space.
What does hardly anyone know about you?
I am a very open person and I talk a lot, so I guess I do not have much left to share.
Would you want to be famous?
I like to be present within a society, but I also love to have personal space. To be recognized while doing the groceries: not my thing.
What is your motto in life?
Make choices that keep you happy. As long as you stay true to yourself, you will be surrounded by people and activities that suit you.
What is your favorite color?
My favorite color is burgundy, like we have on our passports.
Which were your favorite cartoons when you were little?
Totally Spies, especially Sam with the red hair.
Describe your ideal pizza?
A thin, just not yet crunchy bottom, covered richly with buffalo mozzarella, cherry tomatoes, and basil. I ate it last summer in Bologna and it was the best pizza ever.
What can make you very mad?
I cannot stand unfairness.
Are you a morning person or evening person?
I can better say that I am a daylight person. I am awake and active when the sun comes up. I also like summers more for that reason, the days are more brighter and greener and everyone is more happy. ◄

Introduction: Bridges

By: Lieneke van der Molen
Editor KOersief

A bridge is a structure that provides passage over obstacles such as valleys, rough terrain, or bodies of water by spanning those obstacles with natural or manmade materials. The history of bridges is very rich, filled with incredible achievements and new technologies. This article provides a small introduction in this edition's theme of the KOersief: Bridges. It will highlight some essential revolutions and designs over the years.

The first bridges were constructed by leveling up uneven terrain, crudely covering the entire surface below the deck of the bridge with stone or wood. Over time, builders discovered new methods of constructing bridges, resulting in different shapes and designs.

Wooden bridges

The first bridges made of wood date from 1500 BC. At first, very simple techniques were used, such as timber piles and crude woodwork to cross small rivers. Later on, as the manufacturing techniques and tools became more advanced, wooden bridges with advanced designs were used all across the world. The earliest examples of bridges made from wood can be found in Switzerland, starting with small footbridges up to larger and wider bridges. One of the most famous wooden bridge is the Holzbrücke Rapperswil-Hurden; a wooden pedestrian bridge constructed between 1358 and 1360 across Lake Zürich. The bridge remained in use for 500 years and had a length of 1,450 meters and 4 meters wide. In 2001, the bridge was reconstructed to its old glory and opened for public (*Figure 1*).

Figure 1: Holzbrücke Rapperswil-Hurden over Lake Zürich

Arch bridges

With the arrival of the Roman Empire, bridge building techniques were revolutionized with the introduction of arches. Architects of that time built their bridges with arching shapes as it enables the downward force from the top of the arch to meet the equal force that was pushed from the ground into the bridge foundations. The result of this revolution was a very rigid and strong bridge structure. A well-known example of an arch bridge is the Pond du Gard, built around 19 BC (*Figure 2*). The construction of stone arch bridges was not an easy task. First, builders had to create wooden arches in exact measurements as a completed bridge. This wooden structure was then used as a container for stones and mortar. These stones were usually found locally, but mortar components had to be imported from far away (ground up volcanic rock).

Figure 2: Pond du Gard nearby Nîmes and Uzès

Suspension bridges

The earliest versions of suspension bridges were built by Thangtong Gyalpo in the 15th century. Gyalpo built over 58 iron chain suspension bridges (*Figure 3* shows an example) around Tibet and Bhutan and one of his bridges survived until 2004, when it was destroyed by a flood. Rope suspension bridges were brought back to Europe from Central and South America, but did not lead to a revolution. After the fall of the Roman Empire, bridge building techniques in Europe and Asia stagnated until the 18th century.

Figure 3: A chain suspension bridge by Thangtong Gyalpo

The use of iron

The 18th century brought a new construction material, namely cast iron, which resulted in the creation of new bridge designs such as truss systems. Wrought iron did not have the tensile strength to support heavy structures,

Thomas Telford (1757-1834)
Manai Suspension Bridge (417 meters): one of the first long-span suspension bridges.

John Roebling (1806-1869)
The Brooklyn Bridge: Roebling died before the bridge was completed, after which his son finalized the project.

Joseph Strauss (1870-1938)
Golden Gate Bridge: Strauss got the opportunity and was asked to design a bridge that would be remembered forever.

Robbert Maillart (1872-1940)
Salginatobel Bridge: this design went beyond the common boundaries in that time, and therefore revolutionary.

Santiago Calatrava (1951)
Margaret Hunt Hill Bridge: Calatrava's most famous cable stayed bridge.

Figure 4: Bridge designers and their bridges

but this was solved with the advent of steel and the ideas of Gustave Eiffel. The Maria Pia bridge of Eiffel shows this revolution (*Figure 5*).

Figure 5: Maria Pia bridge in Porto over River Douro

Famous bridge designers

There are plenty of unique bridge designs and many famous bridge designers that accomplished something in this field of expertise, a few are mentioned in *Figure 4*. ◀

References:

[1] *http://www.historyofbridges.com/*

Figures:

1 *https://en.wikipedia.org/wiki/Holzbr%C3%BCcke_Rapperswil-Hurden*
2 *http://www.ancient.eu/image/125/*
3 *http://aglimpseofbhutan.weebly.com/iron-chain-bridge-and-tachog-lhakhang-dzong-paro.html*
5 *https://www.bridgeinfo.net/bridge/index.php?ID=55*

A story about the construction of Nijmegen's second Waal bridge

Building an iconic bridge in Nijmegen

By: Tom Godthelp
Editor KOersief

For years, the city of Nijmegen struggled with a poor accessibility: the northern part of the city has been separated from the city center by the river Waal. From the northern part, the city was only accessible by the 'Waalbrug'. Since 2013, this problem has been solved by the opening of a new iconic bridge called 'De Oversteek' referring to operation Market Garden in 1944.

The bridge design

The design of 'De Oversteek' is obtained from a design competition held by the Nijmegen city council. All the design proposals were reviewed in their cost-effectiveness, feasibility, and esthetical quality. The choice for an arched main span design was supported by the inhabitants of Nijmegen of which 60% voted in a poll for an arched bridge.

The design competition was won by Ney Poulissen Architects & Engineers, who designed an arched bridge that in terminology could be separated into two bridge ramps and one main span. The two bridge ramps are made of in-situ poured concrete whereas the main bridge is made of high strength steel (S460 and S690). The designers chose for these high steel qualities to be able to span the 285 meters with minimum material use, resulting in a lower self-weight in comparison to lower steel qualities. Furthermore, the lower self-weight results in a more slender bridge and lower material costs. However, high strength steel requires special welding procedures, for instance, controlled preheating and cooling down of the welding spot. Therefore, and to be able to create an efficient construction methodology and verifiable working conditions, the complete main bridge was built from five prefabricated parts in the floodplains. After the construction was completed, the bridge was moved by barges to its final destination. This required procedures that are discussed in the implementation part of this article.

During the design process, the arch shape of the main bridge is optimized. However, results showed that a constant radius is the most optimal and safest shape considering structural redundancy. The structural height of the arch varies from a minimum of 2 to 3 meters: the largest height

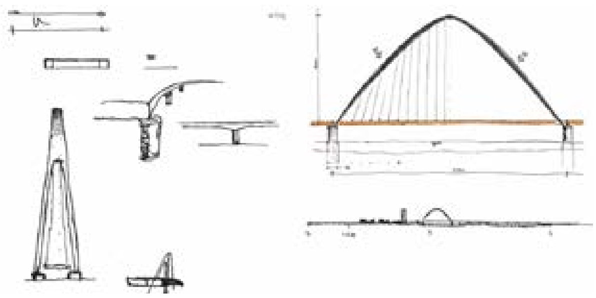

Figure 1: The first design sketches of 'De Oversteek' [1]

Project data 'De Oversteek'

Design process:	2010 - 2011
Construction:	2011 - 2013
Architect:	Ney Poulissen Architects & Engineers
Engineering:	NP-BRIDGING
Construction:	BAM and Max Bögl
City:	Nijmegen, Netherlands
Bridge length:	1,195 meters
Main span:	285 meters
Budget:	€ 141,000,000 ex. vat

is found at the birth of the arch whereas the lowest height is found at a quarter of the length. This results in a slenderness of h/l = 1/142. This slenderness is similar to a conventional bridge slenderness of 1/100 found in similar structures but with a smaller span.

The total length of the bridge, including the bridge ramps, is 1,195 meters in which the width is varying from 25 to 32.5 meters. The bridge ramps are designed as an integral bridge which means that there are no joints or hinges between the inner transitions. This results in driving comfort, low noise nuisance, and reduced maintenance costs. However, to build the bridge ramps without inner hinges required additional implementation measurements.

Figure 2: One bridge ramp of structural concrete and with masonry infill

Implementation

The bridge ramps are designed as continuous in-situ poured concrete arches (*Figure 2*) that could only transfer their horizontal forces to the two outer abutments. Because the inner supports could not transfer these horizontal forces

Figure 3: Moving the main bridge in position with barges and jacks

to the foundation during construction, stabilization cables were used to prevent a collapse. After completion, the inner arches provide their own horizontal equilibrium considering symmetry. The outer supports only have to take care of the horizontal force of the outer arch and forces that are created by unequally distributed loads. The horizontal forces resulting from the arch of the main bridge are supported by the bridge's two main girders. The main bridge was built in a special made dry-dock in the floodplain of the Waal river. After the assembly of the bridge out of five prefabricated steel elements, the whole bridge was jacked, loaded onto barges and floated into position (*Figure 3*). Hereafter, the cables where tensioned and the concrete deck was poured. An additional structure, used to distribute the support forces during transportation, was then removed. In addition, all uncovered parts where painted to protect the structure for the next 25 years. The contractor is in this case not only responsible for the implementation, but also for the maintenance of the bridge for over 25 years. Therefore, the contractor benefits from a well-designed and conserved structure.

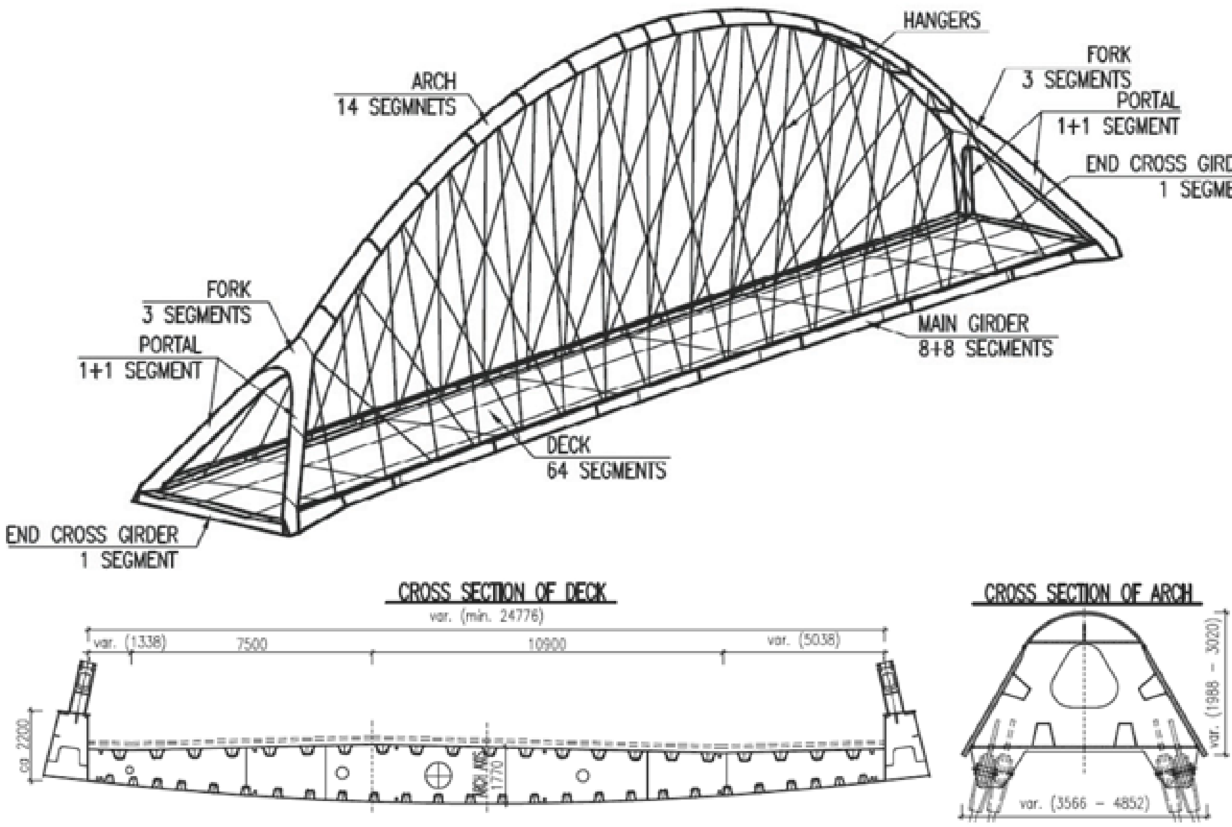

Figure 4: The segments and cross sections of the structural elements of the main bridge

History

The maintenance period for the contractor is 25 years. However, the bridge is designed to last 100 years and would probably stand for longer. The first 'Waalbrug' stands since 1936 and was the first bridge in the Netherlands that is designed in corporation between an architect and engineer. Before that time, bridges where designed by an engineer and the design task was considered as being purely functional and technical. The corporation between an architect and an engineer for the first 'Waalbrug' resulted in a monumental design and influenced the designers of 'De Oversteek' to design an arched bridge. This is shown in *Figure 5*. However, the 'Waalbrug' was built over the river with scaffolding and rivets, and not in a special dry-dock. The structural improvement and progression between 1936 and 2013 is beautifully visible between the two adjacent bridges.

The structural composition of the main bridge

The deck of the main span is designed as a closed box girder with an orthotropic deck plate that is stiffened with trapezoidal closed ribs in longitudinal direction and cross girders in transverse direction (*Figure 4*). A concrete layer of C40/50 on top of the deck provides the load distribution. This layer was applied after the bridge was placed in its final position. The total height of the steel deck is approximately 1.8 meters at midspan which reduces in the direction towards the supports where the bending moments are smaller. The supports of the deck are two main girders with a height of approximately 2.2

Figure 5: The 'Waalbrug' from 1936 and 'De Oversteek' from 2013

meters. These girders are also tensioned by the tensile load that is resulting from the arch. The single arch is divided at the ends into 'A' shaped portals. These portals ensure the transverse stability and transfer the forces from the arches to the adjacent structural elements. However, this 'fork' part is the most complicated structural part of the bridge and required innovative manufacturing. The cables that support the main deck are connected to the arch in a crossed pattern that is structural efficient and beautiful from an esthetical point of view. ◀

References:

[1] *Laurent Ney. 2014. Nijmegen: Designing the 'City Bridge'. ISBN 9789460041747*

[2] *D. Franc and A. Pechal. 2012. Arch Bridge in Nijmegen - New 3D Approach to Workshop Plans. Steel Structures and Bridges 2012*

Figures:

Header	*Thea van den Heuvel and Stijn Bollaert*
1	*Laurent Ney [1]*
2-3	*Paul Beerten. Over de Waal. ISBN 9789081450027*
4	*D. Franc and A. Pechal [2]*
5	*Paul Beerten. Over de Waal. ISBN 9789081450027, Thea van den Heuvel and Stijn Bollaert*

The story of an innovative eye catcher in Copenhagen

Bridge of problems

By: Thomas van Vooren
Editor KOersief

During the Multiple Day Excursion with our study association KOers in Copenhagen, we also visited the Inner Harbor Bridge a.k.a. the 'Kissing Bridge'. By its finishing in 2016, the bridge completes the Harbor Circle: a serie of routes for cyclists and pedestrians to explore and enjoy Copenhagen's offering along the Harbor front. However, besides the unique design, this bridge has also an interesting construction history..

The Bridge Design
Back in 2009, COWI and Studio Bednarski won an international competition for a new pedestrian and cycle bridge in Copenhagen. It was located in the Inner Harbor. The design was created with assistance from Hardesty & Hanover (M&E), Speirs and Major associates (lighting), and COWI A/S (geotechnical design).

The winning design is an innovative 180-meter-long bridge with a unique sliding mechanism of two sculpted box girders which form the moving spans in the inner part of the bridge. These spans will retract back into the fixed spans when a ship passes through. This open and closing principle is also the reason of the bridge's nickname: the 'Kissing Bridge'.

The bridge, with a width of 8 meters, has a low profile combined with transparency and a sinuous shape. Besides this low profile, and therefore its minimal obstruction to views along the Inner Harbor, the bridge's main attraction is the opportunity of people to stand on four viewing platforms on the fixed concrete spans. The moving box girders consist out of innovative triangulated inner webs, resulting in a nice view for passing vessels below the bridge.

Figure 1: View of the bridge from the center side of Copenhagen

Construction (problems)

The project started in 2009 (constructions started in 2011) and was originally planned to be completed by February 2013, but a number of problems kept postponing the deadline. *Figure 2* shows an overview of the construction problems in a chronological order.

Figure 2: Overview of construction problems and delays

(1) The list of problems began in early 2012 when two of the main support beams arrived 60 centimeters too tall. An extra four months were added to the project as time was taken to pat down the beams until they were at the appropriate height.

(2) The second problem, in May 2013, included two steel moving platforms, made by a Spanish company, which showed serious flaws. Despite these effects, the project still continued using these platforms due to contractual agreements.

(3) Thirdly, also in spring that year, cracks were found on the surface, which needed to be reinforced.

(4) As the summer continued, again weaknesses were found in the concrete arch underneath the bridge deck. Extra reinforcement was needed to sufficiently strengthen the bridge. In August, Pihl and Søn, the main contractors of the project, and international contracting group in business for over 100 years, declared their bankruptcy and the construction of the bridge stopped for nine months, until the city of Copenhagen took over the project.

(5) After this delay, the construction had some months of steady progress, until a storm in December 2013 flooded a machine room below the bridge, which caused irreparable damage to two motors of the bridge. This caused another delay and even more rise of costs.

(6) Spring 2014. Another delay formed by the fear of too little reinforcement, even though this fear was a false alarm, the delay still piled up.

(7) Again, some stable months of construction progress until August, when one of the draw-wire systems that pulled the arms in the fixed spans snapped.

(8) A new problem occurred in November 2015. One of the boogie-systems' wheels, which enables the platform to move back and forth, was discovered to be too weak. The system had to be redesigned, calculated, and installed which was finished in April 2016.

(9) In May 2016, the final problem occurred. The bridge is designed in a slight S-shape and has two retractable arms that meet in the middle, as explained before. When perfectly aligned, they automatically connect when protruding bolts enter complementary gaps in the other span. However, and you will feel it coming, there was a difference in alignment of bolts and gaps of nearly 8 centimeters. An explanation for this issue could be found in the change of warm air combined with the still-cold harbor water which causes the bridge to bend and skew. The combination of cold days, bright sunshine and chilly seawater has created conditions, the engineers did not entirely expect. Municipality construction adviser Erik Sørensen explains: "When the sun begins to shine, the retracting arms' surface is much warmer than their bottom, as is also the case with the curving bridge. This is actually taken into account with the design. However, if the heating is uneven, an unexpected twist occurs which means the bridge cannot close". This issue also caused extra delay because of new changes in the design which also included extra costs.

Figure 3: View from one of the viewing platforms of the bridge

Finally

All these setbacks have caused an huge increase in construction costs, which is another problem. Who is going to pay? It is now highly debated between Copenhagen and Phil and Søn contractors. The original costs were supposed to be around 200 million krone but after constant delays this has become 300 million krone and the costs of Copenhagen's share has already tripled.

It is said that the Inner Harbor Bridge was hit by Murphy's famous Law: 'anything that can go wrong, will go wrong.'

However, it has to be said, during our Multiple Day Excursion in Copenhagen, we passed the bridge several times and I have to admit that the design of the bridge is very interesting and it is fascinating to see it open and close for passing vessels. I think, despite many delays and problems in the construction phase, Copenhagen can be proud of the end result of this innovative design and after a few years all the problems will be water under the bridge. ◀

Figures:

Header	*COWI*
1,3	*https://www.thelocal.dk/20160708/copenhagen-inner-harbour-bridge-inderhavnsbroen-opens*
2	*www.copenhagenize.com/2016/07/copenhagens-inderhavnsbro-inner-harbour.html*

Update: six months after installation

Bio-based bridge at TU/e Campus

By: Rijk Blok
Assistant Professor Innovative Structural Design

In November 2016, the world's first fully bio-based bridge was installed at the TU/e Campus in Eindhoven, Netherlands over the river Dommel. The *Header* shows the bridge after installation and in use, last December. The bridge has a length of 14 meters and uses natural fibers: hemp and flax. The used resin is a bio-based epoxy resin around a core of PLA (Polyactic Acid) bio foam in combination with several cork interlayers. The bridge has been designed and built under a so-called 4TU Lighthouse research project in which also other parties have collaborated. For the unit Structural Design at TU/e, and especially the chair ISD, Innovative Structural Design, the main research and design question was whether and how these bio-based composite materials could be used in a structural loadbearing (bridge and building) application.

Probably most of you know about the bio-based bridge at our TU/e campus, because a lot of students have been working on it, in research, in design, in the production, and installation, and now still in evaluating the bridge's behavior. Still here a short introduction is given. The bridge was installed last November (2016), has a length of 14 meters and uses only natural fibers: hemp and flax in a (65%) bio-based epoxy resin. It structurally works as a hollow core section of only 20 millimeters thickness of the bio-composite at the top and bottom and only 10 millimeters at its sides. This way a very lightweight bridge has been created. The bridge's beam profile changes from rectangular (1.2 x 0.3 meters) at the supports to triangular (1.2 x 0.9 meters) in the middle. This is achieved by laser cutting the internal bio-based PLA foam in this shape, wrapping the fibers (both non-directional as well as two directional) around it, and injecting the resin through a process of vacuum infusion. The main reason to build this bridge is to see whether and how bio-based materials can be used in a structural load-bearing application. This is important because we need to work towards a much more circular way of building. Based on the climate goals of the last climate summit in Paris our own government has described its ambitions in "Nederland Circular in 2050" (Kamp and Dijksma): besides a 100% energy neutrality from 2020, using 50% less primary (fossil) materials in 2030 and fully circular in 2050. It becomes clear that we need a different approach towards using materials in construction and that we need to explore different and new solutions if we really want to achieve this. Renewable materials will become much more important.

Our bio-based bridge has 28 optical Fiber Brag Grating sensors incorporated, so we can still monitor its material behavior. Because of the cost, we have not been able to read the equipment at TU/e, but it is definitely our goal to acquire more funds and turn this bridge into a fully self-sensing structure that continuously monitors its behavior. For now, we did some load-tests with hired equipment. The last load test and measurements have been performed by

Denise Kerindongo and Shawn Leeflang (March 2017). They carried 20 weights of 0.3 kN onto the bridge and additionally put the weight of some extra students on top of that. *Figure 1* shows some results of the strains measured in the tension side (at the underside) over the length of the bridge while increasing the loads.

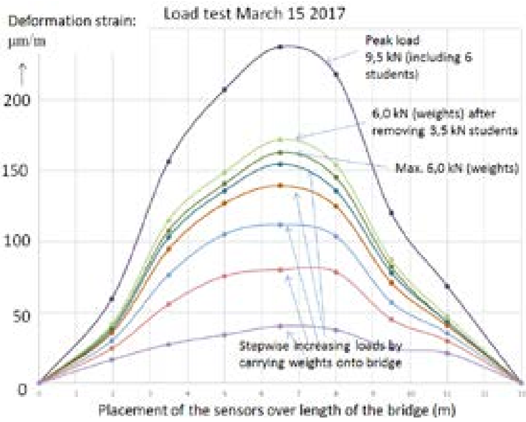

Figure 1: Results of strain measurements March 15th, 2017

Because of the accuracy of the optical fibers it can be seen that there is time dependent behavior. In tension the maximum strain was 163 μm/m at a loading of 600 kilograms. Compared to the result of December 1st 2016, there is a slight increase in strain of 4% of the maximum deformation. The strains increase slightly in time. This behavior is consistent with earlier material tests on the bio-composite material. *Figure 2* shows typical material behavior resulting from a tension test. It can be seen that the strains do not fully return to zero after unloading.

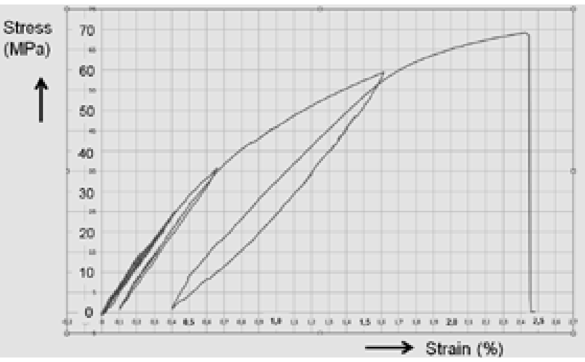

Figure 2: Typical result of a repeated loading-unloading and reloading tension test in the laboratory on a test specimen of Woven (90 degrees) flax fiber composite showing hysteresis behavior

This hysteresis behavior is positive for dynamic damping properties. Also on March 15th 2017, a heel test in the middle of the bridge was performed to test this dynamic behavior. A person, standing on his toes and falling to his flat feet, generated a vertical impulse load. *Figure 3* shows the strains versus the time of sensors SG-01-1-7 and SG 01-2-4, both in the middle and at opposite sides, at the top and bottom, of the bridge.

Based on these measurements the eigen-frequency of the bridge's first (vertical) vibration mode was calculated at 6 Hz (by counting the number of sinewaves within a period). This 6 Hz lies outside the for pedestrians more critical

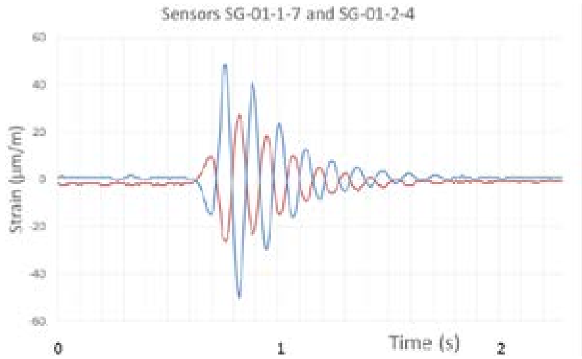

Figure 3: Dynamic damping behavior

zone of 2.5 Hz < f_n < 4.6 Hz where discomfort due to larger accelerations can occur. Also the logarithmic decrement δ = 0.58 in a free decay of the vibration and the damping factor ζ =0.093 can be calculated from these measurements using $\delta = 1/n \ \ln(x_0/x_n)$ and $\zeta = \delta/2\pi$, in which ζ = damping factor, δ = logarithmic decrement, n = number of cycles, x_0= amplitude of the 1st cycle, x_n = amplitude of the nth cycle. This relatively high damping compared to for example steel or concrete bridges further contributes to a good dynamic behavior and pedestrian comfort for this bridge.

In an earlier research project, by Monique Morren and Thijs Martens, it became clear that creep deformation in this material cannot be ignored. *Figure 4* shows results from the creep tests. Because the bridge is a very lightweight structure, the continuous permanent load has a very low impact on creep. But even at 5 MPa it can be seen that the deformation still increases in time. The stress level of the bridge due to self-weight is about 3 MPa. Until now, an insufficient number of measurements have been performed to fully evaluate the time-dependent creep behavior, but in further research this will become more clear.

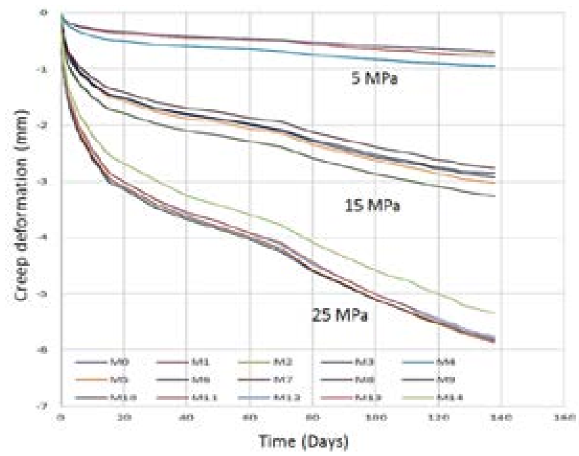

Figure 4: Results of creep tests on bio-composite on woven flax fibers

Given the need for a much more circular economy and a more circular building industry, obviously much more research needs to be done. Amongst others, also the city of Eindhoven has expressed its interest in realizing a bio-composite bridge. This could mean another opportunity to extend our research and knowledge. A case study on the feasibility of this bridge is currently being performed. If you are interested in this or other bio-composite research, you can contact me: R.Blok@tue.nl. ◀

The world's tallest and longest pedestrian glass bridge: Zhangjiajie Grand Canyon Glass Bridge

The invincible bridge

By: Thomas van Vooren
Editor KOersief

How would you deal with a design requirement which states that your design has to be as invincible as possible and also has to span 385 meters? I guess you will think of light structures, slim structures, but I do not think you would actually consider to design a glass bridge for such a huge span. Well, Haim Dotan did. His design is called: The Zhangjiajie Grand Canyon Glass Bridge.

Design

The Zhangjiajie Grand Canyon Glass (ZGCG) Bridge is located near Zhangjiajie City in Hunan Province, in the Republic of China. The bridge is 385 meters long, 6 meters wide and 300 meters above the canyon floor. The bridge was completed in June 2016, opened in October 2016 and can accommodate up to 800 visitors. The ZGCG Bridge is also suited for the world's highest bungee jump and serves as a stage for fashion shows and cultural events.

Figure 1: Safety test of the glass panels at a height of 300 meters

During the opening of the bridge, volunteers were asked to check the safety of the bridge. They were asked to smash the glass panels with sledgehammers. After that, a 4x4 car was driven over the shattered panels to show that the bridge is completely safe. However, a few weeks after the opening, the bridge was closed for some structural improvements. Not because it was a bad design, but the expected amount of daily visitors of 8,000 was exceeded by a factor of 10 in the weeks after the opening.

Structural design

Girder

The ZGCG Bridge can be placed in the category: medium-span suspension bridge. The bridge is located in a typical Karst area. The canyon spans 385 meters and the towers, which support the main cables, stand on each side at a distance of 430 meters. To achieve the architectural goal of a slim design, the maximum height of the beams was set to 0.6 meters. The span height ratio of the structure even became a Chinese record with a value of 625 (375/0.6). The girder is constructed out of two longitudinal steel side beams and a transverse cross beam. The structure is a composite of structural steel plate forms and concrete, with

Figure 2: The bridge during construction

Figure 3: A clear view of the canyon through the glass panels

glass infills, stainless steel handrails, and with side hanging stay cables resembling 'butterfly wings'. "The girder is as thin as a wing, as light as a swallow, and resembles a light slice floating in the sky", stated the chief Chinese bridge engineer.

Glass

The glass panels of the bridge are 3x4 meters and consist of three 16 millimeter layers of laminated glass with two layers of SGP film in between. The glass was tested for safety under extreme loading of 40 tons per panel. Deformation tests show that the glass deforms 21.6 millimeter under a load of 20 tons.

Wind

Because of the light and slim design of the bridge, wind engineering is an important topic in the engineering of the bridge. An additional issue was the special wind effects of the canyon. The wind speed and its angle of attack are different from those on flat ground. All suspension bridges are sensitive to wind, especially the ones with a height-span ratio that reaches 625. The structure was designed to minimize the structural response in strong wind. To ensure this, the bridge was tested for six months in the Wind Test Laboratory at Hunan University in Changsha with wind velocities that reached 56 m/s or 201.6 km/h.

Furthermore, two though structural difficulties had to be combined: structural stiffness and human comfort. Even if the structure is safe, the bridge also has to feel safe for people to walk over. Extensive engineering studies and tests were conducted: aero elasticity, wind velocities, fluttering analysis, gravitational stiffness, vibrations, dynamic analysis, and pedestrian simulations are taken into account. Special measures were devised to ensure that the structural design for wind resistance, safety, and pedestrian vibration requirements were met, with various shock absorbing technologies, damping, and anti-vibration mechanisms. ◀

References:

[1] Haim Dotan Ltd. Architects and Urban Designers.

Figures:

Header, 1-4 Haim Dotan Ltd. Architects and Urban Designers.

Haim Dotan Ltd. Architects and Urban Designers.

Haim Dotan Architects focuses on innovative cutting-edge architecture & urban design, research, and construction. The firm designs public and private projects in Asia, the Persian Gulf, Africa, Israel, and Europe. Haim Dotan is an architectural pioneer in developing construction techniques for residential, commercial, industrial, educational, and public institutions. In his projects, architect Dotan creates a new language in the global architectural landscape.

In 2006, Haim Dotan was the recipient of the Israeli Building Construction Center Award for 'New Architectural Language in Israel through 17 years of Development and Improvement of New Building Technologies'.

In 2007, Haim Dotan was nominated for the Israel Prize in Architecture. The firm has won numerous competitions and awards.

In 2008, Haim Dotan won the Israel Foreign Ministry DBOT Tender as the developer, contractor, and architect of the Israel Pavilion in EXPO 2010 World Exhibition in Shanghai, China.

BRDI – China Railway Major Bridge Reconnaissance & Design Institute Co.Ltd.

China Railway Major Bridge Reconnaissance & Design Institute Co., Ltd. (BRDI), a secondary subsidiary of China Railway Group Limited (CREC), was founded in 1950 as one of the earliest specialized bridge engineering consultancy companies in China. BRDI is leading in the design of large span suspension bridges, large span cable-stayed bridges, rail-cum-road bridges, high speed railway bridges, and sea crossing bridges, owning lots of self-created and valid invention patents and utility model patents both in China and abroad.

With an annual turnover reaching 200 million US dollars, BRDI has grown into a high technology corporation group whose service and business covers the construction of bridges, roads, tunnels, railways, industrial and civil buildings, urban and rural planning, municipal works and D&B project implementation management both in China, and dozens of foreign countries. In bridge engineering, BRDI has provided expertise consultancy services and design for more than 1,000 major projects of various types throughout China and the world.

FEM and bridges

By: ir. P.J.Th. (Pieter) Pollemans
Civil engineer at PT Structural bv

Over the past 25 years, our small firm has developed computational models using the Ansys™ Finite Element program. The tools may have changed but the objective has always remained the same, namely creating the best possible prediction of the actual behavior of the bridge in question, under the loadings prescribed by rules and regulations. Using FEM, a one-time effort can create a whole bunch of output values. This article gives a brief summary of past and present actions as a look behind the scenes of a very practical engineering team.

Early days: handmade input

Our first serious bridge was the Dutch 'Overstad bridge' in the beautiful city of Alkmaar. It is a classic rotary bridge, still in function, built by the HSM company in Schiedam. Used for cyclists and pedestrians to cross the city's waterway. Ansys was used all the way for the geometric description, even to a point that the Ansys output was fed into the drawing program to cut plates and camber! Usually, it is the other way around, you start (or receive) drawings in electronic format and try to bring this information to the FEM program. But as we were trained in programming the Fortran-like Ansys environment, we could use the strict geometric pattern of the bridge design to actually program the nodes and elements. They were manually named at the time, so easy retrieval of parts could be done. As always in that time, we tried to minimize the mesh to the absolute limit, just to save time and disk space (my today's wrist watch has more GB than our harddisk back in 1997).

In one or two iterations, we received all the required output: deadweights of modeled parts, support reactions at the hinges, stresses under load, deflections, even the lowest frequencies! All in a single operation and model. So an optimized weight was easy to get, the only limitation

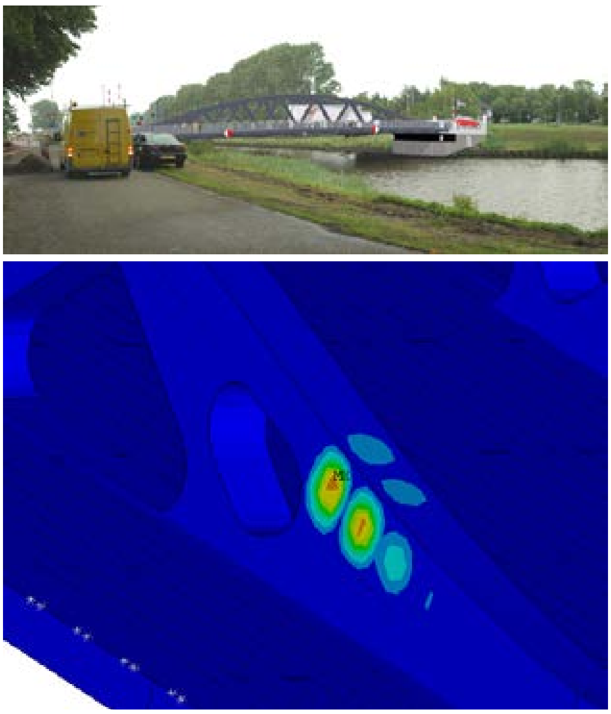

Figure 1: Zuidhoorn bridge: check for buckling sensitive areas

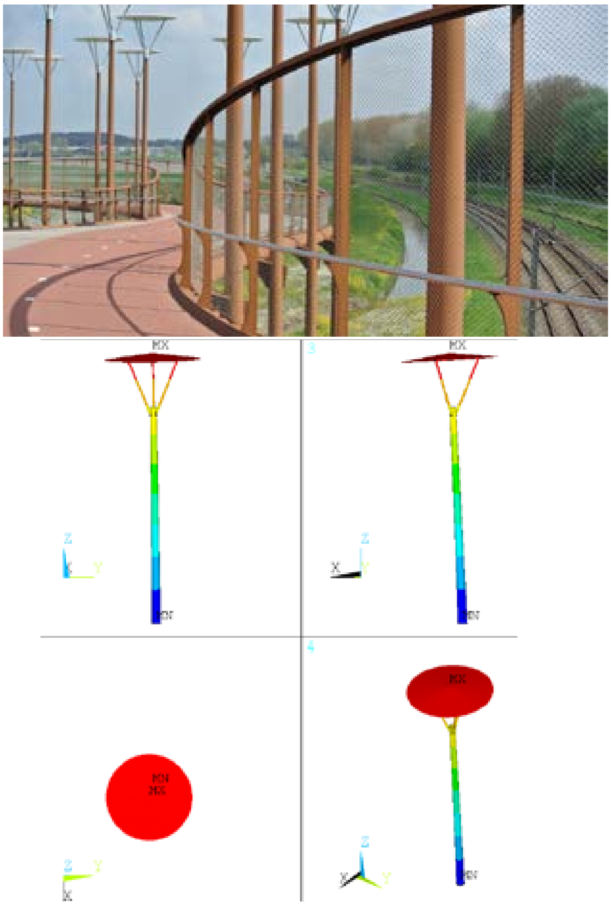

Figure 2: Jan de Waaijerbrug, Zoetermeer: vibration analysis of lamp posts

was the factory's request to stick to a limited number of weld lines and to allow for commercial limitations in plate thickness. Altogether a success, and more was to come.

Ansys growth and client request grows along

As time went by, the same recipe was tried, but the developments in computer drafting went further along. Also we could not cope with the architectural demands for exclusive bends and unique shapes anymore through geometric programming. We then started using Ansys own modeling capacity for just geometrics (the volume and area approach). Meshing was done afterwards. The great advantage was that more refinement was easy to reach in zones of special interest. We still tried to keep the mesh clean, mostly rectangular (4-noded elements, simple but effective) and we always try to avoid sharp edges and sudden changing of patterns. A lot of the experience was found in vessel engineering, with emphasis on crane body integration. This meshing and part-modeling is useful for bridges as well. A number of bridges we calculated had wires connected to the deck, were by definition a huge concentration of load is present. So the sub-modeling technique was applied, either by network patches that changed gradually or by using the Ansys Constraint Equations, a sort of stitching meshed together even though these do not fit, see *Figure 1*. Stitches must be done in relative calm zones where stresses are predictable. Then, a practically smooth transition appears between rough and finely modeled sections.

The advantage is that boundaries are only present at the true ends of the bridge. The full model is active and as little as possible is lost using 'artificial' model ends.

Today's practices

Having plenty of disk space and a top PC line computer, rapid full models with over 1 million DOF's run in minutes. But as an old sayings states, 'expenses rise to meet income' the request for accuracy is growing, too. Today, nearly always a fatigue analysis needs to be done, meaning that a host of load combinations is to be evaluated. Also shapes may be found that were out of the question about 20 years ago. So, now we feed Ansys with a geometric base from third parties (architects) and use the (much improved) own meshing capacity. We still obtain primary results like stresses and deflections, but we also squeeze out of the model:

- Buckling shapes;
- Vibration modes;
- Hoist behavior (hanging in ropes);
- Weld line stresses (where the plate ends, the forces per unit length are retrieved);
- Fatigue behavior, stress concentration factors;
- Early visualizations in teams for other disciplines like foundation experts;
- Accidental load (some plasticity allowed);

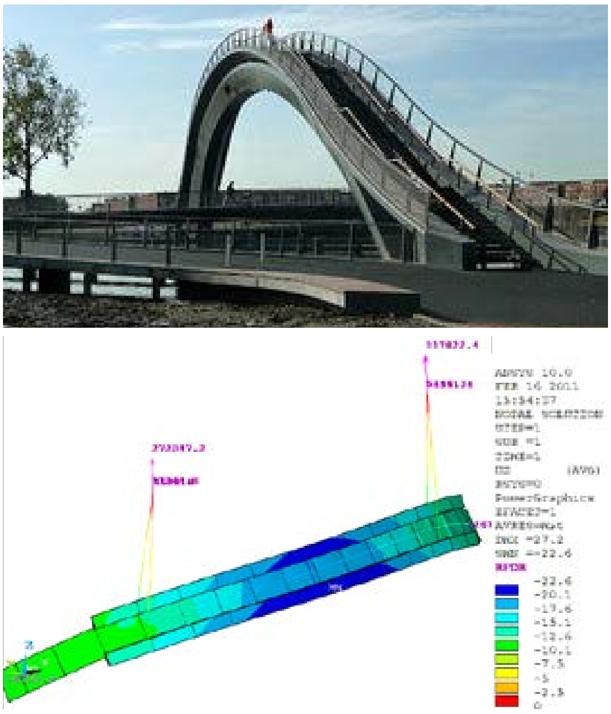

Figure 3: Melkwegbridge, Purmerend, hoisting case analysis

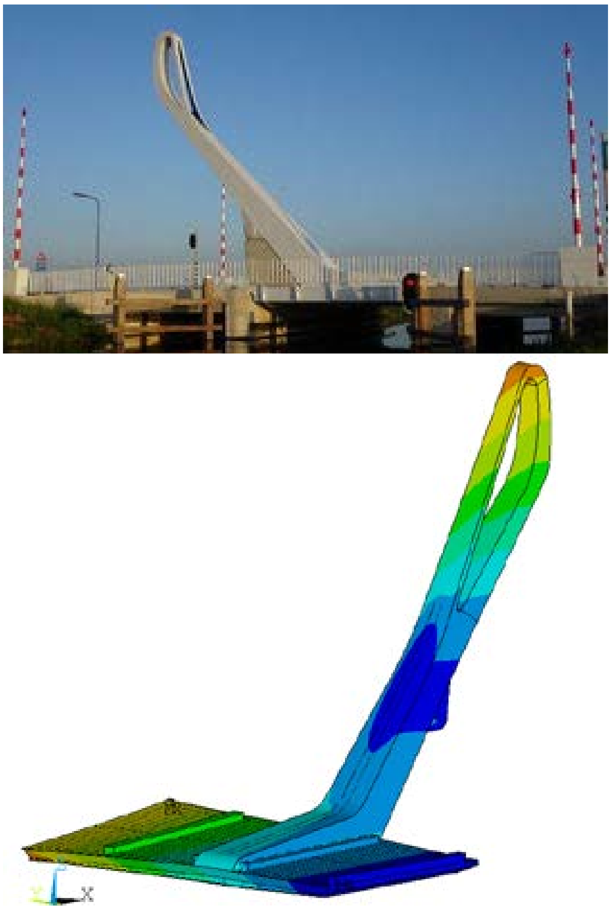

Figure 4: Bridge Eendrachtspolder, North of Rotterdam: form and function

- Forces on the support devices;
- Temperature effects (getting more and more important);
- Dynamics like stop/start, traffic and wind effects;
- Material take off (roughly).

And all this is coming from one master model.

Future outlooks

Bridge engineering is a conservative trade. It takes years for new methods to become accepted. The majority is still analyzed using parallel beams with a formula approach to stress retrieval. However, the interpretation of stresses out of plate and volume models is becoming more and more integrated in the drafting packages themselves. This means a closer cooperation between parties as the true conclusions still needs to be drawn by an experienced human engineer. It is predictable that in the future the sound, the wind loads, and the true dynamic behavior will be more elegant to reach from the same model, as well as the plate-cutting and machining of the parts. On the other hand, it must be done in a much shorter time and be followed by an extensive and fully traceable reporting style. Then we arrive at system engineering in which FEM is only one of the contributors.

In the figures, some highlights are shown giving an impression what more one can do with a FEM model of a bridge (next to an ordinary stress and strength analysis):

1. Buckling predictions;
2. Vibration checks;
3. Partial hoisting in tackles for upright positioning;
4. Deflection for strange forms. ◀

Magdeburg canalbridge over the Elbe

Crossing waters

By: Denise Kerindongo
Editor KOersief

The Magdeburg Water Bridge is a navigable aqueduct in Germany, opened in October 2003, that connects the Elbe-Havel Canal to the Mittelland Canal (*Figure 1*), and allows ships to cross over the Elbe River. With its 918 meters, it is the longest navigable aqueduct in the world. The water bridge joins the former East and West Germany, as part of the unification project after World War II. After the war ended, in 1991 the Government proposed 17 transport projects which aimed to recover the communication links. In the course of the expansion of the Hanover-Magdeburg waterway link, the river bridge across the Elbe is one of the most outstanding subprojects. The detailed constructive design and structural design were a particular challenge for the planners involved in the construction. Taking into account an overall economic view of the waterway crossing Magdeburg, the construction of a canal bridge proved to be the best economical and ecologically way of achieving a water level-independent Elbe crossing.

Overall assembly
The view of the superstructure is different in order to achieve a visual separation between the Main bridge (part of the bridge that spans over the Elbe) and the Foreland bridge (part of the bridge that lays on the land). The outer walls of the primary beams of the bridge, which have been separated into half-timbered structures, are characteristic for the area of the Main bridge, whereas the main bearers of the Foreland bridge are a closed sheet pile wall. This separation is strengthened in prism form by the primary pairs arranged in the transition area as well as at the beginning and end of the bridge on the bridgeheads. The sweeping form of the Foreland pillar reminds of the ship's ribs and thus also provides a symbolic reference to the user of the structure, namely water vehicles.

West abutment
The west abutment is constructed out of a deep foundation from in-situ concrete piles with a diameter of 51 centimeters. Only in the area of the calming basin of the flood relief system integrated into the structure, a deep condensation is carried out. In addition to operating, transformer, and battery rooms, the West abutment is equipped with a flood-relief system for the mid-range canal. This serves to dissipate excess water from the channel in precipitous times. Furthermore, the discharge system is used as a drainage system for draining into the trough.

Figure 1: Location of the bridge with before and after routes

East abutment

The east abutment is located on a deep foundation of 122 in-situ concrete piles. Integrated in the abutment are also operating rooms, tram rooms, and the unit rooms for an air bubble system to be installed to freeze the bridge. The abutment is constructed in two structural sections. The first section is required as the foundation for the displacement of the Main bridge, the second part is required to achieve the final height.

Steel superstructure Foreland bridge

The Foreland bridge is made from a 16-field through-beam carrier as a longitudinally oriented system with open profiles. The steel structure is assembled from the center in two directions. The carriers were delivered by ship and placed on the bearing base on site, see *Figure 2*.

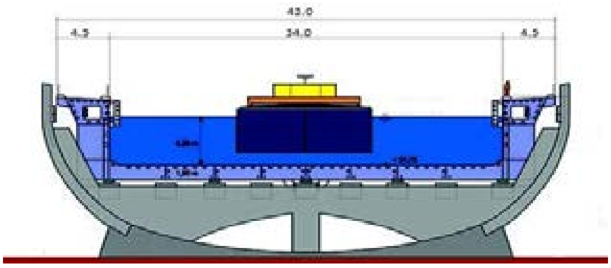

Figure 2: Section Foreland bridge

Overhead Main Bridge

The superstructure of the Main Bridge is made of two edge beams, each approximately 4 meters wide and 8 meters tall, that form a framework on the outside and as a solid wall on the inside, which are connected to each other by an orthotropic plate. On the eastern bank of the Elbe, the river bridge is pushed onto a pre-assembled shunting track and into several individual shafts across the Elbe (See *Figure 3*).

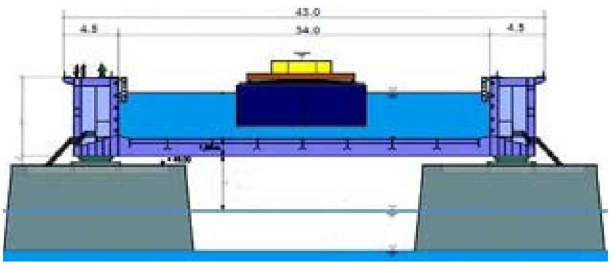

Figure 3: Section Main bridge

Manufacturing the piers

The production of the piers in the Elbe is an essential and technically very demanding part of the entire construction project. In the filled state of the bridge, the current piles must relay 13,000 tonnes reliably into the ground. Since these piers are not deeply founded on piles, but are laid down on flat foundations, large settlements are to be expected. For these sensitive components, a construction process was developed and executed in eight phases.

Construction sequence for the Main Bridge

The construction method for the Main bridge was incremental launching. This was achieved due to the large available space and due to the development of a custom designed machine in order to achieve the great amount of wielding with the required accuracy. All the beams were delivered on site, positioned along with the steel sheets, and welded together. The side truss was made in a similar way. Temporary supports were set between the piers in order to avoid designing the section for the increased construction loads as can be seen in *Figure 4* and *Figure 5*.

Facts

- The Magdeburg Bridge, is the longest conduit that has been constructed measuring 918 meters (Foreland bridge: 690 meters and Main bridge: 228 meters);
- The water bridge has a through width of 34 meters and a depth of 4.25 meters for the vessels to pass through;
- Over 20,000 metrical tons of steel along with 60,000 cubic meters of concrete were needed to construct the Canal bridge.

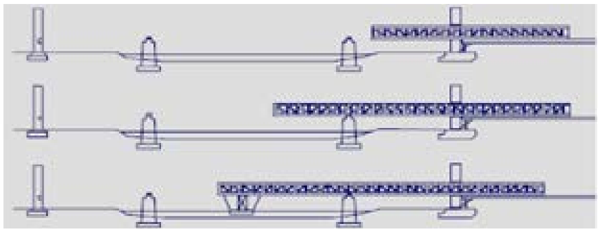

Figure 4: Construction sequence

The Canal bridge over the river Elbe near Magdeburg is one of the exceptional structures of water constructions in steel. The technical processing of this outstanding structure required a high degree of commitment and the will to work as a team of all those involved in the design and construction of the structure. The bridge's construction began in January 1998 and was finished in October 2003 with an overall cost of 500 million dollars.

Figure 5: Temporary piers

The design was done by Igenieurbüro Grassl Gmbh and the main contractors were Belfinger Berger and Dillinger Stahlbau. ◀

References:

[1] *ARGE Kanalbrücke Magdeburg*
[2] *Stahlbau 70 (2001), Heft 6*
[3] *A CRITICAL ANALYSIS OF THE MAGDEBURG CANAL BRIDGE, MAGDEBURG, GERMANY, Christos Ellinas*
[4] *Wasserstraßenkreuz Magdeburg Wasser- und Schifffahrtsdirektion Ost*

Figures:

Header *vidabinaria.com.br*
1,2,3 *Wasserstraßenkreuz Magdeburg Wasser- und Schifffahrtsdirektion Os*
4,5 *A CRITICAL ANALYSIS OF THE MAGDEBURG CANAL BRIDGE, MAGDEBURG, GERMANY, Christos Ellinas*

World's first 3D printed steel bridge in downtown Amsterdam

'Printing outside the box'

By: Thomas van Vooren
Editor KOersief

De Wallen, an area in Amsterdam that is usually known by tourists for other things than structural innovative projects, will hopefully get more competition with the finishing of a 3D printed steel bridge that will be opened this fall and is made by a small innovative Dutch startup: MX3D.

Bridge info

The bridge is designed by Joris Laarman and manufactured by MX3D with assistance of Autodesk, Heijmans, ArcelorMittal, and many others. The span of the bridge will be approximately 8 meters and will be printed of stainless steel 316 alloy. Two robot arms are able to weld the bridge piece by piece from both sides. Because of the crowded and narrow streets in Amsterdam, the actual printing will not take place at the bridge site, but inside a warehouse that is situated in the north of Amsterdam where spectators can witness the construction of the bridge.

3D printing of steel

In 2014, MX3D invented an affordable 6-axis printing tool. They equipped an industrial robot arm with an advanced welding machine and together with Autodesk they developed software to control it. This software is based on Project Dreamcatcher and Dynamo; tools developed by Autodesk. The printing robot is able to print metals, such as steel, stainless steel, aluminium, bronze, or copper and synthetics without the need for support structures. By adding small amounts of molten metal at a time, MX3D is able to print lines in mid air. With the MX3D Bridge project, MX3D wants to show how digital fabrication is finally entering the world of large scale functional objects made of durable materials. MX3D is developing software, parameters, and printing strategies for the different kinds of 3D printable 'lines'. For instance, vertical, horizontal, or spiraling lines require different settings, such as pulse time, pause-time, layer height, or tool orientation. 3D printing like this, leads to a new form language that is not bound by additive layers. This method makes it possible to create 3D objects in many different shapes and sizes. Furthermore, the technology is more cost efficient and scalable than current 3D printing methods.

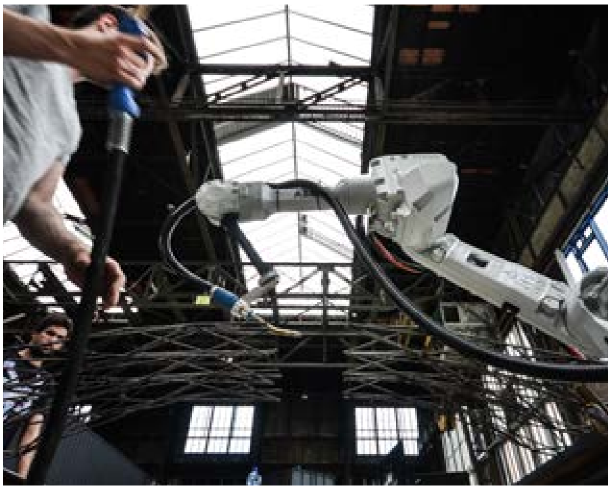

Figure 1: The 3D printer in action

Personal notes

Tim Geurtjens, CTO of MX3D: "What distinguishes our technology from traditional 3D printing methods is that we work according to the 'printing outside the box' principle. By printing with 6-axis industrial robots, we are no longer limited to a square box in which everything happens." Printing a functional, life-size bridge is of course the ideal way to showcase the endless possibilities of this technique. Joris Laarman, designer: "I strongly believe in the future of digital production and local production, in 'the new craft'. This bridge will show how 3D printing finally enters the world of large-scale, functional objects, and sustainable materials while allowing unprecedented freedom of form. The symbolism of the bridge is a beautiful metaphor to connect the technology of the future with the old city, in a way that brings out the best of both worlds." ◀

Figures:
Header,1 MX3D

A collaboration between our University of Technology and BAM Infra

‘Printing bridges to the next level’

By: Thomas van Vooren
Editor KOersief

The 3D concrete printer is a well-known subject and situated in the laboratory of our Built Environment faculty. Because of a signed Memorandum of the Eindhoven University of Technology and the municipality of Eindhoven with the intention of printing a house in the near future, it became national and even international news during the Dutch Design Week in October 2016. At the moment of writing, last Friday, June 16^{th} 2017, the 3D concrete printer became national news by the following innovative project: an eight-meter span cycle bridge printed by the 3D concrete printer.

This innovative project is a collaboration between Eindhoven University of Technology, BAM Infra, Witteveen+Bos, Weber Beamix, Bekaert (reinforcement), and Dywidag (pre-stress systems). The cycle bridge is part of the project Gemert Noord-Om, a project of BAM Infra, which include several roundabouts and bridges that will connect the area to the N272. The structural calculations are done by Witteveen+Bos. The printing of the bridge is mostly performed by the 3D Concrete Printing group that is part of the Chair Concrete structures from the master track Structural Design.

3D concrete printing

3D printing of concrete has some advantages over the traditional way of pouring concrete. First, formworks become unnecessary in the 3D concrete printing technology because of the shape stability. Secondly, due to the lack of formworks, the 3D printing technology results in a decrease of labor.

Figure 1: Printing a 1:2 scale model of a section of the bridge

Especially for complex and unique shapes, this printing technique is very beneficial considering time, labor, and costs. The printing process is executed by a four-axis gantry robot connected to a concrete mixing pump, controlled by a numerical controller. The gantry robot can print in a space of 9.0x4.5x3.0 cubic meters.

The cycle bridge

The cycle bridge will have a span of 8 meters and will be printed in several sections and comprises approximately 800 layers of printed concrete. As shown in the *Header*, the bridge will be placed between two concrete blocks and will be pre-stressed by nine steel cables (three at the top and six at the bottom). First, the sections are printed to approximately 100 layers each. After that, the sections are glued together with an epoxy adhesive and pre-stressed.

On June 16^{th}, a scale model was presented and tested in the laboratory of the faculty. *Figure 1* gives an impression of that morning: a section of the scale model is printed and professor Theo Salet gives an interview for the national television. In reality, the bridge will be twice as wide, twice as high and twice as long as the model presented in the laboratory.

If everything will go as planned, the real bridge will be open for public by the end of September and will be located over the ring road of Gemert. Follow the progress on the 3D Concrete Printing page at the website of the university. ◀

Figures:

Header www.3ders.org/articles/20170619-dutch-cyclists-to-enjoy-benefits-of-3d-printed-concrete-bridge-following-tu-eindhoven-bam-collaboration.html

1 3dprintingindustry.com/news/royal-bam-group-concrete-3d-printer-concrete-bicycle-bridge-with-tu-eindhoven-116359/

Rozet, Arnhem
Foto: scagliolabrakkee/
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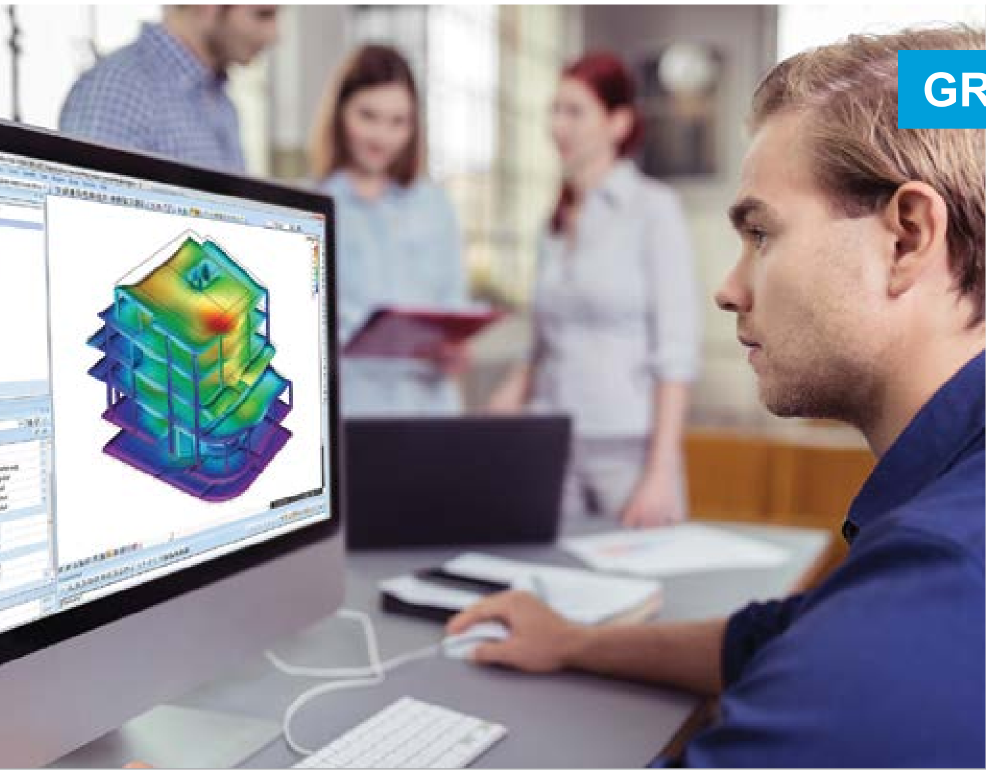
Bastionder, Den Bosch
Van Roosmalen Van Gessel



By: Angelique van de Schraaf MSc
Editor KOersief

It is generally known that a lot is happening in the building industry. Unfortunately, the TU/e does not always have time to provide the student with all the latest facts. Hence, the KOersief committee has decided to add a section to the KOersief with the latest news from the business community itself.

Lower pile class factors

Geotechnics teaches us that Koppejan's formula is an ideal tool for determining the bearing capacity of foundation piles. The equation of Koppejan (*Equation I*) assumes that the pile point fails according to sliding surfaces in the shape of a logarithmic spiral.

$$p_{r;\max} = \frac{1}{4} q_{c;I;gem} + \frac{1}{4} q_{c;II;gem} + \frac{1}{2} q_{c;III;gem} \qquad \text{(I)}$$

However, research has shown that the desired level of security with this equation cannot be achieved. This indicates that the pile class factors need to be lowered, even more research showed that they have to be reduced by 30%. The NEN-EN 1997-1 + C1 + A1: 2016 describes the new factors, and since December 2016 this is included in National Annex. For small projects this will have little effect, but for large projects the effect will be immense. The total cost increase in the building sector is estimated at 20 to 30 million euros per year [1]. This during bad times where piles are already scarce and the queue is six months.

Hyperloop test facility

In 2013, Elon Musk presented his idea for the Hyperloop. The idea is to have special capsules, travel in an air duct in order to reduce the air resistance. This allows to travel at higher speeds than in the open air. Although Musk has no ambition to develop the Hyperloop, he does promote the development. In the SpaceX Hyperloop Pod Competition, organized by Elon Musk, each team could test a self-built Hyperloop capsule in a test tube. When designing a capsule, the most important aspects are: stabilizing your vehicle at high speeds, accelerating but also braking, floating to minimize resistance, and most importantly: safely braking if there is a problem.

The Hyperloop capsule from TU Delft won overall ranking. As a result, the first Hyperloop test facility was built in Delft, through a partnership between Hardt (which is founded by winners of the Hyperloop competition) and BAM. This 30 meter long structure has a 3.2 meter tube diameter and will be used in the coming years to test all major systems in a vacuum. [2] [3]

Law of quality control

The matter everyone spoke of last year: the law of quality control. Introducing this new law means that quality control is no longer carried out by municipalities but by contractors themselves, who then will become responsible for submitting a report after the construction that states that the building satisfies the agreements/regulations that has been made. In this way, clients can keep the contractor more easily responsible for repair work if the agreed arrangements/regulations are not met. On February 21st, the House of Representative approved the law. After this, some municipalities expressed their doubts about this law. An important counter argument against this law is that the responsibility of the municipality is challenged, because the responsibility for supervision is removed from the municipality. However, it is expected that the municipality will intervene if there are signs of lack of quality. On July 7th, it was decided to postpone the vote on the law. [4]

Longest suspension bridge in the world just opened

In Switzerland, the longest suspension bridge in the world is opened across the Europaweg. The bridge is 494 meters long and a connecting road in the hiking track from Grächen to Zermatt. The bridge is built in just 10 weeks! A major problem with suspension bridges is usually the fluctuations, but thanks to a new damping system developed by swissrope/Lauber AG, the bridge can hardly move. [5] Check it out if you are in the neighborhood! ◄

References:

[1] *https://www.cementonline.nl/lagere-paalklassefactoren-nu-officieel*
[2] *https://www.scientias.nl/hyperloop-testfaciliteit-geopend-delft/*
[3] *http://www.baminfra.nl/nieuws/hardt-toont-europas-eerste-hyperloop-testfaciliteit-in-delft*
[4] *https://www.cobouw.nl/bouwbreed/nieuws/2017/7/wet-kwaliteitsborging-kabinet-koopt-tijd-aankondiging-novelle-blijft-uit-101250567*
[5] *http://www.1815.ch/news/wallis/aktuell/europabruecke-wird-eroeffnet/*

Figures:

1 http://swissrope.com/website/?page_id=25#!
https://www.nzz.ch/

Figure 1: The connection of the bridge into the mountain (left), the anchor from the north side (middle), and the bridge itself (right)

From Main Building to Atlas

TU/news

By: ir. Jan Willem Hoekstra
Senior Advisor at Van Rossum Raadgevend Ingenieurs Amsterdam

The former Main Building was designed in the 1960s by S.J. van Embden and the structural engineer was Arohnson. The building has a prominent position on the TU/e campus, because of its height, length, and positioning (*Header*). However, the building got so old that it did not meet current requirements regarding sustainability and comfort. The design for the new Atlas building was made by Team RSVP, consisting of Team V, Valstar Simonis, Peutz, and Van Rossum. After the final design phase, Van Wijnen has been chosen as Engineer and Construct contractor. They are responsible for the development and the construction of the design. Currently, the construction is in full swing.

Important for the design are the connections within the building, both between the floors of the high-rise part as the connection with the low-rise part. These connections will be made by a continuous staircase in the center of the building. In addition, the upper and lower floor areas will be much more open than the maze that was the original floor plan.

Figure 1: Stripped existing floor with the concrete main floors and the lightweight steel interfloor. The original design included the possibility of linking an intermediate floor to each column.

In the design, the existing structure was used as a starting point to reuse as much material as possible. In the high-rise part, the concrete main floors are maintained and the original, flexible steel beams of the intermediate floors are rearranged as much as possible to obtain the desired floor plan (*Figure 1*). This does not completely prevent the use of new steel for the intermediate floors, but it is minimized. The construction of both the concrete main floors and the lightweight intermediate floors is completely renewed to meet the current comfort and sustainability requirements. Besides these floors, the facade columns for the triple glass facade are reused, remaining the recognizable appearance of the facade.

Structural adjustments in the high-rise are thus limited, however in the low-rise more adjustments are needed to accommodate the campus' broad functions. In particular, the lecture halls did not appear to fit within the existing floor heights. Therefore, columns are removed in the low-rise and the basement to allow the realization of the lecture halls.

The most substantial structural modification relates to the new saving in the middle of the thick table structure. This saving creates the connection between both the high-rise and the low-rise part. Structurally, this is made possible by applying two trusses between the table structure and the floors located above it (*Figure 2*). In addition, the openness of the upper building is restored by removing the existing bridges.

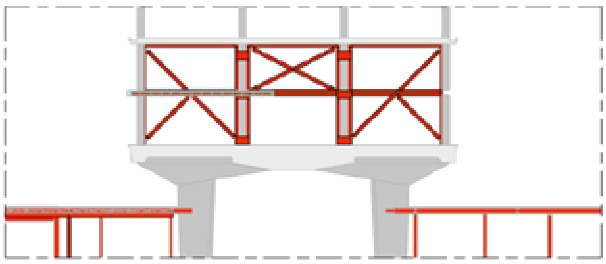


Figure 2: Provision for making the new savings in the table construction

After the renovation, that will be completed in 2018, the Main Building will be named Atlas. It will become the faculty building of Industrial Design and Industrial Engineering & Innovation Sciences. Furthermore, it will house the Executive Board, the University Club and support services. Atlas won, during the design phase, the BREEAM award 2017 in the category Education & Health with a score of 93.8%. ◀

Master's thesis (1)

By: Frits Rooyackers MSc

"Dynamics Control of Adaptive Structures"

In order to meet the high demands of the modern society, buildings constantly evolve into more sophisticated ones to increase the comfort and usability of its users. Recent revolution within the field of control theory allows structural engineers to drastically change the concept of architectural and structural design. The field of control theory is mainly concerned with practical applications and how to control certain variables within those systems. The aim of this master's thesis is to design a pedestrian bridge in which the deflection and the vibration are used as the control variable under an external dynamic excitation. The goal is to decrease the amount of material used in the structure while satisfying strength and stiffness criteria. A control system will be implemented including a deflection sensor and actuator. The actuator will apply a force to the structure in order to counter the deflection. A dynamic system with an external force and an actuator that responds to the deflection and velocity can be approximated numerically by (*Equation I*).

$$M\ddot{x}(t) + C\dot{x}(t) + Kx(t) = F_{ext}(t) + F_{act}(\dot{x}(t), x(t), t) \qquad \text{(I)}$$

$$F_{act} = K_p e(t) + K_i \int e(t)dt + K_d \frac{de(t)}{dt} \qquad \text{(II)}$$

$$\text{where: } e(t) = x_{setpoint}(t) - x_{sensor}(t)$$

For this research, the PID algorithm (*Equation II*) is used to determine the actuator force, which is a function of the deflection of the previous time steps. A State Space model is used to rewrite this set of second order differential equations

Figure 1: Proof of concept for the infinitely stiff structure

to a larger set of first order differential equations. Using a time stepping approach based on an Euler-Forward explicit scheme, enhanced with a Runge-Kutta algorithm, the total response can be solved for in a numerical fashion. To complement the numerical simulations, a serie of prototypes have been built in the laboratory to prove the potential of these adaptive structures. The test setups proved that an aluminium strip can be bent elastically in such a way that both sensors are able to reach the desired value specified by the user given that they lie within the capacity of the system. Therefore, the structure could be considered as infinitely stiff. For structures in which deflection is governing, this could drastically save material costs since the deflections can be controlled and is no longer governing. The goal for the final phase of this master's thesis is to proof the concept on a prototype of 5 x 2 meters. ◀

By: Elske van Heuveln MSc

"Material and structural design aspects of a prefabricated balcony of lightweight concrete"

The aim of this research is the development of a lightweight concrete mixture that can be used to produce structural reliable prefabricated lightweight balconies. The main reason to save weight is reducing the permanent loading on the total and underlaying structure. In this research, both material and structural design aspects of a prefabricated balcony are taken into account.

Several lightweight concrete mixtures are developed with the optimized packing, applying the modified Andreasen and Anderson model. Natural expanded silicate particles (Rotocell Plus lightweight aggregates) are used as lightweight aggregates, with a maximum particle size of 4 millimeters. An important advantage of these aggregates is the relatively high strength to density ratio, which makes them suitable to use in structural lightweight concrete. The material characteristics of the designed lightweight concrete mixture are experimentally determined. This results in a mean density of 1,760 kg/m^3 and a mean compressive strength of 42 N/mm^2. The bond behavior is comparable to that of normal weight concrete.

Finally, the crack behavior of the balcony is determined experimentally with four-point bending tests. From the tests it is concluded that the results are similar among the three tested specimens for the following relationships: loading-deflection, moment-curvature, and steel stress-crack width. The experimentally determined relations are compared with theoretically calculated relations. It is found that the analytical short term M-κ-curve, based on mean material characteristics, can be used to describe the behavior of the test specimens quite well. The calculation of the characteristic crack widths according to Eurocode 2 leads to somewhat greater crack widths than the mean crack widths observed in the tests.

Figure 1: Curvature and cracking during the four-point bending test

So far, the results are promising, but the mixture is not ready to use in practice. The determination of the material characteristics is still in development. It is recommended to optimize the mixture design to reduce the amount of air bubbles at the sides and investigate the long-term characteristics of the mixture. ◀

By: Wim Raedts

"Investigation on Fiber-Reinforced Printed Concrete"

A little over two years ago, researchers at the TU/e started investigating 3D Printed Concrete. In this period of research, several properties of Printed Concrete have been tested. The use of only concrete has some downsides: a low tensile strength and a brittle structural behavior. Therefore reinforcement needs to be added to obtain more tensile strength, which results in the possibility to create free shaped structures. In traditionally casted concrete, fibers are used to add ductility to the concrete structure. A lot of research has already been conducted on Fiber Reinforced Concrete (FRC). Since fibers can be manufactured in different dimensions, materials are not limiting the possibilities to create Fiber Reinforced Printed Concrete (FRPC).

Research focusses on the applicability to create FRPC. First, variations need to be considered to obtain the most effective way to add fibers to the concrete. Several prototypes led to a device which is able to add fibers to the concrete. FRPC is produced by transporting this mixture to the print nozzle.

Experimental research on controlling the FRPC is conducted by use of a Crack Mouth Opening Dimension (CMOD) test. In this way, the FR printed concrete can be compared to traditionally casted FR concrete. This test principle will be executed on casted and printed specimens. For the printed specimen, a nozzle is used that is able to print homogeneous layers with a cross-section of 40x40 millimeters, which is equal to the cross-section of the traditionally casted specimen.

Figure 1: CMOD test

With these CMOD tests, the crack behavior and deflection of both specimen types can be analyzed. The changing stiffness, caused by this crack behavior, of the bottom part of the cross-section can be analyzed with use of a numerical model. The determined deflection of the beam is inserted in a variable stress-strain relation within a multilayer model. The resulting moment-curvature of this model, together with the moment-area method can be used to determine the deflection of the cross-section. Both deflections, of the experiments and the model can be compared. If these deflections are equal the properties of the FRCP are validated. ◀

By: Jeff Modderman

"Nonlinear behavior of stiffened sandwich panels and creep behavior of EPS"

For approximately 10 years, various research subjects are elaborated at the TU/e on wood-based sandwich panels, developed by Kingspan Unidek. These sandwich panels are able to span a large variety of roof-structures while the demands on deformation and strength are met. The sandwich panel consists of an Expanded Poly-Styrene (EPS) core and thin particleboard faces (3 millimeters). When a sandwich panel is loaded in bending, the particleboard, loaded in compression, will be susceptible to local instability-phenomena. To strengthen the particleboard, the faces are reinforced by timber stiffeners.

The sandwich panels are to be calculated with a beam theory that takes into account deformation due to shear, because shear deformations can hold up to 50% of the total deformation. Currently, the Timoshenko beam theory is applied in order to calculate the deformation of the panel. The bending stiffness (EI) and the shear stiffness (GA) can be determined by applying a variety of analytical models. However, much remains unclear on the shear coefficient factor (κ), which takes into account the non-uniform distribution of shear stresses in the cross-section.

For a homogeneous cross-section the shear coefficient is determined to be κ=(5+5ν)/(6+5ν), e.g. κ=5/6 when the Poisson's ratio ν=0, while for a sandwich panel the shear coefficient is assumed to be κ≈1.0, as *Figure 1* implies. This research focusses on describing the Timoshenko beam theory parameters for wood-based sandwich panels and the effect of applying timber stiffeners. Experimental research implies that applying timber stiffeners provides reinforcement against local instability phenomena (at least up to 250 millimeters over the width), a higher bending stiffness, and a lower shear stiffness. The latter is due to the timber stiffeners not being connected to the EPS core layer which results in a complex shear stress distribution in the cross-section. ◀

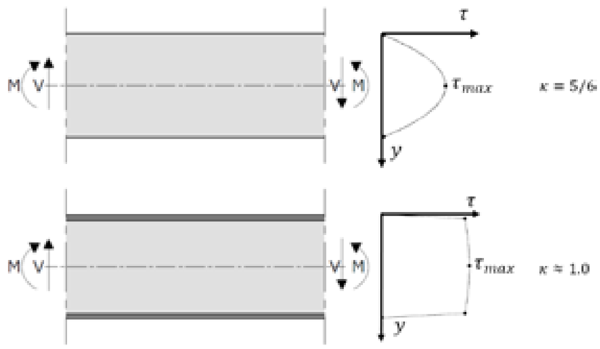


Figure 1: Shear stress distribution for a homogeneous cross-section (upper) and sandwich panel (lower)

Buckling of a stacked poly falsework system

By: Kees Govers MSc
Supervisors: Prof.ir. H.H. Snijder, Prof.dr.ir. A.S.J. Suiker

This graduation project is done in cooperation with Safe BV, a company that designs and leases falsework. They also have their own engineering department and are always trying to improve their system, for which this research is conducted. The buckling behavior of the civil poly elements was studied by Lin Luu in 2015. The result of that study should be confirmed by an experimental research. In addition to this experimental research, a numerical research is conducted. This research is done to determine the influence of the jacks on the buckling mode of a poly falsework system.

The main reason for initiation of this research is to extend the knowledge on the bearing capacity of the poly falsework elements. These elements consist out of a middle piece and a jack. As a follow-up on previous research, experimental research will be to conducted to verify the results. After this experimental research, a numerical simulation will be done to determine the level of influence on the buckling mode and load for different variants.

Experimental research
The goal of the experimental research is to determine the buckling load of a stacked scaffold framework. This is done by testing full scale towers in different configurations. The test setup and test specimen both can have variations, which are described further on.

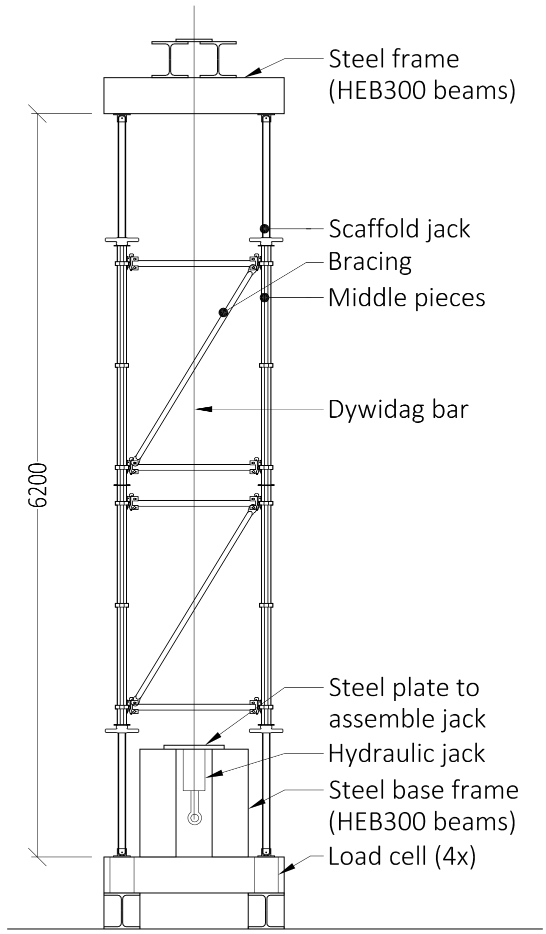


Figure 1: Test setup with basic test configuration

A variation in height of the jacks, and additional bracing between the jacks, are the differences between the test specimens. In total, four different test configurations are used. *Figure 1* shows the basic test specimen, which is used for most tests. Test configuration 2 has additional bracing between the scaffold jacks. Test configurations 3 and 4 are similar to specimen 1, only the height is varied.

The tests are performed with different loads and boundary conditions. Three of these configurations are used to do the tests; test case 1a, test case 1b, and test case 2:

- *Test case 1a*
  A vertical and horizontal load are applied on an unrestrained tower. The horizontal load is approximately 1% of the total vertical force.
- *Test case 1b*
  A vertical load is applied on an unrestrained tower (as shown in *Figure 1*). No horizontal forces are introduced.
- *Test case 2*
  The loading on the structure is a vertical load, centrally applied to the tower, so the same as for test case 1b. The tower is horizontally supported at the top.

The horizontal deformation of the tower is measured at mid height and at the top of the tested specimen. The vertical deformation is measured for each column during testing. Before testing, the geometric imperfections are also measured to determine the initial curve and sway imperfection.

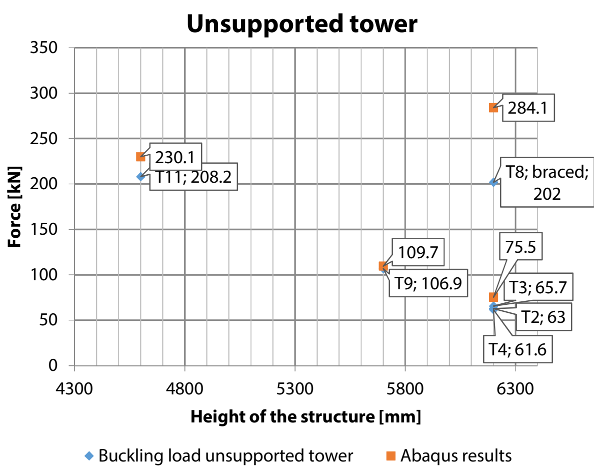


Figure 2: Numerical and experimental results of an unsupported tower

Figure 3: Failure of test 5 (left), failure of test 1 (middle), and failure of test 11 (right)

In total, eleven full scale tests are done. Each of these tests give four load displacement diagrams, one for each column.

Comparing all tests, it can be concluded that four different failure modes can occur. The structure can rotate about its central axis causing either the top or bottom jacks to fail. The jacks can also fail while the structure does not rotate, a half sine shape occurs over the total height. In this case, the bottom and top jacks both fail. When the jacks are relatively short (test 11) or restrained due to additional bracing (test 6, 8), the middle pieces will fail due to buckling (*Figure 3*). When a horizontal and vertical load are simultaneously applied, the whole structure will tilt due to its shallow base. The failure modes of the experiments can be seen in *Figure 3*.

Numerical research

The model is used to determine the buckling load of a stacked poly falsework structure. Once the finite element model is validated, it is easy to adapt the geometry and create other configurations which are not included in the experimental program.

Figure 4 shows the different configurations which are going to be modeled. In this stage, only a 2D model is made to compare to the experimental results. The initial geometrical imperfections measured in the experiments are used as input for the models. Also the material properties and sectional properties are taken from measurements, so no nominal values are used. This all to simulate the test conducted in the laboratory.

Figure 2 shows the failure loads of the numerical and experimental research for an unrestrained tower. The deviation of the failure load of the tested configurations are within 3% - 47% compared to the experimental results. The highest offset is caused by the rotation of the structure, which is not included in a 2D model. The high deviation of the braced structures is caused by the unequal distribution of forces over the two columns in the model (the other column has a much lower load). The experiments show a very small variation in force.

Conclusions

- The buckling behavior of a stacked poly falsework system is similar to the theoretical behavior;
- Distribution of forces over the columns should be looked at during 3D modeling of the structure;
- Poly falsework towers with additional bracing between the jacks can bear a much higher load than the towers without the bracing. ◄

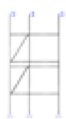
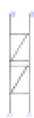
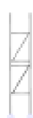
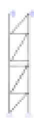
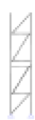
			2 bay, supported at top	1 bay, supported at top. Without additional bracing	1 bay, free at top. Without additional bracing	1 bay, supported at top. With additional bracing	1 bay, free at top. With additional bracing
2d/3d	Analysis	Imperfections					
2d	Geometric non-linear analysis with imperfections	Imperfections from Eurocode	V	V	V	V	V
	Geometric non-linear analysis with imperfections	Imperfections measured in lab.		V	V	V	V
3d	Geometric non-linear analysis with imperfections	Imperfections from Eurocode		V	V	V	V
	Geometric non-linear analysis with imperfections	Imperfections measured in lab.		V	V	V	V

Figure 4: Conducted numerical analyses


heijmans.nl

Science meets art

By: Rianne Luimes MSc
PhD candidate April 2014 – April 2018

How can science be of value for the preservation of susceptible art objects? Imagine a cloudy rainy day and, instead of relaxing on your couch, you catch the next train heading to Amsterdam Central Station. After a refreshing walk withstanding the pouring rain, you, together with a group of international tourists, enter the Rijksmuseum in Amsterdam. Wandering through the exhibition rooms you enjoy the diversity of the art objects. Still feeling uncomfortable because of your damp clothes, you stop to admire the elegancy of a 17th century oak wooden cabinet (*Figure 1a*). Suddenly, you take a step backwards as you realize that your damp clothes could harm the susceptible art object.

At this point, science can play an important role. The potentially harmful effects of the visitors' damp cloths become evident in a rise in the ambient relative humidity which causes expansion of the oak wooden cabinet. On the other hand, a decrease in the ambient relative humidity could also damage the cabinet as this causes shrinkage. The effects of fluctuations in the ambient relative humidity need to be investigated as preeminent museums aim for a low risk preservation of their objects. Based on experiments and numerical modeling, science can help by advising museums on future conservation strategies and the development of guidelines for sustainable indoor climate specifications.

Within the Climate4Wood project, which is initiated and financed by the Netherlands Organization for Scientific Research (NWO), science and art merge naturally as conservators and scientists collaborate to analyze the effects of climate fluctuations on susceptible art objects. Empirical data and the condition of naturally aged oak wooden panels in cabinets and panel paintings, mostly part of the Rijksmuseum collection, are systematically documented. Aspects as number of boards, dimensions and type of joints are researched and it is analyzed whether damage such as shrinkage, cracks in glue lines or cracks in wood can be observed. Combined with experiments and numerical modeling, this allows for an in-depth analysis of hygrothermal-mechanical-coupled behavior of oak wood and damage patterns observed in the art objects.

The numerical modeling part of the Climate4Wood project is incorporated in the PhD project 'thermo-hygro-mechanical coupled modeling' performed by Rianne Luimes. A sequentially coupled numerical model is developed in which heat conduction and moisture diffusion are coupled to the mechanical behavior of oak wood. With this model, discrete cracks induced by fluctuations in temperature and relative humidity can be simulated.

The development of the sequentially coupled model is performed in steps thereby gradually increasing the complexity of the model. The PhD project started with the development of uncoupled heat and moisture finite elements models. This was followed by the experimental-numerical characterization of the discrete fracture behavior of oak wood. For this part of the PhD project, discrete fracture with snap-back behavior was simulated by using a mixed-mode interface damage model and a dissipation-based path-following solution method. A good agreement between the simulations and the experimental results was found, as can be observed from *Figure 1b*.

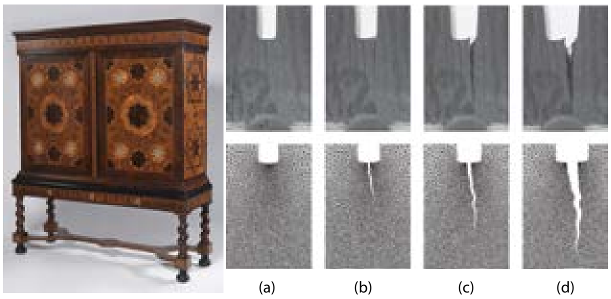


Figure 1a: 17th century oak wooden cabinet (photo by: P.H.J.C. van Duin, 2010, Amsterdam: Rijksmuseum)
Figure 1b: Observed (top row) and simulated (bottom row) fracture path. (a) Elastic response. (b) Crack initiation. (c) Crack propagation. (d) Ultimate failure.

Currently, the focus of the PhD project is on the finalization of the numerical model for which the heat, moisture and discrete fracture models are coupled. Additionally, the moisture model is extended by implementing a hysteresis model to accurately determine the wood moisture content. In parallel, an experimental program is set up to be able to validate the numerical model. Currently, mock-ups of historical cabinet door panels, made by the furniture conservation department of the Rijksmuseum, are tested under varying climate conditions.

In the next months, the development of the numerical model and the experiments on the mock-ups will be completed. Finally, a numerical case study will be performed to analyze a representative art object in more detail. The results of the PhD project will increase the knowledge about the relation between climate fluctuations and the damage patterns observed in oak wooden panels in cabinets and panel paintings and will provide better understanding of how damage can be prevented. Therefore, science is of great importance for the preservation of susceptible art objects for future generations. ◀

Internship experiences of a KOers member

By: Derk Bos
Master student Structural Design

In the second semester of my master, I followed a part-time internship at Tentech; an innovative design- and engineering consultancy in Utrecht, specialized in lightweight structures. The structures that I worked on at Tentech are mostly tents and temporary structures, which makes them somewhat different from what we as students usually design. I picked two projects that I worked on to highlight some of the lessons that I learned during my internship.

Temporary structures can be torn down and are less likely to be exposed to extreme loads as permanent structures. Therefore, it is unnecessarily conservative to apply the same loads to temporary structures as to permanent structures. The structural engineer can reduce the wind load and declare the structure safe up to that wind load. This reduces the force in the structure, and therefore makes the structure more slender. Secondly, the forces that act on these types of structures are depending on the form of the structure. If the sag is large, the force is low. This opposes a dilemma, because in general the usability of the shape increases for smaller sags, but the force distribution becomes less optimal. This results in an interesting field of design possibilities, in which the structural engineer and client should find an optimum between usability of the structure and use of material. In the structure that can be seen in *Figure 1,* the interaction between force and form is extremely high, because the membrane, which is comparable to a bathing suit fabric, has a very low stiffness.

Figure 1: Tent for Q-Dance

When the membrane is loaded, it will deform relatively easy and the forces in the membrane will become smaller. The forces in the cables where the membrane is connected are rather large, since the sag of the cables is small. At a certain wind load, the membrane is calculated to be torn out. This will remove the load, since the wind does not have a point to grab on. It will also allow the main structure to function at even higher wind loads.

In a tent structure, mostly axial forces occur, which is very beneficial for the dimensions and calculation of the elements. In the joints, however, a lot of effort has to be put into transferring the force from one element's axis to the axis of the element that it is connected to. An example of this can be found in *Figure 2*. Forces in the membrane of this structure are brought to the edge of the membrane, after which they are transferred to the perimeter cables. These, as well as the membrane itself, are connected to the membrane plate, which can be seen on the right side of the detail. The force is transferred further to the column head where the line of work of the three forces cuts in the line of work of the column. To transfer the force from the membrane to the column head, the main body of the membrane plate is welded slightly lower to the connecting parts.

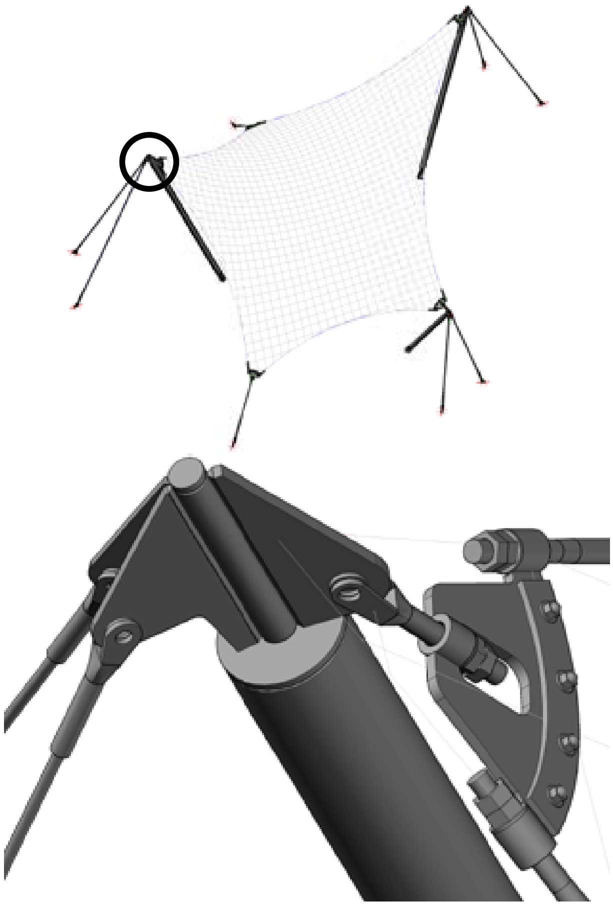


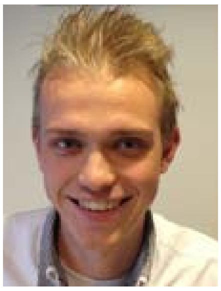
Figure 2: Connection detail

The connection from the membrane plate to the column head is again slightly higher, to bring the force back at the right angle at the column head. The detail shows that working with axial forces may be efficient for the design of elements, but gives complications in the design of good joints. The joints at the column head of the first structure are far less complicated and do in fact not prevent eccentricity in the columns. By connecting the columns in the hyperboloid to one another, the critical buckling length is reduced which makes a slender design possible.

The experience of...

By: Steven Schoenmakers
Project manager at Van Rossum Raadgevende Ingenieurs

In 'The experience of...' a person from the business community tells his or her story about the experience in and around the built environment. This time it is Steven Schoenmakers, who has graduated in 2013 from the TU/e, with a master Structural Design. After four years of working experience at Van Rossum Raadgevende Ingenieurs, Steven won the Dutch structural engineering award "Aanstormend talent van het jaar".



Four years ago, I graduated from the master Structural Design at Eindhoven University of Technology. At that time, the construction industry was affected by the economic crisis and finding a job after graduation was not self-evident. A former student told me that Van Rossum was looking for a starting structural engineer. After an interview, I was able to start, with full enthusiasm, at Van Rossum, just two weeks after graduation.

VAN ROSSUM RAADGEVENDE INGENIEURS
Van Rossum is a structural consulting firm that translates challenging construction plans into structural solutions. They act as advisor to the client and as part of the design team, Van Rossum understands that the construction process is an integral process, which is more than translating a program of requirements into a design.

Their interest is to achieve ambitions. That is why their work consists of directing; being the link between client, the users, the architect, the project management, and the other advisers. In order to achieve the optimal result, the structural engineers must have knowledge of all construction disciplines. Only so, they are able to engineer extremely sharp and allows them to design creatively.

During my master Structural Design, I had already gained some experience in the structural industry. Through KOers, I came into contact with a steel structural engineering firm, where I worked one day of the week as draftsman and detailing engineer. This experiences gave me a lot of benefits when I started at Van Rossum. I had insight in construction processes and knew what was expected from me as a structural engineer. When I started at Van Rossum, I worked on several smaller projects, which involved calculations varying from a steel hall on the Maasvlakte to the re-determination of a hotel. Slowly, the projects and my role became larger, such as the great opportunity to work on the Pontsteiger in Amsterdam (*Figure 2*).

Figure 1: Steel bridge structure of Pontsteiger, Amsterdam

After working for six months, I was able to elaborate a part of the Ponsteiger project, namely the steel structure of the bridge, which spans between two 90 meter tall towers (*Figure 1*). In order to optimize the amount of steel in the structure, I conducted a parametric study. For this assignment I gained all freedom to carry out the optimization: the number of trusses, the number of floors over which this structure would span, and the shape of the trusses. Once I got familiar with the project, I was given the opportunity to tackle other issues and became involved in the construction meetings.

Figure 2: RAI hotel (left) and Pontsteiger (right), Amsterdam

This way I progressed my career to project leader with projects like Pontsteiger, the RAI hotel (*Figure 2*), and the Sluishuis, all in Amsterdam. Therefore, my daily work consists of less calculation at the office, but is alternated with meetings with clients and architects. During this growth process, I have learned to handle with getting and taking responsibility. This is not something you learn at the TU/e, but by taking on chances that cross your path, you can grow this skill in your own way.

Early practical experience is definitely a good start for a structural engineer. Try for example to gain experience with an internship or working a few days a week at an engineering company. Practical experience with construction processes are a valuable addition to the knowledge you are thought at the TU/e. ◄

Royal HaskoningDHV
Consultancy, Engineering & Management

Royal HaskoningDHV is een onafhankelijk internationaal adviserend ingenieurs- en projectmanagementbureau met meer dan 130 jaar ervaring. Ons hoofdkantoor is gevestigd in Nederland, met belangrijke kantoren in het Verenigd Koninkrijk, Zuid-Afrika, India en Zuidoost Azië.

Wij voeren wereldwijd, vanuit 100 kantoren in 35 landen, projecten uit die de leefomgeving raken. Onze 7000 professionals voelen zich hierbij gesteund door de kennis en ervaring van hun collega's. Door de combinatie van wereldwijd opgedane kennis en kennis van de lokale situatie leveren we toegevoegde waarde voor onze klanten in hun projecten.

Wij zien een belangrijke rol voor onszelf in innovatie en duurzame ontwikkeling. Daarom willen we bijdragen aan oplossingen om onze maatschappij duurzamer te maken, samen met onze klanten en anderen die eenzelfde visie hebben.

Stage lopen of een afstudeeronderzoek doen bij Royal HaskoningDHV is een goed begin van een succesvolle carrière. Vaak ben je lid van een projectteam en werk je mee aan onderdelen van een project. Nieuwe inzichten en kennis zijn zeer welkom bij het zoeken naar de meest ideale oplossing voor een klantvraag.

Op onze website staat meer informatie over wie we zijn, waar we ons in de praktijk mee bezig houden en ons actuele aanbod afstudeeronderzoeken, stages en vacatures.

"Duurzaam bouwen draagt bij aan een positieve invloed van gebouwen op mens en milieu, nu en in de toekomst. Dat vergt een innovatieve aanpak met het oog op de hele levenscyclus van een gebouw."

Michiel Visscher, Constructief Ontwerper

royalhaskoningdhv.com

Being an exchange student

By: Martin Schmuck
Master student from Bratislava

When I was 17 years old, I spent one year of high school in Washington, USA. It was an opportunity that the generation of my parents could only dream of. Before the Velvet revolution in 1989, the communist party was in charge in Czechoslovakia and traveling abroad was a privilege only for chosen ones. This experience opened my eyes and made me realize that no place really is too far. I always tell myself, in distance travels one learns the most about himself.

Now, as a master student, I traveled again thanks to the European Union program Erasmus+. There was a number of universities to choose from, but the one in Netherlands was clearly my first choice. The Netherlands is among the most advanced countries in Europe and is known by its high quality technical universities, which is also proven by various rankings. Master studies are lectured fully in English language, open, and accessible for students from abroad. Including myself, Martin Schmuck from Slovakia.

Campus TU/e is a dominant part of the city of Eindhoven. I lived in the dormitory house Aurora within the campus, which was just finished before my arrival at the beginning of academic year 2016-2017. Living in this house was more than comfortable. There were times when the only reason to leave the campus was to buy food. The campus itself is a modern colossus and just walking around there motivated me to work.

Every morning I drove my bike, then fresh morning air in combination with morning coffee at the ground floor of Vertigo woke me up, followed by lectures. In Bratislava, the system of teaching works differently. There are lectures given by professor and exercise classes where students consult their assignments mostly with PhD students week to week. In the Netherlands there are only lectures, the work assignments are mostly worked out by a group of students, handed over in a report. In the majority of the courses that I have taken, an important part was to present the work to others, while being exact in choosing the right terminology and formulation of words. This is a skill, that is underestimated at my home university.

Another difference is to have the school year divided into four quartiles. In Bratislava, the school year is divided into two semesters and both ended by six exam weeks. Each semester consists of five courses and one design project. I prefer the system in Eindhoven, where students follow less courses and can focus on these more intensely in a shorter period of time.

Themes that are subjected to research are discussed in lectures. This research is often conducted directly at TU/e campus, which again brings up a feeling to the students that the road to be part of innovation is not that long and by working hard you can be part of it.

Throughout the year, I worked on two master design projects. In Bratislava it is common that the student receives an architectural proposal from the supervisor, and then the structural design is worked out. Whereas in Eindhoven the student dedicates the first weeks to his own architectural design. Therefore, one is able to gain much greater relationship to the project and between architectural and structural design.

At the TU/e, there is a clear connection between studies, research, and the commercial world. Students are motivated to search for internships and these can be recognized as part of their study. The master program Structural Design, has five major mandatory classes and relative freedom to focus more on subjects in preferred specialization. In Bratislava this freedom is absent. Almost all subjects for each semester are defined. Exams at the TU/e are more focused on the actual understanding of the subject rather than numerical exercises. Students must understand the fundamental logic, which serves as basics for further work or research.

"The year I spent in the Netherlands was an experience that spread my horizons, moved me forward and I am very thankful for it."

There are a number of associations at the TU/e, which have a focus according to the department and direction of studies. These associations organize events, study trips, workshops, where the student will develop new skills and especially meet new people, who may have similar thoughts, ideas or problems to discuss. Or simply let the student just relax and have an informal conversation with your professor. After a long day of work, students need to relax, maybe by having a drink with fellow students. In Eindhoven, you can get it right at the faculty at the student bar.

I wish that more of these events and workshops were in English. But on the other hand, the level of English language of the Dutch is almost perfect and you have no problem talking, whether it is with your professor or salesman at the Saturday market. ◀

The 3D printed canoe in Cologne

Concrete Canoe Race

By: Derk Bos and Lia de Mooij
Members of the Concrete Canoe Race Committee

Every other year the German equivalent of the Concrete Canoe Race is held. This year, the so-called Betonkanu-Regatta took place close to home which gave the team the opportunity to not only compete in the Dutch race in Enschede, but also in the German race in Cologne.

After our arrival on Thursday, we displayed our canoes so they could be admired by the jury and other participants. The fleet consisted of two Canadian canoes and one 3D-printed canoe. The latter competed in the open class: a parade of beautiful vessels of which the buoyancy was obtained using only concrete. The Canadian canoes were used in the race for both men and women.

Figure 1: Display of the canoes

Figure 2: Canadian canoe in action

The 3D-printed concrete canoe was constructed by the committee of this year to conquer the waters of Enschede and Cologne with innovation from Eindhoven. 3D printing of concrete structures is not yet a matter of pressing Ctrl + P, which makes designing a 3D printed canoe a rather extensive process. The biggest difficulties that had to be overcome were reducing the weight, applying reinforcement, and closing the canoe in three independent planes. The solution turned out to be a modular prestressed canoe. By applying prestress, the tensile stresses are prevented across the canoe. By reinforcing the concrete with the prestressed bars, the possibility was opened to make a modular canoe with joints that are based on compression. Additionally, a modular canoe would solve the problem of a heavy weight since the canoe can be transported in segments.

Figure 3: Print table with the entire segments that were halved to create the canoe

Because not everything is known about 3D printing, several tests had to be conducted to verify the possibility of the design. Before the final print, slant printing, adding steel while printing, and the water tightness were tested. We started testing slant printing because this would have the biggest impact on the possible design of the total canoe. Since the concrete is still very vicious in the dormant phase, it is impossible to print slant without a support.

The slant part is important for the point of the canoe, so we tried to make a cone with a temporary support. This design was chosen since it is a closed shape which makes it possible to use sand as a support without flowing away and it would provide us with two beautiful points when cut in half. The sand was scooped into the cone while printing so it would flow in the correct shape to provide support without altering the design.

Figure 4: Production of the canoe point

We tested the addition of steel while printing. We needed steel plates in the separate segments to be able to guide and prestress the steel bars over the length of the canoe. The connection between the concrete and the steel was expected to be critical. Because of this, a test was conducted where a steel plate was inserted between two layers to determine its influence on the concrete. It seemed that the printing around a steel plate would have a limited influence on the quality of the product, and therefore it was decided that this would be a good detail for applying the prestress to the concrete.

Figure 5: Segment with embedded steel plates

To test the water tightness, four segments were printed on which a rubber wire was glued at one side. By prestressing the segments and filling it with water, the water tightness could be determined. In addition to a few imperfections in the prints, which were expected to be prevented in the final print, the concrete and connections were watertight.

Figure 6: The segments were equipped with a watertight connection

The Concrete Canoe Race Committee would like to thank Continu, ENCI, BASF, Hakron, Liaver, Cement&BetonCentrum, Weber Beamix, Aronsohn, Bouwen met Staal, Mapei, Bayards, dr. Qingliang Yu, Rob Wolfs, Zeeshan Ahmed, the employees of the Pieter van Musschenbroek and Building Physics laboratory, and the organization for making this event possible!

Figure 7: Concrete Canoe Race Committee f.l.t.r. Nick Visser, Derk Bos, Stijn van Kuijk, Tijs Martens, and Lia de Mooij

After these tests and the theoretical evaluation of the buoyancy, stability, concrete and steel stresses, the design of the canoe was finished. At this stage, 3D printing started to become advantageous since the final print took a few hours to make and was not labor intensive compared to the traditional Canadian canoes. Since the weight of the total canoe still was hundreds of kilos, a solution had to be found to get the canoe in the water. The solution was to built a raft that could sink by removing steel drums after the canoe was put together.

Figure 8: Pulling the printed canoe into the water

Unfortunately, no prizes where taken back to Eindhoven, but a lot of inspiration was obtained for the Concrete Canoe Race 2018 that will be organized by KOers in Eindhoven! ◄

Figure 9: Group picture with all the participants of KOers

Namens KOers: Ad bedankt!

Een "Nieuwe Medewerker" neemt afscheid

Door: dr.ir. A.J.M. (Ad) Leijten
Universitair Hoofddocent (UHD) bij de leerstoel Houtsconstructies aan de TU/e

Op 1 december 2006 werd dr. ir. A.J.M. Leijten, later beter bekend als Ad Leijten, benoemd bij de leerstoel Houtconstructies. Hij volgde Frank Schot op, die eerder met vervroegd pensioen de universiteit had verlaten. Eind dit jaar gaat hij ons verlaten omdat ook hij niet kan ontsnappen aan het verplichte ontslag, dat samengaat met het bereiken van een bepaalde leeftijd. In 2006 was KOERS er als de kippen bij om de nieuwe medewerker voor KOersief te interviewen. Nu ben ik weer gevraagd om iets te schrijven, maar dan als een soort van overzicht van mijn ervaringen op deze faculteit.

Mijn vorige werkgever was de TU-Delft waar ik ook studeerde en promoveerde en waar ik 22 jaar werkte bij de groep Houtconstructies aan de faculteit der Civiele Techniek. Hoewel ik in Delft vele jaren met plezier heb gewerkt kwam ik slechts incidenteel bij enkele colleges met studenten in aanraking. Mijn aandacht was meer gericht op het houtonderzoek. Mijn eerste werkdag in Eindhoven was verrassend. Niet dat ik een uitgestoken vlag en een ontvangstcomité verwachtte maar toch. Het was Ad Vermeltvoort van Steenconstructies die mij ontving en rondleidde. Er waren opvallend weinig mensen op vloer 9. Toevallig hadden we precies dezelfde opleiding gevolgd vanaf de LTS – timmeren tot promoveren aan de TU; het klikte. Al snel voelde mijn nieuwe werkkring als een warm nest. Collega's waren niet stug maar gedroegen zich collegiaal. Geen sarcastische opmerkingen meer over de competitie tussen constructiematerialen. Als geboren Brabander voelde ik me gelijk thuis. In het lab kon ik het goed vinden met de medewerkers die joviaal en meedenkend waren en die bijna hetzelfde dialect spraken. Ze moesten even slikken toen ik beweerde dat het echte Brabants uit Breda komt… Als snel werd het hun duidelijk dat ik vaak grappige woordspelingen in mijn sterke beweringen inbouwde. Ze kennen me nu wel.

De eerste vraag die het interviewteam van KOERS mij in 2006 stelde was, welke auto ik bezat, want dan konden ze mij in een hokje plaatsen. Was het een BMW, Mercedes of een Lelijke Eend. Nee hoor, ik bezit geen auto antwoorde ik en daarmee was ik gelijk een vreemde eend. Behalve houtonderzoek kwam ik in aanraking met het ontwerpen van gebouwen waar ik samenwerkte met de onlangs overleden architect en medewerker Hans van Well. HTS-instap en Grote-overspanningen waren vakken waar ik samen met de studenten mooie ontwerpen zag groeien.

Ad Leijten heeft twee sabbaticals gehad, onder andere in Kyoto, Japan. "Het leuke aan Japanners is dat hoe meer ze drinken hoe meer Engels ze blijken te spreken"

Ook het geven van colleges, klein- of groot bezet met studenten, gingen me steeds beter af. Enthousiasme gekoppeld aan humor in combinatie met toneelvaardigheden zoals mijn oude HTS mechanica leraar ir. Schlatmann dat kon, waren mijn leidraad. In dat opzicht snijdt het mes aan twee kanten en gaan de docent en de student met plezier naar een college. Laat me een voorbeeld geven. Toen ik het tweedejaarscollege Ontwerpen van Constructies (COM) voor het eerst moest geven, nu bekend als Dimensionering of Structures (DOS), verzon ik een inleiding die in goede aarde viel. Iedere student wist intussen dat een ontwerpuitgangspunt voor een architect gebaseerd kan zijn op een metafoor. Ik nam het water waarmee de borden in de collegezaal werd schoongemaakt als metafoor voor wat we als docenten wilde bereiken. Het water in deze emmer stond voor al die "moeilijke" theorieën en opgaven van de docenten; heel bijzonder water dus. Op de tafel had ik een dienblad uit de Mensa, een spons en een plastic bekertje. Als docent zouden we een klein beetje van onze kennis uitspreiden. Het bekertje werd gevuld en het water vloeide over het dienblad. "Deze (droge) spons zijn jullie" zei ik. Het is dus de bedoeling dat jullie onze kennis absorberen. Hoeveel jullie absorberen zoeken we uit bij het tentamen waarbij ik gelijktijdig de spons uitwrong. Het kwartje was gevallen en zowel een gelach en lach vulde de zaal. Zulke kleine dingen blijven je bij. Er zijn eigenlijk teveel leuke hoogtepunten die ik nog zou kunnen vertellen.

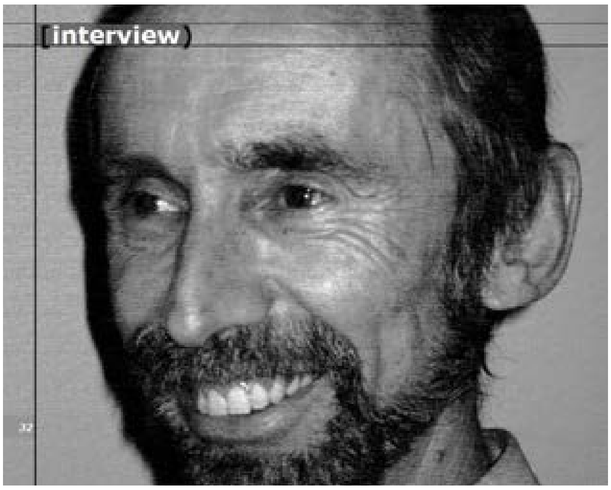


Figure 1: Header afbeelding van het interview uit 2006, KOersief 71

Met het naderende afscheid kan ik niet nalaten lof toe te zwaaien aan mijn collega's en in het bijzonder aan André Jorissen, die met zijn warme persoonlijkheid een klimaat weet te creëren waar ik en ook zijn afstudeerders zich prettig bij voelen; geweldig. ◀

Bridges and politics

Hans Lamers

One of the high profile examples of building bridges, at this moment, is the bridge between Russia and Crimea (The Krim). The annexation of Crimea by the Russian Federation in March 2014 was the cause of acceleration of plans. Crimea can only be reached by boat (ferry) or plane from Russia. To strengthen the influence of Russia, a bridge for both road and rail travel was ordered by Russian president Vladimir Putin. A clear and unambiguous political decision. The future 'navel cord' made out of an immense amount of steel and concrete with a length of about 19 kilometers between Russia and Crimea is a statement of an eternal bond. The bridge goes from Taman (Russia) to Kerch (Crimea), via Tuzla Island over the Kerch Strait. In the original plans, the bridge was a joint venture of Ukraine and Russia. Nowadays, the project is completely Russian; this is of course much cheaper for Ukraine, but surprisingly they are not happy with this new connection to the mainland of Russia.

At the start of 2015, the contract for the construction was awarded to the SGM Group, owned by Mr. Arkady Rotenberg, a childhood friend and also judo partner of Vladimir Putin himself. A shameless act of transparency, but who will protest against the choice of Putin for this company that never has built a bridge before, only pipelines? Strange enough, nearly 15 centuries ago, the Greek already came up with the idea of a bridge over the Kerch Strait. In the nineteenth century, the British wanted a railroad from England to India, through the Crimea and across Kerch Strait. This turned out to be too expensive. Next, the Germans wanted this bridge for the invasion of the Caucasus. After building about one third of the bridge, the Germans already had to retreat and the 'Wehrmacht' blasted the completed part of the bridge. Bridges are strategic objects that give meaning to land and prestige to its people. It is just a pity that the initiative is driven by the cheap greed of power.

Colophon
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